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SOIL EROSION STUDIES FOR FORESTED WATERSHEDS

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Abstract

Soil erosion and sedimentation are the two important natural processes which need immediate attention from the scientific community. Two major types of erosion are geological erosion and erosion from human or animal activities Geological erosion includes soil-forming as well as soil eroding processes that maintain the soil in a favorable balance, suitable for the growth of most plants. Geological erosion has contributed to the formation of our soils and caused many of our present topographic features, such as canyons, stream channels, and valleys. Conversely human tillage or vegetation removal by animals or other natural events may cause accelerated erosion, which leads to loss of soil productivity.

Water erosion is the detachment and transport of soil from the land by water, including rainfall and runoff from melted snow and ice. Types of water erosion inter-rill (raindrop and sheet), rill, gully, and stream channel erosion. Water erosion is accelerated by farming, forestry, grazing and construction. Due to these activities in the upper catchments most of the reservoirs get silted up and the storage capacity gets reduced to a minimum. Therefore, it is necessary to understand the process of soil erosion and also to identify the erosion prone areas in the catchment.

In the present study an attempt is made to estimate the soil erosion rate in Malaprabha representative basin by using WEPP model and Universal soil loss equation. It is observed that the WEPP model results are more comparable with the actual erosion rate than USLE. However, due to lack of observed data study provide a general outlook of the severity of the soil erosion problem in the catchment. The study is carried out by Dr. B. K. Purandara, Sc `B', with the assistance of Mr. N. Varadarajan, SRA Regional Centre, Belgaum.

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CONTENTS

List of Figures

List of Tables

1.0 Introduction

Soil loss is defined in erosion literature as the amount of soil lost in a specified time period over an area of land, which has experienced net soil loss. Soil loss is expressed in units of mass/unit area, such as t/ha or kg.m2, and may be for a number of years, or for any other specified time period. Soil loss is of interest primarily in terms of on-site effects of erosion such as loss of crop productivity. Sediment yield is defined as the mount of sediment which leaves a specified area of land in a given time period. Sediment yield refers to a mass of sediment, which crosses a boundary (kg/m), or mass per unit area (kg/m2). . Sediment yield is important in terms of off-site effects of erosion such as siltation in ditches, streams and reservoirs. Sediment is also a primary carrier of agricultural chemicals that can pollute streams and lakes. In most cases not all soil particles are deposited on the field before leaving the field boundary. In other words, most fields have some areas that experience net soil loss and the spatially integrated net deposition is what leaves the field, herein termed sediment yield.

1.1 Modeling Soil erosion

Modeling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces. There at least three reasons for modeling erosion. (a) Erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, and for regulation; (b) physically based mathematical models can predict where and when erosion is occurring thus helping the conservation planner target efforts to reduce erosion; (c) models can be used as tools for understanding erosion processes and their interactions, and for setting research priorities. There are basically three types of erosion models: empirical, conceptual and physically based. Empirical models are based primarily on observation and are usually statistical in nature. Empirical models are based on inductive logic, and generally are applicable only to those conditions for which the parameters have been calibrated. The Universal Soil Loss equation (USLE) is the empirical erosion model, which has been used most widely for predicting soil erosion. The greatest criticism of the USLE has been its ineffectiveness in applications outside the range of conditions for which it was developed. Adaptation of the USLE to a new environment requires a major investment of resources and time to develop the database required driving the model. The primary focus of the empirical models has been in predicting average soil loss, although some extensions to sediment yield estimates have been developed.

Conceptual models lie somewhere between physically based models and empirical models, and are based on spatially lumped forms of water and sediment continuity equations. The focus of the conceptual models has been to predict sediment yields, primarily using the concept of the unit hydrograph.

Physically based models are intended to represent the essential mechanisms controlling erosion. The power of physically based models is that they represent a synthesis of the individual components that affect erosion, including the complex interactions between various factors and their spatial and temporal variability. The result is synergistic, the model as a whole represents more than some of the individual pieces. The research scientist can use the physically based erosion models to help identify which parts of the system are the most important to the overall erosion process, and therefore should be given attention in research and development of erosion prediction technology. The conservation planner can use a physically based model as an interactive conservation design tool, targeting critical seasons or months in which major erosion events occur as well as critical positions on the hillslopes where the greatest soil loss takes place. The planner can also quickly suggest and evaluate new conservation strategies for individual fields.

In the present study therefore, an attempt is made relate the results obtained by empirical model and physically based model, i.e., and WEPP model. The objective of the WEPP is to develop new generation erosion prediction technology for use by the conservation planner at the field level. The technology is based on fundamentals of erosion and hydrologic sciences and is computer driven. The two WEPP models referred to herein as examples of physically based models are the WEPP hillslope profile model and the WEPP watershed model.

2.0 Literature Review

The rainfall erosion research began with the work of a German Scientist, Wollny (1988) in the last quarter of the 19th century but the systematic study on the soil loss prediction from agricultural fields was conducted in United States beginning around in 1930's. Cook (1936) gave mathematical relationship between the factors that cause soil erosion and listed three factors:

(1) The susceptibility of soil to erosion (soil erodibility), including need for tests to evaluate
an erodibility index,

(2) The potential erosivity of rainfall and runoff, including the influence of degree of slope
and slope length, and

(3) The degree of protection afforded by vegetal cover.

Later the concepts of empirical soil loss equations and specified soil loss limits began around 1940 with the work of Smith and Zingg in Missouri (U.S.A.). In the year 1947, a committee chaired by Musgrave proposed a soil equation having some similarity to the present day Universal Soil Loss Equation (USLE). The USLE concept of a generally applicable equation, with its basic soil loss rate and all its factors free of geographically oriented reference points and regional boundaries, was developed in the 1950's from analysis at the ARS Data centre at Purdue.

Wischmeier and Smith (1965) developed a mathematical procedure from statistical analysis of more than 10,000 plots years data from about 50 locations in 24 states and this equation is known as USLE. This equation was later modified with more recent data from runoff plot, rainfall simulations, and field experience (Wischmeier and Smith, 1978). The USLE was developed to provide a means of estimating longtime average soil losses in runoff from specified field areas under specified cropping and management practices. this equation predicts only the losses from rill and sheet erosions under specified conditions. The USLE is one of the most convenient working tools for conservationists. It enables land management planners to estimate average annual erosion rates for a range of rainfall, soil, slope, crop, and management conditions and to select alternative land use and practice combinations that will limit erosion rates to acceptable levels. The equation involves six major factors that affect upland soil erosion by water, rainfall erosiveness, soil erodibility, slope length, slope steepness, cropping and management techniques, and supporting conservation practices.

2.1 Development of USLE

Erosion is caused by rainfall and by surface runoff and is affected by a number of natural and anthropogenic agents. It may be expressed as the relation between the erosivity of rainfall, i.e., and the potential ability of rain to cause erosion and soil erodibility, i.e., the susceptibility of the soil to erosion. Rain as the principal erosion agent was usually characterized by intensity, size of raindrop and raindrop velocity, soil properties were expressed by coefficients showing the effects of soil texture and structure on the soils and by other factors affecting the origination and course of erosion processes, namely slope gradient, slope length, the vegetative cover etc.

Mathematically,

$$A = R.K.L.S.C.P \qquad \text{--------} (1)$$

Where A is the predicted soil loss per unit area, computed by multiplying values for the other six factors. As usually used, it is an estimate of the average annual sheet plus rill erosion from rainstorms for field size upland areas. It generally excludes gully or stream bank erosion, snowmelt erosion, or wind erosion, but it includes eroded soil that is deposited before it reaches downslope streams or reservoirs.

R is rainfall and runoff factor for a specific location. Usually, R is expressed as average annual erosion index units.

K is the erodibility factor for a specific soil horizon. K is expressed as soil loss per unit of R for a unit plot. (A unit plot is 72.6 feet long with uniform 9% slope, maintained in continuous fallow, with tillage when necessary to break surface crusts. These dimensions were selected because most early erosion research plot in United States were 72.6 feet along with slopes that averaged about 9%. Continuous fallow was selected as a base because no cropping system is common to all agricultural areas. Residual and current crop and management effects that vary from one location to another would influence Soil loss from any other plot condition).

L is a dimensionless slope-length factor not actual slope length and expressed as the ratio of soil loss from a given slope length to that from a 72.6 feet slope length under same condition.

S is a dimensionless slope-steepness factor not actual slope steepness and computed as the ratio of a given slope steepness to that of a 9% slope under the same conditions.

C is a dimensionless crop and management or cropping management factor and expressed as a ratio of its soil loss from the condition of interest to that from tilled continuous fallow.

P is a dimensionless supporting erosion control practice factor and expressed as a ratio of the soil loss with practices such as contouring, strip cropping, or terracing to that with farming up-and-down slope.

Cook also described in detail the subfactors affecting each factor. Use of equations to calculate field soil loss began when Zingg (1940) published the results of his comprehensive study on the effect of degree of slope (S) and slope length (L) on soil loss (X). Zingg recommended the following relationship:

$X = CS^{1.4} L^{1.6}$ -------- (2)

in which C is a constant of variation and X is the total soil loss or

$A = CS^{1.4} L^{0.6}$ ------------- (3)

Where A is average soil loss per unit area.

The following year, Smith (1941) added crop (C) and supporting practice (P) factors to the equation and expressed a following form of equation

$$A = C\,S^{7/5}\,L^{3/5}\,P \quad \text{--------------} (4)$$

Smith used this equation to develop a graphic method for selecting the necessary conservation practice on Shelby and associated soil in the Midwest regions of the USA. The C-factor included effects of weather and soil as well as cropping system. Smith also introduced the concept of specific annual soil loss limit for mid-western soils. Browning et al. (1947) added soil erodibility and management factors and prepared more extensive tables of relative factor values for different soils, rotations, and slope lengths. This approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepness with and without contouring, terracing, or strip-cropping. The National committee of U.S.A. (1946) presented and adopted the Cornbelt equation. They added a rainfall factor in the land slope practice method and suggested the following equation which is also known as the Musgrave equation:

$$A = FC\,(S_g^{1.35}/10)(L^{0.35}/72.6)(P_{30}^{1.75}/1.375) \quad \text{----------}(5)$$

Where A is the sheet erosion in tons/acre, F is the soil factor basic erosion rate in tons/acre/year, C is the cover factor, and P_{30} is the maximum 30 minutes duration 2 year frequency rainfall in inches. The so called Musgrave equation that resulted included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects. The 1.75 power of the 2 years, 30 minutes rainfall was adopted on the rainfall factor. Slope length and steepness exponents were lowered from Zingg's 0.6 and 1.4 (1940) to 0.35 and 1.35 respectively. Annual cover factors were estimated relative to a value of 100 for either continuous fallow continuous row crop. A soil factor was devised by adjusting measured annual soil losses at the experimental locations for differences in rainfall, slope, and cover. Quantitative values for the factors in the equations were limited, particularly for different cropping covers. This earlier equation was further modified by Musgrave (1947) for estimating gross erosion from large, heterogeneous watershed and for flood abatement programs as

$A = K\ C\ R(S_g^{1.35}/10)\ (L^{0.35}/76.6)$ -------- (6)

In which R is the rainfall factor (rainfall erosion index), and K is the soil factor in tons/acre/year/unit rainfall index.

Smith et al. (1947) presented a method for estimating soil losses from field of clay-pan soils. They described the effect of slope percentage (S) as

$A\ \alpha\ a + Bs^{314}$ -------- (7)

Where `a' and `b' are constants. The effect of slope length (l) was described as $A\ \alpha\ L^{1.6}$. Soil loss ratios at different slopes were given for contour farming, strip cropping, terracing. Recommended slope length limits were presented for contour farming. Relative erosion rates for a wide range of crop rotations were also given.

The following year, Smith et al. (1942) presented the following rational erosion estimating equation for the principal soils of Missouri:

$A = C\ S\ L\ K\ P$ ------- (8)

Where C factor was the average annual soil loss from clay pan soils for a specific rotation on a 3 percent slope. 90 feet long framed up-and-down slope. The other factors for slope (S), length (L), Soil group (K), and supporting practice (P) were dimensionless multipliers to adjust the value of C to other conditions. P-factor values were discussed in detail. The work also acknowledge and the need for a rainfall factor to make this equation applicable over several states.

Musgrave (1942) discussed the importance of designing agronomic practices to meet specific erosion hazards, and showed how the rainfall erosion hazard changes through the year at different locations in United States, and also stressed the need to use cropping practices that provide soil cover during periods of serious erosion hazards. Graphs to solve the Musgrave equation for use 'on the spot for a specific set of conditions were prepared by Lloyd and Eley (1952).

Van Doren and Bartelli (1950) proposed the following erosion equation.

$A = f(T,S,L,P,K,I,E,R,M)$ ----------- (9)

Where, A annual estimated soil loss, T measured soil loss, S steepness of slope, L was the length of slope, P practice effectiveness, K was soil erodibility, I was intensity and frequency of 30 minutes rainfall, E was previous erosion, R was rotation effectiveness, and M management level. The key value for T was 3.5 tons per acre for Flanagan silt loam on a 2 percent slope, 180 feet long, cropped continuously to corn. Estimates of other conditions were made using $S^{1.5}$ and $L^{0.38}$ ($L < 200$ feet). Other factor values were given in table and graphs for application on soils and cropping conditions throughout Illinois.

In 1955, SCS state conservationists in the nine mid-western states requested the latest available information on the slope-practice approach, Powered this end, joint conferences of personnel from SCS, the Soil and Water Conservation Research Branch of the Agricultural Research Service, and Cooperating Service Agencies were held at Purdue University in February 1956 and July 1956. This group concentrated its efforts on reconciling differences among existing soil-loss equation and extending this technique to regions where no measurements of erosion by rainstorm had been made. The equation considered at this workshop was

$$A = C.\ M.\ S.\ L.\ P.\ K.\ E \quad ---------- (10)$$

in which A was estimated soil loss, C was a crop rotation factor (C = 100 for continuous corn), M was a management factor (value from 0.5 to 0.8 for different residues and methods of tillage), S was degree or percent of slope factor ($S \alpha$ steepness $^{1.4}$ with continued study of a proposed quadratic relationship), L was the length-of-slope factor(L α length $^{0.3}$+0.1), P was a conservation practice factor (specific values for slope groups from 1.1 to 24%), K was the soil erodibility factor (each soil given a value of 0.75, 1.0, 1.25, 1.5 or 1.75) and E as a previous erosion factor (not evaluated, but considered when establishing the permissible soil loss limits for each soil).

Subsequent efforts by Wischmeier and Smith, (1960) led to combination of the crop rotation and management factors and to a rainfall factor for the states east of the Rocky Mountains. The resulting universal soil loss equation was introduced at a series of regional soil loss prediction workshops from 1959 through 1962. Which was revised in the year 1978.

Sediment yield is sometimes estimated by estimating gross erosion with the USLE and then multiplying by a delivery ratio to obtain sediment yield (ASCE, 1975). For small watersheds, especially fields, this method is often inadequate and can lead to totally false conclusions. Thus, it should be used only as a first approximation. A typical delivery ratio for terraces is 0.2 (Wischmeier and Smith, 1978) meaning that 80 percent of the sediment produced on inter terrace interval is trapped in the terrace channel. In many watersheds, especially those larger than fields, some deposition usually occurs, the overall sediment yield response is influenced by a variety of deposition features rather than by a single major feature. When deposition does occur, sediment yield is highly correlated with runoff characteristics, since flow control, sediment transport capacity which is closely related to sediment load when deposition occurs. Williams (1975) modified the universal soil loss equation to estimates sediment yield for individual runoff events from a given watershed by replacing the USLE rainfall erosivity factor with:

$$R = 0.05 \, (Vq_p)^{0.56} \quad \text{---------} \quad 11.$$

Where V = volume of runoff (m^3) and Q_p peak discharge rate (m^3/sec). The USLE with this R factor is referred to as the Modified Universal Soil Loss Equation of MUSLE.

2.2 Work on USLE in India

Nema et. al. (1978) determined some parameters of the USLE from runoff plot study conducted at Soil Conservation Research Demonstration and Training Centre (ICAR). Vasad. Singh et. al. (1981) evaluated the universal soil loss equation parameters for different regions of the country and presented a report on soil loss prediction research in India. The work showed the applicability of this equation for different land use pattern, soil condition, rainfall conditions, erosion control-practices and topographic conditions. Pratap Narain et al. (1982) presented a method for determination of different parameters of USLE from runoff plot at Soil Conservation Research Center, Kota. Das (1982) based on the Williams equation proposed the following equation for estimation of sediment yield from Naula watershed of Ramaganga reservoir catchment. He also proposed the equation:

$$S_y = 11.8\,(Q.q_p)^{0.257}\,K.L.S.C.P \quad \text{--------} \ (12)$$

where S_y = the sediment yield from watershed in m.tons per storm, Q = the runoff amount in cu.m, q_p = the peak rate in cum per second and other factors remain same. Chinnamani et al (1982) showed the applicability of the universal soil loss equation in mountain watershed in semiarid and humid regions. They applied universal soil equation to sixteen subwatershed (13 from the hills and 3 from the plains) of the Bhavani basin. The soil loss in the basin has been broadly subdivided into eight categories namely extremely low, very low, low, moderately low to medium, moderately to high, high, very high and extremely high. They also determined the sediment delivery ratio. Mehta (1986), and Tiwari (1986) have determined the values of the parameters of the USLE for the Himalayan sub-watersheds of Ramaganga river. They applied USLE equation as determined by Das (1982) and showed the applicability of the equation for the mountainous watershed of Ramaganga River.

2.3 Application of WEPP Model in India

In an analysis of the Biara Watershed, located in northern India on the edge of the Himalayas. WEPP input files were developed for a steep hillslopes with 3 OFEs: forest, pasture, and wheat. WEPP was then run for ten years for a climate typical of northern India. The average annual precipitation was 1082 mm, including some snow events. The major locations of erosion on the hillslopes were at the upper parts of the pasture where slopes were still 60% and at the upper part of the wheat element where the slope was still 20%. The sub-watershed was modeled as a hillslope with 4 OFEs. The final OFE representing a channel element with a slope of 10 percent at the top and 9 percent at the bottom. The soil file developed for the sub-watershed channel was used for the fourth element. Overall hillslope element lengths varied from 1500 m to 8000 m for the 19,500 ha watershed of interest. The gradient of the channel was set at 8 percent. WEPP was run for 10 years for this large watershed.

For all three cases, about half of the eroded sediment deposited on the hillslope. Once the channel elements were incorporated, there was considerable more deposition in the channel, or about 90 percent of the sediment that entered the channel.

The sub-watershed delivered about 3000 t/yr of sediment, or about 3 t of sediment for every meter width. When the complex 4-OFE hillslope was developed for the watershed scenario, the predicted results show that about 32% of the detached sediment was delivered to the main channel, which was about 4:6 t/yr/m width. Hence, the 4 OFE hillslope model appears to be over predicting the sub-watershed yield by about 50%. As the sediment delivery from the main river is limited by the transport capacity of the main channel, users may not need to be concerned about this over prediction when determining sediment yield. With further calibration, it may be possible to adjust the hillslope geometry to get a better prediction from the hillslope modeling the sub-watershed.

2.4 WATBAL and WATSED Models

The WATBAL model has been under constant development since 1973, with a stated objective of estimating water yields in response to cumulative watershed development and vegetative manipulation and recovery over time. Presently, WATBAL is designed to simulate the potential and most likely effects of primary forest management practices (timber harvest, road development, and fire) on the responses of watershed and water resource systems with regard to stream flow and sediment regimes.

In this model, watersheds are divided into areas that are relatively homogeneous (land types), for which a number of response characteristics are determined. The physical characteristics measured include; slope angle, slope shape, slope length, surface drainage, soil depth, soil texture and soil structure, soil consistency, bed rock type, bed rock weathering, bed rock structure and vegetative habitat. From these characteristics, each land type is assigned a series of hazard ratings that describe potential

a) Rotational mass erosion,

b) Debris avalanche,

c) Surface erosion from undisturbed soil surfaces,

d) Surface erosion from subsurface horizons, and

e) Surface erosion from the substrata (Patten, 1989).

The model output from these original hazard ratings serves as the estimates of natural sediment yield in tons/sq mile per year. The natural sediment yield values are based upon sediment measurements from several representative land types. These measurements were then extrapolated to other land types using an algorithm which assumed that approximately, 80% of the natural sediment is derived from long-term mass erosion process, the remainder is from surface erosion processes related to the prior history of the land type. Each individual land type file also includes the stream density within that particular land type.

Additional surface erosion is assumed as induced, and mass erosion accelerated, by different logging, fire, and road building activities. Thus excess (above natural amounts) erosion is a function of the type and location of different management activities. The acceleration factors for mass erosion were derived from a landslide study by Megahan et al (1978). Acceleration factors for roads and burned areas are also included. Surface erosion, which is assumed to be insignificant in undisturbed forests (Cline et al. 1981) is estimated for roads, burned regions, and logged areas. Each is modified by the physical characteristics of the land and the age, size, and intensity of the disturbance.

Purandara(1997) compared WEPP model with other soil erosion models like WATSED and WATBAL models and reported that WEPP model is more suitable for Indian condition. Chandramohan et al (1999) studied the Sallopat watershed using WEPP model.

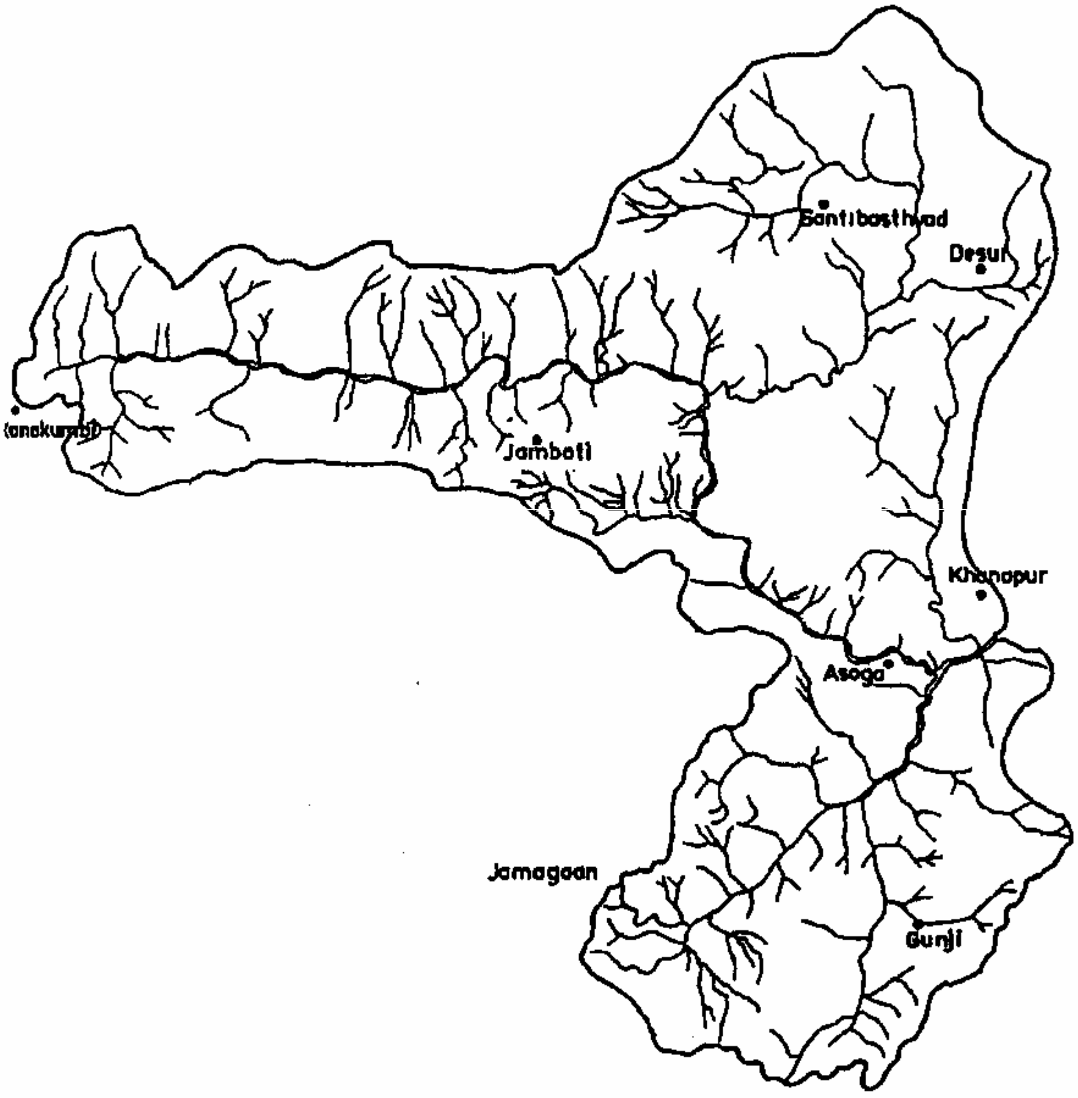

Figure 1. Malaprabha Representative Basin

3.0 Study Area

3.1 Malaprabha Representative Basin

3.1.1 Location

The Malaprabha representative basin lies in the extreme western part of the Krishna basin. It extends in between 74 20 and 74 30 E longitudes, and 15 20 and 15 40 N latitudes and encompasses an area of 540 Sq. km of the Belgaum district in Karnataka state. (fig.1) Two major roads run through the Malaprabha representative basin are Belgaum - Goa (N 4A) and Belgaum - Mapusa state high way. This representative basin is the major source of water yield for the Naviluteerth Dam constructed at 35-45 km downstream of its mouth. This dam impounds about 1377 mcm water and provides water for irrigation approximately for 2.17 lakh ha land.

3.1.2 Hydrometeorological Network

There are five raingauge stations, and two hydrometeorological stations consisting of stevenson screen (to record temperature and humidity), pan evaporimeter, anemometer, wind vane, self recording raingauge and ordinary raingauges at different places in the Malaprabha representative basin The representative basin is gauged at its mouth viz., Khanapur by WRDO Karnataka.

3.1.3 Geology

Geologically the Malaprabha representative basin comprises of two main geological formation (i) Tertiary basalts, (ii) Sedimentary Formations of Pre-Cambrian age.

(i) Tertiary Basalts

A major part (96%) of the representative basin is covered by Tertiary basalt. The hydrology of basalt is different from that other type of hard rocks. One of the main differences is that the various basalt flow units can form a multi-aquifer system some what similar to a sedimentary rock sequence, having alternate pervious and impervious horizons.

(ii) Sedimentary Rocks

The sedimentary formation is of Pre-Cambrian age. These types of rocks are confined in the south eastern part of the study area. Sedimentary rock generally acts as a good aquifer if intertrappean clays and other impermeable rocks do not interrupt it.

3.1.4 Soils

Pedologically speaking, the basin rocks are covered by this (0.5 m) to thick (10 m) layer of soils, which are divisible into two major groups (fig.2). These are red loamy soils and medium black soils.

(i) Red Loamy Soils

The upper reaches of the basin, i.e., on crest and gently sloping mid-crest regions, viz. pediplains are characterised by red loamy soils. The top soil texture varies between sandy loam to clay loam underlain by gravel and sandy loam, sub-soil horizon, About 80 % area of the Malaprabha representative basin is covered by red loamy soils.

(ii) Medium Black Soils

This type of soils occurs extensively in parts of Khanapur taluk. Soils are moderately deep to very dark grayish brown, dark reddish brown or black in colour, usually calcareous cracking and clayey. These are moderately well drained with low permeability.

3.1.5 Landuse Pattern

Land use pattern of the Malaprabha representative basin is very complex comprising of forest, agriculture, shrubs and barren land. Area under different category of

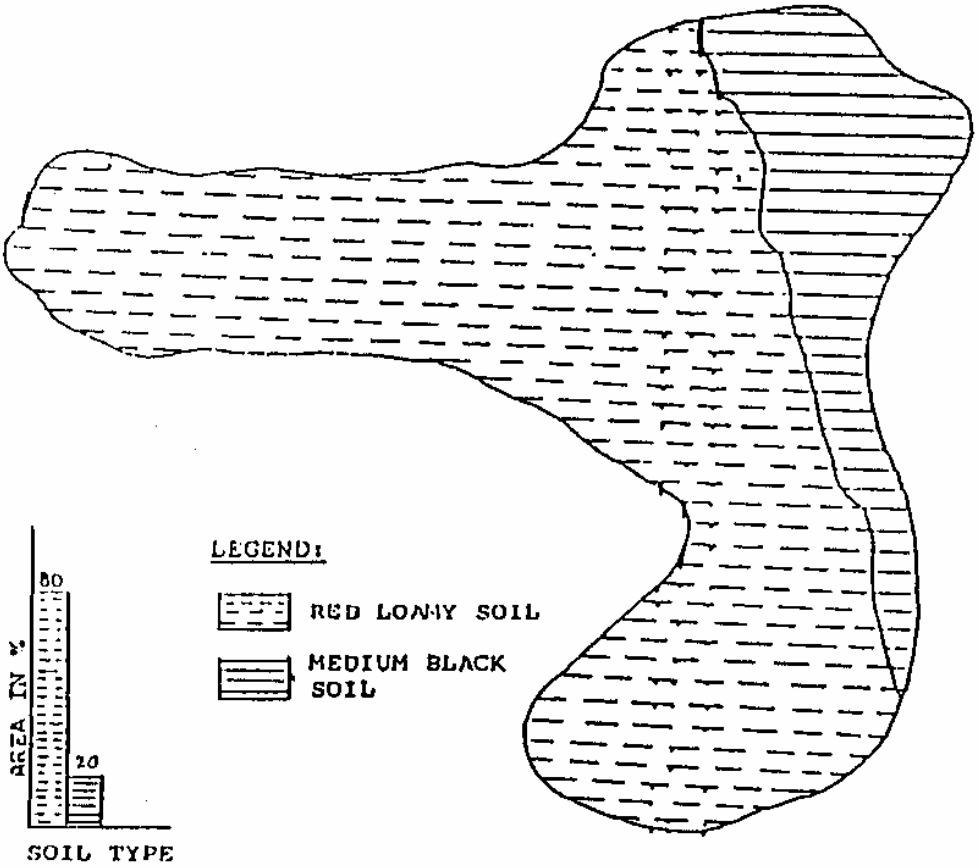

Fig.2. Soil Map

land is presented. A brief description of the different land use based on IRS-1A-LISS-II (fig.3) imageries and subsequent field check is presented below.

(i) Forests

Dry tropical forests cover about 62.65 per cent of the Malaprabha representative basin in Kankumbi, Jamboti and Gunji areas. The major species are covered by teak wood, rosewood, jack wood, Bamboo etc. The ground of this forest is covered by shrubs (2-4 m high) and grasses.

(ii) Shrubs

Shrubs and small trees and bushes (3-5 m high) cover the eastern facing watersheds of the area having steep slope (20-30). The most important feature of this class of land is that these are relatively shallow soil areas. About 19.3 % area of the basin is covered by shrubs.

(iii) Agriculture Land

The gentle slopes and level valley bottom areas, where the most fertile soil is confined, have been occupied by man for the cultivation of various cereal (paddy, ragi etc.) and cash crops (cotton, sugarcane). About 16.85 % of the total basin area fall under agricultural land.

(iv) Barren Land

About 1.15 % of the area is in the form of small patches, on steep slopes and on the gentle slopes having very thin film of soil, is in the form of barren land. This land is used for the grazing purpose of cattle.

(v) Geomorphology

The relief of the Malaprabha representative basin varies between 668 and 1038 m (fig.4) from the mean seal level. The contour map depicts the morphological characteristics. The pattern closely spaced contours on the water divides indicates that the cress and mid-crest

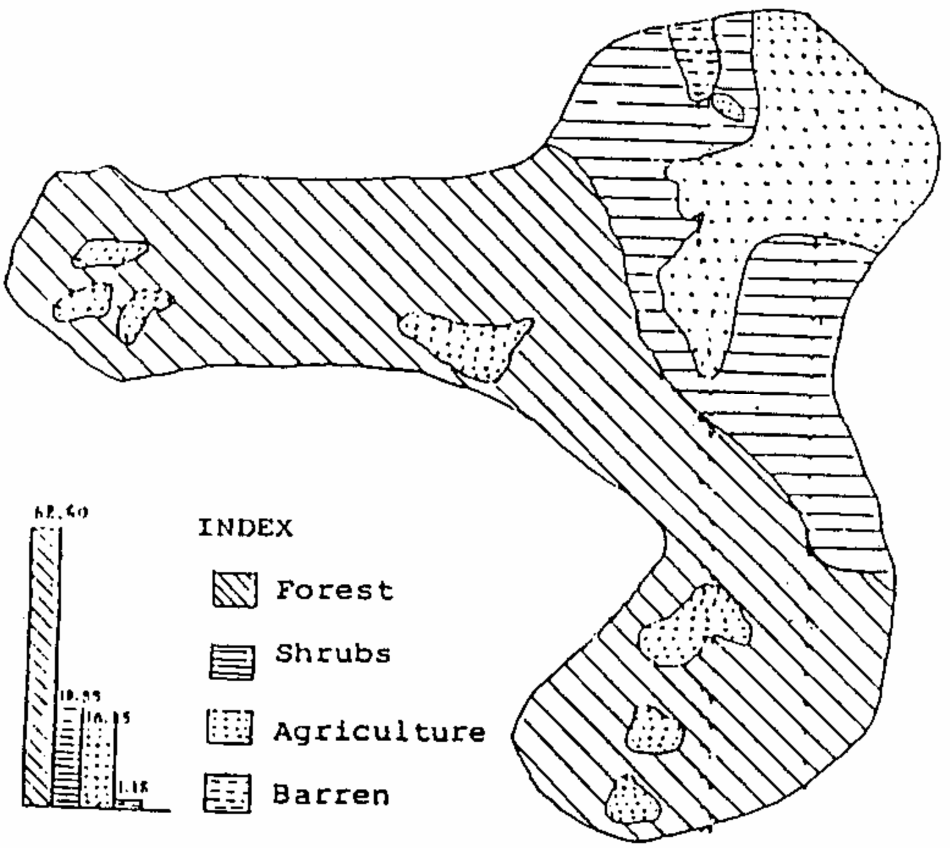

Fig.3. Landuse Map

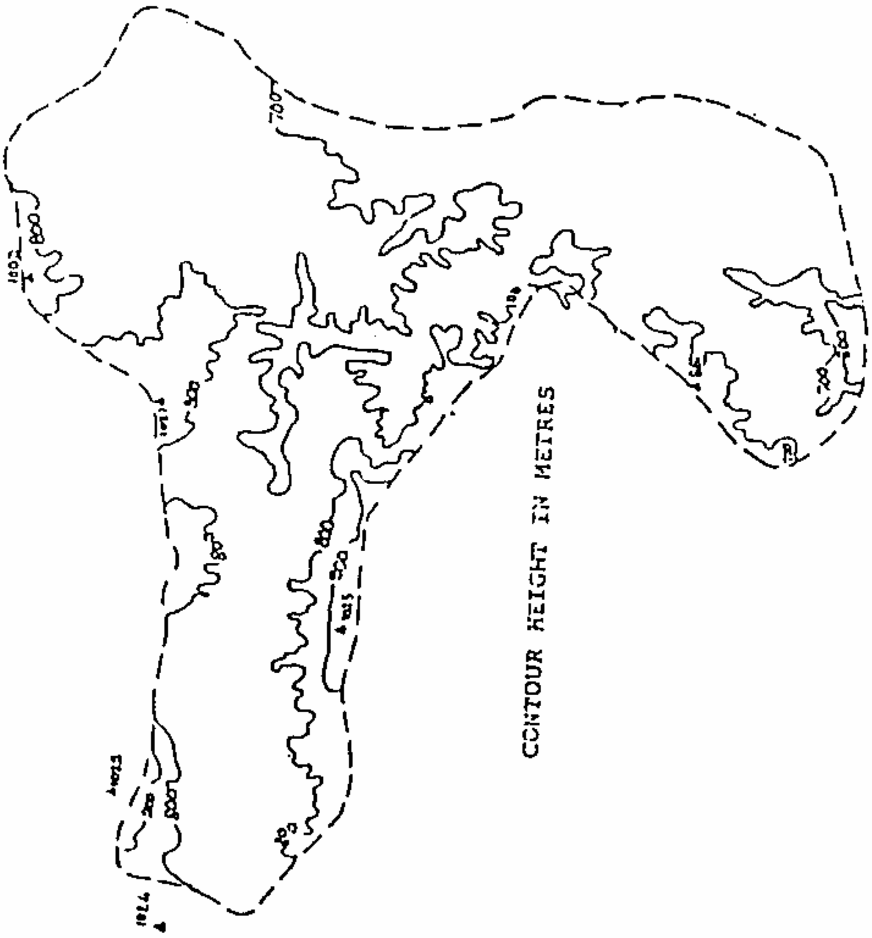

Fig.4. Contour Map

have convexo-concave slope, and the widely spaced contours in the valley bottom indicate gentle and flat valley bottoms. Thus, the basin is divisible into three distinct morphological zones.

These are

* Convex hill summit (more than 900m)
* Concave and gentle mid-crest and (800 - 900 m)
* Flat valley bottom (less than 800 m)

This change in morphological character from hill crest to valley bottom of the basin is largely responsible in the change in behavior of water flow between hillslope and foot slope. Further detailed geomorphological studies are required to understand the change in behavior of the hydrological processes form hillslope to foot slope.

The 800 m contour line divides the area into the hillslope. Above this contour line there is convexo-concave hillslope which has completely erosional environment. This is the zone of maximum overland flow and the minimum infiltration. The area below the 800 m contour line encompassing an area of 86.5 % of the total basin, the gentle and flat slope has depositional environment. This is the maximum recharge zone of the basin as is made up of colluvial materials.

(vi) Drainage Density

The drainage density based on topographic map varies between less than 0.5 km/sq. km on flat low lying depositional areas and more than 2.5 km/sq.km on convex hill crests in southern part of the basin, composed of relatively less resistant rocks of Pre-Cambrian age. The details corresponding to drainage network and the spatial distribution of different drainage density regions of the Malaprabha representative basin is given in table 1.

Table 1: Drainage morphometry of the Malaprabha representative basin

Stream order	No. streams	Bifurcation ratio	T.S.L	M.S.L	S.L.
1	784	3.96	651.16	0.83	-
2	198	3.96	329.3	1.66	2.0
3	50	6.25	97.46	1.95	1.17
4	8	4.0	58.14	7.27	3.73
5	2	2.0	47.62	23.81	3.27
6	1	-	2.35	2.35	0.10

* T.S.L - Total stream length in km
** M.S.L. : Mean Stream Length in km
*** S.L.R. : Stream Length Ratio

4.0 Development of a Physically-Based Erosion Model

Model development may be divided into two phases. The first is the creation of the physical model prototype and the second is model evaluation. The steps involved in model development are outlined in fig 5. The process begins with conceptualizing the natural system through the use of existing information. An example of the conceptualization process for erosion modelling is the set of equations presented by Meyer and Wischmeier. They presented a mathematical formulation of the erosion process based on observations by Elision which included descriptions of:

(a) Detachment by rainfall,
(b) Detachment by flow,
(c) Transport by rainfall, and
(d) Transport by flow.

The second step in the process of model development is to solve the equations and write the solutions in the form of computer code, assuming that the resultant model is to be computer driven. This step includes development of the overall computer model structure, which involves linking the various components of the technology into a complete working unit. Experimentation for developing a parameter database may begin simultaneously with the development of the computer code, since at this point the fundamental equation structure of the model is set.

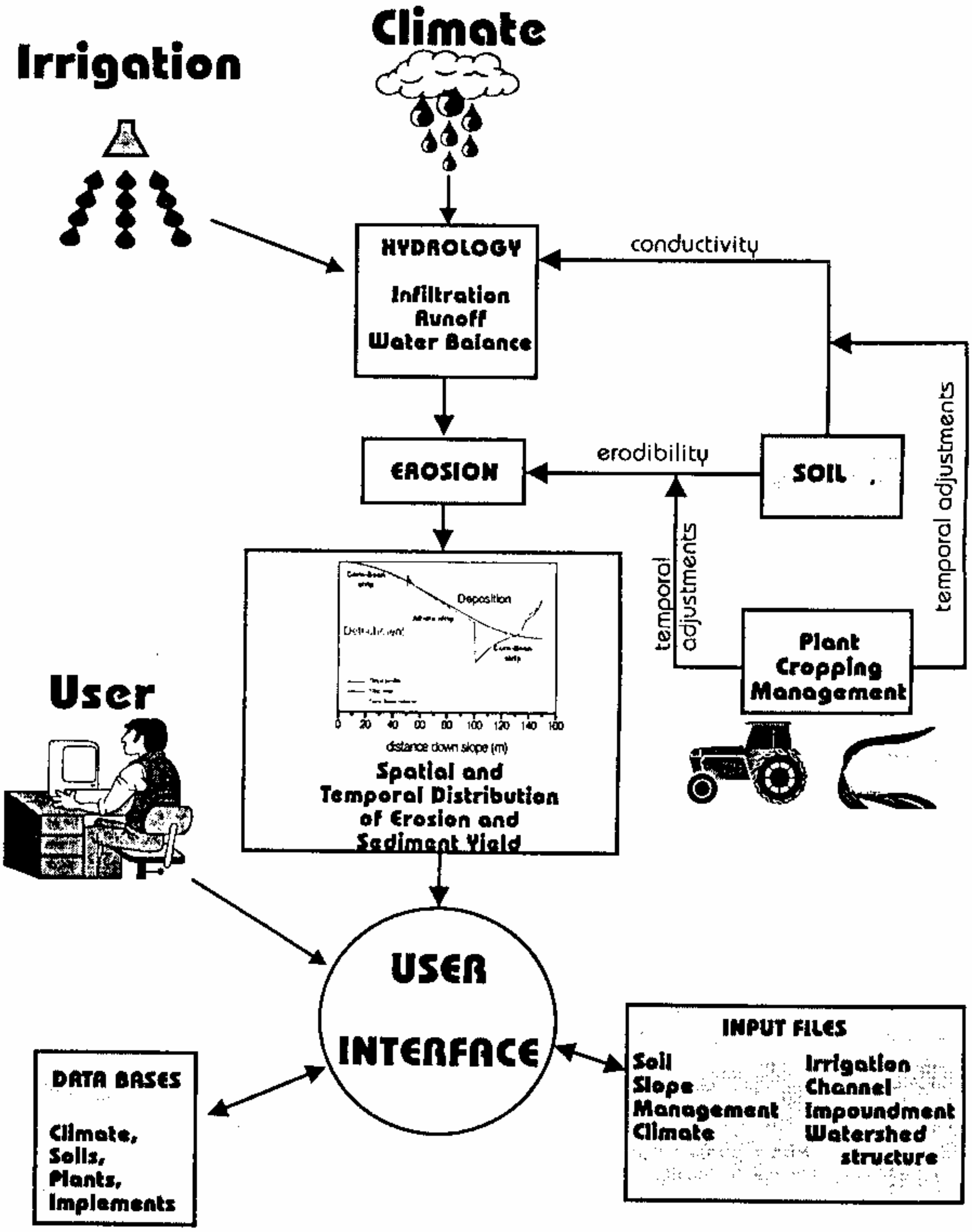

Fig. .5.: Flow chart for the WEPP erosion prediction model system.

After the model code and parameter-experiments are completed, the parameter estimation stage can begin. Parameter estimation involves two distinct steps:

(a) Parameter identification and
(b) Development of Parameter prediction equation or techniques.

Parameter identification is determining the model parameters from an experimental data set. It involves using the existing computer model and an optimization technique to analyze the experimental data to obtain model parameters for the measured data set. The second step is to develop a method for predicting model parameters for soils or environmental conditions not represented in the measured data set. The completed and tested computer code along with the parameter prediction techniques constitutes the prototype physical model, and represents completion of the first phase of the model development.

The second phase of erosion model development is the model evaluation phase, which included

(a) Sensitivity analysis,
(b) Confidence limit analysis, and
(c) Validation with data.

The results of the model evaluation are used to assess the validity of the model and to make the changes in basic equations, model structure, or parameter estimation procedures necessary to development of the validated working model. It is important that changes dictated by the model evaluation phase are followed through in a complete and logical manner. If changes in model structure are required to produce a valid working model, then the entire model development process must be followed again. The new structure will require a new set of parameters, which means that the measured experimental data will need to be re-analyzed and new parameters identified from the data. Then the parameter estimation procedures will need to be re-evaluated and new "prototype" model proposed and evaluated. The process is iterative. The model developers must be cognizant of and sensitive to the user's needs in making the decision as to when the process stops and the model is deemed "valid".

There are four major mechanisms for introduction of error in the modeling process. The first is in the formulation of the basic equations. Any mathematical representation of a natural process is approximate, at least when dealing on the scales related to soil erosion, and will cause the introduction of some error in terms of describing the system. These errors can be large, particularly where a minor factor for most cases, and hence neglected in the mathematical descriptions, is a major factor in a specific case. The second source of error is in the solution and coding to the equations. This should be a minor source of error except in certain cases where approximate solution techniques must be used for the sake of computational efficiency. A third source of error is experimental error and variation in experimental data. Experimental data associated with erosion experiments typically have a high degree of variation. A fourth source of error is in the parameter prediction procedure. any statistical method developed for predicting model parameters for untested situations will have some, and usually a large amount, of error associated with it.

4.1 Erosion Equations for a Steady State Model

The WEPP hillslope profile erosion model is a recent example of a physically based erosion model. The WEPP erosion model uses a steady state sediment continuity equation to describe downslope movement of sediment.

$dG/dx = D_f + D_i$ ----------- (13)

Where x (m) represents distance downslope, G ($kg/s/m^2$) is sediment load, D_i ($kg/s/m^2$) is lateral sediment flow from inter-rill areas, and D_f ($kg/s/m^2$) is rill erosion or deposition rate, Inter-rill sediment delivery. D_i is considered to be independent of x. Rill erosion, D_f, is positive for detachment and negative for deposition.

Inter-rill erosion in the model is conceptualized as a process of sediment delivery to rills, whereby the inter-rill sediment is then either carried off the hillslope by the flow in the rill or deposited in the rill. Sediment delivery from the inter-rill areas is considered to be proportional to the square of rainfall intensity, with the constant of proportionality being the inter-rill erodibility parameter. The function for inter-rill sediment delivery also includes terms to account for ground and canopy cover effects, which are discussed below. The inter-rill function is presented in equation,

$D_r = K_i I^2$ -------------- 14.

Where, D_i = rate of inter-rill sediment delivery to rills.
K_i = inter-rill erodibility parameter.
I = average rainfall intensity integrated over the duration of rainfall excess.

Net soil detachment in rills is calculated for the case when hydraulic shear stress exceeds the critical, shear stress of the soil and when sediment load is less than sediment transport capacity. For the use of rill detachment

$D_f = D_c [1-G/T_c]$ ------------ (15)

Where D_c is detachment capacity by flow as given in equation,

$D_c = K_r (\tau-\tau_c)$ -------- (16)

Where, D_c = detachment capacity.
K_r = rill erodibility.
τ = shear stress of the flow.
τ_c = critical hydraulic shear strength.

and T_c (kg/s/m) is sediment transport capacity in the rill. Rill detachment is considered to be zero when the hydraulic shear stress is less than critical shear strength of the soil.

Net deposition is computed when sediment load, G, is greater than sediment transport capacity, T_c for the case of deposition

$D_f = [V_f/q].[T_c-G]$ -------- 17.

Where V_f (m/f) is effective fall velocity for the sediment, and q (m^2/s) is flow discharge per unit width.

Representations of the effects of land use and management practices on erosion control are perhaps the most important part of an erosion prediction tool if the purpose is to help plan land and farm management systems to control erosion. Residue management and tillage practices on croplands are the mechanisms through which the farmer usually can most directly impact soil loss and effect erosion control. In the WEPP erosion model inter-rill sediment delivery is adjusted to account for effects of ground cover, dead roots, live roots, and canopy cover. Plant and soil management practices also affect infiltration processes greatly; these effects are discussed in Lane and Nearing.

The effect of surface cover in rills is probably overall the greatest single management effect on erosion, because it strongly influences both detachment and sediment transport processes. This effect is incorporated into the WEPP model via the hydraulic friction factor terms, which enable partitioning of the flow energy into that acting on the soil from that acting on the surface cover, including residue and rocks. The effect of buried residue is also accounted for in the WEPP model.

Rill erodibility is also affected by disturbance due to tillage. In the WEPP model, baseline rill erodibility for croplands is for the completely disturbed state, which for practical purposes is defined as that found immediately after moldboard tillage. Each tillage implement is defined with a tillage intensity term to reflect the fact that disturbance may be less (or more, if needed) than for the moldboard plow. From the disturbed state the soil consolidates. Computation of consolidation and changes in rill erodibility as function of time and weathering are made using a fundamentally-based consolidation model of Nearing et al.

Inter-rill erodibility is not adjusted for time in the WEPP model. Various data suggest that inter-rill erodibility does not greatly change with time. A further indication of this can be seen by comparing rangeland and cropland, inter-rill erodibility. Rangelands represent essentially a fully consolidated soil condition and freshly tilled croplands represent a fully unconsolidated soil condition. A comparison of average cropland erodibilities of 36 soils and 11 rangeland soil indicates that inter-rill erodibility for croplands is about four times that for range lands.

4.2 Continuous Simulation Models

The full benefit of an erosion prediction model is gained through the use of a continuous simulation model. By continuous simulation it is meant that the model "mimics" the process, which are important to erosion prediction as a function of time, and as affected by management decisions and climatic environment. Surface residue, for example, plays an important role in terms of predicting the amount of soil lost during a given rainfall event. An erosion model may use a plant growth and residue decay model to estimate the amount of crop residue present on the soil surface for each day through the year. A certain amount of residue is generated by leaf drop during senescence and by harvesting, and a pass of given tillage implement will bury a certain percentage of a given type of residue. An erosion model should adjust surface cover as a function of those and other processes, which affect residue cover. With a continuous simulation model, the user does not need to specify the amount of residue cover as a function of time. Soil parameter, residue amount, crop growth, soil water content, surface roughness, and essentially all other adjustments to model parameters should be calculated on at least a daily time step.

The output of the continuous simulation model represents time integrated estimates of erosion. In nature, as well as in the model predictions, a large percentage of erosion occurs due to a small percentage of rainfall events. The model simulates some number of years of erosion and sums the total soil loss over years for each point on the hillslope to obtain average annual values of erosion along the hillslope. The model calculates both detachment and depositions. It predicts where deposition begins and/or ends on hillslope, which may vary from storm to storm. Certain points on the hillslope may experience detachment during some rainfall events and deposition during other events. The output of the continuous simulation model represents an average over all of the erosion events.

A physically-based erosion model may also be executed in the single storm mode. In that case, all of the parameter used to drive the hydrology and erosion components of the model must be input by the user, including soil conditions for the day of the rainfall event, crop-canopy, surface residue, days since last disturbance, surface random roughness, oriented roughness, etc. In the continuous simulation mode the influence of these user inputs, which represent the initial conditions for the simulation, is small since the model adjusts each of those variable through the continuous simulation. In the single storm mode those inputs have a major influence on the output. The single storm option of the model requires a great deal more knowledge on the part of the user to interpret and use the output for planning, evaluation, and conservation design purposes. The single-storm model helps in understanding and evaluating the factors, which influence erosion on a hillslope; it has limited value in evaluating conservation systems where in condition change as a function of time through the year and from year to year.

4.3 Parameter Estimation

Soil erodibility for an erosion model is defined relative to the form of the erosion equations used. The approach is to first formulate the erosion equations for the model then to analyze experimental results relative to the particular set of erosion equations used. The equations should as accurately as possible describe the physical processes involved and the effects of various environmental factors on the physical processes. But in the model parameterization process we must recognize that every model is simplification of reality. The physical significance of the erodibility parameters is limited to the degree to which the erosion equations fully describe the physical process of erosion. The best alternative for parameterizing a model with experimental data is to use the model to analyze the data. This usually involves using an optimization technique. Which executes the model and searches for the set of erodibility parameters, which provide the best fit between, measured and calculated soil loss.

An example whereby too much physical significance may be placed into the erodibility parameters is with regards to the rill erodibility K_r. The WEPP model assumes that the primary mode of detachment in rills is scour, i.e. by way of the shear stress acting at the fluid/soil interface along the relatively well defined rill wetted perimeter. We recognize, however, that other mechanisms also act to detach soil in rills, including head cutting and side wall sloughing. The erodibility parameters in the physically-based models are more fundamental in nature than erodibility parameters for the USLE for example but still represent a simplification of the erosion processes.

The discussion above does not imply that more fundamentally-based predictors for erodibility parameters are not needed. Better, more fundamentally based predictors of erodibility will go along with improved erosion equation. Universal, fundamentally derived equations for relating soil properties to soil erodibility are very much needed. current methodology is to perform as many physical, chemical, mineralogical, mechanical, and erosion tests as possible on as many soils as possible and relate the soil properties to erodibility using statistical regression techniques. The problem with this approach is that it relies on inductive logic, and hence the results are questionable for applications outside the range for which they were derived.

4.4 WEPP Erosion Prediction Model

The USDA Water Erosion Prediction Project (WEPP) model represents a new erosion prediction technology based on fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hudraulics, and erosion mechanics. The hillslope or landscape profile application of the model provides major advantages over existing erosion prediction technology. The most notable advantages include capabilities for estimating spatial and temporal distributions of soil loss (net soil loss for an entire hillslope or for each point on a slope profile can be estimated on a daily, monthly, or average annual basis) and since the model is process-based it can be extrapolated to a broad range of conditions that may not be practical or economical to field test. In watershed applications, sediment yield from entire fields can be estimated. Figure 5 depicts a small watershed on which the WEPP erosion model could be applied.

Process considered in hillslope profile model applications include rill and inter rill erosion. Sediment transport and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration surface sealing, hydraulics, surface runoff, plant growth residue decomposition, percolation, evaporation, transpiration, snow melt frozen soil effects on infiltration and erodibility, climate, tillage effects on soil properties, effects of soil random roughness, and contour effects including potential overtopping of contour ridges. the model accommodates the spatial and temporal variability in topography, surface roughness, soil properties, crops, and land use conditions of hillslopes.

In watershed applications, the model allows linkage of hillslope profiles to channels and impoundments. Water and sediment from one or more hillslopes can be routed through a small field scale watershed. Almost all of the parameter updating for hillslopes is duplicated for channels. The model simulates channel detachment, sediment transport and deposition. Impoundments such as farm ponds, terraces, culverts, filter fences and check dams can be simulated to remove sediment from the flow.

In the following sections an overview of the WEPP erosion model is presented.

4.5 Program Design and Development

The WEPP erosion model and interface programs have been developed and tested on IBM/compatible personal computers running under MS-DOS 5.0+ operating system environments.

The computer program has been developed in a modular fashion, integrating in a top-down design all the specialized modules (program units) which perform the basic computations. This modular structure has been designed to facilitate substitution of different components and /or subroutines as improved technology is developed. No restrictions have been imposed on the input data length, the only limitation being due to the storage capacity of the hardware support. The source code is written in ANSI FORTRAN 77 for efficiency and portability, especially among personal computers. Work continues on code analyses and reprogramming to a standard coding convention to improve WEPP model maintainability and performance. Figure 6 shows the major calculation blocks and decision sequences in the current version of the computer program.

4.6 Model User Requirements

Expected users of the new generation of erosion prediction models include all current users of the Universal Soil Loss Equation (Wischmeier and Smith, 1978). Anticipated applications include conservation planning, project planning, and inventory and assessment. WEPP model overland flow profile simulations are applicable to hillslopes without concentrated flow channels, while watershed simulations are applicable to field situations with multiple profiles, channels (such as ephemeral gullies, grassed waterways, terraces), and impoundments (Foster and Lane, 1987). The length of the representative profile to which the WEPP hillslope model components can be applied depends upon the topography and land use controlling stream channel density. Hillslope profile applications compute inter rill and rill erosion and deposition along selected landscape profiles, while watershed applications also estimate channel erosion and deposition, and deposition in impoundments. The procedures do not consider classical gully erosion. Also, model application is limited to areas where the hydrology is dominated by Hortonian overland flow (i.e. rainfall rates exceed infiltration capacity and subsurface flow is negligible). The new erosion prediction technology is designed to be operational on personal computers and operate quickly so that several management schemes can be evaluated in a relatively short period of time.

4.7 Basic Concepts

The WEPP erosion model computes soil loss along a slope and sediment yield at the end of a hillslope, Inter rill and rill erosion process are considered. Inter rill erosion is described as a process of soil detachment by raindrop impact, transport by shallow sheet flow, and sediment delivery to rill channels.

Sediment delivery rate to rill flow areas is assumed to be proportional to the product of rainfall intensity and inter rill runoff rate. Rill erosion is described as a function of the flow's ability to detach sediment, sediment transport capacity, and the existing sediment load in the flow.

The appropriate scales for application are tens of meters for hillslope profiles, and up to hundreds of meters for small watersheds. For scales greater than 100 meters, a watershed representation is necessary to prevent erosion predictions from becoming excessively large.

Overland flow processes are conceptualized as a mixture of broad sheet flow occurring in inter rill areas and concentrated flow in rill areas. Broad sheet flow on an idealized surface is assumed for overland flow routing and hydrograph development. Overland flow routing procedures include both an analytical solution to the kinematic wave equations and regression equations derived from the kinematic approximation for a range of slope steepness and lengths, friction factors (surface roughness coefficients), soil textural classes, and rainfall distributions. Because the solution to the kinematic wave equation is restricted to an upper boundary condition to zero depth, the routing process for strip cropping (cascading planes) uses the concept of the equivalent plane. Once the peak runoff rate and their duration of runoff have been determined from the overland flow routing, or by solving the regression equations to approximate the peak runoff and duration. Steady-state conditions are assumed at the peak runoff rate for erosion calculations. Runoff duration is calculated so as to maintain conservation of mass for total runoff volume.

The erosion equations are normalized to the discharge of water and flow shear stress at the end of a uniform slope and are then used to calculate sediment detachment. Transport, and deposition at all points along the hillslope profile. Net detachment in all segments is considered to occur when hydraulic shear stress of flow exceeds the critical shear stress of the soil and when sediment load in the rill is less than sediment transport capacity. Net deposition in a rill segment occurs whenever the existing sediment load in the flow exceeds the sediment transport capacity.

In watershed applications, detachment of soil in a channel predicted to occur if the channel flow shear stress exceeds a critical value and the sediment load in the flow is below the sediment transport capacity. Deposition is predicted to occur if channel sediment load is above the flow sediment transport capacity. Flow shear stress in channels is computed using regression equations that approximate the spatially-varied flow equations. Channel erosion to a non-erodible layer and subsequent channel widening can also be simulated. Deposition within and sediment discharge from impoundment is modeled using conservation of mass and overflow rate concepts.

4.8 Model Components

The WEPP model includes components for weather generation, frozen soils, snow accumulation and melt, irrigation, infiltration, overland flow hydraulics, water balance, plant growth, residue decomposition, soil disturbance by tillage, consolidation, and erosion and deposition. The model includes options for single storm, continuous simulation, single crop, crop rotation, irrigation, contour farming, and strip cropping.

4.8.1 Weather Generation

The climate component (Nicks, 1985) generates mean daily precipitation, daily maximum and minimum temperature, mean daily solar radiation and mean daily wind direction and speed. The number and distribution of precipitation events are generated using a two-state Markow chain model. Given the initial conditions that the previous day was wet or dry, the model determines stochastically if precipitation occurs on the current day. A random number (0-1) is generated and compared with the appropriate wet dry probability. If the random number is less than or equal to the wet-dry probability, precipitation occurs on that day. Random numbers greater than the wet-dry probability give no precipitation. When a precipitation event occurs, the amount of precipitation is determined from a skewed normal distribution function. The rainfall duration for individual events is generated from an exponential distribution using the monthly mean duration. Daily precipitation is partitioned between rainfall and snowfall using daily air temperatures. Daily maximum and minimum temperatures and solar radiation are generated from normal distribution functions.

A desegregation model has been included in the climate component to generate time-rainfall intensity (breakpoint) data from daily rainfall amounts. That is, with a given a rainfall amount and rainfall duration, the desegregation model derives a rainfall intensity pattern with properties similar to those obtained from analysis of break point data. The break point rainfall data are required by the infiltration component to compute rainfall excess rates and thus runoff.

4.8.2 Irrigation

The irrigation component of the WEPP hillslope profile version accommodates stationary sprinkler system (solid-set, side-roll, and hand move) and furrow irrigation systems. four irrigation scheduling options are available;

1) No irrigation,
2) Depletion-level scheduling,
3) Fixed-date scheduling, and
4) A combination of the second and third options.

The first option is the default option for irrigation in WEPP. For the second option, the decision of whether irrigation is necessary is determined by calculating the available soil water depletion levels for the entire soil profile and for the current root depth and comparing to an allowable depletion level. This is conducted on a daily basis. For the fixed-date scheduling option, specific irrigation dates are read into the model from a user-created data file. The fourth option is included primarily to allow a pre-planting irrigation and leaching of salts from the root zone. Parameters for depletion-level and fixed-date scheduling are read from individual data files.

4.8.3 Infiltration

The infiltration component of the hillslope model is based on the Green-Apt equation as modified by Mein and Larson (1973), with the ponding time calculation, for an unsteady rainfall (Chu, 1978). The infiltration process is divided into two distinct stages, a stage in which the ground surface is ponded with water and a stage without surface ponding. During an unsteady rainfall, the infiltration process may change from one stage to another and shift back to the original stage. Under a ponded surface the infiltration process is independent of the effect of the time distribution of rainfall. At this the infiltration rate reaches its maximum capacity and is referred to as the infiltration capacity. At this stage rainfall excess is computed as the difference between rainfall rate and infiltration capacity. Depression storage is also accounted for. Without surface ponding, all the rainfall infiltrates into the soil. The infiltration rate equals the rainfall intensity, which is less than the infiltration capacity, and rainfall excess is zero.

4.8.4 Overland Flow Hydraulics

Surface runoff is represented in two ways in WEPP hillslope model applications, first, broad sheet flow is assumed for the overland flow routing and hydrograph development. Overland flow routing procedures include both an analytical solutions to the kinematic wave equation and an approximate method. The approximate method uses two sets of regression equations, one for peak runoff rate and one for runoff duration. These regression equations were derived from the kinematic approximation for a range of slope gradients and lengths, friction factors (surface roughness coefficients), soil textural classes, and rainfall distributions. Because the solution to the kinematic wave equation is restricted to an upper boundary condition of zero depth, the routing process for strip cropping (cascading planes) uses the concept of equivalent planes. Once the peak runoff rate and the duration of runoff have been determined from the overland flow routing, or by solving the regression equations to approximate the peak runoff rate and duration, steady-state conditions are assumed at the peak runoff rate for rill erosion and transport calculations.

The proportion of the area in rills is represented by a rill density statistic (equivalent to a mean number of rills per unit area) and an estimated rill width. Representative rill cross sections are based on the channel calculations for equilibrium channel geometries similar to those used in the CREAMS model (Knisel, 1980) and width-discharge relationships derived from Gilley et al. (1990). Depth of flow, erosion calculations are then made for a constant rate over a characteristic time to produce estimate of erosion for the entire runoff event.

4.8.5 Water Balance

The water balance and percolation component of the hillslope model is based on the water balance component of SWRRB (Simulator for Water Resources in Rural Basins) (Williams and Nicks, 1985), with some modifications for improving estimation of percolation and soil evaporation parameters. The water balance component maintains a continuous balance of the soil moisture within the root zone on a daily basis. Redistribution of water within the soil is accounted for by the Ritchie evapotranspiration model (Ritchie, 1972) and by percolation from upper layers to lower layers based on a storage routing technique (Williams et al., 1984). The water balance component uses information generated by the weather generation component (daily precipitation, temperature, and solar radiation), infiltration component (infiltrated water volume), and plant growth component (daily leaf area index, root depth and residue cover).

4.8.6 Plant Growth

The plant growth component simulates plant growth for cropland and rangeland conditions. The purpose of this component is to stimulate temporal changes in plant variables that influence the runoff and erosion processes. The cropland plant growth model is based on the EPIC model (Williams et al., 1984) and predicts biomass accumulation as a function of heat units and photosynthetically active radiation. Potential growth is reduced by moisture and temperature stress. Crop growth variables computed in the cropland model include growing degree days, mass of vegetative dry matter, canopy cover and height, root growth, leaf area index, plant basal area etc. The cropland plant growth model accommodates mono, double, rotation, and strip cropping practices.

The range land plant growth model estimates the initiation and growth of above and below-ground biomass for range plant communities by using a unimodel or a biomodel potential growth curve. Range plant variables computed in the rangeland model include plant height, litter cover, foliar canopy cover, ground surface cover, exposed bare soil, and leaf area index. Range management practices such as herbicide application, burning and grazing may be simulated.

4.8.7 Residue Decomposition

The residue decomposition component estimates decomposition of flat residue mass (residue mass in contact with the soil surface), standing material (residue mass standing above ground), submerged residue mass (residue mass that has been incorporated into the soil by a tillage operation), and dead root mass. Decomposition parameters must be specified in the management input file. The decomposition component partitions total residue mass at harvest into standing and flat components based upon harvesting and residue management techniques. The model also sets the initial stubble population at harvest equivalent to the plant population calculated in the plant growth component.

4.8.8 Soil Parameters

Soil parameters that influence hydrology and erosion are updated in the soil component, and include

1) Random roughness,
2) Oriented roughness
3) Bulk density,
4) Wetting-front suction,
5) Hydraulic conductivity,
6) Inter-rill erodibility,
7) Rill erodibility, and
8) Critical shear stress.

Random roughness is most often associated with tillage of cropland soil, but any tillage or soil disturbing operation creates soil roughness. Random roughness decay following a tillage or soil disturbing operation creates soil roughness. Random roughness decay following a tillage operation is predicted in the soil component from a relationship including a random roughness parameter and the cumulative rainfall since tillage. A random roughness parameter is assigned to a tillage implement based upon measured averages for an implement. Oriented roughness results when the soil is arranged in a regular way by a tillage implement. In WEPP hillslope applications, oriented roughness is the height of ridges left by tillage implements. Which can vary by a factor of two or more depending upon implement type. Ridge decay following tillage is computed from a relationship including a ridge height parameter and the cumulative rainfall since tillage. A ridge height value is assigned to a tillage implement based on measured averages for that implement.

Bulk density reflects the total pore volume of the soil and is used to update several infiltration related variables, including wetting front suction. Adjustments to bulk density are made due to tillage operations, soil water content, rainfall consolidation, and weathering consolidation. The approach to account for the influence of tillage operations on soil bulk density is a classification scheme where each implement is assigned a surface disturbance value ranging from 0 to 1, which is similar to approach used in EPIC (Williams et al., 1984).

Effective hydraulic conductivity is a key parameter in the WEPP model that controls the prediction of infiltration and runoff.

The inter-rill erodibility parameter is a measure of the soil resistance to detachment by raindrop impact. Because the soil is disturbed for the cropland erodibility tests and not for rangeland tests (Laflen et al., 1987; Simanton et al., 1987), algorithms for adjusting the inter-rill erodibility parameter are different for cropland and undisturbed rangeland soils. Adjustments to the inter-rill erodibility parameter on croplands are made to account for root biomass, freezing and thawing, canopy cover, residue cover, and sealing and crusting. Adjustments to the inter-rill erodibility parameter on rangeland are made to account for freezing and thawing.

The rill erodibility parameter is a measure of the soil resistance to detachment by concentrated rill flow and is often defined as the increase in soil detachment per unit increase in shear stress of the flow. Critical shear stress is a threshold parameter defined as the value above which a rapid increase in soil detachment per unit increase in shear stress occurs. As for the inter-rill erodibility parameters, different relationships are used for adjustments of the rill erodibility parameters and critical shear stress on cropland and range land soils. These adjusting equation include the effects of incorporated residue and roots, sealing and crusting, and freezing and thawing.

4.9 Hillslope Erosion and Deposition

Soil erosion is represented in two ways for WEPP overland flow profile applications:

1) Soil particle detachment by raindrop impact and transport by sheet flow on inter-rill areas (inter-rill delivery rate), and
2) Soil particle detachment, transport and deposition by concentrated flow in rill areas (rill erosion).

Calculations within the erosion routines are made on a per unit rill width basis and subsequently converted to a per unit width basis.

Inter-rill delivery rate is modeled as proportional to the product of rainfall intensity and inter-rill runoff rate. The mathematical function describing inter-rill delivery rate also includes parameters to account for the effects of soil roughness, slope steepness, and adjusted soil erodibility on inter-rill detachment and transport. Detachment due to rainfall occurs during period when infiltration capacity is greater than rainfall intensity is not considered to contribute to inter-rill detachment.

Rill erosion modeled as a function of the flow's capacity to detach soil, transport capacity, and the existing sediment load in the flow. Net soil detachment in rills occurs when hydraulic shear stress exceeds critical shear stress and when sediment load is less than sediment transport capacity. Net deposition occurs when sediment load is greater than sediment transport capacity. Sediment transport capacity and sediment load are calculated on a unit rill width basis. Sediment load is converted to a unit width basis at the end of the calculations. Sediment transport capacity is calculated as a function of x (distance downslope) using a simplification of a modified Yalin (1963) equation. Conditions at the end of a uniform slope through the end points of the given profile are used to normalize the erosion equations. Distance downslope is normalized to the total slope length. The slope at a point is normalized to the uniform slope. Shear stress is normalized to shear stress at the end of the uniform slope. Sediment load is normalized to transport capacity at the end of uniform slope.

The erosion and deposition component has four dimensionless parameters one for inter-rill sediment delivery to rills, two for rill detachment, and one for rill deposition. The normalized sediment continuity equation is solved analytically when net deposition occurs but it is numerically integrated when detachment occurs.

4.10 Watershed Channel Hydrology and Erosion Processes.

The WEPP watershed model is a process based, continuous simulation model built as an extension of the WEPP hillslope model. The model was developed to predict erosion effects from agricultural management practices and to accommodate spatial and temporal variability in topography, soil properties, and land use conditions within small agricultural watershed. Hillslope OFE hydrologic and erosion output (e.g., runoff volume, peak runoff rate, and sediment concentration) is stored in a hillslope to watershed pass file and then read in and used by the channel component. (as represented conceptually in fig. 6) The watershed model is capable of

1) Identifying zones of sediment deposition and detachment within constructed channels (e.g., grassed waterways or terraces) or concentrated flow (ephemeral) gullies,

2) Accounting for the effects of backwater on sediment detachment, transport, and deposition within channels; and

3) Representing spatial and temporal variability in erosion and deposition processes as a result of agricultural management practices.

It is intended for use on small agricultural watershed (up to 260 ha) in which the sediment yield at the outlet is significantly influenced by hillslope and channel processes.

The channel component can be divided into the hydrology and erosion components. The channel hydrology component computes infiltration, evepotranspiration, soil water percolation, canopy rainfall interception, and surface depressional storage in the same manner as the hillslope hydrology component. Rainfall excess is calculated using Green-Ampt Mein Larson (GAML) (Mein and Larson,1973) infiltration equation.

Two methods are provided for calculating the peak runoff rate at the channel (sub-watershed) or watershed outlet

1) A modified version of the Rational equation similar to that used in the EPIC model (Williams, 1995); or

2) The equation used in the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model. (Knish, 1980).

Channel water balance calculations are performed after the channel runoff volume has been computed. The channel water balance and percolation routines are identical to those used in the hillslope component; Input from the climate, infiltration, and crop growth routines are used to estimate soil water content in the root zone, soil evaporation, plant transpiration, interception, and percolation loss below the root zone.

The watershed model erosion component assumes, that watershed sediment yield is a result of detachment, transport, and deposition of sediment on overland (rill and inter-rill) flow areas and channel flow areas, that is, erosion from both hillslope areas and concentrated flow channels must be simulated by the watershed version. Flow depth and hydraulic shear stress along the channel are computed by regression equations based on a numerical solution of the steady-state spatially-varied flow equation. Outlet conditions for the channel are assumed to be controlled by a downstream uniform flow, critical depth, or a structure having known rating curve (e.g. an experimental flume). Sub-critical flow is assumed unless the user specifies, slope of the energy grade line (friction slope) that equals the channel (bed) slope. Channel computations are made assuming triangular, or naturally eroding channel sections; however, the actual channel must be approximately by a triangular channel to compute the friction slope.

The triangular channel section may have cover, but the naturally eroding channel section is assumed to be bare with no cover.

The movement of suspended sediment on rill, inter-rill, and channel flow areas is based on a steady-state model developed by Foster and Meyer (1972) that solves the sediment continuity equation. Detachment transport and deposition are calculated by a steady-state solution to the sediment continuity equation. Lane and Foster (1980) compute relationships for the detachment capacity of channel erosion using expressions developed from an experimental and analytical rill erosion study. The flow detachment rate is proportional to the difference between:

1) The flow shear stress exerted on the bed material and the critical shear stress; and
2) The transport capacity of the flow and the sediment load.

Net detachment occurs when flow shear stress exceeds the critical shear stress of the soil or channel bed material and when sediment load is less than transport capacity. Net deposition occurs when sediment load is greater than transport capacity. A non-erodible boundary is assumed to exist at some depth below the bottom of the channel. When a channel erodes to the non-erodible boundary, the channel widens and erosion rate decreases with time until the flow is too shallow to cause detachment.

4.10.1 Watershed Impoundment Component

Impoundment can significantly reduce sediment yield by trapping as much as 90% of incoming sediment, dependent upon particle size, impoundment size, and inflow and outflow rates. Typical impoundment includes terraces, farm ponds, and check dams. The watershed model impoundment component calculates outflow hydrographic and sediment concentration for various types of outflow structures suitable for both large (e.g., farm ponds) or small (e.g. terraces) impoundments including culverts, filter fences, straw bales, drop and emergency spillways, and perforated risers. Hydrologic inputs to the impoundment component include precipitation event generated runoff volume and flow rate. Sedimentologic inputs include the sediment concentration, particle size diameter for five particle size classes (clay, silt, sand, small aggregates, and large aggregates), and the fraction of each particle size in the incoming sediment.

The impoundment component contains both hydraulic and sedimentation simulation sections. The hydraulic simulation section numerically integrates an expression of continuity using an adaptive time step, which increases when the inflow and outflow rates are relatively constant. A predicted outflow hydrograph including the time, storage and outflow at each time step is than generated. The sedimentation simulation section determines the amount of sediment deposited and the outflow

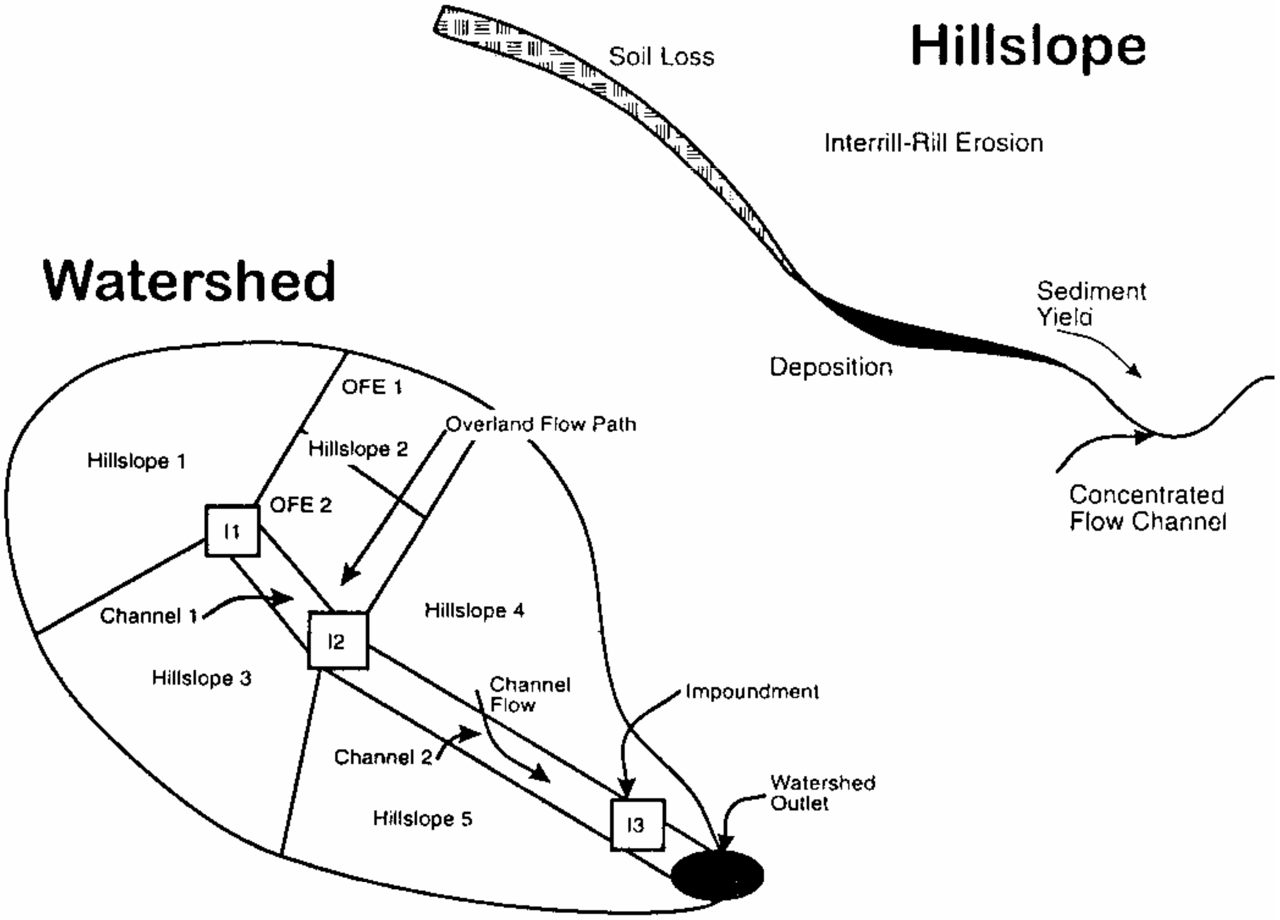

Fig.6. Conceptual representation of Hillslopes in WEPP model

sediment concentration for each time step. Deposition of sediment in the impoundment is calculated assuming complete mixing and later adjusted to account for stratification, non-homogeneous concentrations, and the impoundment shape. Conservation mass balance and overflow rate concepts are used to predict sediment outflow concentration. Impoundment component outputs include:

1) Peak outflow rate and volume leaving the impoundment;
2) Peak sediment concentration and the total sediment yield leaving the impoundment for the five particle size classes; and
3) The median particle size diameter of the sediment leaving the impoundment for the five particle size classes.

5.0 Application WEPP model to Malaprabha Representative basin

WEPP version 97.3 is used for all simulations. A continuous climate file was generated for 45 years using the 5 years observed rainfall data. In the slope file, the width of the hill slopes, number of Overland Flow Elements (OFE), slope and slope length of the study area is given. In the present case, 3 OFEs were considered over a slope length of 5000 m and a most suitable average slope have been considered for the simulation(fig.7).

Soil characteristics including soil albedo, initial saturation, number of soil layers, thickness, initial bulk density, percent sand, percent clay and organic matter have been used from the data collected by the Regional Centre, NIH, Belgaum. Initial saturation was calculated by assuming the porosity values for a particular type of soil. Rill and inter-rill detachment parameters, critical shear stress can be calculated internally. Hydraulic conductivity values have been used from the available data.

The required parameters in the management files for a continuous storm events was assumed initially and the WEPP calculates Arial and ground cover on the basis of biomass above and on the ground.

The parameterization is based on collected data and calculated values; however adjustment to some parameters was made in order to simulate the actual situation in the study area.

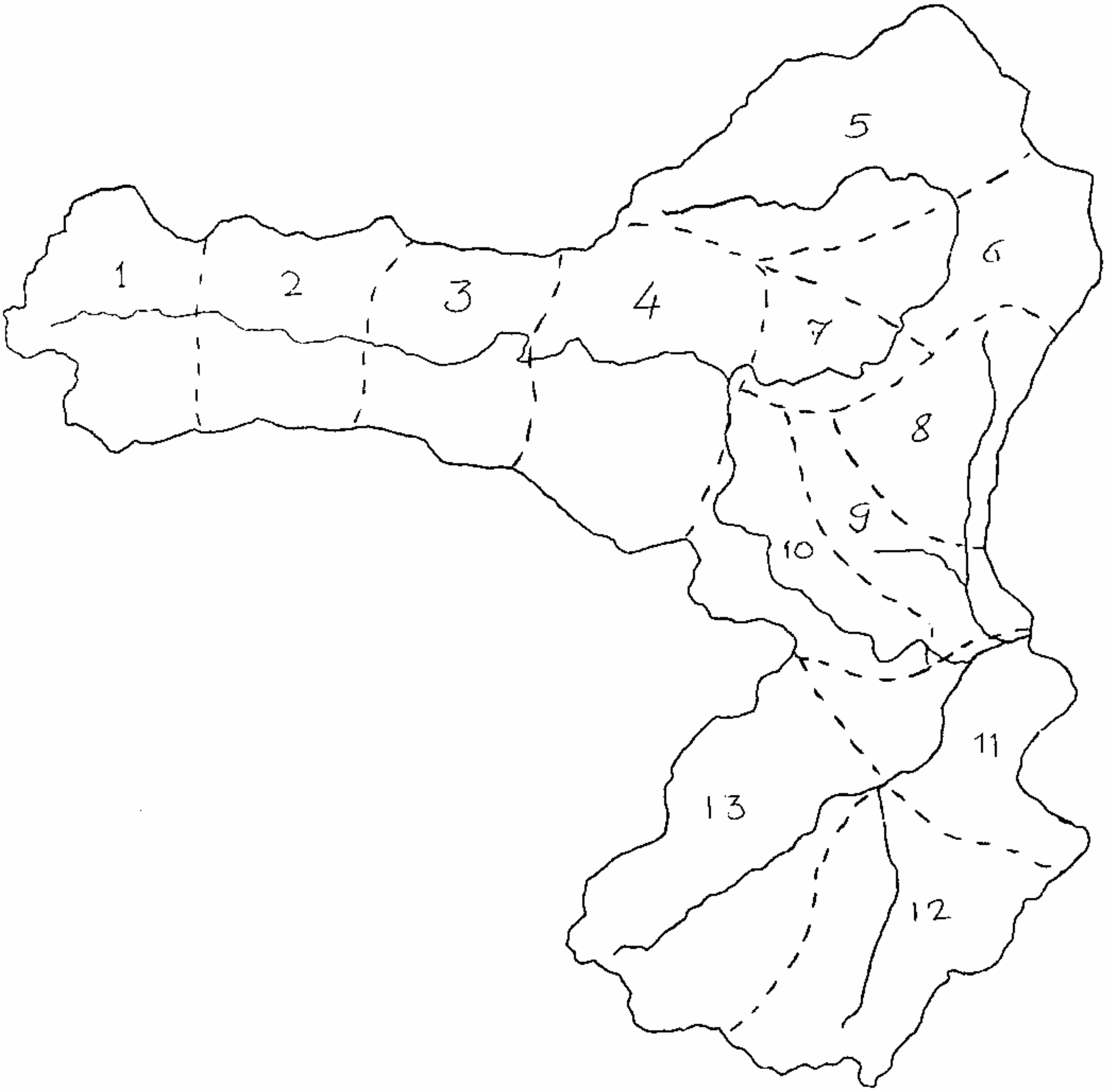

Fig.7. Malaprabha representative basin with delineation of Watersheds

Table : **Precipitation summary**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986				0.078	0.268	1.074	0.488	0.603	0.182	0.413	0.536	
1987				0.5858	0.489	0.213	0.557	0.206	0.494	0.655	0.082	0.216
1988		0.006		0.1824	0.245	0.289	1.157	0.618	0.282	0.144		0.69
1989			0.18	0.383	0.301	0.658	0.994	0.208	0.373	0.091		0.47
1990				0.2362	0.280	0.446	0.780	0.545	0.32	0.814	0.403	

5.1 Other Parameters considered for the study

The surface soil hydrologic properties are discussed below. For prper characterization of the surface soil properties four sites have selected and hydrological analyses were carried out. The first site represent an agriculture land along the course of the Malaprabha river. Various types of agriculture crops are grown in this land. The soil is dominated by sand 56% followed by silt -29% and clay -15%. Average bulk density of the soil sample is 1.48g/cc. Observed saturated moisture content varies between 38% and 44%. The field capacity of the soil is 0.22 and the wilting point is 0.11. The infiltration rate for agriculture land with medium black soil underlain by basalts varied between 1-2 cm/hr and agriculture land with red loamy soil underlain by basalt varied between 2-3 cm/hr. Along the Khanapur-Gunji stretch soil moisture characteristics were observed based on different land use covers.

The sample collected from a depth of 1/2 ft - 1'ft depth shows that the sand percentage is considerably (5%) lower than silt (40%) and clay (55%) particles. In this case, field capacity and wilting point are quite high (48% and 32%). The average bulk density is 1.19g/cc. Observed saturated moisture content was 55%.

The experiments conducted on different forest lands along the same stretch of land show that though the percentage of sand is higher on degraded land. There is considerable decrease in the rate of infiltration and hydraulic conductivity on the degraded land. When the forest cover is afforested with bamboo plantation, there is an improvement in the infiltration and hydraulic conductivity values.

A stretch along the Belgaum - Jamboti belt, the study indicated that the soil characteristic improve with depth. It is noted that there is considerable decrease in hydraulic properties just below the surface layer (at a depth of about 1/2 to 1 ft) and it improved at a depth of 1' - 2'. This increase in hydraulic properties indicate that , in a forested watersheds, the root depth and density plays a significant role in improving the soil properties.

The above description soil is essential for characterization of soil in the basin.

5.2 Estimation of USLE Components

In the representative basin, land and water are the two most important natural resources. In the absence of any integrated policy for their management, both these resources have been deteriorating over time. The indiscriminate use of land in these regions is causing devastating erosion of the land surface and silting of the reservoirs. A need therefore, exists in a comprehensive regional planning programme, to examine not only how land and soils are presently used, but also managed. In order to quantify the rate of soil erosion WEPP model was and USLE was applied to the catchment.

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5.2.1 Rainfall and Runoff factor, R

The rainfall and runoff factor in the USLE is the rainfall erosion index as presented by Wischemier(1959). The term rainfall erosion index implies a numerical evaluation of rainstorm or of a rainfall pattern, which describes its capacity to erode soil from an unprotected field. Differences in rainfall erosion potential are not necessarily associated with comparable differences in rainfall amount. The various intensities involved in specific rain antecedent climatic and surface conditions, interaction effects, and extraneous variable all influence the erosion potential from a storm. Rarely, if ever, is natural rainstorm exactly duplicated. Values of the respective characteristics may occur in anyone of numerous possible combinations. The most useful rainfall erosion index is, therefore, one whose magnitude represents a composite measurement of the various rainstorm characteristics, which influence the rate of erosion.

Wischmeier et al, (1958) concluded from the results of regression analysis that. with soil and slope constant, the most valuable combination of indicator of erosion losses from fallow soil is the following;

i) Rainfall energy

ii) A product term which measures the interaction effect of storm energy and maximum prolonged intensity.

iii) Antecedent moisture index.

iv) Total antecedent rainfall energy since the last tillage operation.

The most accurate single composite erosion index found in the studies is the second of the four variable listed above. The magnitude of the variable for a given storm is the product of the storm energy in foot-tons per acre and its maximum 30-minutes intensity in inches per hour. This product, designated by EI, provides a measure of the specific manner in which energy and prolonged intensity are combined in the storm. Commonly occurring values of the EI term for individual erosion-producing storms range from about 100 to slightly more than 10,000. By dividing the EI values by 100, a rainfall erosion index is defined whose magnitude for a single storm usually lies within the very convenient. Range 1 to 100.

5.2.2 Computation of Rainfall Energy on per Storm Basis

The energy of a rainstorm is a function of the amount of rain and of all the storm's component intensities. Median rain drop size increase with the rain intensity (Wischmeier and Smith, 1950), and terminal velocities for free falling water drops increase with increased drop size (Gunn and Kinzer, 1949). Since the energy of a given mass in motion is proportional to velocity-squared, rainfall energy is directly related to rain intensity. The relationship in metric units is expressed by Wischmeier and Mannering (1969) by the equation.

$KE = 210.3 + 89 \log I$ ---- (18)

Where KE is the kinetic energy in meter tonnes per ha-cm, and I is the rainfall intensity in cm per hr.

In order to compute the kinetic energy of a rain storm, the stôrm rainfall charts were divided into 0.5 hour of intensity increments. The above equation was utilized in computation of kinetic energy for each intensity increment of 0.5 hour. The total kinetic energy (KE) of the storm was obtained by summing up all the kinetic energy values for each 0.5 hour intensity increment. The sum of the kinetic energy in tons meter per hectares gives the total energy of rainstorm.

5.2.3 Determination of Erosion Index (Ei_{30}) Values on Storm Basis

Wischmeier and Smith (1958) stated that the rainfall energy itself is not a good indicator of erosive potential. The total energy storm indicates the volume of rainfall and runoff, but along slow rain may have the same value of as a short term rain at a much higher intensity. The erosion of the soil increases with the increase in the rainfall intensity. The prolonged peak rates of detachment and runoff are indicated by the I_{30} component. The statistical product term EI_{30} measures the interaction that reflects how total energy and peak intensity are combined in each particular storm. The detachment of soil particles and its combination with the transport capacity is technically indicated by the product term EI_{30}.

The erosion index (EI_{30}) values for each storm was determined as the method suggested by Wischmeier and Smith (1958). The product term EI was expressed as:

$EI_{30} = (KE.I_{30})/100$ ----- (19)

Where EI_{30} is the erosion index, KE is the total storm kinetic energy in tons meter per hectare and I_{30} is the maximum 30 minute intensity.

The monthly, seasonal and yearly EI values will be determined by adding the storm EI values for that length of period. In case erosion index values are desired for any particular week, season or growing period, etc. the storm EI values for that length of time may be summed up.

5.2.4 Determination of Soil Erodibility Factor, K

The soil erodibility, K, in the Universal Soil loss Equation is a quantitative description of the inherent erodibility of particular soils. The meaning of the term soil erodibility is distinctly different from that of the term 'soil erosion'. Land slope, rainstorm characteristics, cover and management than may influence the rate of soil erosion in the USLE more by inherent properties of the soil. However, some soils erode more readily than others do even when all other factors are the same. The difference caused by properties of the soil itself is referred to as the soil erodibility.

The soil erodibility factor, as described by Wischmeier and Smith (1965) is a function of complex interaction of a substantial number of its physical and chemical properties. Even a soil with a relatively low erodibility factor may show signs of serious erosion when it occurs on longer or steep slopes or in localities with numerous high intensity rainstorm. A soil with a high natural erodibility factor, on the other hand, may show little evidence of actual erosion under gentle rainfall, or when the best possible management is practiced. For a particular soil the erodibility factor, K, is the rate of erosion per unit of erosion index from a standard plot.

Based on the nomograph suggested by the United States Department of Agriculture (1978), and following the equation for the determination of soil erodibility of soils containing less than 70 percent silt and very fine sand;

$$100\,K = 2.1M^{1.14}(10^{-4})\,(12 - a) + 3.25\,(b - 2) + 2.5\,(c - 3) \quad \text{-----} \quad (20)$$

Where K is the soil erodibility factor, M is the particle size parameter which is equal to (percent silt + very fine sand) (100-percent clay), a is the percentage of organic matter content, b is the soil structure code used in soil classification and c is the profile permeability class. The soil erodibility factor for different land use pattern of Bino sub-watershed of Ramaganga river was computed by using the equation 20, and nomograph by Ashokan (1981). The same is adopted for this case.

The values of soil erodibility factor for different land was as reported by Ashokan (1981) are as below:

i) Forest and wood land	0.59
ii) Grass and waste land	0.43
iii) River bed and paths	0.56
iv) Crop land	0.58

The soil-erodibility factor for the watershed was determined by weighting the K values of each soil in the watershed according to the area covered by the soil.

The soil-erodibility factor is computed by

$$K = (\Sigma K_i.A_i)/A \qquad \text{-----------} \quad (21)$$

[=]

Where K is the soil erodibility factor for the watershed, K_i, is the soil erodibility factor for an individual soil I, A_i is the area of the watershed covered by an individual soil I, A is the area of the watershed, and n is the number of different soils in the watershed.

5.2.5 Computation of Topographic Factor, LS

The topographic factor, LS, is the expected ratio of soil loss per unit area from a field slope to that from 22.13 m length of uniform 9 percent slope under other wise identical condition. The effects of slope length and gradient are represented in the universal soil loss equation as L and S respectively. However, they are often evaluated as a single topographic factor LS. The slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters defined channel. The channel may be part of a drainage network or a constructed channel. Slope gradient is the field or segment slope, usually expressed as a percentage. The topographic component, LS was evaluated by using the contour length method suggested by Williams (1976) for large watershed. Williams (1976) proposed a method for determination of average watershed slope,

$$S = [0.25Z(LC_{25} + LC_{50} + LC_{75})]/A \qquad \text{----------} \quad (22)$$

in which S is the average watershed slope, Z is the watershed relief in km, LC_{25} LC_{50} and LC_{75} are contour lengths at 25, 50 and 75 percent of Z and A is the watershed arc in sq.km.

The soil loss per unit area generally increases substantially as slope length increases. The greater accumulation of runoff on the longer slopes increases its detachment and transport capacities. The average watershed slope length was determined by the following equation proposed by Williams (1976).

$L = (LC.\ LB)/2EP\sqrt{(LC^2 - LB^2)}$ ------- (23)

Where L is the watershed slope length in km, LC is the total contour length in Km which is equal to LC_{25}, LC_{50} and LC_{75}, and LB is the total contour base length in km. Using equation 23, the value of slope length factor for the watershed was determined.

The topographic component, LS for the watershed was evaluated by the following equation:

$LS = L^m(0.065 + 0.0454S + 0.0065S^2)/22.1$ ---------- (24)

in which,

LS = average length slope component,

L = slope length in meter,

S = Average watershed slope in percent and

m = exponent.

Current recommendations (Wischmeier and Smith, 1978 for the component m are:

m = 0.5 if slope $\geq$ 5 percent,

m = 0.4 if slope < 5 percent, and > 3 percent

m = 0.3 if slope $\leq$ 3 percent, and $\geq$ 1 percent, and

m = 0.2 if slope $\geq$ 1 percent,

The average length slope component for the watershed was determined to be ****** by using equation.

5.2.6 Evaluation of Cropping Management Factor, C

The cropping management factor, C, in the universal soil loss equation measures the combined effect of all the inter-related cover and management variables and is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean tilled continuous fallow.

Jaiswal (1982) determined the cropping management factor for different land use patterns in the Gagas sub-watershed, which is one of the sub-watersheds of the Upper Ramaganga catchment. The values of crop management factors proposed by him are listed as below.

i. Cropland 0.32
ii. Hay land and grazing land 0.21
iii. Reserve forest and wood land 0.02
iv. Rokhar and Miscellaneous 1.00

Using the same values the cropping management factor C, for the watershed, is determined by weighting the C values of each crop and management level according to the size of the area growing the crop with the same management level, C is computed by

$$C = (\sum_{i=1} Chi.\ Ai)/A \quad \text{--------} \quad (25)$$

in which C is the cropping management factor for the watershed, C_i = is the cropping management factor for crop I, A is the drainage basin area growing crop i with a particular management level, n is the number of land use areas in the watershed and A is the total watershed area.

5.2.7 Evaluation of Support practice Factor, P

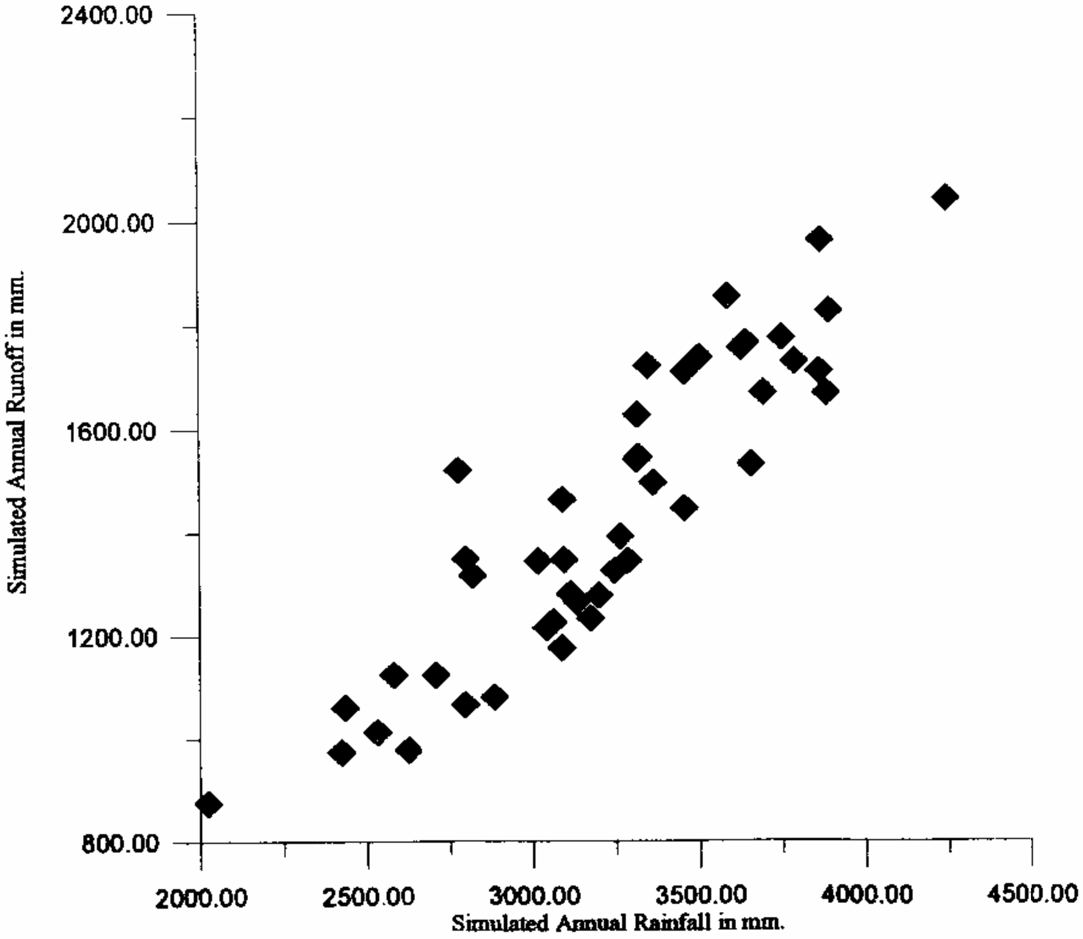
In general, whenever, sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the systems needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil it can carry. The most important of these supporting crop land practices are contour tillage, strip cropping the contour, and terrace systems. Stabilized water ways for the disposal of excess rainfall are a necessary part of each of these practices.

The support practice factor, P in the universal soil loss equation is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture.

In computing the P factor, only the cultivated area of the watershed is considered. The P factor was ascertained to be 0.6 for terraced agricultural land, and for the rest of the land 1.0, based on the method by USDA (1978).

6.0 Analysis of Data

Rainfall analysis of Malaprabha representative basin show that it is rainfed stream. Rainfall is distributed mainly from May to December. The rainfall varies widely over the representative basin (less than 1500 mm to more than 5000 mm). Streamflow is mainly confined to the rainy period. The stream has influent nature. June is month of approaching segment of the water discharge. July is the month which corresponds with rising segment. August is the month of peak discharge. September is the month of gradual recession segment. During October ther is rapid recession. With this typical rainfall variation to assess the soil erosion in the catchment WEPP aand USLE were used. Rainfall-Runoff relationship obtained through WEPP model (fig 8) is quite matching with earlier results reported by various authors. The results obtained by USLE and WEPP are presented table 3 and 4. It is observed that USLE has predicted lesser erosion rate as compared to WEPP model. The model was run for 45 years by generating the rainfall using CLIGEN. Nine crops (5 rotations) were considered for the analysis of soil erosion in an agriculture land. The crops considered are Paddy, Ground nut, Ragi, Jowar/Bajra, Fodder, wheat, Tur, Sugar cane and Cotton. The runoff predicted for the 45 years shows that the runoff varies between 37% and 52% and the average runoff predicted is 44.5 %. The sediment yield obtained through WEPP model varies between 9.49 tonnes/ha/year and 14.97 tonnes/ha/year. The average soil loss predicted per year is 12.3 tonnes/ha/year. The minimum soil loss of 0.07 tonnes/ha was obtained for a forested element. Maximum erosion was noted for an agriculture land (8.21 tonnes/ha/year). However, it is to be noted



Fit Results

Fit 1: Linear, Y=B*X+A
Equation:
Y = 0.564087 * X + -380.023
Number of data points used = 45
Average X = 3214.38
Average Y = 1433.17
Regression sum of squares = 3.08565E+006
Residual sum of squares = 689087
Coef of determination, R-squared = 0.817448
Residual mean square, sigma-hat-sq'd = 16025.3

Fig.8. Predicted Rainfall - Runoff Relationship using WEPP Model.

that the maximum erosion was from ground nut and jowar when compared to other crops considered. This need attention in considering for cropping pattern. This is only preliminary study and evaluation require intensive field study to confirm the above results. maximum erosion obtained is 277.27 tonnes/ha/year at a distance of 3015 meters. However, this is quite high and need further study to update the result.

USLE results indicated that the sediment yield in the forested areas Malaprabha representative basin varied between a minimum of 0.37 tonnes/ha/yr and 3.57 tonnes/ha/yr and the average yield is 1.24 tonnes/ha/year. Also, it is clear that forested watersheds play a significant role in soil conservation. In an agriculture land the sediment yield showed a significant increase compared to forested region, i.e. 12.3 tonnes/ha/year. Sediemnt yield in the agriculture land varied between 9.49 tonnes/ha/year and 14.97tonnes/ha/year. From the present study it is imperative that the cropping pattern seriously influences the rate of soil erosion. Therefore, it is necessary to go for planned cropping pattern in such areas. A detailed field level study is required to arrive at a specific conclusion.

7.0 RECOMMENDATIONS

7.1 Erosion Control Structures for Agricultural Lands

The important principles to be kept in view while planning measures for proper conservation and utilization of water are:

- Increasing the time of concentration and thereby allowing more runoff water to be absorbed and held in the soil profile.
- Intercepting a long slope into several short ones, so as to maintain less than a critical velocity for the runoff water; and
- Protection against damages owing to excessive runoff.

Terracing (bunding) is by far the most effective and widely practiced field measure for controlling or preventing erosion in different soil conservation regions. Terracing has also been adopted in different ways to meet varied physiographic and climatic conditions. In a general way, it can be defined as a series of mechanical barriers across the land slope to break the slope length and also to reduce the slope degree wherever necessary.

7.1.1 Different Types of Bunds

- Bunds constructed along contours or with permissible deviations from contours are called contour bunds.
- Bunds constructed at extreme ends of the contour bund, running along the slope are called side bunds.
- Bunds constructed along the slope in between two side bunds in order to prevent concentration of water along one side and to break the length of contour bund into convenient bits are called lateral bunds.
- Bunds constructed between two contour bunds so as to limit a horizontal spacing to the maximum required are called supplemental bunds.
- Bunds constructed along margins of the watershed, road margins, river or stream margins, gully margins and the like are called marginal bunds.

7.2 Erosion Control Structures for Non-agricultural, Denuded and Wasteland

These lands have one or more limitations of slope, erosion, stoniness, rockiness, shallow soils, wetness, flooding, climate, etc., which make them generally unsuited to cultivation for agricultural crops and limit their use largely to pasture, forest, wildlife and recreation. Out of a total area of 74.85 m ha of forest land, it is estimated that about 26% area are subject to soil erosion. Further a total area of about 56.5-m ha (17% of total geographical area) classed, as "wastelands" do not contribute anything to the Gross National Product (GNP) of India, on the contrary these lands are the source of maximum sediment, run-off and floods. These denuded forest lands and wastelands are in fact "wastelands", as they have a great potential for producing fodder, fuel, fibre, minor fruits and low quantity timber. To achieve this, it is necessary to adapt following suitable soil and water conservation engineering measures supplemented with proper afforestation techniques, horticultural practices, grassland development, etc.

- Contour and staggered trenches for hill slopes and wasted lands.
- Gully control structures for arresting gully erosion.
- Permanent drop structures for narrow and deep ravines.
- Contour stone walls on steepslopes of hilly areas, especially for tea plantations, etc, and
- Retaining walls for stabilizing precipitous hilly slopes.

Table . : USLE summary sheet

Shed	Landuse	R	K	LS	C	P	A t/ha
1a	Forest	1.5	0.59	0.346	0.02	0.85	$5.2055X10^{-3}$
1b				0.372			$50596X10^{-3}$
2a	Forest	1.5	0.59	0.123	0.02	0.85	$2.177X10^{-3}$
2b				0.1186			$2.099X10^{-3}$
3a	Forest	1.5	0.59	0.36	0.02	0.85	$6.372X10^{-3}$
3b				0.265			$4.69X10^{-3}$
4a	Forest	1.5	0.59	0.099	0.02	0.85	$1.7523X10^{-3}$
4b				0.114			$2.0178X10^{-3}$
5a	Agriculture	1.5	0.58	0.1085	0.32	0.85	0.03148
5b				0.116			0.03365
6a	Agriculture	1.5	0.58	0.14	0.32	0.85	0.04062
6b				0.13			0.03772
7a	Agriculture	1.5	0.58	0.1429	0.32	0.85	0.04146
7b				0.094			0.02727
8a	Agriculture	1.5	0.58	0.09	0.32	0.85	0.02611
8b				0.11			0.03191
9a	Forest	1.5	0.59	0.068	0.02	0.85	$1.0236X10^{-3}$
9b				0.088			$1.5576X10^{-3}$
10a	Forest	1.5	0.59	0.093	0.02	0.85	$1.6461X10^{-3}$
10b				0.086			$1.5222X10^{-3}$
11a	Forest	1.5	0.59	0.129	0.02	0.85	$2.2833X10^{-3}$
11b				0.555			$9.8235X10^{-3}$
12a	Forest	1.5	0.59	0.1058	0.02	0.85	$1.8726X10^{-3}$
12b				0.109			$1.9293X10^{-3}$
13a	Forest	1.5	0.59	0.112	0.02	0.85	$1.9824X10^{-3}$
13b				0.0456			$8.0712X10^{-3}$

Net rate of soil loss = 0.33 t/ha = 0.33kg/m^2

Table: Predicted Rainfall-runoff and soil loss for 45 years using WEPP model

Sl.No.	Rainfall (mm)	Runoff (mm)	Soil Loss kg/sq.m
1.	3260.20	1391.80	35.60
2.	3130.30	1264.90	39.46
3.	3039.40	1214.07	38.39
4.	3746.30	1777.05	48.29
5.	2815.20	1315.77	44.84
6.	3111.80	1279.53	54.70
7.	3196.50	1277.52	24.09
8.	3889.80	1827.00	73.67
9.	4242.00	2041.78	4.78
10.	3087.50	1462.91	88.89
11.	2422.30	972.61	30.65
12.	3860.40	1711.63	22.33
13.	2530.00	1011.17	40.14
14.	3314.70	1546.61	40.14
15.	3583.60	1855.85	73.22
16.	2792.80	1065.11	41.82
17.	3342.80	1722.61	57.97
18.	3283.50	1345.54	2.53
19.	3453.20	1446.30	81.60
20.	2881.60	1079.55	33.62
21.	3654.30	1533.57	33.87
22.	3453.50	1711.38	34.66
23.	2577.70	1123.00	39.49
24.	2773.30	1520.90	84.68
25.	3243.20	1324.70	69.75
26.	3880.40	1670.30	46.63
27.	3863.80	1963.50	1.83
28.	3639.90	1766.68	106.84
29.	3172.90	1232.56	51.87
30.	2622.70	976.56	28.28
31.	2023.30	874.81	20.94
32.	3623.30	1757.99	100.54
33.	3308.40	1540.80	82.66
34.	3092.10	1346.17	64.15
35.	3059.60	1224.80	67.80
36.	2705.60	1122.97	0.89
37.	3310.30	1627.74	101.73
38.	3013.50	1343.97	58.87
39.	3785.00	1731.46	37.30
40.	2996.00	1348.09	29.56
41.	3360.30	1496.02	58.63
42.	3498.30	1738.95	84.76
43.	3690.20	1671.38	85.37
44.	3084.80	1175.44	43.80
45.	2431.70	1059.38	6.04

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