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ESTIMATION OF SEDIMENT YIELD AND RUNOFF FROM SMALL WATERSHED USING 'WEPP' MODEL

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ANNEXURES

ABSTRACT

The USDA Water Erosion Prediction Project (WEPP) model is a continuous simulation model developed to predict soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flow in small channels, and sediment deposition in impoundments. In addition to the erosion component, it also includes a climate component which uses a stochastic generator to provide daily weather information, a hydrology component which is based on a modified Green-Ampt infiltration equation and solutions of the kinematic wave equations, a daily water balance component, a plant growth and residue decomposition component, and an irrigation component. The model computes spatial and temporal distributions of soil loss and deposition, and provides explicit estimates of when and where in a watershed or on a hill slope the erosion is occurring so that conservation measures can be selected to most effectively control soil loss and sediment yield.

In this study, WEPP Model is used to estimate the sediment yield and runoff from Sallopat watershed located within Mahi river basin, which is having a geographical area of 38.4 sq.km. Hill slope and Watershed versions of the model have been tested. Simulated rainfall data for 25 years was used for the analysis and the average annual sediment yield from the watershed is estimated as 4333 Kg/m and the average annual runoff at the outlet is estimated as 317 mm.

1.0 INTRODUCTION

Soil erosion is the removal of surface material by wind or water. When rain drop falls on a surface, the soil particles are splashed. Higher is the velocity of impact, greater is the amount of soil splashed. The detached soil particles are then carried further, either by runoff or wind. This whole process is known as erosion. The soil erosion affects the infiltration rates, crop production, water holding capacity, removal of organic matter and plant nutrients. Further, transported sediments lead to decrease in water quality, increasing eutrophication, and reduce the life of reservoirs.

The process of sediment yield is a natural phenomenon which occurs whenever the flow of sediment carrying river is impounded by any kind of obstacle. This results in reduction of storage capacity, water supply capability, power generation, discharge control, etc. of reservoirs, rivers, or catchments. The erosion in catchment changes groundwater regime and results in lowering of water table at some places and rise at the other with the formation of arid zones and marshes respectively. The fertility of soil and its chemical composition will also be changed due to erosion.

The soil loss and sediment yield problems are important in India, because of varying topographical and geological conditions, pressure of human and animal population on the land resources, and small land holdings. This is further aggravated by improper land use and faulty land management practices being adopted in the upland watersheds. It is estimated that at present 150 million ha. (about 45 % of total area of the country) of land under agriculture, forests, grass lands, and other land uses, is in need of soil conservation.

Problems associated with soil erosion and sedimentation may be divided into those which are on-site and off-site in character. On-site problems are associated with a net loss of sediment, and off-site problems, with a net gain of sediment. These types of problems are:

On-site Problems: Loss of plant nutrients, Loss of organic matter, Damage to soil structures, Subsoil exposure.

Off-site Problems: Siltation of streams, rivers & estuaries, Siltation of dams, Damage to crops, roads, culverts, etc., Deposition of soil pollutants.

Factors affecting erosion and sediment yield are;

Hydrology:	rainfall and runoff
Catchment Characteristics:	size and slope of the catchment and length of overland flow
Soil Characteristics:	soil erodibility, soil transportability, soil texture and soil structure
Land use Cover:	plant canopy, mulches, plant residue
Management Practices:	tillage, soil conservation structures, terraces, diversions, bunds, etc.

Of all the factors mentioned above, rainfall and runoff provide the basic energy input to drive the erosion process. Steepness of slope plays an important role in the process of erosion. Soil properties such as soil texture, structure, and the land cover also have a major role in erosion process.

The effects of land use on sediment yield are closely linked to those of climate and physiography, since the latter may exert a major control on land use practice. Where it's effect can be isolated, it is clear that the major contrasts in sediment yield may be attributed to the influence of land use. The precise sequence and timing of land use change within a basin will exert a strong control on the resultant pattern of sediment yield.

Scientific study of soil erosion has a long history in the geographic and geomorphic sciences, where much of the emphasis is on erosion as one of the natural landscape forming processes. Human activity, and expanding activities of agriculture, has led to an acceleration of soil erosion commonly associated with agricultural practices. Therefore, early agriculturally focused research on soil erosion depend on successful agronomic research methodologies. These methodologies were typified by planned experimentation followed by quantitative (often statistically guided) analysis of the results obtained.

Later on, researchers tried alternative methodologies in which more emphasis is being made on physical theory to provide a framework in which experimental data are analysed. In this approach, parameters are used, which have to be experimentally determined and which are more closely related to the processes to be involved in erosion and deposition. This new approach to soil erosion and deposition proved useful at the scale of runoff plots and small agricultural plots and efforts are being made at a rapid pace to utilise this approach to interpret erosion and deposition processes on larger scales.

There is growing recognition of interacting erosion experimentation with the development of models of the processes involved. Experimentation is essential to provide the database which models must be able to comprehend. However, models of erosion processes are not simply based on data, but on basic physical theory applied to the interpretation of such processes. Nevertheless, the experience of interacting models based on theory with experimental data has been shown to be most helpful, and progress in such interaction is taking place most rapidly in slope erosion studies.

Common Techniques for Estimating Sediment Yield

Sediment yield estimating techniques vary in their complexity depending on a large part upon the objective of the investigation and the availability of data. The methods commonly used in estimating sediment yield and some comments regarding problems of using each are given below (Renard, 1985);

1. The sediment rating curve/flow duration method : This method is highly dependent upon the accuracy of sediment concentration measurements at field locations. Meaningful data are difficult to obtain from this method on small watersheds because discharge of water and sediment vary rapidly and there is not enough time to sample accurately without sophisticated, permanent sampling equipment.

2. The sediment delivery ratio method : Sediment delivery ratio is a percentage relationship between sediment yield and gross erosion in a watershed. Sediment delivery ratios have been determined for many areas and found to be related to the drainage area.

3. Reservoir sediment deposition surveys : Sediment yield is estimated by adding the estimated amount of sediment that have passed through the reservoir, based on the reservoir's trap efficiency. These estimates can be used to relate sediment yield to drainage area. This approach provides information about magnitude and variation of average annual sediment yield, but has little value for forecasting sediment yield over a short time.

4. Field measurements of erosion and deposition : The difference between erosion and deposition estimates or measurements can be used to estimate sediment yield. The uncertainty of both erosion and deposition measurements can lead to large error.

5. Bedload relationships : The coarse fraction of sediment yield can be estimated using bedload relationships. Most of these relationships were developed primarily from laboratory flume studies.

6. Mathematical simulation models : Such models use relationships for the process of soil detachment, transport and deposition. These relationships are incorporated into a hydrologic model to estimate sediment yield. This method, widely used in research, is undoubtedly an important method. However, there are many limitations concerning parameter definition, extensive data requirement and computer cost.

7. Predictive equations based on watershed parameters such as drainage area, runoff, temperature, slope, soils, and cover : Eventhough such equations apply to a limited range of conditions, they are frequently used. Such predictive equations can be grouped into two categories; statistical and parametric.

2.0 REVIEW OF LITERATURE

Several models are available for predicting individual storm sediment yield from agricultural watersheds. Most of these models vary in complexity and are designed for use on small watersheds. Complex two-dimensional models have been developed for predicting individual storm sediment yield and determining the location and amount of deposition on small watersheds. These models would be quite useful for detailed studies.

Sediment transport model development began long before the days of modern computers. DuBoys (1879) is one of the modern giants in sediment transport modelling with his deterministic model for bedload transport, which he published in 1879. He was the first to postulate the theory of tractive force in streambed erosion, which has been used and built upon over the years.

In 1895, Kennedy published his work on permissible velocity of flow for the design of stable canals in India. He related velocity to the depth of flow as $V = cD^m$ where c and m are coefficients; c varies with characteristics of bed particles. He found that m was relatively constant for non-eroding, non-depositing canals.

Lacy (1930) followed up on DuBoy's work with tractive force theory to determine permissible velocities for stable canals.

Efforts of mathematically predict soil erosion started only about a half century ago. The development of erosion prediction technology began with analyses such as those by Cook (1936) who identified three major variables that affect soil erosion, susceptibility of soil to erosion, potential erosivity of rainfall and runoff, and soil protection afforded by plant cover. Several years later, Zingg (1940) published the first equation for soil erosion loss which described the effects of slope steepness and slope length on erosion. In 1941, Smith added factors for cropping systems and supporting practices to this equation.

Browning et al. (1947) added soil erodibility and management factors to the Smith equation and prepared extensive tables for relative factor values for different soils, rotations, and slope lengths. Smith and Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. The following year, Smith and Whitt (1948) presented a rational erosion-estimating equation, $A = CSLKP$. The C factor was the average annual soil loss for a specific rotation, slope length, slope steepness, and row direction. 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.

Erosion experiment stations were established in the 1930's by US Soil Erosion and Soil Conservation Services, which were concerned about the conservation of agricultural lands. These stations were responsible for measuring rainfall, runoff, and soil erosion from small plots. As a result of the erosion plot research, the first erosion models (equations) were developed. Ellison (1945) showed the effect of rainfall energy in sheet erosion by the equation $E = KV^{4.33} d^{1.07} I^{0.65}$, where E is the grams of soil intercepted in splash sampler during a 30 min. period, V is the velocity of drops in ft./sec., d is the diameter of the drops in mms, I is the intensity of rainfall in in./hr., and K is a constant. Musgrave (1947) analysed 40000 plot-years of data to develop his relationship to incorporate land characteristics as, $E=IRS^{1.35}L^{0.35}P_{30}{}^{1.75}$, where E is soil loss in acre-inches, I is the inherent erodibility of soil in inches, R is a cover factor, S is degree of slope in percent, L is the length of slope in feet, and P30 is the 2hr. 30 min. rainfall amount in inches.

Graphs to solve the Musgrave equation were prepared by Lloyd and Eley (1952). Van Doren and Bartelli (1956) proposed an erosion equation for different soils and cropping conditions that estimated annual soil loss as a function of nine factors.

During 1950, Einstein developed methodologies for bedload functions and bedload transport for rivers and major streams. Wischmetr and Smith (1958) re-examined the erosion plot data used by Musgrave and US Weather Bureau rainfall data and in 1958 published their first results which ultimately lead to the development of the Universal Soil

Loss Equation (USLE). USLE was published by Wischmeier and Smith (1965) and was based on over 10,000 plot years of natural and simulated runoff data. The average annual soil loss in tons/acre A is calculated as A = RKLSCP, where R is a rainfall factor, K is a soil erodibility factor, LS is a slope length and steepness factor, C is a cropping factor, and P is a conservation practice factor. This is designed to predict the long term average field soil losses in runoff under specific conditions. This model enables the planners to estimate the average rate of soil erosion for each feasible alternative combination of crop system and management practices in association with a specified soil type, rainfall patterns, and topography.

Since 1965, efforts have gone into improvement of the USLE and it has been expanded for additional types of land use, climatic conditions and management practices (Blackburn, 1980).

Renard et al. (1974) modified the USLE to clearly approximate soil loss from rangeland watersheds. They included an additional term to the USLE to accommodate channel erosion. Williams (1975) modified USLE (MUSLE) for predicting individual storm sediment yield from cropland watersheds. A sediment routing technique was developed to route sediment yield from small watersheds through streams and valleys to the outlets of large watersheds. MUSLE estimates sediment delivered to the stream by using a runoff factor instead of the rainfall energy factor. This modification enabled prediction of sediment yield resulting from individual storms. Onstard and Foster (1975) modified the USLE to include both rainfall and runoff energy terms to include both rainfall and runoff energy.

The USDA Forest service, under an interagency agreement with USEPA compiled a set of watershed analyses and prediction procedures (Snyder, 1980). These state-of-the-art techniques are collectively referred to as WRENSS (Water Resources Evaluation of Nonpoint Sources-Silvicultural). The objective of the soil erosion component in WRENSS is to estimate the quantity of accelerated soil loss under given silvicultural activity conditions. An empirical procedure was chosen for estimating soil loss using the USLE, modified for use in forest environments. The cropping management factor and the erosion control practice factor have been replaced by a vegetation management factor to form the Modified Soil Loss Equation (MSLE).

In earlier times, hydrology and erosion/sedimentation transport models generally were developed independently. The erosion and sediment transport equations were developed without corresponding hydrologic relationships. It was not until the development of the digital computer that model components were put together.

In 1962, Crawford and Linsely published one of the earliest hydrologic simulation model known as Stanford watershed Model (SWM). Glymph and Holton (1969) developed an infiltration-based hydrologic model known as USDAHL (US Department of Agriculture Hydrograph Lab) model, to estimate streamflow and uses a concept of soil zones in the watershed. Since water is the carrier of sediments, most sediment transport models were developed by selecting a hydrologic model and by including a sediment component. Crawford and Donigian (1973) developed the Pesticide Transport and Runoff (PTR) model with a revised Stanford watershed model as the hydrologic component. The sediment loss component of PTR consists of a part of Negev's ((1967) relationships for sediment detachment and transport. Although Negev simulated the entire sheet, rill, and channel erosion, the PTR model only uses the sheet and rill erosion components.

Frere et al. (1975) developed an agricultural chemical transport model (ACTMO) with the USDAHL model for the hydrologic component. The erosion-sediment transport component of ACTMO is a modification of the USLE to reflect both rainfall and runoff erosivity and transport processes. The erosion component estimates the contribution of rill and interrill sources to sediment load.

Bruce et al. (1975) developed a parametric model for water-sediment-chemical (WASCH) runoff for single storm events. The sediment component of WASCH considers the rill-interrill erosion concepts developed by Foster and Meyer (1975), but uses erosion and routing functions for both rill and interrill erosion.

Donigian and Crawford (1976) modified the PTR model and the revisions resulted in the Agricultural Runoff Management (ARM) model. Donigian and Crawford (1976) developed a Nonpoint Source Pollutant loading (NPS) model, which is having hydrology and erosion components identical with those in ARM.

Beasley et al. (1977) developed a distributed deterministic model (ANSWERS) for predicting runoff and erosion/sediment transport for different agricultural management systems for basin size areas. The erosion component of ANSWERS is a modification of the USLE. Two soil detachment processes were included, rainfall detachment and overland flow detachment.

Simons et al. (1977) developed a model to predict runoff and sediment from small basins. The sediment component considers erosion by raindrop splash and shear stress of overland flow. Raindrop erosion is expressed as a power function of rainfall intensity and an empirically determined erodibility factor. Erosion by overland flow uses a detachment coefficient that requires calibration for specific soils. Sediment transport in the model considers transport capacity for individual sediment sizes.

Williams and Hann (1978) developed a basin scale model to consider surface runoff, sedimentation, and plant nutrients. The hydrologic component is a modification of the SCS curve number model. The USLE was modified for the erosion component by replacing the rainfall energy term with a product of storm runoff volume and peak rate of discharge raised to a power.

Wade and Heady (1978) developed National Water Assessment (NWA) model, based on agricultural crop production considering sediment as a pollutant. This model does not contain a hydrologic component, but estimates annual erosion using the USLE.

USDA, Science and Education Administration-Agricultural Research developed a field-scale model in 1980, to estimate chemicals, runoff, and erosion from agricultural management systems (CREAMS). It is a physically based, daily simulation model that estimates runoff, erosion/sedimentation, plant nutrient and pesticide yield form field sized areas. The erosion component maintains elements of the USLE, but includes sediment transport capacity for overland flow.

Rohlf and Meadows (1985) developed a mathematical model for simulating rill formation during the overland runoff-erosion process. The model couples the water-sediment continuity equation, sediment continuity equation, and the kinematic approximation to the water-sediment momentum equation with sediment transport, erosion and channel boundary shear relationships for the prediction of sediment discharge and channel geometry variation during rill formation.

Lopes and Lane (1990) stated that physically based mathematical models for sediment yield provide several advantages over existing sediment yield models. The physically based models provide an improved understanding of the fundamental sediment producing processes, having the capability to access the spatial and temporal variations of sediment entrainment, transport and deposition processes. They formulated a process based mathematical model for simulating the spatial and temporal variations of sediment entrainment, transport, and deposition process on a small semiarid watershed called WESP (Watershed Erosion Simulation Program), which is physically based, distributed parameter, event-oriented, one dimensional, numerical model. WESP includes components for computing rainfall excess rates, broad sheet flow (interrill flow), concentrated flow (rill and stream channel flow), and erosion, sediment transport, and deposition on interrill, rill, and stream channel systems.

Glidden et al. (1990) used MUSLE (Modified Universal Soil Loss Equation) alongwith HEC-1 and a sediment transport model which was designed to operate conjunctively with HEC-2, to simulate hydrologic, hydraulic, sediment yield, and sediment characteristics of the watershed. Their aim was to demonstrate the effectiveness of watershed management in sediment control.

There are a number of hydrological models available in the literature, other than the models mentioned in the preceding pages, in which soil erosion and transport is an important component. Some of those models are described below.

STORM is another hydrologic model which provides a means for analysis of the quantity and quality of runoff. Computation of land surface erosion is a component of this model which uses USLE. The model considers the interaction of 7 storm water elements; rainfall/snowmelt, runoff, dry weather flow, pollutant accumulation and washoff, land surface erosion, treatment rates, and detention reservoir storage.

Hydrologic Engineering Centre (HEC), California has brought out a sediment transport model, HEC-6. This programme models the interaction between the water-sediment mixture, sediment material forming the stream's boundary, and the hydraulics of flow, thereby allowing the analysis of scour and deposition. It is a one dimensional steady flow model with no provision for simulating meander development or laterally distributing the sediment load across a section.

HYMO (Hydrologic Model) simulates surface runoff and sediment production from watersheds. It can be used to analyse effects of storms with varying intensities and distributions, determine flood hydrographs, and investigate sediment yields from segments of the watershed under different storm characteristics.

LUMOD (Land Use Simulation Model) is used to simulate the short term and long term hydrologic impacts, including sediment yield, of combinations of timber harvesting and weather modifications to develop management strategies for planning intervals which can vary from a few years to the rotation age of subalpine forests.

WASED (Water and Sediment Routing Program) is a physical process model simulating water and sediment hydrographs from individual storms on small watersheds. The model includes a water balance on the single storm basis, loose soil detachment by raindrop impact and by moving water, and water sediment routing features for both overland flow and channel systems.

Renard et al. (1991) revised the USLE to RUSLE by retaining the six factors to calculate annual soil loss from a hillslope. The technology for evaluating these factor values has been altered and new data added. The technology has been computerised to assist with the calculation. Major changes were made for each of the factors; the R factor and K factor is changed to reflect variability within the year, the L factor and S factor are changed to reflect the ratio of interrill to rill erosion, and the C factor is calculated as the product of terms reflecting prior land use, surface cover, crop canopy, and surface roughens.

In recent years, number of studies have been conducted using WEPP model, a process oriented model, which predicts hydrologic and erosion processes. It simulates rainfall, infiltration, water balance, runoff, plant growth, and erosion impacts in order to predict effects of management on erosion. In 1994, Elliot et al. have attempted prediction of sedimentation from roads at stream crossings. Elliot et al. (1995) have validated WEPP model for low volume forest and further applied it to timber harvest areas. Tysdal et al. (1997) have attempted to model insloped road erosion process with WEPP watershed model. Purandara (1997) applied WEPP model to an Indian catchment to estimate runoff and soil loss. He made a comparative study of the performance of WEPP with other two erosion models; WATBAL and WATSED.

3.0 OVERVIEW OF WEPP 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, hydraulics, and erosion mechanics. It is a continuous simulation computer program which predicts soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flow in small channels, and sediment deposition in impoundments. In addition to the erosion components, it also includes a climate component which uses a stochastic generator to provide daily weather information, a hydrology component which is based on a modified Green-Ampt infiltration equation and solutions of the kinematic wave equations, a daily water balance component, a plant growth and residue decomposition component, and an irrigation component.

A watershed is defined in WEPP as one or more hill slopes draining into one or more channels and/or impoundments. The smallest possible watershed includes one hillslope and one channel. Fig.1 shows the schematic representation of a hillslope and watershed for WEPP application.

The controlling variables which affect hillslope erosion are rainfall intensity, rainfall duration, peak flow rate, and flow shear stress. Processes considered in hillslope profile model application include rill and interrill erosion, sediment transport and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration ad 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 landuse conditions on hill slopes.

USDA-Water Erosion Prediction Project (WEPP)

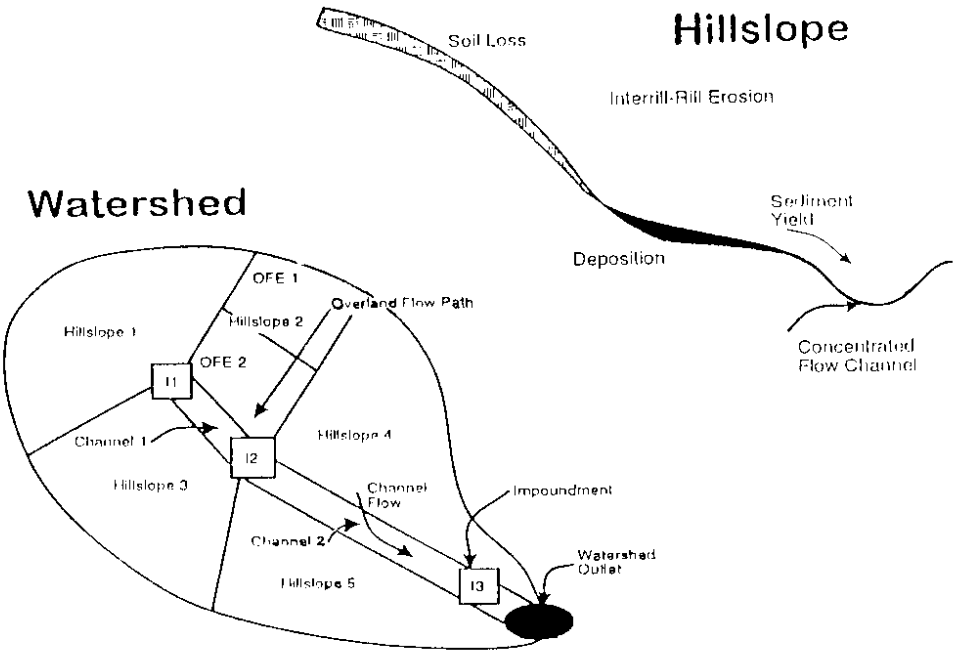


FIG. 1: Schematic Diagram of Hillslope & Watershed for WEPP Application

The primary purpose of the hillslope component is to supply the erosion calculations with peak discharge, duration of runoff, and flow shear stress. Infiltration is computed using a formulation of the Green-Ampt equation for the case of unsteady rainfall. Rainfall excess is defined as the difference between rainfall and infiltration during the period when the infiltration rate is less than the rainfall rate. The peak runoff rate at the bottom of the hillslope is estimated by a method based on a semi-analytical solution of the kinematic wave equation for overland flow or using regression equations derived from the kinematic solution for a range of slope steepness and lengths, surface roughness coefficients, soil textural classes, and rainfall distributions. Soil erosion is described on overland flow areas as interrill detachment of soil particles by raindrop impact and sediment transport by sheet flow, and rill detachment, transport, and deposition of soil particles by concentrated flow. The interrill erosion is taken as a function of soil detachment by raindrop impact, sediment delivery to rill flow areas by broad sheet flow, and rill erosion as a function of the flow's ability to detach sediment, sediment transport capacity and the existing sediment load in the flow

In watershed applications, the model allows linkage of hillslope profiles to channels and impoundments. The model is made up of three major components; hillslope, channel, and impoundment. The channel erosion and deposition calculations are similar to those of the hillslope with the major difference that only entrainment, transport, and deposition by concentrated flow are simulated, and the flow shear is calculated based on the spatially varied flow equations. Channel infiltration is calculated by either the Green-Ampt or a transmission loss equation. Watershed peak discharge rate is calculated by a method based on a semi-analytical solution of the kinematic wave equation. Flow depth and hydraulic shear stress along the channel are computed by regression equation based on a numerical solution of the steady state spatially varied flow equation. Detachment, transport, and deposition within permanent channels or ephemeral gullies are calculated by a steady state solution to the sediment continuity equation. The impoundment component computes deposition and sediment yield from terrace and reservoir impoundments.

Basic Concepts

The basic concept guiding the development of WEPP model is that sediment yield from a watershed is the result of detachment, entrainment, transport, and deposition of sediment on overland (rill and interrill) flow areas. Interrill 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 interrill 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.

Overland flow processes are conceptualised as a mixture of broad sheet flow occurring in interrill areas and concentrated flow in rill areas. Broad sheet flow on an idealised surface is assumed for overland flow routing and hydrograph development. Overland flow routing procedures include both an analytical solution to the kinematic wave equation and regression equations derived from the kinematic approximation for a range of slope steepness and lengths, friction factors, soil textural classes, and rainfall distributions. Once the peak runoff rate and the duration of runoff have been determined, steady state conditions are assumed at the peak runoff rate, for erosion calculations.

The erosion equations are normalised 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 a rill segment 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 is 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 channel is computed using regression equations that approximate the spatially varied flow equations. Deposition within the sediment discharge from impoundments is modeled using conservation of mass and overflow rate concepts.

Model Components

1. Weather Generation : The climate component generates mean daily precipitation, daily maximum and minimum temperature, daily solar radiation, and daily wind direction and speed. The number and distribution of precipitation events are generated using a two-state Markov chain model. Given the initial condition that the previous day was wet or dry, the model determines stochastically if precipitation occurs in the current day.

2. Winter Processes : The winter processes which the WEPP model simulates are frost and thaw development in the soil, snow accumulation, and snow melting. In order to make more accurate predictions, the average daily values for temperature, solar radiation, and precipitation are used to generate hourly temperature, radiation and snow fall values.

3. Irrigation : The irrigation component accommodates stationary sprinkler systems and furrow irrigation systems. Four irrigation schemes are available: a) no irrigation, b) depletion-level scheduling, c) fixed-date scheduling, and d) combinations of the second and the third options.

4. Infiltration : The infiltration component is based on the Green-Ampt equation modified by Mein and Larson (1973), with the ponding time calculation for an unsteady rainfall. 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.

5. Overland Flow Hydraulics : Surface runoff is represented in two ways in WEPP. a) Broad sheet flow is assumed for the overland flow routing and hydrograph development. Once the peak runoff rate and the duration of runoff have been determined, steady state

conditions are assumed at the peak runoff rate for rill erosion and transport calculations, and b) The proportion of the area in rills is represented by a density statistics and an estimated rill width. Depth of flow, velocity and shear stress in the rills are calculated assuming a rectangular channel. The erosion calculations are then made for a constant rate over a characteristic time to produce estimates of erosion for the entire runoff event.

6. Water Balance : This component of the hillslope model is based on the water balance component of SWRRB (Simulator for Water Resources in Rural Basins) with some modifications for improving estimation of percolation and soil evaporation parameters. This maintains a continuous balance of soil moisture on a daily basis. It uses information generated by the weather generation, infiltration, and plant growth components.

7. Plant Growth : It simulates plant growth for crop land and rangeland conditions. The purpose of this component is to simulate changes in plant variables that influence the runoff and erosion processes.

8. Residue Decomposition : This component estimates decomposition of flat residue mass, submerged residue mass, and dead root mass. Decomposition parameters must be specified in the management input file.

9. Soil Parameters : Soil parameters that influence hydrology and erosion are updated in the soil component, and include: random roughness, oriented roughness, bulk density, wetting front suction, hydraulic conductivity, interrill erodibility, rill erodibility, and critical shear stress.

10. Hillslope Erosion and Deposition : Soil erosion is represented in two ways in WEPP applications: a) soil particle detachment by rain drop impact and transport by sheet flow on interrill areas, and b) soil particle detachment, transport and deposition by concentrated flow in rill areas. Calculations within the erosion routines are made on a per unit rill width basis and subsequently converted to a per unit field width basis.

11. Watershed Channel Hydrology and Erosion Processes . This component was developed to predict erosion effects from management practices and to accommodate spatial and temporal variability in topography, soil properties and land use conditions within small agricultural watersheds. The watershed model is capable of ; a) identifying zones of sediment deposition and detachment within constructed channels or concentrated flow gullies, b) accounting for the effects of backwater on sediment detachment, transport, and deposition within channels, and c) representing spatial and temporal variability in erosion and deposition processes as a result of agricultural management practices.

12. Watershed Impoundment Component : Impoundments 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. This component calculates outflow hydrographs and sediment concentration for various types of outflow structures suitable for both large or small impoundments.

Limitations

The WEPP model is intended to be used on small agricultural watersheds in which the sediment yield at the outlet is significantly influenced by hillslope processes. Model application is constrained by the following limitations of application of the model; 1) no partial area response, 2) no headcutting, 3) no bank sloughing, and 4) no perennial streams. Also the currently available version of WEPP (March 1997) does not include forest and road options in the management file builder.

4.0 STUDY AREA

The study area, Sallopat Watershed, falls under the basin of river Anas, which is a part of Mahi river basin. The watershed is having a geographical area of 3840.10 ha., and is located between latitude 23° 10’ to 23° 15’ N. and longitudes 74° 10’ to 74° 15’ E. Physiographically, the watershed can be divided into hills, pediments, and alluvial plains. Elevation of watershed ranges form 230 to 310 m above msl. The soils of the watershed are characterised by light textured sandy loam to sandy clay loam. In some pockets, medium to heavy textured soil have also been encountered.

The climate is characterised by average maximum temperature of 44.2°C, minimum temperature 8.6°C, maximum evaporation of 11.6 mm/day, maximum wind velocity of 12.44 km/hr. and medium erratic rainfall. The average annual precipitation recorded at Sallopat raingauge station is 946.06 mm. About 90% of this rainfall is received from June to September, July and august being the wettest months. The average climatological data of the watershed is presented in the table 1.

Table 1: Average Climatological Data of Sallopat Watershed

Month	Max. Temp. (° C)	Min. Temp. (° C)	RH %		Rainfall (mm)	Wind speed (kmph)
			Max.	Min.		
January	28.3	8.6	82	24	2.32	3.14
February	29.5	9.4	80	22	0.00	2.66
March	36.0	12.6	79	19	0.00	2.98
April	40.6	8.9	75	17	0.84	4.24
May	44.2	23.6	69	10	6.40	7.45
June	41.3	26.7	71	28	98.11	12.44
July	39.4	23.7	90	38	280.36	11.37
August	31.7	22.2	91	63	375.14	7.52
September	36.9	22.8	87	43	135.78	3.78
October	37.2	16.5	81	25	31.10	3.40
November	33.4	13.0	75	18	12.04	2.46
December	31.0	10.7	71	22	1.00	2.72

In a study by conducted by Durbude (1997), various watershed parameters like drainage network, land use pattern, soil type, etc. have been extracted for this watershed using remote sensing techniques. These data and maps have been used for this study.

Drainage Network

The main stream which flows through the watershed is a 4th order stream. The location and drainage network of the watershed is shown in Fig. 2.

Landuse

The land use/land cover parameters of watershed are helpful in estimation of various losses such as infiltration, evapo-transpiration, and interception. The quality of runoff and the sediment yield is greatly dependent on the land use characteristics of a watershed. The major land use/land cover categories of the Sallopat watershed are as shown in Fig. 3 and explained below:

Agricultural land: The category includes crop land and pastures, orchards, groves and vineyards, nurseries and ornamental horticultural areas and confined feeding operations. Agricultural area occupies about 52.4 % of the total geographicai area

Forest land: This category is associated with rocky, gravelly and buried pediments and sand stone plateau. Forest cover of the watershed is 3.14% of the total area.

Shrubs: Shrubs is generally used intensively through establishment of receded and highly shallow soil with less than 30% gravels and slopes not exceeding 25-30%. These are found along the banks of the drainage and streams. The shrubs cover is about 5.78 % of total watershed area.

Grass land: The grass land which is mostly used for grazing purpose associated with hills and rocky gravelly pediments and characterised by flat and undulating topography. Grass land covers about 20% of the geographical area. De to shallow depth of soil and gravel spread over the entire area, this area cannot be used for cultivation.

Stony waste land: This category of land use comprising of sand stone, granites, rhyolite and sheet rocks is characterised by steep slope, boulders, cobbles, and gravelly sand. About 17.1 % of the total area is covered by this category of land use.

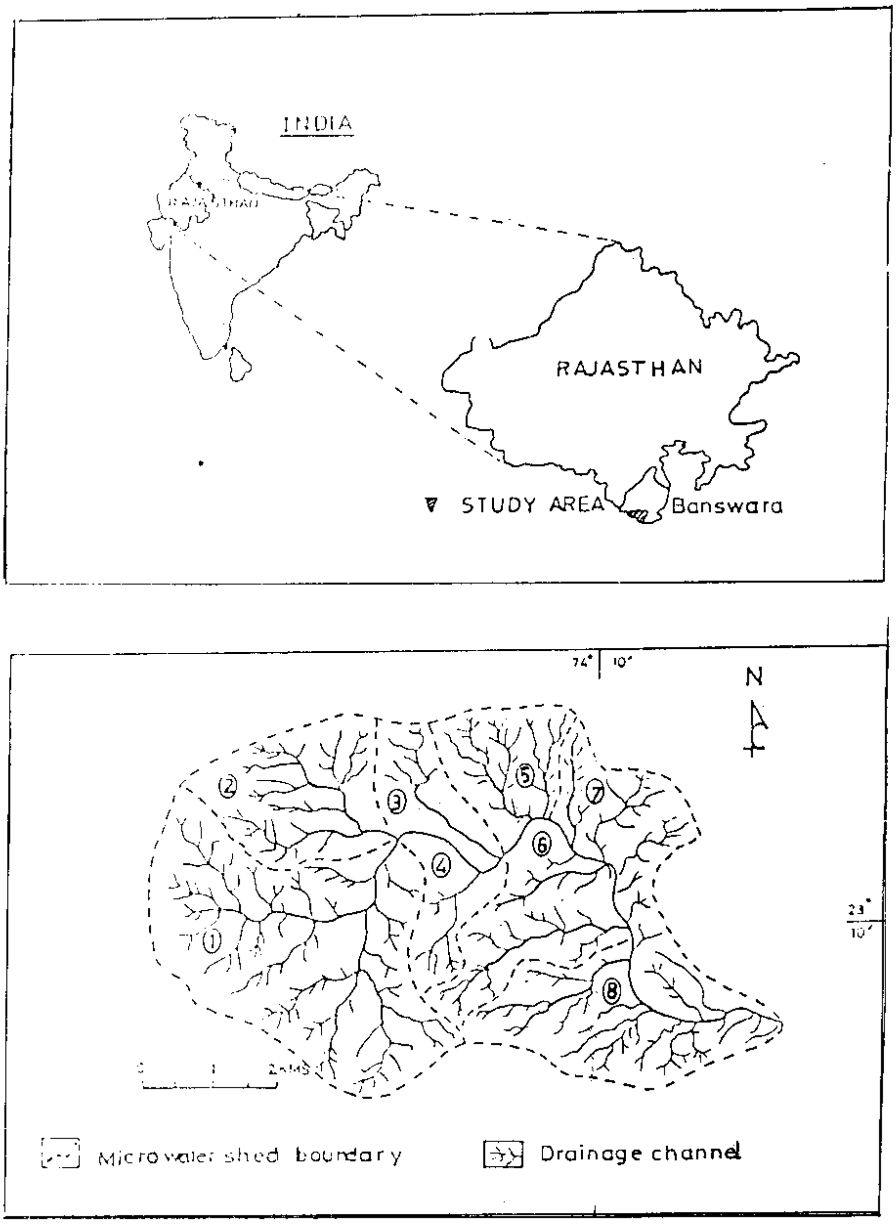


FIG. 2: Location of Study Area and Drainage network

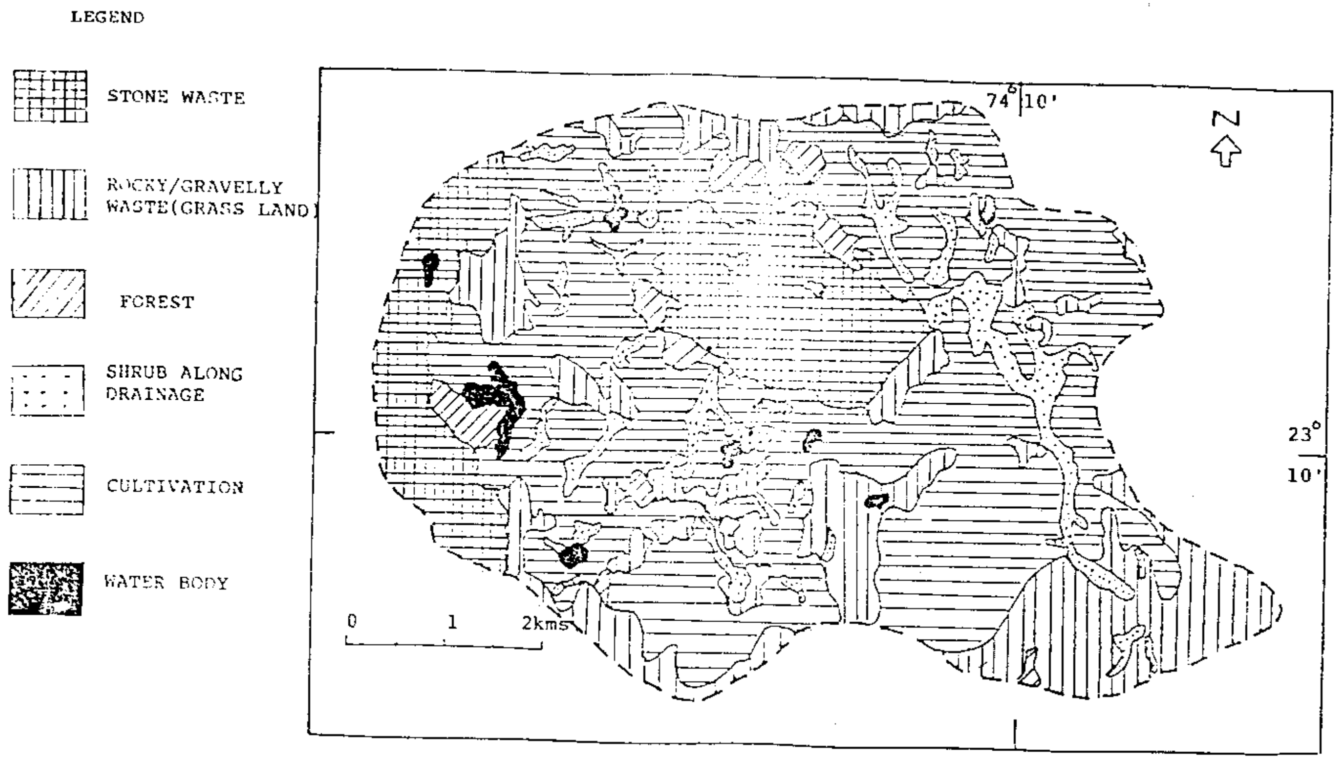


FIG. 3: Land Use Types in the Watershed

Soils

The soil characteristics of watershed viz., texture, structure and infiltration plays a significant role in estimation of runoff and sediment yield. There are 5 different types of soils found in the watershed as shown in Fig.4. Generally, agricultural land and shrubby area are covered with sandy loam to loamy soils, forest and grass land by shallow gravelly sandy clay loam soils, and stony waste land by brown soils.

Most of the methodologies for estimating sediment yield require an idea of the slopes and hydraulic characteristics. The slope details of each hill slope is to be computed for the WEPP model. Contour map, which is used for this purpose is shown in Fig.5. Hydraulic soil classification for the watershed is given in Fig.6.

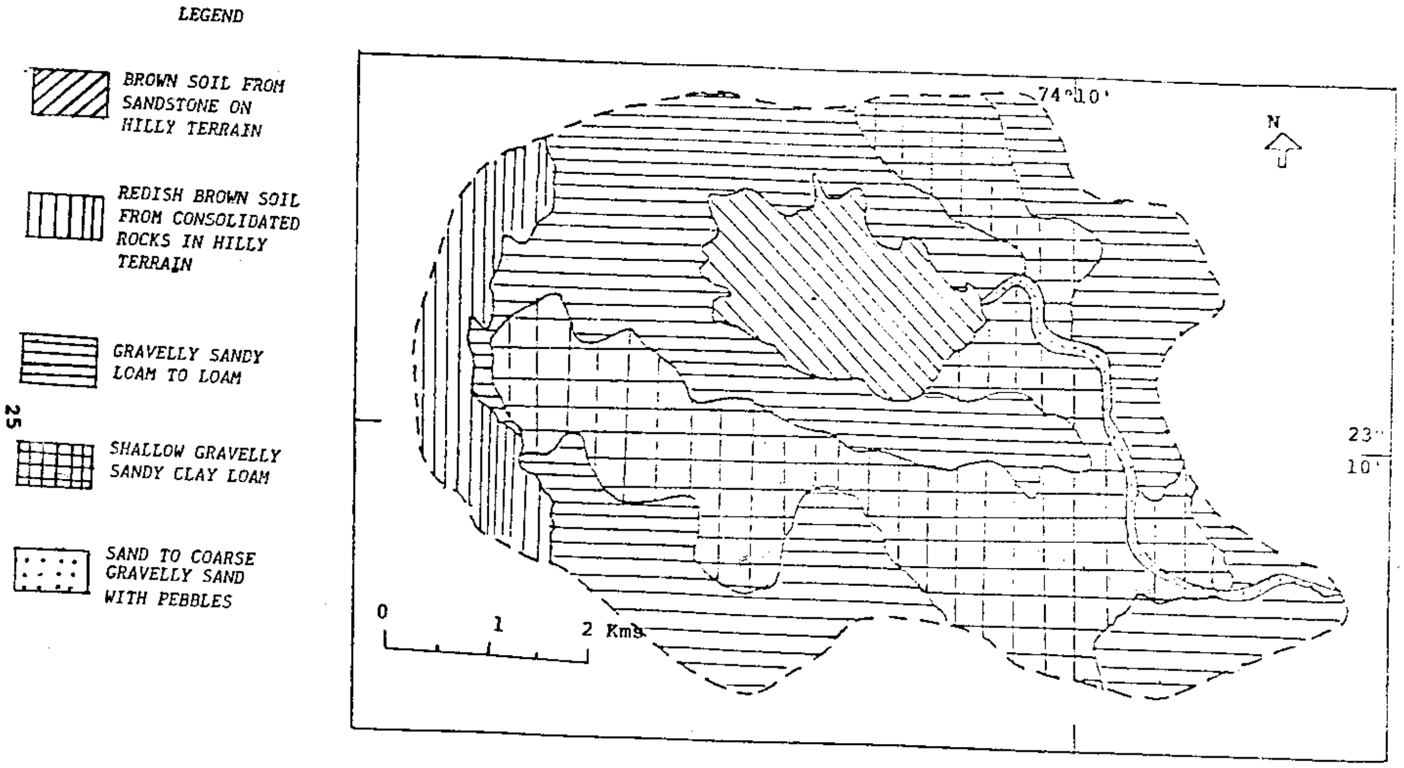


FIG. 4: Soil Types in the Watershed

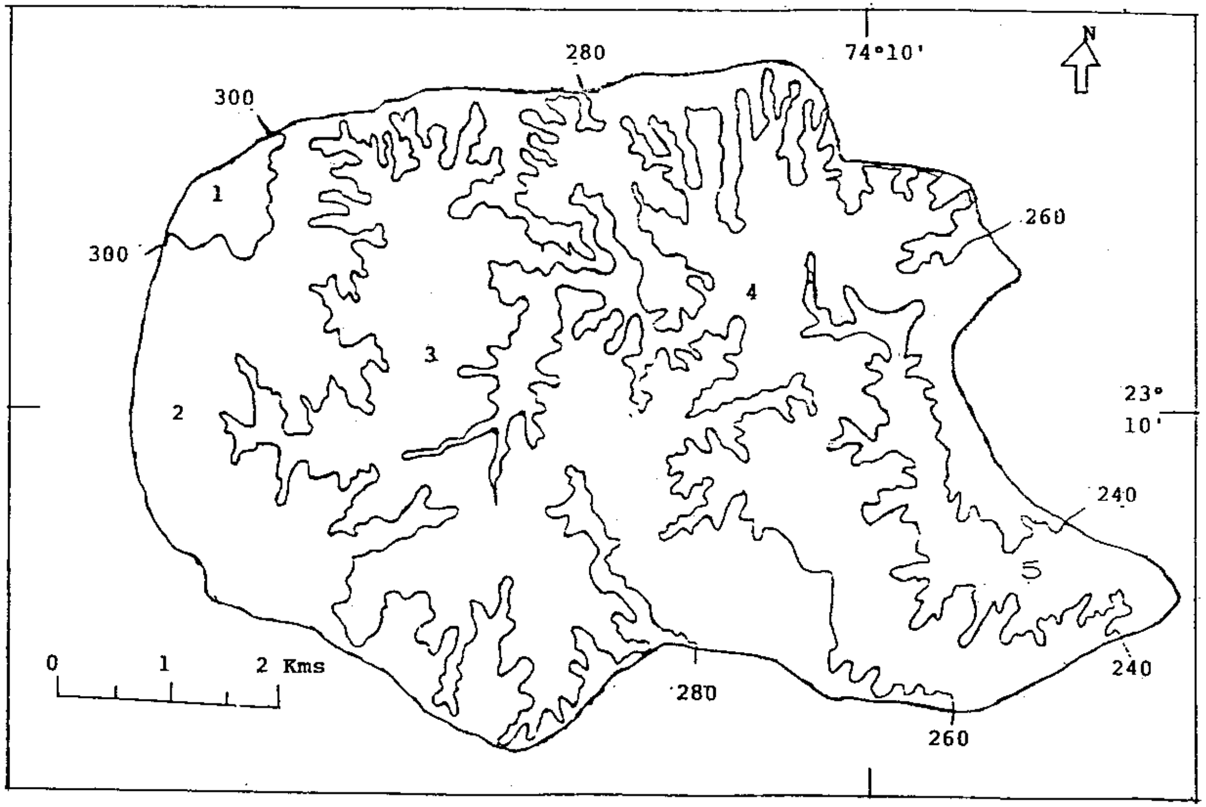
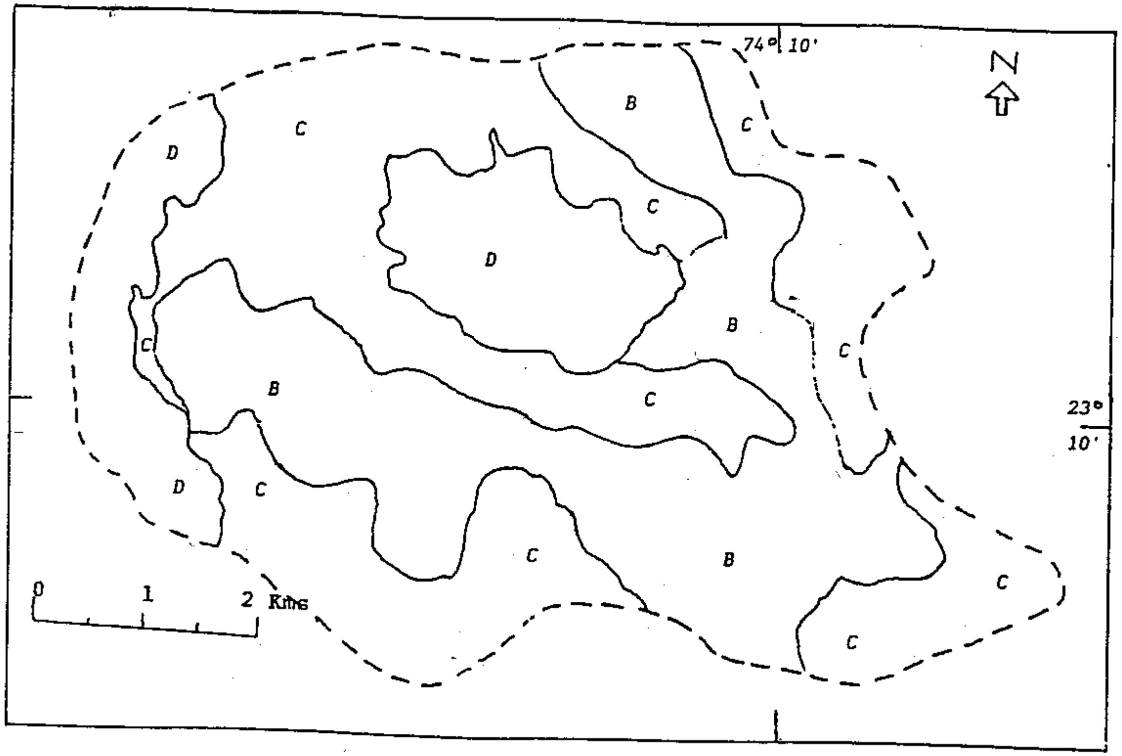


FIG. 5: Contour Map of the Watershed



LEGEND - A, B, C, D, BASED ON U.S.D.S.

FIG. 6: Hydraulic Soil Types in the Watershed

5.0 ANALYSIS & RESULTS

Preparation of input files form the base of this model. Number of input files required for WEPP, depend on the application for which it is being applied. However, the major input files for any WEPP model application are climate, cropping/management, soil and slope files. The optional input files include irrigation, channel and impoundment characteristics, and watershed configuration.

In climatic input file, it is possible to provide either a single storm event or a continuous rainfall series. Actual data can be supplied, or where only rainfall statistics are available, a program called CLIGEN is provided in the model which can be used to generate data series of any length. Similarly, for the preparation of other data files, input file builders are provided in the model. The slope file builder has the added advantage of allowing the user to graphically preview the slope shape. Information on soil properties to a maximum depth of 1.8 meters (upto 8 different soil layers) can be input to the model through soil input file. The management file builder contains a large number of built in cropping pattern and management practices, which can be easily brought into our data file to suit the prevailing conditions on each overland flow elements within a hill slope.

First step in the application of WEPP is the process of dividing the study area into a number of hill slopes and channels. Each hill slopes are made up of one or more overland flow elements (OFE). OFE is an area of uniform cropping, management, and soil characteristics. The current version of WEPP allows simulation of upto 10 OFEs on an individual hill slope. The input files are prepared for each hill slopes. Soil, slope, and management parameters for each OFE on the hill slope profile are provided in the input files. The model run has been done foı individual hill slopes and runoff and sediment yield are calculated at the foot of the hill slope. In the watershed modelling option, these are routed through channels and the quantities are calculated at the outlet of the watershed.

The WEPP program produces many kinds of output, in various quantities. The most basic output contains the runoff and erosion summary information, on a storm-by-storm, monthly, annual, or average annual basis. The output gives detachment or deposition at each of a minimum of 100 points on a hill slope.

Hillslope Model

For the application of hillslope version of WEPP model, the watershed has been subdivided into 8 subwatersheds and these subwatersheds, to small hill slopes, each of which are having one or more combinations of soil and land cover characteristics. A total of 32 such hill slopes were identified and each of these slopes have been divided into one or more OFEs, as shown in Fig. 7. Climate, Slope, Soil and Management data files were created for each of these 32 hill slopes. Some typical example input files are given in annexure 1.

Soil characteristics for each hillslope, including type of soil, hydraulic conductivity, soil albedo, initial saturation, number of soil layers, thickness, bulk density, sand, clay, and organic matter percentage, etc. have been provided in Soil input file. Number, length and width of each OFEs and slope details are given in Slope input file. Cropping pattern/management types have been provided in the Management input file.

For checking the sensitivity of the model to various input parameters, daily rainfall data for the year 1994 was fed into the climate input file and runoff and erosion processes were simulated from the hill slopes. Total rainfall for the year was 1882 mm, which resulted in an average runoff of 618.2 mm (32.85%) and a sediment yield of 4657 Kg/m, from the watershed. It was seen during the analysis that the management practices and slope details are the most influencing factors in WEPP, in determining the amount of runoff and sediment yield.

Using CLIGEN program and average climatological parameters for the study area, a climate file has been created for 25 years. The CLIGEN climate generator reads climate

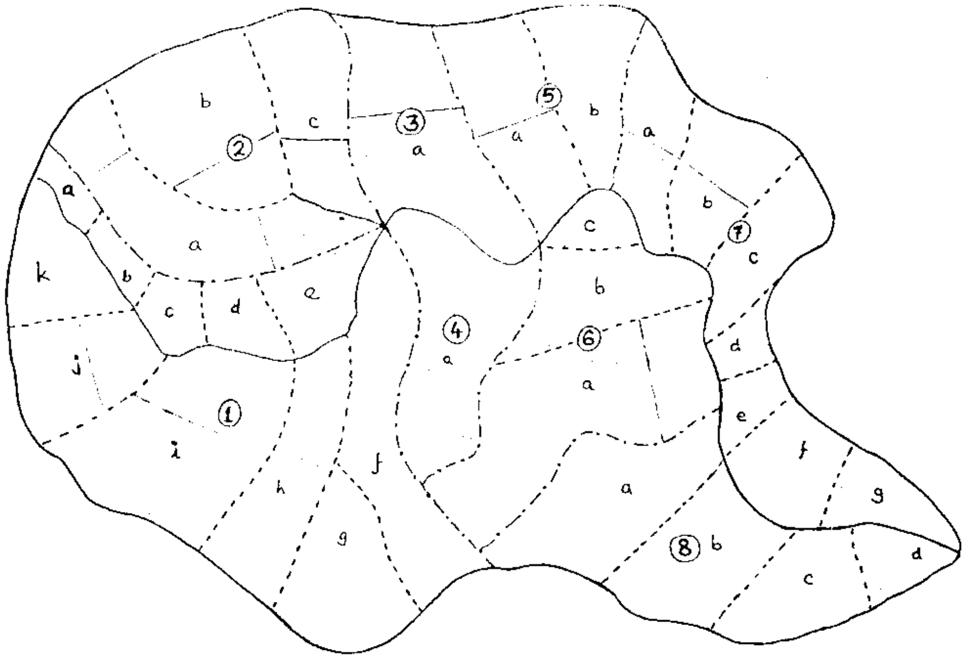


FIG. 7: Schematic Representation of the Sallopat Watershed for the WEPP Hill Slope Model Application

statistics (such as monthly average rainfall, temperatures, solar radiation, probability of wet day, etc.) for a given station, and from these statistics, builds a stochastic climate data of any length. The most important variables are the monthly average rainfall amounts and the likelihood of rainfall occurring.

The climate data file containing 25 years of data is then used to simulate the flow and erosion processes from the hill slopes for 25 years. A sample output file showing the average annual summaries (for hillslope 6A) is given in the annexure 2. The runoff predicted for 25 years shows a variation from 24 % to 44 % of rainfall with an average of 33.5 %. For an average annual rainfall of 946.06 mm, the runoff produced is 316.6 mm and the sediment yield is 4633 Kg/m, at a rate of 6.37 Kg/m^2. Average Runoff, erosion and sediment details (for 25 years) for each hillslope are given in Table 2. The average values for the whole watershed for 25 years is given in Table 3.

The results are analysed to get a relationship between rainfall and runoff values and runoff and resulting sediment yield. These are as shown in Fig. 8 & 9.

Watershed model

For the application of the watershed version of the WEPP model, the study area has been divided into hill slopes and channels. For this purpose, 17 hill slopes are considered which allows water and sediments to flow into 8 channels. The schematic representation of these hill slopes and channels are shown in Fig. 10. In this figure, a, b, c, etc. represents the 32 hill slopes considered in the hillslope version application; 1, 2, 3, etc. the subwatershed numbers; and C_1, C_2, C_3, etc. are the channels.

In addition to the slope, soil and management characteristics of the hill slopes, channel properties such as width and depth of channels, hydraulic properties, channel bank management details, soil characteristics, etc. has to be given as input data. For the study area, the details about size and hydraulic properties of the channel was not available. So approximate values were assumed for the simulation. So the results are of only academic

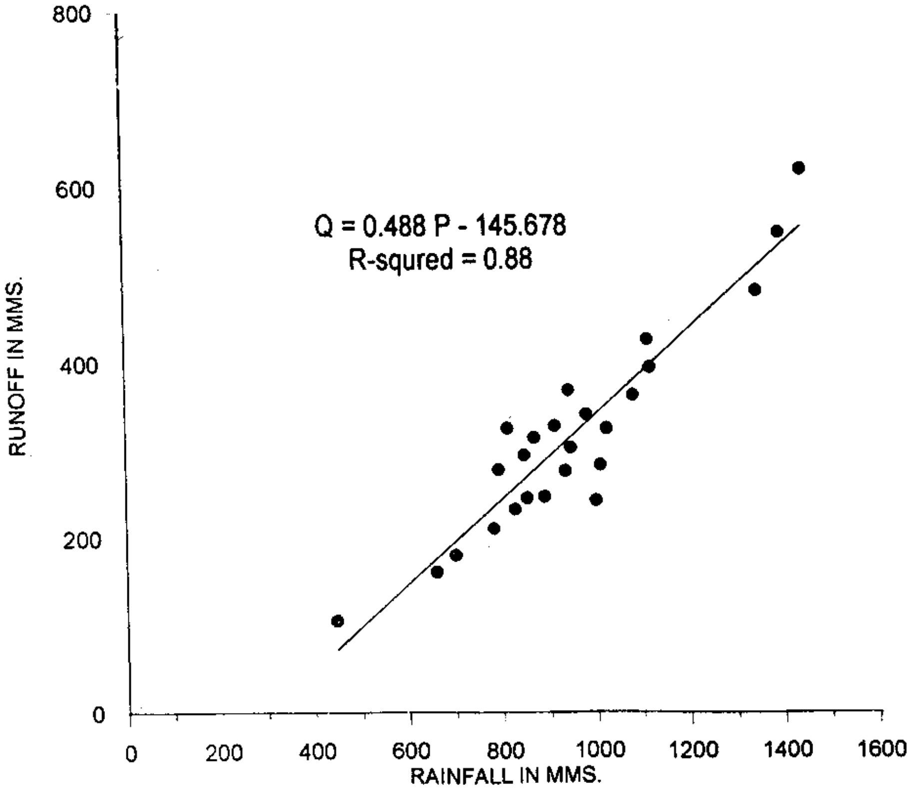


FIG.8: RAINFALL-RUNOFF RELATIONSHIP FOR THE WATERSHED

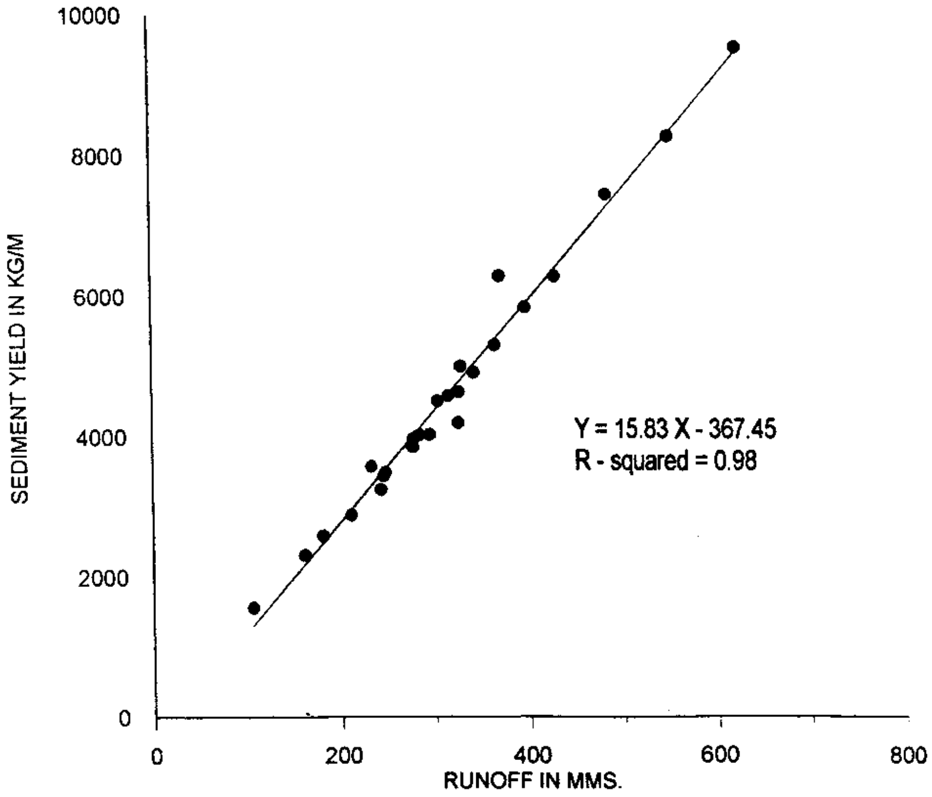


FIG.9: RUNOFF Vs SEDIMENT YIELD FOR THE WATERSHED

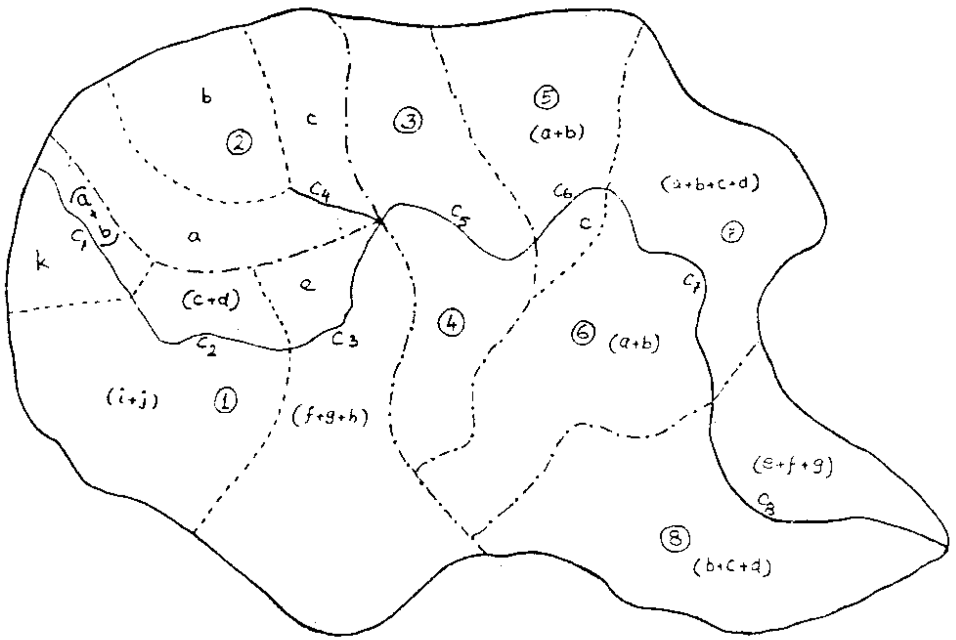


FIG. 10: Schematic Representation of the Sallopat Watershed for the WEPP Watershed Model Application

interest, to demonstrate this capability of the WEPP model. The simulation resulted in an average annual runoff of 367.43 mm and an average sediment yield of 3981 Kg/m.

Table 2: Average Runoff and Sediment values for individual hill slopes
(for an average annual rainfall of 946.06 mm)

Hillslope	**Runoff (mm)**	**Average Erosion (Kg/m2)**	**Average deposit. (Kg/m2)**	**Sediment Yield (Kg/m)**	**Sediment Enrichment Ratio**
HS 1A	353.2	5.7	2.2	1303.1	1.3
HS 1B	413.5	4.3	4.2	1388.0	1.3
HS 1C	393.5	9.5	8.3	3244.2	1.4
HS 1D	399.9	10.3	7.7	3178.3	1.3
HS 1E	278.1	17.7	20.6	5895.6	1.8
HS 1F	173.7	31.7	33.9	5858.2	3.2
HS 1G	285.2	21.7	18.7	5570.4	1.9
HS 1H	279.0	18.3	15.4	4516.8	2.0
HS 1I	227.6	15.8	26.6	4428.4	2.1
HS 1J	225.3	26.7	26.4	4279.6	2.1
HS 1K	377.0	8.6	3.9	4238.3	1.3
HS 2A	222.7	40.8	32.6	8411.1	2.8
HS 2B	281.8	28.6	35.5	7392.1	2.5
HS 2C	297.9	25.4	17.7	5749.6	2.2
HS 3A	339.4	39.5	33.3	7896.2	2.2
HS 4A	256.8	27.7	24.2	6500.5	2.5
HS 5A	321.7	34.8	24.7	7384.3	2.4
HS 5B	329.1	9.3	4.0	5501.3	1.4
HS 6A	208.8	43.5	26.7	5976.8	2.8
HS 6B	286.5	8.4	3.8	6709.6	1.2
HS 6C	361.5	17.8	8.1	3703.8	1.5
HS 7A	363.8	23.0	25.8	7533.3	1.7
HS 7B	280.6	16.9	17.0	1506.4	2.4
HS 7C	332.6	10.0	5.2	4766.2	1.5
HS 7D	405.7	9.2	3.2	3129.2	1.1
HS 7E	366.3	8.7	5.0	2575.9	1.2
HS 7F	304.7	3.0	0.8	1479.2	1.2
HS 7G	327.6	2.2	0.8	542.3	1.2
HS 8A	257.1	7.7	4.8	6729.2	1.4
HS 8B	341.4	17.7	17.0	6714.6	1.9
HS 8C	409.0	4.2	3.6	2282.1	1.3
HS 8D	428.7	4.6	0.6	1867.4	1.1
Average	316.6	17.3	14.5	4632.9	1.8

Table 3: Average Runoff and Sediment values for individual simulation years

Year	**Rainfall (mm)**	**Runoff (mm)**	**Average Erosion (Kg/m2)**	**Average deposit. (Kg/m2)**	**Sediment Yield (Kg/m)**	**Sediment Enrichment Ratio**
1	1021.5	325.3	16.1	14.6	4209.3	1.8
2	845.8	294.6	14.5	12.0	4043.2	1.8
3	811.3	325.4	15.9	12.9	4646.6	1.8
4	978.5	341.5	18.6	15.5	4924.4	1.8
5	699.8	180.3	108	9.10	2593.1	1.8
6	1110.0	427.4	19.9	15.6	6290.6	1.7
7	932.7	276.9	16.0	13.8	3865.5	1.8
8	1439.7	621.0	29.0	22.0	9534.5	1.7
9	1391.4	548.8	26.5	21.0	8290.4	1.7
10	792.0	277.9	15.0	12.7	3981.9	1.8
11	851.3	245.7	14.2	12.2	3445.6	1.8
12	1341.6	482.3	24.9	20.6	7453.6	1.7
13	867.3	314.9	16.4	13.7	4590.6	1.8
14	1007.3	284.2	16.7	14.5	4034.4	1.8
15	998.0	242.8	16.8	15.2	3255.5	2.0
16	825.9	232.9	15.2	13.4	3581.3	1.9
17	1116.0	395.7	22.1	18.8	5855.3	1.8
18	1079.0	363.5	21.3	18.2	5313.0	1.8
19	944.7	303.2	17.4	14.8	4515.2	1.8
20	659.0	161.2	10.9	9.6	2317.9	1.9
21	911.4	328.3	18.7	15.5	5010.0	1.8
22	888.4	247.4	15.2	13.1	3493.2	1.9
23	780.6	210.7	13.8	12.5	2887.7	2.0
24	445.2	105.9	7.2	6.3	1569.1	1.9
25	940.1	369.1	20.4	15.9	6297.4	1.7
Average	946.06	316.6	17.3	14.5	4632.9	1.8

6.0 CONCLUSIONS

The WEPP model is a distributed, continuous, small agricultural watershed erosion model. Its' intended purpose is to simulate the effects of management practices and land use changes on the spatial and temporal variability of the erosion processes within a watershed system. The major features of this model are the ability to (i) delineate areas of detachment and deposition on a hillslope or along a channel reach, (ii) account for the effects of management and land use changes on the erosion process, and (iii) account for the effects of backwater on detachment, transport, and deposition processes within channels.

In the present study, the model was used to simulate flow and erosion processes in Sallopat watershed. An attempt has been made to utilise the hillslope and watershed versions of the WEPP model. Since there was no runoff or sediment yield observations available from this watershed, the results could not be compared with measured values. However, Durbude (1997) calculated the average runoff from the watershed using SCS method. The result from the study shows that the average runoff from the watershed is 362 mm. This compares with the average value obtained from the model application.

From this study, it is found that WEPP is capable of simulating erosion and deposition processes in hillslope or along a channel course. It gives precise locations of erosion and deposition so that proper management strategies can be taken up to tackle these problems. Using the various components of the WEPP, a large amount of details can be obtained about the watershed behaviour for a set of climatological, soil, slope and management factors. Since it gives an idea of the overland flow over hill slopes and progress of these outflows from the hill slopes through the channels, it can also be used as a rainfall-runoff model for small watersheds.

ACKNOWLEDGEMENTS

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Director	Dr.S.M. Seth
Head	Dr.B. Soni
Study Group	Mr. Chandramohan T.

ANNEXURE I

CLIMATE INPUT FILE

```
4.00
 1  0   1
 Station:  SALLOPAT                                          CLIGEN VERSION 4.0
Latitude Longitude Elevation (m) Obs. Years   Beginning year  Years simulated
   23.18    74.17          255          1               1               1
Observed monthly ave max temperature (C)
 28.3  29.5  36.0  40.6  44.2  41.3  39.4  31.7  36.9  37.2  33.4  31.0
Observed monthly ave min temperature (C)
  8.6   9.4  12.6   8.9  23.6  26.7  23.7  22.2  22.8  16.5  13.0  10.7
Observed monthly ave solar radiation (Langleys/day)
274.0 342.0 417.0 504.0 528.0 544.0 618.0 515.0 448.0 393.0 327.0 267.0
Observed monthly ave precipitation (mm)
 2.3   0.0   0.0   0.9  6.4  98.1  280.4  375.2  135.8  31.1  12.1   1.0
da mo year  prcp  dur   tp      ip  tmax  tmin  rad  w-vl w-dir  tdew
            (mm)  (h)               (C)   (C)  (l/d) (m/s)(Deg)   (C)
 1  1     1   0.0  0.00 0.00   0.00  25.6   9.0 156.  6.2  292.  10.4
 2  1     1   0.0  0.00 0.00   0.00  27.0  13.9 198.  6.0  276.  15.5
 3  1     1   0.0  0.00 0.00   0.00  28.1  13.5 251.  3.8  134.  15.7
 4  1     1   0.0  0.00 0.00   0.00  24.1  14.8 221.  6.7  298.  15.1
 5  1     1   0.0  0.00 0.00   0.00  25.4   9.4 192.  6.1  256.  12.4
 6  1     1   0.0  0.00 0.00   0.00  28.0   8.8 185.  6.3  266.  11.1
 7  1     1   0.0  0.00 0.00   0.00  24.5   8.1 197.  4.1   62.   9.6
 8  1     1   0.0  0.00 0.00   0.00  26.8   8.3 254.  3.1  182.  10.2
 9  1     1   0.0  0.00 0.00   0.00  23.1   8.8 247.  6.2    7.  12.9
10  1     1   0.0  0.00 0.00   0.00  23.6  11.0 237.  4.8  314.  13.8
11  1     1   2.0  0.50 0.20   1.50  23.6  13.6 266.  4.0  348.  18.2
12  1     1   8.0  0.70 0.50   2.50  22.5  12.3 212.  7.5  334.  17.5
13  1     1   0.0  0.00 0.00   0.00  25.2   7.7 224.  6.5  306.   9.5
14  1     1   0.0  0.00 0.00   0.00  28.2  10.2 234.  3.9  232.  11.9
15  1     1   0.0  0.00 0.00   0.00  26.3   8.9 248.  6.0  327.  11.5
16  1     1   0.0  0.00 0.00   0.00  24.3  11.3 292.  3.3   92.  14.5
17  1     1   0.0  0.00 0.00   0.00  23.1   4.0 225.  9.5  275.  12.2
18  1     1   0.0  0.00 0.00   0.00  21.7  10.4 208.  6.3  303.  14.3
19  1     1   0.0  0.00 0.00   0.00  25.4  10.1 290.  1.0  189.  15.5
20  1     1   0.0  0.00 0.00   0.00  22.4  11.4 271.  5.2  288.  13.2
21  1     1   0.0  0.00 0.00   0.00  27.5  10.2 278.  3.0   88.  13.5
22  1     1   0.0  0.00 0.00   0.00  21.6   9.1 280.  0.0    0.  11.6
23  1     1   0.0  0.00 0.00   0.00  24.5   8.0 285.  5.4  191.  12.9
24  1     1   0.0  0.00 0.00   0.00  22.9   6.0 258.  4.2  201.  11.9
25  1     1   0.0  0.00 0.00   0.00  25.7  11.2 249.  4.0   71.  12.9
26  1     1   0.0  0.00 0.00   0.00  27.2   8.0 302.  7.4  293.  10.4
27  1     1   0.0  0.00 0.00   0.00  22.7   9.2 238.  2.1  205.  11.1
28  1     1   0.0  0.00 0.00   0.00  27.9   9.6 320.  9.5  242.  16.2
29  1     1   0.0  0.00 0.00   0.00  26.0   8.1 269.  7.5  210.  14.2
30  1     1   0.0  0.00 0.00   0.00  22.1  10.7 234.  7.5  175.  15.0
31  1     1   0.0  0.00 0.00   0.00  22.7  10.7 296.  4.4  215.  10.8
 1  2     1   0.0  0.00 0.00   0.00  26.1  10.7 253.  4.8   22.  11.5
 2  2     1   0.0  0.00 0.00   0.00  22.2  11.7 268.  9.3  242.  12.7
 3  2     1   0.0  0.00 0.00   0.00  23.6   9.2 244.  5.9   66.  12.6
 4  2     1   0.0  0.00 0.00   0.00  21.2   9.8 297.  7.5  121.  16.9
 5  2     1   0.0  0.00 0.00   0.00  26.5   9.5 266.  3.8   33.  10.3

*** Daily Climate data has to be continued for the desired period ***
```

— SOIL INPUT FILE

```
95.7
#
#       Created on 14Feb99 by `WSOL', (Ver. 15Apr95)
#       Author: chandramohan
#
For Subwatershed 1 - Hslope F
4       1
'sandy loam'    'sandy loam'    1       0.15    0.8     7.5e+006        0.01
200     72      16      2       8       20
'sandy clay loam'       'sandy clay loam'       1       0.15    0.75    7.5e+006
200     69      21      2       10      25
'sandy loam'    'sandy loam'    1       0.15    0.85    7.5e+006        0.01
200     72      16      2       8       15
'brown soil'    'sandy loam'    1       0.2     0.45    1.5e+006        0.01
250     70      15      1.5     10      10
```

SLOPE INPUT FILE

```
94.0
4
10      750
4       900
0,0     0.2,0.08  0.6,0.06  1,0.04
4       1700
0,0.04  0.4,0.07 0.7,0.05  1,0.03
4       500
0,0.03 0.3,0.06  0.6,0.04  1,0.02
4       600
0,0.02  0.3,0.05  0.7,0.035  1,0.01
```

MANAGEMENT INPUT FILE

```
95.7
#       Created on 9Apr99 by `wman', (Ver. 15Apr95)
#       Author: chandramohan

1       # number of OFEs
25      # (total) years in simulation

#################
# Plant Section #
#################

1       # looper; number of Plant scenarios

#       Plant scenario 1 of 1
#
ALFALFA3
`Alfalfa - Low Fertilization Level'
(from WEPP distribution database)

1       # `landuse' - <Cropland>
WeppWillSet
14      23      8       4       5       30      0.1     0.152   0.7     0.0045
0.85    0.9     0.65    0.99    12      0       0.9     0.8
2       # `mfo' - <Non-fragile>
0.015   0.015   20      0       0.006   2.43    0.33    0.6     14      32
0.5     6       0

#####################
# Operation Section #
#####################

0       # looper; number of Operation scenarios

##############################
# Initial Conditions Section #
##############################

1       # looper; number of Initial Conditions scenarios

#       Initial Conditions scenario 1 of 1
#
OEF00001
STONY WASTE LAND WITH POOR VEGETATION

1       # `landuse' - <Cropland>
1.05    0.02    178     56      0       0
1       # `iresd' - <ALFALFA3>
1       # `mgmt' - <Annual>
56      0       0       0       0
1       # `rtyp' - <Temporary>
0       0       0.1     0.2     0
0       0
```

```
###########################
# Surface Effects Section #
###########################

0       # looper; number of Surface Effects scenarios

######################
# Contouring Section #
######################

0       # looper; number of Contouring scenarios

####################
# Drainage Section #
####################

0       # looper; number of Drainage scenarios

##################
# Yearly Section #
##################

1       # looper; number of Yearly scenarios

#       Yearly scenario 1 of 1
#
YEAR0001
STONE WASTE WITH POOR VEGETATION
AND SHRUBS

1       # `landuse' - <Cropland>
1       # `itype' - <ALFALFA3>
0       # `tilseq' - <NotUsed>
0       # `conset' - <NotUsed>
0       # `drset' - <NotUsed>
1       # `mgmt' - <Annual>
        316     # `jdharv' - <11/12>
        158     # `jdplt' - <6 /7 >
        0
        6       # `resmgmt' - <None>

######################
# Management Section #
######################
MNT1
STONY WASTE LAND WITH POOR VEGETATION
conservation zone of microwatershed

1       # `nofe' - <number of Overland Flow Elements>
        1       # `Initial Conditions indx' - <OEF00001>
25      # `nrots' - <rotation repeats..>
1       # `nyears' - <years in rotation>
#
#       Rotation 1 : year 1 to 1
#
        1       # `nycrop' - <plants/yr; Year of Rotation :  1 - OFE : 1>
                1       # `YEAR indx' - <YEAR0001>
#
#       Rotation 2 : year 2 to 2
#
```

*** * will be continued for the number of years of simulation**

ANNEXURE II

SAMPLE OUTPUT FILE

```
          USDA WATER EROSION PREDICTION PROJECT
          -------------------------------------
          HILLSLOPE PROFILE AND WATERSHED MODEL, VERSION    97.300

    MANAGEMENT: C:\WEPP\INPUT\MAN\DATA\MNT19.man
    MAN. PRACTICE:  Medium Productivity Level
         SLOPE: C:\WEPP\INPUT\SLOPE\DATA\SLOPE19.slp
       CLIMATE: C:\WEPP\INPUT\CLIMATE\DATA\SALLOPAT.cli
       Station: SALLOPAT                          CLIGEN VERSION  4.20
          SOIL: C:\WEPP\INPUT\SOIL\DATA\SOIL19.sol
      PLANE  1 sandy loam          sandy loam
      PLANE  2 sandy clay loam     sandy clay loam
      PLANE  3 sandy loam          sandy loam

     ANNUAL AVERAGE SUMMARIES FOR HILLSLOPE 6A
     -----------------------------------------
I.   RAINFALL AND RUNOFF SUMMARY
     -------- --- ------ -------
      total summary:  years    1 -   25

      1383 storms produced                       23651.52 mm of precipitation
      1096 rain storm runoff events produced      5218.90 mm of runoff

      annual averages
      ---------------
        Number of years                                 25
        Mean annual precipitation                   946.06    mm
        Mean annual runoff from rainfall            208.76    mm

II.  ON SITE EFFECTS  ON SITE EFFECTS  ON SITE EFFECTS
     --------------  ---------------  ---------------
  A.  AREA OF NET SOIL LOSS
    ** Soil Loss (Avg. of Net Detachment Areas) =   43.465 kg/m2 **
      ** Maximum Soil Loss  =  229.980 kg/m2 at  712.00 meters **

      Area of    Soil Loss   Soil Loss    MAX   MAX Loss   MIN   MIN Loss
      Net Loss     MEAN       STDEV      Loss    Point     Loss   Point
        (m)       (kg/m2)     (kg/m2)  (kg/m2)    (m)     (kg/m2)  (m)
--------------------------------------------------------------------------
   0.00- 434.00    6.102       5.486    16.118  350.00    0.144     7.00
 700.00-1180.00   67.027      45.155   229.980  712.00    0.125  1180.00
1921.00-2082.00   73.936      35.567   112.786 2040.00    7.704  2082.00

  B.  AREA OF SOIL DEPOSITION
    ** Soil Deposition (Avg. of Net Deposition Areas) =   -26.720 kg/m2 **
      ** Maximum Soil Deposition  =   -63.410 kg/m2 at 2236.00 meters **

      Area of    Soil Dep   Soil Dep     MAX    MAX Dep    MIN   MIN Dep
      Net Dep     MEAN       STDEV       Dep     Point     Dep    Point
        (m)      (kg/m2)     (kg/m2)   (kg/m2)    (m)    (kg/m2)   (m)
--------------------------------------------------------------------------
 434.00- 700.00  -2.502      1.235     -4.897  700.00    -0.074   441.00
1180.00-1921.00 -24.205     16.825    -46.300 1907.00    -1.239  1192.00
2082.00-2600.00 -42.755     12.994    -63.410 2236.00    -4.474  2089.00
```

```
C.  SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE
      Profile distances are from top to bottom of hillslope

distance soil   flow      distance    soil  flow      distance    soil  flow
  (m)    loss  elem         (m)       loss  elem        (m)       loss  elem
        (kg/m2)                      (kg/m2)                     (kg/m2)
---------------------------------------------------------------------------------
  14.00      0.258  1      724.00    184.411  2      1914.00    -24.828  3
  28.00      0.314  1      748.00    125.875  2      1928.00     10.242  3
  42.00      0.326  1      772.00     94.488  2      1942.00     40.957  3
  56.00      0.328  1      796.00     77.887  2      1956.00     65.030  3
  70.00      0.328  1      820.00     69.295  2      1970.00     82.547  3
   ''
   ''
 210.00      8.472  1     1060.00     66.951  2      2110.00    -29.606  3
 224.00      9.184  1     1084.00     43.293  2      2124.00    -40.116  3
 238.00      9.826  1     1108.00     23.199  2      2138.00    -47.771  3
 252.00     10.612  1     1132.00     11.395  2      2152.00    -53.287  3
 266.00     11.456  1     1156.00      4.299  2      2166.00    -57.199  3
 280.00     12.363  1     1180.00      0.125  2      2180.00    -59.893  3
   ''
   ''
 420.00      1.578  1     1420.00     -7.465  2      2320.00    -46.903  3
 434.00      0.413  1     1444.00     -7.743  2      2334.00    -45.215  3
 448.00     -0.502  1     1468.00     -8.016  2      2348.00    -43.770  3
 462.00     -1.252  1     1492.00    -11.470  2      2362.00    -42.498  3
 476.00     -1.902  1     1516.00    -21.151  2      2376.00    -41.349  3
 490.00     -2.499  1     1540.00    -27.155  2      2390.00    -40.288  3
   ''
   ''
 630.00     -3.314  1     1780.00    -42.594  2      2530.00    -31.468  3
 644.00     -3.629  1     1804.00    -43.316  2      2544.00    -30.647  3
 658.00     -3.942  1     1828.00    -44.020  2      2558.00    -29.830  3
 672.00     -4.259  1     1852.00    -44.713  2      2572.00    -29.015  3
 686.00     -4.579  1     1876.00    -45.397  2      2586.00    -28.202  3
 700.00     -4.897  1     1900.00    -46.074  2      2600.00    -27.391  3

note:  (+) soil loss - detachment      (-) soil loss - deposition

III. OFF SITE EFFECTS  OFF SITE EFFECTS  OFF SITE EFFECTS
     ----------------  ----------------  ----------------
     A.  AVERAGE ANNUAL SEDIMENT LEAVING PROFILE  5976.756 kg/m

     B.  SEDIMENT CHARACTERISTICS AND ENRICHMENT
     Sediment particle information leaving profile
-------------------------------------------------------------------------------+----
                                       Particle Composition          Detached Fraction
Class  Diameter   Specific   -------------------------------------   Sediment  In Flow
         (mm)     Gravity    % Sand    % Silt    % Clay    % O.M.    Fraction  Exiting
------------------------------------------------------------------------------------
  1     0.002       2.60       0.0       0.0     100.0      21.1      0.049     0.297
  2     0.010       2.65       0.0     100.0       0.0       0.0      0.000     0.000
  3     0.030       1.80       0.0      36.7      63.3      13.3      0.110     0.320
  4     0.380       1.60      76.4      11.7      11.9       2.5      0.597     0.323
  5     0.200       2.65     100.0       0.0       0.0       0.0      0.244     0.060
------------------------------------------------------------------------------------

     Average annual SSA enrichment ratio leaving profile =    2.77
```

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