

**SIMULATION OF RUNOFF AND EROSION FROM
FIELD SIZE AREAS IN VERTISOLS OF NORTHERN
DRY-ZONE OF KARNATAKA**

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JANUARY, 2002

**SIMULATION OF RUNOFF AND EROSION FROM
FIELD SIZE AREAS IN VERTISOLS OF NORTHERN
DRY-ZONE OF KARNATAKA**

**Thesis submitted to the
University of Agricultural Sciences, Dharwad
in partial fulfillment of the requirements for the
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IN
SOIL AND WATER CONSERVATION ENGINEERING**

By

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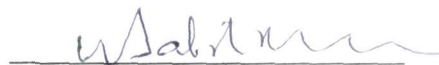
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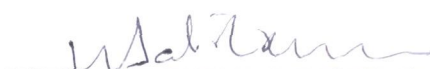
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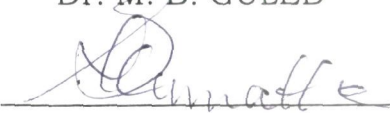
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With regardful memories

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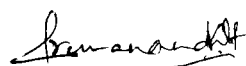
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INTRODUCTION

I INTRODUCTION

The rapidly expanding population of India has a great influence on the agricultural economy of the country due to the increasing pressure on the limited land and water resources. The geomorphic situation, climatic factors and above all, human interference and over exploitation of these resources have caused an appreciable degradation of our eco-system. Industrialization during the last few decades has further aggravated this problem of land degradation to a great extent. Out of 329 M. ha of the geographic area of the country, an estimated 175 M ha of both arable and non arable land has been found to be subjected to serious erosion hazards due to water and wind, shifting cultivation, water logging, salinity and alkalinity and shifting water courses. It is estimated that annually about 5334 M tonns of soil (16.35 tonns/ha) along with about 8.2 M tonns of nutrients is removed as a result of soil erosion.

Most of the semi-arid regions in India,(about 82.2 M ha of land) suffers from severe rainfall erosion, often more than in humid tropics because of the high erosive capacity of erratic rains received on merge or fragile vegetative protection. The rainy season in semi arid topics is characterized by short duration and variable intensity rains, interspersed with unpredictable dry spells. There are two major soil groups in Northern Karnataka namely black cotton soil (Vertisols) and

red soils (alfisols), each of which are further characterized by certain sets of physico-chemical properties and together in combination with the prevailing climatological conditions and topographic factors, will play vital role in selection of cropping pattern, cultivation practices and determine the yield levels.

The agroclimatic conditions of Northern Dry Zone in Karnataka (Zone – III of Region – I) is spread in the districts of Bijapur, Bagalkot, Belgaum, Bellary, Raichur, Koppal, Dharwad, Gadag and parts there off. It is the biggest agro-climatic zone in Karnataka and receives an annual average rainfall of 583.30 mm (100 years). The medium to deep black soils of this zone are subjected to sheet and rill erosion, resulting in an annual average sediment yield ranging between 17-43 tonnes per ha per year. The problem of fast depletion of soil productivity due to water and wind erosion needs to be addressed comprehensively, by taking into account the prevailing energy, resistance and protection factors simultaneously.

“Water balance technique” is a standard procedure to account for all the processes of the hydrologic cycle, encompassing precipitation, abstractions, runoff and evapo-transpiration, based on the principle of conservation of mass and is applicable to any hydrological unit however small or big. The water balance technique helps in scanning the extent of optional utilization of water resources

within a natural or man made hydrological unit and provides means to assess the dynamics of soil moisture conserved over space and time both qualitatively and quantitatively. The information thus obtained helps in understanding the upper and lower limits of the soil metric potential, which is a vital factor in planning a proper cropping programme. In its application to small watersheds or field size areas in particular, where responses of hydrologic processes are immediate, runoff will be a key process among other components of hydrological cycle and helps in evaluation of the response of a catchment to a rainfall event. Further, in case of ungauged catchments, there is a need of a hydrological model which is location and time tested to predict the runoff that is significantly not different from the actual runoff, for the purpose of designing of soil and water conservation structures.

Sediment yield at a given place is a function of sediment production due to erosion of soil and its subsequent transport along the governing slope. Further, the erosion or sediment transport capacity of the agent may limit the sediment yield, depending upon the topography, soil characteristics, vegetative cover and rainfall-runoff rates and quantities. The controlling mechanism changes from season to season, storm to storm or even within a storm event. Thus sediment production and its transportation along with the runoff are location

and time specific. Therefore, there is a need for investigation of the sediment yield under different agroclimatic conditions in order to quantify the actual soil loss quantities and their tolerance limits.

The Universal Soil Loss Equation (Wischmeir and Smith, 1965) which is a premier model for estimation of the rate of soil loss, and takes into consideration the causative factors namely rainfall erosivity, soil erodibility, topography, vegetative protection and tillage practices, cannot give the best results over a broad range of conditions, especially on field size areas, because it takes all those factors on an average basis over the period under consideration. Further more, the relation between the erosion and transport processes is a non-linear one and is interactive in nature for each storm. Hence, it prevents the use of separate equations to estimate accumulation of the erosion or transport capacity of the runoff linearly over the several storms that occur during a rainy season.

The information on surface runoff volume, its peak rate and sediment yield is essential for several purposes including hydrologic and hydraulic design of soil and water conservation structures, for studying the effectiveness of land treatments and planning the supplemental irrigation facilities. The physically based predictive models (empirical-mathematical models) can predict the

sediment yield from field size areas for each storm event by incorporating all the elements of the “Universal Soil Loss Equation” at the same time.

In semi arid tropics, there exist a few runoff and sediment yield records pertaining to several rainy seasons to enable an accurate assessment of watershed characteristics. Therefore, these models are capable of utilizing the available rainfall-runoff and sediment yield records to simulate the runoff and soil erosion rate over each storm and will be of great help in extending the obtained results to ungauged watersheds. Keeping this in view, investigations involving simulation of runoff and evaluating, sediment yield models were carried out, working on storm basis for field size areas at Madabhavi micro watershed in Bijapur taluk under the agro-climatic conditions of the Northern Dry Zone with the following objectives.

1. Investigating the soil and topographical characteristics of the field size areas in the selected micro-watershed.
2. Predicting the runoff and sediment yield using feasible runoff and sediment yield models.
3. Evaluation of the efficacy of the model by comparing the predicted runoff and sediment yield with the measured runoff and sediment yields as applied to field size areas.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

In view of conducting the investigation pertaining to simulation of runoff and sediment yield, the following review of related work carried out during the past are presented under following categories.

1. Soil infiltration
2. Evapotranspiration
3. Runoff and soil loss as influenced by topography and physical properties of soil
4. Runoff
5. Effect of different crops and crop canopies and vegetative barriers on runoff and soil loss
6. Erosion and sediment yield
7. Rainfall variability and its effect of runoff and erosion

2.1 Soil infiltration

Chatterjee *et al.* (1965) reported that infiltration rate was the highest in case of forest soils which have light texture, high organic matter content, low percentage of sand and the plots under permanent vegetation, as compared to soils under arable crops.

Agarwal *et al.* (1974) studied the variations in infiltration rate in relation to the texture of the soil and reported that infiltration

rate decreased with decrease in sand content and increase in “silt plus clay”. The effects of quantity of silt and clay on infiltration rate is found to be partially additive.

Ghosh (1977) evaluated the infiltration parameters (a and b) of Lewis – Kostiaikov’s equation ($I = at^b$) using the data pertaining to antecedent moisture content in the field soil. The percentage variations in constants ‘a’ and ‘b’ as explained by the ratio of initial moisture content to moisture content at saturation were in the range of 80.58 to 98.92 and 86.52 to 98.95 per cent respectively.

Joshi and Sharma (1982) conducted an experiment on infiltration rates of different soils. They reported that higher contents of coarse sand in soils of Mathania series which was associated with high infiltration rate whereas chirai soils of Agolai contained more fine sand which was associated with relatively low infiltration rate.

Mohan and Gupta (1983) studied the infiltration rates of soils under various land uses in Bhaintan watershed which is a typical catchment in the Ganga river basin, by employing the double ring infiltrometer method. They observed that infiltration the rate during the first hour was in the range of 3.2 to 5.2 cm/hr in case of forest lands, followed by 2.4 to 7.05 cm/hr for crop lands, 3.7 to 4.05 cm/hr for land under horticultural crops and 4.25 cm/hr for grass lands. The average infiltration rates were found to be highest in case

of terraced crop lands followed by decreasing order by poorly terraced crop lands, grass lands and forest lands.

Batta (1987) analysed the infiltration rates of 33 soil series existing in Narmada command in Gujarat state and evaluated the infiltration parameters namely S and A of Philip equation $Y = St^{1/2} + At$. He grouped the soils into different permeability classes according to their basic infiltration rates and their suitability for different methods of irrigation.

Very low	:	<0.13 cm/hr
Slow	:	0.13 to 0.55 cm/hr
Moderately slow	:	0.5 to 2 cm/hr
Moderate	:	2 to 5 cm/hr
Moderately rapid	:	5 to 15 cm/hr
Rapid	:	15 to 25 cm/hr
Very rapid	:	> 25 cm/hr

Dongale (1988) studied the effect of different cropping systems and tillage practices on infiltration rates and found that double cropping has increased both the cumulative infiltration (CI) and average infiltration rates (IR) in non-calcareous medium black soils of Konkan (25.74 and 33.7 % respectively) as compared to infiltration in case of soil under monocropping. Tillage has also increased both the CI and the IR depending upon the extent of vegetative canopy

developed by the cropping system. The observed infiltration rate after an elapsed time of 180 minutes varied from 1.4 to 2.38 cm/hr under different tillage and cropping systems. It was concluded that these soils could be categorized under good to medium class of irrigability on the basis of their infiltration characteristics.

Lal and Vandoren (1990) conducted experiments on the effect of tillage on infiltration rates of soils in Ohio state (U.S.A) and found that cumulative and average infiltration rates, depended on the soil water sorptivity, transmissivity and storage co-efficient and they derived exponents of Kostiaikov's model from double ring infiltration experiment. The equilibrium infiltration rate was of the order of 1.3, 1.5 and 1.6 cm/hr for south chalestan and 6.2, 5.3 and 8.5 cm/hr for Wooster sites were reported for the treatments that used mould board plowing, chisel plowing and no till condition.

Bharambe, (1993) stated that the infiltration rate in shallow soil was observed to be higher than that of medium deep and deep soils. They also reported that the infiltration characteristics of alkali soils were considerably different from those of normal soils.

Hirekurubar *et al.* (1991) studied the infiltration characteristics of vertisols derived from different parent rocks in Northern Karnataka and observed that higher infiltration rates of the order of 11.1×10^{-6} m/sec. were observed in case of soils derived from

lime stone, because they possessed higher amount of sand fractions, lower clay content and higher percentage of non-capillary pores. Lower infiltration rates of the order of 0.83×10^{-6} m/sec were observed in soils which are weathered from the granite – gneiss rocks because of the presence of higher amounts of exchangeable Na^+ and consequent dispersion of clay and clogging of the non-capillary pores.

Ravender Singh and Bhargava (1994) reported that due to the presence of deep cracks in clay and the clay loam soils, they were found to have high initial infiltration rates (2.993×10^{-4} m/sec) and reached the steady state infiltration of 1.66×10^{-6} m/sec in clay and 5×10^{-6} m/sec in clay loam soil, after 328 minutes, while sandy loam soil had shown higher infiltration rates of 1.333×10^{-5} m/sec. The cumulative infiltration rates for these soils after 328 minutes were 0.332 m, 0.526 m and 1.098 m for clay, clay loam and sandy loam soils respectively.

2.2 Evapotranspiration

Doorenbos and Pruitt (1977) reported that the crop coefficient (K_c) must be used to estimate the actual crop evapotranspiration. Further they reported that the pan coefficient values for class 'A' evaporation pan placed in dry fallow area varies from 0.55 to 0.85 depending upon the average relative humidity and wind velocity.

Batchelor (1984) studied the accuracy of modified penman equation to predict the evapotranspiration for North-East Sri Lanka in order to illustrate the importance of empirical equations. The study has revealed that the different empirical relationships used to estimate the net radiation and the wind function of the modified penman equation and the penman equation which estimated the evapotranspiration quantities with 23 % difference as compared to annual reference crop evapotranspiration.

Choudhary *et al.* (1992) determined the soil evapotranspiration and potential and actual plant transpiration for maize crop based on crop season data of two years (1989 – 1990). The ET ratio which was correlated with the ratio of leaf area index, dry biomass had showed that the actual plant transpiration was significantly related to the evaporation from the top soil.

Guled *et al.* (1995) worked out the values of reference crop evapotranspiration based on modified Penman method for Raichur, Bidar, Gulbarga and Bijapur districts of Karnataka using climatological data (averaged over 35 years) and found that the crop co-efficient was 0.75 for cotton crop during the grand growth period.

Rangaraju and Iruthayaraj (1995) estimated and compared the ET using Blaney Cradle, Radiation, Penmann and Panevaporation methods for groundnut crop. The different empirical methods for a

watershed area. The daily data pertaining to pan evaporation, rainfall, temperature, wind velocity and relative humidity were used to calculate evapotranspiration. The penman method was found to be the dependable, followed by pan evaporation method.

Raghuvanshi and Wallender (1998) proposed a methodology to convert pan evaporation to evapotranspiration, which is an easy approach for predicting K_p values that includes both categorical and quantitative data, which is developed using the indicator regression approach. The predicted K_p values performed better than those used in the existing equations.

2.3 Runoff and soil loss as influenced by topography and physical properties of soil

Verma and De (1970) found that the extent of erosion by water depends not only on the time of contact of the soil with water but also on the slope and physical and chemical properties of soil.

Anonymous (1976), reported that on a 1.5 per cent slope the fallow plots prior to tillage operations and sowing of crops allowed runoff to the extent of 78 per cent with 23 to 36 mm of rainfall. The ploughed land allowed not more than 50 per cent runoff till two to three good showers were received. Amongst the crops, groundnut had the least runoff in the early stages of crop growth as compared to

maize and ragi. The average runoff from maize crop was 9.5 per cent of rainfall as against 12.5 per cent in ragi. The average runoff in case of groundnut was about 9.2 per cent. Fallow plots generally recorded higher (30.0 %) runoff and soil loss.

Balasubramanian and Sivanappan (1981) studied runoff from field laboratory experiment with 0, 2, 3 and 4 per cent slopes and reported that runoff and soil loss were significantly influenced by rainfall duration and degree of slope. Application of sugarcane trash on the soil surface as mulch was found to significantly reduced the runoff and soil loss.

Flanagan *et al.* (1986) studied the effect of storm pattern on runoff, infiltration and soil erosion. The results showed that storms peaking at the end of 60 minutes resulted in greater runoff and erosion than storms peaking earlier. Previous storm type also affected the runoff, infiltration and erosion from subsequent storms.

Hartage (1987), stated that erodibility depends on the relation between infiltration and surface water. The degree of compaction involved as well as crust formation are generally considered as major factors affecting runoff rate and volume. Both these can reduce infiltration considerably.

Badnur *et al.* (1990) conducted an experiment at the Regional Research Station, Bijapur to evaluate the effect of organic

matter on physical and chemical properties of Vertisols by incorporation of sorghum stubble and cotton stalks in the soil at the rate of 5 t/ha for each plot and found that the infiltration rate, bulk density and field capacity of the soil were significantly increased.

Laryea *et al.* (1991) studied the soils of the semi-arid tropics and stated that out of 14 soil orders, about 5 orders occupy 80% of the areable land area with Vertisols spread over 7.3 per cent of semi arid tropics. Further, they reported that vertisols generally occur on level to undulating slopes in large areas of Central India, Northern Australia, Ethiopia, Sudan and Scattered over Eastern, Central and Sub Saharan Africa, particularly in Chad. He grouped the Vertisols of the India in to chromic and pellic orders out of which chromic are slightly yellower and browner than the pellic vertisols.

Patil and Bangal (1991) stated that the soil loss was reduced due to sowing across the slope. The soil loss reduced from 34.2 to 32.6 per cent when the land slope reduced from 1.6 to 1.0 per cent with three storms of rainfall intensities 73.1, 65.4 and 30.0 mm per hour and it produced a mean runoff of 18.7 per cent.

Kale and Durge, (1992) conducted the experiments at dry farming research station, Solapur to test the runoff and soil loss rate under different cropping systems and found that intercropping system over a land slope of 1 per cent has produced the minimum runoff

(118.75 mm) soil loss (2.47 t/ha) and the maximum returns (Rs. 3392 /ha) as compared to cropping system sown over land slope of 1.25 per cent which yielded a decreased runoff (132.96 mm), soil loss (3.03 tonnes/ha) and returns (Rs. 3272/ha).

Sewaram and Khola (2000), conducted an experiment to quantify the effect of 0.5, 2.5, 4.5 and 9.5 per cent land slopes on erosion losses and maize-wheat productivity. The runoff increased by 39.8, 89.8, 151.5 per cent, soil loss by 109.8, 331.7 and 587.8 per cent and loss of nutrients (NPK) by 69.0, 117.3 and 165.9 per cent with the increase in land slope from 0.5 to 2.5, 4.5 and 9.5 per cent respectively. The grain yield of maize was similar at 0.5 at 2.5 per cent but decreased by 15.9 at 9.5 per cent slope. The grain yield of wheat was highest at 0.5 per cent slope and it decreased by 38.0, 24.7 and 36.3 per cent at 2.5, 4.5 and 9.5 per cent slopes respectively. The decrease in yield at higher slopes was due to reduced availability of soil moisture at different growth stages.

2.4 Runoff

Anonymous, (1972) determined the retention parameter 'S' based on antecedent moisture condition (AMC) under Indian conditions and found $I_a=0.35$ hence they presented following two formulae for different regions of India.

$$Q = \frac{(P-0.35)^2}{P + 0.75} \quad \text{for black soil region under AMC - I}$$

$$Q = \frac{(P-0.15)^2}{P + 0.75} \quad \text{for black soil region under AMC - II}$$

To make the procedure more usable, 'S' is related to the runoff curve number CN by the relationship

$$S = \frac{2500}{N} - 254$$

Ramchandran and Narayana (1988) studied the extent of runoff volume and sediment yield generated from the runoff plots grown with Ragi (*Eleusine coracana*), maize (*zeways*) and groundnut (*Arachis hypogaea* L.) at the Regional Research Station, Bangalore and found that the average runoff volume generated was 22.0, 17.0 and 12.0 per cent of the rainfall received as compared to fallow field which produced a maximum runoff of 27.0 per cent of rainfall. Similarly the sediment yield from the experimental fields were observed to be maximum in case of maize (2.4 t/ha), followed by groundnut (4.1 t/ha).

Boughton and Freebairn (1981) studied the variations in unit hydrographs measured from six storms resulting from a 1.2 ha catchment at Green Mount. The peak rates of runoff in those six storms ranged from 1.12 mm/ha to 50.13 mm/ha. All unit

hydrographs were derived from multi-period storms using an iterative procedure. The unit hydrographs have shown a considerable variation among themselves, with peak runoff rate values ranging from 2.18 mm/hr to 9.45 mm/hr. The peak rate of surface runoff generated per unit hydrograph ranged from 1.12 mm/ha to 50.15 mm/ha with a corresponding increase in the storm runoff quantity from 5 to 86 %.

James and Gregory (1982) determined the time of concentration for prediction of peak runoff with rational methods. It is a known fact that the intensity of rainfall and hydraulic roughness coefficient effect the velocity of runoff. He used the Mannings equation to develop an equation for estimation of the time of concentration which takes into account surface roughness variables.

Neilsen and Panda (1988) developed a physically based, water yield model for small semi-arid watersheds in India to predict and integrate the processes of storm runoff, soil moisture storage, evaporation, transpiration and deep percolation using seasonal data. By virtue of its physical basis, it was reported that the model was found to have a possible wide range of applications in irrigation scheduling, ground water recharge and evaluating hydrological effects of land use changes in the watersheds. The model was found to simulate runoff volume significantly not differing from observed storm

events except in the first few rainfall events wherein runoff was over predicted due to prevailing high infiltration rate.

Srivastava and Jangwad (1988) evaluated erosion rate and components of water balance equation using parametric Runoff Simulations Model (RUNMOD) for 12 years at ICRISAT, Hyderabad and compared the *improved* management system (double cropping system over broad bed furrow practice) with the *traditional* management system (*Kharif* follow and followed by *rabi* crop). The results have shown that under the improved system, the runoff and soil loss were 13.7 % of rainfall and 1.46 Mg/ha/year respectively as compared to runoff of 24.1 % of rainfall and soil loss of 6.38 Mg/ha/year in case of the traditional system. Further, the model was found to over predict the evapotranspiration and deep percolations rates and under predicted the soil evaporation under the experiment conducted with improved system over the traditional system. They opined that the study has demonstrated the importance of management practices in controlling soil erosion rate and in reducing the runoff.

Ramprasad (1988) developed a single parameter hydrologic model for small agricultural watersheds to predict the surface runoff and deep percolation. The model was used to predict runoff and soil profile moisture content subsequent to a rainfall event following a soil moisture accounting procedure on each successive day.

Sarkar and Bhattacharya (1988) reviewed various water balance methodologies in use and found that it is necessary to quantify the different relevant components of water balance equations namely water storage, distributions, disposal and soil conservation for meaningful evaluations of water balance of field sized areas.

Pathak *et al.* (1989) modified soil conservation service (SCS) runoff model and its soil moisture accounting procedure to simulate runoff excess for small watersheds. The model and its moisture accounting procedure for small watersheds were validated for the vertisols at ICRISAT, Hyderabad in India. The measured and simulated daily, monthly and annual runoff were in good agreement. The root mean square error values between the measured and simulated annual, monthly and daily runoff from a Vertisol watershed were 5.2, 3.1 and 1.6 mm respectively. The modified model and its moisture accounting procedure could simulate runoff and soil moisture for the high, low as well as normal rainfall years under a semi arid environment.

Vinod Kumar and Rastogi (1989) analyzed instantaneous unit hydrographs (IUH) developed for a small agricultural watershed (5-6 ha) based on time area histogram and the hydrographs were found to be in agreement with the observed runoff hydrographs with reasonable accuracy. They also stated that IUH theory is based on

time-area histogram, which can be used for determination of direct runoff quantity from agricultural watersheds.

Abo Ghobar and Kay (1990) demonstrated that the kinematic wave model developed for large catchments can also be applied to micro-catchments to predict the runoff and infiltration rates. Further, he found that the model was validated over a wide range of water application rates under sandy loam and clay loam soils.

Narsimha Reddy *et al.* (1991) proposed a water balance model to estimate the surface runoff using daily pan evaporation, rainfall, evapotranspiration as the input parameters.

The surface runoff in the basin was computed from daily rainfall data through SCS runoff curve number model under the prevailing soil, land use, vegetation and hydrologic complex conditions. The pan evaporation data was split into transpiration and soil evaporation components to use the water balance equation.

Tien *et al.* (1993) evaluated three models namely Agricultural Non Point Source Pollution (AGNPS), Areal Non Point Source Watershed Environmental Response Simulation (ANSWERS) and Chemical Runoff Erosion from Agricultural Management Systems (CREAMS) models and found that computed and measured runoff are in good agreement. The average ratio of computed and measured

sediment yields for various storms and watersheds have shown large variations for large streams. The ANSWERS model provided the most consistent results in estimating the runoff even though this model along with the other two models under predicted the sediment yield.

Dharmasena (1994) proposed an empirical relationship to estimate the runoff from small agricultural lands, forest and scrub lands using kinematic wave theory and discharge flow depth relationship

The relationship is:

$$A = 19 (1 - S^2)^{0.5} A (C_c I - C_s F)$$

Where,

A = rate of runoff, m³/hr

S = land slope, m/m

A = area in, ha

I = rainfall intensity, mm/hr

F = infiltration rate, mm/hr

C_c = canopy co-efficient

C_s = surface co-efficient

From the results, he opined that the higher canopy co-efficient and lower surface co-efficient will generate maximum runoff.

Shirmohammadi *et al.* (1997) reported that proper selection of curve number values will improve the capability of SCS

curve number procedure in predicting runoff. The experimental results indicated that using CN-II method without internal conversion to curve CN-I SCS method, every method provides better runoff and erosion predictions than the original version of GLEAMS and versions with seasonal curve numbers when tested with four years data.

Sanchez-cohen *et al.* (1997) developed a simple water balance model for small scale water harvesting systems having a few parameters. The model includes runoff threshold functions for different soil types and for different initial soil moisture contents. The evapotranspiration component of the model accounts for the dynamics of water extraction by roots using regression equations which correlate the canopy cover with root growth as a function of time. It produces good result for several crops provided the leaf area indices and crop stage co-efficients are within an acceptable range.

The agreement between simulation outputs and field observed data indicated that the model can accurately describe the water balance equation properly.

George *et al.* (2000) validated two layer soil water balance model for irrigated areas under field conditions. The model considers the dynamics of soil water balance by incorporating an empirical model to predict growth. The input data required for the model are mainly the values of rainfall, irrigation water and reference crop

evapotranspiration. The model estimates daily variation of soil moisture content in the field. The root depth computed using Borg and Grimes model were compared with the measured ones. The runoff was estimated using SCS curve number technique combined with soil moisture accounting procedure. The simulated and measured values of soil moisture content in the active and passive root zone were found to be in close agreement.

2.5 Effect of different crops and crop canopies and vegetative barriers on runoff and soil loss

Rao (1971) observed that on plots of 25 m x 2 m, cowpea allowed minimum soil loss followed by paddy and maize. Bare soil allowed maximum soil loss. On the same slope with 50 m x 2 m plot, pigeon pea allowed less soil loss than bare plot on the same slope. On a slope of 3.5 per cent paddy lost less soil than bare soil plot.

Sharma and Panwar (1977) reported that urd groundnut plus arhar offered better cover, thereby reducing the soil loss; whereas growing crops such as maize, jowar plus arhar and bajra plus arhar had a poor canopy, high erosion index and low soil cover and hence failed to reduce the soil loss efficiently.

Elitz *et al.*, (1980) reported that erosion losses in the plots under grassland and cultivated pasture were insignificant in

comparison with that in bare soil, which lost 53 tonnes of soil per hectare per year. The gradual cover provided by wheat and soybean resulted in a decrease in erosion as compared with bare soil. Soybean provided a better soil cover than wheat.

Kemper and Derpsch (1981) stated that efficient soil conservation can be achieved by double cropping of soybean, which also increases the soil permeability and water infiltration rates through the biological loosening effects of the root system. Erosion control can also be achieved by no-tillage techniques, which results in higher biological activity in the soil and higher yields of wheat and soybean than under conventional tillage.

Bonde *et al.*, (1982) found that runoff and soil losses were minimum in *Dichanthium annulatum* and maximum in cotton crop with traditional method of planting followed by green manure with traditional method. A ridge across the slope in both green manure and cotton reduced the runoff by 55.2 and 44.3 per cent and soil loss by 52.0 and 52.8 per cent respectively over traditional method of planting of these crops with increased yield.

Dickey *et al.*, (1984) reported that for identical tillage systems, soil loss under soybean averaged 40.0 and 3.5 per cent greater than in a maize plot on 5.0 and 10.0 per cent slope respectively. Twenty per cent ground cover of either soybean or maize

reduced the soil erosion by 50.0 per cent of that occurring from a cleanly tilled soil surface.

Hargrave *et al.* (1984), observed that legumes were significantly more effective than small grains in directing the rainfall to the soil profile thereby reducing runoff and soil erosion. They can also provide significant quantities of nitrogen for a subsequent grain crop.

Prasad *et al.* (1984), revealed that early sowing before 25th June of crops were produced better crop cover, lower splash erosion, maximum yield and net profit as compared to their delayed sowing between 1st July and 7th July. Among those crops, soybean gave the highest canopy cover, lower splash loss and highest net income, followed by upland paddy and maize.

Freebairn and Boughton (1985) studied the effects of crop residues and management practices on runoff volume and peak discharge for six years and found that the burning of the stubbles has produced higher peak discharge and runoff volume as compared to an experiment with uniform mulching with stubbles.

Finnker *et al.* (1986), investigated the effect of application of varying rates of sorghum residue on runoff and erosion. Increased surface cover caused a reduction in runoff, sediment concentration and soil loss.

Sud and Mittal (1987), reported that on five per cent slope in sandy loam soil, Bhabbar grass on an average produced 19.3 per cent of the rainfall as runoff during three months of monsoon. In July, the runoff was more (25%). This was obviously due to less canopy formation in July. Nearly 57 per cent of the total average soil loss occurred in July when plant canopy was at its minimum. It was followed by August (42%). It was found that the fibrous root system and good canopy cover of the grass helps in reducing soil losses.

Abiyo (1987), stated that the grass cover was most effective in controlling soil erosion when about 85 per cent of plots were covered with the grass. Soil erosion was more severe with ridge planting than with broadcasting at the beginning of the cropping season.

Khan *et al.* (1988) made a laboratory study to predict the influence of simulated crop canopy cover, canopy height and straw mulch cover on runoff and soil loss and found significant decrease in runoff (56 per cent) with increase in mulch cover. However, runoff volume and soil loss quantity were found to be unaffected with the change in the height more than 1 m and the extent of crop canopy.

Adhikari *et al.* (1996) studied the effect of surface mulch cover on runoff and soil loss under simulated condition. It was observed that sorghum mulch reduced the runoff. The soil loss was reduced with mulch cover but increased with increase in degree of

slope. Further, they found that the vegetative measures including *in-situ* moisture conservation practices can act as an effective complementary tool to graded bund for conservation planning in clay soil having slope less than 2 %.

Mishra *et al.* (1999), reported the efficacy of vegetative barriers in *in-situ* conservation of rainwater, checking runoff and soil loss. The vegetative barriers used on 3 per cent slope were *khus* (*Vetivera ziziniodes*), thin Napier (*Pennisetum purpureum*), sabai (*Eulahiopsis binata*) and hill broom (*Thysanolaena maxima*) were planted at a contour interval of 8 m. Sabai and hill broom were replaced by *Jatropha jatropha* sp. and Agave (*Agave sisalana*) due to their poor adaptability. During the 1st year, maximum soil moisture was conserved by Napier followed by *Khus* grass. During the 2nd year, *Khus* performed the best among all the vegetative barriers. Agave and *jatropha* established well but were unable to conserve soil moisture due to slow vegetative growth.

Kabango Freddie *et al.* (2000), conducted a field experiment to quantify runoff and soil loss under nine treatments. The total runoff and soil loss in control was 9.4 per cent of rainfall (17.2 mm) and 1.5 t/ha respectively. Ridges and furrows on contour with *khus* barrier recorded the maximum reduction in runoff (92.2 %) and soil loss (92 %) compared to control. Dead furrows on contour, with

Khus barrier was the next best treatment resulting in reduction of 85.5 per cent runoff and 81.9 per cent soil loss compared to control. From this it is evident that *Khus* grass which forms a dense hedge acted as a barrier, reducing the velocity of runoff, resulting in more infiltration opportunity to water to enter the soil.

2.6 Erosion and sediment yield

Wischmeir and Smith (1965), developed a predictive equation for estimating the soil loss, called as Universal soil loss equation. The equation is given by

$$A = RKLSCP$$

Where,

A = average annual soil loss (t/ha)

R = annual rainfall erosivity factor

K = soil erodibility factor (t/ha/EI₃₀)

LS = slope length and slope steepness factor

C = cover management factor

P = supporting practice factor

Williams (1975), modified the USLE by replacing the rainfall erosivity factor of the USLE with a runoff erosivity factor which eliminated the need for a delivery ratio and significantly improved USLE estimates for individual storms.

The modified USLE by Williams (1975) is

$$E = 11.8 \{(RO) Q_p^{0.56}\} KLSCP/\text{area}$$

Where,

E = soil loss (tonnes/ha)

RO = runoff (m^3)

Qp = peak runoff rate (m^3/sec)

Area = catchment area (ha)

Van Vliet *et al.* (1976) compared the sheet and rill type soil erosion losses that are evaluated by the Universal Soil Loss Equation with measured soil loss data generated for 4-6 years from runoff plots at two locations in Southern Ontario. The results indicated no significant differences ($p=0.01$) between predicted and measured soil losses.

Elwell (1978) proposed a mathematical model approach to soil loss estimation and to bring together all sources of information in to a formal arrangement.

The model is simple and direct and predicts the mean annual soil loss at the rate of 1.7, 2.6 and 4.3 t/ha in 50%, 70% and 90 % of cases respectively and the predictions of soil loss are within the normal range for agricultural lands.

Beasley (1980) developed an event based model namely ANSWERS, which consists of hydrologic and sediment plus detachment components describing both overland and channel flow

using distributed parameters. The potential utility of ANSWERS as a planning tool was used for simulating several management alternatives for primary ungauged agricultural watersheds in North Eastern India.

Foster and Lane (1981) developed a reasonably simple simulation model that incorporates the fundamental principles of erosion, sediment transport and deposition process. The model provides a comprehensive representation of the hydrological behaviour of a field, by considering channel flow and impoundment's. The model estimates transport of sediment which is composed of primary (Sand, silt, clay) and secondary particles.

Foster, *et al.* (1982) reported that the widely used Universal Soil Loss Equation satisfactorily estimates the average annual soil loss as a result of rainfall. However, it is unsatisfactory for estimating soil loss from individual storms. Several erosivity factors that could be used to estimate soil loss from individual storms were investigated during the study. Rainfall erosivity factor that includes both rainfall rate and amount terms was found to be a much better factor to predict the soil loss than a factor that include rainfall amount alone. Rainfall intensity and runoff amount were found to be even better predictors of soil loss than EI_{30} , whereas erosivity factors with separate terms for rainfall and runoff erosivity were found to be the best.

Foster *et al.* (1982) derived predictable equations of soil loss by modifying rainfall erosivity factor (R) in USLE equations from individual storm events. It was observed that while evaluating the erosivity factor it is better to include both rainfall rate and quantity than rainfall quantity alone for better predictions.

Morgan *et al.* (1984) developed a model for predicting the annual soil loss from field sized areas, consisting of both water and a sediment phase. The rainfall energy and runoff volume were estimated from annual rainfall amount in the water phase. The predicted rates of soil loss were compared with a top soil renewal rate to determine the changes in top soil depth over time. The model validation was carried out by comparing the predicted and observed values of annual runoff and erosion at 67 sites in 12 countries.

Bhusan (1984) conducted an experiment for three years (1981-83) in a set of 8 standard runoff plots on 2% slope to assess soil loss and runoff from different cropping systems and to estimate the soil erodibility factor. The runoff volume and the erosion quantity was observed to be maximum in cultivated fallow plots and minimum in case of *Cenchrus ciliaris* grass plot. Among the different cropping systems bajra crop of uniform canopy permitted maximum runoff (28%) and soil loss (6.34 t/ha). The inter cropping of bajra with

cowpea or moong was found to reduce the soil loss to 4 t/ha (40 % the average values of soil loss). The erodibility factor, K of USLE was evaluated as 0.202 t/ha/unit of rainfall factor.

Bhushan *et al.* (1984) derived the average monthly and annual rainfall erosion index (El_{30}) for Agra and found it to be 416 metric units. Annual El_{30} values were found to be concentrated in the months between June and September. The average El_{30} annual values estimated for Agra region were 386, 540 and 640 for the periods of 2, 5 and 10 years respectively.

Santhana Bosu and Rastogi (1985) developed a Muskingum sediment yield model based on combined approach of translation and routing for simulating graphs for mynaly sub-watershed in Lower Bhavani catchment. The parameters of the model were estimated using Lagrange multipliers method the sediment graphs generated by the model were found to be in close agreement with the measured sediment graphs. The result also supports the adaptability of the model to real time forecasting of sediment flows.

Freebairn and Wockner (1986) studied the effects of soil surface conditions on runoff and soil loss generation on two major clay soils of the Darling Downs, Queensland and presented the technique that was used to measure soil loss between field contour bays under natural rainfall from ten contour bay catchments (66 plot

years). Soil movement was separated into rill, interrill, suspended sediment and channel deposition. In an annual winter wheat-summer fallow system, removal of stubble resulted in soil movement of 29.62 t/ha / year. Retention of stubble reduced the soil loss to less than 5 t/ha/year.

Greater than 75% of the variation in soil movement from single events was explained by surface cover and peak runoff rate.

Freebairn and Wockner (1986) studied soil erosion of Vertisols of the eastern Darling downs in Queensland. The runoff water was sampled as it discharged through a weir which was installed at the outlet of the 1 ha contour catchments. The vegetative cover, rainfall intensity, flow conditions and soil tilth are important factors determining the concentration of suspended sediment in runoff. The mean delivery ratio for a gray clay and a black earth were found to be 0.19 and 0.13 respectively. The contour bunds reduced the sediment loads reaching the bottom of slopes by at least six fold.

Ahluwalia *et al.* (1988) developed an event based mathematical model to simulate the overland flow and to determine sediment delivery ratio for small watersheds. The overland flow was simulated using Saint - Venant equations with kinematic wave approximation and dynamic conservation of mass equation was used to simulate sediment routing. The empirical relationship between rill

and inter rill were used for estimating soil detachment rate. Modified Yalin's equation was used to compute the transport capacity of flow for non- uniform sediment mixtures. The solution to the governing partial differential equation of flow and sediment have been obtained using finite-element technique. The event based soil erosion model, which utilizes the distributed parameter approach had given a good agreement with the total soil loss from the overland of slow and needs verification for its temporal distribution.

The model has the potential to asses the effect of land use changes on the sediment yield because it utilizes the cropping and management factor of the USLE in the soil erosion component of the model.

Sachan and Srivastava (1988) tested three models namely RUNMOD, a Modified Curve Number Model (MCNM) and Numerical Technique Runoff Model (NTRM) under the prevailing conditions of vertisols and allisols at ICRISAT, Hyderabad and found that the first two models require calibration at a given site, whereas the third model can be used without calibration. The first model requires daily rainfall amount and duration whereas the second model requires only daily rainfall amount and the third model requires data on storm intensity and duration. The first two models namely, RUNMOD and MCNM could be used for extrapolating the future runoff records for small

watersheds using at least one to two years of measured runoff data, to predict water yield for nearly ungauged watersheds. The NTRM model provides event based outputs and requires data on physical processes involved. However, it necessitates further improvements.

Silburn and Loch (1989) evaluated the sensitivity of the soil erosion component of the CREAMS model to the changes in various input parameters and found it to be suitable to predict erosion from aggregated clay soil plots. The prediction of total sediment yield was sensitive to changes in number of parameters and interactions between parameters namely specific gravity of sediment (S_{gi}), slope steepness, total runoff (V_u), USLE factors, shear parameter (n_{bov}), peak runoff rate (d_p), storm erosivity (EI_{30}), slope length (L_c), sediment size distribution and kinematic viscosity.

Freebairn *et al.* (1989), assessed the universal soil loss equation (USLE) and two modified USLE (Williams Onstad and Foster) for their ability to predict soil erosion on contour bay catchments on the Darling Downs, in Queensland. The models were applied using the USLE hand book values as well as optimized values determined by fitting the models to the experimental data. All three models explained greater than 80 per cent of the variance in measured soil loss with no single model being consistently superior to the other.

The modified USLE given by Williams (1975) is as follows

$$E = 11.8 \{(RO) Q_p^{0.56}\} KLSCP / \text{Area}$$

Where,

E = soil loss (t/ha)

RO = runoff (m^2)

Q_p = peak runoff rate (m^3/sec)

Area = catchment area (ha)

Elliot and Laflan (1993) developed a mathematical model that accounted for different processes that caused sediment detachment in an eroding rill, to predict rill erosion. The rill erosion data from nine cropped land soils were studied using USDA water erosion prediction project (WEPP) model and found that the detachment capacity of water flowing in a rill was best predicted by a storm power function.

$$\text{Detachment capacity} = K_p (WQS/W_r) - P_c$$

Where,

K_p = soil erodibility coefficient

W = specific weight of water

Q = out flow rate of water in the rill,

S = rill slope

W_r = rill width

P_c = critical stream power below which no soil particle detachment occurs.

The prediction capacity of the model was not improved by additional terms to describe detachment.

Owoputi and Stolte (1995) studied the physical soil erosion processes to quantify the rate of detachment from a storm event. They also evaluated two parameters namely the critical conditions for erosion and soil erodibility, in addition to the impact of flow and soil moisture variation and concluded that there is a need to derive a more fundamental equation for predicting the soil detachment rate. They also highlighted the necessity of developing some fundamental concepts that may be useful in deriving a more physically and engineering based soil detachment equation.

Sutaria *et al.* (1997) derived rainfall erosion index (EI_{30}) in the Anand region as 772.59. Nearly 98 per cent of the annual erosion index was found to be concentrated during June to September, wherein July was the most erosive month. Predictive models thus developed using EI_{30} Index were found to be useful in quick determination of kinetic energy and erosion index of storms.

Ted *et al.* (1999) evaluated the Performance of Spatially Integrated Models for Erosion (SIMPLE) in predicting runoff volume sediment loss from two watersheds at field scales. Cell level simulation provided similar estimates of runoff volume as compared to field level simulations for both the watersheds. However, observed sediment

yields were better evaluated with the predicted values at the cell level simulation as compared to field level simulation. The results have confirmed that predictive ability of the model is acceptable for screening applications but not for site specific quantitative predictions.

Devanarayana and Bhusan (2000) conducted runoff plot based studies on erosion in relation to canopy development under different crops in deep alluvial soils. A set of eight standard runoff plots on 2% slope at Agra, were chosen to evaluate the runoff, soil loss and splash erosion under different rainy seasons and crops of the region. Among the crops sown, greengram and cowpea developed the canopy at a faster rate and covered the ground surface effectively. Among the different treatments, the maximum runoff (257.4 mm) soil loss (13.4 tonns/ha) and splash (53.3 gram) were recorded under cultivated fallow and the minimum runoff (73.3 mm), soil loss (1.02 tonns/ha) and splash (13.6 gram) were recorded under grass (*Cenchrus ciliaris*) cover. Among the different field crops, the minimum runoff (117.8 mm), soil loss (2.63 tonns/ha) and splash erosion (20.9 gram) was recorded under cowpea and the maximum under castor (runoff 173.5 mm) soil loss 5.42 t/ha and splash 25.2 gram). The evaluated values of crop management factor 'C' for greengram, cowpea, sesame, clusterbean, pearl millet, castor and *Cenchrus ciliaris* were 0.232, 0.197, 0.279, 0.281, 0.334, 0.406 and 0.077 respectively. The

value of soil erodibility factor 'K' of USLE equation for deep alluvial soil was found to be 0.225.

Satapathy *et al.* (2000) analysed the erosion index for Umiam region and found that August is the most erosive month of the year. The average annual erosion index (EI_{30}) was found to be 854.3, out of which 790.4 occurred during *kharif* season. The linear regression equations were also developed between the factors namely kinetic energy (KE), erosion index (EI_{30}), erosive rain and monthly total rainfall.

2.7 Rainfall variability and its effect on runoff and erosion

Rose (1960) revealed that the rate of soil detachment under a given rainfall was approximately constant. Rate of soil detachment per unit area depends more closely on the momentum per unit area and duration of the rain than on kinetic energy per unit area and time.

Rogers *et al.* (1964), Reported that for a given rainfall intensity, soil loss increased at an increasing rate with increased rainfall amount and runoff increased slightly with rainfall intensity and length of slope. Most of the variation in runoff was due to rainfall amount.

Epstein and Grant (1971), Reported that after 10 minutes of incidence of rainfall, the soil loss remained constant at the rate of 625 g/joule/sq cm. This is believed to be due to formation of a consolidated seal. The seal underlying crust was mainly due to the physical impact of raindrop.

Arora *et al.* (1974), Conducted an experiment on the land with 0.2 per cent slope in sandy loam soil and found that the peak rate of runoff increased with rainfall intensity with non linear relation. The rainfall volume was found to have a direct relationship with runoff volume.

Gopalakrishna *et al.* (1975), studied runoff and soil loss for four years from 1937 to 1941 at Hagari. The total rainfall for the period was 531 mm. The average amount of water lost as runoff was found to be 108 mm per hectare on the land with 1.2 per cent slope. The average soil loss was found to be 15.8 tonnes per hectare when the rainfall was heavy. Runoff generation in red soils was ranged from 250 to 300 mm per hectare and soil loss ranged from 1 to 4 tonnes per hectare per year.

Snatic and Taysum, (1979), had obtained positive correlation between soil loss and runoff determined at different slopes, rainfall intensity and rainfall duration. Resistance to the soil loss

showed no significant changes with a change in slope, rainfall intensity or rainfall duration.

Sharma and Singh (1981), found that increase in rainfall intensity, depth and antecedent soil moisture reduces the rainwater infiltration. They also found that the catchment on 5 per cent slope and North-South orientation yielded maximum runoff from minimum slope length.

Budhar and Gopalswamy (1985) computed the coefficient of variation for the annual, seasonal, monthly and weekly periods using 29 years of rainfall data. They worked out the dependability of rainfall in different periods and proposed a number of cropping systems based on their analysis.

Baskaran Rao *et al.* (1986) studied monthly, seasonal and yearly rainfall variation using 23 years data of Bellary district. The months of drought, normal rainfall and abnormally high rainfall were computed using frequency and probability analysis. They reported that drought and normal months accounted for 50 and 38 per cent of the total months respectively. The seasonal rainfall analysis showed that 34 per cent of the season was drought prone during *kharif* and 51 per cent during the *rabi* season.

Guy *et al.* (1986), reported that the rain drop impact contributes towards dominant portion of inter-rill transport capacity.

Use of momentum or kinetic energy flux in the place of intensity provides improved results. Limited flow competence and the size distribution of the soil available for transport also found to affect the transport capacity.

Kothari and Verma (1990) studied the rainfall data collected from 80 raingauge stations covering several parts of India to develop general relationships for the estimation of rainfall intensity of various durations.

Kavi *et al.* (1990) studied the variations of rainfall characteristics for each of annual, seasonal, monthly and weekly periods using the daily rainfall data of forty-years (1950-89) pertaining to Dharwad area. The frequency of annual normal rainfall during this period shows a decreasing trend first three decades and increasing trend during the last two decades. The coefficient of variation in rainfall was highest in December month and was least in the month of July. The weekly analysis of rainfall has shown that the most appropriate cropping season should be selected between 24th and 34th standard weeks.

Patil and Patil (1991) analysed 24 years of rainfall of Dhule area (Maharashtra state) and computed the standard deviation (S_D) and coefficient of variation (C_v) for monthly, seasonal and yearly time

series. They reported that July was the wettest month and February the driest. The coefficient of variation of annual rainfall was found to be 25.95 per cent.

Manohar *et al.* (1992) studied the probable one day maximum precipitation over Northern Karnataka using Hershfield technique and reported that the highest one day probable maximum precipitation at Raichur was 376.6 mm.

Kavi (1992) studied the nature of rainfall variability in Raichur and Koppal districts of Karnataka based on the recent thirty years of daily rainfall data. Out of nine taluks, eight taluks have shown increased rainfall variability from first decade to second decade. But the tendency of this increase from second to third decade (1978-87) was found to be continued further for only two taluks and all the other remaining taluks had exhibited declining trend.

Adhikari *et al.* (1993) analysed the rainfall data of Bellary region which consists most of its area under rainfed conditions and opined that ill-distribution of rainfall creates either drought or flood. Further, he reported that the average rainfall distribution that received during September and October months leads to total failure of *kharif* season.

He reiterated that the probability analysis of rainfall helped to identify sowing period for crops whereas the return period

analysis is useful for designing of soil and water conservation structures and in determining the size of hydraulic structures.

The results of this study helped in planning the watershed management project and suggested to be extended to similar agro-climatic regions of Karnataka.

Chinnamuthu and Palaniappan (1995) analysed 40 years rainfall record and developed a comprehensive crop plan for Trichy district. The study revealed that out of 40 years for which the data was collected, the distribution pattern of annual rainfall was normal in 15 years, deficit in 10 years, excess in 13 years and scanty in 2 years. They reported that the North-Eastern monsoon has contributed the highest amount of rainfall, followed by the South-West monsoon.

Kahlon and Khera (1997) conducted the experiment on surface soil sample from five representative sites varying in texture and land uses *viz.*, bare, arable, grass and forest were exposed to three rainfall intensities (18, 38 and 68 mm/hr) using artificial rainfall simulator. Both runoff and soil loss increased significantly with increase in rainfall intensity. Runoff increased from 1.5 to 11.5 mm and soil loss from 2.1 to 42.5 t/ha, when rainfall intensity was increased from 18 mm/hr to 68 mm/hr. The higher intensity rains increased raindrop impact on soil surface causing detachment of soil

particles and surface sealing, resulting in greater soil loss and water. Compared to bare soil condition runoff and soil loss decreased from 61 to 48 per cent and 23.1 to 13.8 t/ha under forest land use.

Salil *et al.* (2000) analysed rainfall characteristics for annual, seasonal, monthly and weekly periods and observed the rainfall during rainy period, non-rainy period and summer seasons as 1229.32, 10.86 and 28.8 mm respectively with annual average of 1369 mm. The analysis has shown that the month of August receives the highest rainfall (495.08 mm) and April (3.68 mm) the lowest. About 89% of total annual rainfall was received between 23rd and 34th meteorological week. The normal probability distribution was used for predicting the weekly rainfall probabilities of these which received at least 10, 20, 30 and 40 mm of rainfall.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The investigations were carried out in selected plots in the Madabhavi micro-watershed of Bijapur taluk during 2000-01. The investigation was consisted of two phases. In the first phase, the runoff volumes and corresponding soil losses were measured for the selected storm events with the help of the experimental setup, established in the identified field size areas of the Madabhavi micro watershed in Bijapur taluk. Later, the runoff model developed by Pathak *et al.* (1989) for semi arid tropics and soil loss prediction model developed by Williams *et al.* (1975) were used for prediction of runoff and soil loss respectively for the runoff events. The measured runoff and soil loss values were compared with the corresponding predicted runoff and soil loss values using statistical methods to test their applicability for the field size areas. The details of the methodology and the techniques adopted during the course of investigation are presented in this chapter.

3.1 Description of Madabhavi micro watershed

3.1.1 Location

Geographically, the micro watershed is located between 16° 48' to 16° 52' North latitude and 75° 49' to 75° 53' East longitude and at a mean elevation of 592.24 m, above the Mean Sea Level. The

micro watershed area is a part of the Bijapur taluk and is located 20 km away from the Regional Research Station, Bijapur which is a part of UAS, Dharwad, on Bijapur-Gulbarga state highway (Fig. 3.1).

3.1.2 Climate

Agroclimatically, the micro watershed is a part of the Northern dry zone of Karnataka and also a part of the agroecological region 2 and 6 of the country. The aridity index of 64.4 (Anonymous, 1997) shows that the climatic conditions of the zone can be classified as semi-arid and sub-humid type.

The northern agroclimatic dry zone consists of parts of Bijapur, Bagalkot, Gulbarga, Belgaum, Dharwad, Gadag, Raichur and Koppal districts of Karnataka. Analysis of 97 years of historical record (1901-1997) of the rainfall distribution pattern of Bijapur district has shown a trend of increasing rainfall in the last 36 years. The data revealed that out of 97 years under consideration, the district has received a rainfall quantity less than 400 mm in 14 years and a quantity in the range of 400-600 mm of rainfall in 36 years (Anonymous, 1997). Further, the analysis also revealed that out of every five consecutive years in the last 97 years, one year was subjected to severe drought, one year of moderate drought, two years of average rainfall and one year of more than average rainfall in a row.

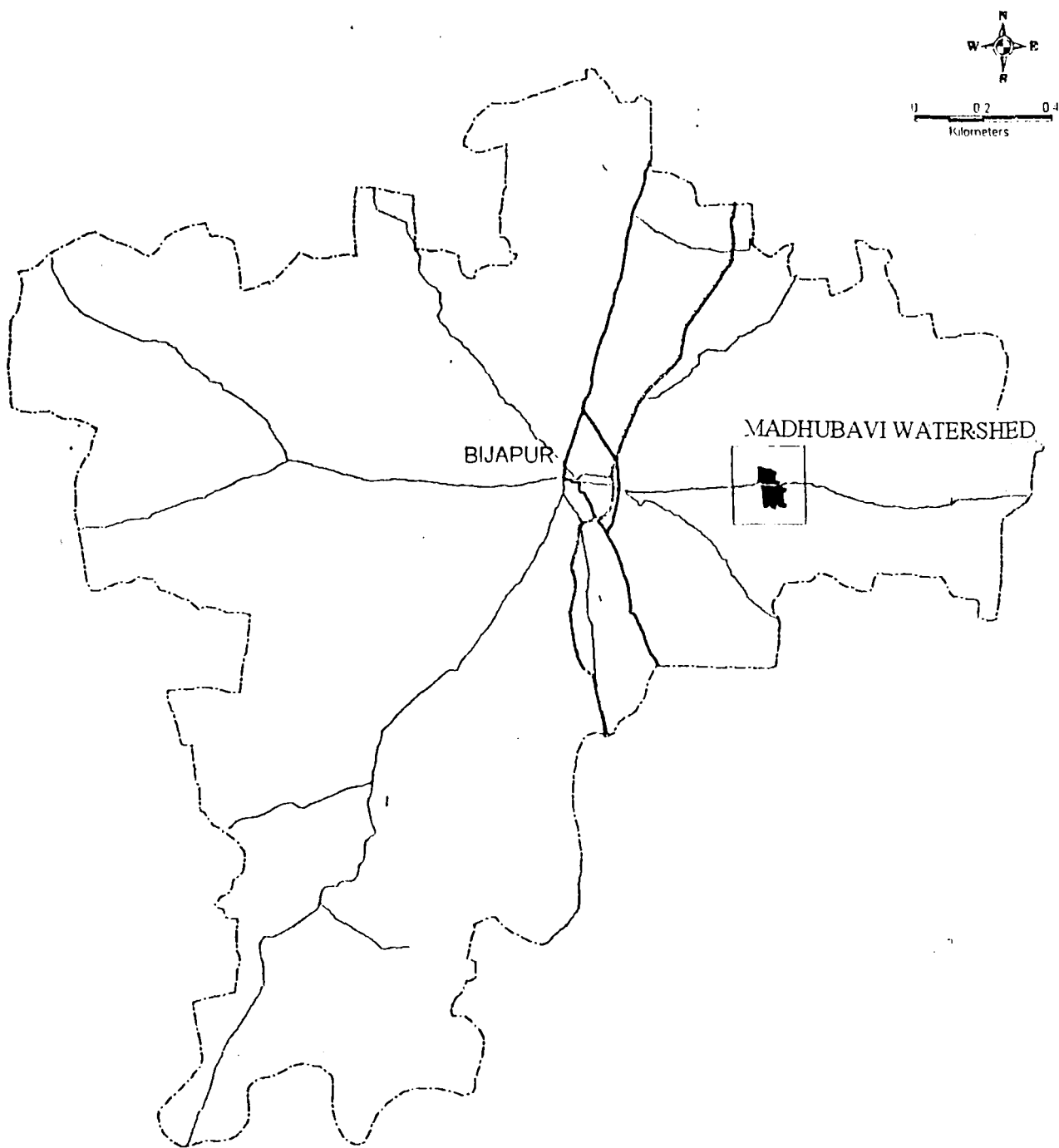


Fig. 3.1. Location map of Madhubavi micro watershed in Bijapur taluk

The average maximum temperature recorded in the month of May was in the range of 41° to 44° C and the average minimum temperature was recorded in the month of December in the range of 17° to 21° C.

3.1.3 Soils

The soils of the micro watershed belong to Managoli, Sasalatti, Rajapur and Jambagi series and are classified as typic chromusters and vertic ustochrepts. The soils of the watershed are classified into deep black (25% of the area), medium deep black (30 of the area), shallow black (30% of the area) and marginal soils (15% of the area) and the same are shown in Fig. 3.2. These soils are derived from deccan trap and gniess and are classified based on the following physical properties.

3.1.3.1 Deep black soils

The depth of these clay textured soils ranges from 90 to 150 cm depth, with montmorillonite type of clay and the clay content of around 60 per cent. These soils occur on lands that are nearly level, with very low infiltration rate (0.2 to 0.82 cm/hr) and moderate to poor drainage capacity.

In general, these soils belong to land capability class II and III. The available water holding capacity of these soils is around 20 cm/meter depth and they provide 90 to 120 days of growing period to

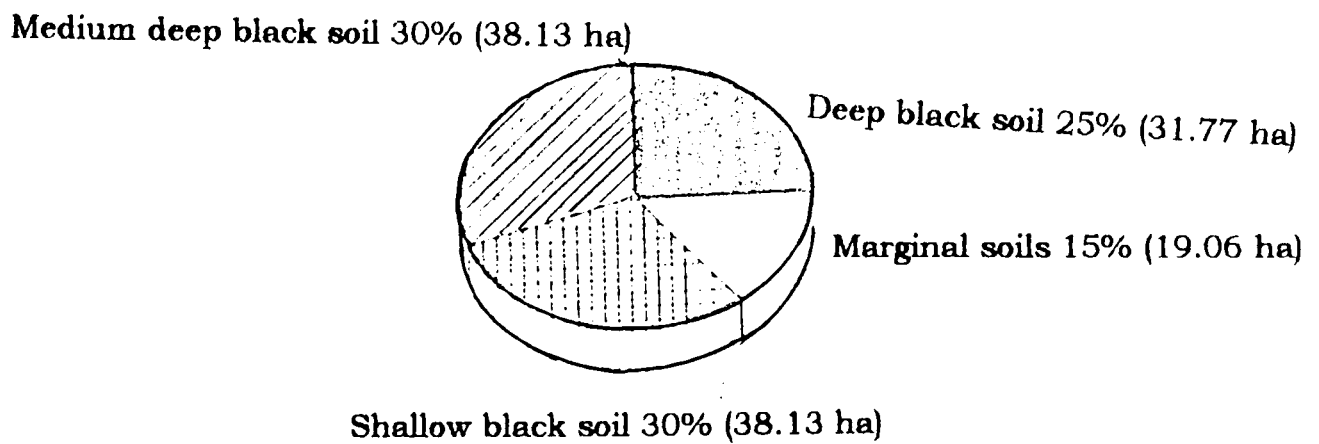


Fig. 3.2. Soil classification of Madhubavi micro watershed

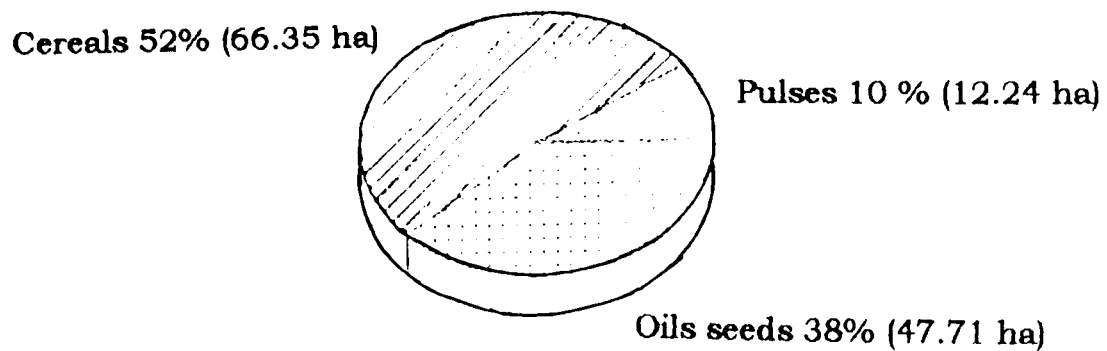


Fig. 3.3. Cropping pattern in Madhubavi micro watershed

the crops. The soil erosion hazard is moderate to high, depending upon the prevailing topographic conditions. These soils are alkaline in reaction with pH values ranging from 8.8 to 9.0. These soils are low in nitrogen and available phosphorous but are rich in exchangeable and non exchangeable potassium. The CaCO_3 content in the soil is about 7 to 8 per cent.

3.1.3.2 Medium deep black soils

These soils have depths varying from 45 to 60 cm, clay content around 50 per cent which restricts the infiltration rate to a range of 0.8 to 1.0 cm/hr. The available water holding capacity of the soils is around 10 cm per meter depth and possesses 75 to 89 days length of growing period. The soils are base saturated and alkaline in reaction (pH 8.5). The CaCO_3 content increases with depth and it ranges from 10-12 per cent. Soils are low in nitrogen and available phosphorus content and rich in potassium. These soils are also show deficiency of Fe and Zn in some pockets.

3.1.3.3 Shallow black soils

The depth of these soils is less than 30.0 cm. The clay content ranges from 35 to 40 per cent. The infiltration rate is moderate to high (2.0 to 3.5 cm/hr). The available water holding capacity varies form 6.0 to 7.0 cm per meter depth. These soils belong

to land capability classes III and IV. The CaCO_3 content increases with depth. The soils are alkaline in reaction ($\text{pH} = 8.5$).

The physical and chemical properties of the soils of Madabhavi micro watershed are presented in Table 3.1.

3.1.3.4 Cropping pattern

The cropping pattern in the micro watershed is confined to a few field crops. During the *kharif* season, bajra is grown as the main crop which occupies 33 per cent of the total area, followed by groundnut (23%), sunflower (17%) and greengram (17%). The remaining 10 per cent of the area is occupied by other field crops like horse gram. During the *rabi* season, jowar is grown as a sole major crop occupying 50 per cent of the total cultivated area. The sunflower and greengram crops are grown in 28 and 9 per cent of the area respectively (Fig. 3.3).

3.2 Location

3.2.1 The selected experimental site is a part of the survey No. 140 in Madabhavi micro watershed and is located 20 km away from the Regional Research Station of the University of Agricultural Sciences Campus, Bijapur on the Bijapur-Gulbarga state high way. The location map of the study area is shown in Fig. 3.4.

Table 3.1. Physical and chemical properties of the soils of Madabhavi micro-watershed

Soil type Soil properties	Deep black soil	Medium black soil	Shallow black soil
Coarse sand (%)	17.50	16.20	29.10
Fine sand (%)	3.50	6.30	7.10
Silt (%)	15.50	13.20	10.80
Clay (%)	59.60	54.30	40.50
Texture	Clay	Clay	Clay
Absolute specific gravity	2.41	2.43	2.51
Porosity (%)	59.60	58.80	55.20
pH	9.10	8.70	8.10
EC (ds/m)	0.30	0.45	0.30



Fig. 3. 4. Location map of study area in Madhubani micro watershed

The experimental site is divided into two rectangular hydrological units (hence forth referred as plots) and have the areas of 0.85 ha (Plot-I) and 0.90 ha (Plot-II). Both of these neighboring plots are surrounded by the field boundaries which provides them a status of independent hydrological units. The field dimensions are shown in Fig. 3.5a & 3.5b.

3.2.2 Topographical features

The contour maps pertaining to these plots were prepared at a vertical interval of 0.25 m. The terrain of each field plot was shaped to form in to single terrace system having a single out let. The highest slope in case of Plot-I was 0.90 per cent followed by 0.74 per cent in case of Plot-II. The details of contour maps of the two plots are shown in Fig. 3.5a & 3.5b.

3.2.3 Soil properties

A detailed study was carried out in respect of physical properties of soils of the individual plots in order to quantify their responses to the rainfall events. The soil samples were drawn randomly from each plot at two depths namely 0-30 cm and 30-120 cm from their upper, middle and lower reaches, following standard soil sampling techniques.

The samples were analyzed in respect of the following properties.

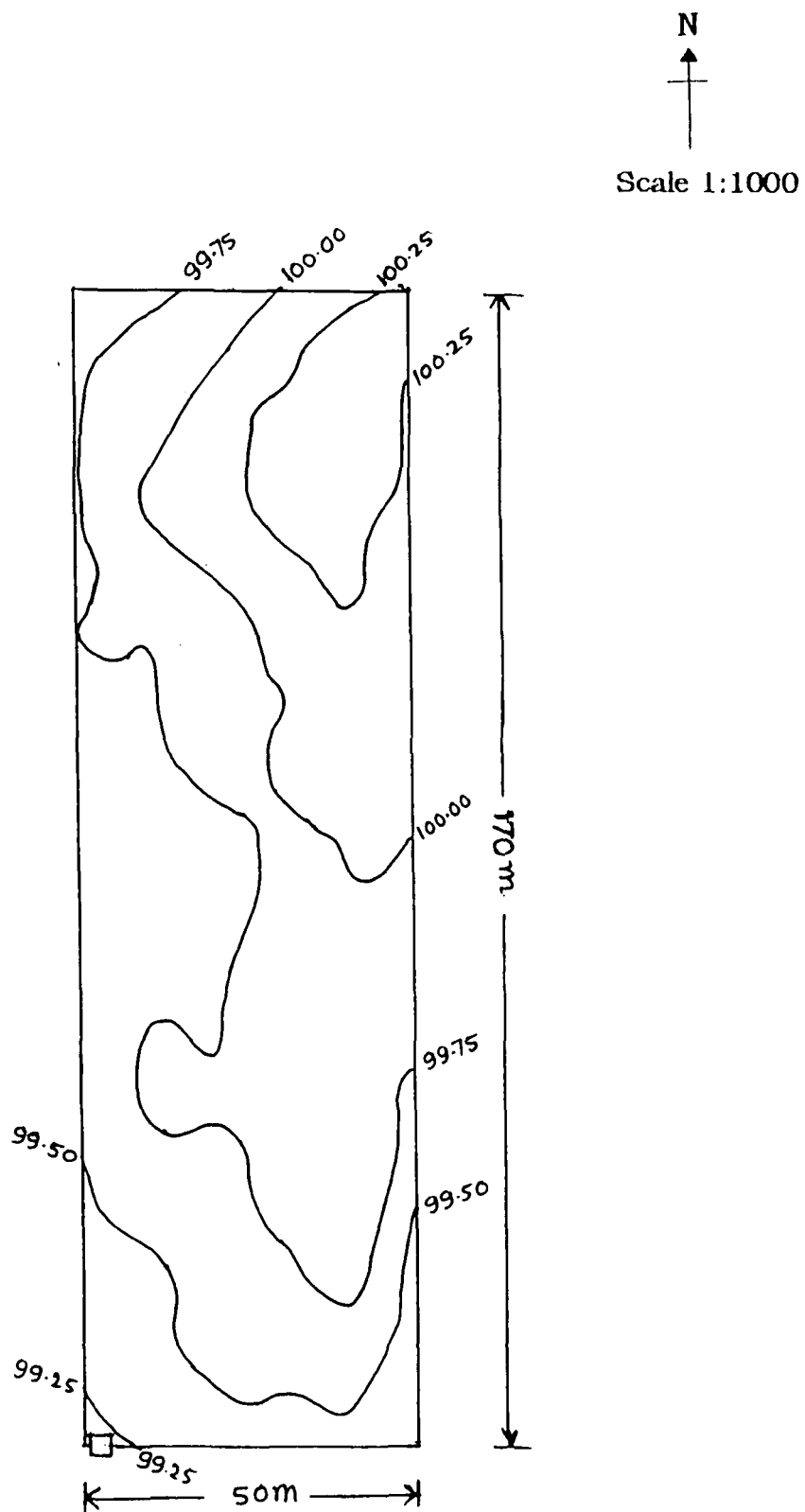


Fig. 3.5a. Map showing topographical features of plot I

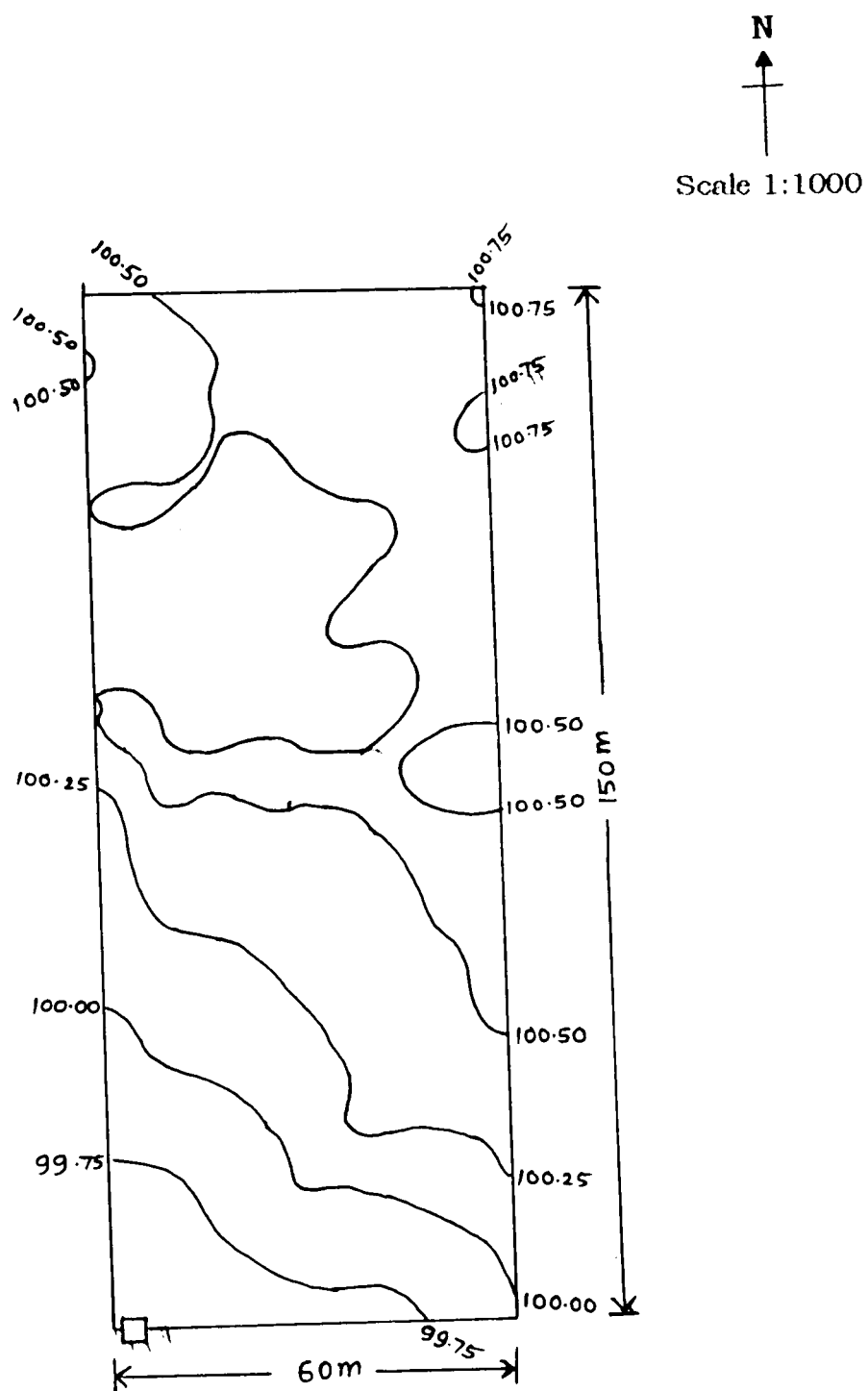


Fig. 3.5b. Map showing topographical features of plot II

3.2.3.1 Soil texture

Texture refers to the size distribution of the primary particles *viz.*, sand, silt and clay which constitute most of the soil media. The distribution of particle sizes was calculated in accordance with standard sieve analysis method, followed by hydrometer analysis. The results of the textural analysis of soil samples at different depths for Plot-I and Plot-II are given in Table 3.2a and 3.2b.

3.2.3.2 Soil structure

Soil structure refers to the arrangement of the primary particles to form stable aggregate within the soil mass. Soil structure has a definite influence on water-air movement, resistance to water flow, penetration of roots and crop production. During the course of the investigation, structural property of the soils were used for determination of 'K' factor from visual inspection and interpretation in the profile. The structural classification of the soils of the two plots are presented in Table 3.3.

3.2.3.3 Soil infiltration

Infiltration rate is the rate at which water enters the soil under prevailing surface conditions, including the presence of depression storage. The nearly constant rate that develops after a certain elapsed time from the start of the application of water is called

Table 3.2a. Particle size analysis of soils of the experimental plots

Sl No.	Sample	Depth (cm)	Plot-I				Plot-II			
			Fine sand (%)	Coarse sand (%)	Silt (%)	Clay (%)	Fine sand (%)	Coarse sand (%)	Silt (%)	Clay (%)
1.	Upper reach	0-30	13.44	7.40	22.21	56.00	13.64	7.21	19.21	58.01
		30-60	13.76	8.0	20.21	57.20	11.36	6.92	21.21	58.80
		60-90	9.65	8.2	21.50	59.80	10.80	7.34	20.91	60.10
2.	Middle reach	0-30	12.63	7.8	22.41	56.31	13.21	7.24	19.46	58.00
		30-60	10.79	8.4	23.00	57.01	11.81	8.00	20.46	58.91
		60-90	13.51	7.9	17.58	60.21	8.42	6.92	24.21	60.45
3.	Lower reach	0-30	9.36	6.9	21.58	61.21	10.24	7.00	22.45	60.31
		30-60	9.86	7.0	22.00	60.34	8.91	7.20	23.52	59.41
		60-90	11.00	7.2	21.00	60.00	11.83	7.40	20.91	59.86

Table:3.2b. Soil textural classification of study area

Sl. No	Depth (cm)	Plot	Textural classification
1	0-30	Plot-I	Clayey
	30-60		
	60-90		
2	0 -30	Plot-II	Clayey
	30-60		
	60-90		

Table 3.3. Details of soil structure of study area

Sl No.	Soil Sample	Plot-I	Plot-II
1	Upper reach	Fine granular	Medium granular
2	Middle reach	Fine granular	Medium granular
3	Lower reach	Fine granular	Medium granular

the basic infiltration rate and the total quantity of water that enters the soil in a given time is called cumulative infiltration.

The infiltration tests were conducted in the two plots (Plot- I and Plot-II) under bare soil conditions, with the help of a double ring infiltrometer, adopting the falling head method. The infiltration values were observed at increasing intervals of 5, 10, 15, 30 and 60 minutes, for a total period of 6 hours. The infiltration curves showing the basic and cumulative infiltration rates are presented in Fig. 3.6a & 3.6b.

3.2.3.4 Bulk density

The dry bulk density of soil at 0-30 cm and 30-120 cm depths were determined using the core cutter method and the average bulk density of the two plots were found to be 1.21 and 1.24 g/cc.

3.2.3.5 Soil depth

It is the thickness of soil, present above the bed rock or the impermeable layer. The trial pits were excavated to examine the soil profile and the average depth was recorded as 1.20 m for the two plots.

3.2.3.6 Soil permeability

Permeability of soil is defined as its capacity to transmit water or air through the soil medium. It can be expressed

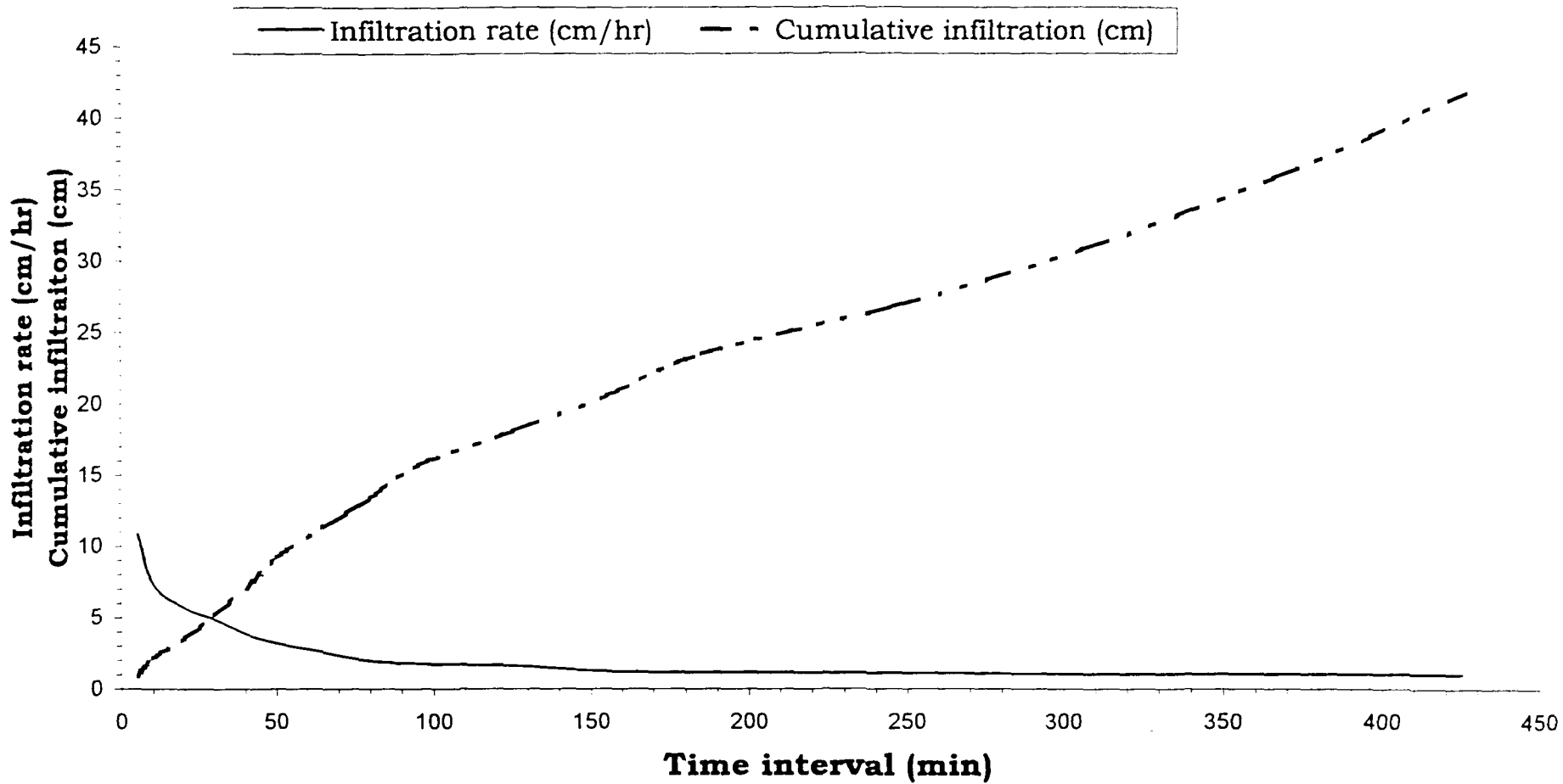


Fig. 3.6a. Infiltration characteristics of plot-I

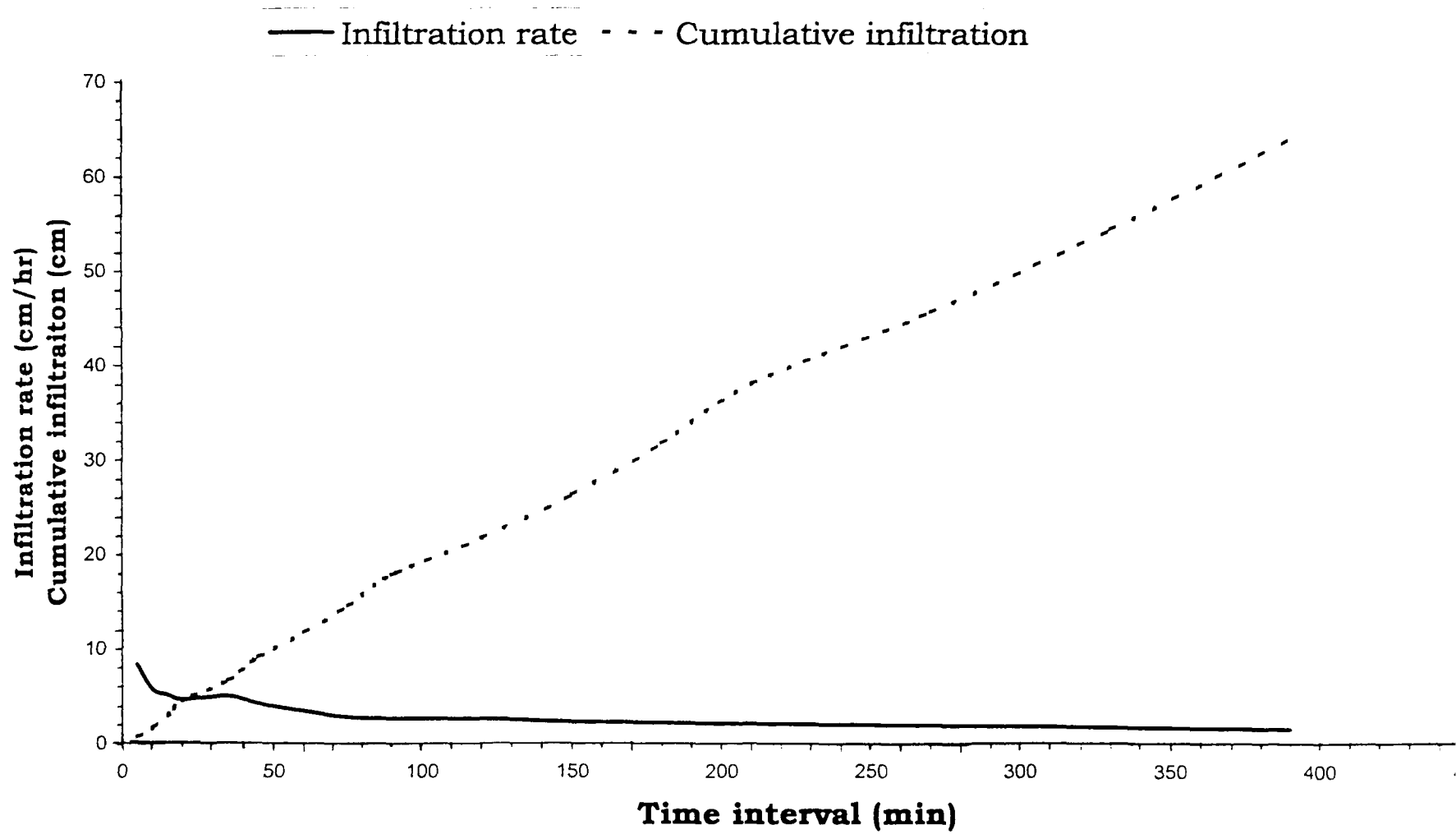


Fig. 3.6b. Infiltration characteristics of plot-II

qualitatively, in terms of rate of flow of water through a unit cross section of saturated soil per unit time under specific hydraulic conditions. The permeability tests on soil samples that were collected from the different reaches (lower, middle and upper) of the two plots were conducted and were found to be in the range of 0.8 to 1.2 cm/hr.

3.2.3.7 Soil pH

The samples drawn at specified locations and depth were tested to determine the soil pH. Soil water suspension of 1:2.5 ratio were subjected for determination of soil pH using digital pH meter (digital water and soil testing kit model 161 E). The results pertaining to pH are shown in Table 3.4.

3.2.3.8 Electrical conductivity of soil (EC)

The electrical conductivity of the soil was determined using a conductivity bridge. The samples previously collected for testing the soil pH were used for testing the conductivity of the soil samples and the same are given in Table 3.4.

3.2.3.9 Organic matter content

The organic matter in soils represents the quantity of residues of plants, animals and microorganisms in various stages of

Table 3.4. Chemical properties of soils of study area.

Sl No.	Soil sample	Depth (cm)	pH		EC	
			Plot-I	Plot-II	Plot-I	Plot-II
1	Lower reach	0-30	8.80	8.82	0.20	0.20
		30-60	9.30	8.87	0.20	0.30
		60-90	9.04	9.04	0.30	0.30
2	Middle reach	0-30	9.30	8.89	0.30	0.30
		30-60	9.24	8.63	0.20	0.30
		60-90	9.27	8.75	0.10	0.20
3	Upper reach	0-30	8.87	9.10	0.30	0.20
		30-60	8.89	8.92	0.20	0.10
		60-90	8.90	9.01	0.10	0.30

decomposition. The organic matter (in percentage) available in the soil is determined by estimating the quantity of organic carbon (%).

The organic carbon content (OC) in the selected soil samples were evaluated by wet oxidation method (Walkely and Blacks Rapid filtration method). The organic matter content of the soil sample was derived using the following conversion factor.

$$\text{Percentage of organic matter (OM)} = \frac{\text{Organic carbon}}{58^*} \times 100$$

* Generally any organic matter contains 58 per cent of carbon on an average.

The organic mater content of the soils of the study area are shown in Table 3.5.

3.3 Agronomical practices

The cropping pattern adopted in the experimental plots during the study period 2000-01 was as follows.

Plot 1: *Kharif* fallow, followed by *Rabi* sorghum (*Sorghum bicolor* L. moench)

Plot 2: *Kharif* greengram (*Vigna radiata*) followed by *rabi* sorghum

The Plot-I was kept fallow during *kharif* season. *Rabi* sorghum crop was sown in the plot on 1st of October 2000, and harvested on 4th of February 2001. The crop period was 123 days.

Table 3.5 Organic matter content of the soils of study area

Sl. No	Soil sample	Plot-I		Plot-II	
		Organic carbon	Organic matter	Organic carbon	Organic matter
1	Upper reach	0.52	0.89	0.49	0.85
2	Middle reach	0.54	0.93	0.60	1.04
3	Lower reach	0.59	1.02	0.61	1.05
4	Average	0.55	0.95	0.57	0.98

The greengram (*Vigna radiata*) crop was sown on 12-6-2000 and was harvested on 19-8-2000. The crop period of greengram was 68 days. The whole crop residue after separation of pods for grain purpose was incorporated in the soil after the harvesting of the crop. Later, during the *Rabi* season, sorghum was sown on 1-10-2000 and was harvested on 4-2-2001. The crop period of *rabi* sorghum was 123 days.

3.3.1 Crop canopy

The term crop canopy refers to extensive spreading of the foliage of a plant which increases with crop growth, starting from the stage of germination. Each crop differs in its canopy development from another in terms of its spread in the horizontal plane and vertical growth.

The canopy of a crop as a function of time and space has a direct bearing on proportional transpiration or photosynthesis, resistance to kinetic energy of rainfall and decrease in soil evaporation. In the present study, the development of crop canopy of the *kharif* crop of greengram and *rabi* crop of sorghum were measured in terms of percentage of unit area at different stages of growth and are recorded in Table 3.6a and 3.6b.

3.6a. Details showing crop parameters of the study area during *kharif* season

Sl. No	Crop: Fallow. Plot-I			Crop: Greengram. Plot-II		
	Days after sowing	Crop height (cm)	Percent canopy	Days after sowing	Crop height (cm)	Percent canopy
1	-	-	-	8	3.0	8.0
2	-	-	-	16	7.0	17.0
3	-	-	-	24	16.0	24.0
4	-	-	-	32	13.0	32.0
5	-	-	-	40	28.0	46.0
6	-	-	-	48	33.0	70.0
7	-	-	-	56	36.0	80.0
8	-	-	-	64	36.0	76.0

3.6b. Details showing crop parameters of the study area during *rabi* Season

Sl No	Crop: <i>rabi sorghum</i> Plot-I			Crop: <i>rabi sorghum</i> Plot-II		
	Days after sowing	Crop height (cm)	Canopy development (%)	Days after sowing	Crop height (cm)	Canopy development (%)
1	8	9.0	6.0	8	9.0	6.0
2	16	15.0	14.0	16	15.0	14.0
3	24	24.0	20.0	24	24.0	20.0
4	32	35.0	28.0	32	35.0	28.0
5	40	50.0	35.0	40	50.0	35.0
6	48	70.0	48.0	48	70.0	48.0
7	56	98.0	60.0	56	98.0	60.0
8	64	120.0	85.0	64	120.0	85.0
9	72	140.0	90.0	72	140.0	90.0
10	80	158.0	95.0	80	158.0	95.0
11	88	162.0	95.0	88	162.0	95.0
12	96	162.0	90.0	96	162.0	90.0
13	104	162.0	80.0	104	162.0	80.0
14	112	162.0	75.0	112	162.0	75.0
15	120	162.0	72.0	120	162.0	72.0

3.4 Experimental setup

The experimental setup consisted of a drum type vertical water height level recorder, San Dimass flume for measuring continuous runoff, installed at the outlet of each plot, a self recording rain gauge, and an open pan evaporimeter. The whole experimental setup was installed under the Australian Centre for International Agricultural Research (ACIAR) project, Regional Research Station, UAS, Campus, Bijapur.

a). Drum type vertical water height level recorder.

The drum type vertical water height level recorder mechanically converts the vertical movement of the float into a curvilinear graph of height of the surface of the water in relation to a datum plane and with respect to time. The time element in this type of height level recorder is designed in such a way that for every 1.822 min, the vertical drum rotates through a distance of 1 mm. The movement of the float is transmitted to a pen carriage and it moves on the chart which is fixed over the drum. The drum takes 24 hours for each rotation. The translation of variability of the runoff with respect to time is obtained on the chart as a runoff hydrograph in terms of stage which can also be obtained for a real time basis by marking the initial time of the drum movement (Plate 2).

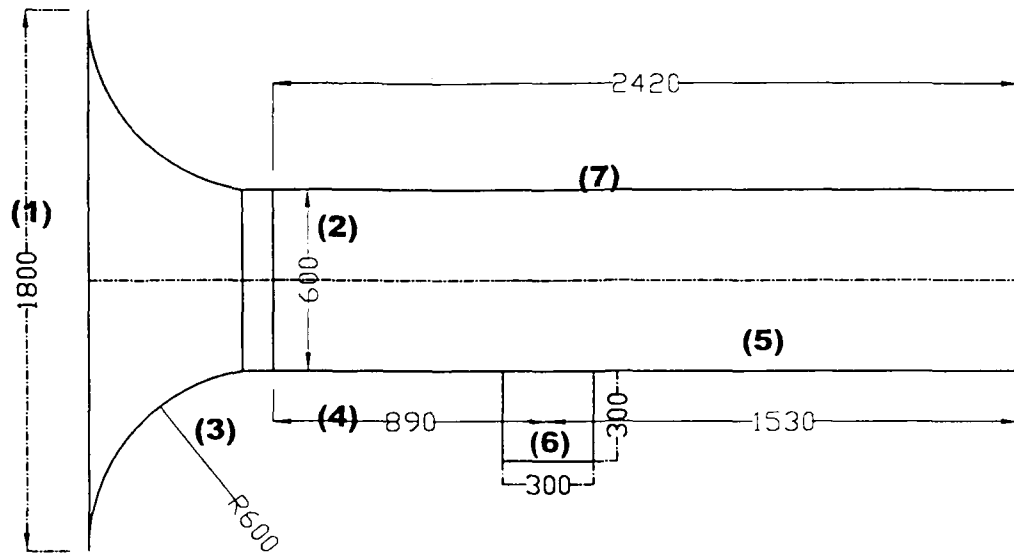
b). San Dimas flume

The San Dimas flume is a flume designed to provide flow measurement at sub-critical velocities, sufficient to transport bed load rapidly through the flume and to keep the floor unscoured (Fig. 3.7)

Its inlet section is a cylindrical quadrant with a radius of curvature equal to the flume width and is designed to replace the bottom contraction. The transition section is a level surface and is followed by a rectangular and parallel wall section with a floor having a slope of 3 per cent. Sub-critical velocities are expected to occur in this section. The flume functions as a broad crested weir, having contraction from the sides but not from the bottom. The San Dimas flume has the following advantages.

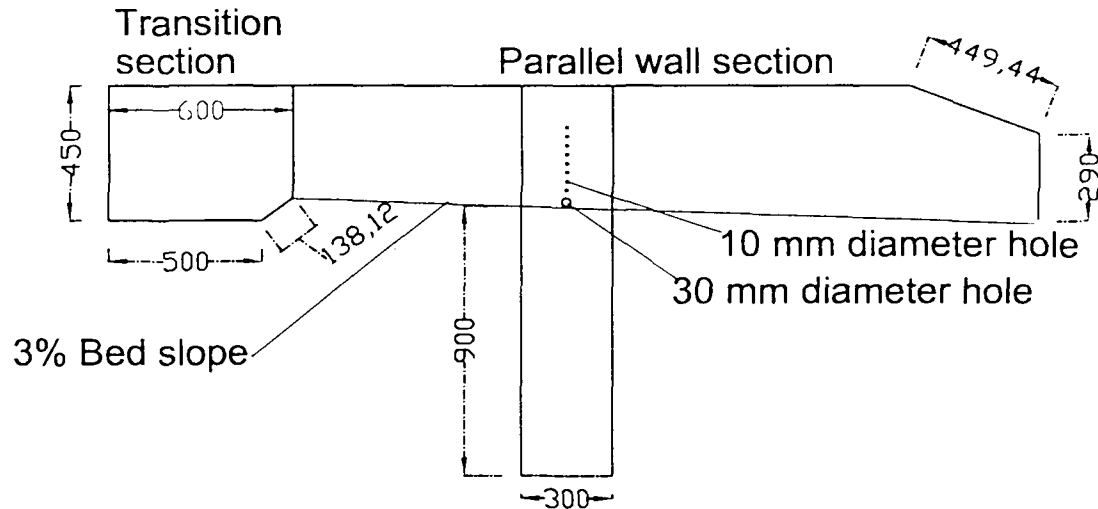
1. The flow measurements are not seriously affected by the velocity of approach or back water conditions.
2. Presence of bed load does not disturb the depth-discharge relation-ship appreciably.
3. It can be successfully used to gauge a stream with a step channel gradient.

The size of San Dimas flume is measured in terms of its throat width in the experimental setup. The San Dimas flume with the



PLAN

1. Inlet width
2. Throat width
3. Radius of wing
4. Distance to stilling well inlet
5. Flume tail length
6. Stilling well
7. length of parallel flume section



ELEVATION

All dimension are in mm

Fig. 3.7 Constructional details of San Dimas Flume



Plate 1. A view of experimental setup at the outlet including San Dimas flume and height level recorder

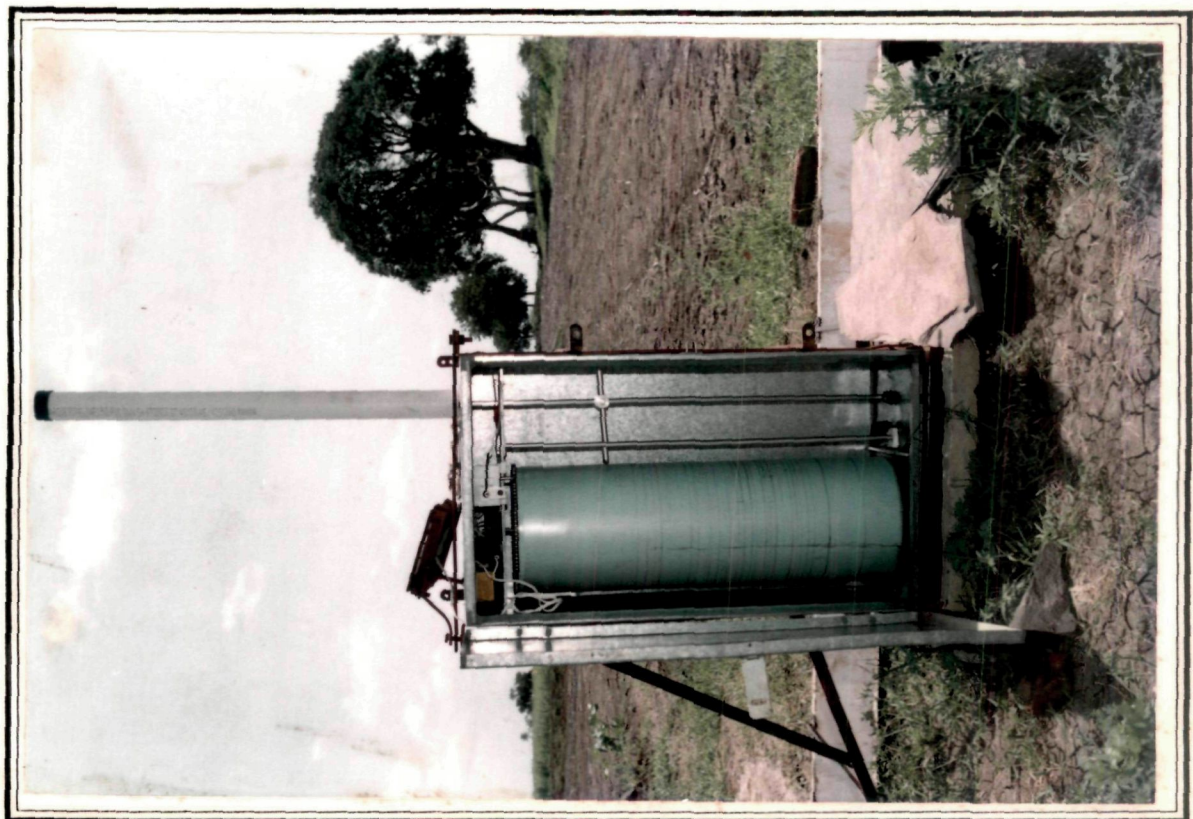


Plate 2. A view showing different parts of height level recorder

throat width of 2 feet was fixed and used in the current study in each plot. The flume was calibrated for actual discharge and the following equation was used to calculate the discharge

$$Q = 0.249415 H^{1.27655}$$

Where,

Q = discharge (lit/sec)

H = head, (mm)

The constructional details of San Dimas flume are shown in Fig. 3.7.

3.5 Measured runoff

At the outlet of each plot, a San Dimass flume coupled with a water level recorder recorded the runoff hydrographs which were obtained in the form of stage (m) v/s time during the runoff events. These runoff hydrographs were then converted into graphs of discharge lit/sec v/s time (min).

The measured runoff volumes were calculated as summation of area under hydrographs and were expressed in terms of (mm) and litres. The peak discharge (lit/sec) from the runoff hydrograph curves were also recorded.

3.5.1 Measured soil moisture

Daily antecedent soil moisture contents were measured in the layer-I (0-30 cm) and layer-II (30-120 cm) of the study area by means of gravimetric method and are recorded.

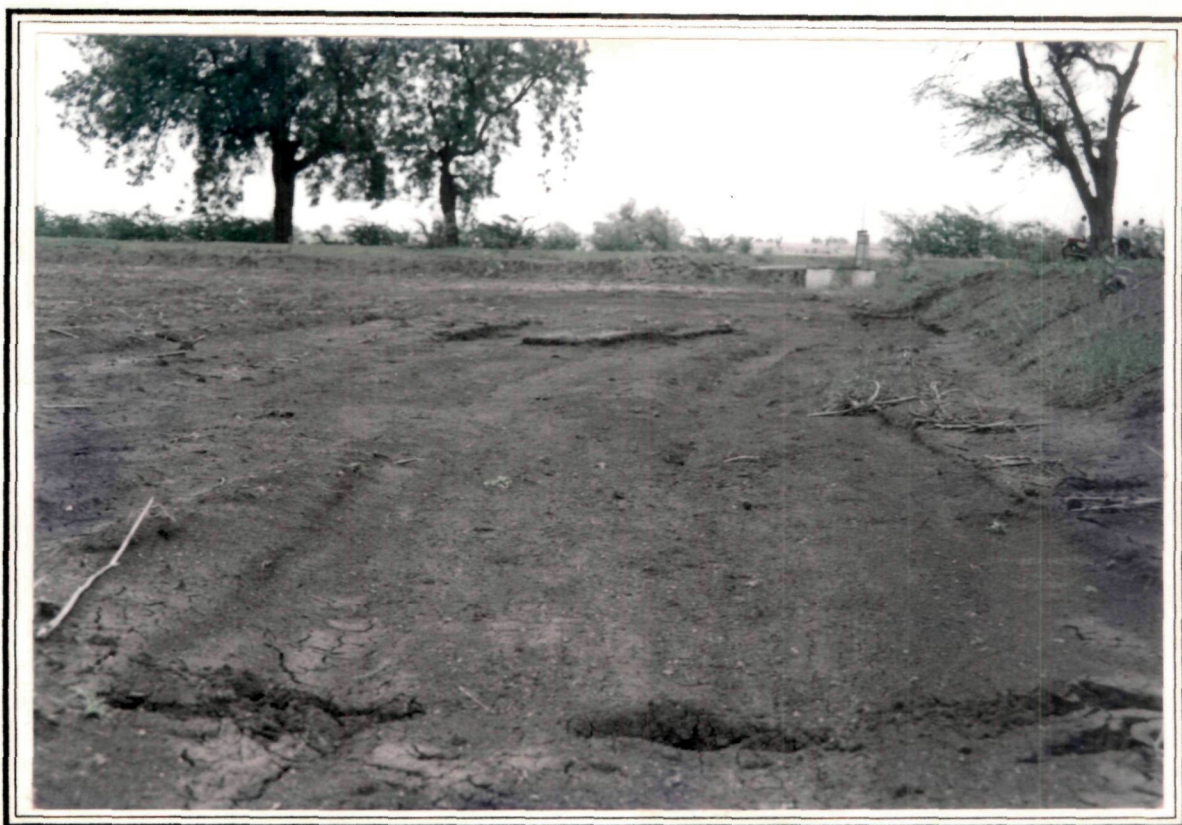


Plate 3. A view of bare plot (Plot -I) during *kharif* season



Plate 4. A view of Plot-II grown with greengram crop (*Vigna radiata*) during *kharif* season

3.6 Prediction of runoff

The hydrologic models are essential to predict runoff and other components of the hydrologic cycle, in order to enable the transfer of the runoff data from gauged to ungauged watersheds. Many hydrological models have been proposed from time to time to simulate the runoff with adequate precision from a catchment, which varies from catchment to catchment depending on the catchment size and other aspects. However, many of these models cannot predict the runoff from field size areas with significant accuracy. The soil conservation service (SCS) curve number method (SCS, USDA 1972) was found to be capable of estimating the runoff volume and its peak rate of flow from small field size watersheds with a reasonable degree of accuracy, out of the various models in vogue.

In the present study, a modified soil conservation service (SCS) curve number runoff model (Pathak *et al.*, 1989) developed at ICRISAT, Hyderabad, which consists of a soil moisture accounting procedure, was used to simulate runoff generated from field size areas.

3.6.1 USDA SCS curve number method

This method requires data on depth and intensity of rainfall from individual storm events, land use status, hydrologic soil characteristics and antecedent soil moisture conditions of a watershed. In this method, the potential maximum retention storage (S) of the

watershed is related to the relevant curve number, which itself is a function of land use, different land treatments, antecedent soil moisture condition and soil type of the watershed. The curve number is a dimensionless number and its value varies from 0 to 100. For a simple storm, the relation between rainfall, runoff and retention (S) in which rainfall and runoff begin simultaneously over a watershed is given by

$$\frac{F}{S} = \frac{Q}{P} \dots\dots\dots (3.1)$$

Where,

F = actual retention, mm

S = potential maximum retention ($P \geq F$)

Q = actual runoff, mm

P = potential maximum runoff ($P \geq Q$)

The parameter 'S' in this equation does not contain the initial abstractions and is a constant for a particular storm because it is the maximum possible retention over a watershed under existing conditions. The retention (F) is the difference between P and Q at any point on the mass curve.

$$\text{i.e., } F = P - Q \dots\dots\dots (3.2)$$

The equation 3.1 then becomes

$$\frac{P - Q}{S} = \frac{Q}{P} \dots\dots\dots (3.3)$$

Solving for Q, equation 3.3 results in

$$Q = \frac{P^2}{P + S} \dots\dots\dots (3.4)$$

Which is a linear rainfall – runoff relation in which the initial abstraction is ignored. Taking initial abstraction into account 3.1 becomes

$$\frac{F}{S} = \frac{Q}{P - I_a} \dots\dots\dots (3.5)$$

For $F \geq S$ and $Q \leq (P - I_a)$

Where,

I_a = Initial abstraction

Now equation 3.2 becomes

$$F = (P - I_a) - Q \dots\dots\dots (3.6)$$

$$\frac{(P - I_a) - Q}{S} = \frac{Q}{P - I_a} \dots\dots\dots (3.7)$$

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \dots\dots\dots (3.8)$$

Where,

Q = runoff depth, mm

P = rainfall depth, mm

S = maximum retention potential, mm

I_a = Initial abstraction, mm

The initial abstraction consists of mainly interception, infiltration and surface storage, which occur over the surface before runoff begins. The relation between I_a and S was developed by conducting experiments on rainfall and runoff, in respect of small watersheds. (SCS, USDA, 1964) and it was found that

$$I_a = 0.2 S \dots\dots\dots (3.9)$$

Therefore the equation for runoff estimation becomes

$$Q = \frac{(P - 0.2 S)^2}{P + 0.8 S} \quad \text{for } P > 0.2 S \dots\dots\dots (3.10)$$

$$Q = 0 \quad \text{for } P < 0.2 S$$

The parameter describing water retention in the soil is related to CN by the relationship.

$$S = \frac{25400}{CN} - 254$$

Where,

CN = Curve number (0-100)

S = retention parameter, mm

The curve number parameter varies from 0 to 100 and is a function of the dominant soil type, vegetative cover, land use and antecedent soil moisture content (SCS, USDA, 1972). The curve number parameter presents criteria for discrete partitioning of soil moisture as

- i. Dry conditions with low runoff potential (AMC – I).
- ii. Average conditions with medium runoff potential (AMC – II).
- iii. Wet condition with high runoff potential (AMC-III).

This partitioning suggests that rainfall-runoff relationship is a discrete one, implying that a change in curve number (CN) will result in a corresponding change in the calculated runoff. In reality, a CN varies continuously with the soil moisture content and thus has many continuous values instead of only two conditions. Hence, the accuracy of runoff simulation was improved considerably by using soil moisture accounting procedure to estimate the value of 'S' for each storm (Pathak *et al.*, 1989).

3.6.2 Soil moisture accounting procedure

Assumptions made

1. The soil profile is divided in to two layers namely layer-I (0-30 cm) and layer-II (30 to 120 cm).
2. Whenever there is rainfall or irrigation, the upper layer is fully recharged first and later, the excess moisture is transmitted to the lower layer.
3. Daily evaporation loss will occur uniformly and exclusively from top layer (0-30 cm) and only after the moisture in this layer is depleted that evaporation loss will occur from the lower layer.

3.6.3 Water balance equation in the crop root zone

The moisture accounting procedure was used to simulate the soil moisture condition in layer-I (0-30cm) and layer-II (30-120 cm).

The soil moisture in the first layer was calculated using the equation

$$(SM_2)_1 = (SM_1)_1 + \{P_1 - Q_1 - E_1 - T_1 - D_1\} \dots\dots\dots (3.11)$$

Where,

$(SM_2)_1$ = soil moisture content of the first layer for the day
under consideration, mm

$(SM_1)_1$ = soil moisture content of the previous day of the
same layer, mm

P_1 = rainfall amount on the day under consideration, mm

Q_1 = runoff generated on the day, mm

E_1 = soil evaporation on the day, mm

T_1 = transpiration losses on the day, mm

D_1 = deep percolation on the day, mm

The soil moisture level for the layer-II was calculated using the equation

$$(SM_2)_2 = (SM_1)_2 + \{D_1 - E_1 - T_2 - D_2\} \dots\dots\dots (3.12)$$

Where,

$(SM_2)_2$ = soil moisture content of the second layer for the
day under consideration, mm

$(SM_1)_2$ = soil moisture content in the second layer on the
previous day, mm

E_2 = soil evaporation losses on the day under
consideration, mm

T_1 = transpiration losses on the day under
consideration, mm

D_2 = deep percolation losses on the day under
consideration, mm

The retention parameter 'S' is calculated using the
relationship

$$S = C(SM_{\max} - SMT)$$

Where,

$SM_{\max}$ = soil moisture at saturation in mm

SMT = actual soil moisture in mm at any particular
point of time

C = A coefficient whose value is determined through
calibration, using the water balance relationship of
the past years for the watershed.

For vertisols at ICRISAT Centre, C was 1.29. The same
value was used in the present study.

The deep percolation in mm per day is calculated using the
expression

$$D = df (SM_a - SM_f)$$

Where,

D = deep percolation in mm per day, from a given layer.

Df = time delay factor for the soil layer.

S_{Ma} = soil moisture content at the beginning of the day in mm,

S_{Mf} = field capacity moisture content for that layer in mm.

3.6.4 Evaporation and transpiration

The soil evaporation and transpiration were calculated using the following equations

$$E^* = \frac{\beta E}{t^*} \dots\dots\dots (3.13)$$

$$T = (1 - \beta) E_o \dots\dots\dots (3.14)$$

Where,

E = open pan evaporation, mm

E* = evaporation from soil, mm

β = the light interception co-efficient (radiation transmission co-efficient), which ranges from 0 to 1.

T = transpiration, mm

t* = the time factor, days

The value of t* depends on the frequency of soil wetting. When soil is wetted either by rainfall or irrigation, t* for the first non rainy day was taken as 1, for second non rainy day it was 2, for third

non rainy day it was 3 and so on throughout the subsequent rainfree days upto a maximum of 10 days. On a rainy day t^* was taken as 2, except in a situation, where there was rainfall greater than open pan evaporation during the previous day under the consideration in which case t^* is started at 1 again. Because one may not be aware at what time during the day the rain occurred. If rainfall is less than pan evaporation, the value of t^* proceeds uninterrupted.

3.6.5 Runoff correction for small cracks

The model estimates the negative contribution of soil cracks on runoff by the equation

$$S_r = \alpha \sum_{1}^n E^* \dots\dots\dots (3.15)$$

Where,

S_r = runoff 'cracking' adjustment factor (mm), which is subtracted from the simulated runoff for the next storm,

α = a function of the amount and type of clay in the soil and represents the inherent tendency of the soil to crack. It is determined by calibration with measured runoff data of previous years

$\sum_{1}^n E^*$ = total evaporative demand on the soil during an extended rainless period.

n = the number of days with no rain or with rainfall less than soil evaporation

3.6.6 Runoff corrections for land smoothness

Land smoothness created by a runoff event is described by the following equations

$$L_s = (Q_1)^{0.5 - 0.85} \quad \text{when } Q_1 \geq 15 \text{ mm} \dots \dots \dots (3.16)$$

$$L_s = 0 \quad \text{when } Q_1 < 15 \text{ mm} \dots \dots \dots (3.17)$$

Where,

L_s = land smoothness correction (mm)

Q_1 = previous storm runoff amount

The contribution of land smoothness to runoff is given by a factor R_s which relates to L_s as follows

$$R_s = L_s \times Q_2^1 / Q_1 \dots \dots \dots (3.18)$$

Where,

Q_2^1 = current runoff volume under consideration

simulated by model before the land smoothness
correction (mm)

Q_1 = utilization factor whose maximum values is unity

3.6.7 Input parameters of the runoff model

The modified SCS curve number model with soil moisture accounting procedure derived by Pathak *et al.* (1989) required the

following input data to run the computer programme written in the Turbo-basic language (1987 version). The flow chart of the programme is depicted in Fig. 3.8 and the details of the programme are also given in Appendix – I.

3.6.7.1 Rainfall

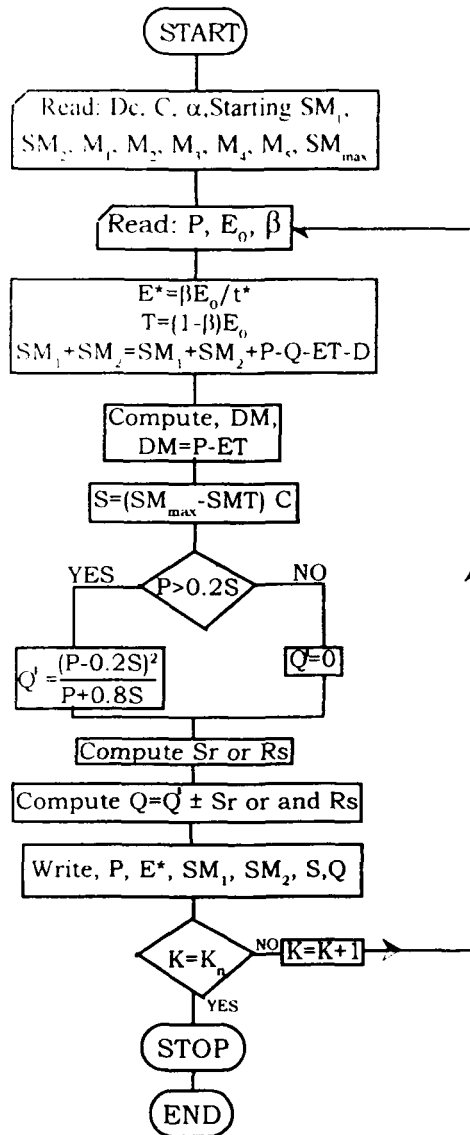
The data pertaining to the measured rainfall quantities of all the events during the period under consideration (May 7th 2000 to February 28th 2001) were entered in terms of depth (mm) and the same are presented in Table 3.7.

3.6.7.2 Pan evaporation

The daily pan evaporation data recorded from USDA class A pan, expressed in mm was taken as an input parameter for the model. The details are shown in Table 3.7.

3.6.7.3 Light interception co-efficient (β)

It represents the portion of light that was intercepted by the crop canopy. The extent of transpiration largely depends upon the intensity of light passing through the canopy and the photosynthetic activity. The extent of interception of light by a crop canopy follows Beers law which states that the amount of light intercepted at any



- Dc = Parameter representing soil depth.
 Sr = Adjustment for cracks
 Rs = Adjustment for land smoothness
 SM = Initial soil moisture of layer I
 SM = Initial soil moisture of layer II
 M₁ = Moisture at field capacity in layer I
 M₂ = Moisture at field capacity in layer II
 M₃ = Minimum moisture level for evaporation
 M₄ = Moisture at wilting point in layer I
 M_c = Moisture at wilting point in layer II
 SM_{max} = Profile moisture at saturation.
 P = Rainfall.
 E₀ = Pan evaporation.
 β = Light interception coefficient.
 E* = Losses by soil evaporation.
 T = Transpiration.
 SMT = Total soil moisture.
 Q = Simulated runoff.
 S = Retention parameter
 DM = Rainfall excess/Deficit.
 C = Coefficient.
 t* = Time factor.
 K, Kn = Starting and Ending dates.
 Q¹ = Simulated runoff before accounting for SR and RS.
 α = Parameter representing soils tendency to crack.
 D = D-percolation.

Fig.3.8. Flow chart of runoff model

Table 3.7. Input parameters of Runoff Model (Pathak *et al* 1989)

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
1.	7-5-2000	0.00	11.60	1.00	1.00
2.	8-5-2000	0.00	12.00	1.00	1.00
3.	9-5-2000	0.00	12.10	1.00	1.00
4.	10-5-2000	0.00	11.80	1.00	1.00
5.	11-5-2000	0.00	11.90	1.00	1.00
6.	12-5-2000	0.00	11.60	1.00	1.00
7.	13-5-2000	0.00	12.00	1.00	1.00
8.	14-5-2000	0.00	12.20	1.00	1.00
9.	15-5-2000	0.00	12.10	1.00	1.00
10.	16-5-2000	0.00	11.00	1.00	1.00
11.	17-5-2000	0.00	11.80	1.00	1.00
12.	18-5-2000	0.00	11.60	1.00	1.00
13.	19-5-2000	0.00	12.10	1.00	1.00
14.	20-5-2000	0.00	12.20	1.00	1.00
15.	21-5-2000	0.00	12.31	1.00	1.00
16.	22-5-2000	0.00	12.10	1.00	1.00
17.	23-5-2000	0.00	12.00	1.00	1.00
18.	24-5-2000	0.00	11.80	1.00	1.00
19.	25-5-2000	17.30	11.60	1.00	1.00
20.	26-5-2000	0.00	11.50	1.00	1.00
21.	27-5-2000	0.00	11.30	1.00	1.00
22.	28-5-2000	0.00	11.00	1.00	1.00
23.	29-5-2000	0.00	8.00	1.00	1.00
24.	30-5-2000	0.00	6.00	1.00	1.00
25.	31-5-2000	19.00	4.80	1.00	1.00
26.	1-6-2000	0.00	4.40	1.00	1.00
27.	2-6-2000	0.00	4.30	1.00	1.00
28.	3-6-2000	0.00	4.80	1.00	1.00
29.	4-6-2000	0.00	5.00	1.00	1.00
30.	5-6-2000	19.00	4.80	1.00	1.00
31.	6-6-2000	0.00	6.00	1.00	1.00

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
32.	7-6-2000	0.00	4.00	1.00	1.00
33.	8-6-2000	0.00	4.00	1.00	1.00
34.	9-6-2000	0.00	4.20	1.00	1.00
35.	10-6-2000	0.00	4.60	1.00	1.00
36.	11-6-2000	0.00	4.00	1.00	1.00
37.	12-6-2000	0.00	3.20	1.00	1.00
38.	13-6-2000	0.00	3.80	1.00	1.00
39.	14-6-2000	0.00	4.20	1.00	1.00
40.	15-6-2000	0.00	4.60	1.00	1.00
41.	16-6-2000	0.00	5.60	1.00	1.00
42.	17-6-2000	0.00	6.20	1.00	1.00
43.	18-6-2000	0.00	7.60	1.00	1.00
44.	19-6-2000	0.00	7.80	1.00	1.00
45.	20-6-2000	0.00	5.80	1.00	0.94
46.	21-6-2000	0.00	6.20	1.00	0.94
47.	22-6-2000	0.00	5.60	1.00	0.94
48.	23-6-2000	0.00	6.20	1.00	0.94
49.	24-6-2000	0.00	6.00	1.00	0.94
50.	25-6-2000	0.00	6.80	1.00	0.94
51.	26-6-2000	0.00	7.00	1.00	0.94
52.	27-6-2000	0.00	7.20	1.00	0.89
53.	28-6-2000	26.90	6.60	1.00	0.89
54.	29-6-2000	0.00	3.40	1.00	0.89
55.	30-6-2000	0.00	2.20	1.00	0.89
56.	1-7-2000	0.00	3.00	1.00	0.89
57.	2-7-2000	0.00	2.40	1.00	0.89
58.	3-7-2000	6.00	5.20	1.00	0.81
59.	4-7-2000	0.00	5.60	1.00	0.81
60.	5-7-2000	12.00	6.40	1.00	0.81
61.	6-7-2000	0.00	6.40	1.00	0.81
62.	7-7-2000	0.00	6.00	1.00	0.81

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
63.	8-7-2000	14.50	5.20	1.00	0.81
64.	9-7-2000	0.00	2.20	1.00	0.81
65.	10-7-2000	0.00	2.00	1.00	0.72
66.	11-7-2000	12.25	2.20	1.00	0.72
67.	12-7-2000	0.00	1.40	1.00	0.72
68.	13-7-2000	0.00	1.80	1.00	0.72
69.	14-7-2000	0.00	3.60	1.00	0.72
70.	15-7-2000	0.00	3.80	1.00	0.72
71.	16-7-2000	0.00	4.20	1.00	0.72
72.	17-7-2000	0.00	5.70	1.00	0.65
73.	18-7-2000	0.00	4.80	1.00	0.65
74.	19-7-2000	0.00	3.60	1.00	0.65
75.	20-7-2000	0.00	4.60	1.00	0.65
76.	21-7-2000	0.00	3.00	1.00	0.65
77.	22-7-2000	0.00	4.30	1.00	0.65
78.	23-7-2000	0.00	6.20	1.00	0.65
79.	24-7-2000	0.00	6.40	1.00	0.57
80.	25-7-2000	0.00	6.20	1.00	0.57
81.	26-7-2000	0.00	5.60	1.00	0.57
82.	27-7-2000	0.00	6.00	1.00	0.57
83.	28-7-2000	0.00	6.80	1.00	0.57
84.	29-7-2000	0.00	7.20	1.00	0.57
85.	30-7-2000	0.00	6.80	1.00	0.57
86.	31-7-2000	0.00	7.40	1.00	0.52
87.	1-8-2000	0.00	7.10	1.00	0.52
88.	2-8-2000	0.00	7.60	1.00	0.52
89.	3-8-2000	0.00	7.40	1.00	0.52
90.	4-8-2000	0.00	7.20	1.00	0.52
91.	5-8-2000	0.00	6.60	1.00	0.52
92.	6-8-2000	0.00	6.00	1.00	0.52

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
93.	7-8-2000	36.50	2.00	1.00	0.47
94.	8-8-2000	20.80	1.00	1.00	0.47
95.	9-8-2000	70.00	1.00	1.00	0.47
96.	10-8-2000	11.00	1.20	1.00	0.47
97.	11-8-2000	30.60	1.00	1.00	0.47
98.	12-8-2000	0.00	4.30	1.00	0.47
99.	13-8-2000	9.80	6.00	1.00	0.47
100.	14-8-2000	0.00	6.20	1.00	0.36
101.	15-8-2000	0.00	6.00	1.00	0.36
102.	16-8-2000	0.00	6.40	1.00	0.36
103.	17-8-2000	0.00	6.30	1.00	0.36
104.	18-8-2000	0.00	6.40	1.00	0.36
105.	19-8-2000	0.00	6.30	1.00	0.36
106.	20-8-2000	0.00	6.20	1.00	0.36
107.	21-8-2000	0.00	6.30	1.00	1.00
108.	22-8-2000	14.50	6.50	1.00	1.00
109.	23-8-2000	1.00	4.50	1.00	1.00
110.	24-8-2000	0.00	2.20	1.00	1.00
111.	25-8-2000	10.50	3.20	1.00	1.00
112.	26-8-2000	0.00	3.00	1.00	1.00
113.	27-8-2000	3.70	4.00	1.00	1.00
114.	28-8-2000	10.29	3.00	1.00	1.00
115.	29-8-2000	0.00	3.20	1.00	1.00
116.	30-8-2000	0.00	4.00	1.00	1.00
117.	31-8-2000	0.00	5.20	1.00	1.00
118.	1-9-2000	0.00	5.90	1.00	1.00
119.	2-9-2000	0.00	6.20	1.00	1.00
120.	3-9-2000	0.00	5.80	1.00	1.00
121.	4-9-2000	0.00	6.40	1.00	1.00
122.	5-9-2000	0.00	5.80	1.00	1.00
123.	6-9-2000	0.00	6.20	1.00	1.00

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
124.	7-9-2000	0.00	6.20	1.00	1.00
125.	8-9-2000	0.00	5.60	1.00	1.00
126.	9-9-2000	0.00	6.20	1.00	1.00
127.	10-9-2000	0.00	6.40	1.00	1.00
128.	11-9-2000	0.00	6.60	1.00	1.00
129.	12-9-2000	0.00	6.80	1.00	1.00
130.	13-9-2000	0.00	6.60	1.00	1.00
131.	14-9-2000	0.00	6.60	1.00	1.00
132.	15-9-2000	0.00	6.80	1.00	1.00
133.	16-9-2000	0.00	6.90	1.00	1.00
134.	17-9-2000	72.00	6.80	1.00	1.00
135.	18-9-2000	0.00	6.70	1.00	1.00
136.	19-9-2000	0.00	5.70	1.00	1.00
137.	20-9-2000	0.00	5.60	1.00	1.00
138.	21-9-2000	25.00	6.40	1.00	1.00
139.	22-9-2000	0.00	6.50	1.00	1.00
140.	23-9-2000	0.00	6.80	1.00	1.00
141.	24-9-2000	0.00	6.50	1.00	1.00
142.	25-9-2000	0.00	6.40	1.00	1.00
143.	26-9-2000	0.00	6.80	1.00	1.00
144.	27-9-2000	0.00	7.20	1.00	1.00
145.	28-9-2000	11.00	5.60	1.00	1.00
146.	29-9-2000	15.40	5.40	1.00	1.00
147.	30-9-2000	0.00	5.00	1.00	1.00
148.	1-10-2000	0.00	4.00	1.00	1.00
149.	2-10-2000	0.00	6.00	1.00	1.00
150.	3-10-2000	0.00	6.20	1.00	1.00
151.	4-10-2000	0.00	6.40	1.00	1.00
152.	5-10-2000	0.00	6.80	1.00	1.00
153.	6-10-2000	0.00	5.80	1.00	1.00
154.	7-10-2000	17.00	6.50	1.00	1.00

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
155.	8-10-2000	0.00	5.20	1.00	1.00
156.	9-10-2000	0.00	5.40	0.96	0.96
157.	10-10-2000	10.30	2.10	0.96	0.96
158.	11-10-2000	5.30	1.30	0.96	0.96
159.	12-10-2000	0.00	3.00	0.96	0.96
160.	13-10-2000	0.00	6.00	0.96	0.96
161.	14-10-2000	13.72	4.70	0.96	0.96
162.	15-10-2000	0.00	5.40	0.96	0.96
163.	16-10-2000	0.00	5.80	0.90	0.90
164.	17-10-2000	0.00	6.60	0.90	0.90
165.	18-10-2000	0.00	6.20	0.90	0.90
166.	19-10-2000	0.00	6.30	0.90	0.90
167.	20-10-2000	23.50	6.00	0.90	0.90
168.	21-10-2000	0.00	6.40	0.90	0.90
169.	22-10-2000	0.00	4.20	0.90	0.90
170.	23-10-2000	0.00	4.60	0.86	0.86
171.	24-10-2000	0.00	5.40	0.86	0.86
172.	25-10-2000	0.00	5.20	0.86	0.86
173.	26-10-2000	0.00	5.00	0.86	0.86
174.	27-10-2000	0.00	6.20	0.86	0.86
175.	28-10-2000	0.00	5.80	0.86	0.86
176.	29-10-2000	0.00	5.30	0.86	0.86
177.	30-10-2000	0.00	5.60	0.81	0.81
178.	31-10-2000	0.00	5.20	0.81	0.81
179.	1-11-2000	0.00	4.80	0.81	0.81
180.	2-11-2000	0.00	4.60	0.81	0.81
181.	3-11-2000	0.00	6.00	0.81	0.81
182.	4-11-2000	0.00	5.80	0.81	0.81
183.	5-11-2000	0.00	4.20	0.81	0.81
184.	6-11-2000	0.00	4.00	0.76	0.76
185.	7-11-2000	0.00	3.80	0.76	0.76

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
186.	8-11-2000	0.00	4.20	0.76	0.76
187.	9-11-2000	0.00	4.60	0.76	0.76
188.	10-11-2000	0.00	5.00	0.76	0.76
189.	11-11-2000	0.00	5.50	0.76	0.76
190.	12-11-2000	0.00	4.50	0.76	0.76
191.	13-11-2000	0.00	5.60	0.70	0.70
192.	14-11-2000	0.00	5.00	0.70	0.70
193.	15-11-2000	0.00	5.40	0.70	0.70
194.	16-11-2000	0.00	5.60	0.70	0.70
195.	17-11-2000	0.00	5.20	0.70	0.70
196.	18-11-2000	0.00	5.40	0.70	0.70
197.	19-11-2000	0.00	5.30	0.70	0.70
198.	20-11-2000	0.00	5.20	0.68	0.68
199.	21-11-2000	0.00	5.20	0.68	0.68
200.	22-11-2000	0.00	5.00	0.68	0.68
201.	23-11-2000	0.00	4.80	0.68	0.68
202.	24-11-2000	0.00	5.20	0.68	0.68
203.	25-11-2000	0.00	4.80	0.68	0.68
204.	26-11-2000	0.00	5.10	0.68	0.68
205.	27-11-2000	0.00	4.80	0.65	0.65
206.	28-11-2000	0.00	4.60	0.65	0.65
207.	29-11-2000	0.00	4.50	0.65	0.65
208.	30-11-2000	0.00	4.80	0.65	0.65
209.	31-11-2000	0.00	4.00	0.65	0.65
210.	1-12-2000	0.00	4.80	0.65	0.65
211.	2-12-2000	0.00	5.00	0.65	0.65
212.	3-12-2000	0.00	5.20	0.61	0.61
213.	4-12-2000	0.00	5.40	0.61	0.61
214.	5-12-2000	0.00	5.60	0.61	0.61
215.	6-12-2000	0.00	5.50	0.61	0.61
216.	7-12-2000	0.00	5.40	0.61	0.61

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
217.	8-12-2000	0.00	5.20	0.61	0.61
218.	9-12-2000	0.00	5.20	0.61	0.61
219.	10-12-2000	0.00	5.30	0.57	0.57
220.	11-12-2000	0.00	4.90	0.57	0.57
221.	12-12-2000	0.00	2.80	0.57	0.57
222.	13-12-2000	0.00	4.00	0.57	0.57
223.	14-12-2000	0.00	4.60	0.57	0.57
224.	15-12-2000	0.00	4.40	0.57	0.57
225.	16-12-2000	0.00	5.20	0.57	0.57
226.	17-12-2000	0.00	5.40	0.50	0.50
227.	18-12-2000	0.00	5.20	0.50	0.50
228.	19-12-2000	0.00	5.00	0.50	0.50
229.	20-12-2000	0.00	4.80	0.50	0.50
230.	21-12-2000	0.00	5.50	0.50	0.50
231.	22-12-2000	0.00	5.60	0.50	0.50
232.	23-12-2000	0.00	5.60	0.50	0.50
233.	24-12-2000	0.00	5.50	0.48	0.48
234.	25-12-2000	0.00	5.80	0.48	0.48
235.	26-12-2000	0.00	5.70	0.48	0.48
236.	27-12-2000	0.00	5.60	0.48	0.48
237.	28-12-2000	0.00	5.40	0.48	0.48
238.	29-12-2000	0.00	5.20	0.48	0.48
239.	30-12-2000	0.00	5.00	0.48	0.48
240.	31-12-2000	0.00	5.10	0.46	0.46
241.	1-1-2001	0.00	5.20	0.46	0.46
242.	2-1-2001	0.00	5.00	0.46	0.46
243.	3-1-2001	0.00	5.10	0.46	0.46
244.	4-1-2001	0.00	4.80	0.46	0.46
245.	5-1-2001	0.00	4.20	0.46	0.46
246.	6-1-2001	0.00	4.40	0.46	0.46
247.	7-1-2001	0.00	4.20	0.40	0.40

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
248.	8-1-2001	0.00	4.60	0.40	0.40
249.	9-1-2001	0.00	5.00	0.40	0.40
250.	10-1-2001	0.00	5.20	0.40	0.40
251.	11-1-2001	0.00	5.00	0.40	0.40
252.	12-1-2001	0.00	4.60	0.40	0.40
253.	13-1-2001	0.00	4.80	0.00	0.40
254.	14-1-2001	0.00	5.00	0.38	0.38
255.	15-1-2001	0.00	5.20	0.38	0.38
256.	16-1-2001	0.00	5.60	0.38	0.38
257.	17-1-2001	0.00	5.50	0.38	0.38
258.	18-1-2001	0.00	5.80	0.38	0.38
259.	19-1-2001	0.00	6.00	0.38	0.38
260.	20-1-2001	0.00	6.20	0.38	0.38
261.	21-1-2001	0.00	6.50	0.36	0.36
262.	22-1-2001	0.00	6.40	0.36	0.36
263.	23-1-2001	0.00	6.20	0.36	0.36
264.	24-1-2001	0.00	6.50	0.36	0.36
265.	25-1-2001	0.00	6.50	0.36	0.36
266.	26-1-2001	0.00	6.40	0.36	0.36
267.	27-1-2001	0.00	6.50	0.36	0.36
268.	28-1-2001	0.00	6.60	0.34	0.34
269.	29-1-2001	0.00	6.40	0.34	0.34
270.	30-1-2001	0.00	6.20	0.34	0.34
271.	1-2-2001	0.00	6.40	0.34	0.34
272.	2-2-2001	0.00	6.60	0.34	0.34
273.	3-2-2001	0.00	6.80	0.34	0.34
274.	4-2-2001	0.00	6.50	0.34	0.34
275.	5-2-2001	0.00	6.70	1.00	1.00
276.	6-2-2001	0.00	6.40	1.00	1.00
277.	7-2-2001	0.00	6.50	1.00	1.00
278.	8-2-2001	0.00	6.60	1.00	1.00

Contd....

Sl. No.	Date	Rainfall (mm)	Evaporation (mm)	Light interception coefficient (β)	
				Plot-I	Plot-II
279.	9-2-2001	0.00	6.50	1.00	1.00
280.	10-2-2001	0.00	6.60	1.00	1.00
281.	11-2-2001	0.00	6.80	1.00	1.00
282.	12-2-2001	0.00	6.90	1.00	1.00
283.	13-2-2001	0.00	6.90	1.00	1.00
284.	14-2-2001	0.00	7.20	1.00	1.00
285.	15-2-2001	0.00	7.50	1.00	1.00
286.	16-2-2001	0.00	7.60	1.00	1.00
287.	17-2-2001	0.00	7.80	1.00	1.00
288.	18-2-2001	0.00	5.60	1.00	1.00
289.	19-2-2001	0.00	6.60	1.00	1.00
290.	20-2-2001	0.00	7.20	1.00	1.00
291.	21-2-2001	0.00	7.40	1.00	1.00
292.	22-2-2001	0.00	7.60	1.00	1.00
293.	23-2-2001	0.00	7.50	1.00	1.00
294.	24-2-2001	0.00	6.80	1.00	1.00
295.	25-2-2001	0.00	6.90	1.00	1.00
296.	26-2-2001	0.00	6.80	1.00	1.00
297.	27-2-2001	0.00	7.20	1.00	1.00
298.	28-2-2001	0.00	7.50	1.00	1.00

particular canopy height varies in an exponential pattern. It is given by the equation.

$$I = I_0 e^{-KL}$$

Where,

I and I_0 = Isolation ratio values below and above the canopy

K = Extinction co-efficient

L = Leaf area index

The amount of light reaching the ground depends upon the light intensity transmitted, percentage of the canopy development and architecture of the plant.

3.6.7.3.1 Light transmission ratio (LTR)

LTR is a portion of light transmitted through a canopy, out of the total light intensity received and is expressed in terms of portion of the radiation available above the canopy.

$$\text{LTR (\%)} = \frac{I_2}{I_0} \times 100$$

Where,

I_0 = light intensity above the canopy

I_2 = light intensity at a point in the canopy

Hence, light intercepted or absorbed = $100 - \text{LTR}$

The intensity of light was recorded at 12 noon to 2 pm during which the light rays are almost perpendicular to the leaf plane on clear days, with the help of a luxmeter kept at 5 cm above and below the canopy of the plant.

The light interception co-efficient (β) was calculated as a co-efficient proportional to LTR (%) which ranges from '0' in case of maximum (100 %) LTR and one in case of minimum LTR. The calculated β co-efficient (expressed as a fraction) represents only the light intercepted by the crop canopy.

Using this methodology the light interception co-efficient (β) for the crops under consideration were determined throughout the season at weekly intervals and the same are presented in Table 3.7. Using the data on open pan evaporation and β co-efficient for the period under consideration the soil evaporation and transpiration were calculated using equation 3.13 and 3.14.

3.6.7.4 Initial soil moisture content in layer-I (SM_1) and layer-II (SM_2)

It is the moisture level measured on the first day (7-5-2000) of the study period (304 days) in the profile of soil layer-I (0-30 cm) and soil layer-II (30-120 cm). The soil samples which were taken at randomly selected locations in plot-I and plot-II were analyzed to evaluate the moisture content by gravimetric method and the same

are presented in Table 3.8. The average values of SM_1 and SM_2 expressed in terms of depth (mm) were used as input data to the model.

3.6.7.5 Moisture levels at field capacity In layer-I and layer-II (M_1 and M_2)

It is the maximum amount of capillary water that can be held in a freely drained soil. The field capacity of the soil at randomly selected locations for layer-I and layer-II in each plot were determined by means of standard procedure and the values are presented in Table 3.9.

The values of moisture content of layer-I expressed in depth (mm) is entered directly as an input parameter, whereas, in case of layer-II the value of the data is entered in terms of mm per cm depth of soil.

$$\text{Moisture at field capacity for layer-II, mm/cm depth} = \frac{\text{Moisture at field capacity in layer-II (mm)}}{\text{Total depth of second layer (cm)}}$$

3.6.7.6 Minimum moisture level for evaporation (M_3)

It is the minimum moisture level in the soil below which significant soil evaporation will not takes place. The minimum soil moisture levels at different locations for each plot are given in Table 3.10.

Table 3.8 Initial soil moisture levels at layer-I and layer-II (SM₁ and SM₂).

Locations	Plot-I				Plot-II			
	Layer-I (0-30 cm), SM ₁		Layer-II (30-120 cm), SM ₂		Layer-I (0-30 cm), SM ₁		Layer-II (30-120 cm), SM ₂	
	Percent	mm	Percent	mm	Percent	mm	Percent	mm
1	17.50	63.52	24.21	270.18	20.10	72.96	20.51	228.90
2	18.21	66.10	22.41	250.09	18.51	67.19	24.56	274.09
3	19.25	69.87	17.41	194.30	17.62	63.97	22.81	254.56
4	17.61	63.93	18.56	207.13	21.21	76.99	23.89	266.61
5	20.21	73.36	25.00	279.00	19.51	70.00	20.51	228.89
6	18.84	68.39	20.21	225.55	17.58	63.82	19.41	216.62
7	17.00	61.71	22.00	245.52	19.21	69.73	20.56	229.45
8	18.25	66.25	23.61	263.49	18.59	67.48	21.59	240.95
9	18.91	68.64	22.41	250.09	17.56	63.75	23.61	263.49
10	17.21	62.47	18.56	207.13	18.69	67.85	17.51	195.42
Average	18.30	66.42	21.43	239.15	18.80	68.24	21.49	239.83

Table 3.9 Soil moisture levels at field capacity at Layer-I and II (M₁ and M₂)

Locations	Plot-I				Plot-II			
	Layer-I (0-30 cm), M ₁		Layer-II (30-120 cm), M ₂		Layer-I (0-30 cm), M ₁		Layer-II (30-120 cm), M ₂	
	Percent	mm	Percent	mm	Percent	mm	Percent	mm
1	36.41	132.17	37.21	415.27	38.56	139.98	34.56	385.69
2	34.21	124.18	33.01	368.40	34.51	125.27	36.41	406.34
3	32.41	117.65	36.51	407.46	33.81	122.73	34.51	385.14
4	35.51	128.90	37.81	421.96	36.51	132.53	37.51	418.62
5	36.71	133.26	38.41	428.66	33.51	121.64	35.89	400.53
6	37.21	135.07	39.51	440.94	32.81	119.10	33.41	372.86
7	33.21	120.55	38.56	430.33	31.00	112.53	36.71	409.69
8	32.81	119.10	42.51	474.42	32.58	118.27	36.91	411.92
9	33.41	121.28	35.81	399.64	30.41	110.39	35.81	399.64
10	31.91	115.83	37.28	416.05	31.59	114.67	37.89	422.85
Average	34.38	124.79	37.67	420.40	33.52	121.67	35.96	401.32

Moisture content (mm) = % moisture content X dry bulk density (gm/cc) X depth (m) x 10

Bulk density for Layer-I = 1.21 gm/cc

Bulk density for Layer-II = 1.24 gm/cc

Table 3.10. Minimum soil moisture level for evaporation (M_3)

Sl No.	Plot-I		Plot-II	
	M_3		M_3	
	%	mm	%	mm
1	18.21	66.10	19.00	68.97
2	17.51	63.56	21.00	76.23
3	18.00	65.34	20.46	74.27
4	17.51	63.56	22.89	83.00
5	18.59	67.48	17.56	63.75
6	19.58	71.08	19.21	69.73
7	20.12	73.04	17.89	64.94
8	18.21	66.10	22.51	81.71
9	20.12	73.04	19.61	71.18
10	18.56	67.38	18.56	67.38
Average	18.64	67.66	19.86	72.10

3.6.7.7 Soil moisture levels at wilting point in layer I and layer

II ($M_4 = M_5$)

It is the water content in soil at which plant can no longer extract sufficient water for its growth and starts wilting on account of further decrease in moisture. The wilting point was determined for the samples of the selected locations and are presented in Table 3.11. The average moisture content value for each plot is used as input data to the model.

1. The average value of moisture at wilting point in layer-I is expressed in terms of the depth of water (mm) and was used as an input data.
2. The average value of moisture at wilting point in layer-II was expressed in terms of depth of water per centimeter depth of soil i.e.,

$$\begin{array}{lcl} \text{The moisture level at wilting} & \text{Moisture at wilting point in layer II (mm)} & \\ \text{point at layer-II (M}_5\text{),} & = & \text{-----} \\ \text{mm/cm depth} & & \text{Total depth of layer II (cm)} \end{array}$$

3.6.7.8 Soil profile moisture at saturation (SM_{max})

It is the maximum moisture content of the soil at which plants can extract the moisture with the least stress. Any further addition of moisture to this moisture content results in runoff. The

Table 3.11 Soil moisture levels at wilting point at layer-I and layer-II (M₄ and M₅)

Locations	Plot-I				Plot-II			
	Layer 1(o-30 cm), SM1		Layer 1(30-120 cm), SM2		Layer 1(o-30 cm), SM1		Layer 1(30-120 cm), SM 2	
	Percent	mm	Percent	mm	Percent	mm	Percent	Mm
1	14.21	51.58	18.10	202.00	15.89	57.69	16.21	180.91
2	13.56	49.23	19.41	216.62	16.21	58.84	19.51	217.73
3	12.61	45.77	15.61	174.21	17.89	65.00	15.66	174.99
4	14.28	51.84	20.41	227.78	15.21	55.21	19.41	216.62
5	15.81	57.40	18.56	207.13	16.58	60.19	17.41	194.30
6	16.21	58.84	14.21	158.59	17.61	63.92	15.61	174.21
7	13.21	47.95	20.51	228.90	14.21	51.58	17.41	194.30
8	14.58	52.93	17.51	195.42	13.00	47.19	16.21	180.91
9	13.81	50.13	16.91	188.72	12.51	45.41	15.51	173.10
10	15.61	56.66	17.21	192.07	14.21	51.58	18.56	207.13
Average	14.38	52.233	17.84	199.144	15.53	55.66	17.15	195.41

soil saturation moisture contents were determined during those rainfall events which had produced runoff and the same are presented in the Table 3.12.

The average moisture contents for each plot is expressed as the depth of soil moisture (mm) per unit depth of soil (cm).

As per the requirement of the model, the average profile moisture at saturation (SM_{max}) was converted into depth of soil moisture (X) per unit depth of soil, expressed as mm of water per cm soil depth.

$$X = \left\{ \begin{array}{l} \text{The profile moisture} \\ \text{(mm) at saturation} \\ \text{(SM_{max}) of a layer} \end{array} \right\} - \left\{ \begin{array}{l} \text{Moisture} \\ \text{(mm) at field} \\ \text{capacity of that} \\ \text{layer} \end{array} \right\} \bigg/ \text{Depth of layer-II (cm)}$$

Where,

X = profile moisture of layer II in mm/cm.

All the required values of input parameters namely SM_1 , SM_2 , M_1 , M_2 , M_3 , M_4 , M_5 and SM_{max} (X) evaluated for both the plots are given in Table (3.13).

3.9 Measured sediment yield (soil loss)

The experimental setup consisting of a San Dimass flume equipped with an arrangement to extract the runoff samples at 3 depths from the flow over the flume. This arrangement facilitates the

Table 3.12. Soil moisture level at saturation point (SM_{max}) for whole profile

Locations	Plot-I		Plot-II	
	SM_{max}		SM_{max}	
	Per cent	mm	Per cent	mm
1	46.21	687.61	48.21	717.37
2	48.91	727.78	50.61	753.08
3	46.21	687.61	47.58	708.00
4	49.24	732.69	49.71	739.69
5	46.51	692.07	47.51	706.95
6	47.24	702.93	50.41	750.110
7	48.56	722.58	45.81	681.66
8	49.21	732.25	47.59	708.14
9	48.51	721.83	47.61	708.44
10	45.21	672.73	46.21	687.61
Average	47.58	708.008	48.12	716.02

Table 3.13. Soil input parameters of runoff model.

Sl. No.	Input parameters	Plot-I	Plot-II
1	SM1-Initial soil moisture level of Layer-I 0-30cm. (mm)	66.42	68.24
2	SM2-Initial soil moisture level of Layer-II, 30-120 cm. (mm)	239.15	239.83
3	M1-Moisture level at field capacity of Layer-I, 0-30 cm. (mm)	124.79	121.67
4	M2- Moisture level at field capacity of Layer-II, 30-120 cm. (mm/cm)	4.67	4.46
5	M3-minimum moisture level for evaporation at Layer-I, 0-30cm. (mm)	67.66	72.10
6	M4 - soil moisture level at wilting point of Layer-I 0-30cm. (mm)	56.66	51.58
7	M5- Soil moisture level at wilting point of Layer-II, 30-20cm. (mm/cm)	2.22	2.13
8	SM _{max} - Soil profile, moisture level at saturation point. (mm/cm)	6.48	4.60



Plate 5. A top view of sediment samplers attached to the San Dimass flume to trap the portion of runoff

collection of samples from suspended, settling and the moving load. The samples consisting of mixed sediment load collected from each runoff event for plot I and plot II are recorded. The quality of sediment load that got transported, along with the runoff volume of each event is estimated and expressed in terms of gram/lit. The quantity of sediment thus estimated from runoff volume of an event is assumed to be equivalent to the quantity that got transported out of the plot area and that the same is received at the outlet. Hence, the sediment load collected is expressed in terms of tonnes per plot area and same is converted to t/ha.

3.10 Prediction of sediment yield (soil loss)

The universal soil loss equation (USLE) is an empirical equation based on more than 10,000 plot years data (Wischmeyer and Smith, 1965) and is widely used to evaluate sediment yield. But universal soil loss equation cannot give the best results over a broad range of conditions in field size areas. Further, the interrelation between the process of erosion and subsequent transportation are non-linear in nature and interactive for each storm, which prevents by using separate equations to linearly accumulate erosion or sediment transport capacity over several storms. Thus in order to simulate erosion and sediment yield on an individual storm basis and to satisfy the need for a continuous simulation, the USLE was modified and used (Williams, 1975).

3.10.1 Description of Williams modified universal soil loss equation (MUSLE)

The model predicts the sediment yield from field size areas with modification in rainfall erosivity factor of USLE (Wischmeier and Smith, 1965) model by replacing the rainfall erosivity factor with a runoff volume and peak discharge which eliminated the need for delivery ratio and significantly improved the USLE estimates for individual storms.

Williams (1975) modified USLE is given by the following relationship

$$E = 11.80 \{(RO) Q_p^{0.56}\} KLSCP$$

Where,

E = soil loss (t/ha)

RO = total runoff volume (m³)

Q_p = peak runoff rate (m³/sec)

K = soil erodibility factor, (ratio)

LS = topographic factor (ratio)

C = crop management factor, ratio

P = support practice factor, ratio

3.10.2 Evaluation of model parameters

3.10.2.1 Runoff volume (RO)

It is the total quantity of runoff observed during each runoff event under consideration. The runoff volume for each rainfall event was calculated with the help of derived runoff hydrographs and are presented in Table 3.14a & 3.14b.

3.10.2.2 Peak rate of runoff (Q_p)

It is the maximum rate of discharge during the rain storm, under consideration. The peak rate of runoff determined in case of measured runoff for the selected rainfall events are used in prediction of sediment yield in Table 3.14a & 3.14b.

3.10.2.3 Soil erodibility factor (K)

In USLE equation, it is a quantitative value defined as rate of soil loss per erosion index and is measured on a “unit” plot, which has been arbitrarily defined as plot of 22 m length and 1.82 m width on 9 per cent slope in continuous fallow, tilled up and down the slope. Direct measurements of ‘K’ on well replicated unit plots neglect the combined effect of all the soil properties that significantly influence the ease with which a particular soil is eroded by rainfall and runoff if it is

Table 3.14a. Input parameters of the sediment model for Plot-I

Sl No.	Storm event	Input parameters								
		RO (m ³)	Qp (m ³ /sec)	Area (ha)	K	L (m)	S (%)	LS	C	P
1	8-8-2000	39.432	0.033	0.85	0.45	170	0.90	0.20	0.98	0.60
2	9-8-2000	341.53	0.114	0.85	0.45	170	0.90	0.20	0.98	0.60
3	17-9-2000	268.93	0.108	0.85	0.45	170	0.90	0.20	0.98	0.60
4	21-9-2000	94.860	0.049	0.85	0.45	170	0.90	0.20	0.98	0.60
5	20-10-2000	22.567	0.0066	0.85	0.45	170	0.90	0.20	0.90	0.60

Table 3.14b. Input parameters of the sediment model for Plot-II

Sl No.	Storm event	Input parameters								
		RO (m ³)	Qp (m ³ /sec)	Area (ha)	K	L (m)	S (%)	LS	C	P
1	8-8-2000	5.770	0.0059	0.90	0.46	150	0.74	0.152	0.125	0.60
2	9-8-2000	357.300	0.1500	0.90	0.46	150	0.74	0.152	0.125	0.60
3	17-9-2000	276.570	0.1113	0.90	0.46	150	0.74	0.152	0.100	0.60
4	21-9-2000	92.493	0.0600	0.90	0.46	150	0.74	0.152	0.100	0.60
5	20-10-2000	15.093	0.0150	0.90	0.46	150	0.74	0.152	0.900	0.60

not protected. However, K is an average value for a given soil and direct measurement of the factor requires soil loss measurements for representative range of storm sizes and antecedent soil moisture conditions. The direct measurement of the erodibility factor is both costly and time consuming and is found to be not feasible under the present study for want of time. Hence, the soil erodibility nomograph (USDA hand book no 537, 1978) was used as an alternative (Fig. 3.9). The derived 'K' factor for plot-I and plot-II are presented in Table 3.14a and 3.14b.

3.10.2.4 Nomograph solution

The data on per cent silt + very fine sand, evaluated for the location is required to be entered in the nomograph scales in the beginning and to then proceed to points representing percent sand (0.10 to 2.0 mm), followed by per cent organic matter, structure code, and permeability class which is illustrated by the dotted line on the nomograph. Using the data in respect of sand, silt and clay composition, followed by organic matter, soil structure and measured permeability, the average 'K' factor was determined.

The details of soil parameters required to determine the soil erodibility factor (K) are presented in Table 3.15a and 3.15b.

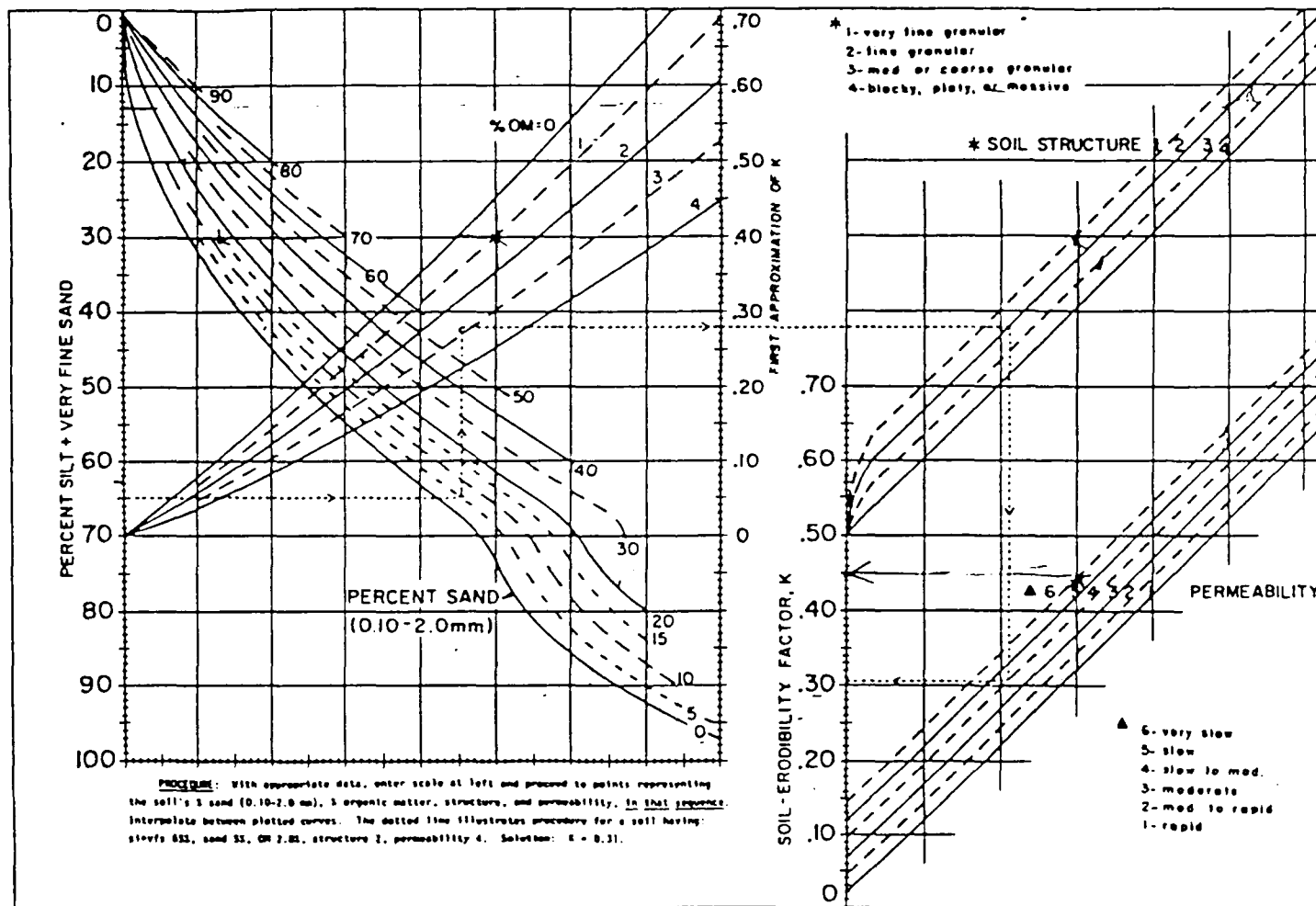


Fig. 3.9. Procedure: With appropriate data, enter scale at left and proceed to points representing the soils % and (0.10-2.0 mm), % organic matter, structure and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having silt + very fines and 65%. Sand 5%, organic matter 2.8 %, structure 2, permeability 4. Solution: $K=0.31$

The soil erodibility nomograph. Where the silt fraction does not exceed 70 per cent, the equation is $100 K = 2.1 M^{1.14} (10^{-4}) (12-a) + 3.25 (b-2) + 2.5 (c-3)$ where $M = (\text{per cent Silt} + \text{Very fine sand}) (100 - \text{per cent C})$, $a = \text{per cent organic matter}$, $b = \text{structure code}$, and $c = \text{profile permeability class}$.

Fig. 3.9. Soil erodibility nomograph (K factor)

Table 3.15a. Parameters required for determining K factor for Plot-I

Sl No.	Soil depth (cm)	Soil type	Fine sand (%)	Coarse sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Soil structure	Permeability	K factor
1.	0-30	Clay	11.81	7.37	22.06	57.84	1.00	Fine granular	Very slow	0.45
	30-60		11.47	7.80	21.74	58.18				
	60-90		11.39	7.77	20.03	60.00				
Average			11.55	7.65	21.28	58.67				

Table 3.15b. Parameters required for determining K factor for Plot-II

Sl No.	Soil depth (cm)	Soil type	Fine sand (%)	Coarse sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Soil structure	Permeability	K factor
1.	0-30	Clay	12.36	7.15	20.37	58.77	1.00	Fine granular	Very slow	0.46
	30-60		10.70	7.37	21.73	59.09				
	60-90		10.35	7.22	22.07	60.13				
Average			11.14	7.25	20.72	59.33				

3.10.2.5 Topographical factor (LS)

LS is the ratio of soil loss per unit area from a field slope with length of 22 meters, on 9 per cent slope under otherwise identical conditions. The plots have a uniform gradient of 0.90 per cent (Plot -I) and 0.74 per cent (Plot-II).

Runoff from cropped land generally increases with increase in slope but the relationship is influenced by the type of crop, surface roughness and profile saturation.

The LS ratio for the present combination of field slope, length and uniform gradient was obtained by referring the slope-length chart (USDA, Hand book N-537, 1978) and is presented in Fig. 3.10.

1. Plot-I
 - a. Length = 170 m
 - b. Slope = 0.90 per cent
2. Plot-II
 - a. Length = 150 cm
 - b. Slope = 0.74 per cent

In order to determine the LS factor, it was required to enter the graph on the horizontal axis of the chart by marking the plot slope and the LS factor was read on the vertical scale. The chart is derived by the equation

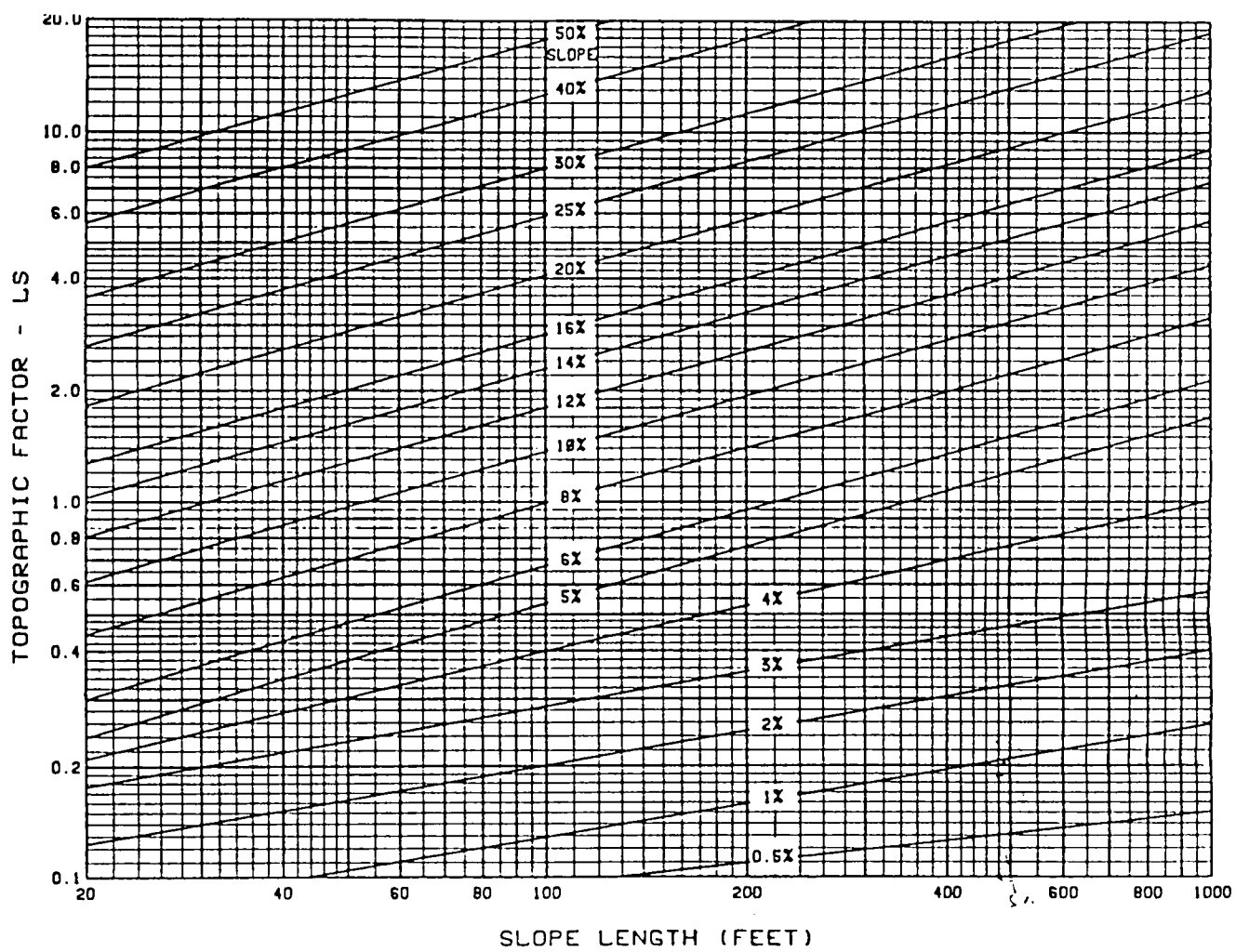


Fig. 3.10. Slope length chart (LS factor)

$$LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where,

λ = slope length in feet;

θ = angle of land slope and

m = a variable depending upon the steepness of land slope

0.5 where per cent slope is 5 or more

0.4 on slopes of 3.5 to 4.5 per cent,

0.3 on slopes of 1 to 3 per cent, and

0.2 on uniform gradient of less than 1 per cent

The derived LS factor for two plots are shown in Table 3.14a & 3.14b

3.10.2.6 Cover and management factor (C)

Factor 'C' in the USLE equation is the ratio of soil loss from cropped land under specified conditions, to the corresponding loss from clear tilled, continuous fallow field. This factor measures the combined effect of all the inter-related cover and management variables.

The change in effectiveness of plant cover within a crop year is divided into a series of crop stages, (USDA hand book No-537, 1978), so that the effects of cover and management can be treated as approximately uniform within each crop growth stage. The

six crop growth stages (periods) were defined with respect to change in plant canopy cover, expressed in percentage and a marked distinction in terms of the existing soil fertility, row spacing, plant population and general growing conditions.

DESCRIPTION OF STAGE:

1. Period F (Rough fallow) : Inversion ploughing to secondary tillage.
2. Periods SB (Seed bed) : Secondary tillage for seedbed preparation until crop has developed 10 per cent canopy cover
3. Period 1 : (Establishment) End of seedbed until crop has developed a 50 per cent crop canopy
4. Period 2 : (Development) : End of period 1 until canopy cover reaches 75 per cent
5. Period 3 : (Maturation of crop) end of period 2 until harvest. This period was evaluated for two levels of final canopy.
6. Period 4 : (residue or stubble) harvest to ploughing or new seeding

The derived 'C' factor for the crops grown is shown in Table 3.16a and 3.16b.

Crop canopy (sub factor of C)

Leaves and branches that do not directly come in contact with the soil have little effect on the amount and velocity of runoff from

Table 3.16a. Details showing evaluation of "C" factor for Plot-I (Crop rotation: summer fallow followed by *kharif* fallow followed by *rabi* sorghum)

Sl No.	Crop stage	Period	Per cent Ground over by canopy	Height of crop (cm)	Main factor	Sub factor*	C factor
1	Period F	June 4 to October 1	Nil	Nil	0.98	Nil	0.95
2	Period 1	October 2 to October 21 (sorghum crop)	10.0	15.0	0.90	Nil	0.90

Table 3.16b. Details showing evaluation of "C" factor for Plot-II (Crop rotation: summer fallow followed by *kharif* green gram followed by *rabi* sorghum)

Sl No.	Crop stage	Period	Per cent Ground over by canopy	Height of crop (cm)	Main factor	Sub factor*	C factor
1	Period F	June 4 to June 12	Nil	Nil	0.95	Nil	0.95
2	Period 1	June 13 to June 22	8.0	3.0	0.90	Nil	0.90
3	Period 2	June 23 to July 27	46.0	28.0	0.25	Nil	0.25
4	Period 3	July 28 to Aug. 19	80.0	36.0	0.125	Nil	0.125
5	Period 4	Aug. 20 to Oct. 1	10.0	Nil	0.10	Nil	0.10
6	Period 1	Oct. 2 to Oct. 21 (sorghum crop)	10.0	15.0	0.90	Nil	0.90

prolonged rains, but they reduce the effective rainfall energy by intercepting the falling raindrops. Water drops falling from the canopy may regain appreciable velocity but it is usually less than the terminal velocities of free falling raindrops. The amount by which the energy expended at the soil surface is reduced depends on the height and density of the canopy. The values of sub factor of C (crop canopy effect) can be estimated for specified conditions by referring to Fig. 3.11.

3.10.2.7 Supported practice factor (P)

The factor 'P' is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up and down cultivation. During the experiment, the plots were maintained as single broad based terraces with an outlet fitted with San Dimass flume. The total soil movement with this single terrace was found to be equivalent to that of from a contour strip with the same length and an identical slope. The 'P' factor for the plots was worked out from the USDA handbook No-537, 1978 as 0.60.

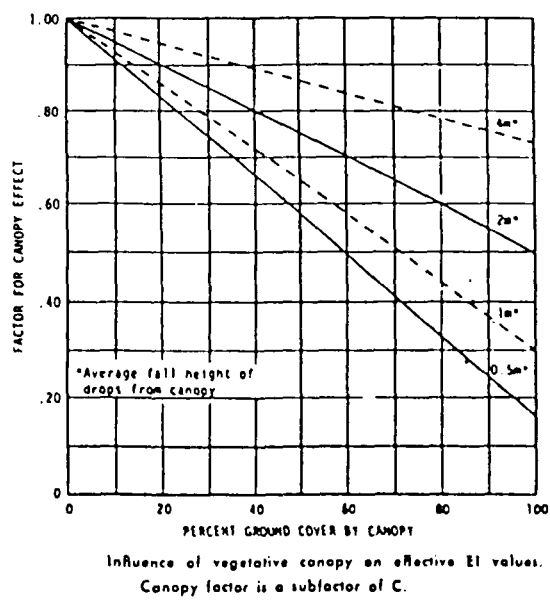


Fig. 3.11. Canopy factor is a sub factor of C

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

The result of the investigations carried out at Madabhavi watershed in Bijapur taluk in respect of runoff and sediment yield as well as simulation of runoff and sediment load using mathematical models viz., SCS curve number method with moisture accounting procedure derived by Pathak *et al.* (1989) and Williams *et al.* (1975) are presented in the following paragraphs

4.1 Measured runoff

The experimental setup consisted of San Dimas flume, together with height level recorders installed at the outlet of each plot. During the course of each runoff event, the continuous change in discharge over a time period was recorded as an out flow hydrograph and expressed in terms of stage (m) v/s time (min). Later, the outflow values were converted into discharge in liters per second v/s time (min) and the same are presented in Fig. 4.1a to 4.1e and 4.2a to 4.2e. During the period of observation (year 2000-2001), there were only five rainfall events which produced runoff. The Tables 4.1a and 4.1b depict the total rainfall of the event in mm, runoff produced in each storm event expressed both in mm and liters and the peak discharge expressed in litres per second for plot-I and plot -II respectively. From

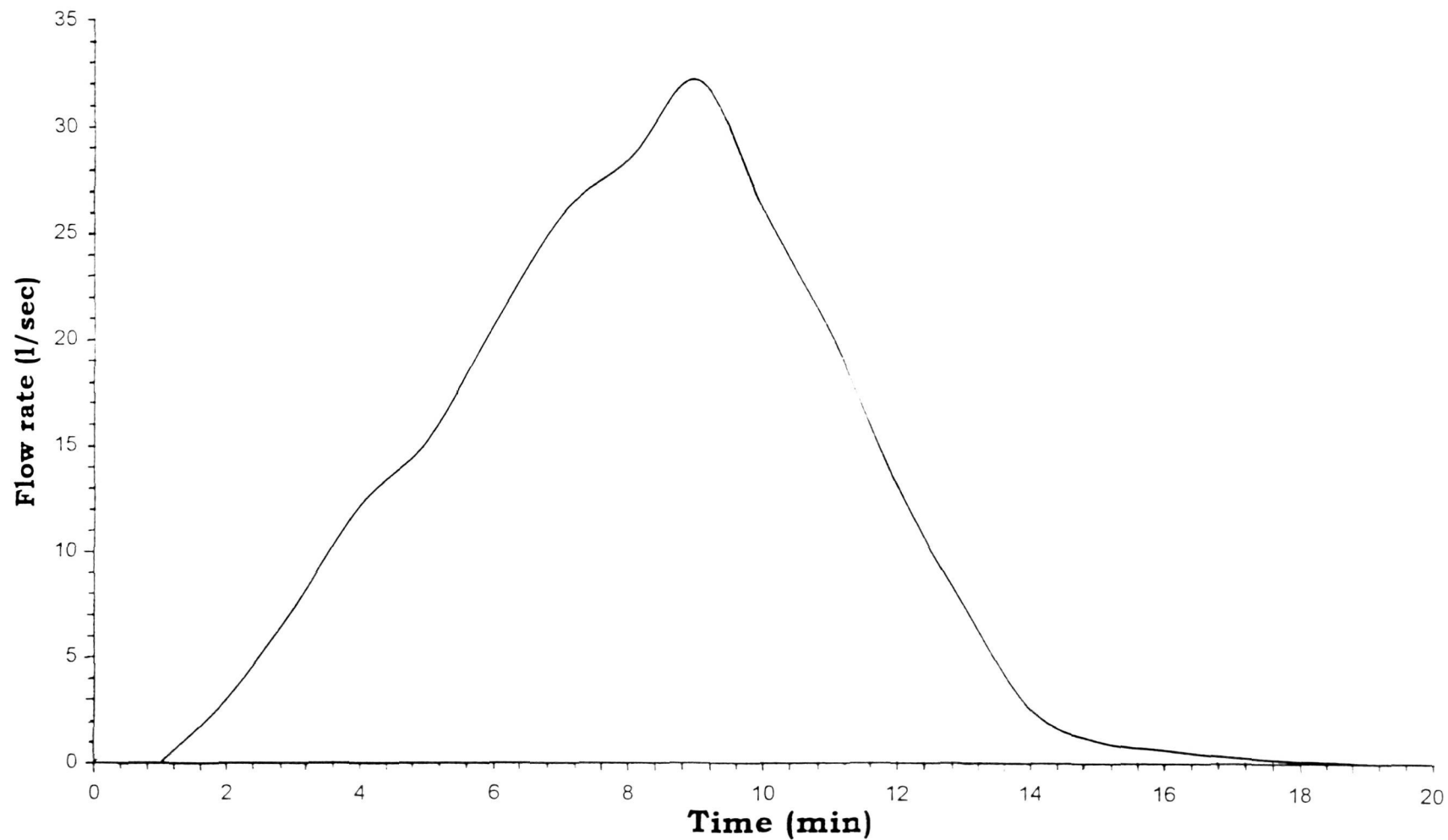


Fig. 4.1a. Measured runoff hydrograph for Plot-I: Date:8-8-2000

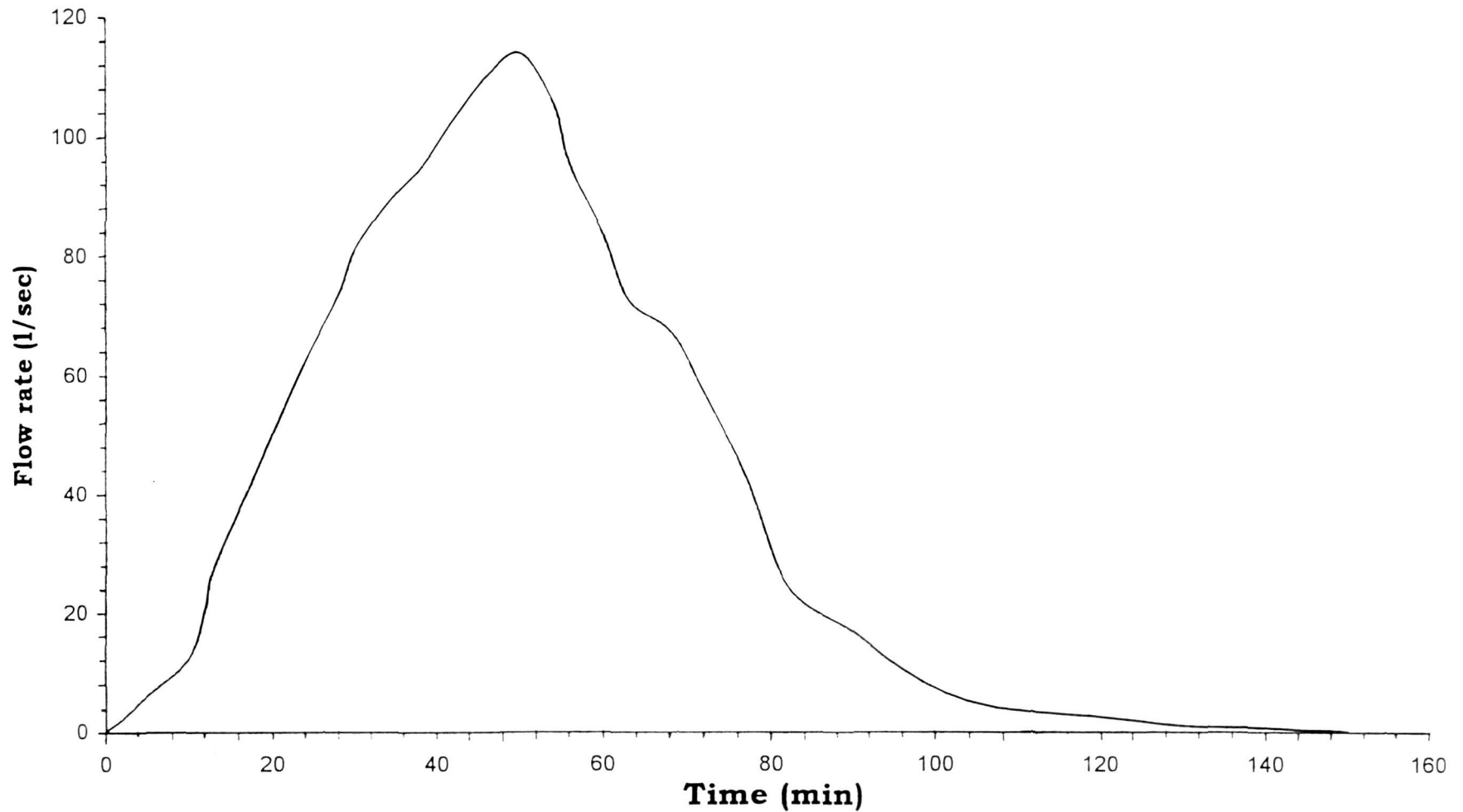


Fig. 4.1b. Measured runoff hydrograph for Plot-I: Date: 9-8-2000

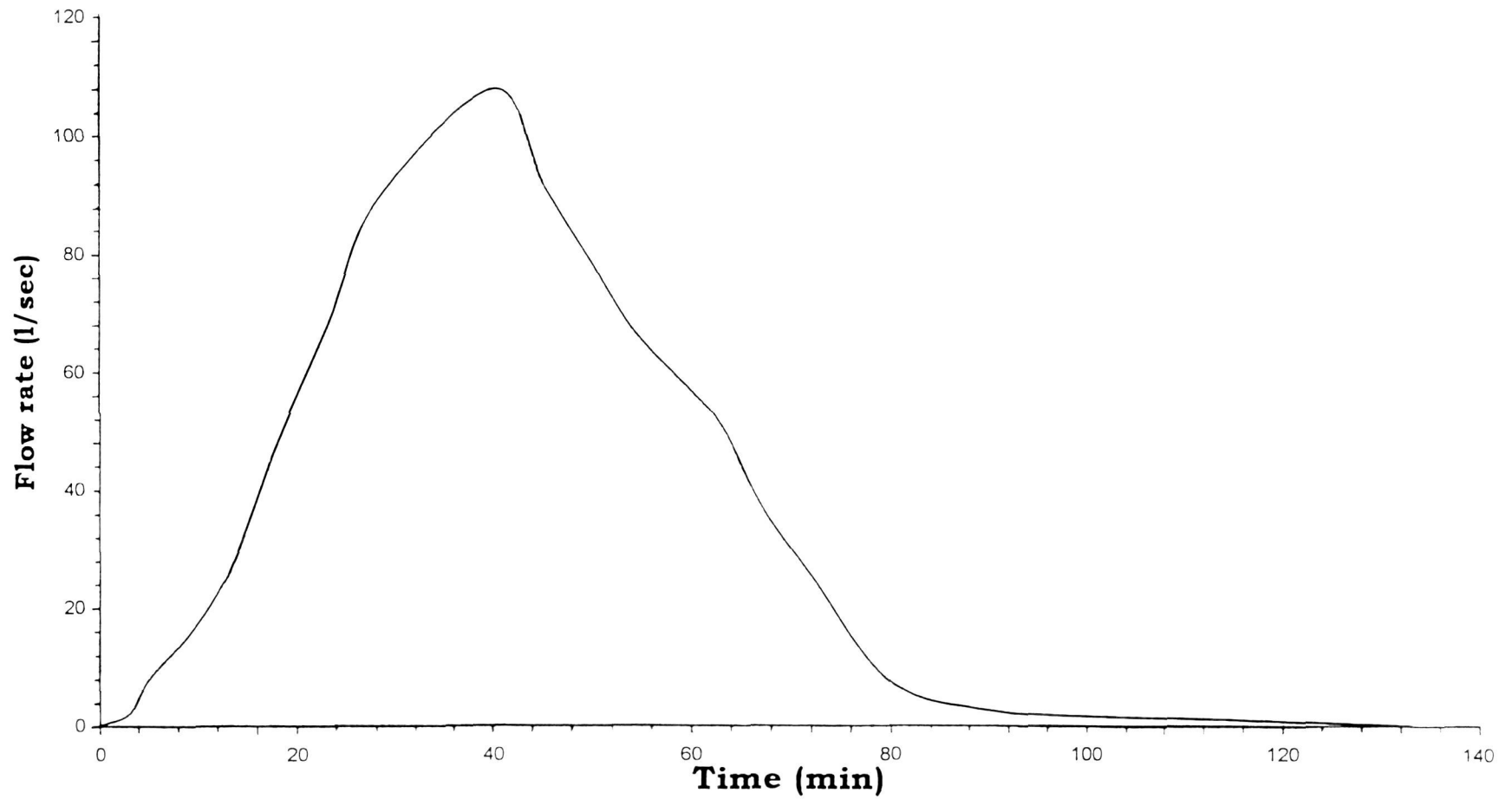


Fig. 4.1c. Measured runoff hydrograph for Plot-I: Date: 17-9-2000

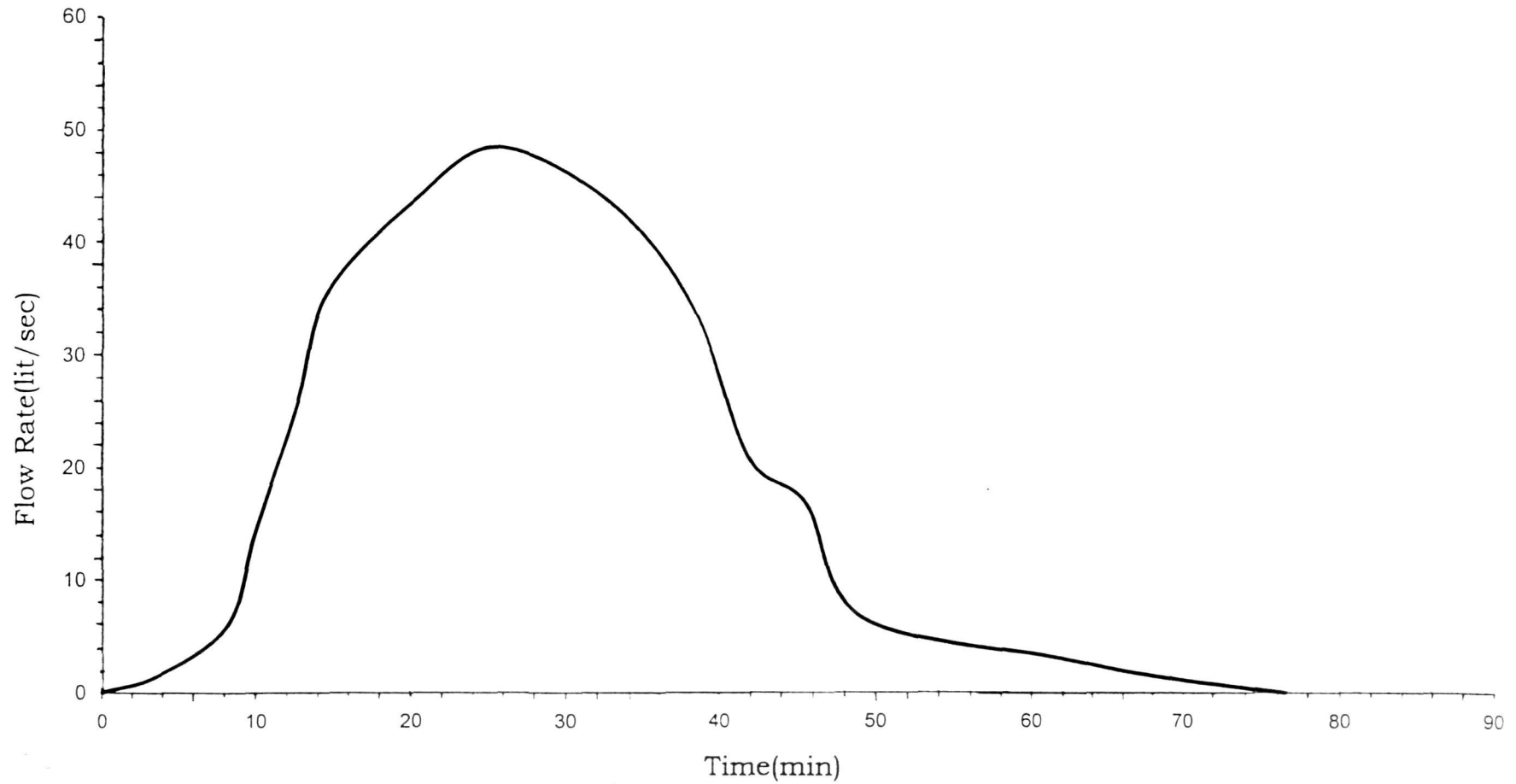


Fig. 4.1d. Measured runoff hydrograph for Plot-I: Date: 21-9-2000

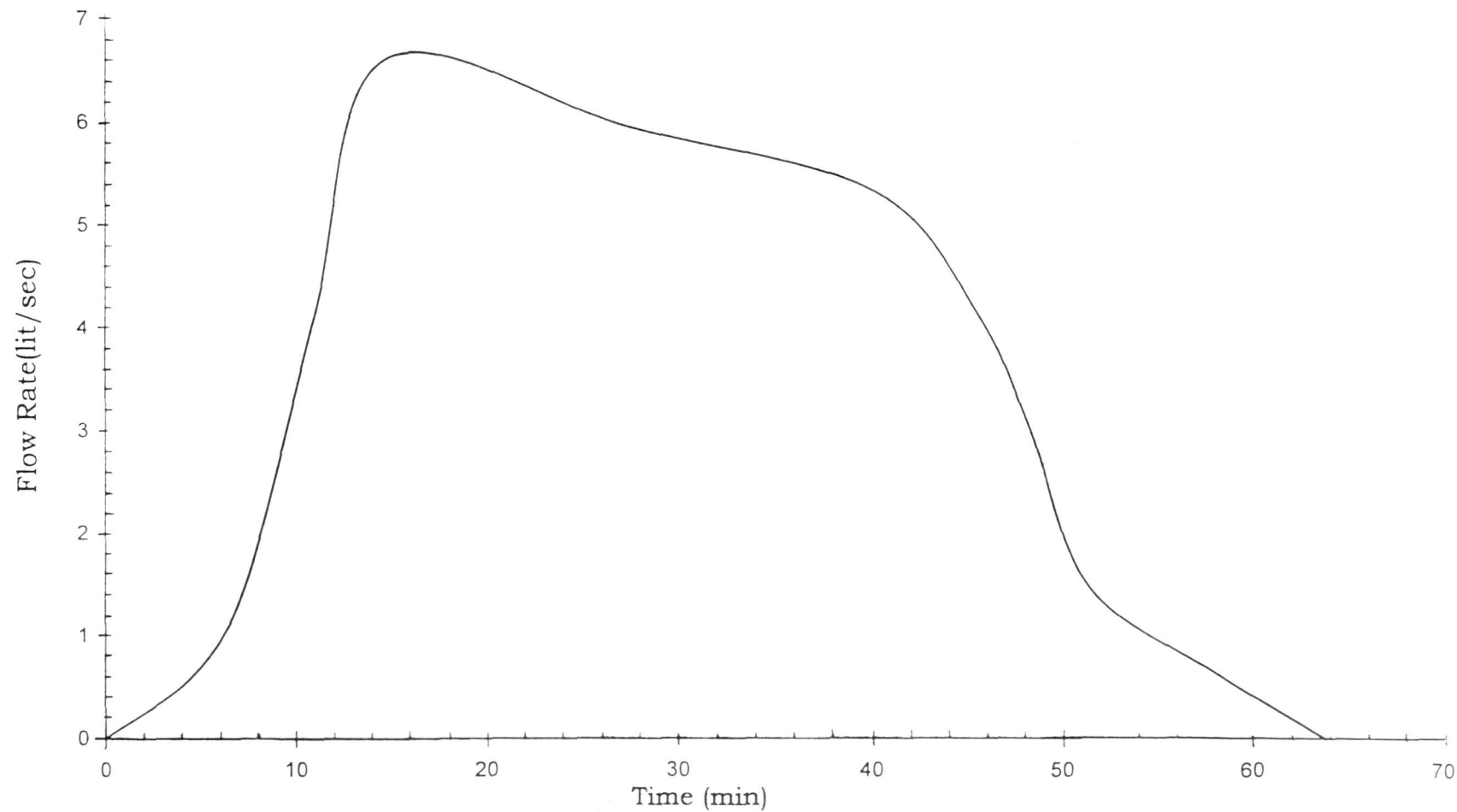


Fig. 4.1e. Measured runoff hydrograph for Plot-I: Date: 20-10-2000

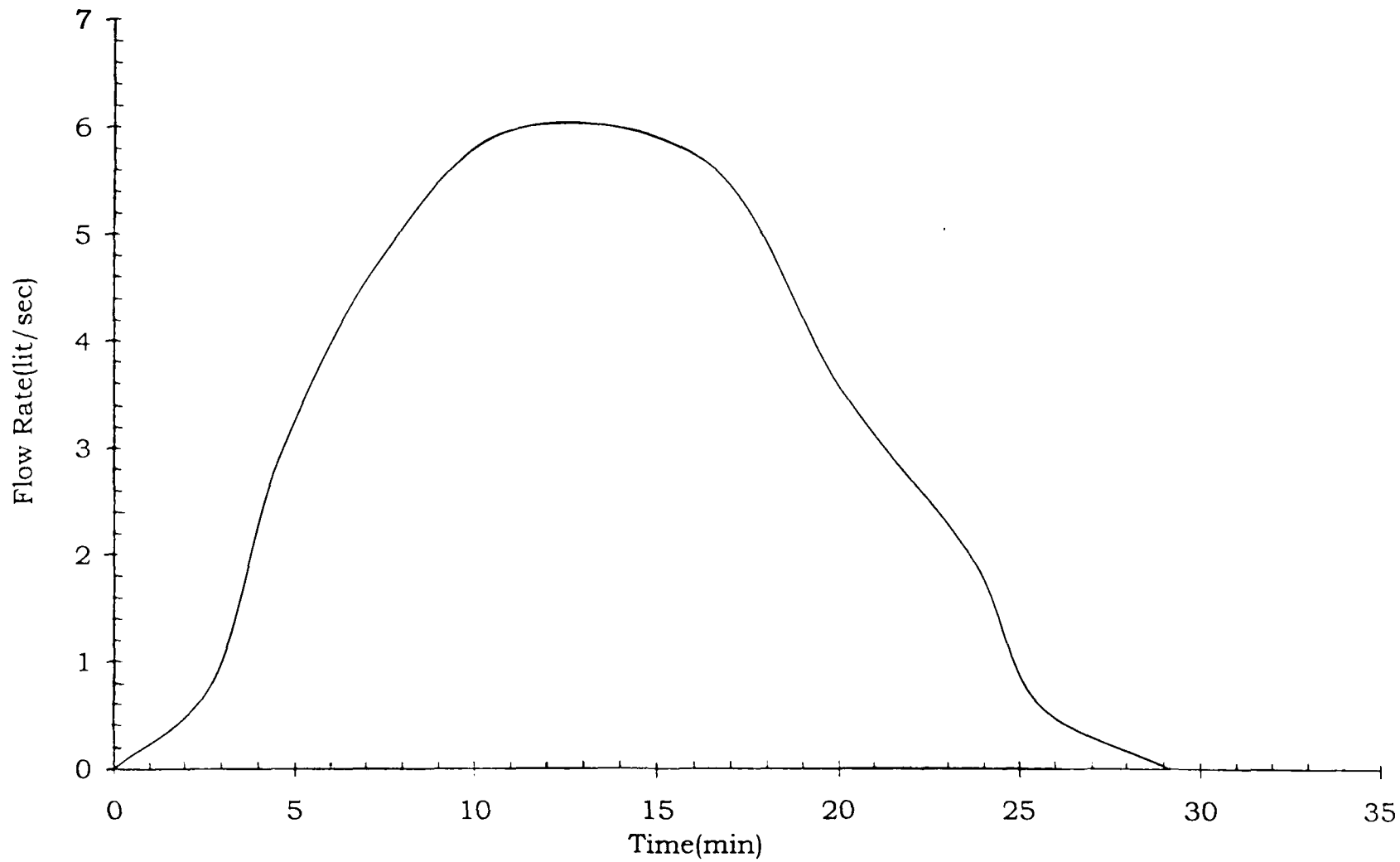


Fig. 4.2a. Measured runoff hydrograph for Plot-II: Date: 8-8-2000

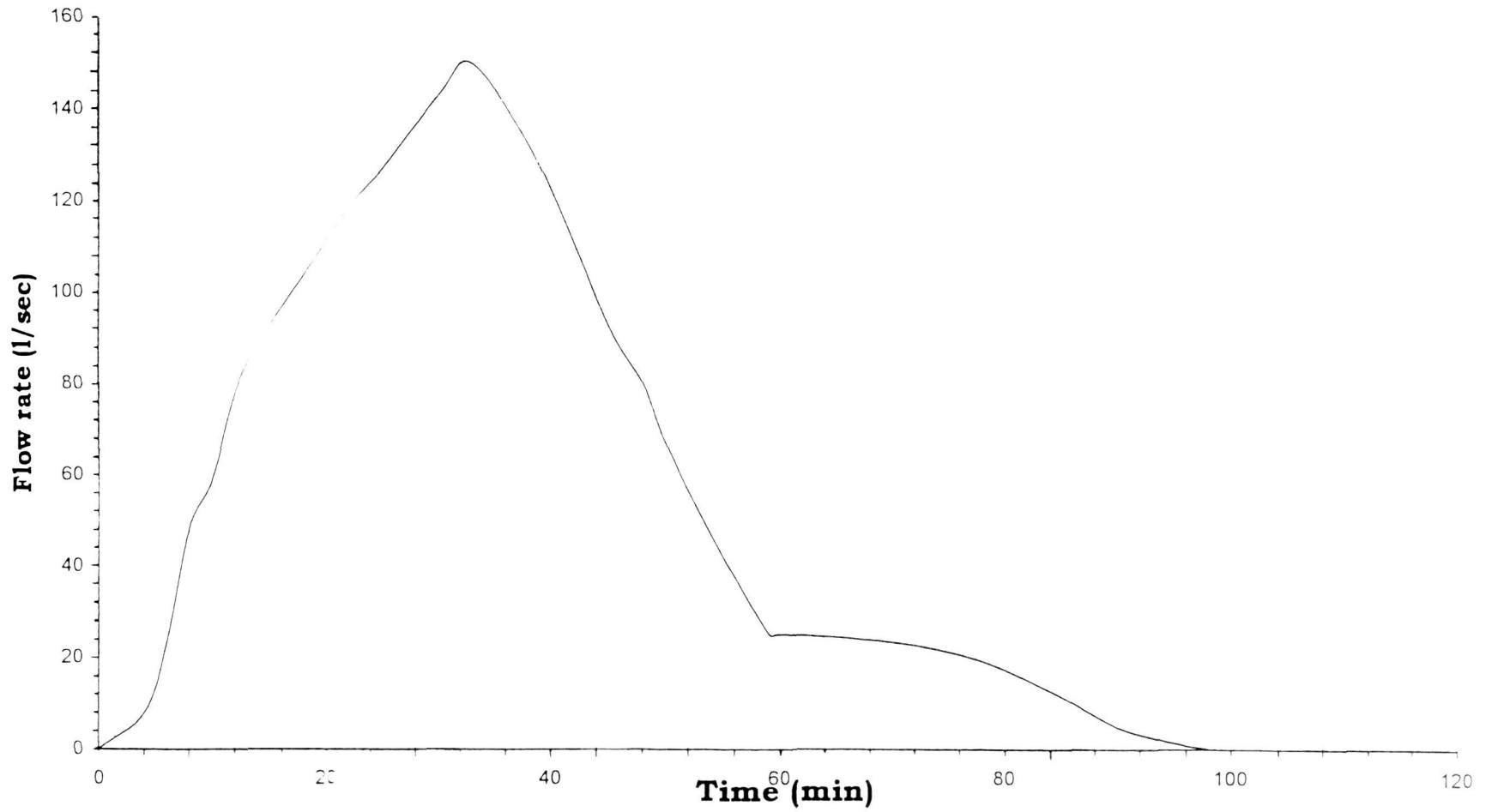


Fig. 4.2b. Measured runoff hydrograph for Plot-II: Date: 9-8-2000

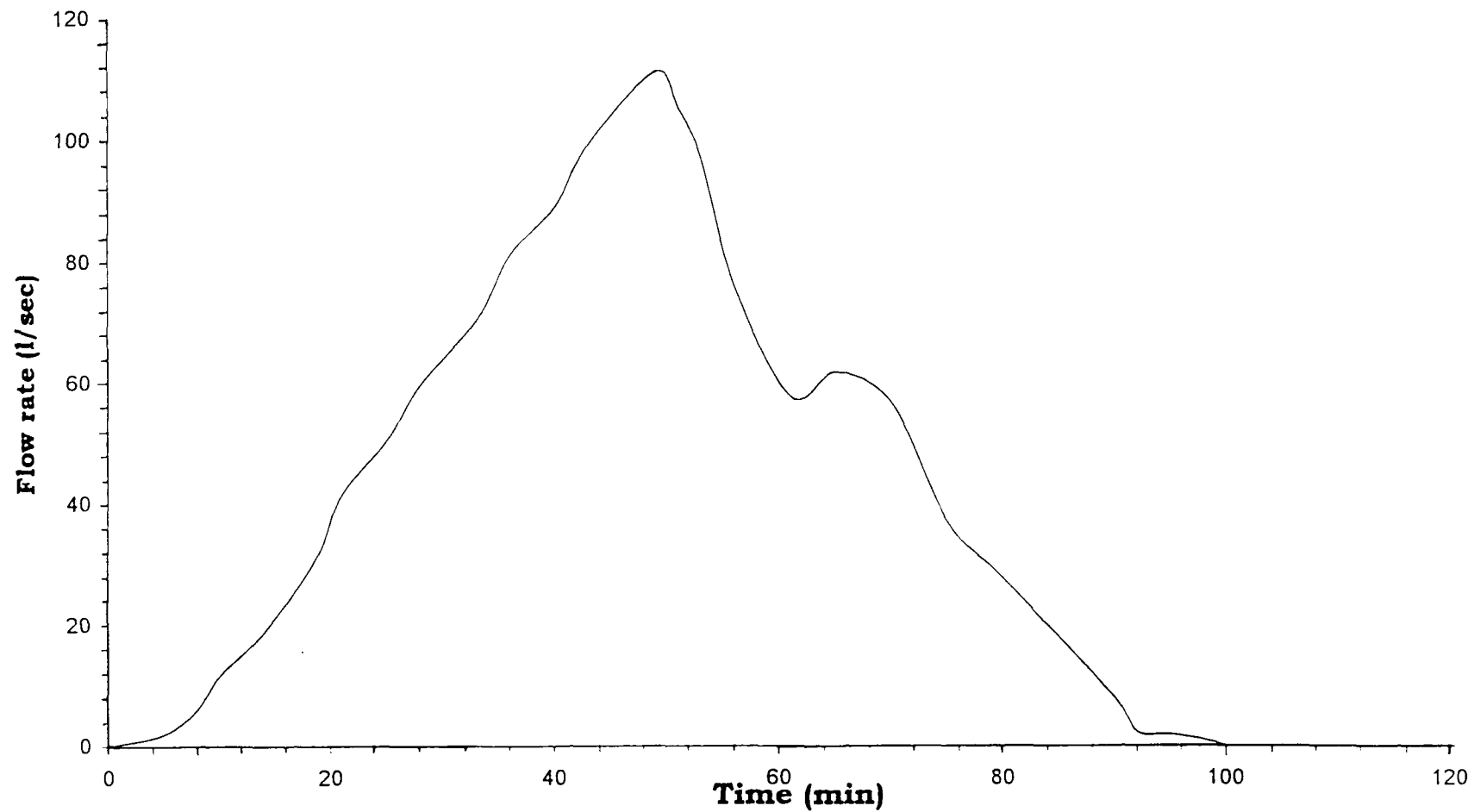


Fig. 4.2c. Measured runoff hydrograph for Plot-II: Date: 17-9-2000

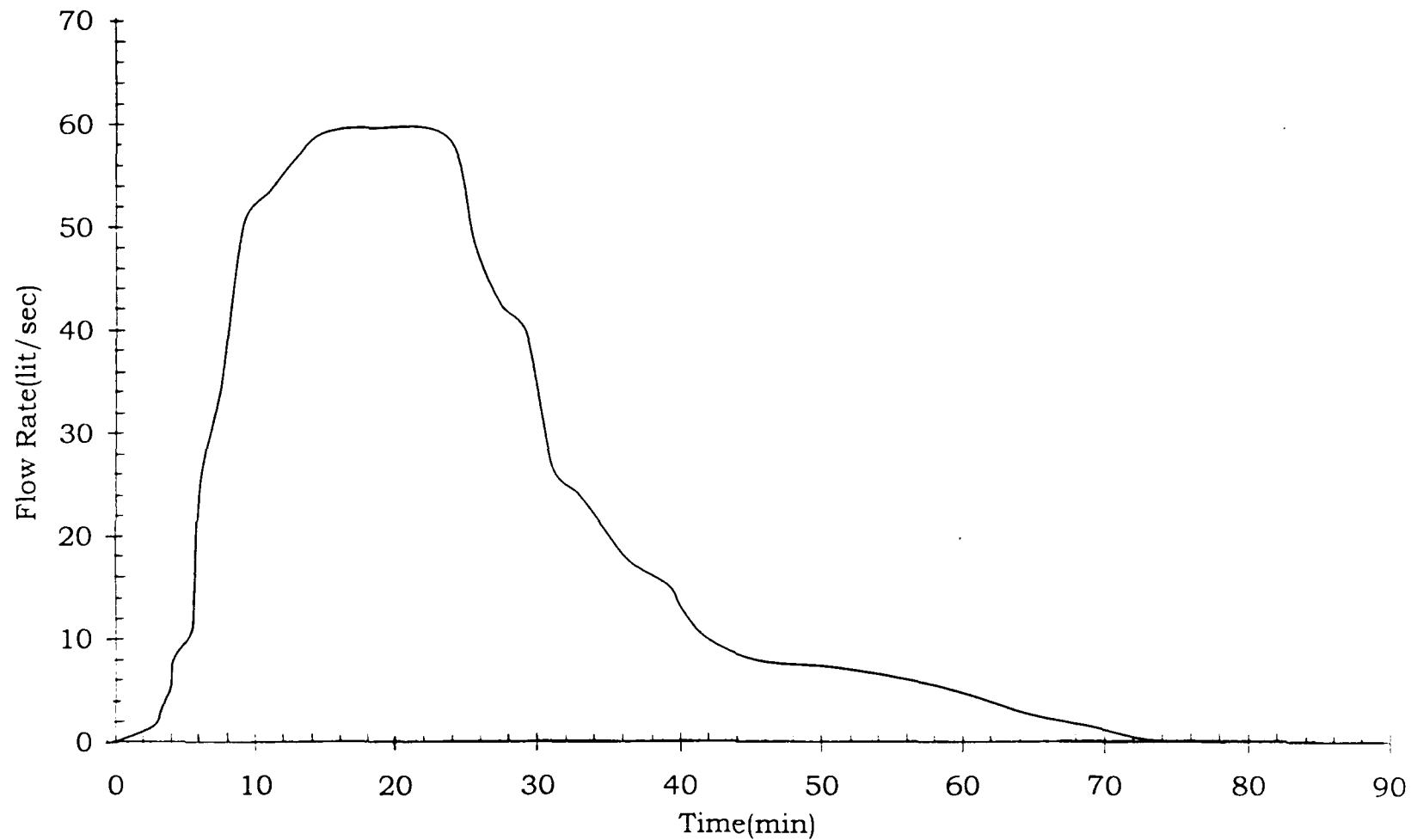


Fig. 4.2d. Measured runoff hydrograph for Plot-II: Date: 21-9-2000

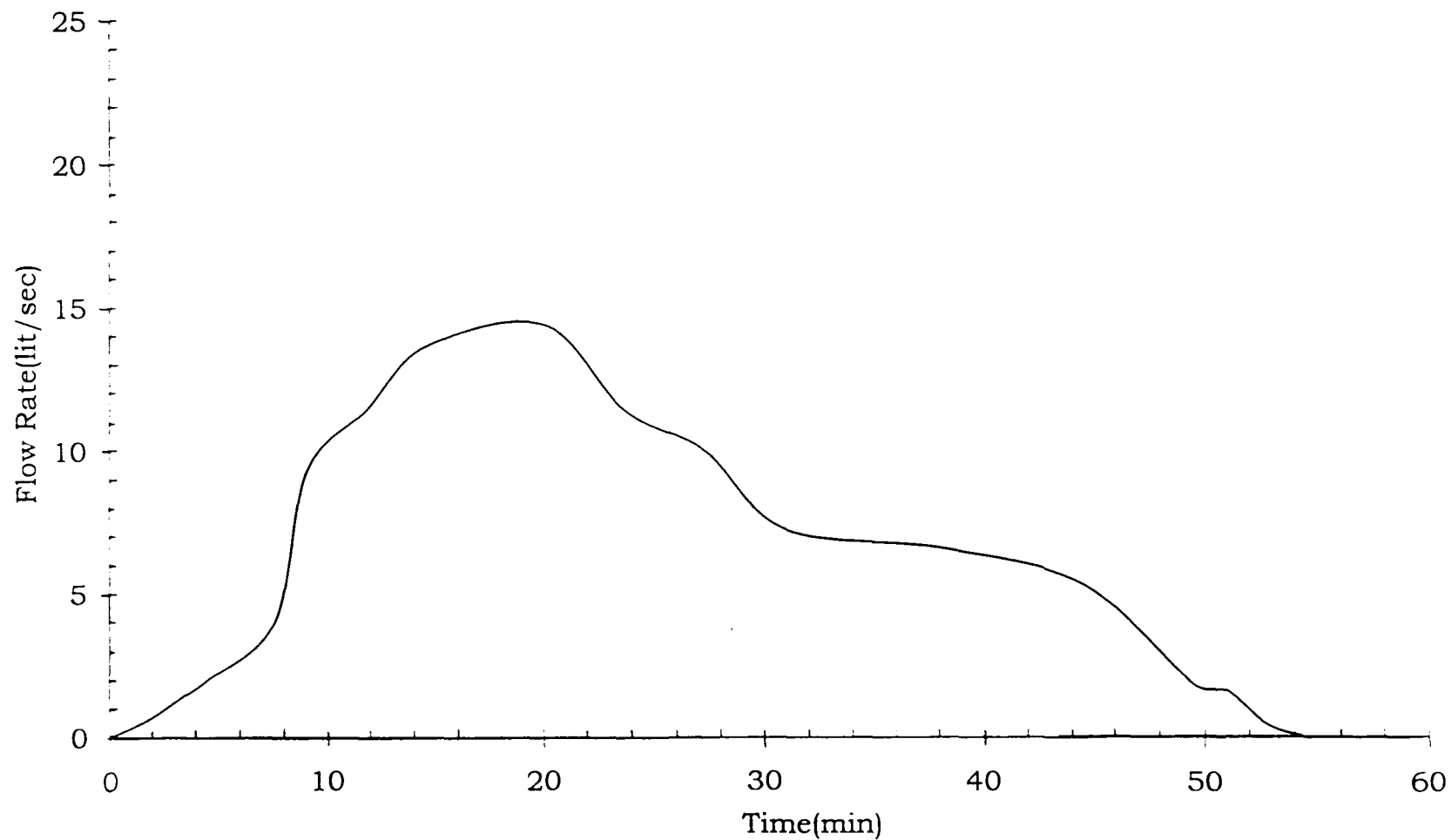


Fig. 4.2e. Measured runoff hydrograph for Plot-II: Date: 20-10-2000

Table 4.1a. Storm wise details of measured runoff of plot-I

Sl No.	Storm event	Rainfall (mm)	Runoff (000' lit)	Peak discharge (lit/sec)	Runoff (mm)
1	8-8-2000	20.83	39.432	32.162	4.651
2	9-8-2000	70.00	341.530	113.685	40.180
3	17-9-2000	72.00	268.930	107.73	31.596
4	21-9-2000	25.00	94.860	48.418	11.160
5	20-10-2000	23.50	22.567	6.600	2.622
Total		211.330	767.319		90.209

Table 4.1b. Storm wise Details of measured Runoff of Plot-II

Sl. No.	Storm event	Rainfall (mm)	Runoff (000' lit)	Peak discharge (lit/sec)	Runoff (mm)
1	8 8 2000	20.83	5.770	5.960	0.617
2	9-8-2000	70.00	357.300	149.560	39.700
3	17-9-2000	72.00	276.570	111.300	30.750
4	21-9-2000	25.00	92.493	59.650	10.277
5	20-10-2000	23.50	15.093	14.416	1.677
Total		211.330	747.226		83.021

table 4.1a and 4.1b it is observed that the first runoff was generated on 8th August 2000. The subsequent runoff events occurred on 9th August, 17th and 21st September and 20th of October 2000, which was the last runoff producing rainfall event during the year 2000.

4.2 Measured soil moisture

The average antecedent soil moisture contents measured at different locations of plot – I and plot-II for the period from 1st August to 31st October 2000 at 0-30 cm and 30-120 cm depths are depicted in Table 4.2. This procedure was followed to help compare the measured values of soil moisture with the corresponding antecedent soil moisture content values predicted from the soil moisture accounting procedure, developed by Pathak *et al.* (1989). The highest soil moisture level in 0-30 cm layer was found to be 137.21 mm on 8-8-2000 and the lowest was 98.14 mm on 16-9- 2000. In the layer-II the highest and lowest soil moisture values of 390.29 mm and 243.65 mm on 20-10-2000 and 3-8-2000 were observed respectively. In case of plot-II, the highest and lowest soil moisture values of layer-I were observed to be 139.41 mm and 87.76 mm on 11-8-2000 and 6-8-2000 respectively. In case of layer – II the highest and lowest soil moisture values were 342.21 mm and 198.26 mm on 9-10-2000 and 7-8-2000 respectively.

Table 4.2. Measured soil moisture level of the study area during August, September and October months (mm)

Sl No.	Date	Plot-I		Plot-II	
		Layer-I (0-30cm)	Layer-II (30-120)	Layer-I (0-30cm)	Layer-II (30-120)
1.	1-8-2000	105.72	245.08	106.56	215.29
2.	2-8-2000	104.92	244.21	102.86	211.28
3.	3-8-2000	104.10	243.65	98.86	207.36
4.	4-8-2000	103.30	246.41	94.86	204.61
5.	5-8-2000	102.45	244.42	91.26	201.68
6.	6-8-2000	101.85	245.28	87.76	199.65
7.	7-8-2000	135.62	246.51	136.94	198.26
8.	8-8-2000	137.21	258.51	137.84	200.61
9.	9-8-2000	137.00	288.90	135.76	282.41
10.	10-8-2000	134.28	297.41	138.56	309.45
11.	11-8-2000	136.29	340.16	139.41	309.51
12.	12-8-2000	135.27	342.51	135.51	305.61
13.	13-8-2000	130.51	343.61	133.51	309.51
14.	14-8-2000	124.31	342.51	130.01	306.51
15.	15-8-2000	120.31	344.81	126.41	302.81
16.	16-8-2000	117.46	346.51	121.91	299.58
17.	17-8-2000	115.88	333.61	117.61	297.56
18.	18-8-2000	114.62	334.21	113.31	295.61
19.	19-8-2000	113.18	333.56	109.33	293.28
20.	20-8-2000	111.98	332.51	105.32	290.61
21.	21-8-2000	100.58	332.00	104.31	290.58
22.	22-8-2000	128.41	331.48	129.46	288.61
23.	23-8-2000	123.91	331.46	125.46	289.51
24.	24-8-2000	120.91	332.86	122.96	288.89
25.	25-8-2000	118.81	333.41	121.36	287.24
26.	26-8-2000	114.61	332.51	118.36	286.58
27.	27-8-2000	110.61	333.41	114.36	285.58
28.	28-8-2000	126.41	334.21	112.86	285.00
29.	29-8-2000	122.31	332.51	126.62	284.52

Contd....

Sl No.	Date	Plot-I		Plot-II	
		Layer-I (0-30cm)	Layer-II (30-120)	Layer-I (0-30cm)	Layer-II (30-120)
30.	30-8-2000	118.91	334.61	123.62	284.10
31.	31-8-2000	116.41	333.51	121.62	253.60
32.	1-9-2000	114.61	332.58	119.92	282.41
33.	2-9-2000	113.11	334.21	118.52	283.00
34.	3-9-2000	111.91	333.51	117.12	281.41
35.	4-9-2000	110.93	338.51	116.12	279.51
36.	5-9-2000	110.15	334.21	115.32	278.56
37.	6-9-2000	109.42	332.41	114.41	276.21
38.	7-9-2000	107.42	330.51	113.81	275.81
39.	8-9-2000	106.22	333.28	113.01	274.28
40.	9-9-2000	105.34	336.51	112.41	273.68
41.	10-9-2000	104.77	334.29	111.93	273.58
42.	11-9-2000	104.29	332.51	111.28	272.56
43.	12-9-2000	101.29	334.21	110.74	271.48
44.	13-9-2000	100.51	334.51	110.14	270.58
45.	14-9-2000	99.91	331.21	109.46	269.44
46.	15-9-2000	99.04	336.28	108.00	269.58
47.	16-9-2000	98.14	337.51	107.21	268.51
48.	17-9-2000	139.46	383.41	106.53	330.26
49.	18-9-2000	132.76	384.51	106.06	330.58
50.	19-9-2000	129.76	382.51	105.78	329.46
51.	20-9-2000	127.26	384.21	156.81	330.41
52.	21-9-2000	140.26	386.51	150.11	332.51
53.	22-9-2000	133.76	386.21	136.21	334.51
54.	23-9-2000	130.36	387.21	128.51	333.81
55.	24-9-2000	127.34	382.51	124.21	334.21
56.	25-9-2000	125.36	383.28	117.71	333.28
57.	26-9-2000	123.36	382.56	114.31	332.56
58.	27-9-2000	122.00	384.21	111.31	334.21
59.	28-9-2000	130.41	386.28	109.71	335.56
60.	29-9-2000	136.00	381.41	108.41	331.28

Contd....

Sl No.	Date	Plot-I		Plot-II	
		Layer-I (0-30cm)	Layer-II (30-120)	Layer-I (0-30cm)	Layer-II (30-120)
61.	30-9-2000	131.00	382.41	107.21	333.44
62.	1-10-2000	128.50	384.51	116.28	331.58
63.	2-10-2000	126.00	382.81	142.21	335.61
64.	3-10-2000	124.10	380.21	119.29	331.48
65.	4-10-2000	122.82	382.41	117.81	333.28
66.	5-10-2000	121.69	383.51	115.71	335.61
67.	6-10-2000	120.86	384.21	113.91	339.21
68.	7-10-2000	132.41	386.29	112.63	331.21
69.	8-10-2000	126.48	387.51	111.53	341.56
70.	9-10-2000	124.28	386.21	110.70	342.21
71.	10-10-2000	122.78	384.21	125.21	335.92
72.	11-10-2000	121.54	385.48	120.01	334.29
73.	12-10-2000	118.54	383.29	117.51	333.21
74.	13-10-2000	115.74	384.21	116.51	332.81
75.	14-10-2000	129.41	386.51	114.58	333.81
76.	15-10-2000	123.41	384.21	111.51	328.56
77.	16-10-2000	121.48	386.81	128.41	326.41
78.	17-10-2000	119.61	387.81	122.41	324.81
79.	18-10-2000	117.92	386.41	119.41	323.51
80.	19-10-2000	116.11	384.21	116.91	320.61
81.	20-10-2000	136.51	390.29	114.41	318.51
82.	21-10-2000	130.51	389.41	126.28	315.61
83.	22-10-2000	124.58	388.91	120.48	320.21
84.	23-10-2000	123.01	388.00	117.98	318.056
85.	24-10-2000	121.08	387.21	115.98	316.21
86.	25-10-2000	120.56	386.48	113.48	313.21
87.	26-10-2000	119.72	384.29	111.68	310.61
88.	27-10-2000	118.97	383.28	109.88	308.58
89.	28-10-2000	117.21	382.61	106.81	306.21
90.	29-10-2000	116.28	381.42	104.21	304.18
91.	30-10-2000	114.21	380.10	102.21	300.56
92.	31-10-2000	111.89	378.21	101.00	300.56

4.3 Predicted (simulated) parameters from runoff model

Predicted runoff

The modified SCS curve number model (Pathak *et al.*, 1989) predicted the runoff in terms of mm for each runoff event for plot-I and plot-II and the same are presented in Table 4.3.

The table 4.4a & b corresponding to plot – I and plot – II respectively, depict the different components of water balance equation as a result of changes caused due to incident rainfall during the period from 1st August to 31st October 2000. Annexure II and III depict these parameters from 7th May 2000 to 28th February 2001 including the input and output parameters.

The area where the experiment was conducted received the first summer showers on 7th May 2000. The required values of out put parameters on 7th May 2000 were considered to start soil moisture accounting from 7th May onwards. However, in order to compare the values between measured and predicted values, the period was restricted between 1st August and 31st October, because all the runoff events occurred during the above period (Table 4.4a & 4.4b). The values of the output parameters for other periods i.e., 7th May to 31st July 2000 and 1st November 2000 to 28th February 2001 pertaining to both the plots are presented in Annexure II & III, which form the output file of the runoff model (Pathak *et al.*, 1989). The output

Table 4.3. Storm wise predicted runoff.

Sl. No.	Storm event	Predicted runoff (mm)	
		Plot-I	Plot-II
1	8-8-2000	6.920	0.000
2	9-8-2000	45.420	43.570
3	17-9-2000	37.340	35.410
4	21-9-2000	8.180	8.180
5	20-10-2000	2.270	2.270

Table 4.4a. Output parameters of the runoff model:

Plot-I

Sl. No	Date	Soil evaporation E* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM ₁ (mm)	Soil moisture level at Layer-II, 30-120 cm SM ₂ (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
1.	1-8-2000	0.710	0.000	89.190	239.160	328.350	477.760
2.	2-8-2000	0.760	0.000	88.430	239.160	327.590	478.610
3.	3-8-2000	0.740	0.000	87.690	239.160	326.850	479.530
4.	4-8-2000	0.720	0.000	86.970	239.160	326.130	480.410
5.	5-8-2000	0.660	0.000	86.310	239.160	325.470	481.280
6.	6-8-2000	0.600	0.000	85.710	239.160	324.870	482.070
7.	7-8-2000	1.000	0.000	121.210	239.160	360.370	482.790
8.	8-8-2000	1.000	0.000	124.800	254.100	378.900	35.000
9.	9-8-2000	1.000	0.000	124.800	293.880	418.680	35.000
10.	10-8-2000	1.200	0.000	124.800	303.680	428.480	15.000
11.	11-8-2000	1.000	0.000	124.800	333.280	458.080	35.000
12.	12-8-2000	4.300	0.000	120.500	333.280	453.780	15.000
13.	13-8-2000	3.000	0.000	124.800	335.780	460.580	15.000
14.	14-8-2000	6.200	0.000	118.600	335.780	454.380	15.000
15.	15-8-2000	3.000	0.000	115.600	335.780	451.380	15.000
16.	16-8-2000	2.133	0.000	113.470	335.780	449.250	15.000
17.	17-8-2000	1.575	0.000	111.890	335.780	447.680	15.000
18.	18-8-2000	1.280	0.000	110.610	335.780	446.400	15.000
19.	19-8-2000	1.050	0.000	109.560	335.780	445.350	15.000
20.	20-8-2000	0.886	0.000	108.680	335.780	444.460	15.000
21.	21-8-2000	0.788	0.000	107.890	335.780	443.670	15.000
22.	22-8-2000	3.250	0.000	119.140	335.780	454.920	15.000
23.	23-8-2000	4.500	0.000	114.640	335.780	450.420	15.000
24.	24-8-2000	2.200	0.000	112.440	335.780	448.220	15.000
25.	25-8-2000	1.600	0.000	121.340	335.780	457.120	15.000
26.	26-8-2000	3.000	0.000	118.340	335.780	454.120	15.000
27.	27-8-2000	4.000	0.000	114.340	335.780	450.120	15.000

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Sl. No	Date	Soil evaporation E* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM ₁ (mm)	Soil moisture level at Layer-II, 30-120 cm SM ₂ (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
28.	28-8-2000	1.500	0.000	123.130	335.780	458.910	15.000
29.	29-8-2000	3.200	0.000	119.930	335.780	455.710	15.000
30.	30-8-2000	2.000	0.000	117.930	335.780	453.710	15.000
31.	31-8-2000	1.733	0.000	116.200	335.780	451.980	15.000
32.	1-9-2000	1.475	0.000	114.720	335.780	450.500	15.000
33.	2-9-2000	1.240	0.000	113.480	335.780	449.260	15.000
34.	3-9-2000	0.967	0.000	112.510	335.780	448.300	15.000
35.	4-9-2000	0.914	0.000	111.600	335.780	447.380	15.000
36.	5-9-2000	0.725	0.000	110.870	335.780	446.660	15.000
37.	6-9-2000	0.689	0.000	110.190	335.780	445.970	15.000
38.	7-9-2000	0.620	0.000	109.570	335.780	445.350	15.000
39.	8-9-2000	0.560	0.000	109.010	335.780	444.790	15.000
40.	9-9-2000	0.620	0.000	108.390	335.780	444.170	15.000
41.	10-9-2000	0.640	0.000	107.750	335.780	443.530	15.000
42.	11-9-2000	0.660	0.000	107.090	335.780	442.870	15.000
43.	12-9-2000	0.680	0.000	106.410	335.780	442.190	15.000
44.	13-9-2000	0.660	0.000	105.750	335.780	441.530	15.000
45.	14-9-2000	0.660	0.000	105.090	335.780	440.870	15.000
46.	15-9-2000	0.680	0.000	104.410	335.780	440.190	15.000
47.	16-9-2000	0.690	0.000	103.720	335.780	439.500	15.000
48.	17-9-2000	3.400	0.000	124.800	370.130	494.930	35.000
49.	18-9-2000	6.700	0.000	118.100	370.130	488.230	15.000
50.	19-9-2000	2.850	0.000	115.250	370.130	485.380	15.000
51.	20-9-2000	1.867	0.000	113.380	370.130	483.510	15.000
52.	21-9-2000	3.200	0.000	124.800	370.240	495.040	35.000
53.	22-9-2000	6.500	0.000	118.300	370.240	488.540	15.000
54.	23-9-2000	3.400	0.000	114.900	370.240	485.140	15.000

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Sl. No	Date	Soil evaporation E* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM ₁ (mm)	Soil moisture level at Layer-II, 30-120 cm SM ₂ (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
55.	24-9-2000	2.167	0.000	112.730	370.240	482.980	15.000
56.	25-9-2000	1.600	0.000	111.130	370.240	481.380	15.000
57.	26-9-2000	1.360	0.000	109.770	370.240	480.020	15.000
58.	27-9-2000	1.200	0.000	108.570	370.240	478.820	15.000
59.	28-9-2000	2.800	0.000	116.770	370.240	487.020	15.000
60.	29-9-2000	5.400	0.000	124.800	372.220	497.020	15.000
61.	30-9-2000	5.000	0.000	119.800	372.220	492.020	15.000
62.	1-10-2000	2.000	0.000	117.800	372.220	490.020	15.000
63.	2-10-2000	2.000	0.000	115.800	372.220	488.020	15.000
64.	3-10-2000	1.550	0.000	114.250	372.220	486.470	15.000
65.	4-10-2000	1.280	0.000	112.970	372.220	485.190	15.000
66.	5-10-2000	1.133	0.000	111.840	372.220	484.050	15.000
67.	6-10-2000	0.829	0.000	111.010	372.220	483.220	15.000
68.	7-10-2000	3.250	0.000	124.760	372.220	496.970	15.000
69.	8-10-2000	5.200	0.000	119.560	372.220	491.770	15.000
70.	9-10-2000	2.592	0.216	116.900	372.070	488.970	15.000
71.	10-10-2000	1.008	0.084	124.800	373.370	498.170	15.000
72.	11-10-2000	1.248	0.052	124.800	377.370	502.170	15.000
73.	12-10-2000	2.880	0.120	121.880	377.290	499.170	15.000
74.	13-10-2000	2.880	0.240	118.930	377.120	496.050	15.000
75.	14-10-2000	2.256	0.188	124.800	382.530	507.330	15.000
76.	15-10-2000	5.184	0.216	119.550	382.380	501.930	15.000
77.	16-10-2000	2.610	0.580	116.770	381.970	498.740	15.000
78.	17-10-2000	1.980	0.660	114.590	381.510	496.100	15.000
79.	18-10-2000	1.395	0.620	113.010	381.080	494.090	15.000
80.	19-10-2000	1.134	0.630	111.690	380.640	492.320	15.000
81.	20-10-2000	2.700	0.600	124.800	386.050	510.850	35.000

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Sl. No	Date	Soil evaporation E* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM ₁ (mm)	Soil moisture level at Layer-II, 30-120 cm SM ₂ (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
82.	21-10-2000	5.760	0.640	118.850	385.600	504.450	15.000
83.	22-10-2000	1.890	0.420	116.830	385.310	502.140	15.000
84.	23-10-2000	1.319	0.644	115.320	384.860	500.180	15.000
85.	24-10-2000	1.161	0.756	113.930	384.330	498.260	15.000
86.	25-10-2000	0.894	0.728	112.820	383.820	496.640	15.000
87.	26-10-2000	0.717	0.700	111.890	383.330	495.220	15.000
88.	27-10-2000	0.762	0.868	110.870	382.720	493.590	15.000
89.	28-10-2000	0.624	0.812	110.000	382.150	492.160	15.000
90.	29-10-2000	0.506	0.742	109.270	381.630	490.910	15.000
91.	30-10-2000	0.454	1.064	108.500	380.890	489.390	15.000
92.	31-10-2000	0.421	0.988	107.780	380.200	487.980	15.000

Table 4.4b. Output parameters of the runoff model :

Plot-II

Sl. No	Date	Soil evaporation E* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM ₁ (mm)	Soil moisture level at Layer-II, 30-120 cm SM ₂ (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
1.	1-8-2000	0.369	3.408	86.190	204.300	290.490	533.560
2.	2-8-2000	0.395	3.648	84.700	201.750	286.450	538.090
3.	3-8-2000	0.385	3.552	83.250	199.260	282.510	542.940
4.	4-8-2000	0.374	3.456	81.840	196.840	278.680	547.670
5.	5-8-2000	0.343	3.168	80.540	194.630	275.170	552.260
6.	6-8-2000	0.312	2.880	79.370	192.610	271.980	556.480
7.	7-8-2000	0.470	1.060	114.340	192.610	306.950	560.310
8.	8-8-2000	0.470	0.530	121.670	204.470	326.140	518.340
9.	9-8-2000	0.470	0.530	121.670	261.720	383.390	35.000
10.	10-8-2000	0.564	0.636	121.670	271.520	393.190	15.000
11.	11-8-2000	0.470	0.530	121.670	301.120	422.790	35.000
12.	12-8-2000	2.021	2.279	118.970	299.520	418.490	15.000
13.	13-8-2000	1.410	3.180	121.670	302.030	423.700	15.000
14.	14-8-2000	2.232	3.968	118.250	299.250	417.500	15.000
15.	15-8-2000	1.080	3.840	116.020	296.560	412.580	15.000
16.	16-8-2000	0.768	4.096	114.020	293.690	407.710	15.000
17.	17-8-2000	0.567	4.032	112.240	290.870	403.110	15.000
18.	18-8-2000	0.461	4.096	110.550	288.000	398.560	15.000
19.	19-8-2000	0.378	4.032	108.960	285.180	394.150	15.000
20.	20-8-2000	0.319	3.968	107.460	282.400	389.860	15.000
21.	21-8-2000	0.788	0.000	106.670	282.400	389.070	15.000
22.	22-8-2000	3.250	0.000	117.920	282.400	400.320	15.000
23.	23-8-2000	4.500	0.000	113.420	282.400	395.820	15.000
24.	24-8-2000	2.200	0.000	111.220	282.400	393.620	15.000
25.	25-8-2000	1.600	0.000	120.120	282.400	402.520	15.000
26.	26-8-2000	3.000	0.000	117.120	282.400	399.520	15.000
27.	27-8-2000	4.000	0.000	113.120	282.400	395.520	15.000

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Sl. No	Date	Soil evaporation E^* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM_1 (mm)	Soil moisture level at Layer-II, 30-120 cm SM_2 (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
28.	28-8-2000	1.500	0.000	121.670	282.640	404.310	15.000
29.	29-8-2000	3.200	0.000	118.470	282.640	401.110	15.000
30.	30-8-2000	2.000	0.000	116.470	282.640	399.110	15.000
31.	31-8-2000	1.733	0.000	114.740	282.640	397.380	15.000
32.	1-9-2000	1.475	0.000	113.260	282.640	395.900	15.000
33.	2-9-2000	1.240	0.000	112.020	282.640	394.660	15.000
34.	3-9-2000	0.967	0.000	111.060	282.640	393.700	15.000
35.	4-9-2000	0.914	0.000	110.140	282.640	392.780	15.000
36.	5-9-2000	0.725	0.000	109.420	282.640	392.060	15.000
37.	6-9-2000	0.689	0.000	108.730	282.640	391.370	15.000
38.	7-9-2000	0.620	0.000	108.110	282.640	390.750	15.000
39.	8-9-2000	0.560	0.000	107.550	282.640	390.190	15.000
40.	9-9-2000	0.620	0.000	106.930	282.640	389.570	15.000
41.	10-9-2000	0.640	0.000	106.290	282.640	388.930	15.000
42.	11-9-2000	0.660	0.000	105.630	282.640	388.270	15.000
43.	12-9-2000	0.680	0.000	104.950	282.640	387.590	15.000
44.	13-9-2000	0.660	0.000	104.290	282.640	386.930	15.000
45.	14-9-2000	0.660	0.000	103.630	282.640	386.270	15.000
46.	15-9-2000	0.680	0.000	102.950	282.640	385.590	15.000
47.	16-9-2000	0.690	0.000	102.260	282.640	384.900	423.970
48.	17-9-2000	3.400	0.000	121.670	318.140	439.810	424.800
49.	18-9-2000	6.700	0.000	114.970	318.140	433.110	15.000
50.	19-9-2000	2.850	0.000	112.120	318.140	430.260	15.000
51.	20-9-2000	1.867	0.000	110.250	318.140	428.390	15.000
52.	21-9-2000	3.200	0.000	120.950	318.140	439.090	35.000
53.	22-9-2000	6.500	0.000	114.450	318.140	432.590	15.000
54.	23-9-2000	3.400	0.000	111.050	318.140	429.190	15.000

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Sl. No	Date	Soil evaporation E^* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM_1 (mm)	Soil moisture level at Layer-II, 30-120 cm SM_2 (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
55.	24-9-2000	2.167	0.000	108.890	318.140	427.030	15.000
56.	25-9-2000	1.600	0.000	107.290	318.140	425.430	15.000
57.	26-9-2000	1.360	0.000	105.930	318.140	424.070	15.000
58.	27-9-2000	1.200	0.000	104.730	318.140	422.870	15.000
59.	28-9-2000	2.800	0.000	112.930	318.140	431.070	15.000
60.	29-9-2000	5.400	0.000	121.670	319.400	441.070	15.000
61.	30-9-2000	5.000	0.000	116.670	319.400	436.070	15.000
62.	1-10-2000	2.000	0.000	114.670	319.400	434.070	15.000
63.	2-10-2000	2.000	0.000	112.670	319.400	432.070	15.000
64.	3-10-2000	1.550	0.000	111.120	319.400	430.520	15.000
65.	4-10-2000	1.280	0.000	109.840	319.400	429.240	15.000
66.	5-10-2000	1.133	0.000	108.710	319.400	428.100	15.000
67.	6-10-2000	0.829	0.000	107.880	319.400	427.270	15.000
68.	7-10-2000	3.250	0.000	121.630	319.400	441.020	15.000
69.	8-10-2000	5.200	0.000	116.430	319.400	435.820	15.000
70.	9-10-2000	2.592	0.216	113.770	319.250	433.020	15.000
71.	10-10-2000	1.008	0.084	121.670	320.550	442.220	15.000
72.	11-10-2000	1.248	0.052	121.670	324.550	446.220	15.000
73.	12-10-2000	2.880	0.120	118.750	324.470	443.220	15.000
74.	13-10-2000	2.880	0.240	115.800	324.300	440.100	15.000
75.	14-10-2000	2.256	0.188	121.670	329.710	451.380	15.000
76.	15-10-2000	5.184	0.216	116.420	329.560	445.980	15.000
77.	16-10-2000	2.610	0.580	113.640	329.150	442.790	15.000
78.	17-10-2000	1.980	0.660	111.460	328.690	440.150	15.000
79.	18-10-2000	1.395	0.620	109.880	328.260	438.140	15.000
80.	19-10-2000	1.134	0.630	108.560	327.820	436.370	15.000
81.	20-10-2000	2.700	0.600	121.670	332.280	453.950	35.000

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Sl. No	Date	Soil evaporation E^* (mm)	Transpiration T (mm)	Soil moisture level at Layer-I, 0-30 cm SM_1 (mm)	Soil moisture level at Layer-II, 30-120 cm SM_2 (mm)	Total soil moisture level, SMT (mm)	Retention parameter S (mm)
82.	21-10-2000	5.760	0.640	115.720	331.830	447.550	15.000
83.	22-10-2000	1.890	0.420	113.700	331.540	445.240	15.000
84.	23-10-2000	1.319	0.644	112.190	331.090	443.280	15.000
85.	24-10-2000	1.161	0.756	110.800	330.560	441.360	15.000
86.	25-10-2000	0.894	0.728	109.690	330.050	439.740	15.000
87.	26-10-2000	0.717	0.700	108.760	329.560	438.320	15.000
88.	27-10-2000	0.762	0.868	107.740	328.950	436.690	15.000
89.	28-10-2000	0.624	0.812	106.870	328.380	435.260	15.000
90.	29-10-2000	0.506	0.742	106.140	327.860	434.010	15.000
91.	30-10-2000	0.454	1.064	105.370	327.120	432.490	15.000
92.	31-10-2000	0.421	0.988	104.650	326.430	431.080	15.000

parameters consisted of the following parameters read form left to right in annexure II and III.

- a. Row: Serial number for each day
- b. Date: The model reads the date with day first, followed by month and year, from 7th May 2000 to 1st March 2001.
- c. Rainfall: The output file also prints the rainfall received in mm, which was already entered on respective dates in the input file. It prints '0.00' on the days where there is no rainfall.
- d. Evap: It is the abbreviated form of evaporation expressed in 'mm' which is the total evaporation quantity that occurred on each day from the USDA class A open pan evaporimeter. The output file prints the open pan evaporation data, which was entered in the input file.
- e. Measured runoff: It reads the values of runoff measured in each event (Annexure II & III) during the period under consideration. On all the days other than days of rainfall events which resulted in runoff, the runoff values are mentioned as '0.00' in the input file and the same values are printed respectively in the output file also.

- f. Beeta (β): It is the beeta co-efficient (light interception co-efficient) derived to apportion the quantities *viz.*, soil evaporation (E^*) and transpiration (T) from the measured data of pan evaporation following the equations presented in section 3.6.4. The ' β ' values presented in this column are in accordance with the values entered in the input file. The ' β ' co-efficient is a qualitative entity and its values are calculated in the range of 1 to 0, with '1' corresponding to fallow condition without vegetation cover and '0' for soil completely covered by vegetation. It is a measure of the fraction of sunlight passing through the foliage and causing soil evaporation.
- g. T: It is a factor which divides the pan evaporation quantity so as to help calculate the soil evaporation (mm) of each day succeeding a rainy day till the next rainy day and assumes values from 1 to 10. The consideration of the 'T' values for each day (Annexure I & II) is in accordance with requirement of the soil moisture accounting procedure explained in the section 3.6.2.
- h. E^* (Soil evaporation): It is the quantity of soil moisture evaporated from the upper soil layer (0-30 cm) directly to

the atmosphere. In the output file, (Annexure II & III) including Table 4.4a and 4.4b, soil evaporation (E^*) is calculated using the relation explained in section 3.6.4.

- i. ET: It calculates the evapotranspiration that takes place on each day, apportioned from total pan evaporation depending upon the values of ' β ' co-efficient (Annexure II & III). The computer aided programme calculates ET using the relation explained in section 3.6.4 for the period under consideration
- j. DM: It is the abbreviation of rainfall excess or deficit which gives the portion of rainfall quantity that is received on a day and made available for the layer-I of the soil profile to raise its antecedent moisture level to field capacity and with or without a quantity that leaves the plot as runoff. The DM depends on the quantity of soil evaporation (E^*) and transpiration (T) (Annexure II & III).

$$DM = \text{Rainfall quantity} - (E^* + ET)$$

Where,

E^* = Soil evaporation (mm)

ET = transpiration (mm)

- k. SM_1 (Soil moisture level in layer-I) – The soil moisture accounting procedure has predicted the antecedent soil moisture in the upper layer (0-30 cm) on each day during the period under consideration. The available average moisture content in layer-I was measured between 124.94 mm (field capacity) and 67.66 mm (minimum moisture level for evaporation) and the same is presented in Annexure II and III.
- l. SM_2 (Soil moisture level in the layer II): The model calculates the moisture content in the second layer of the profile in accordance with the water balance equation as detailed in section 3.6.3. The maximum moisture was predicted to be on 20th October 2000 (386.05 mm) in case of plot I and 332.280 mm incase of plot II.
- m. SMT (Total soil moisture level of the profile): It is the sum of the total moisture stored in the entire profile *viz.*, layer I & II ($SM_1 + SM_2$) (Annexure II & III).
- n. S (Soil moisture retention): It is the maximum possible retention over a watershed under existing conditions of soil profile and its surface and is constant for each storm. The

model predicts the same and uses its values for calculation of the runoff through SCS model.

- o. PQ (Predicted runoff): The SCS curve number model with soil moisture accounting procedure calculates the runoff using the retention parameter (S) as detailed in section 3.6 and the same are presented in the Table 4.3 and Annexure II & III.

4.4 Measured sediment yield

The San Dimass flume has the facility for collecting the runoff samples at three different heights for assessment of the quantity of sediment leaving the plots. The runoff samples obtained from each storm event for plot-I and plot-II were analyzed and sediment yields were calculated in terms of tones per area and the same are converted in terms of tonnes per hectare (Table 4.5).

4.5 Predicted sediment yield

The sediment yield model *viz.*, Williams *et al.* (1975) which is a modification of USLE model, predicted the sediment yield in terms of t/ha from each runoff event and the same are given in Table 4.6.

4.6 Evaluation of runoff model

The efficacy of the model was evaluated by comparing the measured and predicted runoff volume expressed in terms of depth

Table 4.5. Storm wise measured Sediment yield

Sl No.	Storm event	Measured sediment yield (t/ha)	
		Plot-I	Plot-II
1	8-08-2000	0.520	0.080
2	9-08-2000	6.040	4.590
3	17-09-2000	5.630	2.950
4	21-09-2000	1.900	1.090
5	20-10-2000	0.310	0.160
Total		14.400	8.870

Table 4.6 Storm wise predicted sediment yield

Sl. No.	Storm event	Predicted sediment yield (t/ha)	
		Plot-I	Plot-II
1	8-08-2000	4.290	0.022
2	9-08-2000	74.367	8.491
3	17-09-2000	56.813	4.449
4	21-09-2000	12.638	1.053
5	20-10-2000	18.832	0.712

(mm) for each event. The regression of measured runoff value on predicted values were plotted and R^2 values were determined and the relative error between the measured and predicted values are presented in Table 4.7 and depicted in Fig. 4.3a, 4.3b, 4.4a and 4.4b.

4.6.1 Evaluation of soil moisture accounting procedure

The measured daily soil moisture values, for layer – I (0-30 cm) and layer II (30-120 cm) for plot-I and plot-II were compared with the predicted soil moisture values for layer-I and layer-II and the same are presented in Fig. 4.5a and 4.5b.

4.7 Evaluation of the sediment yield model

The efficacy of the sediment yield model Williams *et al.* (1975) was evaluated by comparing the measured sediment yield with the predicted sediment yield for each of the storm events for the plot – I and plot – II. The regression of the measured values of sediment yield was plotted against the predicted ones and the R^2 values were determined. The results are presented in table 4.8 and are also depicted in Fig. 4.6a, 4.6b, 4.7a & 4.7b.

Table 4.7. Storm wise comparison of measured and predicted runoff

Sl No	Storm event	Plot-I				Plot-II			
		Measured runoff (mm)	Predicted runoff (mm)	Per cent error	Co-efficient of regression (R^2)	Measured runoff (mm)	Predicted runoff (mm)	Per cent error	Co-efficient of regression (R^2)
1	8-8-2000	4.650	6.920	48.818	0.9851	0.617	0.00	100.00	0.9934
2	9-8-2000	40.180	45.420	13.042		39.700	43.570	9.749	
3	17-9-2000	31.596	37.340	18.180		30.750	35.410	15.155	
4	21-9-2000	11.160	8.180	26.703		10.278	8.180	20.413	
5	20-10-2000	2.622	2.270	13.425		1.677	2.270	35.361	

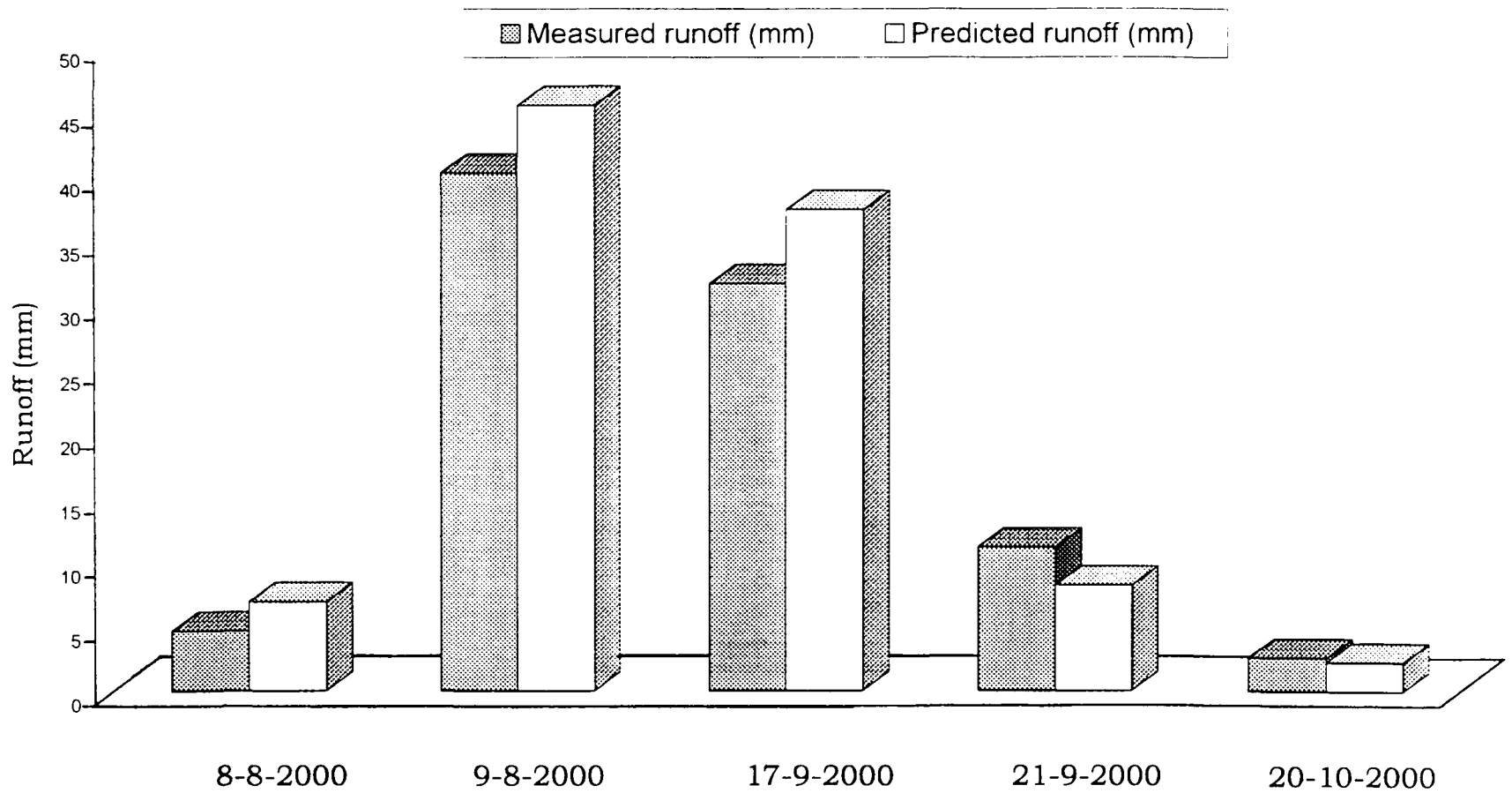


Fig. 4.3a. Comparison of storm wise measured and predicted runoff in Plot-I

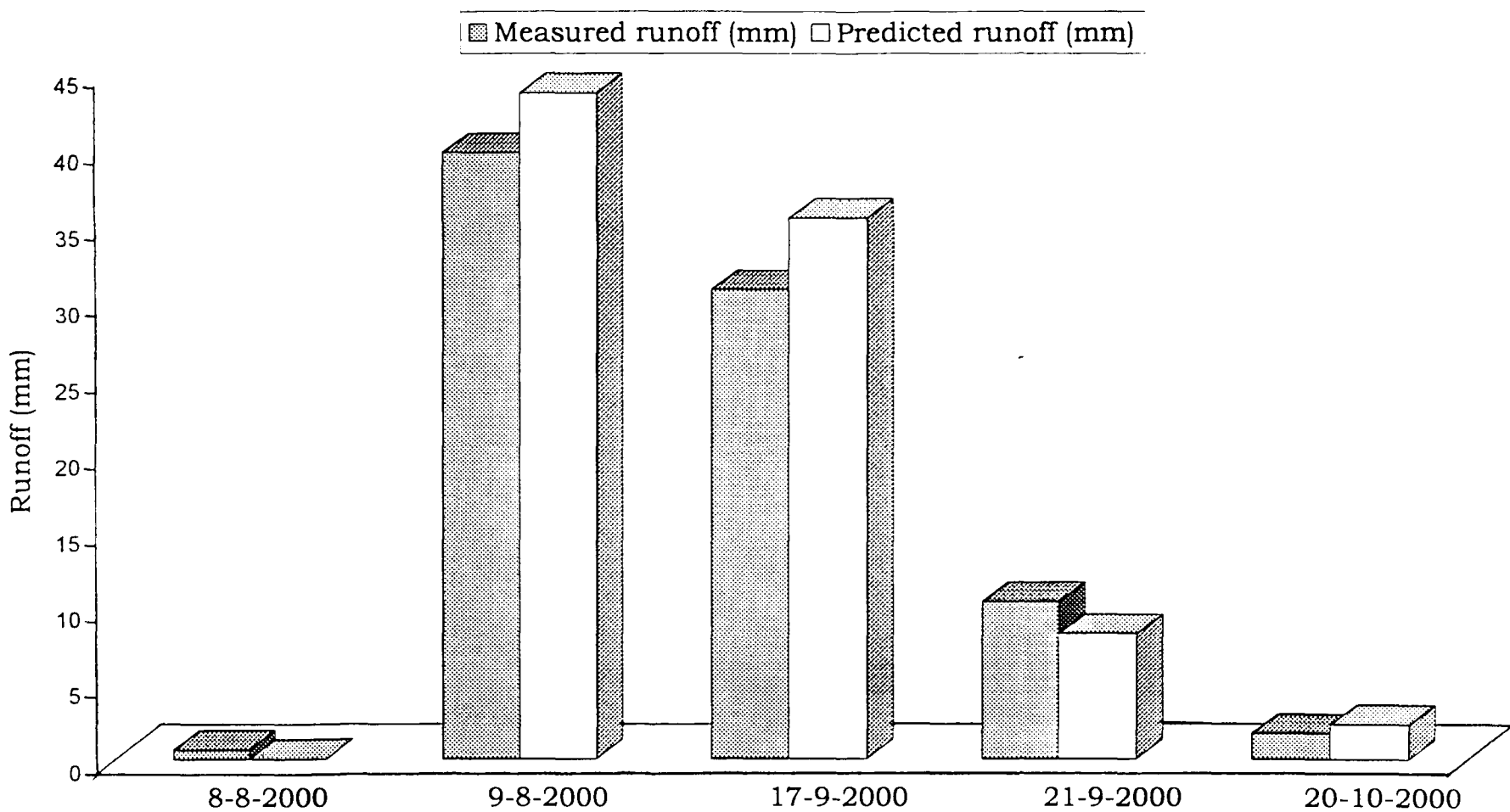


Fig. 4.3b. Comparison of storm wise measured and predicted runoff in Plot-II

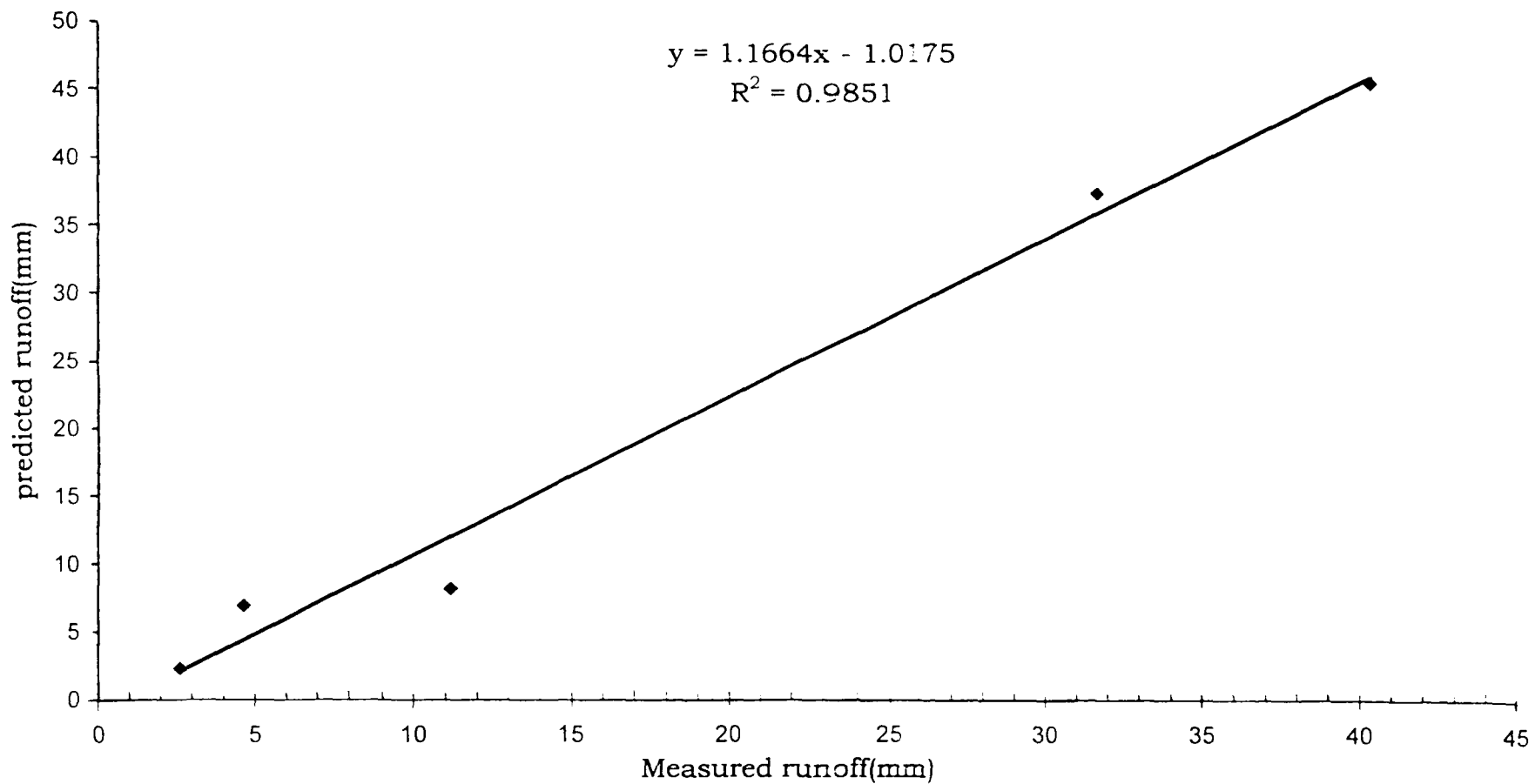


Fig. 4.4a. Comparison of measured and predicted storm wise runoff in plot-I

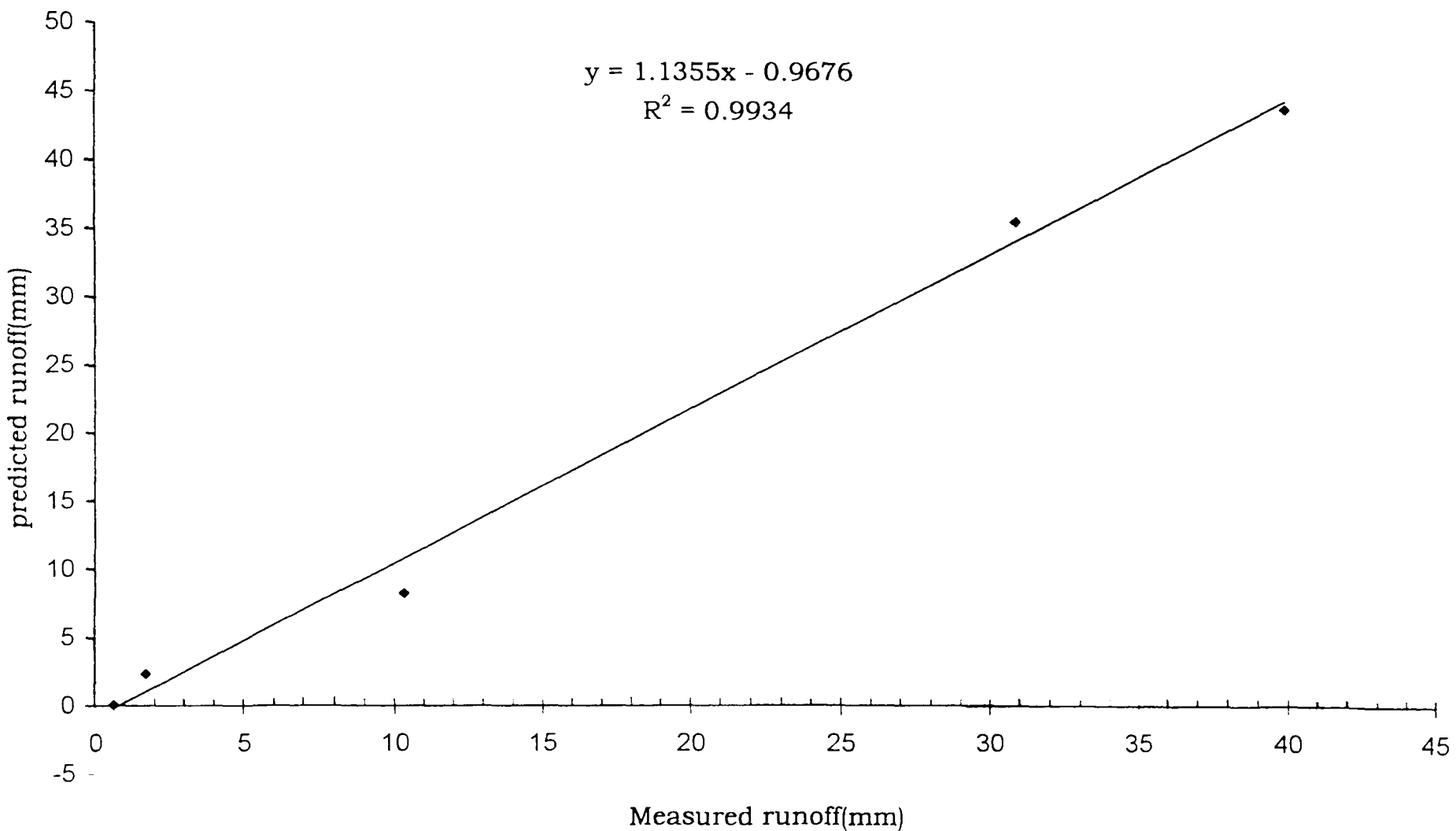


Fig. 4.4b. Comparision of measured and predicted storm wise runoff in plot-II

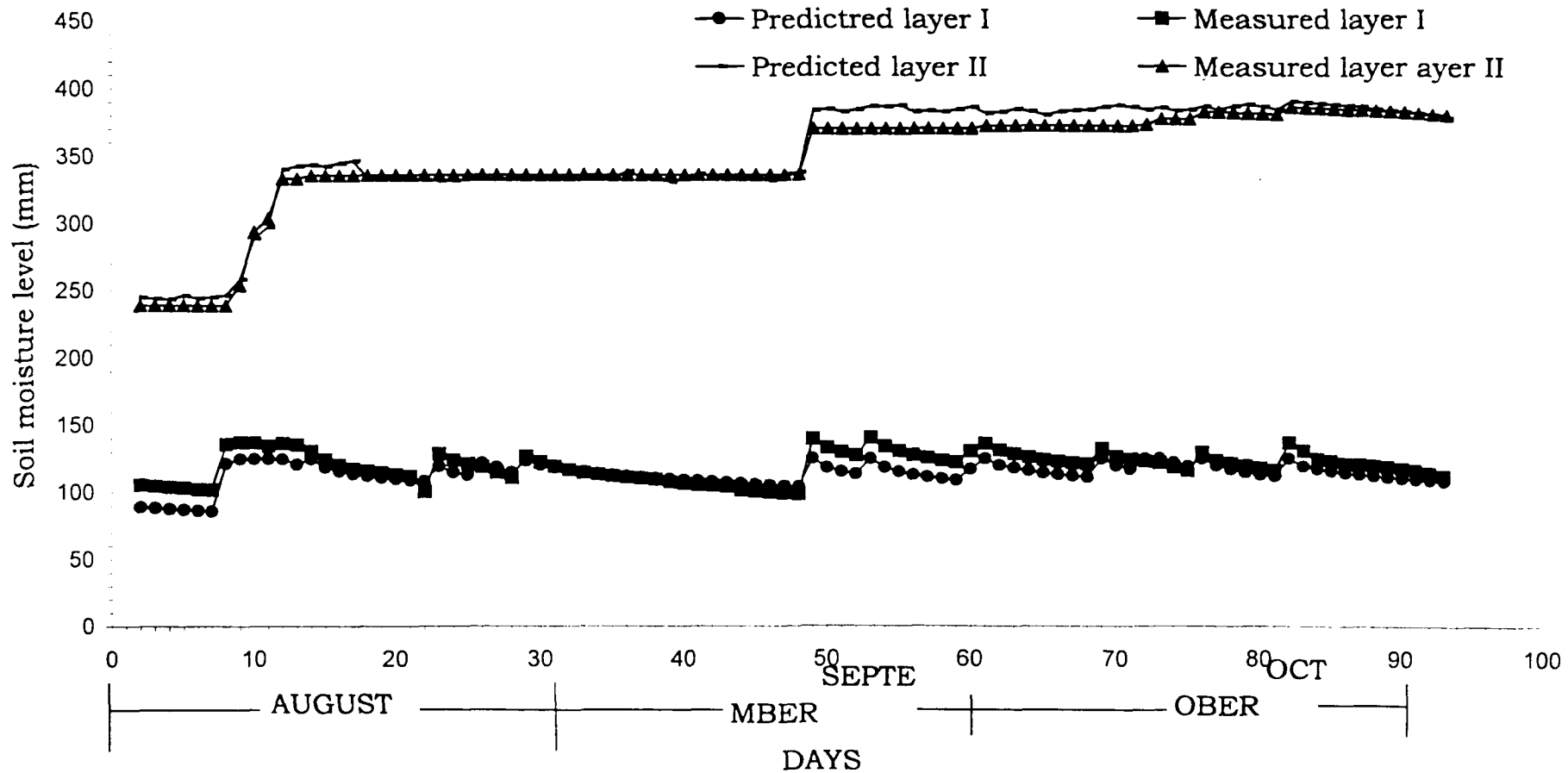


Fig.4.5a. Comparison of measured and predicted soil moisture level at layer I and layer II of plot I

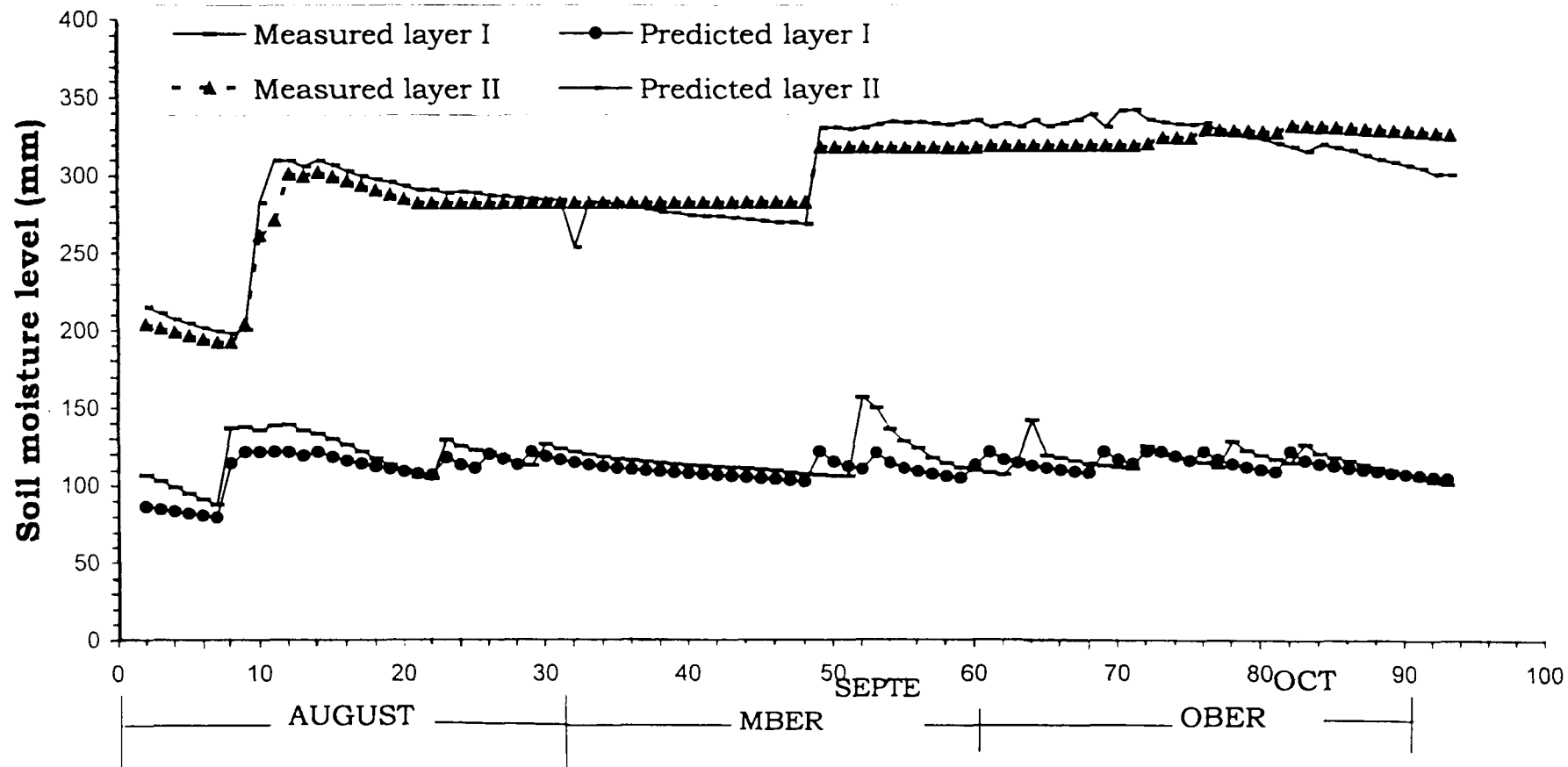


Fig. 4.5b. Comparison of measured and predicted soil moisture level at layer-I and layer-II of plot-II

Table 4.8. Storm wise comparison of measured and predicted sediment yield

Sl No	Storm event	Plot-I				Plot-II			
		Measured sediment yield (t/ha)	Predicted sediment yield (t/ha)	Per cent error	Co-efficient of regression (R ²)	Measured sediment yield (t/ha)	Predicted sediment yield (t/ha)	Per cent error	Co-efficient of regression (R ²)
1	8-8-2000	0.520	4.290	725.00	0.8997	0.080	0.020	75.000	0.9700
2	9-8-2000	6.040	74.367	1131.242		4.590	8.491	84.990	
3	17-9-2000	5.630	56.813	909.112		2.950	4.449	50.814	
4	21-9-2000	1.900	12.638	565.158		1.090	1.053	3.395	
5	20-10-2000	0.310	18.832	82.658		0.160	0.712	345.00	

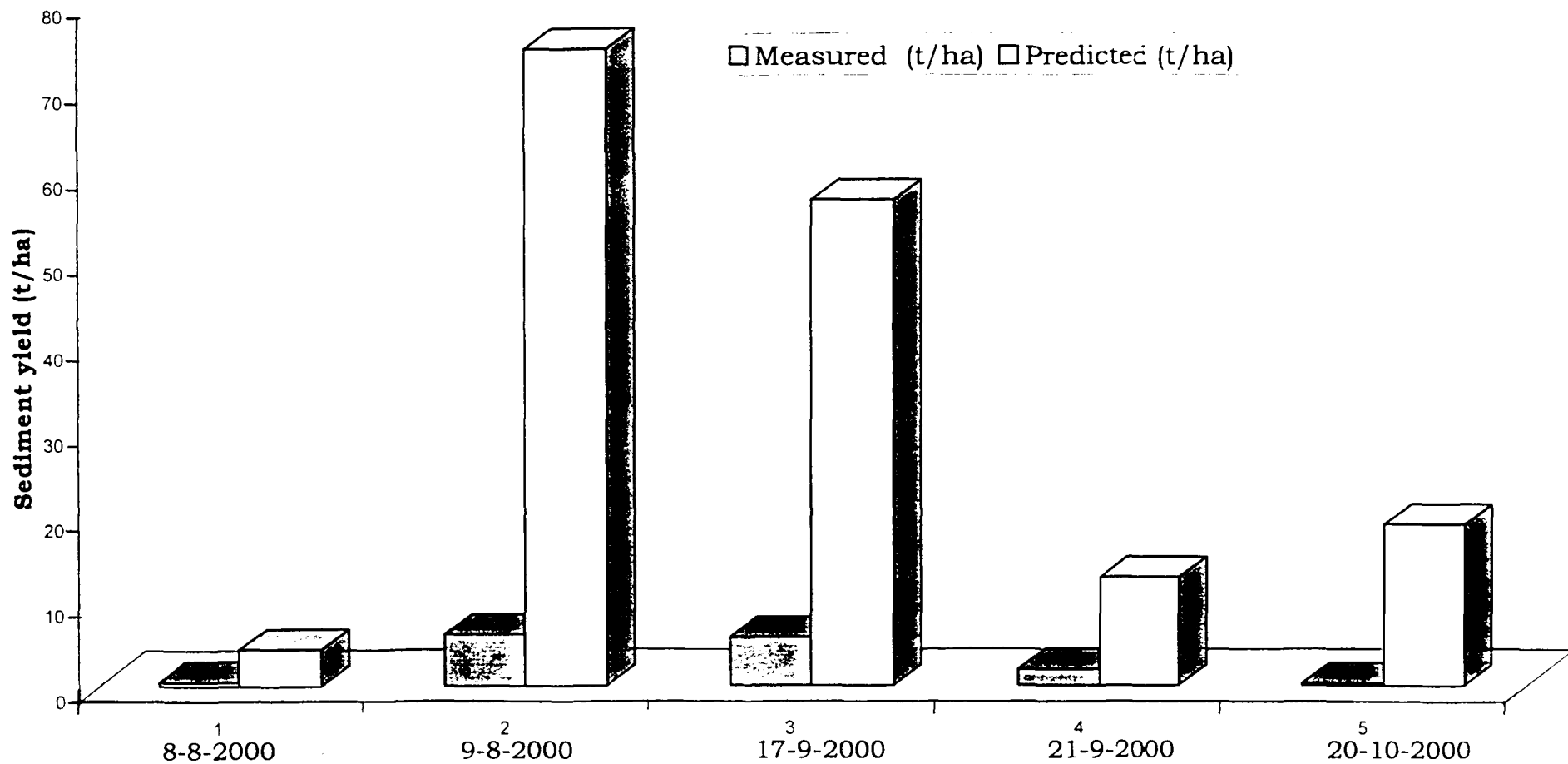


Fig. 4.6a. Comparison of storm wise measured and predicted sediment yield in Plot-I

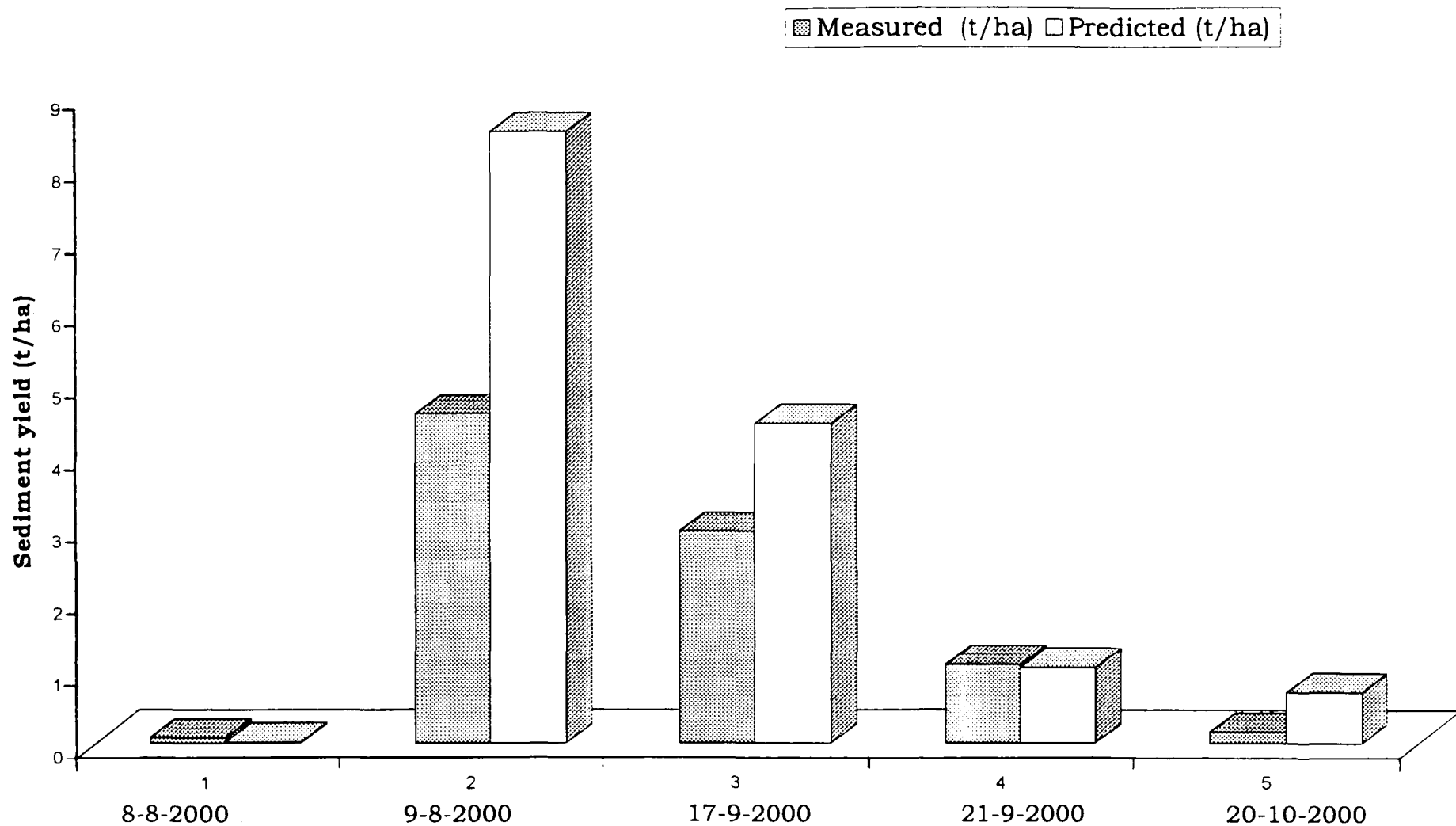


Fig. 4.6b. Comparision of storm wise measured and predicted sediment yield in Plot-II

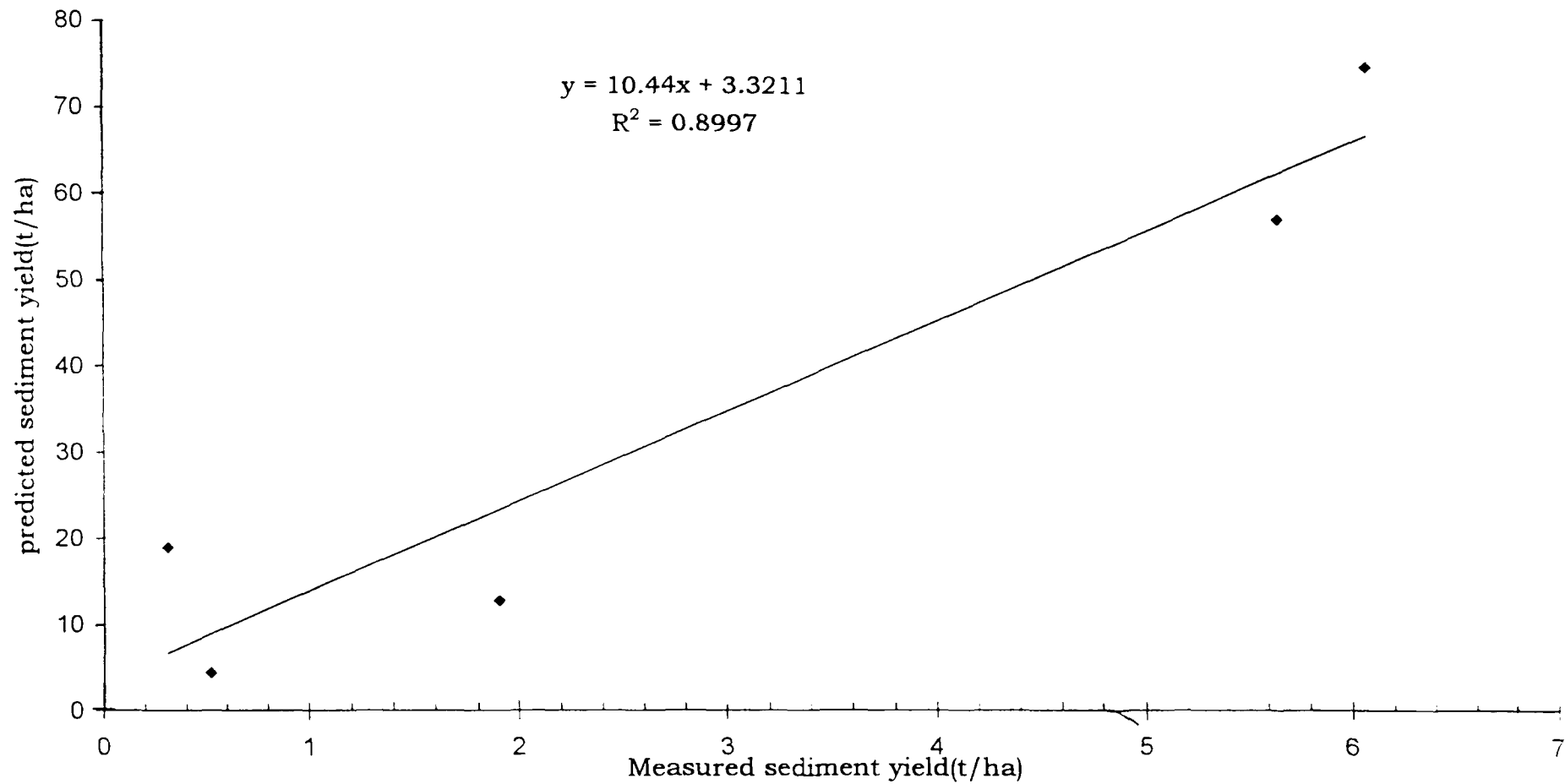


Fig. 4.7a. Comparison of measured and predicted storm wise sediment yield in plot-I

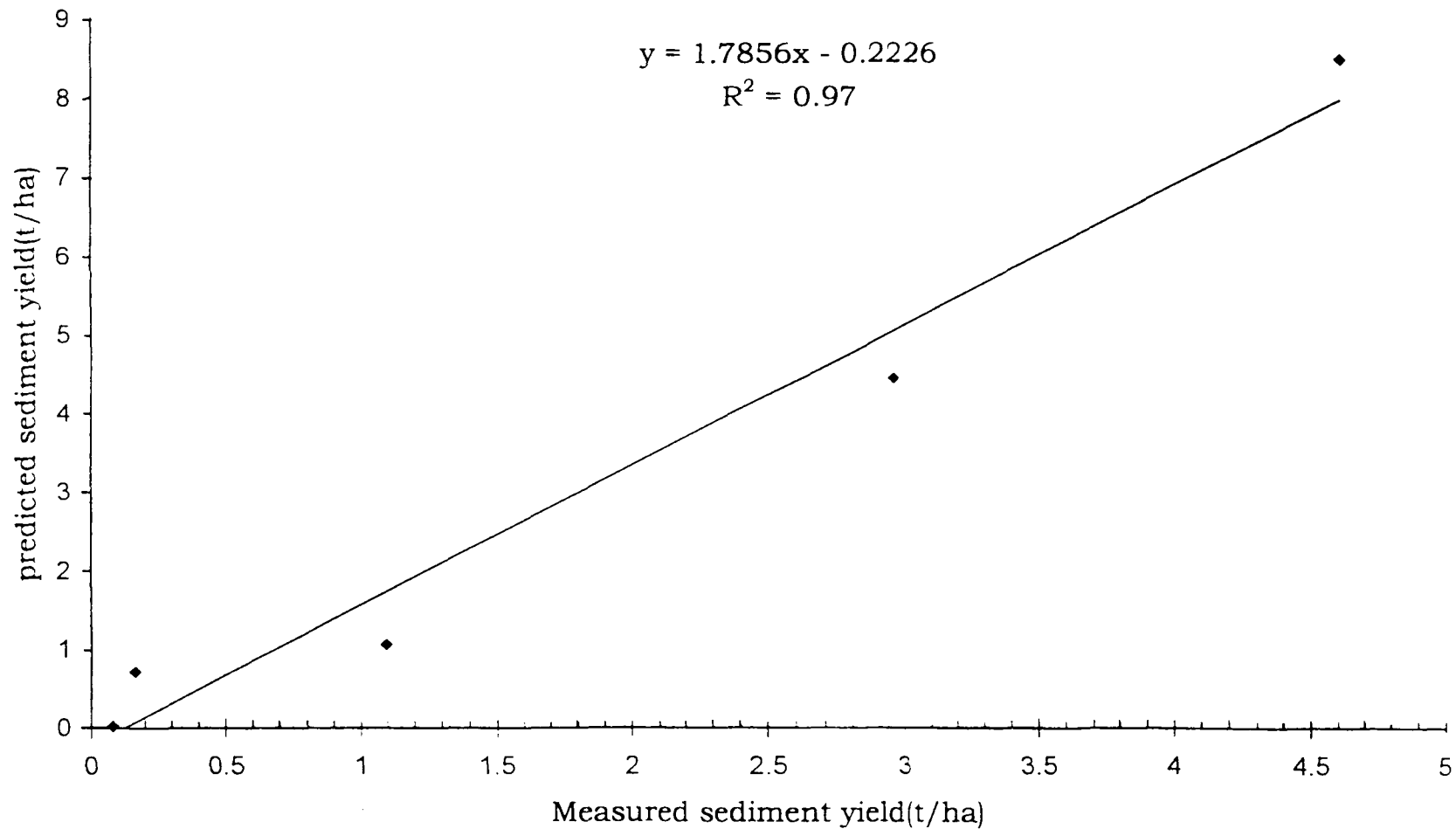


Fig. 4.7b. Comparison of measured and predicted storm wise sediment yield in plot-II

DISCUSSION

V DISCUSSION

In this chapter it is intended to interpret the nature of results that were obtained during the course of the investigation and efforts are made to explain the factors and situations which influence those results.

4.1 Agro-climatic conditions of micro-watershed

The selected field size areas in the Madabhavi micro watershed of Bijapur district which forms a part of the Northern Dry-zone of Karnataka. Here the rainfall distribution pattern is such that, out of five consecutive years of rainfall, there is at least two years of drought, two years of average rainfall (680 mm) and one year of more than average rainfall. This indicates the inconsistency in annual rainfall and its distribution from year to year, which in turn suggests a strong need for implementation of soil and water conservation practices to store available moisture efficiently. The Madabhavi micro watershed (127.09 ha) which has 30 per cent area, each under shallow black and medium deep black soils and another 25 per cent area under deep soils and hence most of the watershed area has a high moisture holding and retention capacity. The deep black soil is capable of holding 20 cm of water per meter depth of soil. They also provide increased crop growth period with increase in soil depth to a maximum extent of 90-120 days. The soils of the watershed, which

belong to Managoli, Jambagi, Sasalatti and Rajapur series, possess a clay content upto 60 per cent. The general land slope is 1 to 3 per cent. The soils have a very low infiltration rate of 0.2 – 0.8 cm/hr and a moderate to poor drainage capacity, causing surface water ponding problems during heavy storm events.

The erratic rainfall coupled with insufficient vegetative protection during wet spells causes sheet erosion in a large area and is a major soil conservation problem in the area. Farmers grow bajra in about 33 per cent of the area, groundnut in 25 per cent, sunflower in 17 per cent and green gram in 17 per cent area during *kharif* season. During the *rabi* season, sorghum is the major crop which takes advantage of the high available moisture reserves in the black soils during the post monsoon period.

The information about the agro-climatic conditions of Madabhavi micro watershed indicates that the watershed has a good scope to grow crops in two seasons provided the farmer is able to capitalize on the high intensity, low duration showers and conserve the moisture in the soil without letting it being subjected to sheet erosion which is more prevalent in clay soils under the above condition. The spatial and temporal variability of rainfall and the soil properties indicate a good scope for intensive research to draw specific information about the rainfall-runoff relationship, which inturn, will be

very useful in preparing appropriate plans for soil and water conservation structures, practices and crop production on a watershed basis.

4.2 Experimentation in field size areas (plots)

If individual field size areas (1-2 ha), are treated as a separate hydrological units by rearranging the field boundaries, it will be possible to evaluate the hydrological response at field level and help to plan the soil conservation practices and the crop production systems.

The runoff and sediment yield measured at the out let of a hydrological unit has two parameters which can be used to evaluate the extent of soil degradation that has taken place over a time period. In a hydrological cycle, runoff is a phase whose flow volume and rate constitute a direct consequence of the rainfall, and geomorphologic characteristics of a catchment.

Similarly, the quantity of sediment carried in the runoff helps to quantify the prevailing rate of soil loss and to evaluate the soil loss tolerance limits of the watershed. The information on rate and quantity of runoff and soil loss is vital in optimizing the crop yield.

Keeping the above factors in mind Australian Centre for International Agricultural Research (ACIAR), Dry-land Agriculture, with

the financial aid from the Australian Government has identified and setup field size plots in a representative area of the watershed to measure the runoff and soil loss. The observations were made during the year 2000-01. The two plots are of 0.85 hectare and 0.90 hectare size and their governing slopes are 0.90 per cent and 0.74 per cent respectively. The whole area was prepared as a single terrace plot with a single outlet. The plot – I was maintained as a fallow during the *kharif* season, fallowed by *rabi* sorghum, whereas, plot – II was grown with *kharif* green gram, followed by *rabi* sorghum and the variability of runoff between these two plots was compared.

4.3 Measured runoff

There were five runoff producing rainfall events in the rainy season of 2000-01. Of these, two were in August, two in September and one in October. According to the recorded data, there were early showers in May (55.30 mm), June (26.90 mm), July (38.75 mm) and on the day previous to the occurrence of the first runoff i.e., on 7-8-2000 which did not produce any runoff. The total moisture received upto that point of time was just sufficient to raise the soil moisture and to meet the evaporation demand. Most of the rainfall was observed in the soil upto this point of time because, the plots were ploughed and the surface was left under cloudy condition. The

prevailing deep cracks have also contributed to moisture absorption by the soil.

There were five runoff hydrographs recorded from the experimental setup which helped to calculate the total runoff volume and peak discharge. From the Table 4.1a, it is observed in plot-I that on 8th August 2000, there was 4.651 mm of runoff as a result of 20.83 mm of rainfall, due to the saturated condition of the soil as a result of the rain that had occurred earlier. On 9th of August as result of a heavy down pour of 70.00 mm, 40.180 mm of runoff with a peak discharge of 113.685 lit/sec was recorded from plot – I. The amount of rainfall received on the next two successive days i.e., 10th of August (11.0 mm) and 11th of August (30.60 mm) as shown in Table 3.7, has yielded no runoff, which may probably be the effect of low rainfall intensity and all the rainfall was accounted for by soil absorption and evaporation. The rainfall that occurred after a dry spell of 10 days, on 22nd August (14.50 mm) followed by one on 25th August (10.50 mm) and 28th August (10.28 mm) did not result in any runoff, as all the rainfall was accounted for evaporation and soil moisture build up. On 17th September, a rainfall of 72.00 mm resulted in 31.596 mm of runoff, with a peak discharge of 107.73 liters/sec. Subsequently, on 21st September there was 25 mm of rainfall which resulted in 11.160 mm runoff, with a peak discharge of 48.418 liters/sec. There was a critical dry spell of 28 days till 20th of October on which only 2.622 mm

of runoff occurred, as a result of 23.52 mm rainfall, with a low peak discharge of 6.6 lit/sec. Subsequently, there was a rainfall of 11.0 mm and 15.40 mm on 28th and 29th of September respectively (Table 3.7), 17.00 mm rainfall on 7th October, 10.30 mm rainfall on 10th October, 5.3 mm of rainfall on 11th October and 13.72 mm of rainfall on 14th October 2000, none of which resulted in a runoff, with all these rainfall amounts accounting for soil absorption and evaporation/evapotranspiration. In the plot – II, during the *kharif* season, greengram crop was sown on 12th June and its transpiration demand increased with increase in its foliage. This factor is indicated by the β coefficient whose value decreased from 0.94 on 20th June to 0.36 on 20th August (table 3.7). The β coefficient is a measure of the amount of light intercepted by the canopy whose value tends to decrease with increased interception of light .

The greengram crop which was harvested on 19th of August was incorporated into soil and rabi sorghum crop was sown on 1st October. The table 4.1b depicts the runoff that occurred in this plot (Plot – II) during the corresponding rainfall events already described earlier. The rainfall events on 8th and 9th August 2000 resulted in runoff values of 0.617 mm and 39.70 mm, as compared to 4.651 mm and 40.180 mm in case of plot – I (fallow plot). For the storm events which lead to runoff subsequent to the harvest and incorporation of

kharif green gram plants in to the soil, one could not observe much difference in runoff on 17th September (30.75 mm) and on 21st September (10.27 mm) as compared to the corresponding values in the bare plot (Plot – I) which gave runoff values of 31.596 mm and 11.160 mm respectively. On 20th of October, i.e., 20 days after sowing of *rabi* sorghum, 23.52 mm rainfall resulted in a runoff of 1.677 mm as compared to 2.622 mm in case of bare plot (Plot – I).

4.4 Measured soil moisture

The Table 4.2 depicts the average soil moisture levels in both the layer – I and layer – II in Plot – I and Plot – II respectively from 1st August to 31st October 2000. The average field capacity values for layer – I and layer – II, in plot – I were observed to be 124.79 mm and 420.40 mm respectively (Table 3.9). The corresponding soil moisture content values were 34.38 per cent and 37.67 per cent respectively. The two layers together, were found to attain the profile saturation at 708.00 mm or 47.58 per cent of moisture content (Table 3.12). In case of plot – II, the values of the average field capacity for layer – I and layer – II were observed to be 121.67 mm and 401.32 mm, the corresponding soil moisture content being 33.52 per cent and 35.96 per cent. The two layers together were found to attain profile saturation at 716.02 mm of moisture or 48.12 per cent of moisture content.

4.5 Predicted runoff

The prediction of runoff is essential because actual measurement of runoff is not practically feasible in case of each and every watershed due to difficulties in logistics. The runoff at the outlet of field size areas or small watersheds can be better predicted by SCS curve number method (SCS, USDA, 1972) as compared to other complex methods like CREAMS and EPIC. However, SCS curve number model in its original form cannot predict the runoff with sufficient degree of accuracy.

The curve number (CN) parameter of SCS model varies between 0 to 100 and is a function of the dominant soil type in the watershed, infiltration behaviour of the soil, vegetative cover, antecedent moisture content and land use. The guide lines for determination of CN are documented in SCS, USDA, 1972 which also presents the criteria for discrete partitioning of soil moisture between wet condition with high runoff potential (AMC-III), average condition with medium potential (AMC-II) and dry conditions with low runoff potential (AMC-I). The partitioning suggests that rainfall-runoff relationship is a discrete one, meaning that the antecedent moisture conditions cannot be confined to only AMC-I, II and III alone and needs suitable modifications. In reality, CN varies continuously with the change in soil moisture and it will have continuous values instead of

three values only. Thus the model developed by Pathak *et al.*, (1989) considered that the accuracy of runoff simulation can be improved considerably by using a soil moisture accounting procedure (SMAP) to estimate the retention parameters 'S' in the SCS model.

The SMAP considers partitioning of pan evaporation in to soil evaporation and transpiration characteristics through β coefficient, which varies from '0' for maximum coverage of foliage to '1' for fallow conditions. The Pathak *et al.* (1989) model has been developed by accounting for changes in soil surface conditions namely correction for small cracks and land smoothness also.

When the measured and predicted runoff values (mm) for the plots under study were compared, it was observed that this model predicted the measured runoff with a low relative error of 13.042 per cent in case of the rainfall event on 9-8-2000 and with the maximum error of 48.18 per cent on 8-8-2000 in case of plot – I. The regression of measured values on predicted values have shown a good agreement between them (R^2 value of 0.981). Similarly, in case of greengram plot (Plot – II), the model predicted the runoff with a low relative error of 9.749 per cent on 9-8-2000. The relative error was maximum (100.00 %) in case of the runoff event on 8-8-2000.

The R^2 value of 0.9851 and 0.9934 for both of plots respectively shows that the measured and predicted values are in good

agreement for most of the runoff events in both the plots. However, as the findings are based on the data available from only one year and continued collection of data is called for, in order to confirm these results. Further, the Evaluation of runoff prediction also depends upon the input parameters *viz.*, SM_1 , SM_2 , M_1 , M_2 , M_3 , M_4 and SM_{max} recorded on the day before the rainfall event. At this juncture, it needs to be reiterated that a set of data of at least three years are needed for a better estimation.

4.6 Predicted soil moisture

Since the last shower of the season was received on 20th October 2000, it was last contribution to soil moisture. The accumulated moisture at this stage acted as soil moisture reserve in the crop root zone for subsequent crop growth. Therefore the soil moisture reserve including that contributed by the last shower on 20th October 2000 was treated as a bench mark and the actual profile soil moisture values in both the layers and plots were determined and compared with predicted values of soil moisture on 20th October 2000.

Incase of the bare plot, the model predicts the soil moisture values in all the runoff events to the limit of field capacity and any moisture in excess of field capacity, it transfers to the second layer. In reality the actual recorded moisture content was above the

field capacity of the soil. This is because the model considers the transfer of moisture from layer – I to layer – II, when the top layer reaches the field capacity. The lower layer was found to have reached the maximum moisture content of 386.05 mm (34.6%) on 20th October 2000 as compared to 390.299 mm, which was the actual measured moisture content in the field. On 20th of October, the predicted moisture levels in the upper and lower layers were 124.80 mm and 386.05 mm respectively with a total of 510.85 mm, as compared to actual measured profile soil moisture of 526.80 mm.

In case of greengram plot (plot – II), in all the runoff events, the layer – I was predicted to reach the field capacity (121.67 mm), whereas, the moisture was observed at higher levels, to a maximum of 156.81 mm in actual field conditions on 20th of September 2000. The second layer was predicted to attain the maximum moisture content of 332.28 mm on 20th October whereas, maximum measured moisture content of layer – II was reached on 9th October (324.21 mm) itself. On 20th October, after receiving the last shower of the season, the moisture levels in the upper and lower layers were predicted to reach 121.67 mm and 332.28 mm respectively and both of them together were predicted to account for 453.95 mm of moisture which was 21.03 mm more than the measured value of 432.92 mm.

4.7 Measured sediment yield

The soil loss that occurred in each of the runoff event was measured in t/ha (Table 4.6). In case of plot – I, the sediment yield was as low as 0.520 t/ha on 8th August 2000 and it increased to the maximum value of 6.040 t/ha on 9th August 2000 due to increased runoff (40.180 mm). Further, under fallow condition of the soil surface, the sediment yield decreased to 5.63 t/ha due to the runoff of 31.596 mm on 17th September 2000, followed by 1.900 t/ha from a runoff of 11.160 mm on 21st September 2000. Similarly, incase of greengram plot (Plot – II), the lowest measured sediment yield was 0.080 t/ha resulting from a runoff of 0.617 mm on 8th August 2000 which increased to 4.59 t/ha with corresponding runoff of 39.700 mm on 9th August 2000. During the subsequent runoff events on 17th and 21st September, the measured sediment yield was 2.950 t/ha and 1.090 t/ha respectively which resulted from the runoff values of 30.750 mm and 10.277 mm respectively. On 20th October 2000 as a result of 1.677 mm of runoff that occurred, only 0.16 t/ha of sediment yield was collected.

4.8 Predicted sediment yield

The amount of soil erosion cannot be measured for each and every watershed over extended periods of time, which needs to be arrived at an average values to help in planning for soil conservation

works. Therefore, soil erosion models are used to extrapolate and interpolate the data from already gauged watersheds to the sites where direct measurement of runoff and sediment yield is not possible. The USLE (Wishmeier and Smith, 1965) estimates an average annual soil erosion by using rainfall erosivity (R), soil erodibility (K), topography (LS), crop management factor (C) and the support practice factor (P).

Williams (1975), modified the USLE by replacing the rainfall erosivity factor by runoff volume (RO) in cubic metre and peak discharge (Qp) in cubic metre per sec. With this modification, the model can also be used for predict the watershed response in terms of sediment yield to individual runoff event.

On comparison of the predicted values of sediment yield, with the measured values form Plot-I, it was seen that in bare plot (Plot-I), the highest relative error in prediction has occurred in case of the runoff event on 9th August 2000, wherein the measured sediment yield, predicted sediment yield and relative error were 6.04 t/ha, 74.367 t/ha and 1131.242 per cent respectively. The minimum error of prediction occurred on 20th October 2000 wherein the measured sediment yield, predicted sediment yield and the relative error were 0.310 t/ha, 18.832 t/ha and 82.658 per cent respectively ($R^2 = 0.8997$).

In plot – II, it was seen that the highest relative error in prediction occurred in case of the runoff event on 9th August 2000,

wherein the measured sediment yield, the predicted sediment yield and the relative error were 4.590 t/ha, 8.491 t/ha and 84.990 per cent. The minimum error of prediction occurred on 21st September 2000, wherein the measured sediment yield, the predicted sediment yield and the relative error were 1.090 t/ha, 1.053 t/ha and 3.395 per cent ($R^2 = 0.97$).

4.9 Need for continuation of project

From the findings of study, it is seen that for the agro-climatic conditions of Madabhavi watershed, the Pathak *et al*, (1989) model for runoff prediction and the modified USLE by Williams *et al*, (1975) are apparently not able to predict the runoff and soil loss respectively with sufficient accuracy and need suitable modification. However, since the observations are based on only one years data, it would be worthwhile to carry out long term experiments on the above aspects, which will help to predict the required information at a higher confidence levels.

SUMMARY

VI SUMMARY

In the Northern Dry zone of Karnataka, there is a severe problem of fast depletion of soil productivity on account of spatially and temporally ill distributed rainfall and high rainfall intensities. The water balance technique which accounts for all the components of the hydrological cycle, provides a platform to assess the dynamics of soil moisture distributed over space and time in a hydrological unit. The runoff is a key process among other components of the hydrological cycle and helps in evaluation of the responses of a catchment to rainfall events. The data on runoff volume, its peak discharge and the sediment yield that results from the watershed is required for the purposes of hydrologic and hydraulic design of soil and water conservation structures and for studying the effectiveness of land treatments and planning of water harvest and its recycling. The runoff and soil erosion predictive models, which are capable of utilizing the available rainfall – runoff and sediment yield records to simulate runoff and soil erosion rate, over each storm will be of great help in extending the measured results to ungauged watersheds, where a few runoff and sediment yield records are available.

Keeping the above points in mind, two field size areas (plots) were equipped with runoff- sediment measuring devices at their outlets in Madabhavi micro watershed of Bijapur District. The two

plots of 0.85 and 0.90 ha size had clay soils, (soil erodibility factor $K=0.46$) and they were reshaped to form two broad based terraces with individual single outlets on a slope of 0.90 and 0.74 per cent for plot – I and plot – II respectively. The plot – I was left fallow in Kharif season whereas in the other plot (Plot – II), greengram was grown, fallowed by *rabi* sorghum in both the plots after incorporation of greengram plant residue in plot – II.

The data on rainfall – runoff recorded during the year 2000-2001 revealed that there were five runoff events spread over the months of August, September and October, with critical dry spells between them. During the course of the investigation, it was found that 90.209 mm of runoff was generated for the season from the bare plot (Plot – I) and 83.201 mm from the greengram plot (Plot – II). Out of the total annual rainfall of amount of 553.66 mm received, 211.350 mm was the total quantity of the five runoff producing rainfall events.

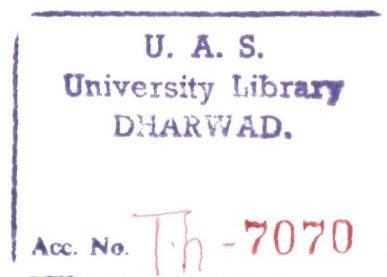
The soil moisture accounting procedure described by Pathak *et al.* (1989) is a water balance technique which was used to evaluate the retention parameter 'S' of the SCS curve number model on a daily basis. The model predicted the measured values of runoff with R^2 values of 0.9851 in case of bare plot (Plot – I) and 0.9934 in case of green gram plot (Plot – II). The model also predicted the daily moisture levels with a reasonable degree of accuracy as compared with the

measured values of moisture contents. On 20th October 2000, Which was the last rainy day of the year, it was noted that in case of bare plot, the predicted total soil profile moisture content was 510.85 mm as against the measured value of 526.8 mm. Similarly, in case of green gram plot (Plot – II), the predicted total soil profile moisture content was 453.95 mm as against the measured value of 432.92 mm.

During the course of investigation, it was found that a total of 12.24 t/ha (14.400 tonnes) of soil was eroded from plot-I which was fallow in *kharif* and sown with sorghum during the *rabi* season. Similarly, the soil erosion quantity was 7.98 tonnes (8.87 t/ha) in case of plot – II with greengram in *kharif* followed by sorghum during *rabi* season. The modified USLE sediment yield model Williams *et al.* (1975) predicted the soil loss with R^2 values of 0.8997 in case of greengram plot and 0.97 in case of bare plot. It was found that the prediction was not satisfactory for prediction of soil loss under the prevailing agro-climatic conditions of the watershed and needs further, investigation for the purpose of modifying the relevant empirical constant and exponent of the Williams models by generating the requisite data over a period of at least 5 to 6 years.

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Released on -- -- --
20 SEP 2003



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APPENDIX

APPENDIX I.

Sample calculation of prediction of sediment yield using Williams model.

Plot-I , Event: 8-8-2000

Williams equation

$$E = 11.80 \{ (RO) Q_p^{0.56} \} KLSCP$$

$$RO = \text{total runoff volume} = 39.432 \text{ m}^3$$

$$QP = \text{peak runoff rate} = 0.033 \text{ m}^3/\text{sec}$$

$$K = \text{soil erodibility factor} = 0.45$$

$$LS = \text{topographic factor} = 0.2$$

$$C = \text{crop management factor} = 0.98$$

$$P = \text{support practice factor} = 0.6$$

$$\begin{aligned} E &= 11.80 \{ (39.44) 0.033^{0.56} \} 0.45 \times 0.2 \times 0.98 \times 0.6 \\ &= 4.29 \text{ t/ha} \end{aligned}$$

ANNEXURE

ANNEXURE - I

COMPUTER PROGRAMME OF RUNOFF MODEL

```
1000 CLS
1050 L$= "#### #### ###.## ###.## ##.### ##.## ## ###.###
1060 REM SWB FOR SOIL OF TWO LAYERS
1061 REM DIM Z(1000,10)
1062 DIM DTE(366),RAIN(366),PAN(366),RO(366),BEETA(366)
1065 DATA 12,27,52,77,102
1066 LOCATE 13,14:INPUT "ENTER THE DATA FILE NAME "; FILE$
1067 LOCATE 13,14:PRINT "
1070 OPEN FILE$ FOR INPUT AS #1
1075 WHILE NOT EOF(1)
1080 'LOCATE 13,14: PRINT USING "READING THE DATA ### ";K
1085 LINE INPUT #1,DAT$
1095 K= K+1
1096 DTE(K) = VAL(MID$(DAT$,1,4))
1097 RAIN(K) = VAL(MID$(DAT$,5,7))
1100 PAN(K) = VAL(MID$(DAT$,12,6))
1105 RO(K) = VAL(MID$(DAT$,18,7))
1106 BEETA(K) = VAL(MID$(DAT$,26,6))
1116 WEND
1118 CLOSE #1 :CLS
1120 'OPEN "BETA.TXT" FOR INPUT AS #2
1122 'K = 0
1123 'WHILE NOT EOF (2)
1124 'K = K+1
1125 'INPUT #2, DAT,BEETA(K)
1126 'WEND
1128 'CLOSE #2
1130 'OPEN "ICRIPE.PEN" FOR INPUT AS #3
1132 'K = 0
1134 'WHILE NOT EOF (3)
1135 'K = K+1
1136 'INPUT #3, DUM,PAN(K)
1137 'WEND
1138 'CLOSE #3
1140 'INPUT "ENTER THE NUMBER OF RECORDS IN YOUR DATA FILE "; NR
1150 INPUT "ENTER A NAME FOR OUTPUT FILE";M$
1160 OPEN M$ FOR OUTPUT AS #4
1170 'INPUT "ENTER THE STARTING AND ENDING DATES SEPERATED BY COMMAS";N1,N2
1180 INPUT "ENTER THE STARTING SM1,SM2";S1,S2
1190 INPUT "ENTER THE DEPTH VALUE";D1
1200 INPUT "ENTER THE VALUES OF M1,M2,M3,M4,M5";M1,M2,M3,M4,M5
1210 INPUT "ENTER THE VALUES OF X3";X3
1220 'PRINT #2," ***** LAND AND WATER MANAGEMENT SOIL WATER BALANCE
FOR SOIL OF TWO LAYERS *****"
1230 'PRINT #2," STARTING SM1,SM2=";S1,S2;" DEPTH VALUE IS=";D1:PRINT #2, " "
1240 'PRINT #2," M1,M2,M3,M4,M5,X3 VALUES ARE =
";M1,M2,M3,M4,M5,X3:PRINT #2," " : PRINT #2,STRING$(132,42)
1250 PRINT #4," ROW DATE RAIN EVAP RUNOFF BEETA T E*
ET DM SM1 SM2 SMT S PQ"
```

```

1390 D2=D1 -30
1395 M2=D2*M2
1396 M5=D2*M5
1400 G1=0: G8=0
1410 J=1
1420 R1=0:R2=0:C=0
1430 E5=0
1440 T=0:U=6:D2(0)=1.5:O=2
1450 FOR L=1 TO K
1460 'NCO= NCO+1
1470 T6=RAIN(L)
1480 IF T6>0 THEN 1500
1490 NEXT L
1500 A1=0
1510 A2=0
1520 FOR I = 1 TO K
1530 T6=RAIN(I):T7=PAN(I)
1540 'NCO= NCO+1
1550 D=T6 - T7
1560 IF I=L THEN 1670
1570 IF T6=0 THEN A1=0 : GOTO 1590
1580 GOTO 1610
1590 IF A2=1 THEN A2=0 : GOTO 1640
1600 T=T+1 : GOTO 1640
1610 IF D>0 THEN A2=1 : GOTO 1670
1620 IF A1=1 THEN T=1:E2=T7/T : GOTO 1700
1630 E2=T7/T : GOTO 1700
1640 IF T>10 THEN T=10
1650 IF T=0 THEN T=1 : E2=T7/T : GOTO 1700
1660 E2=T7/T : GOTO 1700
1670 IF A1=0 THEN T=0:E2=T7/O:A1=1 : GOTO 1700
1680 T=1 : E2=T7/T
1690 S7=S6
1700 GOSUB 1740
1710 J=J+1
1715 NEXT I
1720 GOTO 2740
1740 T8=RO(I)
1750 S=S1+S2
1770 B=BEETA(I):E3=(1- B)*T7
1780 E2=E2*B
1790 D5=T6-T8-E2-E3
1800 S5=D2*X3+144:P2=1.2*(S5 -(M1+M2))
1810 P3=P2+4
1820 IF D5<=0 THEN 1890
1830 S1=S1+D5
1840 IF S1>M1 THEN S5=S1-M1:S1=M1:GOTO 1860
1850 S5=0
1860 S2=S2+S5
1870 IF S2>M2 THEN S2=M2
1880 GOTO 1980
1890 IF S1<M4 THEN S1=S1 -E2 : GOTO 1930
1900 S1=S1 -.3*E3
1910 IF S1<M4 THEN S1=M4

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1920 S1=S1 -E2
1930 IF S1<M3 THEN S1=M3
1940 IF S2<M5 THEN S2=M5 : GOTO 1970
1950 S2=S2 -.7*E3
1960 IF S2<M5 THEN S2=M5
1970 IF S2>M2 THEN S2=M2
1980 S5=D2*X3+144
1990 S6=(S5-S)*1.2
2000 G2=0
2010 J9=0
2020 G8=0
2030 R=R1+R2
2040 IF T6>20 THEN 2050 ELSE 2060
2050 IF R>=8 THEN S6=35 : GOTO 2090
2060 IF T6<=20 THEN 2070 ELSE 2120
2070 IF R>=8 THEN S6=15 : GOTO 2090
2080 GOTO 2120
2090 P1=(T6 -.1*S6)^2/(T6+.9*S6)
2100 IF T6<.1*S6 THEN P1=0
2110 GOTO 2160
2120 P9=P1
2130 G8=0
2140 IF T6<.2*S6 THEN E4=T8:P1=0 : GOTO 2160
2150 P1 = (T6 -.2*S6)^2/(T6+.8*S6)
2160 IF B=1 THEN 2170 ELSE 2290
2170 IF T6>=20 THEN 2180 ELSE 2230
2180 C1=I -1:G8=RAIN(C1)
2190 IF G8>=10 THEN 2200 ELSE 2230
2200 P1 = (T6 -.04*S6)^2/(T6+.96*S6)
2210 IF T6<.04*S6 THEN P1 = 0
2220 GOTO 2290
2230 C1=I -4:C2=I -1
2240 IF C1<0 THEN C1=1
2250 FOR J9=C1 TO C2
2260 IF PAN(J9)>RAIN(J9) THEN 2290
2270 NEXT J9
2280 GOTO 2200
2290 C1=I -10
2300 C2=I -1
2310 IF C1<0 THEN C1=1
2320 IF C2<=0 THEN C2=1
2330 FOR J9=C1 TO C2
2340 G8=G8+RAIN(J9):NEXT J9
2350 IF G8<8 THEN P1=P1 -8 : GOTO 2430
2360 C1=I-4:C2=I-1
2370 IF C1<0 THEN C1=1:IF C2<0 THEN C2=1
2380 G8=0
2390 FOR J9=C1 TO C2
2400 G8=G8+RAIN(J9)
2410 NEXT J9
2420 IF G8<8 THEN P1=P1 -5
2430 IF P1<=0 THEN P1=0 : GOTO 2540
2440 IF P9=0 THEN 2540
2450 IF P9>=3 THEN 2460 ELSE 2480

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2460 IF P9<=6 THEN 2470 ELSE 2480
2470 IF P1>0 THEN P1=P1+1 : GOTO 2540
2480 IF P9>6 THEN 2490 ELSE 2510
2490 IF P9<=15 THEN 2500 ELSE 2510
2500 IF P1>0 THEN P1=P1+2 : GOTO 2540
2510 IF P9>15 THEN 2520 ELSE 2540
2520 IF P1>0 THEN P1=P1+4 : GOTO 2540
2530 IF T6<=8 THEN P1=0
2540 IF T6<=8 THEN P1=0
2550 E4=T8 - P1:C=0
2560 IF R<=10 THEN C=R
2570 IF R>10 THEN 2580 ELSE 2590
2580 IF R<=25 THEN C=12 : GOTO 2600
2590 IF R>25 THEN C=17
2600 R2=R - C
2610 R1=T6 - P1+S -309
2620 IF ABS(E4)<=.5 THEN E4=0
2630 IF T6<=4 THEN R1=0
2640 IF R1<0 THEN R1=0
2650 IF R2<0 THEN R2=0
2660 IF ABS(E4)<=.5 THEN E4=0
2670 E5=E5+E4
2680 IF D5<0 THEN D5 = 0
2710 PRINT #4, USING L$; I,DTE(I),T6,T7,T8,B,T,E2,E3,D5,S1,S2,S,S6,P1
2720 G1=G1+1
2730 RETURN
2740 CLS
2750 LOCATE 12,18 : PRINT "JOB IS OVER"
2760 END
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Annexure - II Output parameters of the runoff model

Contd...

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
18	24-5-2000	0.000	11.800	0.000	1.000	10	1.180	0.000	0.000	67.660	239.160	306.820	504.460	0.000
19	25-5-2000	17.300	11.600	0.000	1.000	0	5.800	0.000	11.500	79.160	239.160	318.320	504.460	0.000
20	26-5-2000	0.000	11.500	0.000	1.000	1	11.500	0.000	0.000	67.660	239.160	306.820	15.000	0.000
21	27-5-2000	0.000	11.300	0.000	1.000	2	5.650	0.000	0.000	67.660	239.160	306.820	504.460	0.000
22	28-5-2000	0.000	11.000	0.000	1.000	3	3.667	0.000	0.000	67.660	239.160	306.820	504.460	0.000
23	29-5-2000	0.000	8.000	0.000	1.000	4	2.000	0.000	0.000	67.660	239.160	306.820	504.460	0.000
24	30-5-2000	0.000	6.000	0.000	1.000	5	1.200	0.000	0.000	67.660	239.160	306.820	504.460	0.000
25	31-5-2000	19.000	4.800	0.000	1.000	0	2.400	0.000	16.600	84.260	239.160	323.420	504.460	0.000
26	1-6-2000	0.000	4.400	0.000	1.000	1	4.400	0.000	0.000	79.860	239.160	319.020	15.000	0.000
27	2-6-2000	0.000	4.300	0.000	1.000	2	2.150	0.000	0.000	77.710	239.160	316.870	489.820	0.000
28	3-6-2000	0.000	4.800	0.000	1.000	3	1.600	0.000	0.000	76.110	239.160	315.270	492.400	0.000
29	4-6-2000	0.000	5.000	0.000	1.000	4	1.250	0.000	0.000	74.860	239.160	314.020	494.320	0.000
30	5-6-2000	19.000	4.800	0.000	1.000	0	2.400	0.000	16.600	91.460	239.160	330.620	495.820	0.000
31	6-6-2000	0.000	6.000	0.000	1.000	1	6.000	0.000	0.000	85.460	239.160	324.620	15.000	0.000
32	7-6-2000	0.000	4.000	0.000	1.000	2	2.000	0.000	0.000	83.460	239.160	322.620	15.000	0.000
33	8-6-2000	0.000	4.000	0.000	1.000	3	1.333	0.000	0.000	82.130	239.160	321.290	485.500	0.000
34	9-6-2000	0.000	4.200	0.000	1.000	4	1.050	0.000	0.000	81.080	239.160	320.240	487.100	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
35	10-6-2000	0.000	4.600	0.000	1.000	5	0.920	0.000	0.000	80.160	239.160	319.320	488.360	0.000
36	11-6-2000	0.000	4.000	0.000	1.000	6	0.667	0.000	0.000	79.490	239.160	318.650	489.460	0.000
37	12-6-2000	0.000	3.200	0.000	1.000	7	0.457	0.000	0.000	79.030	239.160	318.190	490.260	0.000
38	13-6-2000	0.000	3.800	0.000	1.000	8	0.475	0.000	0.000	78.560	239.160	317.720	490.810	0.000
39	14-6-2000	0.000	4.200	0.000	1.000	9	0.467	0.000	0.000	78.090	239.160	317.250	491.380	0.000
40	15-6-2000	0.000	4.600	0.000	1.000	10	0.460	0.000	0.000	77.630	239.160	316.790	491.940	0.000
41	16-6-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	77.070	239.160	316.230	492.490	0.000
42	17-6-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	76.450	239.160	315.610	493.160	0.000
43	18-6-2000	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	75.690	239.160	314.850	493.910	0.000
44	19-6-2000	0.000	7.800	0.000	1.000	10	0.780	0.000	0.000	74.910	239.160	314.070	494.820	0.000
45	20-6-2000	0.000	5.800	0.000	1.000	10	0.580	0.000	0.000	74.330	239.160	313.490	495.750	0.000
46	21-6-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	73.710	239.160	312.870	496.450	0.000
47	22-6-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	73.150	239.160	312.310	497.190	0.000
48	23-6-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	72.530	239.160	311.690	497.870	0.000
49	24-6-2000	0.000	6.000	0.000	1.000	10	0.600	0.000	0.000	71.930	239.160	311.090	498.610	0.000
50	25-6-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	71.250	239.160	310.410	499.330	0.000
51	26-6-2000	0.000	7.000	0.000	1.000	10	0.700	0.000	0.000	70.550	239.160	309.710	500.150	0.000
52	27-6-2000	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	69.830	239.160	308.990	500.990	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
53	28-6-2000	26.900	6.600	0.000	1.000	0	3.300	0.000	23.600	93.430	239.160	332.590	501.850	0.000
54	29-6-2000	0.000	3.400	0.000	1.000	1	3.400	0.000	0.000	90.030	239.160	329.190	15.000	0.000
55	30-6-2000	0.000	2.200	0.000	1.000	2	1.100	0.000	0.000	88.930	239.160	328.090	15.000	0.000
56	1-7-2000	0.000	3.000	0.000	1.000	3	1.000	0.000	0.000	87.930	239.160	327.090	478.930	0.000
57	2-7-2000	0.000	2.400	0.000	1.000	4	0.600	0.000	0.000	87.330	239.160	326.490	480.130	0.000
58	3-7-2000	6.000	5.200	0.000	1.000	0	2.600	0.000	3.400	90.730	239.160	329.890	480.850	0.000
59	4-7-2000	0.000	5.600	0.000	1.000	1	5.600	0.000	0.000	85.130	239.160	324.290	15.000	0.000
60	5-7-2000	12.000	6.400	0.000	1.000	0	3.200	0.000	8.800	93.930	239.160	333.090	15.000	0.000
61	6-7-2000	0.000	6.400	0.000	1.000	1	6.400	0.000	0.000	87.530	239.160	326.690	15.000	0.000
62	7-7-2000	0.000	6.000	0.000	1.000	2	3.000	0.000	0.000	84.530	239.160	323.690	15.000	0.000
63	8-7-2000	14.500	5.200	0.000	1.000	0	2.600	0.000	11.900	96.430	239.160	335.590	484.210	0.000
64	9-7-2000	0.000	2.200	0.000	1.000	1	2.200	0.000	0.000	94.230	239.160	333.390	15.000	0.000
65	10-7-2000	0.000	2.000	0.000	1.000	2	1.000	0.000	0.000	93.230	239.160	332.390	15.000	0.000
66	11-7-2000	12.250	2.200	0.000	1.000	0	1.100	0.000	11.150	104.380	239.160	343.540	473.770	0.000
67	12-7-2000	0.000	1.400	0.000	1.000	1	1.400	0.000	0.000	102.980	239.160	342.140	15.000	0.000
68	13-7-2000	0.000	1.800	0.000	1.000	2	0.900	0.000	0.000	102.080	239.160	341.240	15.000	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
69	14-7-2000	0.000	3.600	0.000	1.000	3	1.200	0.000	0.000	100.880	239.160	340.040	463.150	0.000
70	15-7-2000	0.000	3.800	0.000	1.000	4	0.950	0.000	0.000	99.930	239.160	339.090	464.590	0.000
71	16-7-2000	0.000	4.200	0.000	1.000	5	0.840	0.000	0.000	99.090	239.160	338.250	465.730	0.000
72	17-7-2000	0.000	5.700	0.000	1.000	6	0.950	0.000	0.000	98.140	239.160	337.300	466.740	0.000
73	18-7-2000	0.000	4.800	0.000	1.000	7	0.686	0.000	0.000	97.460	239.160	336.620	467.880	0.000
74	19-7-2000	0.000	3.600	0.000	1.000	8	0.450	0.000	0.000	97.010	239.160	336.170	468.700	0.000
75	20-7-2000	0.000	4.600	0.000	1.000	9	0.511	0.000	0.000	96.490	239.160	335.650	469.240	0.000
76	21-7-2000	0.000	3.000	0.000	1.000	10	0.300	0.000	0.000	96.190	239.160	335.350	469.850	0.000
77	22-7-2000	0.000	4.300	0.000	1.000	10	0.430	0.000	0.000	95.760	239.160	334.920	470.210	0.000
78	23-7-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	95.140	239.160	334.300	470.730	0.000
79	24-7-2000	0.000	6.400	0.000	1.000	10	0.640	0.000	0.000	94.500	239.160	333.660	471.470	0.000
80	25-7-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	93.880	239.160	333.040	472.240	0.000
81	26-7-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	93.320	239.160	332.480	472.990	0.000
82	27-7-2000	0.000	6.000	0.000	1.000	10	0.600	0.000	0.000	92.720	239.160	331.880	473.660	0.000
83	28-7-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	92.040	239.160	331.200	474.380	0.000
84	29-7-2000	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	91.320	239.160	330.480	475.190	0.000
85	30-7-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	90.640	239.160	329.800	476.060	0.000
86	31-7-2000	0.000	7.400	0.000	1.000	10	0.740	0.000	0.000	89.900	239.160	329.060	476.870	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
87	1-8-2000	0.000	7.100	0.000	1.000	10	0.710	0.000	0.000	89.190	239.160	328.350	477.760	0.000
88	2-8-2000	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	88.430	239.160	327.590	478.610	0.000
89	3-8-2000	0.000	7.400	0.000	1.000	10	0.740	0.000	0.000	87.690	239.160	326.850	479.530	0.000
90	4-8-2000	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	86.970	239.160	326.130	480.410	0.000
91	5-8-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	86.310	239.160	325.470	481.280	0.000
92	6-8-2000	0.000	6.000	0.000	1.000	10	0.600	0.000	0.000	85.710	239.160	324.870	482.070	0.000
93	7-8-2000	36.500	2.000	0.000	1.000	0	1.000	0.000	35.500	121.210	239.160	360.370	482.790	0.000
94*	8-8-2000	20.800	1.000	4.651	1.000	1	1.000	0.000	18.530	124.800	254.100	378.900	35.000	6.920
95*	9-8-2000	70.000	1.000	39.700	1.000	1	1.000	0.000	39.780	124.800	293.880	418.680	35.000	45.420
96	10-8-2000	11.000	1.200	0.000	1.000	1	1.200	0.000	9.800	124.800	303.680	428.480	15.000	3.680
97	11-8-2000	30.600	1.000	0.000	1.000	1	1.000	0.000	29.600	124.800	333.280	458.080	35.000	13.280
98	12-8-2000	0.000	4.300	0.000	1.000	1	4.300	0.000	0.000	120.500	333.280	453.780	15.000	0.000
99	13-8-2000	9.800	6.000	0.000	1.000	0	3.000	0.000	6.800	124.800	335.780	460.580	15.000	2.960
100	14-8-2000	0.000	6.200	0.000	1.000	1	6.200	0.000	0.000	118.600	335.780	454.380	15.000	0.000
101	15-8-2000	0.000	6.000	0.000	1.000	2	3.000	0.000	0.000	115.600	335.780	451.380	15.000	0.000
102	16-8-2000	0.000	6.400	0.000	1.000	3	2.133	0.000	0.000	113.470	335.780	449.250	15.000	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
103	17-8-2000	0.000	6.300	0.000	1.000	4	1.575	0.000	0.000	111.890	335.780	447.680	15.000	0.000
104	18-8-2000	0.000	6.400	0.000	1.000	5	1.280	0.000	0.000	110.610	335.780	446.400	15.000	0.000
105	19-8-2000	0.000	6.300	0.000	1.000	6	1.050	0.000	0.000	109.560	335.780	445.350	15.000	0.000
106	20-8-2000	0.000	6.200	0.000	1.000	7	0.886	0.000	0.000	108.680	335.780	444.460	15.000	0.000
107	21-8-2000	0.000	6.300	0.000	1.000	8	0.788	0.000	0.000	107.890	335.780	443.670	15.000	0.000
108	22-8-2000	14.500	6.500	0.000	1.000	0	3.250	0.000	11.250	119.140	335.780	454.920	15.000	1.040
109	23-8-2000	1.000	4.500	0.000	1.000	1	4.500	0.000	0.000	114.640	335.780	450.420	15.000	0.000
110	24-8-2000	0.000	2.200	0.000	1.000	1	2.200	0.000	0.000	112.440	335.780	448.220	15.000	0.000
111	25-8-2000	10.500	3.200	0.000	1.000	0	1.600	0.000	8.900	121.340	335.780	457.120	15.000	3.380
112	26-8-2000	0.000	3.000	0.000	1.000	1	3.000	0.000	0.000	118.340	335.780	454.120	15.000	0.000
113	27-8-2000	3.700	4.000	0.000	1.000	1	4.000	0.000	0.000	114.340	335.780	450.120	15.000	0.000
114	28-8-2000	10.290	3.000	0.000	1.000	0	1.500	0.000	8.790	123.130	335.780	458.910	15.000	3.250
115	29-8-2000	0.000	3.200	0.000	1.000	1	3.200	0.000	0.000	119.930	335.780	455.710	15.000	0.000
116	30-8-2000	0.000	4.000	0.000	1.000	2	2.000	0.000	0.000	117.930	335.780	453.710	15.000	0.000
117	31-8-2000	0.000	5.200	0.000	1.000	3	1.733	0.000	0.000	116.200	335.780	451.980	15.000	0.000
118	1-9-2000	0.000	5.900	0.000	1.000	4	1.475	0.000	0.000	114.720	335.780	450.500	15.000	0.000
119	2-9-2000	0.000	6.200	0.000	1.000	5	1.240	0.000	0.000	113.480	335.780	449.260	15.000	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
120	3-9-2000	0.000	5.800	0.000	1.000	6	0.967	0.000	0.000	112.510	335.780	448.300	15.000	0.000
121	4-9-2000	0.000	6.400	0.000	1.000	7	0.914	0.000	0.000	111.600	335.780	447.380	15.000	0.000
122	5-9-2000	0.000	5.800	0.000	1.000	8	0.725	0.000	0.000	110.870	335.780	446.660	15.000	0.000
123	6-9-2000	0.000	6.200	0.000	1.000	9	0.689	0.000	0.000	110.190	335.780	445.970	15.000	0.000
124	7-9-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	109.570	335.780	445.350	15.000	0.000
125	8-9-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	109.010	335.780	444.790	15.000	0.000
126	9-9-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	108.390	335.780	444.170	15.000	0.000
127	10-9-2000	0.000	6.400	0.000	1.000	10	0.640	0.000	0.000	107.750	335.780	443.530	15.000	0.000
128	11-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	107.090	335.780	442.870	15.000	0.000
129	12-9-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	106.410	335.780	442.190	15.000	0.000
130	13-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	105.750	335.780	441.530	15.000	0.000
131	14-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	105.090	335.780	440.870	15.000	0.000
132	15-9-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	104.410	335.780	440.190	15.000	0.000
133	16-9-2000	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	103.720	335.780	439.500	15.000	0.000
134*	17-9-2000	72.000	6.800	31.596	1.000	0	3.400	0.000	55.430	124.800	370.130	494.930	35.000	37.340
135	18-9-2000	0.000	6.700	0.000	1.000	1	6.700	0.000	0.000	118.100	370.130	488.230	15.000	0.000
136	19-9-2000	0.000	5.700	0.000	1.000	2	2.850	0.000	0.000	115.250	370.130	485.380	15.000	0.000

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ROW	DATE	RAIN	EVAP	RUNOFF	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	PQ
137	20-9-2000	0.000	5.600	0.000	1.000	3	1.867	0.000	0.000	113.380	370.130	483.510	15.000	0.000
138*	21-9-2000	25.000	6.400	10.270	1.000	0	3.200	0.000	11.530	124.800	370.240	495.040	35.000	8.180
139	22-9-2000	0.000	6.500	0.000	1.000	1	6.500	0.000	0.000	118.300	370.240	488.540	15.000	0.000
140	23-9-2000	0.000	6.800	0.000	1.000	2	3.400	0.000	0.000	114.900	370.240	485.140	15.000	0.000
141	24-9-2000	0.000	6.500	0.000	1.000	3	2.167	0.000	0.000	112.730	370.240	482.980	15.000	0.000
142	25-9-2000	0.000	6.400	0.000	1.000	4	1.600	0.000	0.000	111.130	370.240	481.380	15.000	0.000
143	26-9-2000	0.000	6.800	0.000	1.000	5	1.360	0.000	0.000	109.770	370.240	480.020	15.000	0.000
144	27-9-2000	0.000	7.200	0.000	1.000	6	1.200	0.000	0.000	108.570	370.240	478.820	15.000	0.000
145	28-9-2000	11.000	5.600	0.000	1.000	0	2.800	0.000	8.200	116.770	370.240	487.020	15.000	0.000
146	29-9-2000	15.400	5.400	0.000	1.000	1	5.400	0.000	10.000	124.800	372.220	497.020	15.000	6.690
147	30-9-2000	0.000	5.000	0.000	1.000	1	5.000	0.000	0.000	119.800	372.220	492.020	15.000	0.000
148	1-10-2000	0.000	4.000	0.000	1.000	2	2.000	0.000	0.000	117.800	372.220	490.020	15.000	0.000
149	2-10-2000	0.000	6.000	0.000	1.000	3	2.000	0.000	0.000	115.800	372.220	488.020	15.000	0.000
150	3-10-2000	0.000	6.200	0.000	1.000	4	1.550	0.000	0.000	114.250	372.220	486.470	15.000	0.000
151	4-10-2000	0.000	6.400	0.000	1.000	5	1.280	0.000	0.000	112.970	372.220	485.190	15.000	0.000
152	5-10-2000	0.000	6.800	0.000	1.000	6	1.133	0.000	0.000	111.840	372.220	484.050	15.000	0.000
153	6-10-2000	0.000	5.800	0.000	1.000	7	0.829	0.000	0.000	111.010	372.220	483.220	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
154	7-10-2000	17.000	6.500	0.000	1.000	0	3.250	0.000	13.750	124.760	372.220	496.970	15.000	2.880
155	8-10-2000	0.000	5.200	0.000	1.000	1	5.200	0.000	0.000	119.560	372.220	491.770	15.000	0.000
156	9-10-2000	0.000	5.400	0.000	0.960	2	2.592	0.216	0.000	116.900	372.070	488.970	15.000	0.000
157	10-10-2000	10.300	2.100	0.000	0.960	0	1.008	0.084	9.208	124.800	373.370	498.170	15.000	3.250
158	11-10-2000	5.300	1.300	0.000	0.960	1	1.248	0.052	4.000	124.800	377.370	502.170	15.000	0.000
159	12-10-2000	0.000	3.000	0.000	0.960	1	2.880	0.120	0.000	121.880	377.290	499.170	15.000	0.000
160	13-10-2000	0.000	6.000	0.000	0.960	2	2.880	0.240	0.000	118.930	377.120	496.050	15.000	0.000
161	14-10-2000	13.720	4.700	0.000	0.960	0	2.256	0.188	11.276	124.800	382.530	507.330	15.000	5.490
162	15-10-2000	0.000	5.400	0.000	0.960	1	5.184	0.216	0.000	119.550	382.380	501.930	15.000	0.000
163	16-10-2000	0.000	5.800	0.000	0.900	2	2.610	0.580	0.000	116.770	381.970	498.740	15.000	0.000
164	17-10-2000	0.000	6.600	0.000	0.900	3	1.980	0.660	0.000	114.590	381.510	496.100	15.000	0.000
165	18-10-2000	0.000	6.200	0.000	0.900	4	1.395	0.620	0.000	113.010	381.080	494.090	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
166	19-10-2000	0.000	6.300	0.000	0.900	5	1.134	0.630	0.000	111.690	380.640	492.320	15.000	0.000
167*	20-10-2000	23.500	6.000	1.677	0.900	0	2.700	0.600	18.530	124.800	386.050	510.850	35.000	2.270
168	21-10-2000	0.000	6.400	0.000	0.900	1	5.760	0.640	0.000	118.850	385.600	504.450	15.000	0.000
169	22-10-2000	0.000	4.200	0.000	0.900	2	1.890	0.420	0.000	116.830	385.310	502.140	15.000	0.000
170	23-10-2000	0.000	4.600	0.000	0.860	3	1.319	0.644	0.000	115.320	384.860	500.180	15.000	0.000
171	24-10-2000	0.000	5.400	0.000	0.860	4	1.161	0.756	0.000	113.930	384.330	498.260	15.000	0.000
172	25-10-2000	0.000	5.200	0.000	0.860	5	0.894	0.728	0.000	112.820	383.820	496.640	15.000	0.000
173	26-10-2000	0.000	5.000	0.000	0.860	6	0.717	0.700	0.000	111.890	383.330	495.220	15.000	0.000
174	27-10-2000	0.000	6.200	0.000	0.860	7	0.762	0.868	0.000	110.870	382.720	493.590	15.000	0.000
175	28-10-2000	0.000	5.800	0.000	0.860	8	0.624	0.812	0.000	110.000	382.150	492.160	15.000	0.000
176	29-10-2000	0.000	5.300	0.000	0.860	9	0.506	0.742	0.000	109.270	381.630	490.910	15.000	0.000
177	30-10-2000	0.000	5.600	0.000	0.810	10	0.454	1.064	0.000	108.500	380.890	489.390	15.000	0.000
178	31-10-2000	0.000	5.200	0.000	0.810	10	0.421	0.988	0.000	107.780	380.200	487.980	15.000	0.000
179	1-11-2000	0.000	4.800	0.000	0.810	10	0.389	0.912	0.000	107.120	379.560	486.680	15.000	0.000
180	2-11-2000	0.000	4.600	0.000	0.810	10	0.373	0.874	0.000	106.490	378.950	485.430	15.000	0.000
181	3-11-2000	0.000	6.000	0.000	0.810	10	0.486	1.140	0.000	105.660	378.150	483.810	15.000	0.000
182	4-11-2000	0.000	5.800	0.000	0.810	10	0.470	1.102	0.000	104.860	377.380	482.240	15.000	0.000
183	5-11-2000	0.000	4.200	0.000	0.810	10	0.340	0.798	0.000	104.280	376.820	481.100	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
184	6-11-2000	0.000	4.000	0.000	0.760	10	0.304	0.960	0.000	103.690	376.150	479.830	15.000	0.000
185	7-11-2000	0.000	3.800	0.000	0.760	10	0.289	0.912	0.000	103.120	375.510	478.630	15.000	0.000
186	8-11-2000	0.000	4.200	0.000	0.760	10	0.319	1.008	0.000	102.500	374.800	477.310	15.000	0.000
187	9-11-2000	0.000	4.600	0.000	0.760	10	0.350	1.104	0.000	101.820	374.030	475.850	15.000	0.000
188	10-11-2000	0.000	5.000	0.000	0.760	10	0.380	1.200	0.000	101.080	373.190	474.270	15.000	0.000
189	11-11-2000	0.000	5.500	0.000	0.760	10	0.418	1.320	0.000	100.270	372.270	472.540	15.000	0.000
190	12-11-2000	0.000	4.500	0.000	0.760	10	0.342	1.080	0.000	99.600	371.510	471.110	15.000	0.000
191	13-11-2000	0.000	5.600	0.000	0.700	10	0.392	1.680	0.000	98.710	370.340	469.040	15.000	0.000
192	14-11-2000	0.000	5.000	0.000	0.700	10	0.350	1.500	0.000	97.910	369.290	467.190	15.000	0.000
193	15-11-2000	0.000	5.400	0.000	0.700	10	0.378	1.620	0.000	97.040	368.150	465.190	15.000	0.000
194	16-11-2000	0.000	5.600	0.000	0.700	10	0.392	1.680	0.000	96.150	366.980	463.120	15.000	0.000
195	17-11-2000	0.000	5.200	0.000	0.700	10	0.364	1.560	0.000	95.310	365.880	461.200	15.000	0.000
196	18-11-2000	0.000	5.400	0.000	0.700	10	0.378	1.620	0.000	94.450	364.750	459.200	15.000	0.000
197	19-11-2000	0.000	5.300	0.000	0.700	10	0.371	1.590	0.000	93.600	363.640	457.240	15.000	0.000
198	20-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	92.750	362.470	455.220	15.000	0.000
199	21-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	91.900	361.310	453.200	15.000	0.000
200	22-11-2000	0.000	5.000	0.000	0.680	10	0.340	1.600	0.000	91.080	360.190	451.260	15.000	0.000
201	23-11-2000	0.000	4.800	0.000	0.680	10	0.326	1.536	0.000	90.290	359.110	449.400	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
202	24-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	89.440	357.950	447.380	15.000	0.000
203	25-11-2000	0.000	4.800	0.000	0.680	10	0.326	1.536	0.000	88.650	356.870	445.520	15.000	0.000
204	26-11-2000	0.000	5.100	0.000	0.680	10	0.347	1.632	0.000	87.810	355.730	443.540	15.000	0.000
205	27-11-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	87.000	354.550	441.550	15.000	0.000
206	28-11-2000	0.000	4.600	0.000	0.650	10	0.299	1.610	0.000	86.220	353.430	439.640	15.000	0.000
207	29-11-2000	0.000	4.500	0.000	0.650	10	0.292	1.575	0.000	85.450	352.320	437.770	15.000	0.000
208	30-11-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	84.630	351.150	435.780	15.000	0.000
209	31-11-2000	0.000	4.000	0.000	0.650	10	0.260	1.400	0.000	83.950	350.170	434.120	15.000	0.000
210	1-12-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	83.140	348.990	432.130	15.000	0.000
211	2-12-2000	0.000	5.000	0.000	0.650	10	0.325	1.750	0.000	82.290	347.770	430.050	15.000	0.000
212	3-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	81.360	346.350	427.710	15.000	0.000
213	4-12-2000	0.000	5.400	0.000	0.610	10	0.329	2.106	0.000	80.400	344.870	425.270	15.000	0.000
214	5-12-2000	0.000	5.600	0.000	0.610	10	0.342	2.184	0.000	79.400	343.340	422.750	15.000	0.000
215	6-12-2000	0.000	5.500	0.000	0.610	10	0.336	2.145	0.000	78.430	341.840	420.270	15.000	0.000
216	7-12-2000	0.000	5.400	0.000	0.610	10	0.329	2.106	0.000	77.460	340.370	417.830	15.000	0.000
217	8-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	76.540	338.950	415.490	15.000	0.000
218	9-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	75.610	337.530	413.140	15.000	0.000
219	10-12-2000	0.000	5.300	0.000	0.570	10	0.302	2.279	0.000	74.630	335.930	410.560	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
220	11-12-2000	0.000	4.900	0.000	0.570	10	0.279	2.107	0.000	73.720	334.460	408.170	15.000	0.000
221	12-12-2000	0.000	2.800	0.000	0.570	10	0.160	1.204	0.000	73.200	333.620	406.810	15.000	0.000
222	13-12-2000	0.000	4.000	0.000	0.570	10	0.228	1.720	0.000	72.450	332.410	404.860	15.000	0.000
223	14-12-2000	0.000	4.600	0.000	0.570	10	0.262	1.978	0.000	71.600	331.030	402.620	15.000	0.000
224	15-12-2000	0.000	4.400	0.000	0.570	10	0.251	1.892	0.000	70.780	329.700	400.480	15.000	0.000
225	16-12-2000	0.000	5.200	0.000	0.570	10	0.296	2.236	0.000	69.810	328.140	397.950	15.000	0.000
226	17-12-2000	0.000	5.400	0.000	0.500	10	0.270	2.700	0.000	68.730	326.250	394.980	15.000	0.000
227	18-12-2000	0.000	5.200	0.000	0.500	10	0.260	2.600	0.000	67.690	324.430	392.120	15.000	0.000
228	19-12-2000	0.000	5.000	0.000	0.500	10	0.250	2.500	0.000	67.660	322.680	390.340	15.000	0.000
229	20-12-2000	0.000	4.800	0.000	0.500	10	0.240	2.400	0.000	67.660	321.000	388.660	15.000	0.000
230	21-12-2000	0.000	5.500	0.000	0.500	10	0.275	2.750	0.000	67.660	319.070	386.730	15.000	0.000
231	22-12-2000	0.000	5.600	0.000	0.500	10	0.280	2.800	0.000	67.660	317.110	384.770	15.000	0.000
232	23-12-2000	0.000	5.600	0.000	0.500	10	0.280	2.800	0.000	67.660	315.150	382.810	15.000	0.000
233	24-12-2000	0.000	5.500	0.000	0.480	10	0.264	2.860	0.000	67.660	313.150	380.810	15.000	0.000
234	25-12-2000	0.000	5.800	0.000	0.480	10	0.278	3.016	0.000	67.660	311.040	378.700	15.000	0.000
235	26-12-2000	0.000	5.700	0.000	0.480	10	0.274	2.964	0.000	67.660	308.960	376.620	15.000	0.000
236	27-12-2000	0.000	5.600	0.000	0.480	10	0.269	2.912	0.000	67.660	306.930	374.590	15.000	0.000
237	28-12-2000	0.000	5.400	0.000	0.480	10	0.259	2.808	0.000	67.660	304.960	372.620	15.000	0.000

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ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
238	29-12-2000	0.000	5.200	0.000	0.480	10	0.250	2.704	0.000	67.660	303.070	370.730	15.000	0.000
239	30-12-2000	0.000	5.000	0.000	0.480	10	0.240	2.600	0.000	67.660	301.250	368.910	15.000	0.000
240	31-12-2000	0.000	5.100	0.000	0.460	10	0.235	2.754	0.000	67.660	299.320	366.980	15.000	0.000
241	1-1-2001	0.000	5.200	0.000	0.460	10	0.239	2.808	0.000	67.660	297.350	365.010	15.000	0.000
242	2-1-2001	0.000	5.000	0.000	0.460	10	0.230	2.700	0.000	67.660	295.460	363.120	15.000	0.000
243	3-1-2001	0.000	5.100	0.000	0.460	10	0.235	2.754	0.000	67.660	293.540	361.200	15.000	0.000
244	4-1-2001	0.000	4.800	0.000	0.460	10	0.221	2.592	0.000	67.660	291.720	359.380	15.000	0.000
245	5-1-2001	0.000	4.200	0.000	0.460	10	0.193	2.268	0.000	67.660	290.130	357.790	15.000	0.000
246	6-1-2001	0.000	4.400	0.000	0.460	10	0.202	2.376	0.000	67.660	288.470	356.130	15.000	0.000
247	7-1-2001	0.000	4.200	0.000	0.400	10	0.168	2.520	0.000	67.660	286.710	354.370	15.000	0.000
248	8-1-2001	0.000	4.600	0.000	0.400	10	0.184	2.760	0.000	67.660	284.780	352.440	15.000	0.000
249	9-1-2001	0.000	5.000	0.000	0.400	10	0.200	3.000	0.000	67.660	282.680	350.340	15.000	0.000
250	10-1-2001	0.000	5.200	0.000	0.400	10	0.208	3.120	0.000	67.660	280.490	348.150	15.000	0.000
251	11-1-2001	0.000	5.000	0.000	0.400	10	0.200	3.000	0.000	67.660	278.390	346.050	15.000	0.000
252	12-1-2001	0.000	4.600	0.000	0.400	10	0.184	2.760	0.000	67.660	276.460	344.120	15.000	0.000
253	13-1-2001	0.000	4.800	0.000	0.400	10	0.192	2.880	0.000	67.660	274.440	342.100	15.000	0.000
254	14-1-2001	0.000	5.000	0.000	0.380	10	0.190	3.100	0.000	67.660	272.270	339.930	15.000	0.000
255	15-1-2001	0.000	5.200	0.000	0.380	10	0.198	3.224	0.000	67.660	270.020	337.680	15.000	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
256	16-1-2001	0.000	5.600	0.000	0.380	10	0.213	3.472	0.000	67.660	267.590	335.250	467.430	0.000
257	17-1-2001	0.000	5.500	0.000	0.380	10	0.209	3.410	0.000	67.660	265.200	332.860	470.340	0.000
258	18-1-2001	0.000	5.800	0.000	0.380	10	0.220	3.596	0.000	67.660	262.680	330.340	473.210	0.000
259	19-1-2001	0.000	6.000	0.000	0.380	10	0.228	3.720	0.000	67.660	260.080	327.740	476.230	0.000
260	20-1-2001	0.000	6.200	0.000	0.380	10	0.236	3.844	0.000	67.660	257.390	325.050	479.350	0.000
261	21-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	67.660	254.480	322.140	482.580	0.000
262	22-1-2001	0.000	6.400	0.000	0.360	10	0.230	4.096	0.000	67.660	251.610	319.270	486.080	0.000
263	23-1-2001	0.000	6.200	0.000	0.360	10	0.223	3.968	0.000	67.660	248.830	316.490	489.520	0.000
264	24-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	67.660	245.920	313.580	492.850	0.000
265	25-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	67.660	243.010	310.670	496.350	0.000
266	26-1-2001	0.000	6.400	0.000	0.360	10	0.230	4.096	0.000	67.660	240.140	307.800	499.840	0.000
267	27-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	67.660	237.230	304.890	503.280	0.000
268	28-1-2001	0.000	6.600	0.000	0.340	10	0.224	4.356	0.000	67.660	234.180	301.840	506.780	0.000
269	29-1-2001	0.000	6.400	0.000	0.340	10	0.218	4.224	0.000	67.660	231.220	298.880	510.430	0.000
270	30-1-2001	0.000	6.200	0.000	0.340	10	0.211	4.092	0.000	67.660	228.360	296.020	513.980	0.000
271	1-2-2001	0.000	6.400	0.000	0.340	10	0.218	4.224	0.000	67.660	225.400	293.060	517.420	0.000
272	2-2-2001	0.000	6.600	0.000	0.340	10	0.224	4.356	0.000	67.660	222.350	290.010	520.970	0.000
273	3-2-2001	0.000	6.800	0.000	0.340	10	0.231	4.488	0.000	67.660	219.210	286.870	524.630	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
274	4-2-2001	0.000	6.500	0.000	0.340	10	0.221	4.290	0.000	67.660	216.210	283.870	528.400	0.000
275	5-2-2001	0.000	6.700	0.000	1.000	10	0.670	0.000	0.000	67.660	216.210	283.870	532.000	0.000
276	6-2-2001	0.000	6.400	0.000	1.000	10	0.640	0.000	0.000	67.660	216.210	283.870	532.000	0.000
277	7-2-2001	0.000	6.500	0.000	1.000	10	0.650	0.000	0.000	67.660	216.210	283.870	532.000	0.000
278	8-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	67.660	216.210	283.870	532.000	0.000
279	9-2-2001	0.000	6.500	0.000	1.000	10	0.650	0.000	0.000	67.660	216.210	283.870	532.000	0.000
280	10-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	67.660	216.210	283.870	532.000	0.000
281	11-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	67.660	216.210	283.870	532.000	0.000
282	12-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	67.660	216.210	283.870	532.000	0.000
283	13-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	67.660	216.210	283.870	532.000	0.000
284	14-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	67.660	216.210	283.870	532.000	0.000
285	15-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	67.660	216.210	283.870	532.000	0.000
286	16-2-2001	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	67.660	216.210	283.870	532.000	0.000
287	17-2-2001	0.000	7.800	0.000	1.000	10	0.780	0.000	0.000	67.660	216.210	283.870	532.000	0.000
288	18-2-2001	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	67.660	216.210	283.870	532.000	0.000
289	19-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	67.660	216.210	283.870	532.000	0.000
290	20-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	67.660	216.210	283.870	532.000	0.000
291	21-2-2001	0.000	7.400	0.000	1.000	10	0.740	0.000	0.000	67.660	216.210	283.870	532.000	0.000

Contd....

ROW	DATE	RAIN	EVAP	Measured runoff	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
292	22-2-2001	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	67.660	216.210	283.870	532.000	0.000
293	23-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	67.660	216.210	283.870	532.000	0.000
294	24-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	67.660	216.210	283.870	532.000	0.000
295	25-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	67.660	216.210	283.870	532.000	0.000
296	26-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	67.660	216.210	283.870	532.000	0.000
297	27-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	67.660	216.210	283.870	532.000	0.000
298	28-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	67.660	216.210	283.870	532.000	0.000
299	1-3-2001	0.000	0.000	0.000	0.000	10	0.000	0.000	0.000	67.660	216.210	283.87	532.000	0.000

★ = Runoff event

Annexure - III. Output parameters of the runoff model

Plot -II

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
1	7-5-2000	14.700	11.600	0.000	1.000	0	5.800	0.000	8.900	77.140	239.820	316.960	517.010	0.000
2	8-5-2000	0.000	12.000	0.000	1.000	1	12.000	0.000	0.000	72.090	239.820	311.910	15.000	0.000
3	9-5-2000	0.000	12.100	0.000	1.000	2	6.050	0.000	0.000	72.090	239.820	311.910	512.390	0.000
4	10-5-2000	0.000	11.800	0.000	1.000	3	3.933	0.000	0.000	72.090	239.820	311.910	512.390	0.000
5	11-5-2000	0.000	11.900	0.000	1.000	4	2.975	0.000	0.000	72.090	239.820	311.910	512.390	0.000
6	12-5-2000	0.000	11.600	0.000	1.000	5	2.320	0.000	0.000	72.090	239.820	311.910	512.390	0.000
7	13-5-2000	0.000	12.000	0.000	1.000	6	2.000	0.000	0.000	72.090	239.820	311.910	512.390	0.000
8	14-5-2000	0.000	12.200	0.000	1.000	7	1.743	0.000	0.000	72.090	239.820	311.910	512.390	0.000
9	15-5-2000	0.000	12.100	0.000	1.000	8	1.513	0.000	0.000	72.090	239.820	311.910	512.390	0.000
10	16-5-2000	0.000	11.000	0.000	1.000	9	1.222	0.000	0.000	72.090	239.820	311.910	512.390	0.000
11	17-5-2000	0.000	11.800	0.000	1.000	10	1.180	0.000	0.000	72.090	239.820	311.910	512.390	0.000
12	18-5-2000	0.000	11.600	0.000	1.000	10	1.160	0.000	0.000	72.090	239.820	311.910	512.390	0.000
13	19-5-2000	0.000	12.100	0.000	1.000	10	1.210	0.000	0.000	72.090	239.820	311.910	512.390	0.000
14	20-5-2000	0.000	12.200	0.000	1.000	10	1.220	0.000	0.000	72.090	239.820	311.910	512.390	0.000
15	21-5-2000	0.000	12.310	0.000	1.000	10	1.231	0.000	0.000	72.090	239.820	311.910	512.390	0.000
16	22-5-2000	0.000	12.100	0.000	1.000	10	1.210	0.000	0.000	72.090	239.820	311.910	512.390	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
17	23-5-2000	0.000	12.000	0.000	1.000	10	1.230	0.000	0.000	72.090	239.820	311.910	512.390	0.000
18	24-5-2000	0.000	11.800	0.000	1.000	10	1.180	0.000	0.000	72.090	239.820	311.910	512.390	0.000
19	25-5-2000	17.300	11.600	0.000	1.000	0	5.830	0.000	11.500	83.590	239.820	323.410	512.390	0.000
20	26-5-2000	0.000	11.500	0.000	1.000	1	11.530	0.000	0.000	72.090	239.820	311.910	15.000	0.000
21	27-5-2000	0.000	11.300	0.000	1.000	2	5.650	0.000	0.000	72.090	239.820	311.910	15.000	0.000
22	28-5-2000	0.000	11.000	0.000	1.000	3	3.657	0.000	0.000	72.090	239.820	311.910	512.390	0.000
23	29-5-2000	0.000	8.000	0.000	1.000	4	2.030	0.000	0.000	72.090	239.820	311.910	512.390	0.000
24	30-5-2000	0.000	6.000	0.000	1.000	5	1.230	0.000	0.000	72.090	239.820	311.910	512.390	0.000
25	31-5-2000	19.000	4.800	0.000	1.000	0	2.430	0.000	16.600	88.690	239.820	328.510	512.390	0.000
26	1-6-2000	0.000	4.400	0.000	1.000	1	4.430	0.000	0.000	84.290	239.820	324.110	15.000	0.000
27	2-6-2000	0.000	4.300	0.000	1.000	2	2.150	0.000	0.000	82.140	239.820	321.960	15.000	0.000
28	3-6-2000	0.000	4.800	0.000	1.000	3	1.630	0.000	0.000	80.540	239.820	320.360	500.330	0.000
29	4-6-2000	0.000	5.000	0.000	1.000	4	1.250	0.000	0.000	79.290	239.820	319.110	502.250	0.000
30	5-6-2000	19.000	4.800	0.000	1.000	0	2.430	0.000	16.600	95.890	239.820	335.710	503.750	0.000
31	6-6-2000	0.000	6.000	0.000	1.000	1	6.030	0.000	0.000	89.890	239.820	329.710	15.000	0.000
32	7-6-2000	0.000	4.000	0.000	1.000	2	2.030	0.000	0.000	87.890	239.820	327.710	15.000	0.000
33	8-6-2000	0.000	4.000	0.000	1.000	3	1.333	0.000	0.000	86.560	239.820	326.380	493.430	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
34	9-6-2000	0.000	4.200	0.000	1.000	4	1.050	0.000	0.000	85.510	239.820	325.330	495.030	0.000
35	10-6-2000	0.000	4.600	0.000	1.000	5	0.920	0.000	0.000	84.590	239.820	324.410	496.290	0.000
36	11-6-2000	0.000	4.000	0.000	1.000	6	0.667	0.000	0.000	83.920	239.820	323.740	497.390	0.000
37	12-6-2000	0.000	3.200	0.000	1.000	7	0.457	0.000	0.000	83.460	239.820	323.280	498.190	0.000
38	13-6-2000	0.000	3.800	0.000	1.000	8	0.475	0.000	0.000	82.990	239.820	322.810	498.740	0.000
39	14-6-2000	0.000	4.200	0.000	1.000	9	0.467	0.000	0.000	82.520	239.820	322.340	499.310	0.000
40	15-6-2000	0.000	4.600	0.000	1.000	10	0.460	0.000	0.000	82.060	239.820	321.880	499.870	0.000
41	16-6-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	81.500	239.820	321.320	500.420	0.000
42	17-6-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	80.880	239.820	320.700	501.090	0.000
43	18-6-2000	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	80.120	239.820	319.940	501.840	0.000
44	19-6-2000	0.000	7.800	0.000	1.000	10	0.780	0.000	0.000	79.340	239.820	319.160	502.750	0.000
45	20-6-2000	0.000	5.800	0.000	0.940	10	0.545	0.348	0.000	78.690	239.580	318.270	503.690	0.000
46	21-6-2000	0.000	6.200	0.000	0.940	10	0.583	0.372	0.000	78.000	239.320	317.310	504.760	0.000
47	22-6-2000	0.000	5.600	0.000	0.940	10	0.526	0.336	0.000	77.370	239.080	316.450	505.900	0.000
48	23-6-2000	0.000	6.200	0.000	0.940	10	0.583	0.372	0.000	76.680	238.820	315.500	506.940	0.000
49	24-6-2000	0.000	6.000	0.000	0.940	10	0.564	0.360	0.000	76.000	238.570	314.570	508.080	0.000
50	25-6-2000	0.000	6.800	0.000	0.940	10	0.639	0.408	0.000	75.240	238.280	313.520	509.190	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
51	26-6-2000	0.000	7.000	0.000	0.940	10	0.658	0.420	0.000	74.460	237.990	312.450	510.450	0.000
52	27-6-2000	0.000	7.200	0.000	0.890	10	0.641	0.792	0.000	73.580	237.430	311.010	511.740	0.000
53	28-6-2000	26.900	6.600	0.000	0.890	0	2.937	0.726	23.237	96.820	237.430	334.250	513.460	0.000
54	29-6-2000	0.000	3.400	0.000	0.890	1	3.026	0.374	0.000	93.680	237.170	330.850	15.000	0.000
55	30-6-2000	0.000	2.200	0.000	0.890	2	0.979	0.242	0.000	92.630	237.000	329.630	15.000	0.000
56	1-7-2000	0.000	3.000	0.000	0.890	3	0.890	0.330	0.000	91.640	236.770	328.410	491.120	0.000
57	2-7-2000	0.000	2.400	0.000	0.890	4	0.534	0.264	0.000	91.020	236.590	327.610	492.590	0.000
58	3-7-2000	6.000	5.200	0.000	0.810	0	2.106	0.988	2.906	93.930	236.590	330.520	493.550	0.000
59	4-7-2000	0.000	5.600	0.000	0.810	1	4.536	1.064	0.000	89.080	235.840	324.920	15.000	0.000
60	5-7-2000	12.000	6.400	0.000	0.810	0	2.592	1.216	8.192	97.270	235.840	333.110	15.000	0.000
61	6-7-2000	0.000	6.400	0.000	0.810	1	5.184	1.216	0.000	91.720	234.990	326.710	15.000	0.000
62	7-7-2000	0.000	6.000	0.000	0.810	2	2.430	1.140	0.000	88.950	234.190	323.140	15.000	0.000
63	8-7-2000	14.500	5.200	0.000	0.810	0	2.106	0.988	11.406	100.350	234.190	334.550	498.910	0.000
64	9-7-2000	0.000	2.200	0.000	0.810	1	1.782	0.418	0.000	98.450	233.900	332.350	15.000	0.000
65	10-7-2000	0.000	2.000	0.000	0.720	2	0.720	0.560	0.000	97.560	233.510	331.070	15.000	0.000
66	11-7-2000	12.250	2.200	0.000	0.720	0	0.792	0.616	10.842	108.400	233.510	341.910	489.400	0.000
67	12-7-2000	0.000	1.400	0.000	0.720	1	1.008	0.392	0.000	107.270	233.230	340.510	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
68	13-7-2000	0.000	1.800	0.000	0.720	2	0.648	0.504	0.000	106.470	232.880	339.360	15.000	0.000
69	14-7-2000	0.000	3.600	0.000	0.720	3	0.864	1.008	0.000	105.310	232.180	337.480	479.450	0.000
70	15-7-2000	0.000	3.800	0.000	0.720	4	0.684	1.064	0.000	104.300	231.430	335.740	481.700	0.000
71	16-7-2000	0.000	4.200	0.000	0.720	5	0.605	1.176	0.000	103.350	230.610	333.960	483.800	0.000
72	17-7-2000	0.000	5.700	0.000	0.650	6	0.617	1.995	0.000	102.130	229.210	331.340	485.930	0.000
73	18-7-2000	0.000	4.800	0.000	0.650	7	0.446	1.580	0.000	101.180	228.040	329.220	489.070	0.000
74	19-7-2000	0.000	3.600	0.000	0.650	8	0.292	1.260	0.000	100.510	227.150	327.660	491.620	0.000
75	20-7-2000	0.000	4.600	0.000	0.650	9	0.332	1.610	0.000	99.700	226.030	325.720	493.480	0.000
76	21-7-2000	0.000	3.000	0.000	0.650	10	0.195	1.050	0.000	99.190	225.290	324.480	495.810	0.000
77	22-7-2000	0.000	4.300	0.000	0.650	10	0.280	1.505	0.000	98.450	224.240	322.690	497.310	0.000
78	23-7-2000	0.000	6.200	0.000	0.650	10	0.403	2.170	0.000	97.400	222.720	320.120	499.450	0.000
79	24-7-2000	0.000	6.400	0.000	0.570	10	0.365	2.752	0.000	96.210	220.790	317.000	502.540	0.000
80	25-7-2000	0.000	6.200	0.000	0.570	10	0.353	2.666	0.000	95.060	218.930	313.980	506.280	0.000
81	26-7-2000	0.000	5.600	0.000	0.570	10	0.319	2.408	0.000	94.020	217.240	311.260	509.900	0.000
82	27-7-2000	0.000	6.000	0.000	0.570	10	0.342	2.580	0.000	92.900	215.430	308.330	513.170	0.000
83	28-7-2000	0.000	6.800	0.000	0.570	10	0.388	2.924	0.000	91.630	213.390	305.020	516.680	0.000
84	29-7-2000	0.000	7.200	0.000	0.570	10	0.410	3.096	0.000	90.300	211.220	301.520	520.650	0.000

Contd....

Row	Date	Rain	Evap	Measure d runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
85	30-7-2000	0.000	6.800	0.000	0.570	10	0.388	2.924	0.000	89.030	209.170	298.200	524.860	0.000
86	31-7-2000	0.000	7.400	0.000	0.520	10	0.385	3.552	0.000	87.580	206.690	294.270	528.830	0.000
87	1-8-2000	0.000	7.100	0.000	0.520	10	0.369	3.408	0.000	86.190	204.300	290.490	533.560	0.000
88	2-8-2000	0.000	7.600	0.000	0.520	10	0.395	3.648	0.000	84.700	201.750	286.450	538.090	0.000
89	3-8-2000	0.000	7.400	0.000	0.520	10	0.385	3.552	0.000	83.250	199.260	282.510	542.940	0.000
90	4-8-2000	0.000	7.200	0.000	0.520	10	0.374	3.456	0.000	81.840	196.840	278.680	547.670	0.000
91	5-8-2000	0.000	6.600	0.000	0.520	10	0.343	3.168	0.000	80.540	194.630	275.170	552.260	0.000
92	6-8-2000	0.000	6.000	0.000	0.520	10	0.312	2.880	0.000	79.370	192.610	271.980	556.480	0.000
93	7-8-2000	36.500	2.000	0.000	0.470	0	0.470	1.060	34.970	114.340	192.610	306.950	560.310	0.000
94*	8-8-2000	20.800	1.000	0.610	0.470	1	0.470	0.530	19.190	121.670	204.470	326.140	518.340	0.000
95*	9-8-2000	70.000	1.000	40.180	0.470	1	0.470	0.530	57.250	121.670	261.720	383.390	35.000	43.570
96	10-8-2000	11.000	1.200	0.000	0.470	1	0.564	0.636	9.800	121.670	271.520	393.190	15.000	3.680
97	11-8-2000	30.600	1.000	0.000	0.470	1	0.470	0.530	29.600	121.670	301.120	422.790	35.000	11.830
98	12-8-2000	0.000	4.300	0.000	0.470	1	2.021	2.279	0.000	118.970	299.520	418.490	15.000	0.000
99	13-8-2000	9.800	6.000	0.000	0.470	0	1.410	3.180	5.210	121.670	302.030	423.700	15.000	2.960
100	14-8-2000	0.000	6.200	0.000	0.360	1	2.232	3.968	0.000	118.250	299.250	417.500	15.000	0.000
101	15-8-2000	0.000	6.000	0.000	0.360	2	1.080	3.840	0.000	116.020	296.560	412.580	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Betta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
102	16-8-2000	0.000	6.400	0.000	0.360	3	0.768	4.096	0.000	114.020	293.690	407.710	15.000	0.000
103	17-8-2000	0.000	6.300	0.000	0.360	4	0.567	4.032	0.000	112.240	290.870	403.110	15.000	0.000
104	18-8-2000	0.000	6.400	0.000	0.360	5	0.461	4.096	0.000	110.550	288.000	398.560	15.000	0.000
105	19-8-2000	0.000	6.300	0.000	0.360	6	0.378	4.032	0.000	108.960	285.180	394.150	15.000	0.000
106	20-8-2000	0.000	6.200	0.000	0.360	7	0.319	3.968	0.000	107.460	282.400	389.860	15.000	0.000
107	21-8-2000	0.000	6.300	0.000	1.000	8	0.788	0.000	0.000	106.670	282.400	389.070	15.000	0.000
108	22-8-2000	14.500	6.500	0.000	1.000	0	3.250	0.000	11.250	117.920	282.400	400.320	15.000	1.040
109	23-8-2000	1.000	4.500	0.000	1.000	1	4.500	0.000	0.000	113.420	282.400	395.820	15.000	0.000
110	24-8-2000	0.000	2.200	0.000	1.000	1	2.200	0.000	0.000	111.220	282.400	393.620	15.000	0.000
111	25-8-2000	10.500	3.200	0.000	1.000	0	1.600	0.000	8.900	120.120	282.400	402.520	15.000	3.380
112	26-8-2000	0.000	3.000	0.000	1.000	1	3.000	0.000	0.000	117.120	282.400	399.520	15.000	0.000
113	27-8-2000	3.700	4.000	0.000	1.000	1	4.000	0.000	0.000	113.120	282.400	395.520	15.000	0.000
114	28-8-2000	10.290	3.000	0.000	1.000	0	1.500	0.000	8.790	121.670	282.640	404.310	15.000	3.250
115	29-8-2000	0.000	3.200	0.000	1.000	1	3.200	0.000	0.000	118.470	282.640	401.110	15.000	0.000
116	30-8-2000	0.000	4.000	0.000	1.000	2	2.000	0.000	0.000	116.470	282.640	399.110	15.000	0.000
117	31-8-2000	0.000	5.200	0.000	1.000	3	1.733	0.000	0.000	114.740	282.640	397.380	15.000	0.000
118	1-9-2000	0.000	5.900	0.000	1.000	4	1.475	0.000	0.000	113.260	282.640	395.900	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
119	2-9-2000	0.000	6.200	0.000	1.000	5	1.240	0.000	0.000	112.020	282.640	394.660	15.000	0.000
120	3-9-2000	0.000	5.800	0.000	1.000	6	0.967	0.000	0.000	111.060	282.640	393.700	15.000	0.000
121	4-9-2000	0.000	6.400	0.000	1.000	7	0.914	0.000	0.000	110.140	282.640	392.780	15.000	0.000
122	5-9-2000	0.000	5.800	0.000	1.000	8	0.725	0.000	0.000	109.420	282.640	392.060	15.000	0.000
123	6-9-2000	0.000	6.200	0.000	1.000	9	0.689	0.000	0.000	108.730	282.640	391.370	15.000	0.000
124	7-9-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	108.110	282.640	390.750	15.000	0.000
125	8-9-2000	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	107.550	282.640	390.190	15.000	0.000
126	9-9-2000	0.000	6.200	0.000	1.000	10	0.620	0.000	0.000	106.930	282.640	389.570	15.000	0.000
127	10-9-2000	0.000	6.400	0.000	1.000	10	0.640	0.000	0.000	106.290	282.640	388.930	15.000	0.000
128	11-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	105.630	282.640	388.270	15.000	0.000
129	12-9-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	104.950	282.640	387.590	15.000	0.000
130	13-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	104.290	282.640	386.930	15.000	0.000
131	14-9-2000	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	103.630	282.640	386.270	15.000	0.000
132	15-9-2000	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	102.950	282.640	385.590	15.000	0.000
133	16-9-2000	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	102.260	282.640	384.900	423.970	0.000
134*	17-9-2000	72.000	6.800	30.750	1.000	0	3.400	0.000	54.910	121.670	318.140	439.810	424.800	35.410
135	18-9-2000	0.000	6.700	0.000	1.000	1	6.700	0.000	0.000	114.970	318.140	433.110	15.000	0.000

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ROW	DATE	RAIN	EVAP	RUNOFF	BEETA	T	E*	ET	DM	SM1	SM2	SMT	S	PQ
137	20-9-2000	0.000	5.600	0.000	1.000	3	1.867	0.000	0.000	113.380	370.130	483.510	15.000	0.000
138*	21-9-2000	25.000	6.400	10.270	1.000	0	3.200	0.000	11.530	124.800	370.240	495.040	35.000	8.180
139	22-9-2000	0.000	6.500	0.000	1.000	1	6.500	0.000	0.000	118.300	370.240	488.540	15.000	0.000
140	23-9-2000	0.000	6.800	0.000	1.000	2	3.400	0.000	0.000	114.900	370.240	485.140	15.000	0.000
141	24-9-2000	0.000	6.500	0.000	1.000	3	2.167	0.000	0.000	112.730	370.240	482.980	15.000	0.000
142	25-9-2000	0.000	6.400	0.000	1.000	4	1.600	0.000	0.000	111.130	370.240	481.380	15.000	0.000
143	26-9-2000	0.000	6.800	0.000	1.000	5	1.360	0.000	0.000	109.770	370.240	480.020	15.000	0.000
144	27-9-2000	0.000	7.200	0.000	1.000	6	1.200	0.000	0.000	108.570	370.240	478.820	15.000	0.000
145	28-9-2000	11.000	5.600	0.000	1.000	0	2.800	0.000	8.200	116.770	370.240	487.020	15.000	0.000
146	29-9-2000	15.400	5.400	0.000	1.000	1	5.400	0.000	10.000	124.800	372.220	497.020	15.000	6.690
147	30-9-2000	0.000	5.000	0.000	1.000	1	5.000	0.000	0.000	119.800	372.220	492.020	15.000	0.000
148	1-10-2000	0.000	4.000	0.000	1.000	2	2.000	0.000	0.000	117.800	372.220	490.020	15.000	0.000
149	2-10-2000	0.000	6.000	0.000	1.000	3	2.000	0.000	0.000	115.800	372.220	488.020	15.000	0.000
150	3-10-2000	0.000	6.200	0.000	1.000	4	1.550	0.000	0.000	114.250	372.220	486.470	15.000	0.000
151	4-10-2000	0.000	6.400	0.000	1.000	5	1.280	0.000	0.000	112.970	372.220	485.190	15.000	0.000
152	5-10-2000	0.000	6.800	0.000	1.000	6	1.133	0.000	0.000	111.840	372.220	484.050	15.000	0.000
153	6-10-2000	0.000	5.800	0.000	1.000	7	0.829	0.000	0.000	111.010	372.220	483.220	15.000	0.000

Contd...

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
153	5-10-2000	0.000	5.800	0.000	1.000	7	0.829	0.000	0.000	107.880	319.400	427.270	15.000	0.000
154	7-10-2000	17.000	6.500	0.000	1.000	0	3.250	0.000	13.750	121.630	319.400	441.020	15.000	2.880
155	8-10-2000	0.000	5.200	0.000	1.000	1	5.200	0.000	0.000	116.430	319.400	435.820	15.000	0.000
156	9-10-2000	0.000	5.400	0.000	0.960	2	2.592	0.216	0.000	113.770	319.250	433.020	15.000	0.000
157	10-10-2000	10.300	2.100	0.000	0.960	0	1.008	0.084	9.208	121.670	320.550	442.220	15.000	3.250
158	11-10-2000	5.300	1.300	0.000	0.960	1	1.248	0.052	4.000	121.670	324.550	446.220	15.000	0.000
159	12-10-2000	0.000	3.000	0.000	0.960	1	2.880	0.120	0.000	118.750	324.470	443.220	15.000	0.000
160	13-10-2000	0.000	6.000	0.000	0.960	2	2.880	0.240	0.000	115.800	324.300	440.100	15.000	0.000
161	14-10-2000	13.720	4.700	0.000	0.960	0	2.256	0.188	11.276	121.670	329.710	451.380	15.000	5.490
162	15-10-2000	0.000	5.400	0.000	0.960	1	5.184	0.216	0.000	116.420	329.560	445.980	15.000	0.000
163	16-10-2000	0.000	5.800	0.000	0.900	2	2.610	0.580	0.000	113.640	329.150	442.790	15.000	0.000
164	17-10-2000	0.000	6.600	0.000	0.900	3	1.980	0.660	0.000	111.460	328.690	440.150	15.000	0.000
165	18-10-2000	0.000	6.200	0.000	0.900	4	1.395	0.620	0.000	109.880	328.260	438.140	15.000	0.000
166	19-10-2000	0.000	6.300	0.000	0.900	5	1.134	0.630	0.000	108.560	327.820	436.370	15.000	0.000
167*	20-10-2000	23.500	6.000	2.620	0.900	0	2.700	0.600	17.580	121.670	332.280	453.950	35.000	2.270
168	21-10-2000	0.000	6.400	0.000	0.900	1	5.760	0.640	0.000	115.720	331.830	447.550	15.000	0.000
169	22-10-2000	0.000	4.200	0.000	0.900	2	1.890	0.420	0.000	113.700	331.540	445.240	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
170	23-10-2000	0.000	4.600	0.000	0.860	3	1.319	0.644	0.000	112.190	331.090	443.280	15.000	0.000
171	24-10-2000	0.000	5.400	0.000	0.860	4	1.161	0.756	0.000	110.800	330.560	441.360	15.000	0.000
172	25-10-2000	0.000	5.200	0.000	0.860	5	0.894	0.728	0.000	109.690	330.050	439.740	15.000	0.000
173	26-10-2000	0.000	5.000	0.000	0.860	6	0.717	0.700	0.000	108.760	329.560	438.320	15.000	0.000
174	27-10-2000	0.000	6.200	0.000	0.860	7	0.762	0.868	0.000	107.740	328.950	436.690	15.000	0.000
175	28-10-2000	0.000	5.800	0.000	0.860	8	0.624	0.812	0.000	106.870	328.380	435.260	15.000	0.000
176	29-10-2000	0.000	5.300	0.000	0.860	9	0.506	0.742	0.000	106.140	327.860	434.010	15.000	0.000
177	30-10-2000	0.000	5.600	0.000	0.810	10	0.454	1.064	0.000	105.370	327.120	432.490	15.000	0.000
178	31-10-2000	0.000	5.200	0.000	0.810	10	0.421	0.988	0.000	104.650	326.430	431.080	15.000	0.000
179	1-11-2000	0.000	4.800	0.000	0.810	10	0.389	0.912	0.000	103.990	325.790	429.780	15.000	0.000
180	2-11-2000	0.000	4.600	0.000	0.810	10	0.373	0.874	0.000	103.360	325.180	428.540	15.000	0.000
181	3-11-2000	0.000	6.000	0.000	0.810	10	0.486	1.140	0.000	102.530	324.380	426.910	15.000	0.000
182	4-11-2000	0.000	5.800	0.000	0.810	10	0.470	1.102	0.000	101.730	323.610	425.340	15.000	0.000
183	5-11-2000	0.000	4.200	0.000	0.810	10	0.340	0.798	0.000	101.150	323.050	424.200	15.000	0.000
184	6-11-2000	0.000	4.000	0.000	0.760	10	0.304	0.960	0.000	100.560	322.380	422.940	15.000	0.000
185	7-11-2000	0.000	3.800	0.000	0.760	10	0.289	0.912	0.000	99.990	321.740	421.730	15.000	0.000
186	8-11-2000	0.000	4.200	0.000	0.760	10	0.319	1.008	0.000	99.370	321.030	420.410	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
187	9-11-2000	0.000	4.600	0.000	0.760	10	0.350	1.104	0.000	98.690	320.260	418.950	15.000	0.000
188	10-11-2000	0.000	5.000	0.000	0.760	10	0.380	1.200	0.000	97.950	319.420	417.370	15.000	0.000
189	11-11-2000	0.000	5.500	0.000	0.760	10	0.418	1.320	0.000	97.140	318.500	415.640	15.000	0.000
190	12-11-2000	0.000	4.500	0.000	0.760	10	0.342	1.080	0.000	96.470	317.740	414.210	15.000	0.000
191	13-11-2000	0.000	5.600	0.000	0.700	10	0.392	1.680	0.000	95.580	316.570	412.140	15.000	0.000
192	14-11-2000	0.000	5.000	0.000	0.700	10	0.350	1.500	0.000	94.780	315.520	410.290	15.000	0.000
193	15-11-2000	0.000	5.400	0.000	0.700	10	0.378	1.620	0.000	93.910	314.380	408.290	15.000	0.000
194	16-11-2000	0.000	5.600	0.000	0.700	10	0.392	1.680	0.000	93.020	313.210	406.220	15.000	0.000
195	17-11-2000	0.000	5.200	0.000	0.700	10	0.364	1.560	0.000	92.180	312.110	404.300	15.000	0.000
196	18-11-2000	0.000	5.400	0.000	0.700	10	0.378	1.620	0.000	91.320	310.980	402.300	15.000	0.000
197	19-11-2000	0.000	5.300	0.000	0.700	10	0.371	1.590	0.000	90.470	309.870	400.340	15.000	0.000
198	20-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	89.620	308.700	398.320	15.000	0.000
199	21-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	88.770	307.540	396.300	15.000	0.000
200	22-11-2000	0.000	5.000	0.000	0.680	10	0.340	1.600	0.000	87.950	306.420	394.360	15.000	0.000
201	23-11-2000	0.000	4.800	0.000	0.680	10	0.326	1.536	0.000	87.160	305.340	392.500	15.000	0.000
202	24-11-2000	0.000	5.200	0.000	0.680	10	0.354	1.664	0.000	86.310	304.180	390.480	15.000	0.000
203	25-11-2000	0.000	4.800	0.000	0.680	10	0.326	1.536	0.000	85.520	303.100	388.620	15.000	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
204	26-11-2000	0.000	5.100	0.000	0.680	10	0.347	1.632	0.000	84.680	301.960	386.640	15.000	0.000
205	27-11-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	83.870	300.780	384.650	15.000	0.000
206	28-11-2000	0.000	4.600	0.000	0.650	10	0.299	1.610	0.000	83.090	299.660	382.740	15.000	0.000
207	29-11-2000	0.000	4.500	0.000	0.650	10	0.292	1.575	0.000	82.320	298.550	380.870	15.000	0.000
208	30-11-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	81.500	297.380	378.880	429.630	0.000
209	31-11-2000	0.000	4.000	0.000	0.650	10	0.260	1.400	0.000	80.820	296.400	377.220	432.020	0.000
210	1-12-2000	0.000	4.800	0.000	0.650	10	0.312	1.680	0.000	80.010	295.220	375.230	434.010	0.000
211	2-12-2000	0.000	5.000	0.000	0.650	10	0.325	1.750	0.000	79.160	294.000	373.150	436.400	0.000
212	3-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	78.230	292.580	370.810	438.890	0.000
213	4-12-2000	0.000	5.400	0.000	0.610	10	0.329	2.106	0.000	77.270	291.100	368.370	441.710	0.000
214	5-12-2000	0.000	5.600	0.000	0.610	10	0.342	2.184	0.000	76.270	289.570	365.850	444.630	0.000
215	6-12-2000	0.000	5.500	0.000	0.610	10	0.336	2.145	0.000	75.300	288.070	363.370	447.660	0.000
216	7-12-2000	0.000	5.400	0.000	0.610	10	0.329	2.106	0.000	74.330	286.600	360.930	450.640	0.000
217	8-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	73.410	285.180	358.590	453.560	0.000
218	9-12-2000	0.000	5.200	0.000	0.610	10	0.317	2.028	0.000	72.480	283.760	356.240	456.380	0.000
219	10-12-2000	0.000	5.300	0.000	0.570	10	0.302	2.279	0.000	72.090	282.160	354.250	459.190	0.000
220	11-12-2000	0.000	4.900	0.000	0.570	10	0.279	2.107	0.000	72.090	280.690	352.780	461.580	0.000

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Row	Date	Rain	Evap	Measured runoff	Beta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
221	12-12-2000	0.000	2.800	0.000	0.570	10	0.160	1.204	0.000	72.090	279.850	351.940	463.350	0.000
222	13-12-2000	0.000	4.000	0.000	0.570	10	0.228	1.720	0.000	72.090	278.640	350.730	464.360	0.000
223	14-12-2000	0.000	4.600	0.000	0.570	10	0.262	1.978	0.000	72.090	277.260	349.350	465.800	0.000
224	15-12-2000	0.000	4.400	0.000	0.570	10	0.251	1.892	0.000	72.090	275.930	348.020	467.460	0.000
225	16-12-2000	0.000	5.200	0.000	0.570	10	0.296	2.236	0.000	72.090	274.370	346.460	469.050	0.000
226	17-12-2000	0.000	5.400	0.000	0.500	10	0.270	2.700	0.000	72.090	272.480	344.570	470.930	0.000
227	18-12-2000	0.000	5.200	0.000	0.500	10	0.260	2.600	0.000	72.090	270.660	342.750	473.200	0.000
228	19-12-2000	0.000	5.000	0.000	0.500	10	0.250	2.500	0.000	72.090	268.910	341.000	475.380	0.000
229	20-12-2000	0.000	4.800	0.000	0.500	10	0.240	2.400	0.000	72.090	267.230	339.320	477.480	0.000
230	21-12-2000	0.000	5.500	0.000	0.500	10	0.275	2.750	0.000	72.090	265.300	337.390	479.500	0.000
231	22-12-2000	0.000	5.600	0.000	0.500	10	0.280	2.800	0.000	72.090	263.340	335.430	481.810	0.000
232	23-12-2000	0.000	5.600	0.000	0.500	10	0.280	2.800	0.000	72.090	261.380	333.470	484.160	0.000
233	24-12-2000	0.000	5.500	0.000	0.480	10	0.264	2.860	0.000	72.090	259.380	331.470	486.510	0.000
234	25-12-2000	0.000	5.800	0.000	0.480	10	0.278	3.016	0.000	72.090	257.270	329.360	488.920	0.000
235	26-12-2000	0.000	5.700	0.000	0.480	10	0.274	2.964	0.000	72.090	255.190	327.280	491.450	0.000
236	27-12-2000	0.000	5.600	0.000	0.480	10	0.269	2.912	0.000	72.090	253.160	325.250	493.940	0.000
237	28-12-2000	0.000	5.400	0.000	0.480	10	0.259	2.808	0.000	72.090	251.190	323.280	496.380	0.000

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Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
238	29-12-2000	0.000	5.200	0.000	0.480	10	0.250	2.704	0.000	72.090	249.300	321.390	498.740	0.000
239	30-12-2000	0.000	5.000	0.000	0.480	10	0.240	2.600	0.000	72.090	247.480	319.570	501.010	0.000
240	31-12-2000	0.000	5.100	0.000	0.460	10	0.235	2.754	0.000	72.090	245.550	317.640	503.200	0.000
241	1-1-2001	0.000	5.200	0.000	0.460	10	0.239	2.808	0.000	72.090	243.580	315.670	505.510	0.000
242	2-1-2001	0.000	5.000	0.000	0.460	10	0.230	2.700	0.000	72.090	241.690	313.780	507.870	0.000
243	3-1-2001	0.000	5.100	0.000	0.460	10	0.235	2.754	0.000	72.090	239.770	311.860	510.140	0.000
244	4-1-2001	0.000	4.800	0.000	0.460	10	0.221	2.592	0.000	72.090	237.950	310.040	512.450	0.000
245	5-1-2001	0.000	4.200	0.000	0.460	10	0.193	2.268	0.000	72.090	236.360	308.450	514.630	0.000
246	6-1-2001	0.000	4.400	0.000	0.460	10	0.202	2.376	0.000	72.090	234.700	306.790	516.530	0.000
247	7-1-2001	0.000	4.200	0.000	0.400	10	0.168	2.520	0.000	72.090	232.940	305.030	518.530	0.000
248	8-1-2001	0.000	4.600	0.000	0.400	10	0.184	2.760	0.000	72.090	231.010	303.100	520.650	0.000
249	9-1-2001	0.000	5.000	0.000	0.400	10	0.200	3.000	0.000	72.090	228.910	301.000	522.970	0.000
250	10-1-2001	0.000	5.200	0.000	0.400	10	0.208	3.120	0.000	72.090	226.720	298.810	525.490	0.000
251	11-1-2001	0.000	5.000	0.000	0.400	10	0.200	3.000	0.000	72.090	224.620	296.710	528.110	0.000
252	12-1-2001	0.000	4.600	0.000	0.400	10	0.184	2.760	0.000	72.090	222.690	294.780	530.630	0.000
253	13-1-2001	0.000	4.800	0.000	0.400	10	0.192	2.880	0.000	72.090	220.670	292.760	532.940	0.000
254	14-1-2001	0.000	5.000	0.000	0.380	10	0.190	3.100	0.000	72.090	218.500	290.590	535.360	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Becta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
255	15-1-2001	0.000	5.200	0.000	0.380	10	0.198	3.224	0.000	72.090	216.250	288.340	537.970	0.000
256	16-1-2001	0.000	5.600	0.000	0.380	10	0.213	3.472	0.000	72.090	213.820	285.910	540.680	0.000
257	17-1-2001	0.000	5.500	0.000	0.380	10	0.209	3.410	0.000	72.090	211.430	283.520	543.590	0.000
258	18-1-2001	0.000	5.800	0.000	0.380	10	0.220	3.596	0.000	72.090	208.910	281.000	546.460	0.000
259	19-1-2001	0.000	6.000	0.000	0.380	10	0.228	3.720	0.000	72.090	206.310	278.400	549.480	0.000
260	20-1-2001	0.000	6.200	0.000	0.380	10	0.236	3.844	0.000	72.090	203.620	275.710	552.600	0.000
261	21-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	72.090	200.710	272.800	555.830	0.000
262	22-1-2001	0.000	6.400	0.000	0.360	10	0.230	4.096	0.000	72.090	197.840	269.930	559.330	0.000
263	23-1-2001	0.000	6.200	0.000	0.360	10	0.223	3.968	0.000	72.090	195.060	267.150	562.770	0.000
264	24-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	72.090	192.150	264.240	566.100	0.000
265	25-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	72.090	191.700	263.790	569.590	0.000
266	26-1-2001	0.000	6.400	0.000	0.360	10	0.230	4.096	0.000	72.090	191.700	263.790	570.130	0.000
267	27-1-2001	0.000	6.500	0.000	0.360	10	0.234	4.160	0.000	72.090	191.700	263.790	570.130	0.000
268	28-1-2001	0.000	6.600	0.000	0.340	10	0.224	4.356	0.000	72.090	191.700	263.790	570.130	0.000
269	29-1-2001	0.000	6.400	0.000	0.340	10	0.218	4.224	0.000	72.090	191.700	263.790	570.130	0.000
270	30-1-2001	0.000	6.200	0.000	0.340	10	0.211	4.092	0.000	72.090	191.700	263.790	570.130	0.000
271	1-2-2001	0.000	6.400	0.000	0.340	10	0.218	4.224	0.000	72.090	191.700	263.790	570.130	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Becta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
272	2-2-2001	0.000	6.600	0.000	0.340	10	0.224	4.356	0.000	72.090	191.700	263.790	570.130	0.000
273	3-2-2001	0.000	6.800	0.000	0.340	10	0.231	4.488	0.000	72.090	191.700	263.790	570.130	0.000
274	4-2-2001	0.000	6.500	0.000	0.340	10	0.221	4.290	0.000	72.090	191.700	263.790	570.130	0.000
275	5-2-2001	0.000	6.700	0.000	1.000	10	0.670	0.000	0.000	72.090	191.700	263.790	570.130	0.000
276	6-2-2001	0.000	6.400	0.000	1.000	10	0.640	0.000	0.000	72.090	191.700	263.790	570.130	0.000
277	7-2-2001	0.000	6.500	0.000	1.000	10	0.650	0.000	0.000	72.090	191.700	263.790	570.130	0.000
278	8-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	72.090	191.700	263.790	570.130	0.000
279	9-2-2001	0.000	6.500	0.000	1.000	10	0.650	0.000	0.000	72.090	191.700	263.790	570.130	0.000
280	10-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	72.090	191.700	263.790	570.130	0.000
281	11-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	72.090	191.700	263.790	570.130	0.000
282	12-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	72.090	191.700	263.790	570.130	0.000
283	13-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	72.090	191.700	263.790	570.130	0.000
284	14-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	72.090	191.700	263.790	570.130	0.000
285	15-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	72.090	191.700	263.790	570.130	0.000
286	16-2-2001	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	72.090	191.700	263.790	570.130	0.000
287	17-2-2001	0.000	7.800	0.000	1.000	10	0.780	0.000	0.000	72.090	191.700	263.790	570.130	0.000
288	18-2-2001	0.000	5.600	0.000	1.000	10	0.560	0.000	0.000	72.090	191.700	263.790	570.130	0.000

Contd....

Row	Date	Rain	Evap	Measured runoff	Beeta	T	E*	ET	DM	SM1	SM2	SMT	S	Predicted runoff
289	19-2-2001	0.000	6.600	0.000	1.000	10	0.660	0.000	0.000	72.090	191.700	263.790	570.130	0.000
290	20-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	72.090	191.700	263.790	570.130	0.000
291	21-2-2001	0.000	7.400	0.000	1.000	10	0.740	0.000	0.000	72.090	191.700	263.790	570.130	0.000
292	22-2-2001	0.000	7.600	0.000	1.000	10	0.760	0.000	0.000	72.090	191.700	263.790	570.130	0.000
293	23-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	72.090	191.700	263.790	570.130	0.000
294	24-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	72.090	191.700	263.790	570.130	0.000
295	25-2-2001	0.000	6.900	0.000	1.000	10	0.690	0.000	0.000	72.090	191.700	263.790	570.130	0.000
296	26-2-2001	0.000	6.800	0.000	1.000	10	0.680	0.000	0.000	72.090	191.700	263.790	570.130	0.000
297	27-2-2001	0.000	7.200	0.000	1.000	10	0.720	0.000	0.000	72.090	191.700	263.790	570.130	0.000
298	28-2-2001	0.000	7.500	0.000	1.000	10	0.750	0.000	0.000	72.090	191.700	263.790	570.130	0.000
299	1-3-2001	0.000	0.000	0.000	0.000	10	0.000	0.000	0.000	72.090	191.700	263.790	570.130	0.000

★ = Runoff event

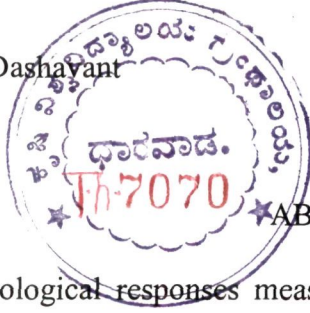
Simulation of Runoff and Erosion From Field Size Areas in Vertisols of
Northern Dry Zone of Karnataka

Mr. Premanand Dashayant

2002

Er. U. Satish Kumar

Major Advisor



ABSTRACT

The hydrological responses measured in terms of runoff volume and its peak discharge and sediment yield helps in evaluation of soil productivity that depleted on account of spatially and temporally ill distributed rainfall. The replicated field size terrace plots (< 1 ha) prepared with a single outlet were established to measure runoff and sediment yield in Madabhavi micro watershed under agroclimatic conditions of northern dry zone of Karnataka. The modified soil conservation service (SCS) runoff model coupled with soil moisture accounting procedure. (Pathak et. al 1989) used for simulation of runoff volume on daily basis, whereas Williams, (1975) model was used to predict the sediment yield..

In the course of investigation it was found that out of total annual rainfall amount of 553.66 mm received, 90.209 mm and 83.02 mm were total quantities of runoff from bare plot and the plot with greengram crop during Kharif season respectively. The SCS runoff model predicted the measured value of runoff for each of five events with R^2 value of 0.985 in case of bare plot (Plot 1) and 0.9934 in case of greengram plot (Plot-II) respectively. The measured sediment yield was found to be 12.24 t/ha in case of bare plot and 8.87 t/ha in case of greengram plot. The modified USLE sediment yield model (Williams 1975) predicted the soil loss with R^2 value of 0.8997 in case of bare plot and 0.97 in case of greengram plot.

