EFFECT OF LAND USE ON WATER YIELD FROM SMALL AGRICULTURAL WATERSHEDS OF WESTERN GHATS

By

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THESIS

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requirement for the degree

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To

Agricultural Engineers

DECLARATION

I hereby declare that this thesis entitled "Effect of Land Use on Water Yield from Small Agricultural Watersheds of Western Ghats" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Tavanur,

28.9.1993.

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CERTIFICATE

Certified that this thesis entitled " **Effect of Land Use on Water Yield from Small Agricultural Watersheds of Western Ghats**" is a record of research work done independently by Shri. **Abdul Hakkim, V.M.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ABDUL HAKKIM, V.M.

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SYMBOLS AND ABBREVIATIONS

Agric.	-	Agricultural
Amer.	-	American
ASAE	-	American Society of Agricultural Engineers
ASCE	-	American Society of Civil Engineers
Assoc.	-	Association
BH	-	Bore hole
Bull.	-	Bulletin
°C	-	Degree centigrade
cm	-	centimetre (s)
cm/hr	-	centimetre per hour
Co.	-	Company
con.	-	concentrated
Conserv.	-	conservation
contd.	-	continued
CSWCRTI	-	Central Soil and Water Conservation Research and Training Institute
CWRDM	-	Centre for Water Resources Development and Management
Engng.	-	Engineering
et al.	-	and other people
etc.	-	et cetra
FAO	-	Food and Agricultural Organisation

Fig.	-	Figure
Geol.	-	Geological
Geophys.	-	Geophysics
G.I.	-	Galvanized Iron
gm	-	gram(s)
ha	-	hectare(s)
hr	-	hour
ICRISAT	-	International Crop Research Institute for Semi Arid Tropics
i.e.	-	that is
Inter.	-	International
I.S.	-	Indian Standard
J.	-	Journal
kg	-	kilogram
km	-	kilometre(s)
km^2	-	Square kilometre(s)
Ltd.	-	Limited
m	-	metre(s)
m^2	-	square metre(s)
m^3	-	cubic metre(s)
min	-	minute
ml	-	millilitre(s)
mm	-	millimetre(s)
m^3/sec	-	cubic metre per second
N	-	Normal

No.	-	Number
Pnet	-	Net precipitation depth
pp.	-	Pages
Proc.	-	Proceedings
Pvt.	-	Private
Res.	-	Research
Resour.	-	Resources
R/F	-	Rainfall
sci.	-	science
sec	-	second(s)
ser.	-	service
soc.	-	society
surv.	-	survey
Tech.	-	Technical
Trans.	-	Transactions
U.H	-	Unit hydrograph
Univ.	-	University
U.S	-	United states
U.S.D.A.	-	United States Department of Agriculture
U.S.W.B.	-	United States Weather Bureau
Viz.	-	Namely
Vol.	-	Volume
Vs	-	Versus
&	-	and
°	-	degree(s)

Introduction

INTRODUCTION

Kerala is a land of rivers and backwaters with forty four rivers cutting across the land and numerous backwater lakes spread all along the coast. With the innumerable tributaries and branches of the rivers the State has an exorbitant potential of surface water. All the rivers originate from the Western Ghats and most of them are harnessed for irrigation and hydel power. The effective life span of these rivers and hydel projects depends on the land use pattern in their catchment areas. The land use pattern has its own effect on the disposition of rainfall in a given climatic zone. It affects the surface runoff, ground water recharge, sediment production and transport and microclimate. These responses can be studied on small watersheds under different land uses.

A watershed or a drainage basin or a catchment is a natural integrator of all the hydrologic phenomena pertaining to its boundaries and, as such, it is a logical unit for planning optimum development of soil and water resources. It refers to the area lying above a common drainage point and can be defined as the area from which the surface water drains through a definite drainage point. It has no physical limits and may embrace less than a hectare or thousands of hectares depending upon the point of reference. A small watershed and its characteristics have been described by the committee on runoff of the American Geophysical Union as follows:

From the hydrological point of view, a distinct characteristic of the small watershed is that the effect of overland flow rather than the effect of channel flow is the dominating factor affecting the peak runoff. Consequently a small watershed is very sensitive to high intensity rainfalls of short duration and to land use. Therefore, a small watershed may be defined as one that is so small that its sensitivity to high rainfalls of short duration and to land use are not suppressed by the channel storage characteristics. By this definition, the size of small watersheds vary from a few hectares to 1000 hectares. The upper limit of the area depends on the conditions at which the above mentioned sensitivities become practically lost due to channel storage.

The Western Ghats of southern peninsular India lie between 8°-14° north latitude and 75°-77° east longitude. It has an average elevation of 1000 metres with peaks ranging from 2500 to 3000 metres above mean sea level. This region is the provenance of all the river systems that sustain the agroeconomy of Kerala. The typical natural vegetation of these high hills were closed canopy ever green forests often interspread with areas of grass and swamps. The pressure of population growth has forced the change from natural vegetation to the cultivation of crops and urbanisation of the hills. Effect of deforestation and other land use changes brought about by human activities on hydrologic cycle continues to be of great concern. Such changes often influence the response of the drainage basin, condition its output through the channels down and modify the hydrologic characteristics of the basin.

The amount of water moving out of a watershed depends on the rainfall, vegetation, the depth and waterholding capacity of the soil and the surface runoff. Thus both the amount of water moving out of a watershed and seasonal flow of the stream are dependant on the land use. The major application of geomorphology to hydrology lies in the prediction of flood peaks, runoff and sediment yield characteristics of a region for which no hydrologic data are available. In restricted areas where geology, climate and land use are uniform, it is the geomorphic variables that influence the hydrologic characteristics of drainage systems. To make geomorphic comparisons for this purpose, it is necessary to obtain quantitative expressions of land form characteristics and then develop quantitative relations between geomorphic and hydrologic variables. Once these relationships are established locally they can be extended elsewhere if other variables are unchanged.

Four small monoculture watersheds planted with perennial crops viz. cashew, rubber, coffee and tea were selected for the present study. The stream gauging and climatological data for these watersheds have been collected by CWRDM, Calicut. The data on soil characteristics were obtained by field observations. The data were analysed to identify the process of runoff and water transfer from upper to lower portions of the catchements. The unit hydrographs developed for predicting the runoff from these monoculture watersheds can be used for predicting the runoff from other similar watersheds. The present investigation was undertaken to study and assess the effect of land use on runoff from the small agricultural watersheds of Western Ghats of Kerala.

The specific objectives of the study are:

1. To study the effect of land use on water yield from small Agricultural Watersheds of Western Ghats.

2. To study the runoff hydrographs for the four selected monoculture watersheds planted with cashew, rubber, coffee and tea.

3. To construct the unit hydrographs for the four selected watersheds.

4. To study the hydrological parameters of the selected watersheds.

5. To study the geomorphological characteristics of the selected watersheds.

Review of Literature

REVIEW OF LITERATURE

The entire area from which the surface runoff due to storm drains through a definite drainage point is considered as a hydrologic unit and is called a drainage basin, watershed or catchment area. The amount of water moving out of a watershed depends on the rainfall, vegetation and the depth and water holding capacity of the soil. The boundary line along a topographic ridge, separating two adjacent watersheds is called a watershed divide. The boundary can be demarcated very accurately on a topographic map or on an aerial photograph. Extensive work on watershed hydrology has been done all around the world and the amount of literature available on the subject is voluminous. This chapter gives a brief review of the works which are relevant for the present study.

2.1 Watershed hydrology

The drainage basin is more than a geomorphological unit; it is also a hydraulic and hydrological unit. Besides, the drainage basin represents the source area of precipitation which is disposed of in several ways through various processes that constitute the hydrological or water cycle.

Thus, the drainage basin provides a convenient and natural unit area from which hydro-meteorological data can be collected and analysed and the details of the hydrological cycle and other physical processes can be meaningfully studied. Because the boundaries of the drainage basin are stable, natural and well defined, and because of the systemic attributes of the drainage basin, it is now increasingly being adopted as a suitable aerial (spatial) unit for development planning.

Basically, there are three methods of studying the drainage basin but all of them require that we have some measured data on forms and processes. The three methods are as follows:

(i) Field study of drainage basin - a real life drainage basin is instrumented and studied in the field.

(ii) Laboratory models by which drainage basin characteristics and processes are carefully simulated.

(iii) Methods of analogy based on knowledge of physical or statistical laws that govern drainage basin forms and their relationships to processes.

In hydrological study of a watershed we may:

(a) direct our attention to the component phenomena and their relationships (Physical hydrology),

(b) develop relationships among physical parameters involved in hydrologic events (Parametric hydrology),

(c) use the statistical characteristics of hydrological variables to generate hydrological data and solve hydrologic problems (Stochastic hydrology).

The qualitative study of geomorphological and other watershed properties for hydrological purposes can be applied to evaluate the water resources of the basin studied (Chiang and Peterson, 1970) and can also be applied for extrapolation of data from one basin to another, although the latter approach has been mainly used in surface run-off estimates and much less for purposes of ground water. Leaving apart the mapping of surface water features, in particular the drainage of swamps, the melting of snow, the identification of salinity encroaching the land, etc., it is basically a multi-disciplinary approach, in which geomorphology has a leading role, particularly when aerial photographs and other remote sensing imagery are used.

Burkham (1976) reported that for a small drainage basin a morphologic index based on the gravitational forces acting on the system and on the relative efficiency of the drainage system should provide a means for evaluation of drainage basin morphology for hydrologic purposes.

The assessment of the groundwater recharge potential is facilitated by a study of the texture and permeability of the surficial materials and deposits in the river bed. A careful study of the soil profile and the evaluation of internal drainage may give a clue to infiltration capacity. Soil erosion and vegetation characteristics are other useful indices. Discharge measurements of small, low order streams in the dry season may give representative data on baseflow characteristics and on medium to long storage in watersheds. If the measurements are carried out at a number of properly selected sites in representative physiographic units, an insight can be gained on the regional differences of long term storage in the drainage basin as a whole. The depression storage in swamps and lakes can be evaluated by a measurement of the fluctuations in their level and extent.

In the quantitative studies of drainage basins, morphometric parameters are emphasized and can be grouped into three catagories: size, shape and relief. When calculating the surface area of a watershed, the entire area between the divide line and the outfall with all sub and inter-basin areas should be considered. Peak discharge becomes proportionally less, whereas the baseflow increases. As a result, the hydrograph of large basins tends to be smoother than that of comparable basins of smaller size. There are several reasons for this situation. The overall rainfall intensity is less when a larger basin is considered, whereas the storage capacity and the time of flood concentration increase. Peak discharge depends on many physical characteristics of the basin concerned, including vegetative cover and anthropogenous impact.

The shape of the basin is another morphometrical factor affecting the discharge characteristics as reflected in the curve of the hydrograph. If we take an elongated basin and an approximately circular one of equal size, the unit hydrograph for the elongated basin will be smoother which is explained by the greater time lag for the water from upper catchment to reach the outlet. In case of a more circular basin, water from the lower, middle and upper catchment reaches the outlet in less time and causes higher discharges during a shorter period.

The slope angle and further relief characteristics of a basin are a third group of morphometrical factors of hydrological relevance (Speight, 1980). Steep slopes generally have high surface runoff values and low infiltration rates. Consequently they add to the steepness of the hydrograph and lead to relatively high peak discharges. The high proportion and velocity of the overland flow easily leads to sheet, rill and ultimately gully erosion. Apart from slope angle, length of slope associated with the relief amplitude should also be considered and in this way, terrain dissection is expressed in drainage density and the gradient of channels. Slope angle can be determined in the field, but contour maps or aerial photographs are more commonly used, because the measurements required are laborious. A crude indication of the basin slope can be obtained by using linear measure, such as the length of the main channel or the distance to the most remote point of the perimeter. However a variety of indices is used which involve parameters such as width, length and perimeter of the basin. Aerial photographs may be used with advantage to their determination.

Runoff comprises the rain water which leaves the drainage basin by surface routes, either as overland flow (water running down slopes in the form of sheet wash, rills and rivulets) or channel flow (water concentrated into streams and rivers). Overland flow is the process which leads to soil erosion (both sheet and gully erosion) and is widely regarded as active in shaping of slopes. It normally comprises a very thin layer of flowing water, rarely more than a few millimetres in depth and covering all or much of the slope surface. On the upper part of the slope, it maintains its character as sheet flow, otherwise sheet wash or concentrated wash. But on the lower part of the slope it may become concentrated into rills or rivulets, forming concentrated wash. One theory to account for overland flow is that proposed by R.E. Horton. Horton accepted that when rain falls at a low or even moderate intensity on a slope, as in humid temperate regions experiencing frontal rainfall, the resultant surface water will sink readily into the ground. This is simply because the intensity, perhaps in the order of 1 to 2 mm per hour, will be below the infiltration capacity of the soil, which may have a capacity to absorb rainwater at a rate of 5 to 50 mm per hour. However, if rainfall intensity, sometimes abbreviated to 'i', is high as during tropical thunderstorms, or the soil infiltration capacity 'f' is low, as in clay soils which have been baked by the sun's heat, then surface water cannot penetrate the soil sufficiently rapidly. The excess water therefore accumulates on the soil surface, where initially it will occupy small irregularities giving rise to depression storage. However, these will quickly fill and then overflow to form a continuous sheet of water flowing down the slope. This type of surface runoff is termed as infiltration excess flow or Hortanian overland flow. At the slope base, overland flow enters the stream or river channel, thus contributing to channel flow.

However, the Horton model is now recognised as having limitations. The model works well in some situations such as semi-arid environments in which rainfall intensity is often high but, in the absence of an effective vegetative cover which aids infiltration and impedes surface flow, infiltration capacity is low. In other situations, infiltration excess flow is rarely generated under natural conditions, that is, where the vegetation cover has not been seriously disturbed or destroyed, or where the upper soil layers have not been compacted by agriculture or removed altogether to expose the less permeable sub-soil. The presence of less permeable layers in the soil, or a relatively impermeable B-horizon can cause the build-up of water as the rainstorm proceeds. Throughflow becomes active resulting in the downslope migration of soil water. This will cause the soil to become saturated at the base of the slope, and then with the passage of time the saturated zone will be gradually extended upslope. When rain continues to fall on saturated soil, it cannot be absorbed, with the result that surface water accumulates and hence overland flow begins; this is known as saturation overland flow. On the lower parts of the slope, this surface flow increases because soil water which has migrated from upslope, by way of throughflow, tends to seep out again. If a rainstorm is particularly prolonged,.the area of the basin experiencing saturation overland flow can be increased very considerably. Moreover, since individual storms differ in duration, different extents of the drainage basin subjected at different times to overland flow of this type.

2.2 Hydrological studies in watersheds

Hoover (1962) has shown how canopy interception forms a greater percentage of light showers and a smaller percentage for flood producing storms. For storms in excess of 2 inches, this interception might well be less than 0.2 inches but the litter covering the floors of conifer stands could be expected to have a field moisture capacity of upto twice this amount.

Helvey and Patric (1965) showed that litter interception losses could reach 5 per cent of the annual precipitation and that it could be much more variable than canopy interception losses, particularly due to human intervention.

Borman and Likens (1967) carried out investigations in a catchment of north-east United States and highlighted the ecological chain of events which are the causes of poor catchment management in a temperate forest.

Patric et al. (1967) conducted studies on hydrologic effects of deforesting two mountain watersheds in West Virginia. They reported that water yield increased from both watersheds averaged almost 6 inches during the half deforested stage and rose to over 10 inches after complete deforestation. The duration of the flows greatly increased on both watersheds.

Tischendorf (1969) has drawn attention to the role of forest litter in promoting lateral down slope flow, as distinct from interception losses or infiltration. He referred to the ability of the litter layer to transmit water without changes in its moisture content and proposed that stormflow in a forested New England watershed was entirely the product of downslope flow in the litter zone.

FAO (1977) reported that the elimination of forest cover generally gives rise to a temporary increase in stream flow, principally due to reduction in evapotranspirational losses.

Klinge et al. (1978) estimated that about 50 per cent of the water falling as rain in the basin is derived from water transpired by the forest, a figure confirmed by a study of the water budget of a tropical rainforest.

According to Hudson (1981) to compute hydrological balance of a catchment, rainfall, runoff, consumptive use by crops, groundwater movement and changes in soil moisture have to be measured.

Nortcliff and Thornes (1981) studied the seasonal variations in the hydrology of a forested catchment near Manaus, Amazon Valley for management purpose.

Singh (1983) has recommended a geomorphic approach to hydrograph synthesis with potential for application to ungauged watersheds. The nature of streamflow in a region is a function of the hydrologic input to that region and the physical, vegetative, and climatic characteristics of that region.

2.2.1 Infiltration

Infiltration is defined as the entry of water from the air side of the air soil interface into the soil profile. The rate of movement of water into the soil will depend on the magnitude of the forces and gradients and also on the factors determining the hydraulic conductivity of the soil. The aspects of infiltration which are being considered important in hydrology are cumulative infiltration and infiltration capacity. Cumulative infiltration is the total quantity of water that enters the soil in a given time and infiltration capacity is the maximum rate at which rain can be absorbed by a soil in a given condition.

The physical properties and depth of the soil are probably the most important controls on subsurface flow production at a site. If the texture is coarse (with predominant sand and stones), vertical flow usually dominates; and when this soil is deep, subsurface flow response may be delayed. If the texture is fine, resistance to vertical flow results and lateral or shallow subsurface flow sometimes occurs quickly. Vegetation cover is directly related to (a) the maintenance of infiltration capacity, and (b) the conditioning effect of organic material on soil structure, bulk density and porosity. Land-use, while highly interrelated with vegetation cover, have direct effects on infiltration. Adverse land-use practices commonly have the greatest effect on infiltration; such abuses or overuse include overgrazing by cattle, repeated burning of litter and humus layers on the forest floor, and topsoil loss by accelerated erosional processes. Climate also has an indirect effect, acting particularly through the development of soil organic matter.

Horton's infiltration theory of runoff hinged on simple assumptions regarding the controls over infiltration capacity and its temporal variation, yet of all the components of the hillslope hydrological cycle none has been subjected to the more critical scrutiny of recent years.

Horton (1933) reported that, of all slope hydrological variables, the infiltration capacity of the soil surface was the easiest to measure with accuracy, and that from it, in conjuction with rainfall-intensity data, both surface runoff and total infiltration to ground water might be determined. In its simplest form, the infiltration theory of runoff predicts that prolonged rain falling on the slopes of a drainage basin having a uniform initial infiltration capacity, if its intensity is greater than the lower limiting infiltration capacity, ultimately produces overland flow (Hortanian) more or less simultaneously over all the basin after an initial abstraction due to surface storage.

Baver (1937) pointed out that water moves into and in the soil mass under the influence of both gravitational and capillary forces, the latter due to molecular forces between the soil particles and the water giving rise to very slow moisture movement from thicker to thinner capillary films. The investigation of the hydraulic effects of soil layers of variable permeability has also revolutionized our view of hill slope hydrology, particularly in terms of the promotion of lateral flow. Baver noted that infiltration rates are governed by the permeability of the least permeable soil horizon.

Sherman (1944) showed how rates of surface infiltration are inverse functions of the volume of capillary moisture in the soil column and that surface capillary intake decreases as the water penetrates deeper into the soil, although gravity flow in the larger channels continues to provide water at depth for lateral capillary absorption.

The field investigations of soil anisotropy by Reeve and Kirkham (1951) showed that, in some sites, horizontal permeability of saturated soil is greater than the vertical permeability.

Holtan (1961) had proposed a variation of Horton's infiltration equation when supply of water at the surface is not the limiting factor, but the problems of estimating infiltration through wide ranges of surface supply remain. Horton's empirical infiltration equation gives poor results for short-term infiltration rates, which are precisely those most important in governing hillslope hydrology.

Dunne and Black (1970) reported that one or more impeding layers, or a progressive decrease in permeability with depth appears to be a pre-requisite for appreciable subsurface stormflow, and it is normal for this flow to be concentrated in a saturated layer.

Poeson (1984) reported that soil saturated on steep slopes will absorb, especially at the beginning of a rainfall event, more rain water compared to the soil saturated on a low slope. This is due to a spatial varying matric potential induced by a gravitation potential.

Varadan and Raghunath (1985) reported that the infiltration rates for latesols of Kerala are 12-20 cm/hr after 6 hr of study. They also reported that infiltration rates increase towards higher elevation and such variation occurred for latesols of Kerala even at an elevation difference of 3 metres.

It is true to say that, whereas both practical and theoretical work on infiltration processes has proceeded apace, there have continued to exist difficulties in linking infiltration rates with the excess of rainfall required to produce the overland flow presumed by Horton to be solely responsible for hydrograph peaks.

2.2.2 Runoff

Although Horton Placed much emphasis on overland flow (rainfall intensity-infiltration rate) as the origin of storm hydrograph peaks and the motor of surface erosion, he was always strangely defensive regarding one's inability to commonly observe this phenomenon, particularly on vegetated and soil-covered slopes. His sequence of events when rainfall intensity exceeds infiltration rate are:

(i) A thin layer forms on the surface and downslope surface flow is initiated.

(ii) The flowing water accumulates in surface depressions.

(iii) When full, these depressions begin to overflow.

(iv) Overland flow enters micro-channels, which combine to form rivulets, in turn discharge into small gullies and this being continued until discharge into major channel occurs.

(v) Along each collecting channel, lateral inflow from the land surface takes place.

Kirkby (1967) has pointed out that Horton overland flow will occur instantaneously over a basin only if it is small and has a really homogeneous soil, soil moisture, interception, depression storage and infiltration conditions. Further, although Horton overland flow is quite common where vegetation is sparse and soil is thin, it is rare where there is a vegetative cover.

Lull and Reinhart (1967) reported that removal of all vegetation from a forested watershed increased annual water yield during the first year after treatment by 4 to 12 inches in humid north eastern united states.

According to Haggett and Chorley (1969) many storms may be expected to produce overland flow from limited contributing areas at much lower rainfall intensities than are required to exceed the infiltration capacities over the whole basin and so to produce universal hortanian overland flow. These limited areas are,

1. Zones at the slope base, immediately marginal to stream channels where, despite the usually thicker soil lateral soil drainage commonly produces high antecedent moisture conditions in the upper layers. The extent of such contributing areas is initially controlled by the soil characteristics and antecedent moisture conditions, but as the storm continues the zone of saturation may extend upslope to an extent determined by the temporal pattern of the storm intensity and the characteristics of the slope soil profile, including hydraulic efficiency and available soil moisture storage.

2. Concavities or topographic hollows where surface flowlines converge. Stream-head hollows are for this reason especially susceptible to surface runoff.

3. Areas of thin soil cover.

According to Royer (1969) most of the storm runoff usually originates from a small portion of the total drainage area and that locations and extent of the source area is dependent upon rainfall intensity, antecedent moisture and depth of 'A' horizon. For a rain storm of constant intensity the contributing area A_c is defined as,

$$A_c = \frac{\text{Storm discharge}}{\text{Rainfall intensity}}$$

where the rainfall intensity varies during the storm and its value in the equation is necessarily an average one weighed towards the most recent intensities.

Tischendorf (1969) studied 55 storm events in the whitehall watershed in the southeastern piedmont (60 acres of vegetated surface, with regolith 30-100 feet deep) during the period January 1967 to March 1968 and observed no overland flow at all during that period, although 10 of the storms produced strong peaks in the runoff hydrograph.

Hewlett and Nutter (1970) recognizing that some surface runoff is commonly made up partly of water which has infiltrated and moved only a few inches or feet in the soil before seeping out downslope, have proposed to limit the term overland flow to rainwater that fails to infiltrate the soil surface at any point on its way from the basin to the gauging station. Thus overland flow would be largely viewed as saturation overland flow resulting from rain falling on already saturated parts of the surface and should be logically treated as an expansion of the perennial channel system into zones of low storage capacity.

Rawitz _et al_. (1970) studying the water balance of a 16-hectare watershed on shallow sandstone and shale soils in east-central Pennsylvania during 10 storms, concluded that viable overland flow from a storm event was a rare event, eventhough the streamflow hydrographs indicate a rapid response to rainfall and have all the characteristics usually attributed to surface runoff.

Roche (1979) developed a methodology to monitor runoff and soil erosion from soils under different land uses. The results obtained indicate that the soil erosion and runoff are influenced by the hydrological characteristics of the soil. High vertical drainage of soil in a watershed resulted in low surface runoff and soil erosion.

2.2.2.1 Hydrograph analysis

The basis of hydrograph analysis is that since a stream hydrograph reflects many of the physical characteristics of the catchment area, similar hydrographs will be produced by similar rainfalls occurring with comparable antecedent conditions. Thus once a typical or unit hydrograph has been determined for certain already defined conditions, it is possible to establish runoff from a rainfall of any duration or intensity.

According to Sherman (1932) the unit hydrograph (originally named unit-graph) of a watershed can be defined as a direct runoff hydrograph resulting from 1 inch (usually taken as 1 cm in SI units) of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration. Sherman originally used the word 'unit' to denote a unit of time, but since that time it has often been interpreted as a unit depth of excess rainfall. Sherman classified runoff into surface runoff and groundwater runoff and defined the unit hydrograph for use only with surface runoff.

The unit hydrograph is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess rainfall. The following basic assumptions are inherent in this model:

1. The excess rainfall has a constant intensity within the effective duration.

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2. The excess rainfall is uniformly distributed throughout the whole drainage area.

3. The base time of the direct runoff hydrograph (the duration of direct runoff) resulting from an excess rainfall of given duration is constant.

4. The ordinates of all direct runoff hydrographs of a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph.

5. For a given watershed, the hydrograph resulting from a given excess rainfall reflects the unchanging characteristics of the watershed.

According to Rodd (1969) the unit hydrograph is a simplified concept of the behaviour of a basin in converting rainfall to streamflow. It is based on the premise that it is effective in causing runoff and the system is time invariant. It is assumed that the runoff from effective rainfalls of the same duration produced by isolated storms on the same basin causes hydrographs of equal length in time. Another assumption is that, ordinates of unit hydrograph are proportional to the total volume of direct runoff from rainfalls of equal duration and uniform intensity irrespective of the total volume of rain.

Gregory and Walling (1973) reported that the unit hydrograph associated with the small contributing area exhibits a rapid rise and recession while that associated with the larger area rises more slowly and provides a more protracted recession.

Heerdegen (1974) reported that under natural conditions, the assumptions of a unit hydrograph cannot be perfectly satisfied. However, when the hydrologic data to be used are carefully selected so that they come close to meet the assumptions, the results obtained by the unit hydrograph model are generally acceptable for practical purposes.

2.3 Cultivated watershed studies

A number of studies have been reported with regard to experimental cultivated watersheds of the United States. Some of these studies describe the general use of the watersheds for purposes such as farming and forestry.

Sharp et al. (1966) reported the results of a comprehensive investigation in Nebraska. They found that conservation practices reduced surface runoff from small watersheds from 25 to 40 per cent particularly in dry years but no satisfactory method was available for transfering such results to large complex watersheds. On small plots the effects of changing from one cropping practice to another are variable and sometimes opposite depending on the particular combination of soil, geology, climate, vegetation and water management practices.

Blaisdell (1979) reported that erosion control structures are needed on agricultural watersheds because vegetation and supporting soil and water conservation practices used alone often are not sufficient to prevent erosion due to concentrations of runoff or flows of long duration.

Russell (1980) reported that it is not necessary to use plantation forests for the protection of watersheds, for in suitable areas perennial crops such as coffee, tea and bananas can take the place of trees. A 750 hectares estate cleared from a high evergreen forest and planted with tea gave similar results as from evergreen forest.

2.4 Small watershed studies in India

Considerable studies have been reported on large watersheds and river catchments in India. But, only a few studies have been reported with regard to small watersheds of the country. Detailed watershed studies may reveal the type of conservation measures and how to manage these watersheds.

Gupta *et al*. (1970) have reported that peak runoff rates can be estimated by the monographs prepared on the basis of (i) rational formula; (ii) Cook's method and (iii) hydrologic soil cover complex method, for small watersheds upto 300 ha in area. They have obtained the value of the constant of the formula for small agricultural watersheds specific for Doon Valley as 0.22.

Rambabu et al. (1974) have observed for Dehra Dun that as a result of field bunding of a small agricultural watershed, there has been a 62 per cent reduction in runoff and 40 per cent reduction in the peak runoff rate.

Investigations conducted by Kaushal et al. (1975) on a 2 ha watershed in the Siwalik ranges of Chandigarh showed that the total runoff and peak rate of runoff were reduced by 60.4 per cent and 58 per cent respectively as a result of the following soil and water conservation measures:

(i) Construction of earthern debris basins,
(ii) earthern pondage banks,
(iii) staggered contour trenches, and
(iv) planting with eucalyptus and acacia catechu.

Kranz et al. (1978) have studied small agricultural watersheds as a part of ICRISAT's research programme on improved resources utilization, the central objective was to make the best use of the rain that falls on a given area.

Materials and Methods

MATERIALS AND METHODS

The amount of water moving out of a watershed and seasonal flow of the stream are dependant on the land use. The present study aims to assess the extend upto which the land use affect the runoff from small agricultural watersheds of Western Ghats. The materials used and methodology adopted for conducting the study are described in this chapter.

3.1 Experimental catchments

Four small watersheds planted with cashew, rubber, coffee and tea were selected for the study. Surveying of the watersheds and collection of meteorological and stream gauging data were already been carried out by CWRDM, Calicut. The location and details of each watershed are given in Table 1. Figure 2 shows the location map of the selected watersheds.

3.1.1 Watershed with cashew plantation

This watershed is located in Perambra village under Quilandy Sub-district of Kozhikkode district, in the catchment area of Peruvannamuzhi reservoir of Kuttiadi Irrigation Project. It is situated at 11°37'38" north latitude and 75°45'8" east longitude. The entire 29.5 hectares of this

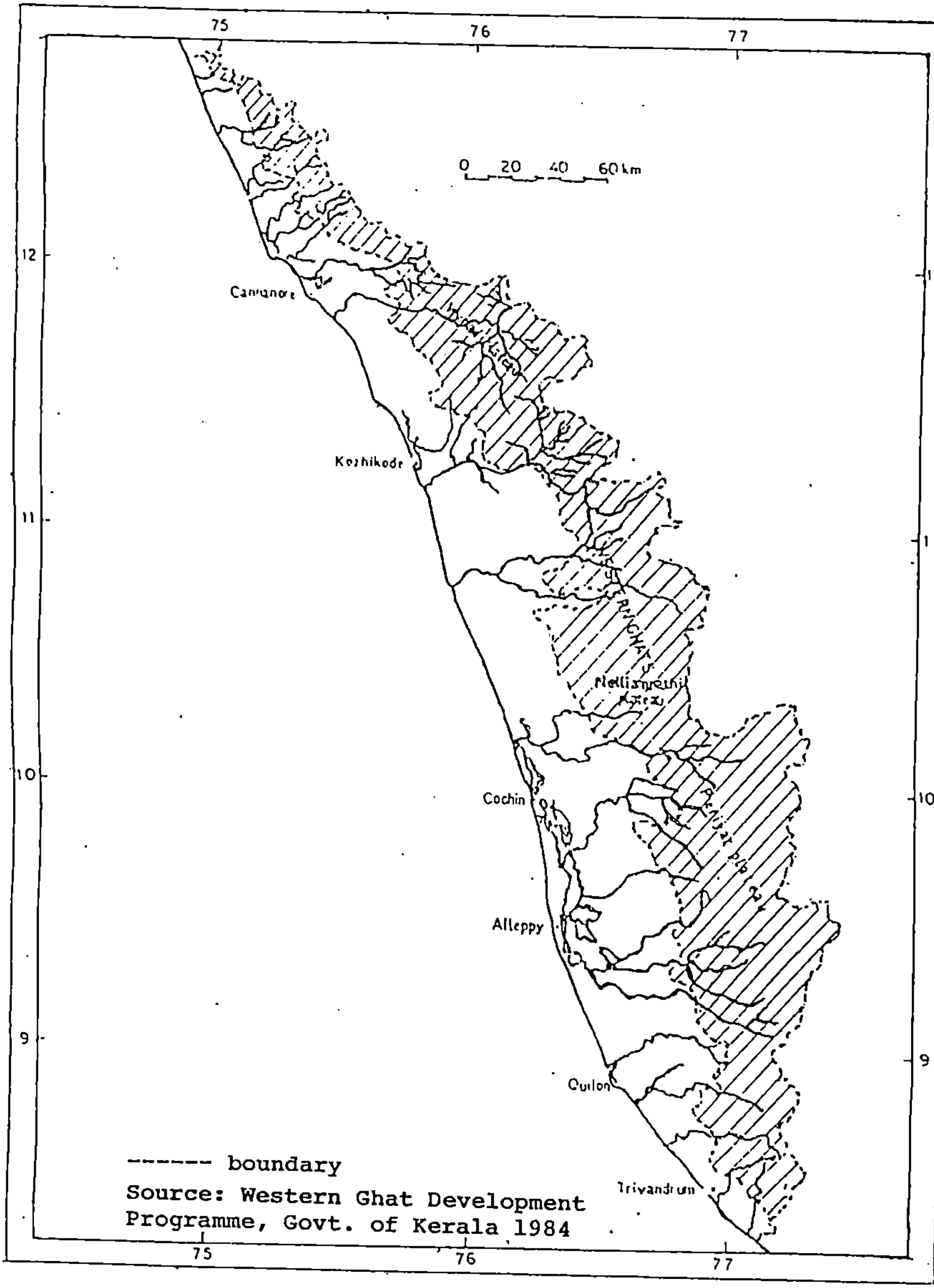


Fig.1 Western Ghats of Kerala

Table 1. Details of the selected watersheds

Sl.No.	Watershed	Land use	Area (ha)
1.	Perambra Estate, Plantation Corporation of Kerala, P.O. Muthucad, Peruvannamuzhi, Calicut.	Cashew Plantation	29.50
2.	Perambra Estate, Plantation Corporation of Kerala, P.O. Muthucad, Peruvannamuzhi, Calicut.	Rubber Plantation	1.90
3.	Beenachi Estate, (A M.P. Govt. undertaking) P.O. Beenachi, Sulthan Bathery, Wyanad.	Coffee Plantation	74.87
4.	Achoor Estate, Harrison Malayalam Ltd., Achooranam (PO), Pozhuthana, South Wyanad.	Tea Plantation	61.74

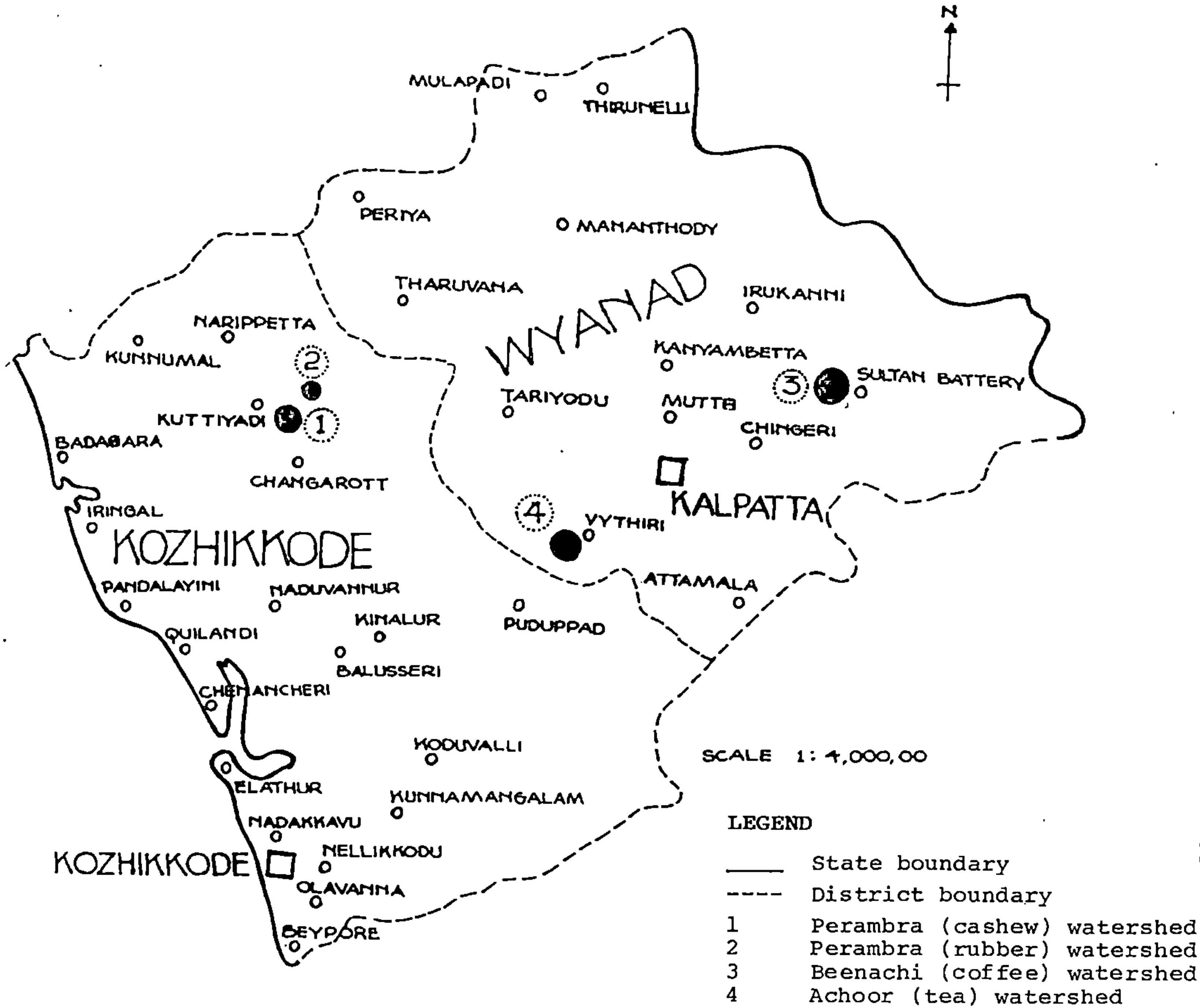


Fig.2 Location map of the selected watersheds

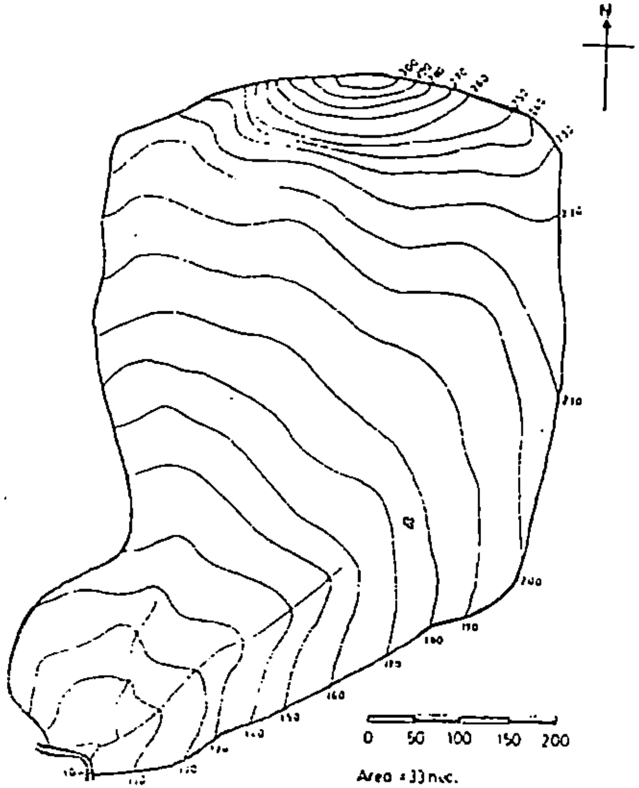


Fig.3 Perambra watershed (cashew)

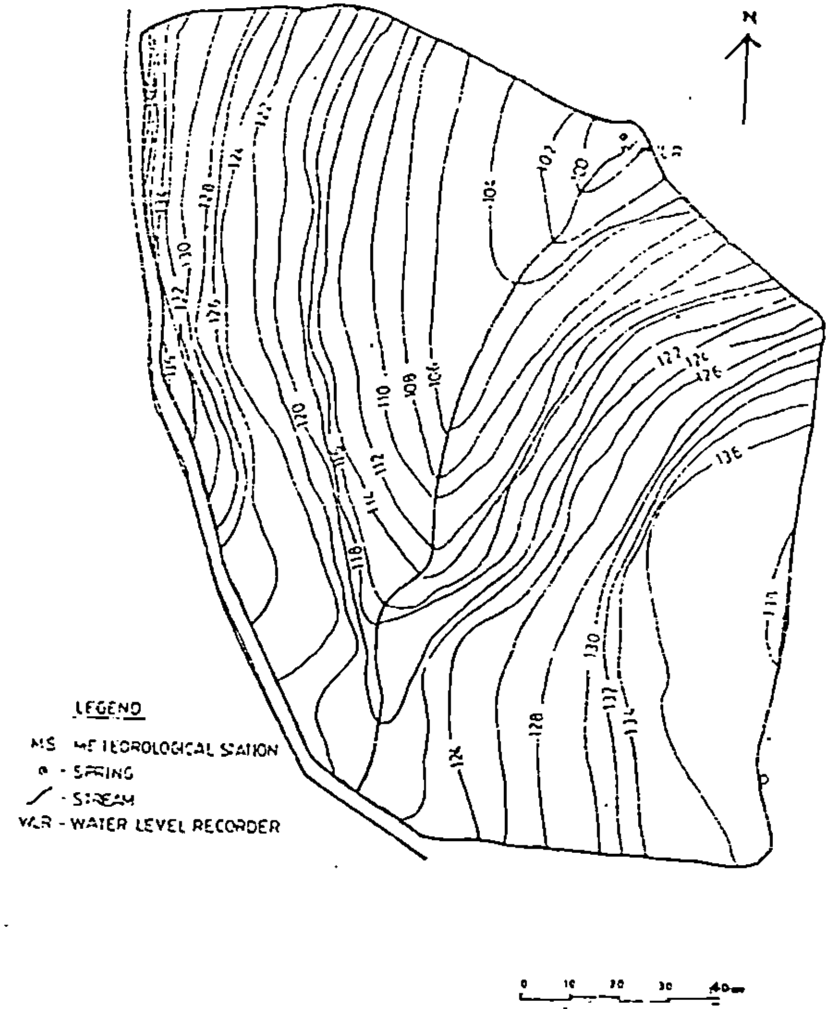
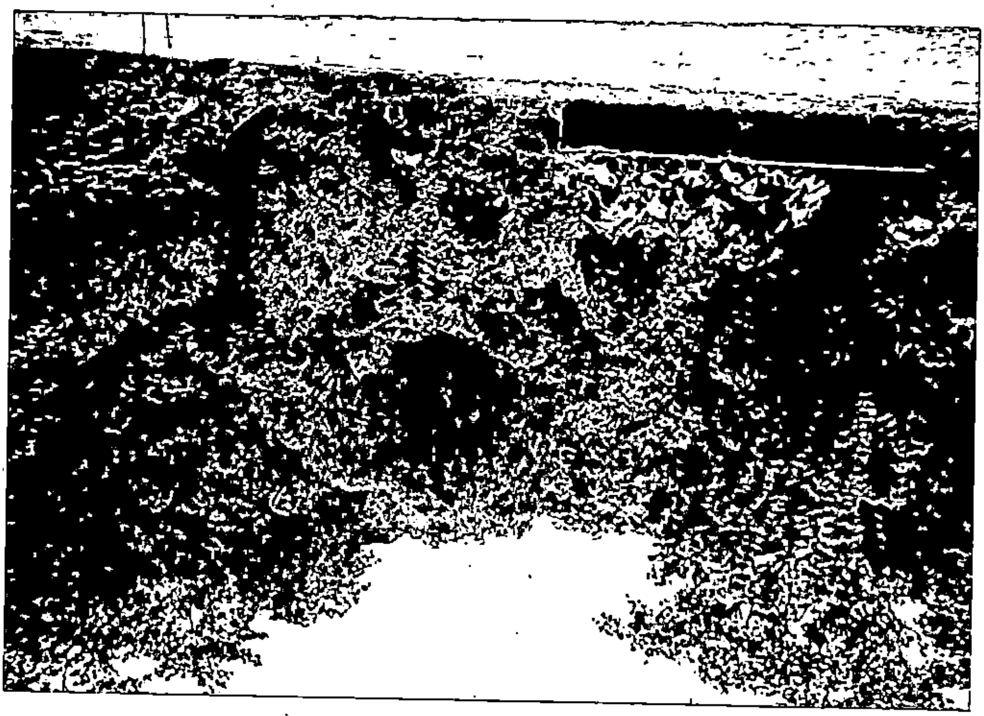


Fig.4 Perambra watershed (rubber)

Plate I A view of Perambra watershed (cashew)

Plate II A view of Perambra watershed (rubber)



watershed is planted with cashew. This leaf shaped watershed has a maximum stream length of 650 m with an elevation difference of 200 m. The perimeter of the watershed is 2150 m. The contour map of the watershed is given in Fig.3. A view of the watershed is given in Plate I.

3.1.2 Watershed with rubber plantation

This watershed is also located in Perambra village under Quilandy Sub-district of Kozhikkode district, in the catchment area of Peruvannamuzhi reservoir of Kuttiadi Irrigation Project. It is situated at 11°37'6" north latitude and 75°45'26" east longtitude. This watershed of 1.9 hectares is nearly triangular in shape and is completely planted with rubber. The perimeter of the watershed is 500 m. This watershed does not have a well defined stream channel. The contour map is given in Fig.4. A view of the watershed is given in Plate II.

3.1.3 Watershed with coffee plantation

This watershed is located in Sulthan Bathery village under Sulthan Bathery Sub-district of Wyanad district. It is situated at 11°38'44" north latitude and 76°10'14" east longitude. The area of the watershed is 74.87 hectares and is planted completely with coffee. The shape of this watershed is irregular and the maximum length of the stream is 1580 m

Plate III A view of Beenachi watershed (coffee)

Plate IV A view of Achoor watershed (tea)

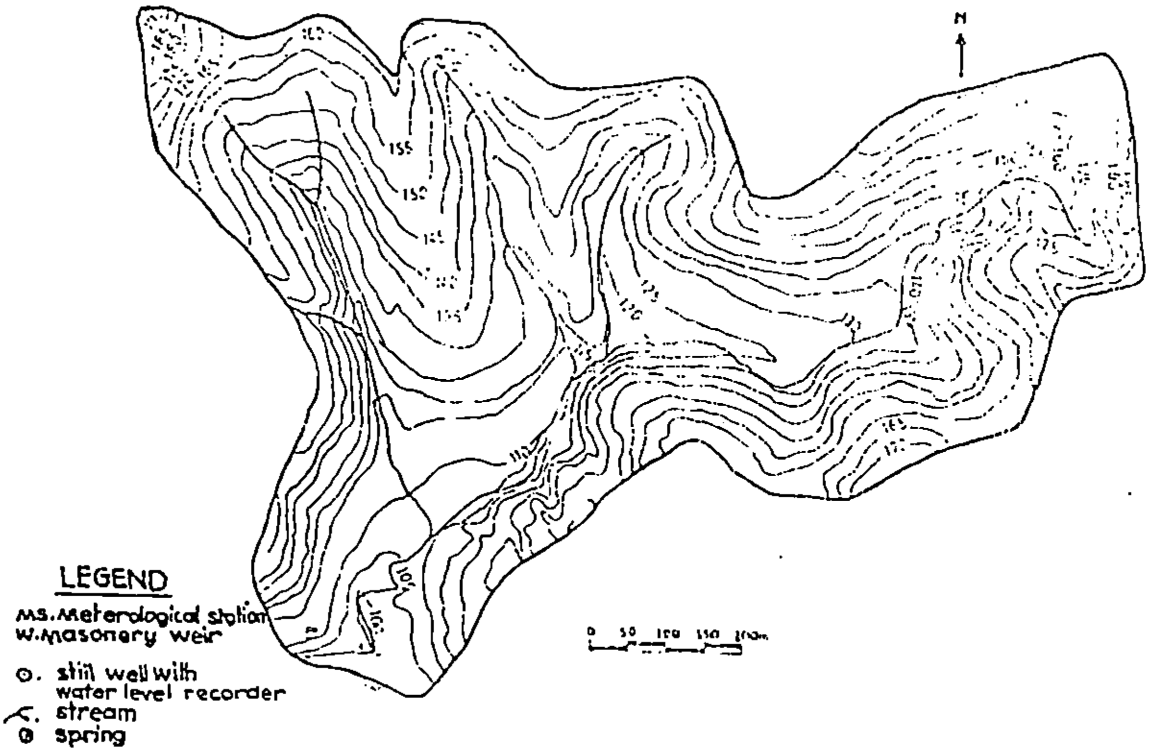


Fig.5 Beenachi watershed (coffee)

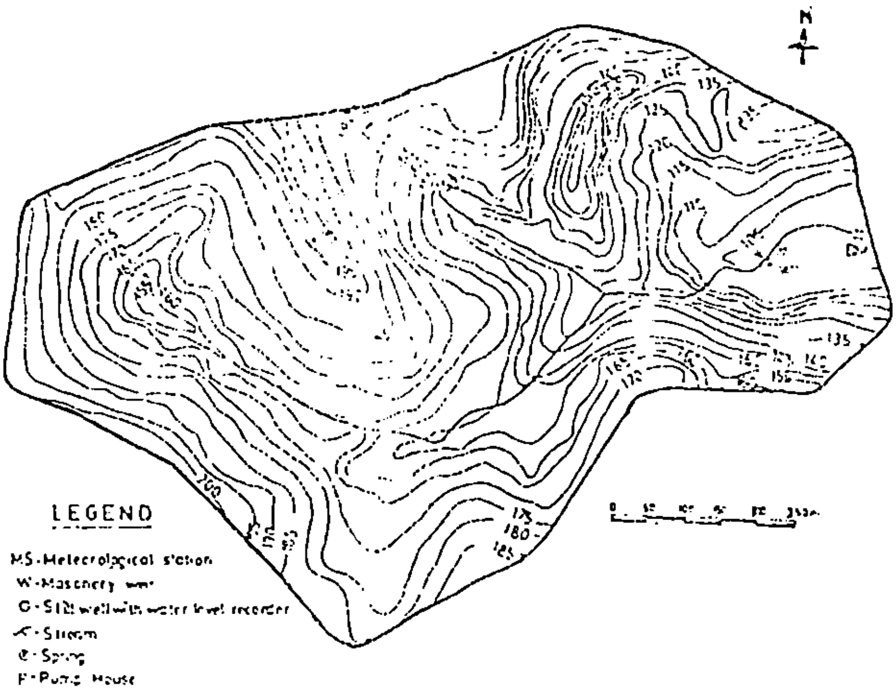


Fig.6 Achoor watershed (tea)

Plate III A view of Beenachi watershed (coffee)

Plate IV A view of Achoor watershed (tea)

with an elevation difference of 90 m. The perimeter of the watershed is 4380 m. The contour map is given in Fig.5. A view of the watershed is given in Plate III.

3.1.4 Watershed with tea plantation

This watershed is located in Achooranam village under Vythiri Sub-district of Wyanad district. It is situated at 11°32'35" north latitude and 76°2'46" east longtitude. This watershed is nearly hexagonal in shape and is entirely planted with tea. The watershed has a well defined stream originating from a natural swamp. The maximum length of the stream is 1080 m with an elevation difference of 95 m. The watershed covers an area of 61.74 hectares with a perimeter of 3240 m. The contour map is given in Fig.6. A view of the watershed is given in Plate IV.

Watershed with cashew plantation, watershed with rubber plantation, watershed with coffee plantation and watershed with tea plantation are referred to as cashew watershed, rubber watershed, coffee watershed and tea watershed respectively in the subsequent sessions for easy reference.

3.2 Instrumentation

Meteorological stations were established in each of these watersheds for recording the rainfall, pan evaporation, temperature and humidity. Stage level recorders along with masonry weirs and flumes were installed to measure the stream flow.

3.2.1 Rain gauges

The source of water available for runoff is the rain that falls on the watershed. The accurate measurement of rainfall is important and it was achieved with the use of non-recording and recording type rain gauges for each watershed. The non-recording type rain gauge was used along with a recording type rain gauge for cross checking. The total rainfall in a given period of time is measured by a non-recording type rain gauge. The rain water is received in a brass funnel and directed to a suitable glass jar, kept enclosed in a metallic cylindrical case. The rainfall characteristics such as intensity, frequency, duration and amount which influence the rate and amount of runoff are obtained by a recording type (automatic) rain gauge. The recording type rain gauge consists of a galvanized iron cylinder, 22.5 cm in diameter and 60 cm high with a funnel. The spout of the funnel leads into an inner circular tube of brass. The recording mechanism consists of a clock-driven drum carrying the record sheet, on which a pen traces the graph of rainfall against time. Fresh charts are set at fixed time after every 24 hours. The recording pen is fixed on a rod which is connected to a float in the inner cylinder. As water accumulates in the cylinder the float rises along with the inking pen, which records the characteristics of the storm. When the cylinder is full, connection is established with the inner cylinder and siphon tube and the entire water in the cylinder is drained away and the float and the inking pen drops back to the zero position.

3.2.2 Open pan evaporimeter

Evaporation measurement was done by the pan evaporimeter. The standard USWB class A pan, the most commonly used evaporation pan was used for this purpose. It is made of 22 gauge G.I. sheet, 120 cm in diameter and 25 cm in depth and is painted white and emposed on a wooden frame in order that air may circulate beneath the pan. It is filled to a depth of about 20 cm. The water surface level is measured by means of a hook gauge in a stilling well and evaporation is computed as the difference between observed levels adjusted for any precipitation measured in a standard rain gauge. The pan has higher rates of evaporation than a free large water surface and a factor of about 0.7 is usually recommended for converting the observed evaporation rate to those for a large water surface area. This factor is called pan coefficient. The evaporation is measured in mm of water evaporated per day.

3.2.3 Thermometers

The measurement of temperature was done with the help of thermometers enclosed in a Stevenson screen. This screen is usually made of pine or similar wood and painted white. It is important that the paint should be kept in good condition to minimise the absorption of radiation by the screen.

3.2.3.1 Maximum thermometer

The mercury thermometer with a constriction in the capillary was used to register the maximum temperature attained during an interval. When temperature rises the column breaks at the constriction leaving a thread of mercury in the tube indicating its highest reading. The thermometer is kept in horizontal position.

3.2.3.2 Minimum thermometer

Minimum thermometer is a spirit thermometer with a small dark glass index in the bore. This index is kept inside the spirit column by the surface tension of the meniscus. The thermometer is always installed in horizontal position and as the temperature fades, the index is pulled towards the bulb, remaining stationary as the temperature rises. The position of the outer end of the index is therefore an indication of the minimum temperature which has occurred since the last setting.

3.2.4 Stage level recorder

Since it is difficult to make continuous direct measurement of the rate of flow in a stream, discharges were derived from stage level recorders. This approach is satisfactory only if there is an adequate correlation between stage and discharge. Stage level recorders were installed along with masonry weirs or flumes. The stage level recorders were housed to one side of the flume above a still well which is connected to the stream by a horizontal tapping pipe. The water level recorder consists of a time element and a water height element which operate together and produce on the chart the rise and fall of water level with respect to time. The time element is a clock operating a recording pen. The water level is recorded with the help of a float and a counter weight operating in a stilling well. The float of the instrument is free to move up and down the well with the variation of the water level and its movements are transferred to the chart with the help of recording pen. The river stage at any time can be converted into discharge by using the stage-discharge rating curve. The stage-discharge relationships were derived for each weir or flume. The discharge values, in units of flow rate are converted into units of depth over the watershed by dividing it with the area of the respective watershed.

The runoff and the meteorological data were calculated on weekly basis for the years 1985, 1986 and 1987. The average weekly values were obtained by taking the average of the values of three years. Standard weeks of 7 days were selected during the monsoon season of each year for all the watersheds. The weeks with unreliable data were not accounted for, while selecting the standard weeks. Though the standard weeks were not the same for all the watersheds, for individual watersheds they were the same for all the years. The data were calculated for rubber and cashew watersheds for 20 such standard weeks and for 23 standard weeks in the case of coffee and tea watersheds.

3.3 Soil analysis

Soil samples were collected from few representative locations of each watershed to determine the different soil characteristics like grain size distriction, pH value and organic carbon content.

3.3.1 Grain size distribution

The grain size distribution of the soils were determined by sieve analysis. The soil samples were hand crushed and kept in an oven at 105°C for 24 hours. One kg each of the oven dried samples were weighed out for sieve analysis. The sieves selected were of 4.75 mm, 2.0 mm, 425

Plate V Collecting soil sample from a watershed

Plate VI Outlet of a watershed

micron and 75 micron IS sieve size. The sieves were arranged in ascending order and kept in a sieve shaker. The sample is transferred to the top sieve and the sieve shaker is operated for 15 minutes. The soil particles retained in each sieve and in the bottom collector plate are weighed separately. The soil particles having size, greater than 4.75 mm are grouped as gravel, 4.75 mm to 2.0 mm are grouped as coarse sand, 2.0 mm to 425 micron are grouped as medium sand, 425 micron to 75 micron are grouped as fine sand and less than 75 micron are grouped as silt and clay.

3.3.2 pH value

The soil pH was determined using a glass electrode pH meter. Twenty gram of the air-dry soil (passed through 2 mm IS sieve) is weighed into a 50 ml beaker. Twenty ml of distilled water is added to this and allowed to stand for 30 minutes. The solution is stirred occasionally with a glass rod. The electrode of the pH meter is inserted into the partly settled suspension and the pH value is noted.

3.3.3 Organic carbon content

The organic carbon content was determined by titration. One gram of the soil sample (passed through 0.5 mm sieve) is weighed into a 250 ml flask. Ten ml of 1 N $K_2Cr_2O_7$ solution is pippetted into the flask and is swirled gently. Twenty ml of con. H_2SO_4 is added rapidly to this and the flask is swirled gently until soil and reagents are mixed, then it is swirled vigorously for one minute. Hundred ml of distilled water is added to this after allowing it to stand for 30 minutes. Thre to four drops of indicator is added to it and titrated with 0.5 N ferrous sulphate solution. As the endpoint is approached, the solution takes on a greenish cast and then changes to dark green. At this point the ferrous sulphate solution is added drop by drop until the colour changed sharply from blue to red in reflected light against a white background. The percentage organic carbon in the soil on air-dry basis is given by,

$$\text{\% organic carbon} = \frac{(\text{me } K_2Cr_2O_7 - \text{me } FeSO_4) \times 0.3 \times f}{\text{gms of air-dry soil}}$$

correction factor, f = 1.33 and

me = normality of solution x ml of solution used

3.4 Infiltration studies

Infiltration studies were conducted in each watershed using double cylinder infiltrometers. The infiltration measurements were taken at two to three representative locations of each watershed and the average values were taken. The lateral movement of water from the inner cylinder is minimized by ponding water in a guard cylinder or buffer area around the cylinder. The cylinders are 25 cm deep and are formed of 2 mm rolled steel. The inner cylinder, from which the infiltration measurements are taken, is 30 cm in diameter and the outer cylinder, which is used to form the buffer pond is 60 cm in diameter. The cylinders are installed about 10 cm deep in the soil. Care is taken to keep the installation depth of the cylinders the same in all experiments. The cylinders are driven into the ground by a falling weight type hammer striking on a wooden plank placed on the top of the cylinder. The water level in the inner cylinder is read with a hook gauge. The hook gauge is set at the desired level to which water is to be added. Water is added to the inner cylinder from a container of known volume and a graduated jar. A stop watch is used to note the instant the addition of water begins and the time the water reaches the desired level. The difference between the quantity of water added and the volume of water in the cylinder at the instant it reaches the desired point is taken as the quantity of water that infiltrated during the time interval between the start of filling and the first measurement. After the first reading, hook gauge readings are noted at different intervals to determine the amount of water that has infiltrated during the time interval. Water is added quickly after each measurement so that a constant average infiltration head could be maintained. The buffer pond is filled with water immediately after filling the inner cylinder. Water levels in the inner cylinder and the buffer pond are kept approximately the same.

The functional relationship between accumulated infiltration, y and elapsed time, t is best represented by the equation $y = at^{\alpha} + b$, where a, b & α are constants. The values of y and t were plotted on a log-log scale to get a straight line relationship. These plots were used to derive the infiltration equations. The procedure for deriving the equation is given in Appendix-I with specimen calculation.

3.5 Geomorphological characteristics of the watersheds

Different factors are used to express the shape and topographical characteristics of the watersheds. It was difficult to work out the important geomorphological characteristics like drainage density and bifurcation ratio for these watersheds. This is because the watershed areas vary from 1.9 to 74.87 hectares and it is difficult to get the stream lengths of different orders from the topo-sheets. The different geomorphological factors worked out for the watersheds were form factor, basin circularity, basin elongation and mean basin slope.

3.5.1 Form factor

The form factor, Rf is defined as the ratio of the basin area to the square of the basin length.

$$Rf = A/L^2$$

where,

A = area of the basin, m^2

L = length of the basin, m

The value of form factor nearer to unity refers to an approximately square basin. In this case the tributaries often tend to come together and join the main stream near the centre of the area. Consequently the separate runoff peaks generated by a heavy rainfall in the individual tributaries are likely to reach the main stream in approximately the same locality and time, thereby resulting in a large and rapid increase in runoff.

3.5.2 Basin circularity

Basin circularity, Rc is defined as the ratio of the basin area to the area of a circle having the same perimeter as the basin.

Let P be the perimeter of the basin

$$P = \pi d \text{ or } d = P/\pi$$

$$\text{Area} = (\pi/4)\, d^2 = \pi/4 \times P^2/\pi^2 = \frac{P^2}{4\pi}$$

Then,

$$\text{Basin circularity, } Rc = \frac{4\pi A}{P^2}$$

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where,

A = area of the basin, m^2

P = perimeter of the basin, m

For a nearly circular basin the value of 'Rc' is approximately equal to 1. In the case of a more circular basin, water from the lower, middle and upper catchments reaches the outlet in less time and causes higher discharge during a shorter period.

3.5.3 Basin elongation

Basin elongation, Re is defined as the ratio of the diameter of a circle whose area is same as the basin area to the length of the basin.

$$\text{Area of the basin, } A = (\pi/4)\, d^2$$

$$\text{ie.} \quad d^2 = \frac{4A}{\pi} \quad \text{or} \quad d = 2\sqrt{A/\pi}$$

$$\text{i.e. Basin elongation, } Re = \frac{2\sqrt{A/\pi}}{L}$$

where,

A = area of the basin, m^2

L = length of the basin, m

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

3.5.4 Mean basin slope

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

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

Steep slopes generally have high surface runoff values and low infiltration rates. Consequently they add to the steepness of the hydrographs and lead to relatively high peak discharges. The high proportions and velocity of overland flow easily leads to sheet, rill and ultimately gully erosion. Specimen calculation of geomorphological characteristics is given in Appendix-II.

3.6 Hydrograph analysis

The basis of hydrograph analysis is that since a stream hydrograph reflects many of the physical characteristics of the basin, similar hydrographs will be produced by similar rainfalls occurring with comparable antecedent conditions. Thus once a typical or unit hydrograph has been derived for certain already defined conditions, it is possible to establish runoff from a rainfall of any duration or intensity.

3.6.1 Runoff hydrograph

The runoff hydrograph or storm hydrograph is a graph showing the flow rate as a function of time at a given location on the stream. To derive the storm hydrograph, the stage hydrograph recorded by the stage level recorder corresponding to the selected storm was obtained. The stage heights at regular time intervals were converted to corresponding flow rates using the stage-discharge rating curve. The flow rates were then plotted against the corresponding time to get the storm hydrograph. The hyetograph of the storm is also plotted on the same time scale in the form of an inverted histogram. A rainfall hyetograph is a plot of rainfall depth as a function of time.

3.6.2 Baseflow separation

The slowly varying flow during rainless periods is called baseflow. A variety of techniques have been suggested for separating baseflow and direct runoff.

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

In the fixed base method surface runoff is assumed to end at a fixed time, N days after the hydrograph peak. The baseflow before the surface runoff began is projected ahead to the time of the peak. A straight line is used to connect this projection at the peak to the point on the recession limb at N days after peak. Where $N = 0.83\ A^{0.2}$, A is the drainage area, km^2.

Baseflow can also be separated by drawing a line from the point of rise to the point on the recession limb, N days after peak.

The above two methods could not be used for the present study because the values of N obtained were more than the total base period of the hydrographs in all the cases.

The variable slope method of baseflow separation (Chow, V.T.) was used here. In this method the baseflow curve before the surface runoff began is extrapolated forward to the time of peak discharge, and the baseflow curve after surface runoff ceases is extrapolated backward to the point of inflection on the recession limb. A straight line is used to connect the endpoints of the extrapolated curves. This type of separation is preferred where groundwater contributions are relatively large and reach the stream fairly rapidly.

3.6.3 Unit hydrograph

The unit hydrograph is defined as the hydrograph of the storm runoff resulting from an isolated rainfall of some unit duration occurring uniformly over the entire area of the basin and produces a unit volume (1 cm) of runoff. The unit hydrograph is a simplified concept of the behaviour of a basin in converting rainfall to streamflow. It is assumed that the runoff from effective rainfalls of same duration produced by isolated storms of the same basin causes hydrographs of equal length in time. The ordinates of unit hydrograph are proportional to the total volume of direct runoff from rainfalls of equal duration and uniform intensity irrespective of the total volume of rain. In general, if a unit hydrograph of a given unit duration is available, unit hydrographs of other durations can be derived by the application of the principle of superposition.

Once the unit hydrograph has been derived, it may be applied to find the direct runoff and streamflow hydrographs. A rainfall hyetograph is selected, the abstractions are estimated and the excess rainfall hyetograph is calculated. The time interval used in defining the excess rainfall hyetograph ordinates must be the same as that for which the unit hydrograph was specified. The streamflow hydrograph is obtained by adding the estimated baseflow to the direct runoff hydrograph.

3.6.3.1 Derivation of unit hydrographs

The procedure used for deriving the unit hydrographs is given below:

(i) Select from the records, isolated (single peaked) intense storms which have occurred uniformly over the catchment and have produced flood hydrographs with appreciable runoff (greater than 1 cm). The unit period selected should be such that the excess rainfall (Pnet) occurs fairly uniformly over the entire watershed. Larger unit periods are required for larger basins. The unit periods may be in the range of 15 to 30 per cent of the peak time period.

(ii) Select the flood hydrograph which has resulted from a unit storm chosen above.

(iii) Separate the baseflow from the total runoff.

(iv) From the ordinates of the total runoff hydrograph (at regular time intervals) deduct the corresponding ordinates of the baseflow to obtain the ordinates of the direct runoff.

(v) Divide the total volume of direct runoff by the area of the watershed to get the net precipitation depth (Pnet) over the watershed.

(vi) Divide each of the ordinates of direct runoff by the net precipitation depth to obtain the ordinates of the unit hydrograph.

(vii) Plot the ordinates of the unit hydrograph against time since the beginning of the direct runoff. This will give the unit hydrograph of the watershed for the duration of the unit storm selected.

Results and Discussion

RESULTS AND DISCUSSION

Western Ghats, being the major water contributor for all the forty four rivers of Kerala, the information regarding the runoff from watersheds of Western Ghats are important. An attempt was made to study and assess the effect of land use on water yield from small agricultural watersheds of Western Ghats. The result obtained from the study are discussed in this chapter.

4.1 Climate

The climatic factors of precipitation, temperature, sunshine and wind all affect the stream runoff. Out of these factors only precipitation and temperature account for major differences among runoff regimes in regions of similar geology and topography. Temperature in conjunction with sunshine and wind determines the evaporation losses and influence the hydrologic cycle. Rainfall as the input to the watershed forms one of the most important factors that influence runoff formation. It is the most common form of precipitation and is certainly the most easily measured. Rainfall is measured on the basis of vertical depth of water that would accumulate where it falls.

Table 2. Average weekly rainfall of the selected watersheds

Week	Average weekly rainfall (cm)			
	Perambra (Cashew) watershed	Perambra (Rubber) watershed	Beenachi (Coffee) watershed	Achoor (Tea) watershed
1.	44.60	22.25	12.60	0.45
2.	49.20	33.00	17.20	4.80
3.	7.90	8.50	6.30	28.00
4.	37.20	28.60	0.91	52.50
5.	22.90	26.20	8.55	13.50
6.	7.90	36.60	9.10	2.30
7.	20.53	18.80	0.31	41.50
8.	37.55	19.80	13.90	18.54
9.	3.90	6.05	10.50	0.58
10.	1.39	2.20	2.60	35.00
11.	3.90	0.30	1.30	27.50
12.	4.60	32.50	1.60	4.20
13.	40.90	18.30	1.80	1.20
14.	9.60	4.01	2.75	6.10
15.	12.10	8.60	5.00	2.50
16.	3.45	8.20	7.10	5.80
17.	6.95	0.50	3.80	4.75
18.	5.60	23.20	0.80	3.20
19.	25.20	34.50	0.44	2.05
20.	7.95	1.50	5.60	3.25
21.	--	--	7.80	6.20
22.	--	--	5.10	8.90
23.	--	--	6.20	0.65

4.1.1 Rainfall

The weekly average values of rainfall received by the watersheds are shown in Table 2. The values are obtained after averaging the rainfall of three years. The maximum and minimum average weekly rainfall received by the watersheds were 49.20, 36.60, 13.80 and 52.50 cm and 1.39, 0.30, 0.20 and 0.45 cm for cashew, rubber, coffee and tea watersheds respectively.

The maximum intensities of rainfall received by the watersheds during the years 1985, 1986 and 1987 are obtained after analysing the rainfall records and are given in Table 3.

Table 3. Maximum intensities of rainfall received by the selected watersheds

Year	Maximum intensity of rainfall received by the watersheds (cm/hr)			
	Cashew	Rubber	Coffee	Tea
1985	8.0	6.80	8.0	7.0
1986	12.2	7.20	6.0	6.6
1987	12.0	8.80	8.0	6.0

The highest intensity rainfall received by cashew watershed was 12.2 cm/hr in 1986, whereas it was 8.80 cm/hr for rubber watershed in 1987. The coffee watershed received the highest intensity rainfall of 8 cm/hr in 1985 and 1987, but for the tea watershed it was 7 cm/hr in 1985.

4.1.2 Mean temperature

The weekly average values of mean temperature obtained after averaging the temperatures recorded for three years are shown in Table 4. The maximum and minimum values of average weekly mean temperature recorded for the watersheds were 187.0, 191.5, 171.4 and 162.75°C and 153.0, 181.75, 147.2 and 139.1°C for cashew, rubber, coffee and tea watersheds respectively.

4.1.3 Evaporation

The weekly evaporation values obtained after averaging the evaporation data of three years are given in Table 5. All the watersheds selected for the study have dense vegetative cover. This canopy reduce soil evaporation by shading the surface from direct solar radiation, keep the surface temperature low and increase the relative humidity of the lower layers of air. In such conditions evaporation from soil surface will be negligible compared to evapotranspiration. The simplest and widespread method of evaporation measurement by means of class A evaporation pans were adopted here also. The maximum and minimum average

Table 4. Average weekly mean temperature of the selected watersheds

Week	Average weekly mean temperature (°C)			
	Perambra (Cashew) watershed	Perambra (Rubber) watershed	Beenachi (Coffee) watershed	Achoor (Tea) watershed
1.	159.15	186.13	159.05	162.75
2.	153.00	181.75	150.15	151.25
3.	171.00	186.13	157.05	144.25
4.	158.25	188.40	157.10	144.75
5.	163.75	184.25	150.90	144.00
6.	170.75	179.75	150.65	141.75
7.	157.40	182.40	154.65	146.00
8.	153.00	182.13	154.95	144.75
9.	162.40	190.25	147.20	142.00
10.	161.25	189.90	158.35	140.60
11.	168.75	187.00	155.03	139.10
12.	164.50	186.60	158.25	140.10
13.	168.50	186.75	153.95	145.75
14.	167.00	186.75	159.10	141.90
15.	187.00	185.50	167.50	139.25
16.	171.00	189.50	166.45	140.60
17.	173.50	191.50	168.45	148.30
18.	163.75	188.25	171.40	144.25
19.	171.50	183.00	162.35	143.40
20.	155.50	185.25	163.70	141.10
21.	--	--	164.15	149.40
22.	--	--	158.80	153.00
23.	--	--	148.80	143.25

Table 5. Average weekly evaporation values of the selected watersheds

Week	Average weekly evaporation (mm)			
	Perambra (Cashew) watershed	Perambra (Rubber) watershed	Beenachi (Coffee) watershed	Achoor (Tea) watershed
1.	15.60	21.18	12.80	14.10
2.	13.20	17.20	9.50	15.40
3.	14.60	15.85	14.10	10.60
4.	19.90	18.61	14.00	11.40
5.	13.40	20.50	13.50	12.60
6.	19.50	24.65	12.20	13.40
7.	17.80	23.25	13.85	13.00
8.	14.10	24.10	13.55	11.20
9.	17.70	21.15	7.85	13.90
10.	16.00	19.75	13.75	11.30
11.	17.40	19.10	13.25	11.40
12.	16.40	18.35	13.30	17.50
13.	17.40	18.60	17.65	18.85
14.	13.50	27.40	14.70	17.05
15.	20.70	16.40	15.70	15.55
16.	14.30	20.20	14.35	15.60
17.	14.50	21.90	17.05	15.85
18.	14.90	18.90	13.55	15.00
19.	14.20	19.10	15.80	14.52
20.	13.30	21.20	11.95	15.80
21.	--	--	14.30	16.15
22.	--	--	11.10	10.60
23.	--	--	11.75	10.80

weekly pan evaporation values for the watersheds were 20.7, 27.4, 17.65 and 18.85 mm and 13.2, 15.85, 7.85 and 10.6 mm for cashew, rubber, coffee and tea watersheds respectively. Compared to other watersheds pan evaporation from the rubber watershed was more and this may be due to the fact that the canopy coverage of rubber is less compared with that of cashew, coffee and tea.

4.2 Soil characteristics

Soil characteristics are important in relation to their effects upon infiltration and generation of interflow. Reduction in hydraulic conductivity with depth in the upper horizons facilitates the formation of interflow during prolonged rainfall. This can lead to the saturation of soil surface and thus generation of overland flow. The soils of the selected watersheds are laterite having high infiltration capacity. Soil samples were collected from representative locations of all the watersheds and were analysed for grain size distribution, pH value and organic carbon content. The results are given in Table 6.

According to Indian Standard Classification all these soils come under coarse grained division because in all the cases more than half of the total materials by weight is larger than 75 micron IS sieve size. The particles finer than

Table 6. Soil characteristics of the selected watersheds

Watershed	Grain size distribution					pH value	Organic carbon (%)
	Fine gravel 20 to 4.75 mm	Sand			Silt and clay <0.075 mm		
		Coarse 4.75 to 2 mm	Medium 2 to 0.425 mm	Fine 0.425 to 0.075 mm			
Cashew	10.07	12.71	49.12	24.26	3.84	5.98	1.83
Rubber	9.07	10.90	54.03	21.98	4.02	5.63	1.77
Coffee	7.74	10.80	50.56	26.36	4.54	5.78	1.86
Tea	8.82	14.91	52.62	19.14	4.51	5.75	1.22

75 micron is less than 5 per cent for all the watersheds. Again more than half of the coarse fraction (>75 micron) is smaller than 4.75 mm IS sieve size for all the watersheds. Hence all these soils come under the sands subdivision which includes sands and sandy soils. The percentage of silt and clay in these soils were 3.84, 4.02, 4.54 and 4.51 per cent for cashew, rubber, coffee and tea watersheds respectively. The gravel component accounted for 10.07, 9.07, 7.74 and 8.82 per cent and the total sand component accounted for 86.09, 86.91, 87.72 and 86.67 per cent for cashew, rubber, coffee and tea watersheds respectively.

The organic carbon content in the soils were estimated as 1.83, 1.77, 1.86 and 1.22 per cent for cashew, rubber, coffee and tea watersheds. This higher component of organic carbon (greater than 1 per cent) infers that the humus content in the soils are high and are forest soils.

The pH of the soils were obtained as 5.98, 5.63, 5.78 and 5.75 for cashew, rubber, coffee and tea watersheds. The pH values of less than 7 indicate that all the soils are acidic. Soil pH values are generally regarded as a very important property since it tends to correlate with other properties such as the degree of base saturation. Within the normal range the two principal factors controlling the soil pH are organic matter and the type and amount of cations. Large amount of organic matter induce acidity except when counterbalanced by high concentration of basic cations.

An analysis of the soil profile of the laterite soils of Western Ghat region was done by CWRDM, Calicut. This was done by drilling six exploratory bore holes within the study area. Based on the examination of the drill cuttings and the observed rates of drilling, lithologs giving the subsurface geologic features at the bore hole sites were prepared. These are shown in Fig.7. The basement rock encountered at all the bore hole sites was granite gneiss. Here after it shall be referred to only as hard rock. The hard rock was also found to be fractured in different depth horizons. The different geologic strata in the sequence with which they occur below the ground level are as given below.

1. Top laterite soil
2. Laterite
3. Clay
4. Weathered rock
5. Hard rock

The following inferences can be made from the subsurface lithologs of the study area.

(i) The overburden above the hard rock comprises of laterite soil, laterite, clay and weathered rock with a total thickness of about 13 m below the ground level.

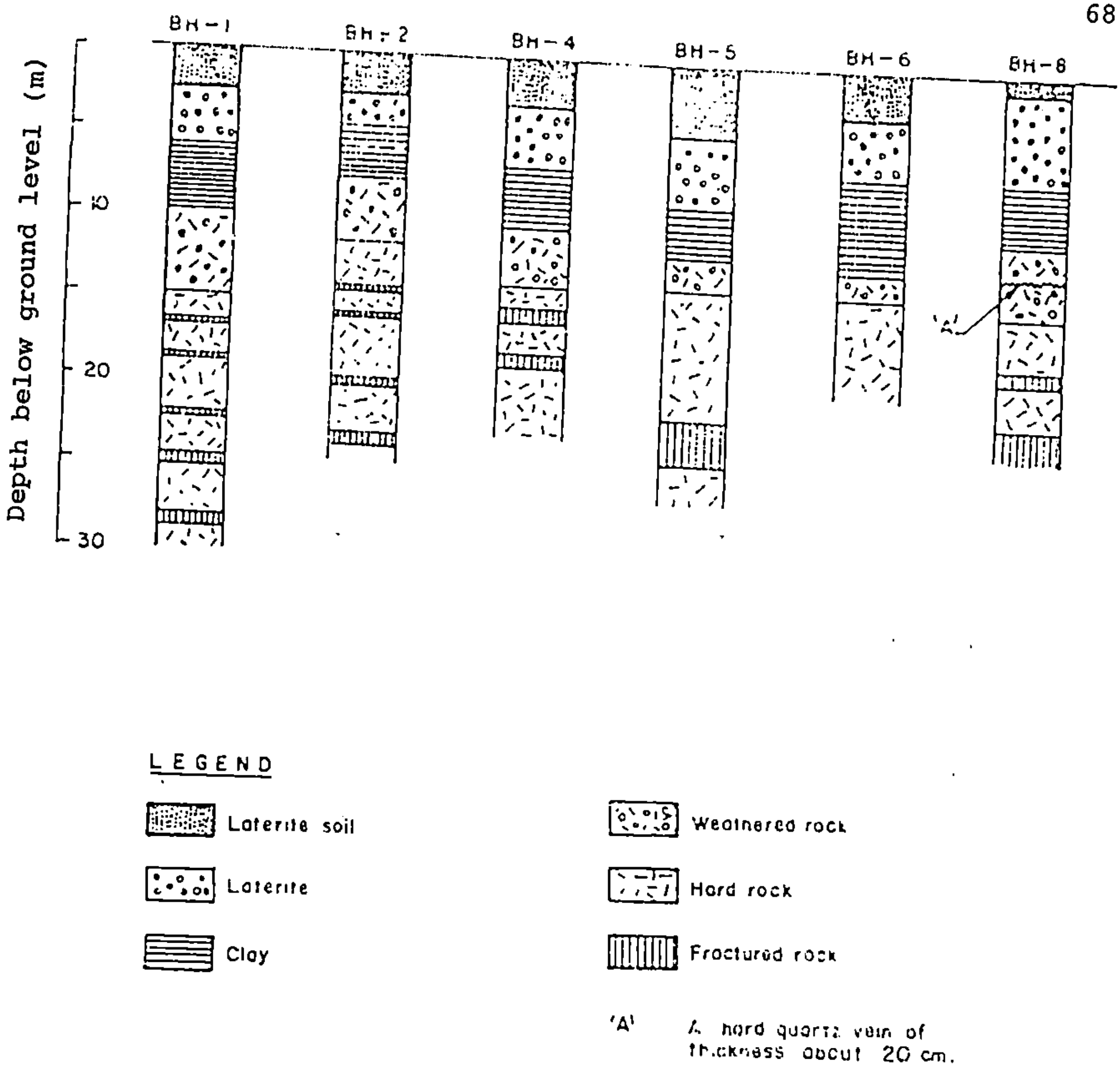

Fig.7 **Subsurface lithologs in exploratory bore holes within the study area**

(ii) The impermeable clay separating the laterite and weathered rock is on the average about 3.5 metres thick and is located in the depth horizon of about 7 to 10.5 metres from the ground level.

4.3 Infiltration

Infiltration measurements were done at two to three representative locations in the watersheds and the average values are taken. The average infiltration rates and cumulative infiltration for the watersheds determined using ring infiltrometers are given in Appendix-III. The infiltration characteristics of the watersheds are shown in Figures 8, 10, 12 and 14. The maximum rate of infiltration obtained for the cashew watershed was 21.6 cm/hr and the rate after saturation (basic infiltration rate) was 12.8 cm/hr. Similarly the values were 18 cm/hr and 12.4 cm/hr, 19.2 cm/hr and 5.6 cm/hr, 22.8 cm/hr and 12.0 cm/hr for rubber, coffee and tea watersheds respectively.

The basic infiltration rates for all the watersheds were very high, and these values are higher than those obtained for laterite soils in other parts of Kerala. These watersheds are forest cleared areas and lack of heavy mechanical manipulations of the soil, maintained the soil profile and the soil structure as it originally was. The

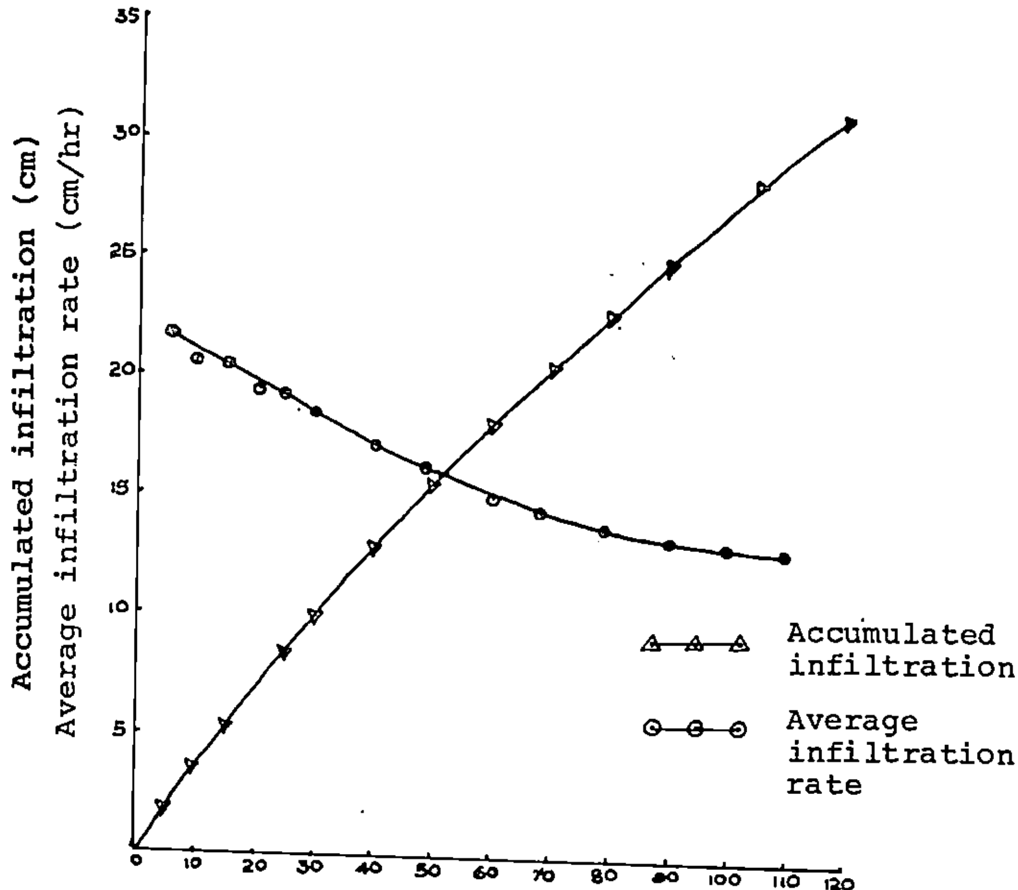

Fig.8 Infiltration characteristics of cashew watershed

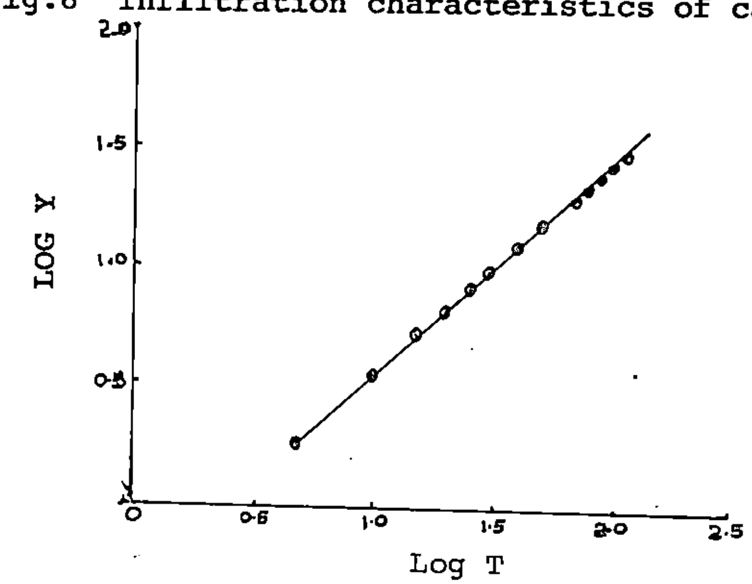

Fig.9 Log T v/s Log Y plot for cashew watershed

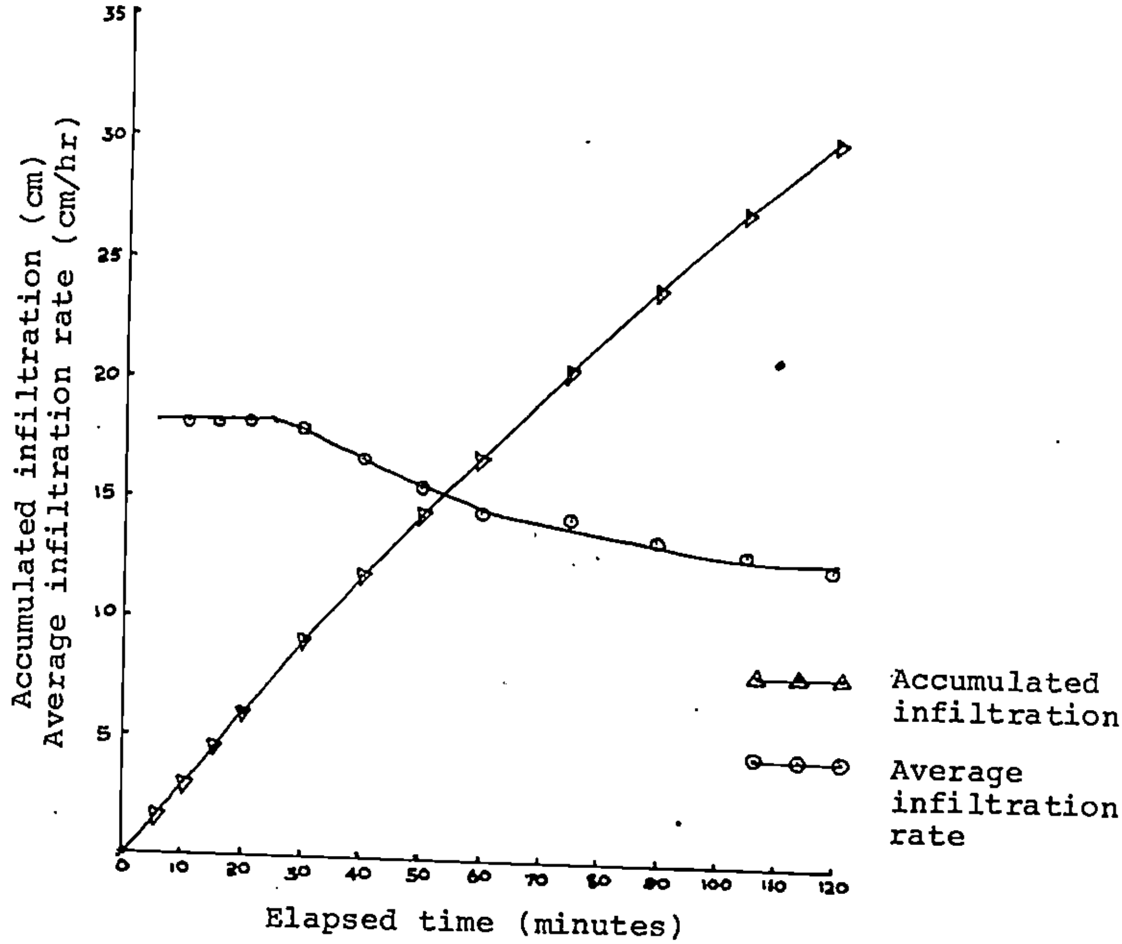

Fig.10 Infiltration characteristics of rubber watershed

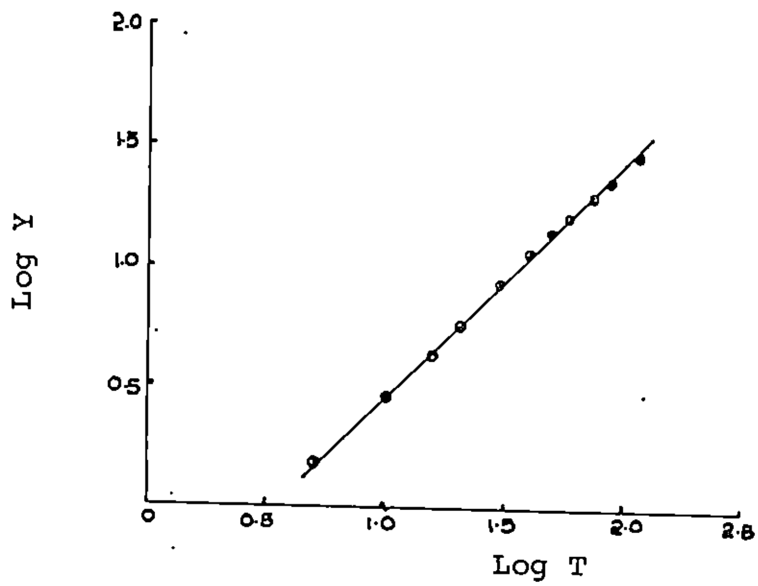

Fig.11 Log T v/s Log Y plot for rubber watershed

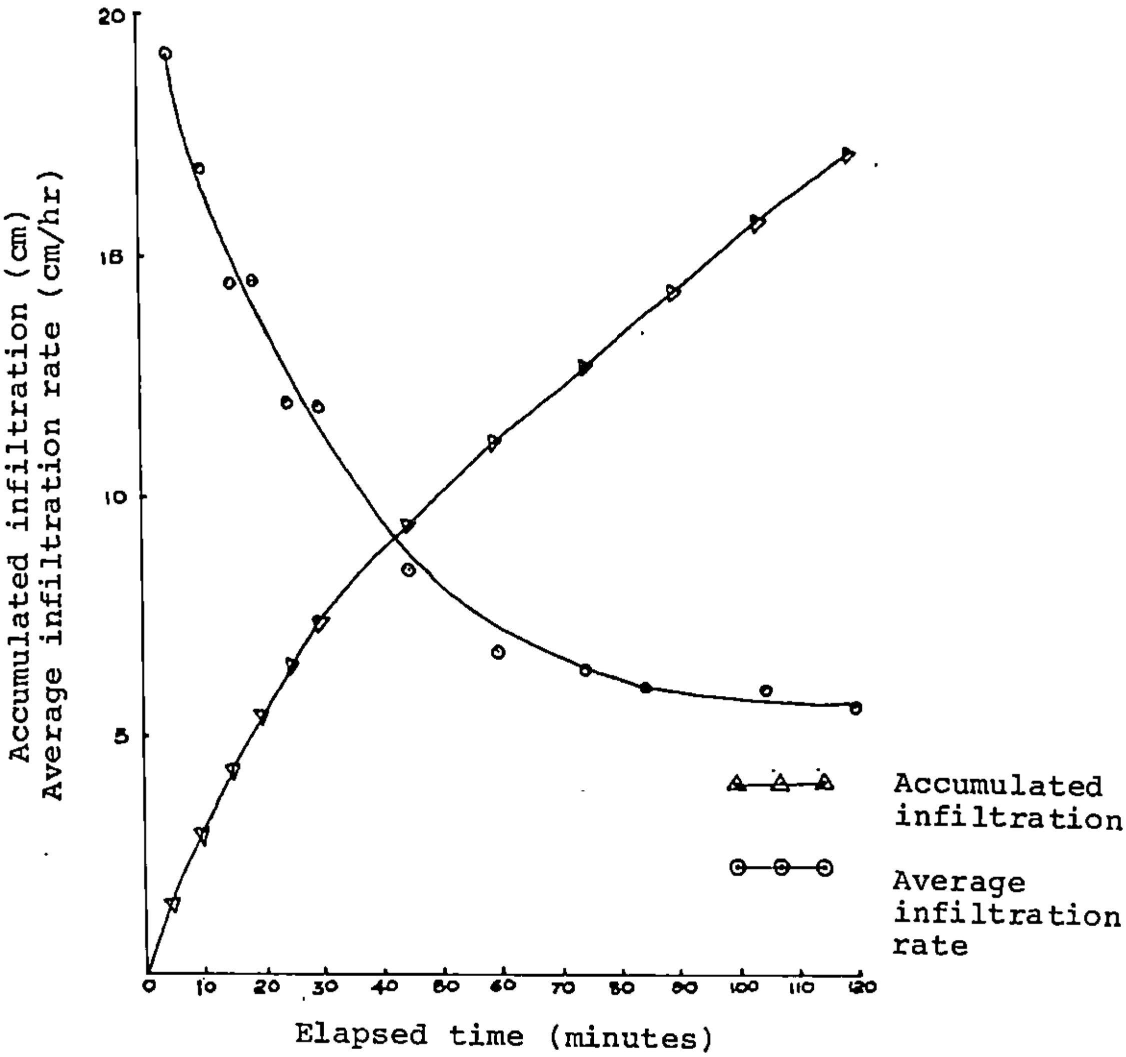

Fig.12 Infiltration characteristics of coffee watershed

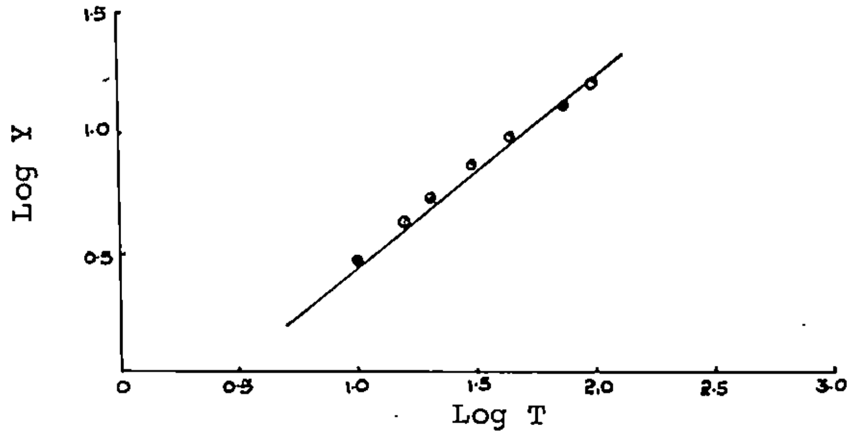

Fig.13 Lot T v/s Y plot for coffee watershed

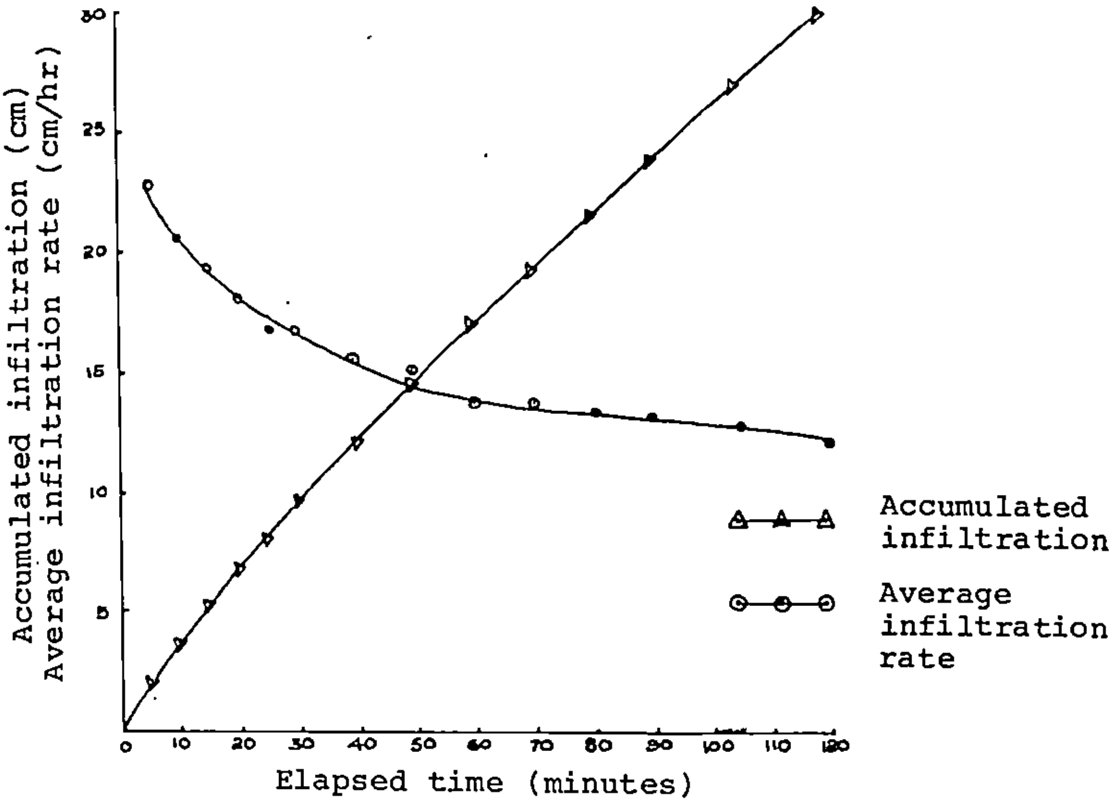

Fig.14 Infiltration characteristics of tea watershed

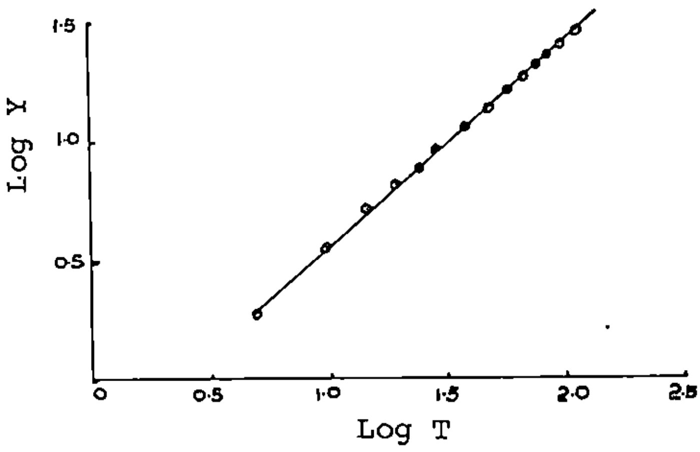

Fig.15 Log T v/s Log Y plot for tea watershed

depth of litter layer in these areas vary from 10 to 25 cm. The organic carbon content of the soils is high (greater than 1 per cent) and it indicates that the humus content is high. All these soils are coarse grained soils with lesser component of silt and clay. These may be reasons for the high infiltration rates.

The cumulative infiltration is plotted against time on a log-log scale for all the watersheds. These are shown in Figures 9, 11, 13 and 15. Infiltration equations were derived from this for all the watersheds. The infiltrations equations are;

(i) $Y = 0.45\ t^{0.901} + 0.044$ - Cashew

(ii) $Y = 0.302\ t^{0.976} + 0.174$ - Rubber

(iii) $Y = 0.41\ t^{0.813} + 0.08$ - Coffee

(iv) $Y = 0.49\ t^{0.858} + 0.041$ - Tea

where,

Y = Accumulated infiltration, cm.

t = Elapsed time, minutes.

4.4 Geomorphological characteristics of the watersheds

An important factor which influence the runoff is the basin shape. Shape influences the runoff through its effects on flood intensities and on mean travel time of a drop of water from its highest point on the surface of the catchment to its point of exit in the main stream. A second pertinent topographical factor is the slope of the catchment which may affect the relative importance of predominantly vertical movement of water by means of infiltration and predominantly lateral movement of water by means of interflow and overland flow. Furthermore the speed of water movement will tend to increase with slope, runoff in steeply sloping areas will reach the streams quickly.

The geomorphological details of the watersheds like form factor, basin circularity, basin elongation and basin mean slope are calculated and shown in Table 7.

Table 7. Geomorphological characteristics of the selected watersheds

Watershed	Form factor	Basin circularity	Basin elongation	Mean basin slope (%)
Cashew	0.698	0.810	0.943	22.7
Rubber	0.844	0.955	1.037	40.0
Coffee	0.300	0.490	0.618	24.0
Tea	0.529	0.739	0.821	25.0

The basin circularity values and the basin elongation values are 0.81, 0.955, 0.49 and 0.739 and 0.943, 1.037, 0.618 and 0.821 for cashew, rubber, coffee and tea watersheds respectively. For the rubber watershed both the elongation and circularity values were nearer to unity and this may be due to the smaller area of the watershed. For all the watersheds the elongation ratio is more than the circularity ratio. The basin mean slope values are 22.7, 40, 24 and 25 per cent for cashew, rubber, coffee and tea watersheds respectively. The slope of the rubber watershed is much more when compared with other watersheds.

Though the drainage density is an important geomorphological characteristic of watersheds it is not calculated for these watersheds. The watershed areas vary from 1.9 ha to 74.87 ha and the drainage density cannot be worked out for the watershed having an area of 1.9 ha. It is very difficult to get stream lengths from toposheets for such small watersheds.

4.5 Runoff

The runoff data computed from the stage and discharge hydrographs are converted into unit depths over the watershed (in cm) and are tabulated on weekly basis. The data collected for three years were averaged to get the average weekly runoff. The values are shown in Table 8. The average weekly values of runoff varied from 0.78 to 26.34 cm for cashew watershed, 0 to 5.92 cm for rubber watershed, 0.108 to 6.28 cm for coffee watershed and 0.23 to 25.30 cm for tea watershed. From the data it was found that the average weekly runoff was much lower for the rubber watershed compared to the average weekly rainfall. The total runoff produced by the rubber watershed was only 14.3 per cent of the rainfall whereas it was 52.8 per cent for cashew, 45.7 per cent for coffee and 48.9 per cent for tea watersheds respectively. One major reason for the low runoff may be the smaller area of the rubber watershed, compared to the other watersheds. The rubber watershed lies adjacent to the kuttiady reservoir and the possibility of the interflow to the reservoir avoiding the measuring channel may be another reason for the comparatively lower runoff value.

The regression equations of average weekly runoff on average weekly rainfall were worked out for all the watersheds. The regression equations and the corresponding correlation coefficients are as follows:

Cashew watershed - $Y = 0.522\ x + 0.113$
Correlation coefficient = 0.998

Rubber watershed - $Y = 0.145\ x - 0.032$
Correlation coefficient = 0.993

Table 8. Average weekly runoff of the selected watersheds

Week	Average weekly runoff (cm)			
	Perambra (Cashew) watershed	Perambra (Rubber) watershed	Beenachi (Coffee) watershed	Achoor (Tea) watershed
1.	23.25	3.29	4.50	0.23
2.	26.34	4.70	6.28	2.32
3.	4.39	1.20	2.32	15.90
4.	19.49	3.96	0.31	25.30
5.	12.11	3.55	3.14	6.40
6.	4.55	5.92	3.27	1.10
7.	11.23	2.63	0.11	19.86
8.	20.58	2.81	4.95	8.90
9.	2.04	1.01	3.72	0.28
10.	0.78	0.32	0.95	16.90
11.	2.02	0.06	0.46	13.20
12.	2.60	4.39	0.58	1.98
13.	20.12	2.89	0.60	0.53
14.	5.02	0.73	1.05	2.92
15.	6.72	0.94	0.80	1.18
16.	1.77	1.15	2.57	2.80
17.	3.60	0.00	1.37	2.31
18.	2.92	3.29	0.31	1.53
19.	12.73	4.86	0.16	0.94
20.	4.30	0.12	2.06	1.57
21.	--	--	2.83	2.94
22.	--	--	1.92	4.30
23.	--	--	2.33	0.29

Coffee watershed - $Y = 0.361\ x + 0.012$
Correlation coefficient = 0.999

Tea watershed - $Y = 0.489\ x - 0.007$
Correlation coefficient = 0.997

where,

Y = Average weekly runoff, cm

x = Average weekly rainfall, cm

These equations can be used as approximate prediction equations for average weekly runoff from these watersheds for rainfalls not exceeding the maximum average weekly rainfall received by the watersheds.

The individual correlations between the weekly average runoff and weekly average evaporation, weekly average mean temperature and weekly average humidity were found to be very poor (i.e. less than 0.4 in all the cases). This may be due to the fact that the weekly values of the climatological parameters may not influence the runoff values significantly. If the data were tabulated on monthly or yearly basis the influence of climatological parameters on runoff could be significant.

The weekly average values of runoff are plotted against the weekly average values of rainfall for all the watersheds and are shown in figures 16 to 19. From the plots it is evident that all the watersheds except rubber watershed

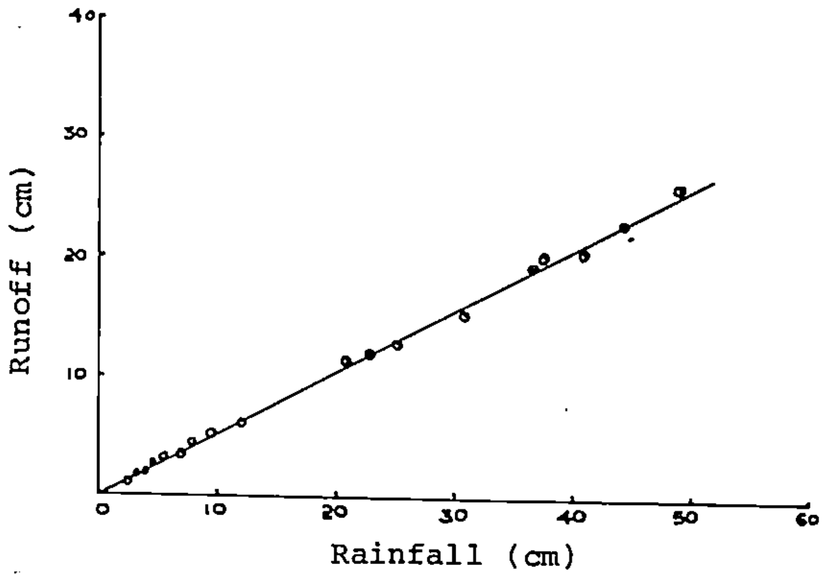

Fig.16 Rainfall-runoff relationship of cashew watershed

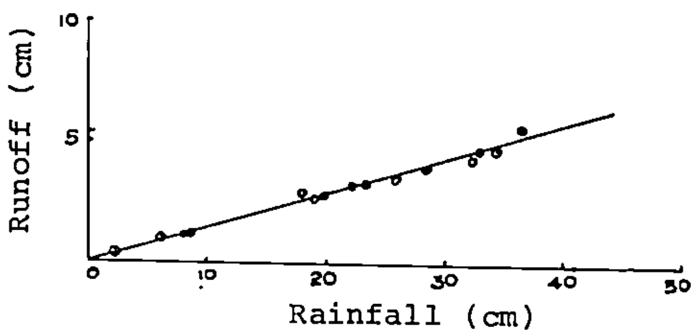

Fig.17 Rainfall-runoff relationship of rubber watershed

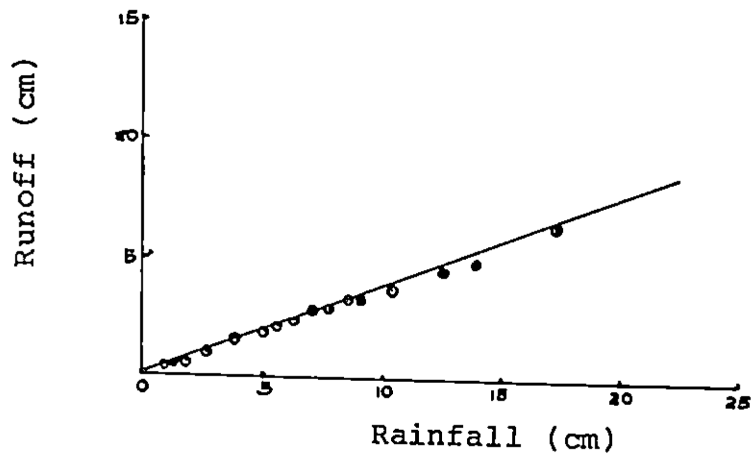

Fig.18 Rainfall-runoff relationship of coffee watershed

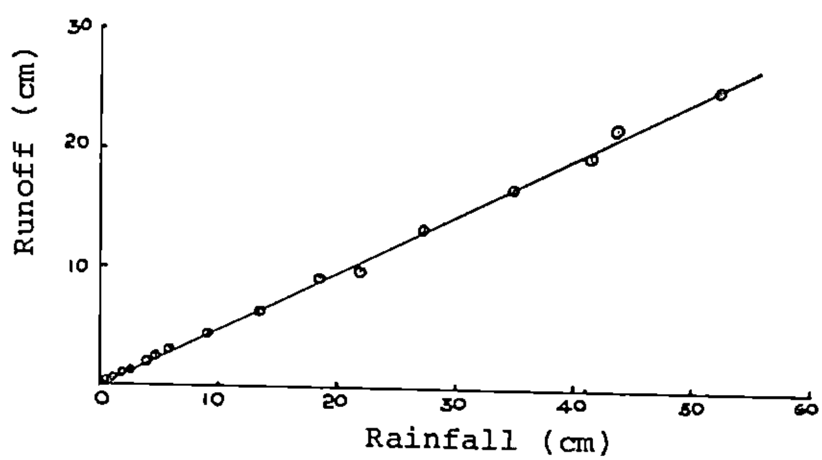

Fig.19 Rainfall-runoff relationship of tea watershed

produce nearly 50 per cent of the rainfall as runoff. But in case of rubber this was only less than 15 per cent. The reason being the smaller area of the watershed and it lies adjacent to the Kuttiadi reservoir. It was reported that after installing the gauging station for the rubber watershed, piping was observed below the gauging station and springs flowing here joins the waterspread area of the reservoir. The flow from these springs could not be measured and thus it is not incorporated in the runoff values obtained from the stage discharge hydrographs. On the otherhand the runoff pattern from the other three watersheds were almost similar and this may lead to the inference that the runoff pattern does not vary much with the land use.

A multiple curvilinear equation was attempted with average weekly rainfall, form factor, basin circularity, basin elongation, mean basin slope and maximum length of stream to get the average weekly values of runoff from the selected small watersheds planted with cashew, coffee and tea. The rubber watershed was not considered while developing this equation because this watershed is very small in area and it does not have a well defined stream channel. Also the runoff data of the rubber watershed is not perfect because the interflow could not be incorporated in the runoff values obtained due to piping below the gauging station. The dependency of this equation was found satisfactory and so this equation can be used to predict the average weekly values of the runoff from the selected small watersheds planted with perennial crops viz. cashew, coffee and tea and other similar watersheds of Western Ghats. The equation is,

$$Y = 2.34\ (x_1)^{0.987}\ (x_2)^{0.187}\ (x_3)^{1.288}\ (x_4)^{-1.162}\ (x_5)^{-0.203}\ (x_6)^{-0.084}$$

where,

Y = Average weekly runoff, cm

x_1 = Average weekly rainfall, cm

x_2 = Form factor

x_3 = Basin circularity

x_4 = Basin elongation

x_5 = Mean basin slope, per cent

x_6 = Maximum length of stream, m

The exponent of the mean basin slope is negative which indicates that the average weekly values of runoff decrease slightly with the increase in the mean basin slope. This may be due to the fact that the runoff values depend on a number of factors and the individual effect of a single factor may not be significant. The slope of Beenachi (coffee) watershed is 25 per cent with a stream length of 1580 m and the slope of Perambra (cashew) watershed is 22.7 per cent with a stream length of 650 m. The slope and stream length of Achoor (tea) watershed are 24 per cent and 1080 m respectively. In the more sloping watershed the length of stream is more with more irregularities and depressions which ultimately increases the time of concentration. This can reduce the runoff from a more sloping watershed compared to that from a less sloping watershed with short and straight stream channels.

Since the effect of mean basin slope on runoff was found negative, another equation was attempted excluding the values of mean basin slope. The equation is,

$$Y = 1.549\ (x_1)^{0.987}\ (x_2)^{0.282}\ (x_3)^{1.17}\ (x_4)^{-1.256}\ (x_5)^{-0.118}$$

where,

Y = Average weekly runoff, cm

x_1 = Average weekly rainfall, cm

x_2 = Form factor

x_3 = Basin circularity

x_4 = Basin elongation

x_5 = Maximum length of stream, m

In this equation the exponent of each parameter is in agreement with the definition of these parameters and hence can be considered superior to the previous equation. This equation can be used to predict the average weekly values of runoff from the selected small watersheds and other similar watersheds of Western Ghats using the values of average weekly rainfall, form factor, basin circularity, basin elongation and maximum length of stream. This equation has a high dependency. The equation was developed with the help of a computer using the package SIGMAPLOT. The programme used for developing this equation is given in Appendix-IV.

4.6 Hydrograph analysis

From the stage and discharge hydrographs, runoff hydrographs were prepared for a few selected storms for all watersheds. From the runoff hydrographs unit hydrographs were prepared for these watersheds for 1 cm rainfall excess. The runoff hydrographs and unit hydrographs are shown in figures 20 to 43. The ordinates of the storm hydrographs and unit hydrographs are given in Appendix V.

Figures 20 and 21 show the runoff hydrograph and unit hydrograph of cashew watershed on 13.10.86. The total rainfall was 8.8 cm and the duration was 2 hours. The peak flow rate was 0.216 m^3/sec, occurred after 1 hour since the commencement of the storm. The direct runoff started after 30 minutes since the commencement of the storm and lasted for a duration of 90 minutes. The runoff hydrographs of cashew watershed on 14.10.87 and 19.10.87 are given in figures 22 and 24. The rainfall values were 5 cm and 4 cm respectively. Corresponding unit hydrographs are given in figures 23 and 25.

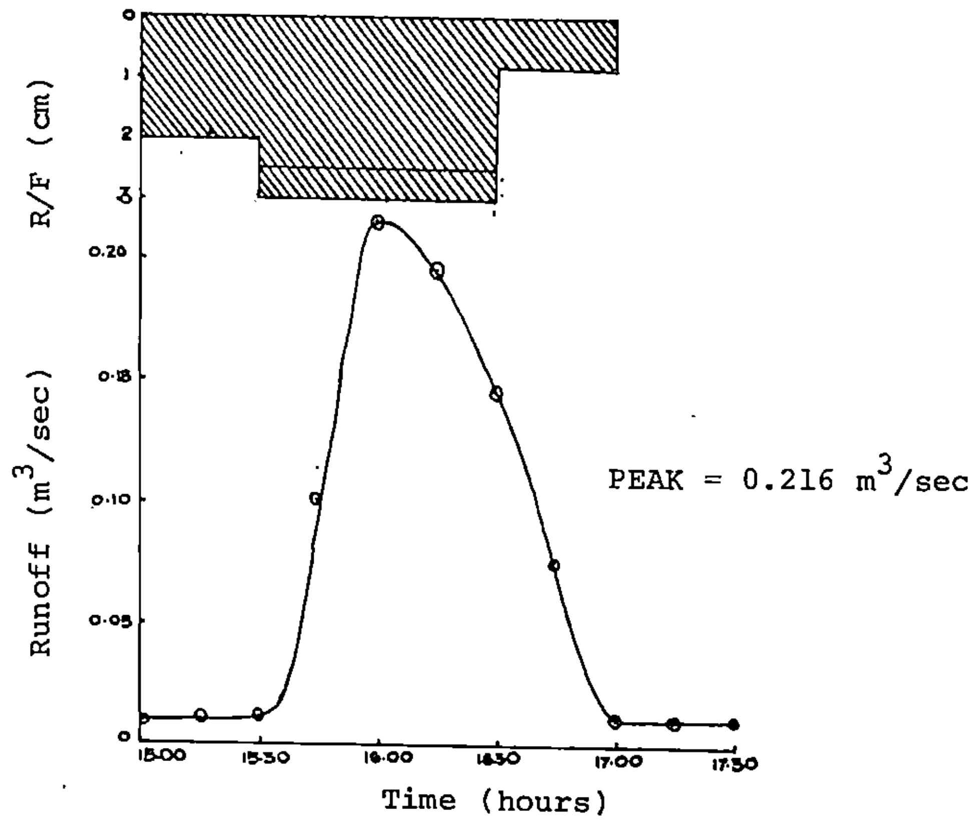

Fig.20 Runoff hydrograph of cashew watershed on 13.10.86

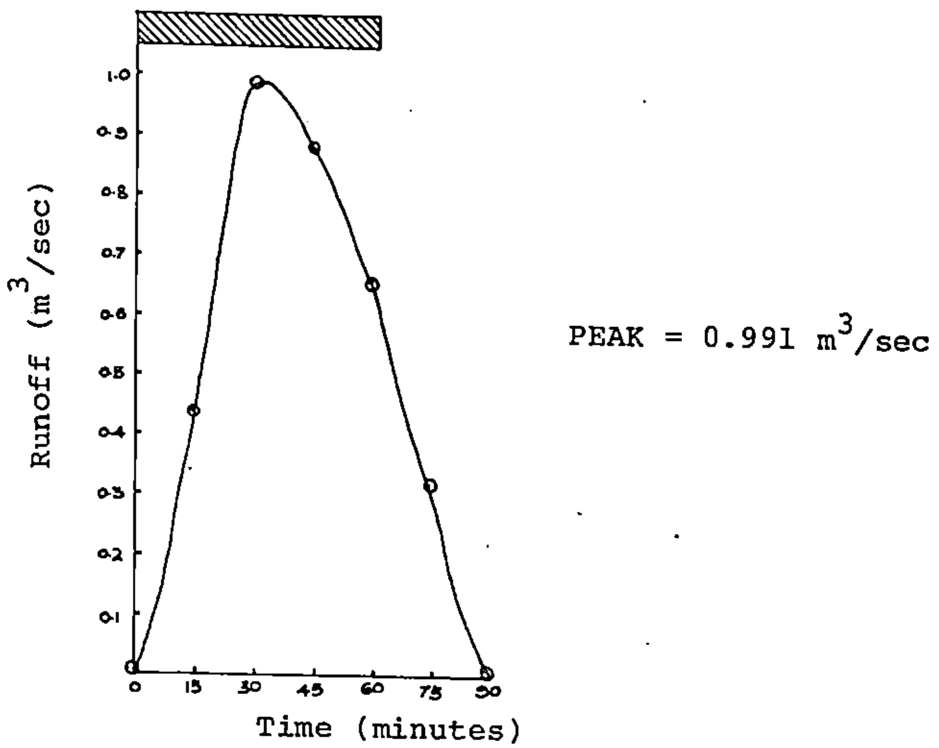

Fig.21 Unit hydrograph of cashew watershed on 13.10.86

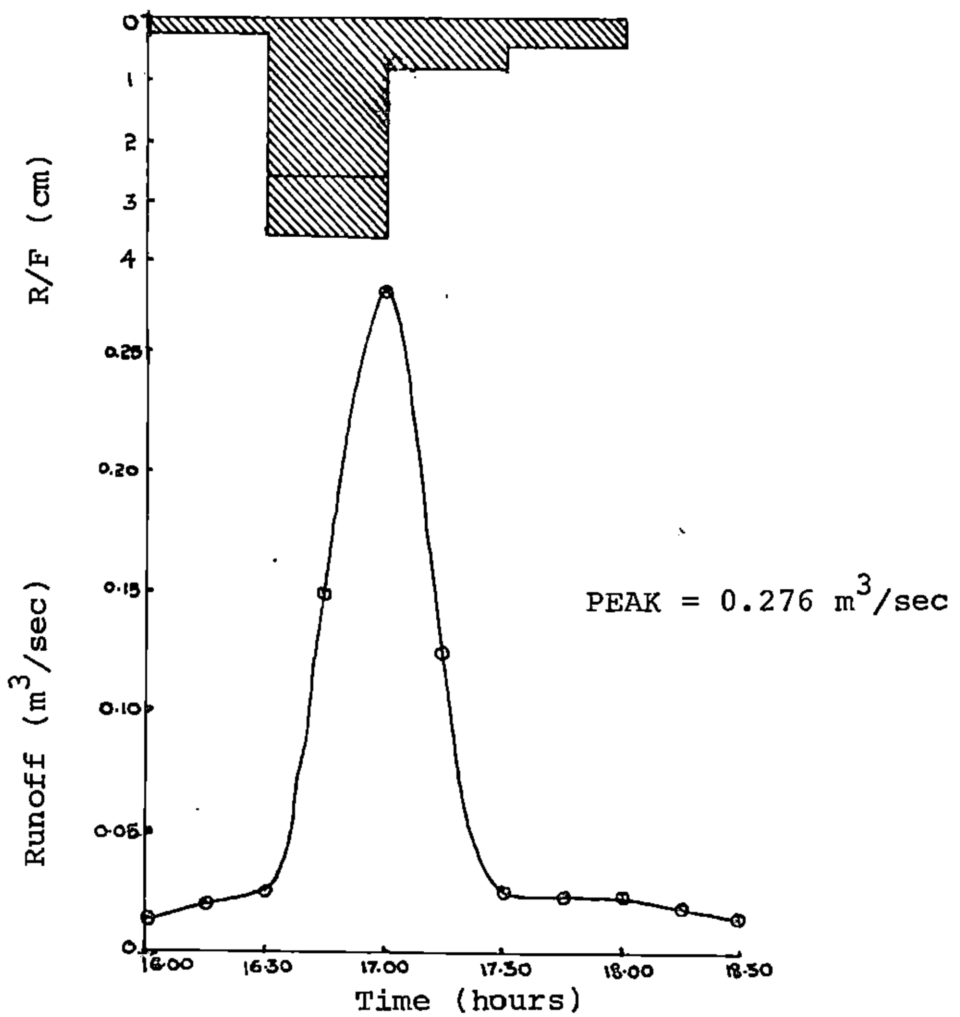

Fig.22 Runoff hydrograph of cashew watershed on 14.10.87

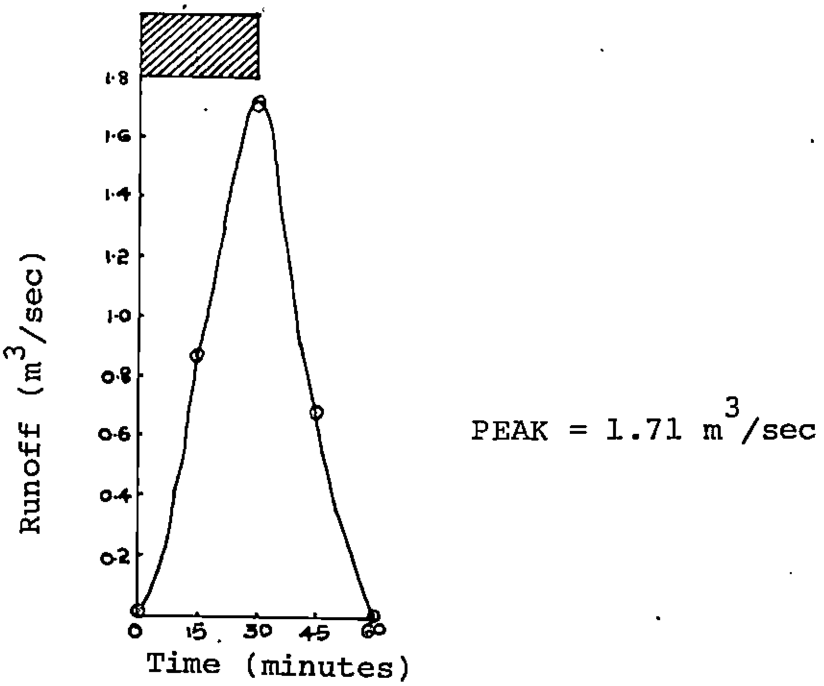

Fig.23 Unit hydrograph of cashew watershed on 14.10.87

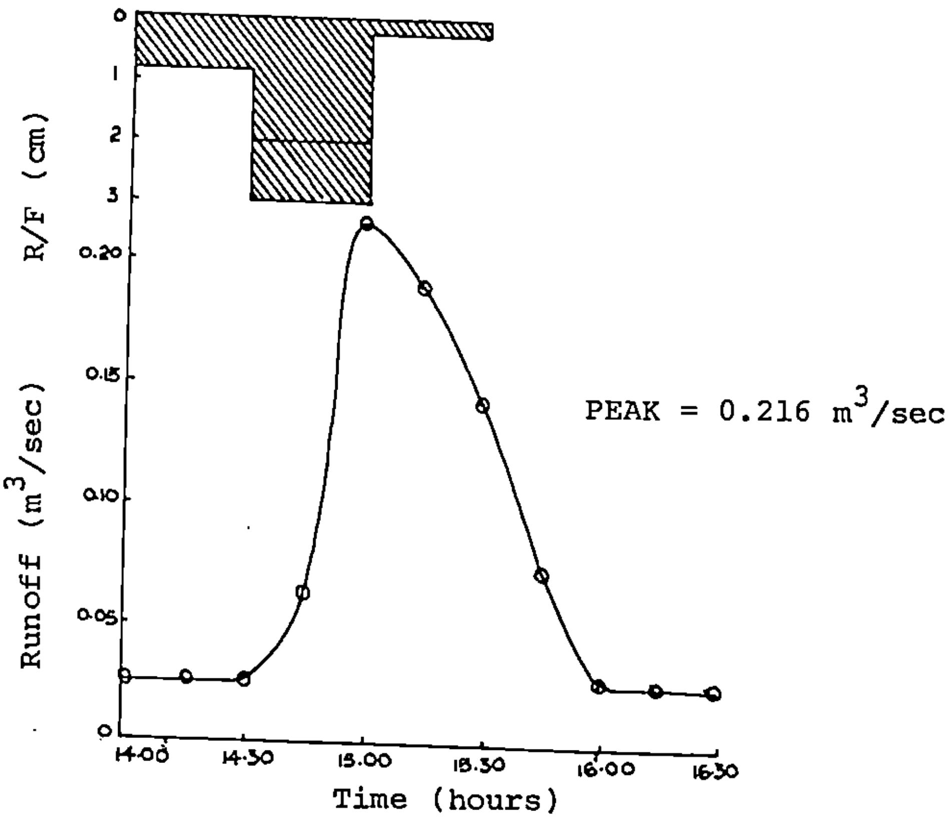

Fig.24 Runoff hydrograph of cashew watershed on 19.10.87

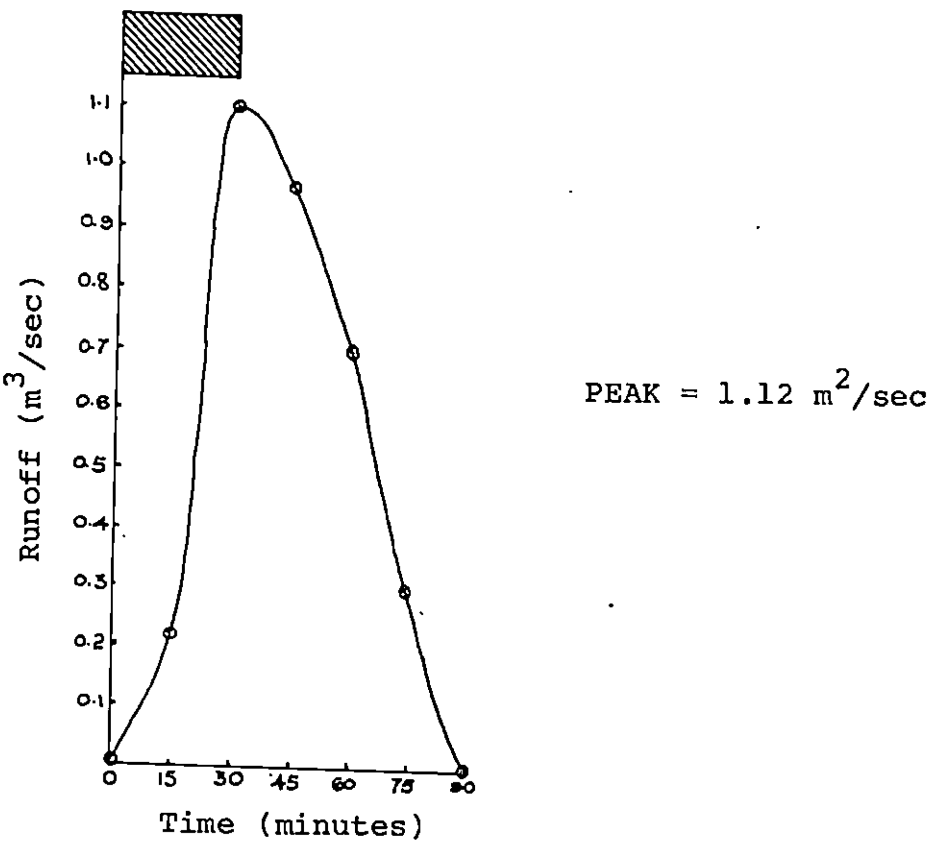

Fig.25 Unit hydrograph of cashew watershed on 19.10.87

In all the cases the direct runoff started after 30 minutes since the commencement of the storm and attained a peak after 30 minutes. The sharp rising limbs of the hydrographs indicate steep sloping terrain with low channel storage. It was observed that there is an appreciable amount of baseflow which is flowing through this watershed.

The runoff hydrograph and unit hydrograph of rubber watershed on 9.10.86 are given in figures 26 and 27. The total rainfall was 1.4 cm and the duration was 1 hour. The peak flow rate of 0.039 m^3/sec was occurred after 30 minutes since the commencement of the storm. The direct runoff lasted for a duration of 90 minutes. Figures 28 and 30 show the runoff hydrographs of rubber watershed on 12.10.87 and 22.10.87. The rainfall values were 5.4 cm and 2.8 cm respectively. Corresponding unit hydrographs are given in figures 29 and 31. The direct runoff started simultaneously with the rainfall in all the cases. From the hydrographs it was observed that there is no baseflow flowing through this watershed. The rising limbs are sharp, indicating steep sloping terrain.

Figures 32 and 33 show the runoff hydrograph and unit hydrograph of coffee watershed on 3.10.86. The total rainfall was 3.2 cm and the duration was 2 hours. The peak flow rate was 0.33 m^3/sec, occurred after 90 minutes since the

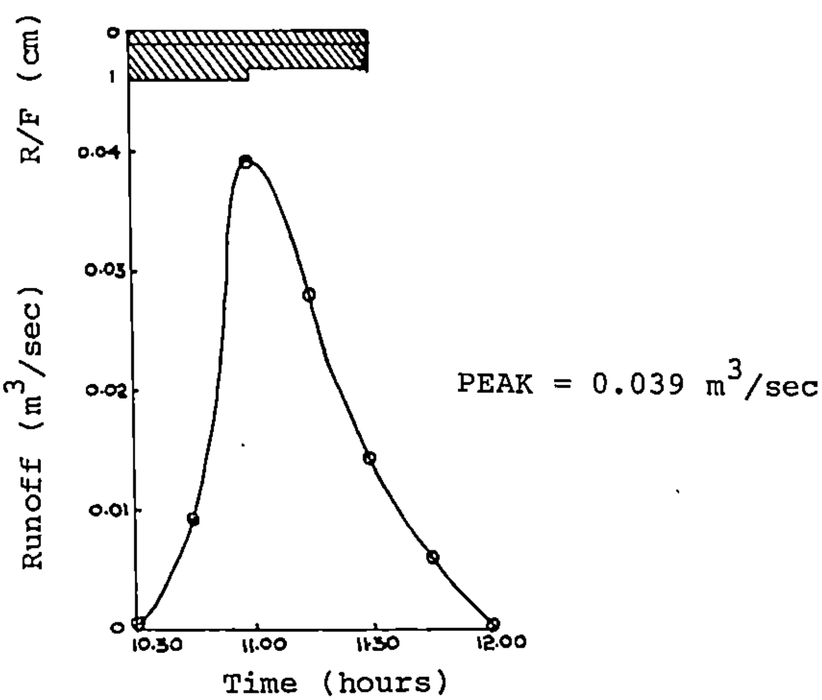

Fig.26 Runoff hydrograph of rubber watershed on 9.10.86

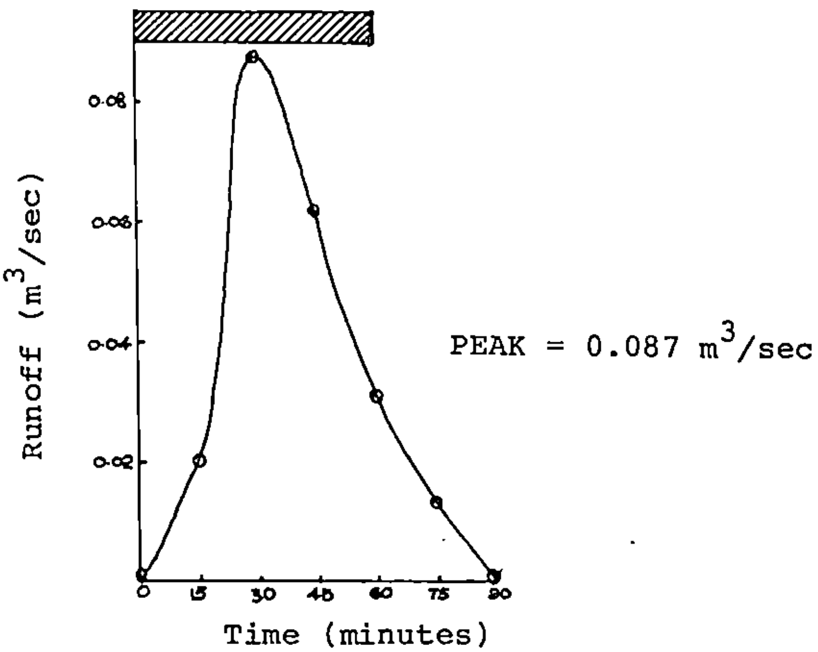

Fig.27 Unit hydrograph of rubber watershed on 9.10.86

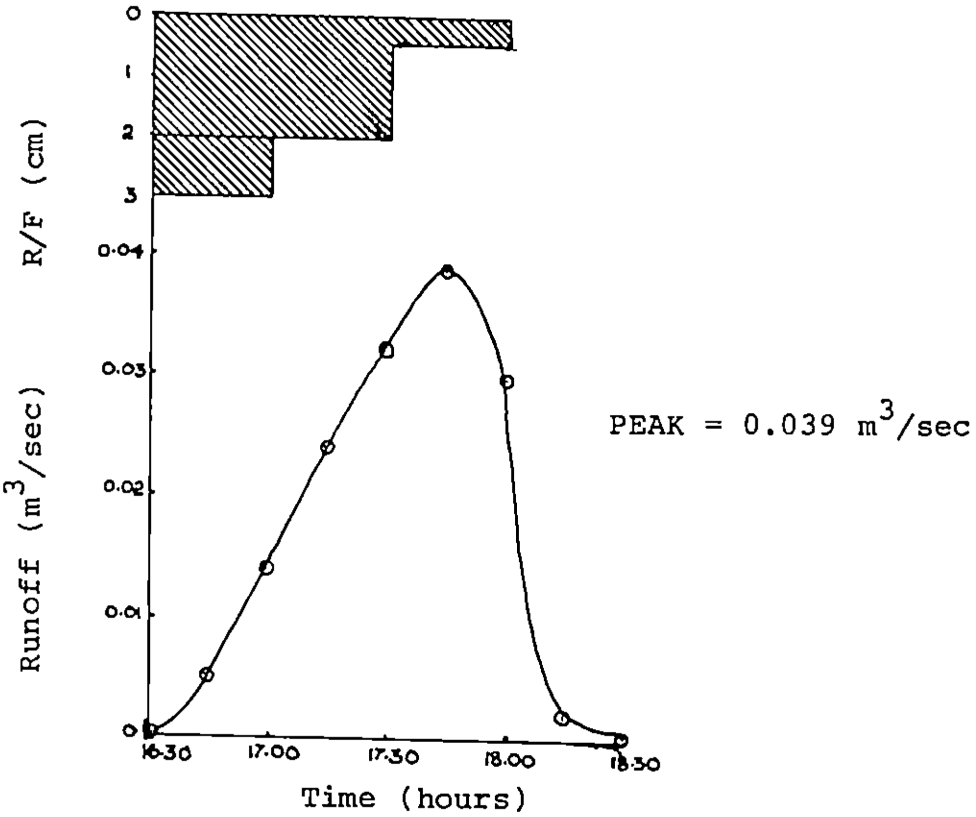

Fig.28 Runoff hydrograph of rubber watershed on 12.10.87

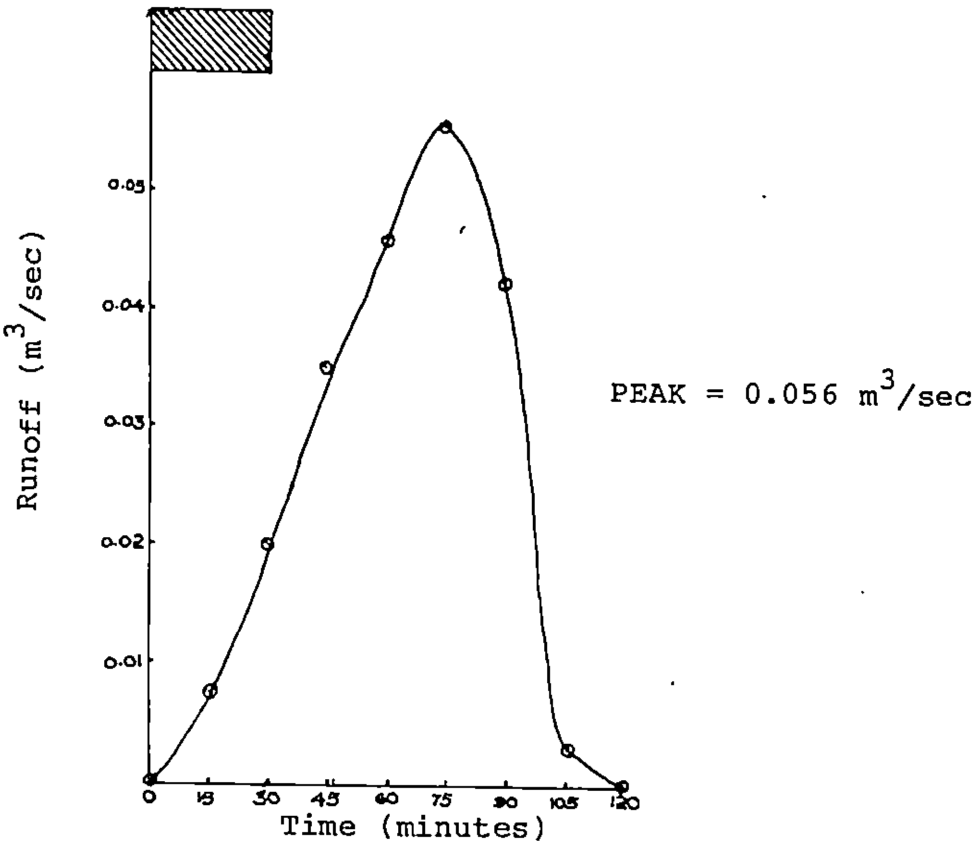

Fig.29 Unit hydrograph of rubber watershed on 12.10.87

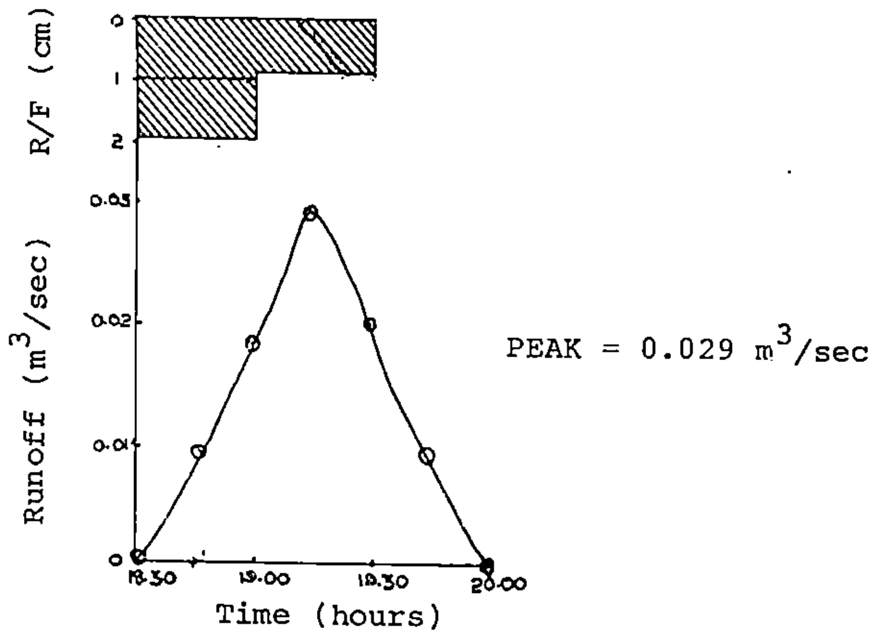

Fig.30 Runoff hydrograph of rubber watershed on 22.10.87

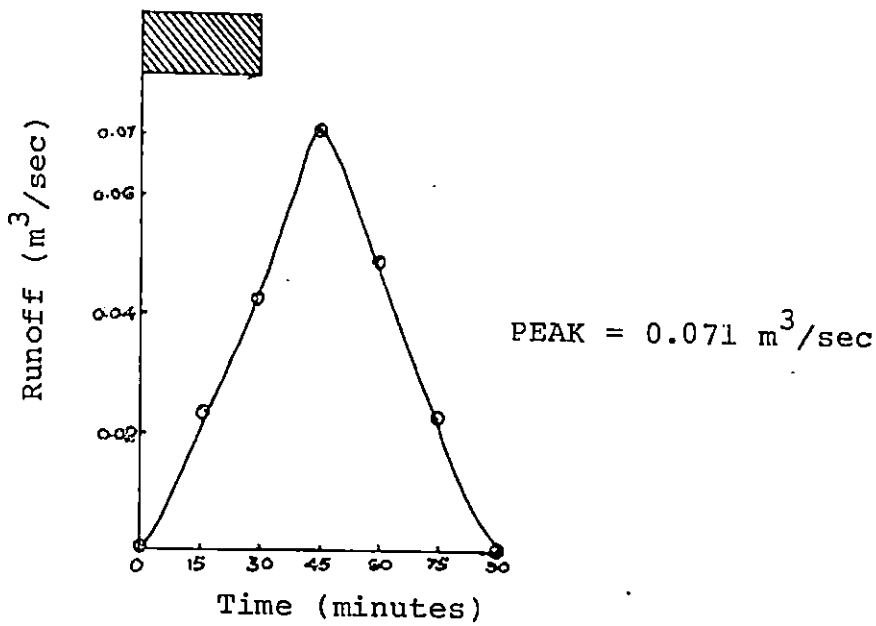

Fig.31 Unit hydrograph of rubber watershed on 22.10.87

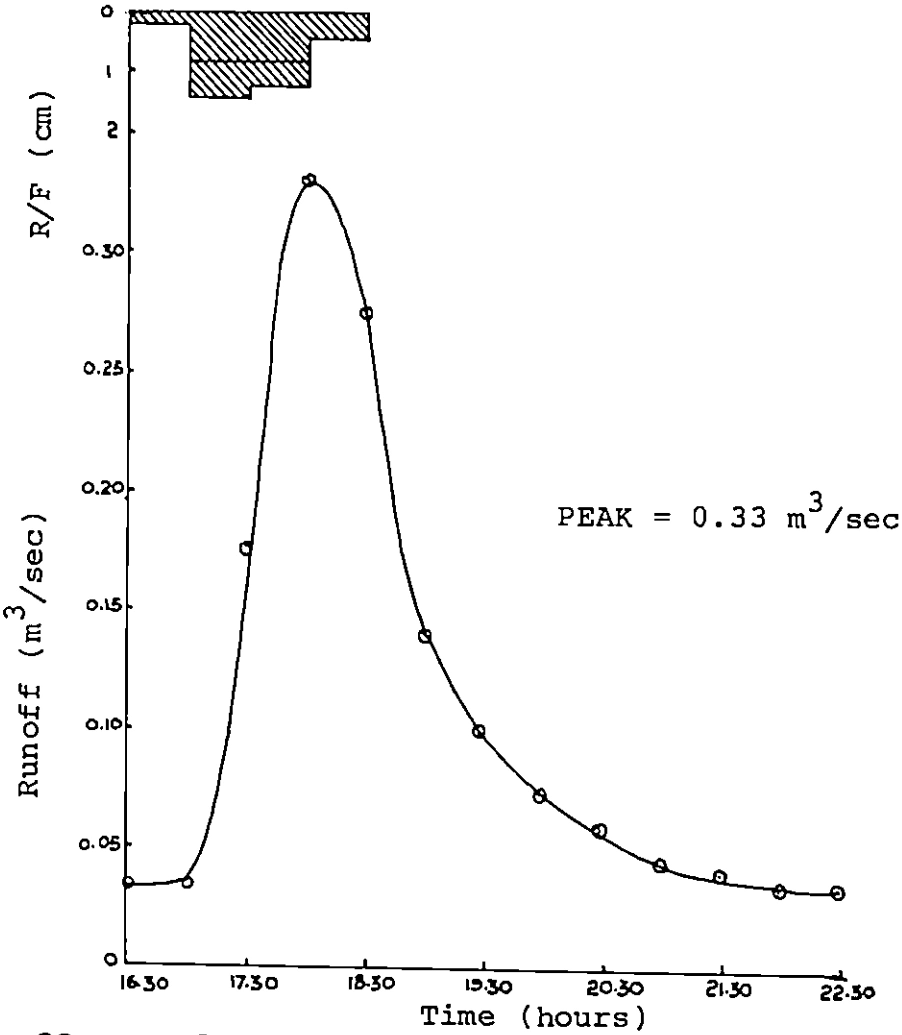

Fig.32 Runoff hydrograph of coffee watershed on 3.10.86

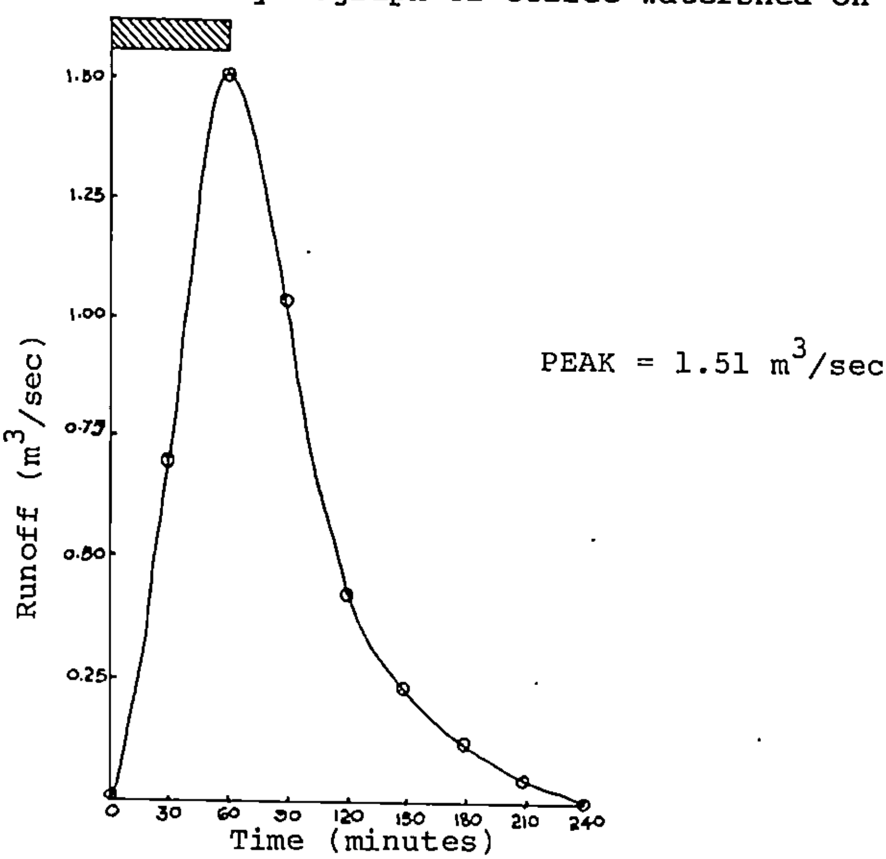

Fig.33 Unit hydrograph of coffee watershed on 3.10.86

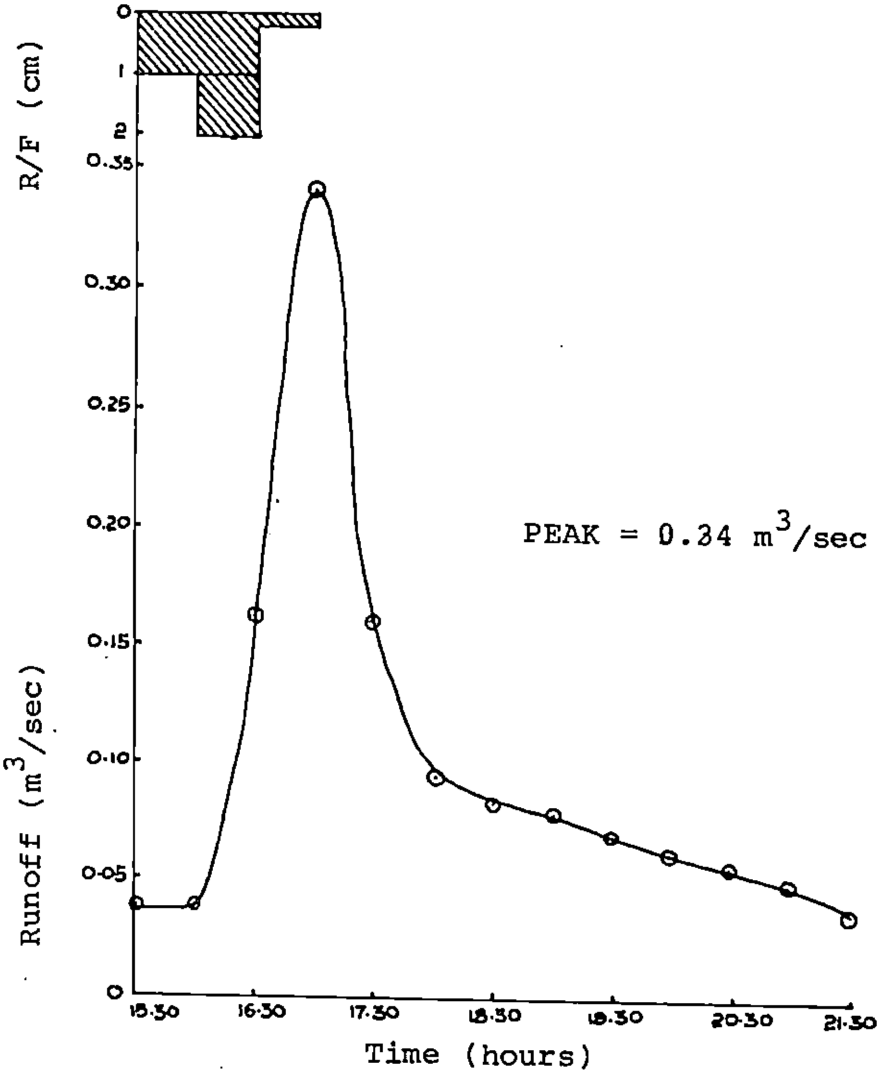

Fig.34 Runoff hydrograph of coffee watershed on 5.11.86

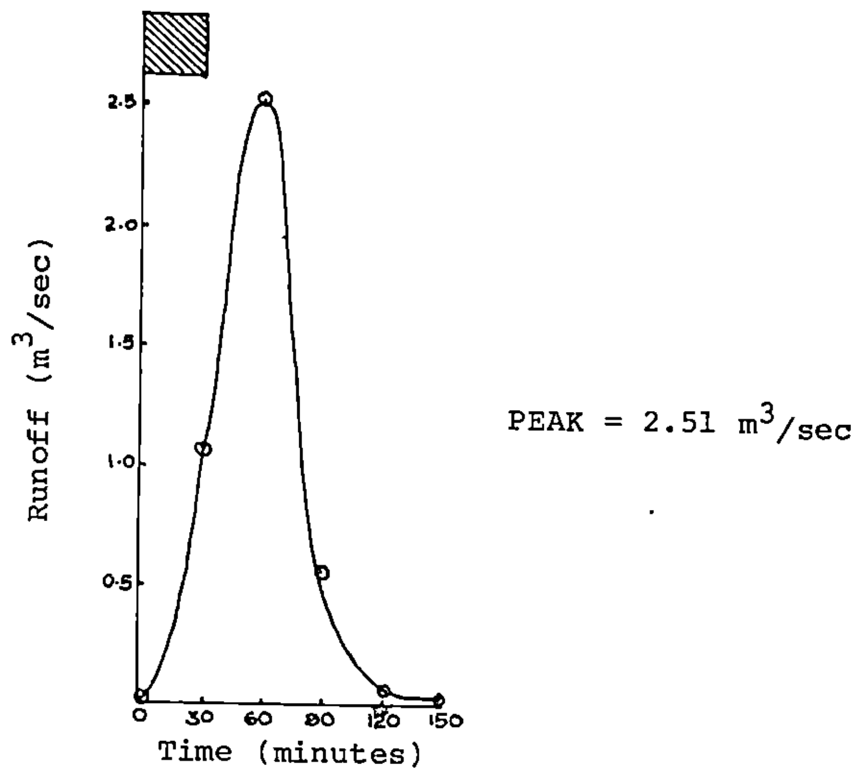

Fig.35 Unit hydrograph of coffee watershed on 5.11.86

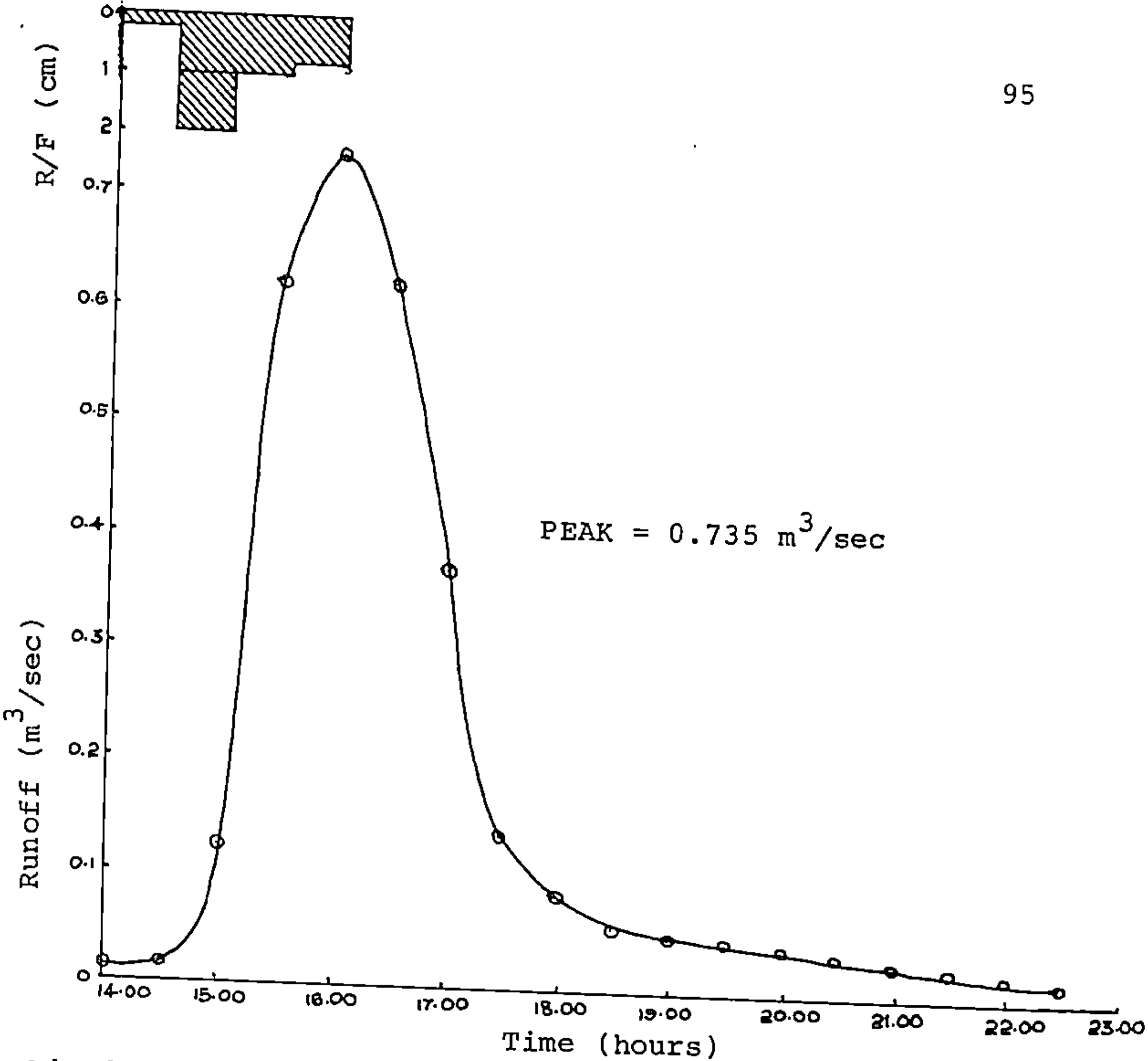

Fig.36 Runoff hydrograph of coffee watershed on 28.9.87

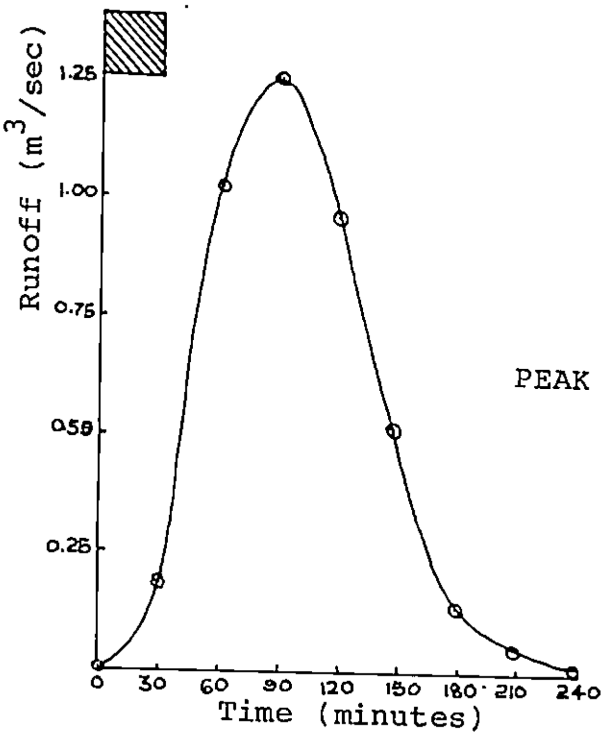

Fig.37 unit hydrograph of coffee watershed on 28.9.87

commencement of the storm. The direct runoff started after 30 minutes since the commencement of the storm and lasted for a duration of 240 minutes. The runoff hydrographs of coffee watershed on 5.11.86 and 28.9.87 are given in figures 34 and 36. The rainfall values were 3.2 cm and 4 cm respectively. Corresponding unit hydrographs are given in figures 35 and 37. In all the cases the direct runoff started after 30 minutes since the commencement of the storm and attained a peak after 60 and 90 minutes. From the hydrographs it was observed that there is an appreciable amount of baseflow which is flowing through this watershed. The sharp rising limbs indicate steep sloping terrain with low channel storage.

The runoff hydrograph and unit hydrograph of tea watershed on 26.10.86 are given in figures 38 and 39. The total rainfall was 4.5 cm and the duration was 2 hours. The peak flow rate of 0.054 m^3/sec was occurred after 2 hours since the commencement of the storm. The direct runoff started after 1 hour since the commencement of the storm and lasted for a duration of 270 minutes. Figures 40 and 42 show the runoff hydrographs of tea watershed on 11.8.87 and 14.10.87. The rainfall values were 1.5 cm and 1.7 cm respectively. Corresponding unit hydrographs are given in figures 41 and 43. The direct runoff started after 30 to 60 minutes since the commencement of the storm and attained a

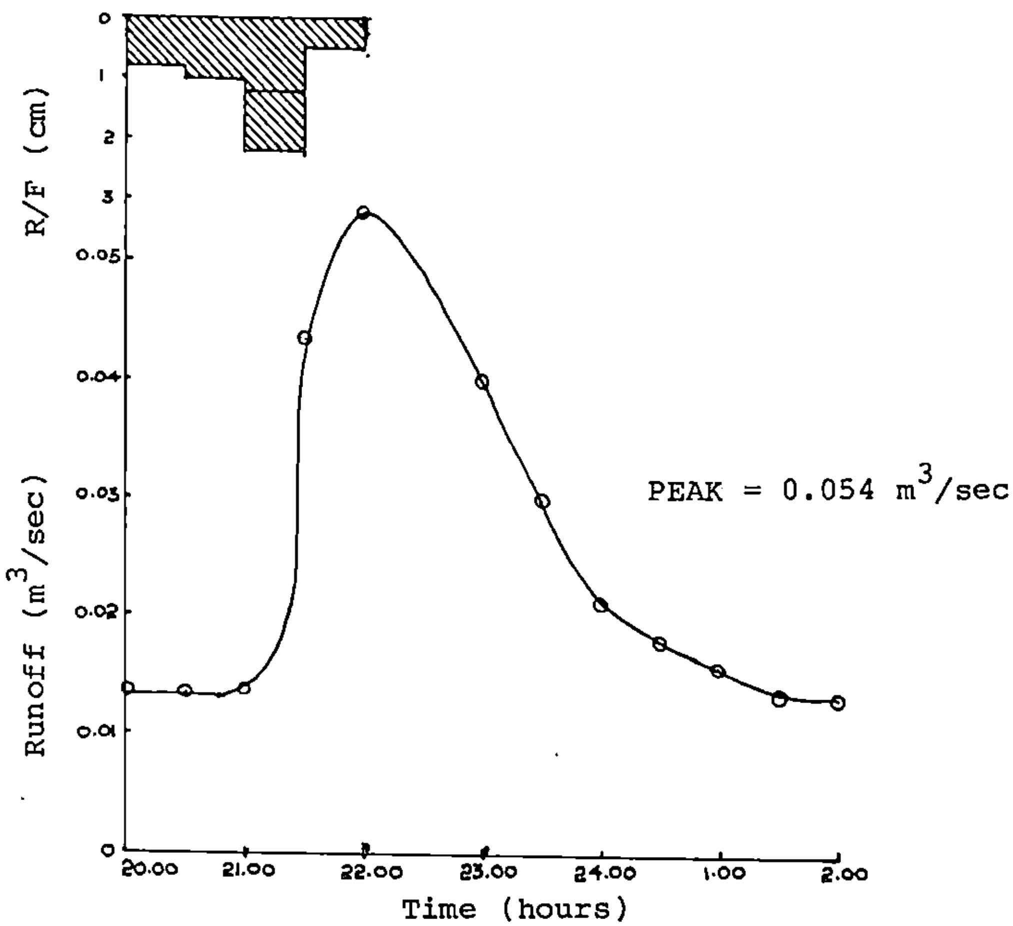

Fig.38 Runoff hydrograph of tea watershed on 26.10.86

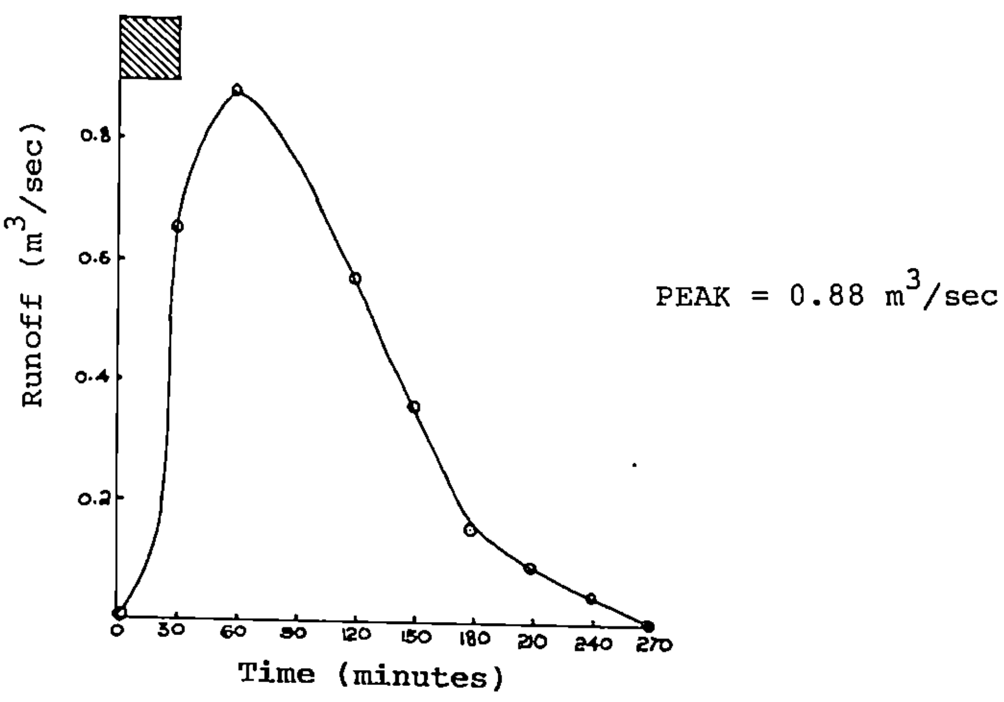

Fig.39 Unit hydrograph of tea watershed on 26.10.86

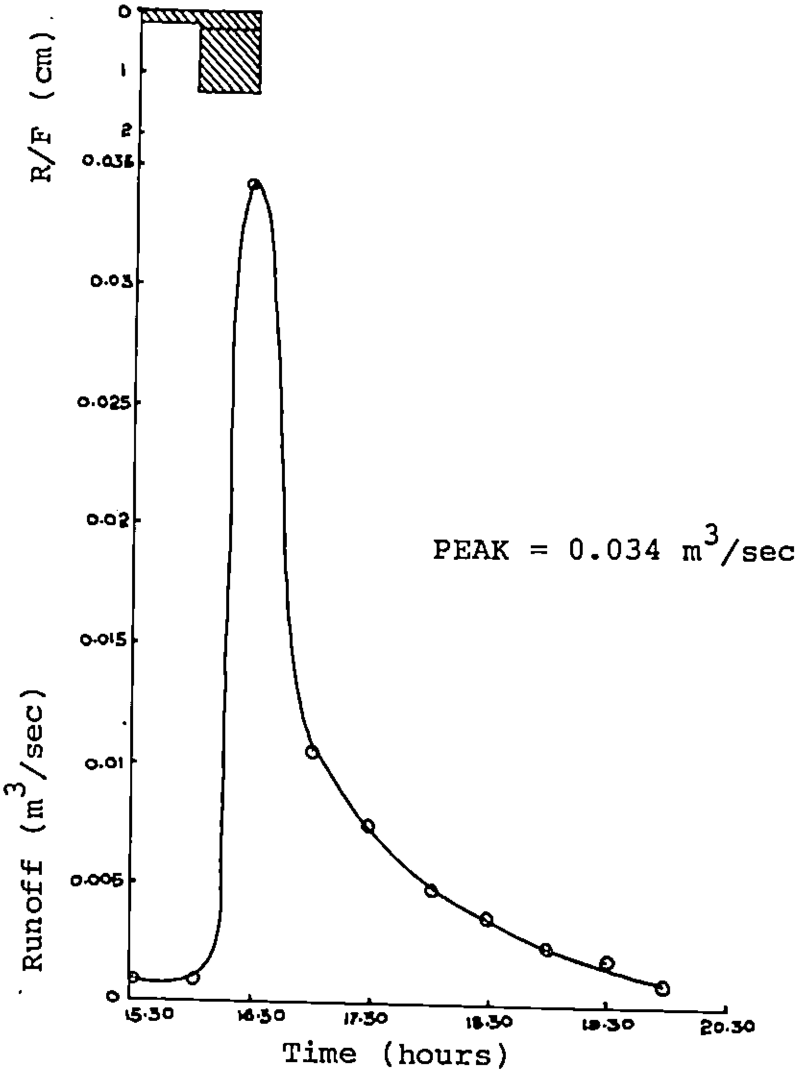

Fig.40 Runoff hydrograph of tea watershed on 11.8.87

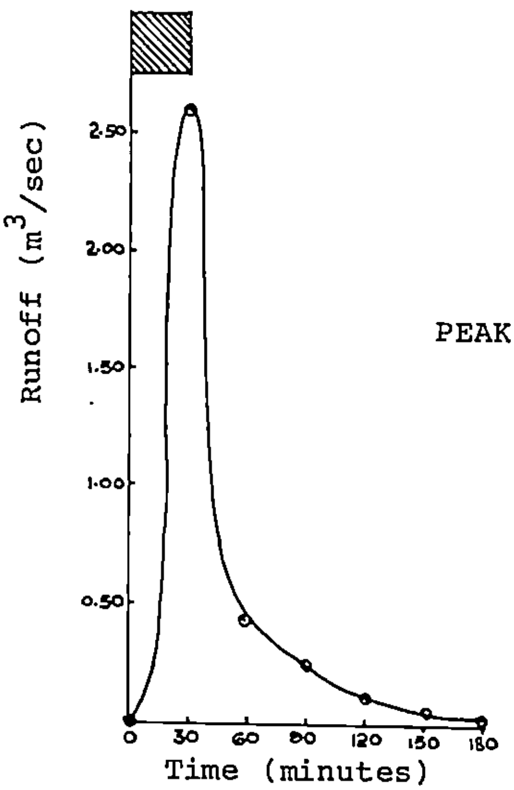

Fig.41 Unit hydrograph of tea watershed on 11.8.87

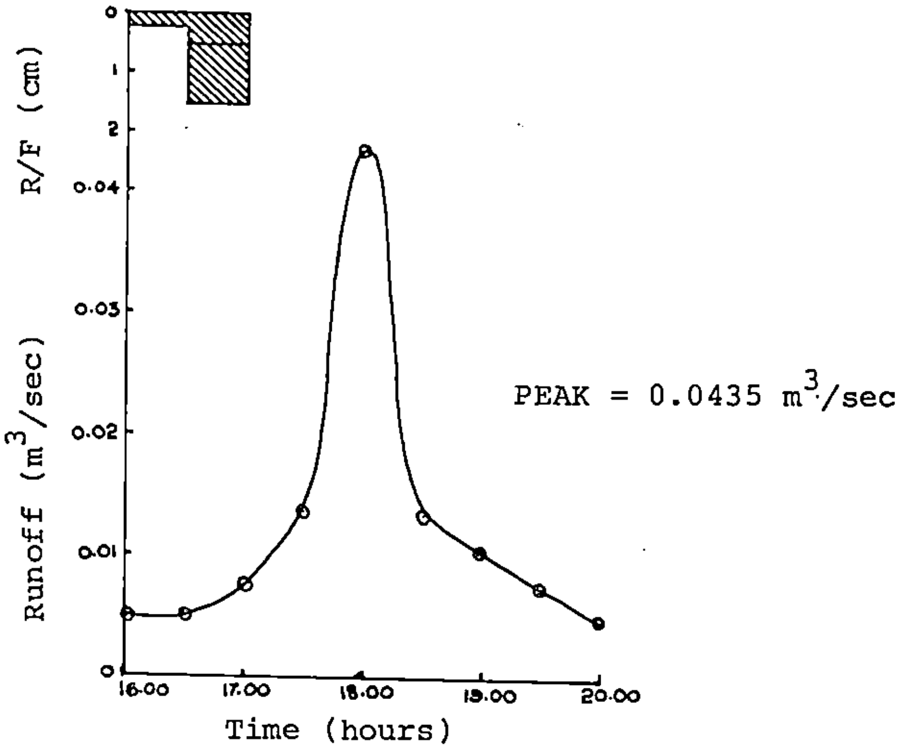

Fig.42 Runoff hydrograph of tea watershed on 14.10.87

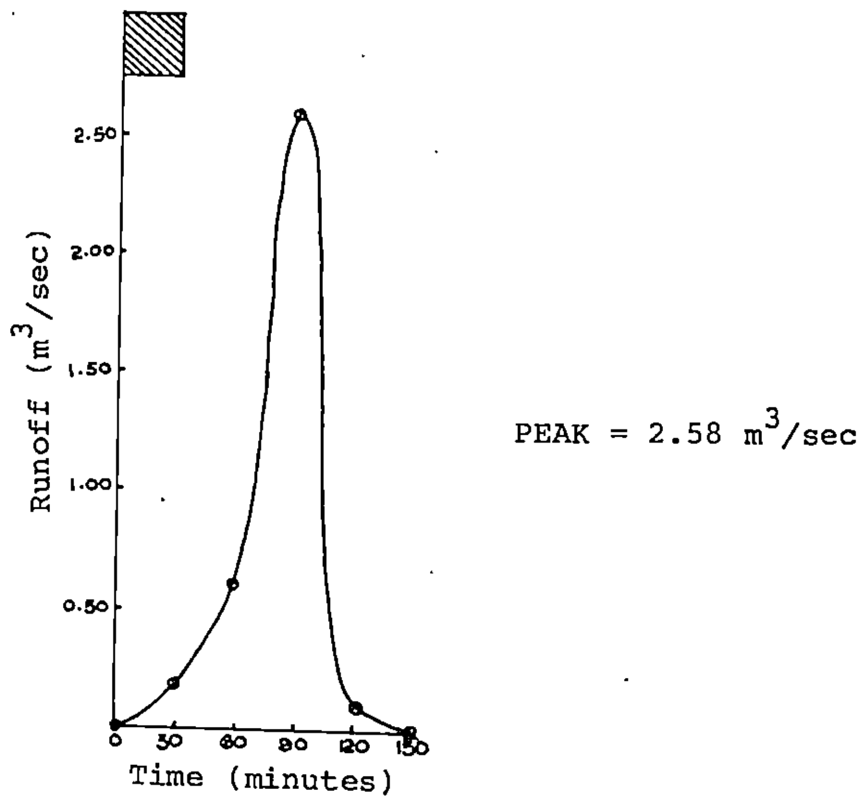

Fig.43 Unit hydrograph of tea watershed on 14.10.87

peak within 90 minutes. The sharp rising limbs of the hydrographs indicate steep sloping terrain with low channel storage and from the hydrographs it was observed that there is an appreciable amount of baseflow which is flowing through this watershed.

From the runoff hydrographs it was observed that the baseflow component was comparatively high for the cashew, coffee and tea watersheds. For the rubber watershed the baseflow was found to be nil. The hydrographs attain a sharp peak immediately as the rain falls, indicating steep sloping terrains having low channel storage. The recession limbs are also found to be somewhat steep for all these watersheds.

From the hydrograph analysis it was observed that as the direct runoff starts it attains a sharp peak and receeds with a steep limb. This indicates that the channel storage for these watersheds are very low. From the hydrographs it was observed that there is a baseflow which is flowing through the three watersheds, except for rubber. Though the infiltration rates of the watersheds are very high, higher than the rainfall intensities the total runoff produced by these watersheds are high. This leads to the inference that the rainfall which infiltrates down into the soil reaches an impermeable layer somewhere in the profile and there it flows laterally through the profile. This lateral interflow reaches at some location in the downstream side and there it saturates the surface. After sometime this area may become super saturated and act like an impervious surface producing 100 per cent surface runoff. When the rain falls on this supersaturated area the total rainfall is converted into surface runoff. This is the reason for the sharp peak and steep rising limb of the hydrographs.

But in the case of rubber watershed the area is very small and it lies adjacent to the kuttiady reservoir. The springs produced by piping below the gauging station joins the waterspread area of the reservoir and this interflow could not be accounted for estimating the total runoff. Since the area is small and the slope is more, i.e. 40 per cent, the portion of rainfall which flows down immediately as it falls on the watershed reaches the outlet as surface runoff and the interflow has not accounted for the total runoff. This may be the reason for the absence of baseflow component for this watershed.

The high infiltration rate and baseflow component are the peculiarity of these watersheds of Western Ghat region. Another characteristic of the stream flow from these watersheds is its lack of sensitivity to changes in rainfall intensity. All these characteristics support the source area concept of runoff formation. That is direct runoff doesn't originate from the whole watershed but from small portions of the total drainage area. According to Kirby (1969) vegetation increases initial depression storage and infiltration rates so that where dense vegetation cover is established, Horton's overland flow is very unusual. The contributing area of the surface runoff is called source area. The runoff contribution by source areas form the vital component of direct runoff from small watersheds with monocrop managements in Western Ghat region and the runoff formation is not significantly influenced by the land use in these watersheds.

Summary

SUMMARY

Four small watersheds planted with cashew, rubber, coffee and tea were studied to assess the effect of land use on water yield from these watersheds. The analysis of the rainfall and runoff data indicated that nearly 50 per cent of the total rainfall leaves these watersheds as runoff except in case of rubber watershed. The infiltration data from these watersheds were analysed and found that all these watersheds have high infiltration rates even after saturation, thereby absorbing even the most intense storms of the period during which the study was conducted. The regression equation of runoff on rainfall was worked out for all the watersheds. The equations are:

Cashew watershed	$Y = 0.522\ x + 0.113$
Rubber watershed	$Y = 0.145\ x - 0.032$
Coffee watershed	$Y = 0.361\ x + 0.012$
Tea watershed	$Y = 0.489\ x - 0.007$

where,

Y = Average weekly runoff, cm

x = Average weekly rainfall, cm

values of rainfall, form factor, basin circularity, basin elongation, mean basin slope and maximum length of stream. The equation is,

$$Y = 2.34\ (x_1)^{0.987}\ (x_2)^{0.187}\ (x_3)^{1.288}\ (x_4)^{-1.162}\ (x_5)^{-0.203}\ (x_6)^{-0.084}$$

where,

Y = Average weekly runoff, cm

x_1 = Average weekly rainfall, cm

x_2 = Form factor

x_3 = Basin circularity

x_4 = Basin elongation

x_5 = Mean basin slope, per cent

x_6 = Maximum length of stream, m

In this equation the exponent of mean basin slope is negative and hence another equation was worked out excluding the values of mean basin slope. The equation is

$$Y = 1.549\ (x_1)^{0.987}\ (x_2)^{0.282}\ (x_3)^{1.17}\ (x_4)^{-1.256}\ (x_5)^{-0.118}$$

where,

x_5 = Maximum length of stream, m

All the other factors are same as above.

These equations can be used to predict the average weekly values of runoff from the selected small watersheds planted with cashew, coffee or tea and other similar watersheds of Western Ghats. The rubber watershed was not considered while developing these equations.

From the hydrograph analysis it was observed that the hydrograps of these watersheds attain a sharp peak immediately as the rainfalls, indicating steep sloping terrains having low channel storage. The recession limbs are also found to be somewhat steep for all these watersheds. From the runoff hydrographs it was found that there is a baseflow which is flowing through the 3 watersheds except for the rubber watershed during the period when the study was conducted. This comparatively larger component of baseflow is responsible for the production of higher runoff values by these watersheds. For the rubber watershed the runoff value is less since there is no baseflow at all. The reason being the smaller area of the watershed and it lies adjacent to the Kuttiady reservoir. So there is a possibility of the ground water flow (interflow) reaching the reservoir avoiding the measuring channel. Small springs produced by piping below the gauging station were found joining the waterspread area of the reservoir and this could not be measured to account for the total runoff.

The geomorphological characteristics of the watersheds were studied. No specific inference could be drawn from these because the watersheds are small and hence it was difficult to work out the most important geomorphological characteristics like drainage density, bifurcation ratio etc. Compared to the other watersheds the slope of the rubber watershed is high.

The analysis of the soil characteristics have indicated that the soils of these watersheds are coarse grained soils with a greater composition of sand. The soils are laterite with high infiltration capacities. All these soils contain more than 1 per cent of organic carbon indicating high humus content. The results of the studies on laterite soils of Western Ghat region by CWRDM, indicated that there is an impermeable clay layer separating the laterite and weathered rock having a thickness of about 3.5 metres and is located in the depth horizon of about 7 to 10.5 metres from the ground level.

From the above results it can be concluded that the impermeable layer within the soil profile impedes the vertical movement of water into the soil and produces the lateral flow. The water which infiltrates down meets this impermeable layer, where it flows laterally through the profile. This lateral interflow reaches the valley portion of the watersheds and where it saturates the soil. After some time this area becomes super saturated and acts like an impervious surface producing 100 per cent surface runoff. This area is responsible for the sharp peak of the runoff hydrographs.

The flow from these watersheds is thus saturation overland flow. Saturation overland flow is produced when subsurface flow saturates the soil near the bottom of a slope and as rain falls on this saturated soil, overland flow generates. Saturation overland flow differs from Hortanian overland flow in that in case of Hortanian overland flow the soil is saturated from above by infiltration, while in saturation overland flow it is saturated from below by subsurface flow. Saturation overland flow occurs most often at the bottom of hill slopes near stream banks. The velocity of subsurface flow is so low that not all the area of a watershed can contribute subsurface flow or saturation overland flow to a stream during a storm. Forest hydrologists (Hewlett et al., 1982) have coined the terms variable source area or partial areas to denote the area of a watershed actually contributing flow to the stream at any time. The variable source area expands during rainfall and contracts thereafter. The source area for streamflow may constitute only 10 per cent of the watershed during a storm in a humid, well vegetated region.

Watersheds of Western Ghat Kerala have an undulating steep sloping terrain with nearly flat swamps or paddy fields at the down stream portion of the valley. This is the typical form of Kerala watersheds. The paddy fields at the downstream area becomes swampy during the monsoon season and this supersaturated area form the source area which is responsible for the runoff production in the watersheds with monocrop managements in Western Ghat region. The runoff production in these watersheds is controlled by the source area and the quantity of runoff produced depends upon the extent of source area which contributes the runoff. Thus the water yield is not influenced by the land use in the selected small agricultural watersheds of Western Ghats of Kerala, but is influenced by the magnitude of source area which contributes the runoff. All the selected watersheds have a dense vegetative cover with good canopy and act almost like natural forests.

The conclusions drawn from this study are given below:

(i) The land use has no significant effect on water yield from the selected small agricultural watersheds* of Western Ghats of Kerala, since land use is not the factor which influences the runoff production from these watersheds.

*Planted with cashew, rubber, coffee and tea

(ii) Direct runoff is generated from source areas and Hortanian overland flow is a rare phenomenon in these watersheds of Western Ghat region. This characteristic makes projecting runoff data from these well-vegetated hill slopes to other areas of Kerala difficult.

(iii) Identification of these source areas is the main prerequisite for evolving rainfall-runoff relationships and planning water resources development for the watersheds of Western Ghats of Kerala.

(iv) More studies need be conducted about the saturation overland flow or source area concept of runoff production, since it is a recently identified phenomenon of runoff production.

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* Original not seen

APPENDIX-I

Derivation of infiltration equation

Coffee watershed: Let $t_1 = 15$ minutes and $t_2 = 110$ minutes

$\log t_1 = 1.18, \quad \log t_2 = 2.04$

From Fig.12,

$\log y_1 = 0.575$ and $\log y_2 = 1.275$

ie. $y_1 = 3.76$ and $y_2 = 18.80$

The form of the equation is $Y = b + at^{\alpha}$

$$\text{ie. } \log Y = \log b + \log a + \alpha \log t$$

$$0.575 = \log b + \log a + \alpha \times 1.18 \quad \ldots\ldots (1)$$

$$1.275 = \log b + \log a + \alpha \times 2.04 \quad \ldots\ldots (2)$$

$$(2)-(1) = 0.7 = (2.04 - 1.18)$$

$$\text{ie. } \alpha = 0.813$$

Again,

$$3.76 = b + a \times 15^{0.813} \quad \ldots\ldots (3)$$

$$18.80 = b + a \times 110^{0.813} \quad \ldots\ldots (4)$$

$$(4)-(3) = 15.04 = a\ (110^{0.813} - 15^{0.813})$$

$$\text{ie. } a = 0.41$$

Substituting the value of a in (4)

$$18.80 = b + 0.41 \times 110^{0.813}$$

$$\text{ie. } b = 18.80 - 0.41 \times 110^{0.81}$$

$$= 0.08$$

The infiltration equation is $Y = 0.41 \times t^{0.813} + 0.08$

Appendix-II

Geomorphological characteristics of the watershed

Cashew watershed: Area, $A = 29.5 \text{ ha} = 295000 \text{ m}^2$

Perimeter, $P = 2150 \text{ m}$

Length of stream, $L = 650 \text{ m}$

(i) Form factor, Rf

$$R_f = A/L^2 = \frac{295000}{650^2} = \underline{\underline{0.698}}$$

(ii) Basin circularity, Rc

$$R_c = \frac{4 \pi A}{P^2}$$

$$= \frac{4 \pi \times 295000}{2150^2}$$

$$= \underline{\underline{0.81}}$$

(iii) Basin elongation, Re

$$R_e = \frac{2\sqrt{A/\pi}}{L}$$

$$= \frac{\sqrt{295000/\pi}}{650} = \underline{\underline{0.943}}$$

(iv) Mean basin slope

$$= \frac{\text{Total length of contour} \times \text{contour interval}}{\text{Basin area}} \times 100$$

$$= \frac{6700 \times 10}{295000} \times 100$$

$$= \underline{\underline{22.7\%}}$$

Appendix-III

Infiltration characteristics of the watersheds

Cashew watershed

Elapsed time (min) t	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Accumulated infiltration (cm) Y	log t	log y
5	1.80	21.60	1.80	0.70	0.26
10	1.70	20.40	3.50	1.00	0.54
15	1.70	20.40	5.20	1.18	0.72
20	1.60	19.20	6.80	1.30	0.83
25	1.60	19.20	8.40	1.40	0.92
30	1.55	18.60	9.95	1.48	1.00
40	2.85	17.10	12.80	1.60	1.11
50	2.70	16.20	15.50	1.70	1.19
60	2.50	15.00	18.00	1.78	1.26
70	2.40	14.40	20.40	1.85	1.31
80	2.30	13.80	22.70	1.90	1.36
90	2.20	13.20	24.90	1.95	1.39
105	3.30	13.20	28.20	2.02	1.45
120	3.20	12.80	31.40	2.08	1.49

Appendix-III (Contd.)

Rubber watershed

Elapsed time (min) t	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Accumulated infiltration (cm) Y	log t	log y
5	1.50	18.00	1.50	0.70	0.18
10	1.50	18.00	3.00	1.00	0.48
15	1.50	18.00	4.50	1.18	0.65
20	1.50	18.00	6.00	1.30	0.78
30	3.00	18.00	9.00	1.48	0.95
40	2.80	16.80	11.80	1.60	1.07
50	2.60	15.60	14.40	1.70	1.16
60	2.40	14.40	16.80	1.78	1.23
75	3.60	14.40	20.40	1.88	1.31
90	3.40	13.60	23.80	1.95	1.38
105	3.30	13.20	27.10	2.02	1.43
120	3.10	12.40	30.20	2.08	1.48

Appendix-III (Contd.)

Coffee watershed

Elapsed time (min) t	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Accumulated infiltration (cm) Y	log t	log y
5	1.60	19.20	1.60	0.70	0.20
10	1.40	16.80	3.00	1.00	0.48
15	1.20	14.40	4.20	1.18	0.62
20	1.20	14.40	5.40	1.30	0.73
25	1.00	12.00	6.40	1.40	0.81
30	1.00	12.00	7.40	1.48	0.87
45	2.10	8.40	9.50	1.65	0.98
60	1.70	6.80	11.20	1.78	1.05
75	1.60	6.40	12.80	1.88	1.11
90	1.50	6.00	14.30	1.95	1.16
105	1.50	6.00	15.80	2.02	1.20
120	1.40	5.60	17.20	2.08	1.24

Appendix-III (Contd.)

Tea watershed

Elapsed time (min) t	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Accumulated infiltration (cm) Y	log t	log y
5	1.90	22.80	1.90	0.70	0.28
10	1.70	20.40	3.60	1.00	0.56
15	1.60	19.20	5.20	1.18	0.72
20	1.50	18.00	6.70	1.30	0.83
25	1.40	16.80	8.10	1.40	0.91
30	1.40	16.80	9.50	1.48	0.98
40	2.60	15.60	12.10	1.60	1.08
50	2.50	15.00	14.60	1.70	1.16
60	2.30	13.80	16.90	1.78	1.23
70	2.30	13.80	19.20	1.85	1.28
80	2.25	13.50	21.45	1.90	1.33
90	2.20	13.20	23.65	1.95	1.37
105	3.20	12.80	26.85	2.02	1.43
120	3.00	12.00	29.85	2.08	1.47

Appendix-IV

Computer programme used for developing the multiple curvilinear equation in SIGMAPLOT Package

```
(Parameters)

     a = 0
     b = 0
     c = 0
     d = 0
     e = 0
     m = 0

(Variables)

     Y  = Col (1)
     X1 = Col (2)
     X2 = Col (3)
     X3 = Col (4)
     X4 = Col (5)
     X5 = Col (6)

(Equations)

     f  =  m* X1** a* X2** b* X3** c* X4** d* X5** e
     fit   f to Y
     (Options)
     iterations = 10
```

Appendix-V

Ordinates of storm hydrographs and unit hydrographs

Cashew watershed, Date 13.10.1986

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
15.00	0.009	0.009	0.000	0.000	-
15.15	0.009	0.009	0.000	0.000	-
15.30	0.009	0.009	0.000	0.000	0
15.45	0.100	0.009	0.091	0.436	15
16.00	0.216	0.009	0.207	0.991	30
16.15	0.193	0.009	0.184	0.882	45
16.30	0.145	0.009	0.136	0.652	60
16.45	0.075	0.009	0.066	0.316	75
17.00	0.009	0.009	0.000	0.000	90
17.15	0.009	0.009	0.000	0.000	-
17.30	0.009	0.009	0.000	0.000	-
			0.684m^3/sec		

Direct runoff = 0.684 m^3/sec
= 0.684 x 15 x 60 m^3 = 615.6 m^3

Area = 29.5 ha

$$Pnet = \frac{615.6}{29.5 \times 10000}\ m = 2.086 \times 10^{-3} m = 0.21 cm$$

Appendix V (Contd.)

Cashew watershed, Date 14.10.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
16.00	0.0165	0.0165	0.000	0.000	--
16.15	0.020	0.020	0.000	0.000	--
16.30	0.026	0.026	0.000	0.000	0
16.45	0.150	0.026	0.124	0.873	15
17.00	0.276	0.033	0.243	1.710	30
17.15	0.125	0.028	0.097	0.683	45
17.30	0.026	0.026	0.000	0.000	60
17.45	0.026	0.026	0.000	0.000	--
18.00	0.026	0.026	0.000	0.000	--
18.15	0.020	0.020	0.000	0.000	--
18.30	0.0165	0.0165	0.000	0.000	--
			0.464 m^3/sec		

Direct runoff = 0.464 m^3/sec
= 0.464 x 60 x 15 m^3 = 417.6 m^3

Area = 29.5 ha

Pnet = $\frac{417.6 \times 100}{29.5 \times 1000}$ cm = 0.142 cm

Appendix V (Contd.)

Cashew watershed, Date 19.10.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
14.00	0.026	0.026	0.000	0.000	--
14.15	0.026	0.026	0.000	0.000	--
14.30	0.026	0.026	0.000	0.000	0
14.45	0.060	0.026	0.034	0.221	15
15.00	0.216	0.026	0.190	1.120	30
15.15	0.190	0.026	0.164	0.970	45
15.30	0.145	0.026	0.119	0.704	60
15.45	0.073	0.026	0.047	0.298	75
16.000	0.026	0.026	0.000	0.000	90
16.15	0.026	0.026	0.000	0.000	--
16.30	0.026	0.026	0.000	0.000	--
			0.554m^3/sec		

Direct runoff = 0.554m^3/sec
= 0.554 x 15 x 60 m^3 = 498.6 m^3

Area = 29.5 ha

Pnet = $\frac{498.6 \times 100}{29.5 \times 1000}$ cm = 0.169 cm

Appendix V (Contd.)

Rubber watershed, Date 9.10.1986

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
10.30	0.000	0.000	0.000	0.000	0
10.45	0.009	0.000	0.009	0.020	15
11.00	0.039	0.000	0.039	0.087	30
11.15	0.028	0.000	0.028	0.062	45
11.30	0.014	0.000	0.014	0.031	60
11.45	0.006	0.000	0.006	0.013	75
12.00	0.000	0.000	0.000	0.000	90
			0.096m^3/sec		

Direct runoff = 0.096m^3/sec
= 0.096 x 15 x 60 m^3 = 86.4 m^3

Area = 1.9 ha

Pnet = $\frac{86.4 \times 100}{1.9 \times 1000}$ cm = 0.455 cm

Appendix V (Contd.)

Rubber watershed, Date 12.10.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
16.30	0.000	0.000	0.000	0.000	0
16.45	0.005	0.000	0.005	0.00723	15
17.00	0.014	0.000	0.014	0.020	30
17.15	0.024	0.000	0.024	0.035	45
17.30	0.032	0.000	0.032	0.046	60
17.45	0.039	0.000	0.039	0.056	75
18.00	0.030	0.000	0.030	0.044	90
18.15	0.002	0.000	0.002	0.0029	105
18.30	0.000	0.000	0.000	0.000	120
			0.146m^3/sec		

Direct runoff = 0.146m^3/sec

= 0.146 x 15 x 60 m^3 = 131.4 m^3

Area = 1.9 ha

$$\text{Pnet} = \frac{131.4 \times 100}{1.9 \times 10000} \text{ cm} = \underline{\underline{0.692 \text{ cm}}}$$

Appendix V (Contd.)

Rubber watershed, Date 22.10.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
18.30	0.000	0.00	0.000	0.000	0
18.45	0.010	0.00	0.010	0.024	15
19.00	0.018	0.00	0.018	0.041	30
19.15	0.029	0.00	0.029	0.071	45
19.30	0.020	0.00	0.020	0.049	60
19.45	0.0093	0.00	0.0093	0.023	75
20.00	0.00	0.00	0.000	0.000	90
			0.0863m^3sec		

Direct runoff = $0.0863 m^3/sec$

= $0.0863 \times 15 \times 60 \ m^3$ = $77.67 \ m^3$

Area = 1.9 ha

Pnet = $\frac{77.67 \times 100}{1.9 \times 10000}$ cm = 0.41 cm

Appendix V (Contd.)

Coffee watershed, Date 3.10.1986

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=$\frac{(4)}{Pnet}$	Time of beginning of direct runoff (minutes) (6)
16.30	0.036	0.036	0.000	0.000	--
17.00	0.036	0.036	0.000	0.000	0
17.30	0.1752	0.036	0.1392	0.718	30
18.00	0.3287	0.036	0.2927	1.51	60
18.30	0.274	0.0625	0.2115	1.09	90
19.00	0.1419	0.060	0.0819	0.422	120
19.30	0.1016	0.055	0.0466	0.240	150
20.00	0.0744	0.050	0.0244	0.126	180
20.30	0.0589	0.0475	0.0114	0.059	210
21.00	0.0465	0.0465	0.000	0.000	240
21.30	0.0429	0.0429	0.000	0.000	--
22.00	0.0390	0.0390	0.000	0.000	--
22.30	0.0360	0.0360	0.000	0.000	--
			0.8077m^3/sec		

Direct runoff = 0.8077m^3/sec
= 0.8077 x 15 x 60 m^3 = 1453.86 m^3

Area = 74.87 ha

Pnet = $\frac{1453.86 \times 100}{74.87 \times 10000}$ cm = 0.194 cm

Appendix V (Contd.)

Coffee watershed, Date 5.11.1986

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
15.30	0.0362	0.0362	0.000	0.000	--
16.00	0.0362	0.0362	0.000	0.000	0
16.30	0.1638	0.0362	0.1276	1.046	30
17.00	0.3429	0.0362	0.3067	2.510	60
17.30	0.1638	0.0950	0.069	0.566	90
18.00	0.0922	0.0875	0.0047	0.038	120
18.30	0.0832	0.0832	0.000	0.000	150
19.00	0.0794	0.0794	0.000	0.000	--
19.30	0.0711	0.0711	0.000	0.000	--
20.00	0.0619	0.0619	0.000	0.000	--
20.30	0.0579	0.0579	0.000	0.000	--
21.00	0.0502	0.0502	0.000	0.000	--
21.30	0.0362	0.0362	0.000	0.000	--
			0.508m^3/sec		

Direct runoff = 0.508m^3/sec
= 0.508 x 60 x 30 m^3 = 914.4 m^3

Area = 74.87 ha

Pnet = $\frac{914.4 \times 100}{74.87 \times 10000}$ cm = 0.122 cm

Appendix V (Contd.)

Coffee watershed, Date 28.9.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
14.00	0.015	0.015	0.000	0.000	--
14.30	0.015	0.015	0.000	0.000	--
15.00	0.120	0.015	0.105	0.182	0
15.30	0.620	0.015	0.605	1.050	30
16.00	0.735	0.015	0.720	1.250	60
16.30	0.620	0.070	0.550	0.953	90
17.00	0.370	0.065	0.305	0.529	120
17.30	0.135	0.060	0.075	0.130	150
18.00	0.085	0.055	0.030	0.052	180
18.30	0.055	0.055	0.000	0.000	210
19.00	0.050	0.050	0.000	0.000	240
19.30	0.045	0.045	0.000	0.000	--
20.00	0.040	0.040	0.000	0.000	--
20.30	0.035	0.035	0.000	0.000	--
21.00	0.030	0.030	0.000	0.000	--
21.30	0.025	0.025	0.000	0.000	--
22.00	0.020	0.020	0.000	0.000	--
22.30	0.015	0.015	0.000	0.000	--
			2.390m^3/sec		

Direct runoff = 2.39 m^3/sec
= 2.39 x 60 x 30 m^3 = 4302 m^3

Area = 74.87 ha

Pnet = $\frac{4302 \times 100}{74.87 \times 10000}$ cm = 0.575 cm

Appendix V (Contd.)

Tea watershed, Date 26.10.1986

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
20.00	0.0136	0.0136	0.000	0.000	--
20.30	0.0136	0.0136	0.000	0.000	--
21.00	0.0136	0.0136	0.000	0.000	0
21.30	0.0435	0.0136	0.0299	0.650	30
22.00	0.0540	0.0136	0.0404	0.878	60
22.30	0.0435	0.0136	0.0299	0.650	90
23.00	0.040	0.0136	0.0264	0.574	120
23.30	0.030	0.0136	0.0164	0.356	150
24.00	0.021	0.0136	0.0074	0.161	180
00.30	0.018	0.0136	0.0044	0.096	210
1.00	0.0162	0.0136	0.0026	0.048	240
1.30	0.0136	0.0136	0.000	0.000	270
2.00	0.0136	0.0136	0.000	0.000	--
			0.1574 m^3/sec		

Direct runoff = 0.1574 m^3/sec
= $0.1574 \times 30 \times 60\ m^3$ = 283.32 m^3

Area = 61.72 ha

Pnet = $\frac{283.32 \times 100}{61.72 \times 10000}$ cm = 0.046 cm

Appendix V (Contd.)

Tea watershed, Date 11.8.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
15.30	0.00093	0.00093	0.000	0.00	--
16.00	0.00093	0.00093	0.000	0.00	0
16.30	0.0339	0.00093	0.03297	2.62	30
17.00	0.0105	0.005	0.0055	0.436	60
17.30	0.0075	0.0045	0.003	0.24	90
18.00	0.0048	0.00375	0.00105	0.08	120
18.30	0.0040	0.00325	0.00075	0.06	150
19.00	0.0026	0.0026	0.00	0.00	180
19.30	0.0020	0.0020	0.00	0.00	--
20.00	0.0093	0.00093	0.00	0.00	--
			0.04327m^3/sec		

Direct runoff = 0.04327m^3/sec

= 0.04327 x 30 x 60 m^3 = 77.886 m^3

Area = 61.72 ha

Pnet = $\frac{77.886 \times 100}{61.72 \times 10000}$ cm = 0.0126 cm

Appendix V (Contd.)

Tea watershed, Date 14.10.1987

Time (hours) (1)	Discharge (m^3/sec) (2)	Baseflow (m^3/sec) (3)	Direct runoff ordinate (m^3/sec) (4) (2)-(3)	U.H. ordinate (m^3/sec) (5)=(4)/Pnet	Time of beginning of direct runoff (minutes) (6)
16.00	0.0048	0.0048	0.00	0.00	--
16.30	0.0048	0.0048	0.00	0.00	0
17.00	0.0075	0.0048	0.0027	0.180	30
17.30	0.0136	0.0048	0.0088	0.590	60
18.00	0.0435	0.0048	0.0387	2.580	90
18.30	0.0136	0.0120	0.0016	0.110	120
19.00	0.0105	0.0105	0.00	0.00	150
19.30	0.0075	0.0075	0.00	0.00	--
20.00	0.0048	0.0048	0.00	0.00	--
			0.0518 m^3/sec		

Direct runoff = 0.0518 m^3/sec

= 0.0518 x 30 x 60 m^3 = 93.24 m^3

Area = 61.72 ha

Pnet = $\frac{93.24 \times 100}{61.72 \times 10000}$ cm = 0.015 cm

EFFECT OF LAND USE ON WATER YIELD FROM SMALL AGRICULTURAL WATERSHEDS OF WESTERN GHATS

By

ABDUL HAKKIM, V. M.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

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ABSTRACT

Effects of deforestation and other land use changes brought about by human activities on hydrologic cycle continues to be of great concern. A study was conducted to assess the effect of land use on water yield from small agricultural watersheds of Western Ghats of Kerala.

Four small watersheds planted with cashew, rubber, coffee and tea were selected for the study. To get information regarding rainfall, temperature, humidity and daily evaporation; raingauges, thermometers and USWB class A Pan evaporimeters were installed in each watershed. The runoff which is of specific concern was measured using stage level recorders along with weirs and flumes. Infiltration measurements were done using double cylinder infiltrometers. Soil samples were collected from each watershed and were analysed for grain size distribution, soil pH and organic carbon content. Different geomorphological characteristics of the watersheds were also worked out.

Analysis of the rainfall and runoff data indicated that nearly 50 per cent of the total rainfall leaves these watersheds as runoff except in the case of rubber watershed. The infiltration studies indicated that all these watersheds have high infiltration rates even after saturation, thereby

absorbing even the most intense storms of the study period. From the hydrograph analysis of these watersheds it was observed that the hydrographs attain a sharp peak immediately as the rainfalls and there is a baseflow which is flowing through the 3 watersheds, except in the case of rubber watershed. The rubber watershed is very small and lies adjacent to the kuttiadi reservoir. The interflow from the rubber watershed was observed to join the reservoir avoiding the measuring channel. From the soil profile analysis of Western Ghat region it was observed that there is an impermeable clay layer lying below the laterite having an average thickness of 3.5 m located at 7 to 10.5 m below the ground surface.

The results of the study leads to the conclusion that the infiltrated rain water meets the impermeable layer and there it flows laterally through the soil. This lateral interflow reaches the valley portion of the watersheds where it saturates the soil. This saturated area acts like an impervious layer producing 100 per cent surface runoff and it is responsible for the sharp peak of hydrographs. Runoff is generated from these source areas and Hortanian overland flow is a rare phenomenon in these watersheds. Thus from the study it was concluded that land use has no significant effect on water yield from the selected small agricultural watersheds of Western Ghats of Kerala.