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RAINFALL - RUNOFF MODELLING OF WESTERN GHAT REGION OF KARNATAKA

आपो हि ष्ठा मयोभुव

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (INDIA)

ABSTRACT

The water yield is an integration of discharge as a function of time for a specified duration and reflects the volumetric relationship between rainfall and runoff. The estimation of water yield is required for solution of water resources problems normally encountered in design of storage facilities, water availability for agriculture, industrial or drinking purpose, dependable water suply for power genaration, planning irrigation operation and design of irrigation projects. Keeping in this view, the effort has been made to develop a regional conceptual catchment water balance model paramtres which can be used to estimate the water yield from ungauged catchments located in the same region. In the present study, five catchments in the western ghat region have been selected. Out of which, tthree river basins are westward flowing and two rivers are eastward flowing in nature.

The regionalised parameters of the catchment water balance model have been obtained by developing relationship between model parametres such as wetting potential, vaporisation potential, initial abstraction coefficient of baseflow and surface flow with mean annual rainfall, and vegetation cover of the basin. However, coefficient of determination between vegetation cover and the model parametres found to be very high and where as the relatinship between mean annaual rainfall and model parametres is very low. The regional parametres obtained are compared with calibrated parametres and found to be within the tolerable limits. Water balance components are simulated using both regionalised and calibrated parametres of the model. The variation between the simulated values are within 10 per cent. Therefore it is suggested that model parametres can be obtained from the established relationship between vegetation cover of the basin and the model parametres.

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1.0 Introduction

Water yield refers to the volume of water available in the stream at a specified point over a specified period of time. The emphasis on the volume of flow rather than the instantaneous discharge. Therefore the water yield is the integration of discharge as a function of time for a specified duration and reflects the volumetric relationship between rainfall and runoff. The yield is expressed for monthly, seasonal or annual periods.

Many factors effect water yield depending on the period of its determination(DeCourcy,1965). Some of these factors are interdependent. These factors can be classified as;

a. Meteorologic factors

b. Watershed factors.

Space and time distribution of precipitation amount, intensity and duration, and space and time distribution of temperature are some of the most important meterological factors. Some important watershed factors include, surface vegetation, soil moisture, soil characteristics, surface topography, and drainage density.

Estimation of water yield is required for solution of water resources problems such as design of storage facilities, water availability for agriculture, industrial or drinking purpose, dependable water supply for power generation under varying pattern of rainfall, planning irrigation operation, and design of irrigation projects and etc..

There are several approaches to determine the water yield. These can be grouped into three classes;

a. Theoretical

b. Conceptual

c. Emperical.

Theoretical and Emperical models are exactly opposite in meaning with conceptual models lying somewhere in between them.

Conceptual models are simplified representations of the physical processes usually relying on mathematical descriptions, which simulate complex processeses in the mean by relying on a few key conceptual parameters. The extensive use of conceptual models in catchment hydrology reflects the inherent complexity of the phenomena and the practical inability to account for deterministic components in all instances. Therefore, conceptual models are useful and practical alternative for deterministic models.

1.1.0 Catchment Water Balance Model

A catchment water budgeting is one of the tools to estimate the water yield from the basin. The catchment water balance can be described by a set of equations (L'vovich 1979).

Precipitation can be separated into two components:

$$P = S + W \qquad (1)$$

in which,

P = annual precipitation, S = surface runoff, i.e., the fraction of runoff originating on the land surface; and W = catchment wetting, the fraction of precipitation not contributing to surface runoff.

Likewise, wetting consists two components:

$$W = U + V \qquad (2)$$

in which,

U = baseflow, i.e., the fraction of wetting which exfiltrates as the dry-weather flow of rivers, and V = vaporization, the fraction of wetting returned to the atmosphere as water vapour. Deep percolation, i.e., the portion of wetting not contributing to either baseflow or vaporization, is a very small fraction of precipitation and is usually neglected on practical grounds.

Vaporization, which comprises all moisture returned to the atmosphere, has two components:

$$V = E + T \qquad (3)$$

in which,

E = nonproductive evaporation, and T = productive evaporation, i.e., that resulting from plant transpiration.

From Eqs. 1 to 3, runoff consists of two components;

$R = S + U$ (4)

in which,

R = runoff. Likewise, precipitation consists of two components:

$P = R + V$ (5)

Equations 1 to 5 constitute a set of water balance equations. Combining 4 and 5 leads to:

$P = S + U + V$ (6)

that is, annual precipitation is separated into its three major components, surface runoff, baseflow, and vaporization.

Equations 2 and 5 enable the definition of water balance coefficients. The baseflow coefficient is (L'vovich 1979)

$K_u = U/W = U/(U+V)$ (7)

the runoff coefficient is

$K_r = R/P = R/(R+V)$ (8)

1.2.0 Estimation of Water Balance Components

Several approaches are available for the computation of water balance components. These vary in complexity from the simple empirical formulae to the complex models based on continuous simulation. However, conceptual catchment water balance model (Ponce and Shetty) is the alternative model which uses the water balance equations to separate precipitation into it's various components. Water balance components such as precipitation, surface runoff, baseflow, wetting, and vaporisation are estimated to analyse each components with respect to the precipitation.

1.2.1 Conceptual model of water balance

The conceptual model of water balance (Ponce and Shetty) is suitable for wide range of climatic conditions. The model separates annual precipitation into its three major components: surface runoff, baseflow, and vaporization. It is based on two-step sequential application of a proportional relation linking with two variables such as precipitation and surface runoff, and wetting and baseflow.

L'vovich(1979) has shown that the wetting reaches an upper bound symptotically($W \rightarrow W_p$) as precipitation and surface runoff increases unbounded($P \rightarrow \infty$; $S \rightarrow \infty$) and Vaporization reaches an upper bound asymptotically($V \rightarrow V_p$) as wetting and baseflow increases unbounded ($W \rightarrow \infty$; $U \rightarrow \infty$). In this way, two-step separation of annual precipitation into its three major components such as surface runoff, baseflow and vaporization is accomplished.

The surface runoff submodel is :

$S = (P - \lambda s W_p)^2 / [P + (1-2\lambda_s) W_p]$ (9)

subjected to $P > \lambda_s W_p$, $S = 0$ otherwise,

With λ_s = surface runoff initial abstraction coefficient.

Likewise, baseflow model is :

$U = (W - \lambda_u V_p)^2 / [W + (1-2\lambda_u) V_p]$ (10)

subjected to $W > \lambda_u V_p$, $U = 0$ otherwise,

With λu = baseflow initial abstraction coefficient.

The initial abstraction coefficient of surface flow and baseflow, and potentials of wetting and vaporization have to be calibrated. In order to calibrate the initial abstraction coefficient of surface flow and baseflow, and potentials of wetting and vaporization, the observed data set for the paired values of precipitation and surface runoff, and wetting and baseflow is used.

1.3.0 Regionalisation of Model Parameters

Most of the commonly used prediction technique require the estimation of one or more parameters. A variety of methods are generally available for the estimation of the rameters, but there is often some controversy about the effectiveness of these procedures. Most procedures employ a significant amount of historic hydrologic data, and therefore it is not easy to determine parameter values for catchments in which little or no hydrologic data are available. The prospects for the successful solution of the problem of parameter estimation under these conditions do not appears to be good, but nevertheless, there is an urgent requirement for such work to be undertaken in catchment hydrology. Perhaps the Regionalisation of data and parameters, is the only reasonable approach to this problem to;

a. synthesise long term records of the basin,

b. extrapolate to similar basins in the same representative region,

c. extrapolate to basins with different combinations of geology, land form, soil and vegetation, and forecast possible hydrologic effects of changes in land use on any catchment within the range of type land use sampled by the representative basin network.

The regional analysis comprises the study of hydrologic phenomena with aim of developing mathematical relations to be used in regional context. The mathematical relations are developed so that information from gauged or long-record catchments can be readily transferred to neighbouring ungauged catchments of similar hydrologic characteristics.

The main aim of the study, to develop a regional conceptual catchment water balance model parameters which can be used to estimate the quantity of water yield from the ungauged catchments.

The catchment water balance model (Ponce and Shetty) has parameters like wetting potential, vaporisation potential, initial abstraction coefficient of surface flow and initial abstraction coefficient of baseflow. The parameters of the model are function of annual rainfall, vegetation covers, soil moisture, soil characteristics, surface topography and drainage density.

$$(W_p, V_p, \lambda_s \text{ and } \lambda_u) = f(P_N, V_C, S_M, S_C, T_{phy}, D_D) \qquad (11)$$

Where,

W_p = Wetting potential

V_p = Vaporisation potential

λ_s = Initial abstraction coefficient of Surface flow or initial abstraction of surface flow(W_p x λ_s = I_{abs})

λ_u = Initial abstraction coefficient of baseflow or initial abstraction of baseflow(V_p x λ_u = I_{abu})

P_N = Normal rainfall

V_C = Vegetation cover

S_M = Soil moisture

S_C = Soil characteristics

T_{phy} = Topography

D_D = Drainage density

The relationship may be established between model parameters and factors effecting the water yield of the catchment. However, in the present study, the following relationships are tried to establish the regional parameters of the model with simple linear regression technique;

a. Mean annual rainfall and Wetting potential

b. Mean annual rainfall and Vaporisation potential

c. Mean annual rainfall and Initial abstraction of Surface flow

d. Mean annual rainfall and Initial abstraction of baseflow

e. Percentage of Vegetation cover and Wetting potential

f. Percentage of Vegetation cover and Vaporisation potential

g. Percentage of Vegetation cover and Initial abstraction of Surface flow(Wp x λs)

f. Percentage of Vegetation cover and Initial abstraction of baseflow (V_p x λu)

The study has been carried out for three eastward flowing rivers namely Malaprabha, Barchi, and Dandavathi river bisin and two westward flowing rivers are Netrravathi and Sithanadi.

2.0 DESCRIPTION OF THE STUDY AREA

In the present study, three westward flowing rivers which are originated in the Wetern ghat. However two of the rivers which is considered in the study is a part of the upland of Western ghat and other one which covers all the high land, midland and lowland of the area. In the case of eastward flowing rivers, one catchment in the highland of Western ghat and one more in the midland of the Ghat.

2.1.0 Nethravathi Basin

The Netravathi river is one of the important West flowing rivers of Karnataka. It rises at an elevation of +1000 m., in Western ghats between Kudremukh and Ballalrayan durga in the South Kanara district of Karnataka. The map of Netravati basin is shown in figure 2.1.1. The latitude and longitude of its origin are 13° 10'N and 75° 20E respectively. It flows in North-South direction for the first 40 km., upto Gohattu where it takes a turn towards the west and flows in East-West direction upto its outfall into Arabian sea near Mangalore. Kumaradhari is its major left bank tributary joining it near the village of Uppinangadi. The total length of the Netravati river is 103km from its origin to its outfall into in Arabian sea. Other small tributaries namely Gundiahole, Charmadihole, Gowri hole, Neriahole, Shislahole, Mundajahole, Upparhalla, Kallajehole, Beltangadi hole, Aniyurhole and Yettin hole also join the main Netravati river at different places from its both the sides. The Netravati river basin lies between the latitudes of 12^0 29'11"N and 13^0 11'11" and longitude of 74^0 49'08"E and 75^0 47'53"E. It is surrounded on the North by Tungabhadra sub-basin, on the North-West by Gurpur basin, on the East by Cauvery basin, on the South by Payaswani basin, on the South-West by Uppala basin and on the West by Arabian sea. The basin is nearly fan shaped. The basin drains an area of about 3657 Km^2.

The catchment area of Netravati basin can be broadly divided into three distinct sub-regions namely, coastal plains, the intermediate or transitory sub-mountains region with undulating upland or spurs and hilly region or western ghats. The coastal lands are best

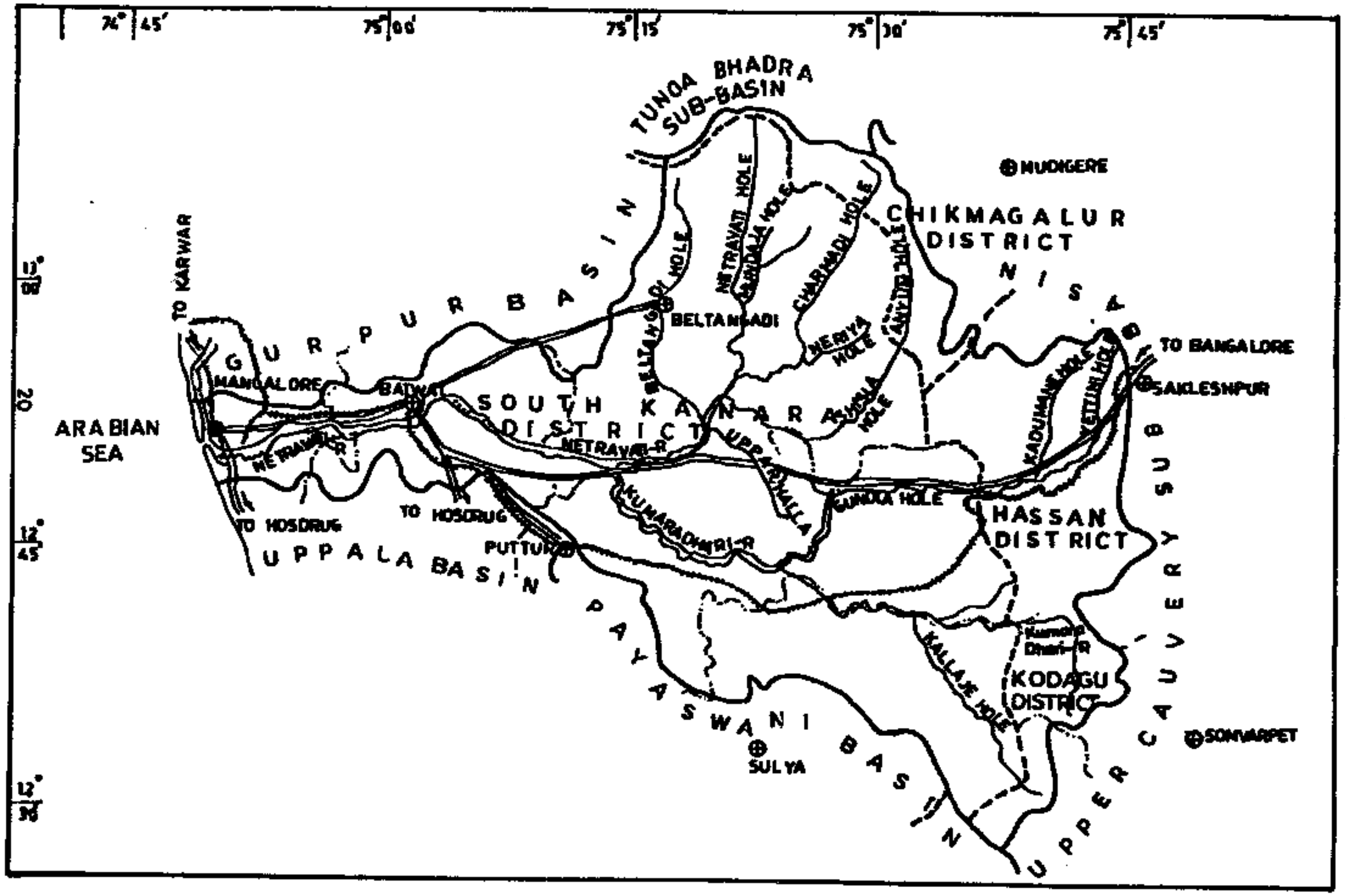


Fig.2..1. 1 Netrravathi Basin

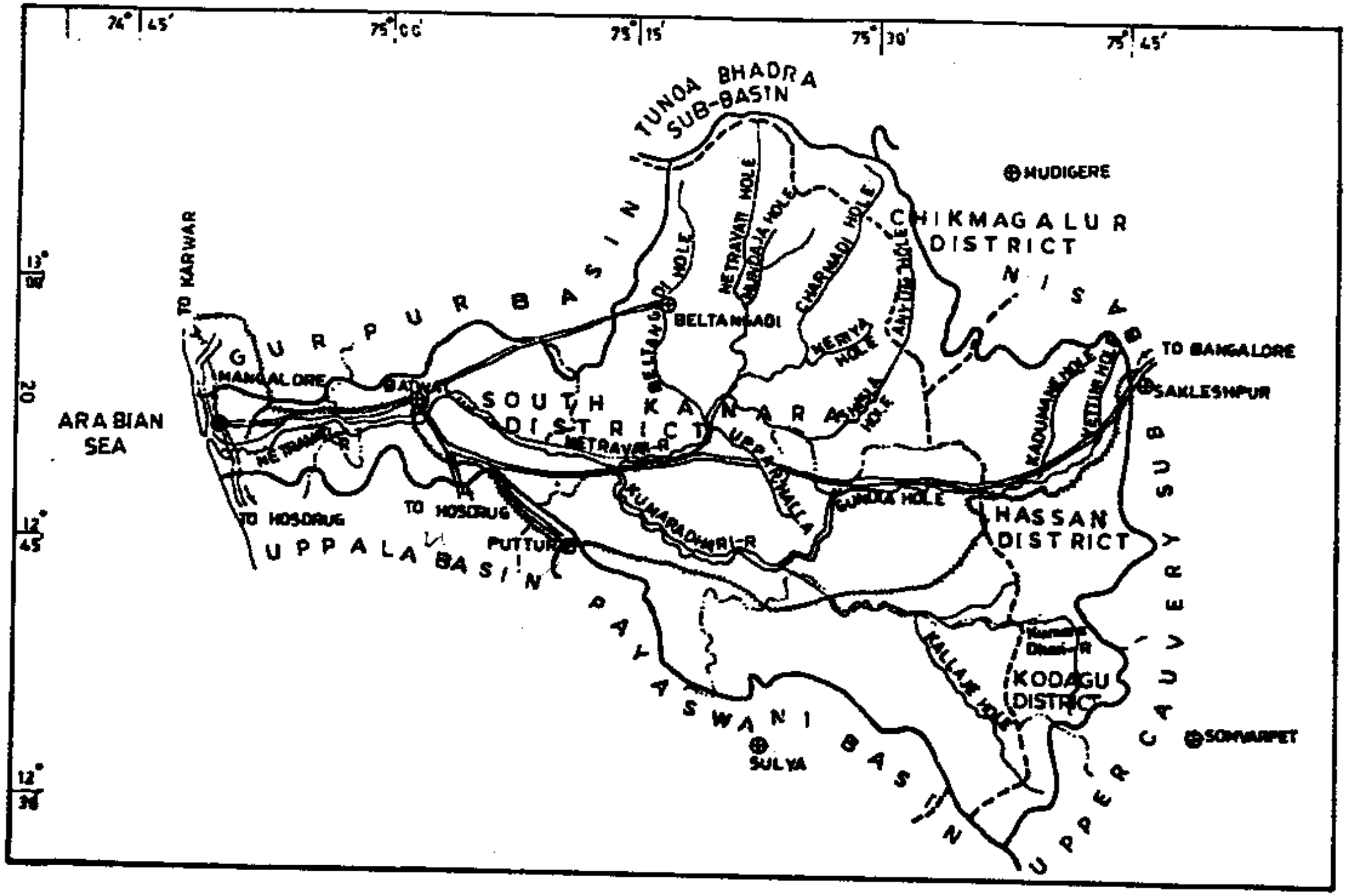


Fig. 1 Map showing study area

Netravati

developed areas with a high degree of economic development and a high density of population. The intermediate or transitory regions is mostly covered with forest and human activity is seen only along the roads and at crossings in the ghats. Undulating uplands are partly under forest and partially under agriculture. The basin consists of recent and sub-recent which includes alluvial formation, clays red and dark clay soils and lateroid formation.

Intrusive includes dolerite, basic and ultra basic rocks, charnockity and granitic gneiss.

Dharwars includes older metamorphic rocks, graniteferrous quartz, sillimanite, talc-schists, hornblende schists, chlorite schists and banded haematite quartzite. These soils generated from the formations are mostly permeable.

Structurally the area has been subjected to folding and faulting. These fractured rocks are favourable locations for groundwater storages.

2.2.0 Sithanadi Basin

Sitanadi is one of the west flowing rivers of Dakshina Kannada district of Karnataka state. It takes its origin in the slopes of Western Ghats near Agumbe and flows towards west. The catchment area with an area of 650 sq.km. lies between 13^0 20' and 13^0 35' north latitudes and 74^0 40' and 75^0 10' east longitude (fig.2.2.1) after descending the ghats, it flows in west direction cutting across the district on three typical topographic terrains and finally empties into the Arabian sea. The river valleys which are quite shallow cannot hold the flow but results in flooding.

Catchment area is relatively short in length and river flows in a meandering course on a level ground in low land region. It confluences with Swarna river before joining Arabian sea and becomes susceptible to salt water ingression during high tides. The water in the river thus turns saline upto 15 to 20 km from the river mouth during high tides.

The catchment area is physiographically divided into three divisions on the basis of terrain and altitude.

The low land region is 2-8 km wide sandy tract running parallel to the coast. It extends upto a distance of 16 km along the river course. It has small lateritic ridges with cultivable low lands in between small exposures of gneiss and laterite hillocks with sparse

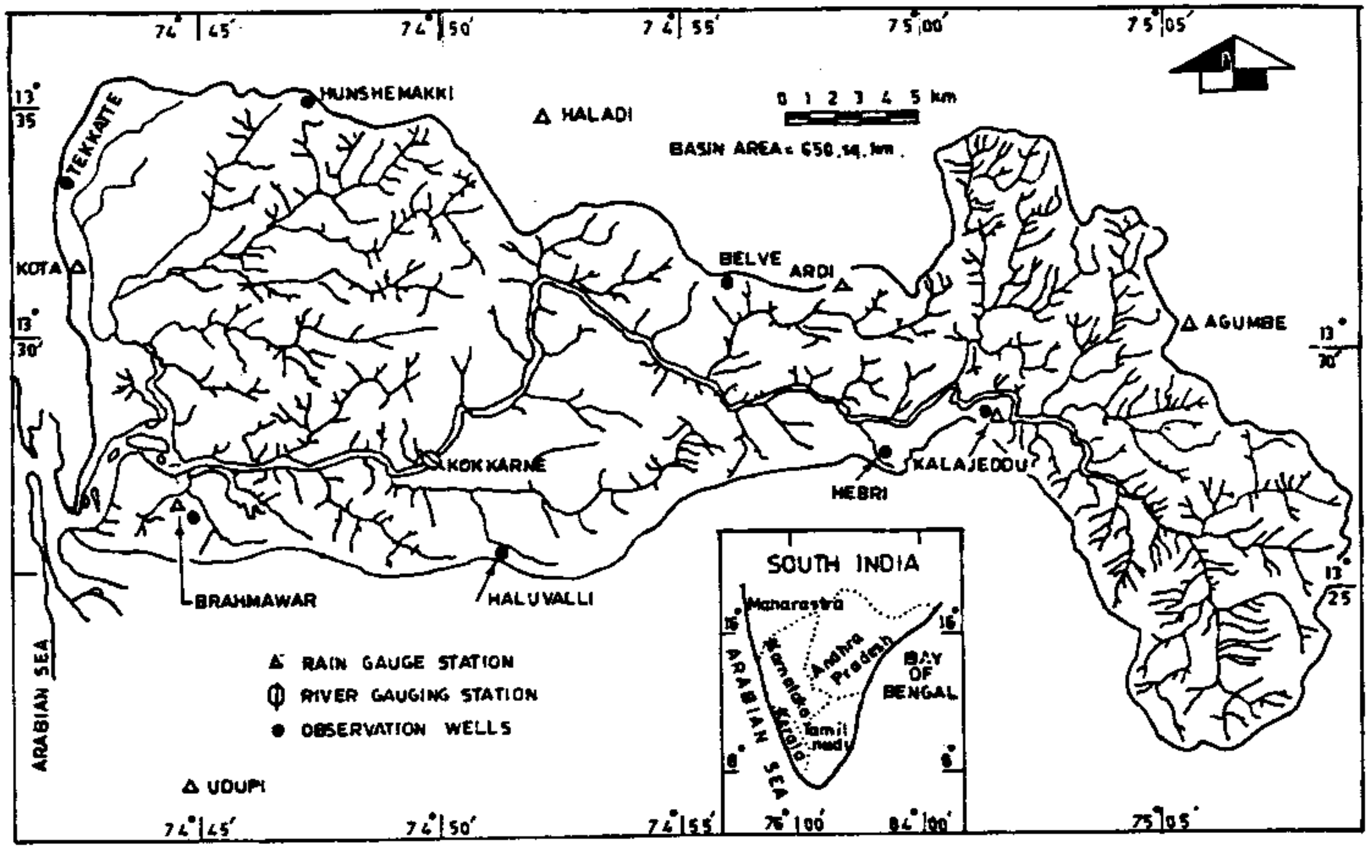


Fig.2.2. 1 Sithanadi Basin

vegetation. In low land region, the river follows a meandering course with wide channels and from some large land masses in the centre.

The mid-land region consists of laterite ridges, mesas and also residual hills composed of gneiss with incised narrow valleys of younger cycle. The laterite ridges exhibit step like topography. The regional elevation varies from 30-70 m. The mid-land region situated between low land and high land constitutes the largest belt. The region consists of dissected low hills with or without laterite capping.

High land region consists of dissection high hills and ridges forming part of the foot hills of the western ghats. It consists of steep hills and valleys interspersed with thick vegetation. These high hills are mostly archaean gneiss and metavolcanics and metasediments of Dharwar supergroup of proterozoic age. Scarp faces bounding these hills are steep having a drop of more than 250 m.

Vegetation reflects the environment in which it is grown. Good water, soil and climate favours the growth of luxurious vegetation. Sitanadi catchment is one of the catchments which lies in the foot hills of Agumbe ghats.

Agumbe is well known for highest rainfall region in Karnataka. High rainfall and humid climatic conditions favour luxurious growth of vegetation. Nearly 53.86% of Sitanadi catchment area is covered by forest vegetation. About 233.48 sq.km. area is covered with dense forest vegetation, 71.73 sq.km. area is covered with open forest vegetation and 68.88 sq.km area is covered with scrub type of forest vegetation (Srinivas, 1990).

The low land region of the basin consists of shrubs and bushes like vegetation commonly known as mangroves. Typical species are Rhizophora and Avicannia (Untawale and Wafar, 1986). Mangroves are resistant to saline habitat, strong tidal currents and fluctuations of water level stabilise the river embankments against erosion.

The mid land region has patches of thick natural vegetation with cultivated coconut and arecanut palms on the shoulders of the valley region. Natural vegetation comprises mainly of forest vegetation with trees, shrubs, creepers etc., common species are ote, kokke, kendage, nenale, banni, bamboo, mango, jack, tamarind etc..

On the western part, the slopes of the Western Ghats from north to south are beautifully clothed with dense forest of magnificent timber. Rose wood is common in north eastern part of the catchment. The principal timber yielding trees in this area are, matti,maravu, benteak, jack, wild jack etc. (Gazetteer,1973).

2.3.0 Malaprabha Basin

The Malaprabha catchment upstream of Khanapur located in the Western Ghat and sub-basin of Krishna River as shown in Figure 2.3.1

Malaprabha river originates from Kanakumbi in the Western Ghat at an altitude of about 793 m and 16 km west of Jamboti in the Belgaum district of Karnataka state. The river flows in on a easterly direction and joins the Krishna river. In the present study, the basin upstream of Khanapur has been considered with an catchment area 520 square kilometres. It is a principal source of supply from Ghat section of the basin.

The location of the catchment area lies between 74° E and 75° E longitude and around 16° latitude along the border of Karnataka and Maharashtra.

The Malaprabha basin has four distinct season in the year, such as cold weather, the hot weather and the southwest monsoon and postmonsoon.

The red, black and laterite soils are the principal soils found in the study area.

2.4.0 Dandavathi catchment

The Dadavathi catchment upstream of Sorab located in the Western Ghat and sub-basin of Krishna River as shown in Figure 2.4.1

Dadavathi river originates from Karjikoppa in the foot hill of Western Ghat at an altitude of about 2775ft. and 16 km south of Sorab in the Shimoga district of Karnataka state. The river flows in on a northerly direction and joins the Varada river which is a tributary of Krishna river. The total catchment area of Dandavathi basin is 118.88 square kilometres.

The location of the catchment area lies between 75° E and 75° 30' E longitude and around 13° 45' latitude along the border of Soraba and Sagar taluk.

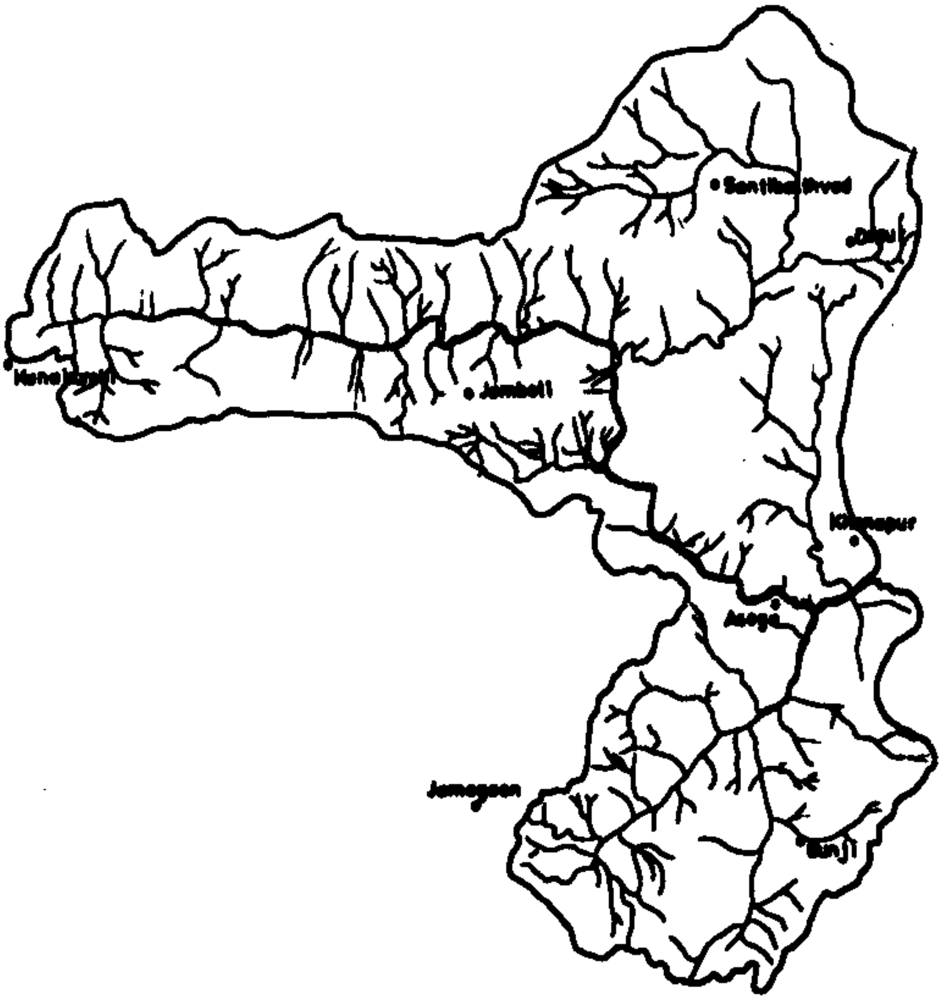
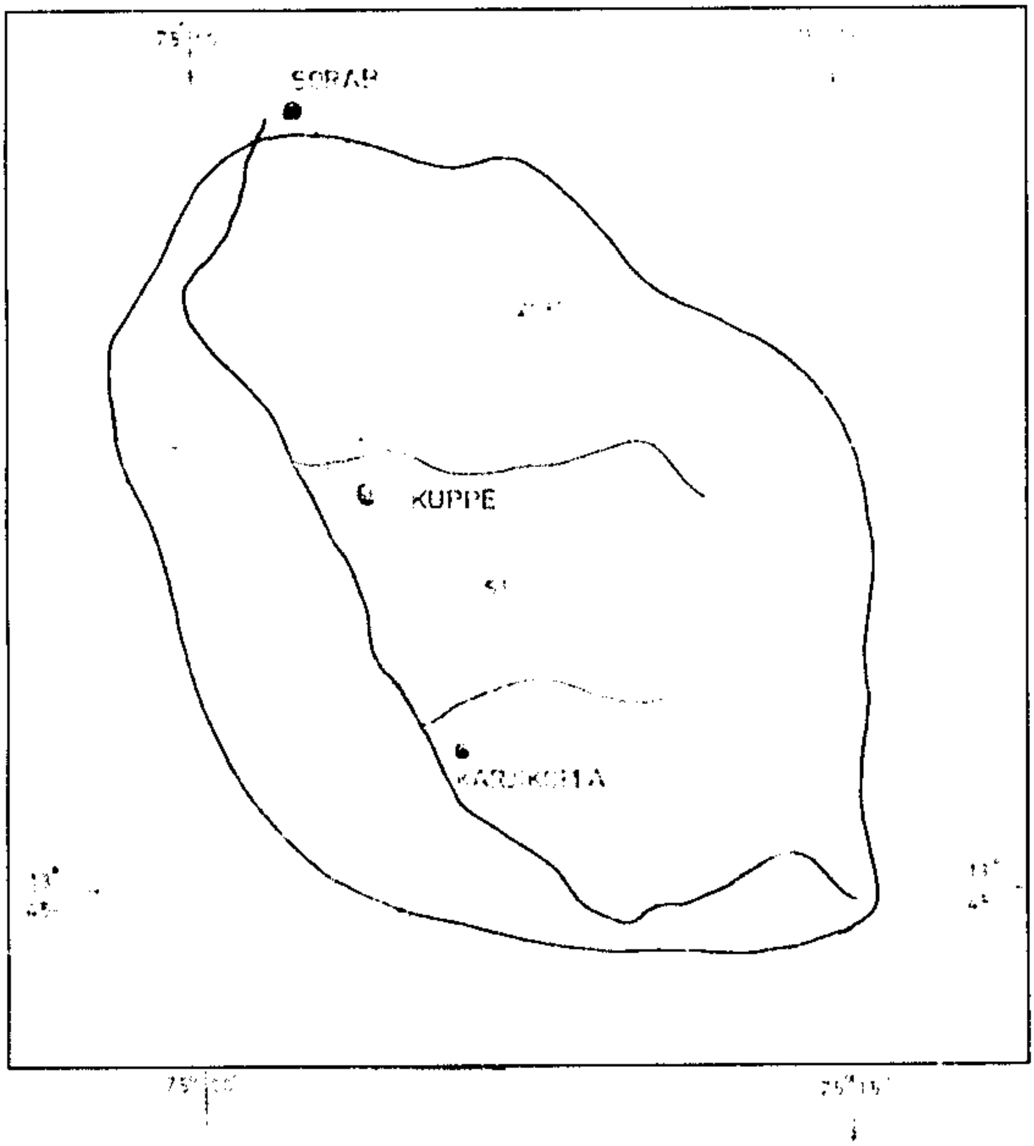


Fig.2.3.1. Malaprabha Basin Map



2.4.1. Dandavathi Catchment

The Dandavathi catchment has four distinct season in the year, such as cold weather, the hot weather and the southwest monsoon and postmonsoon.

The red and gravelly soils are the principal soils found in the study area.

2.5.0 Barchi Catchment

The Barchi catchment upstream of Dandeli located in theleeward side of Western Ghat and sub-basin of Kali River as shown in Figure 2.5.1

Barchi river originates from Thavargatti of Western Ghat at an altitude of about 734m. and 20 km north of Dandeli in the Uttara Kannada district of Karnataka state.The catchment is relatively short in width t and the river flows in on a southerly direction and joins the main stream of Kal river near Dandeli and flows in on westerly direction. Finally it will flow towards the coast and joins Arabian sea. The total catchment area of Barchi catchment is 14.5 square kilometres. The location of the catchment area lies between 75^{o} 35'E and 75^{o} 40'E longitude and between 13^{o} 18' and 15^{o}24' latitude.

High land region consists of dissection of high hills and ridges forming part of the foot hills of western ghats. It consists of steep hills and valleys intercepted with thick vegetation. The slopes of the ghats covered with dense deciduous forest. Most of the trees looses its leaves during the later part of the summer months. The Barchi catchment has four distinct season in the year, such as cold weather, the hot weather and the southwest monsoon and postmonsoon.

The red and gravelly soils are the principal soils found in the study area.

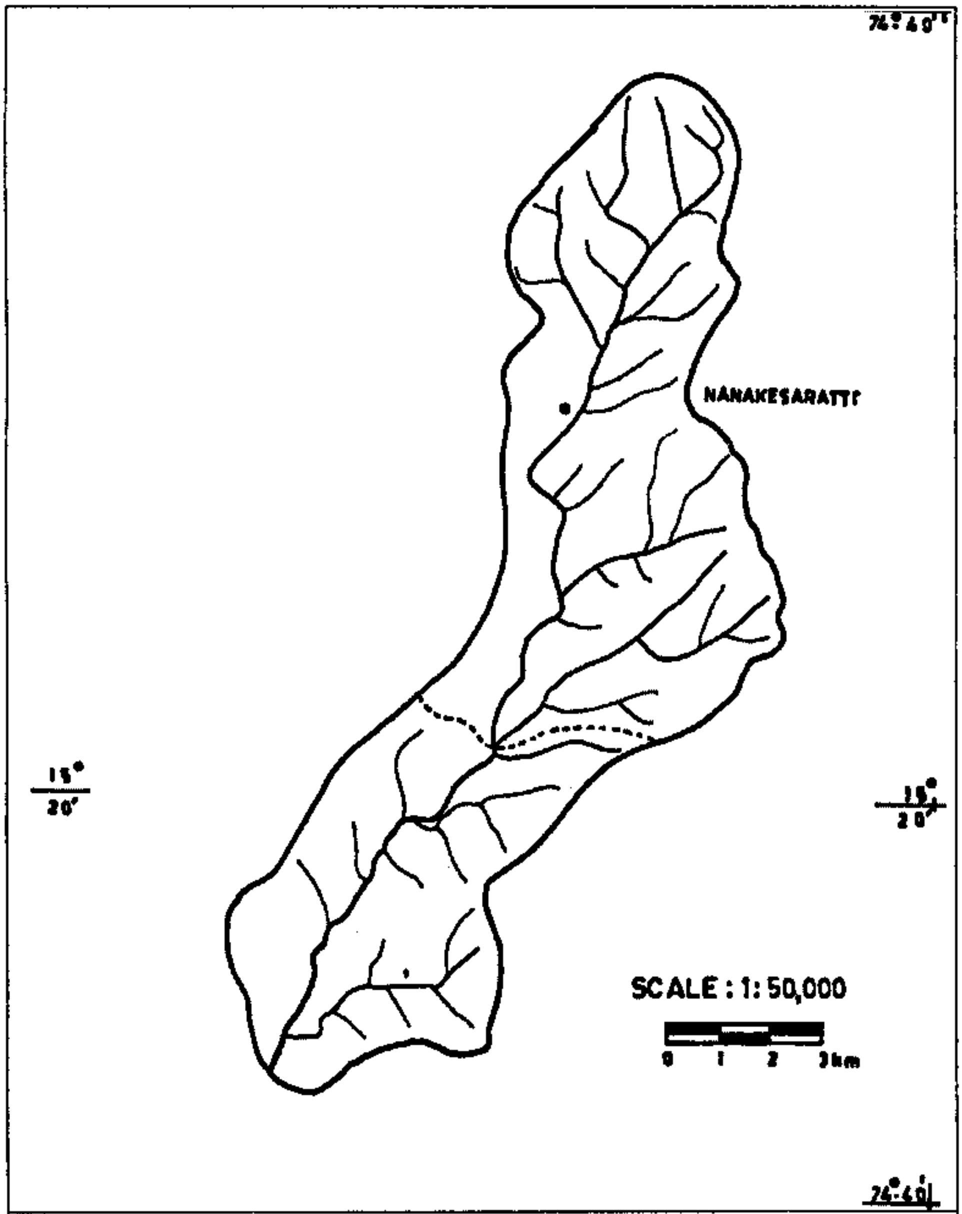


Fig. 2.5.1. Barchi Catchment

3.0 Methodology

In the present study, the effort has been made to regionalise the catchment water balance model for the leeward and winward side of the Western ghat catchments. It is also tried to separate the water balance components of the selected catchments and to develop Rainfall-Runoff-Runoff coefficient relationship and model parameters. The regionalisation of model parameters also attempted for the simulation of yield for ungauged catchments in the western ghat region.

3.1.0 Estimation of Water Balance Components and Model Parameters

The catchment water balance model (Ponce and Shetty) has been applied to separate the precipitation into wetting and surface runoff, and wetting into vaporization and baseflow. The model parameters were determined using measured weighted monthly rainfall for Sithanadi, Nethravathi as West flowing rivers and Malaprabha, Barchi and Dandavathi as East flowing rivers, and daily discharge at Kokkarne for Sithanadi(1973-1989) and at Panemangalore for Nethravathi(1973-1986), Malaprabha at Khanapur(1980-1990), Barchi(1980-1995) at Barchi and Dandavathi(1976-95) at Soraba. Yearly runoff has been calculated by integrating the daily hydrograph over a year.

The daily hydrograph is drawn based on the daily discharge data obtained at gauging sites. The baseflow separation line has been drawn and the area under these curves has been integrated to find out the volume of the baseflow. Consequently, surface runoff, wetting and vaporization have been calculated using catchment water balance equations.

The proportional curve has been fitted for (1) precipitation and surface runoff, and (2) wetting and baseflow based on the observed data as shown in Figures 3.1.1 to 3.1.5. A set of paired values of surface runoff and precipitation, and wetting and baseflow has been obtained from the fitted proportional curve for the calibration of the model parameters.

In order to calibrate the initial abstraction coefficient of surface flow λ_s and baseflow λ_u, and potentials of wetting W_p and vaporization V_p of the study area, the observed data has

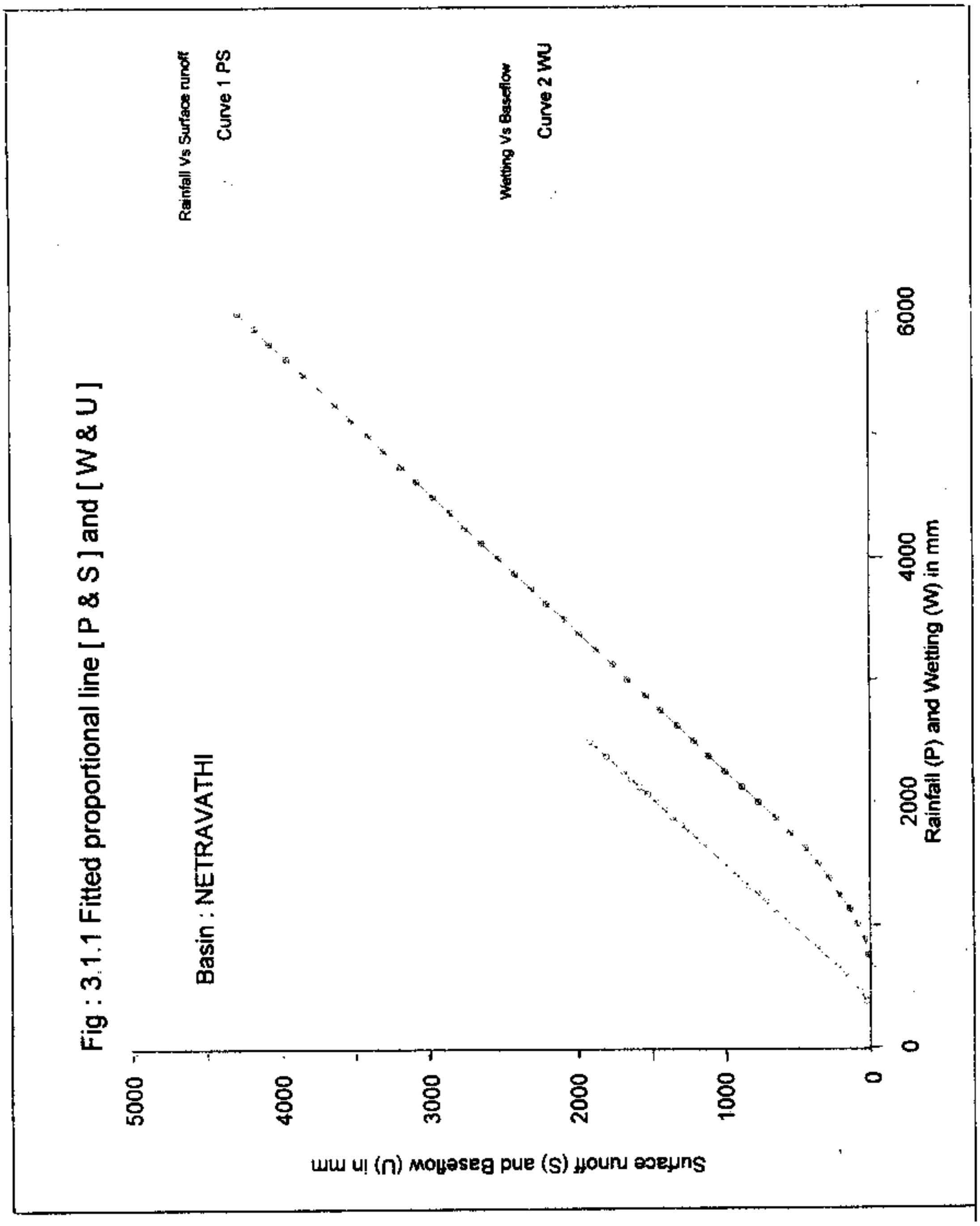


Fig : 3.1.1 Fitted proportional line [P & S] and [W & U]

Fig : 3.1.2 Fitted proportional line [P & S] and [W & U]

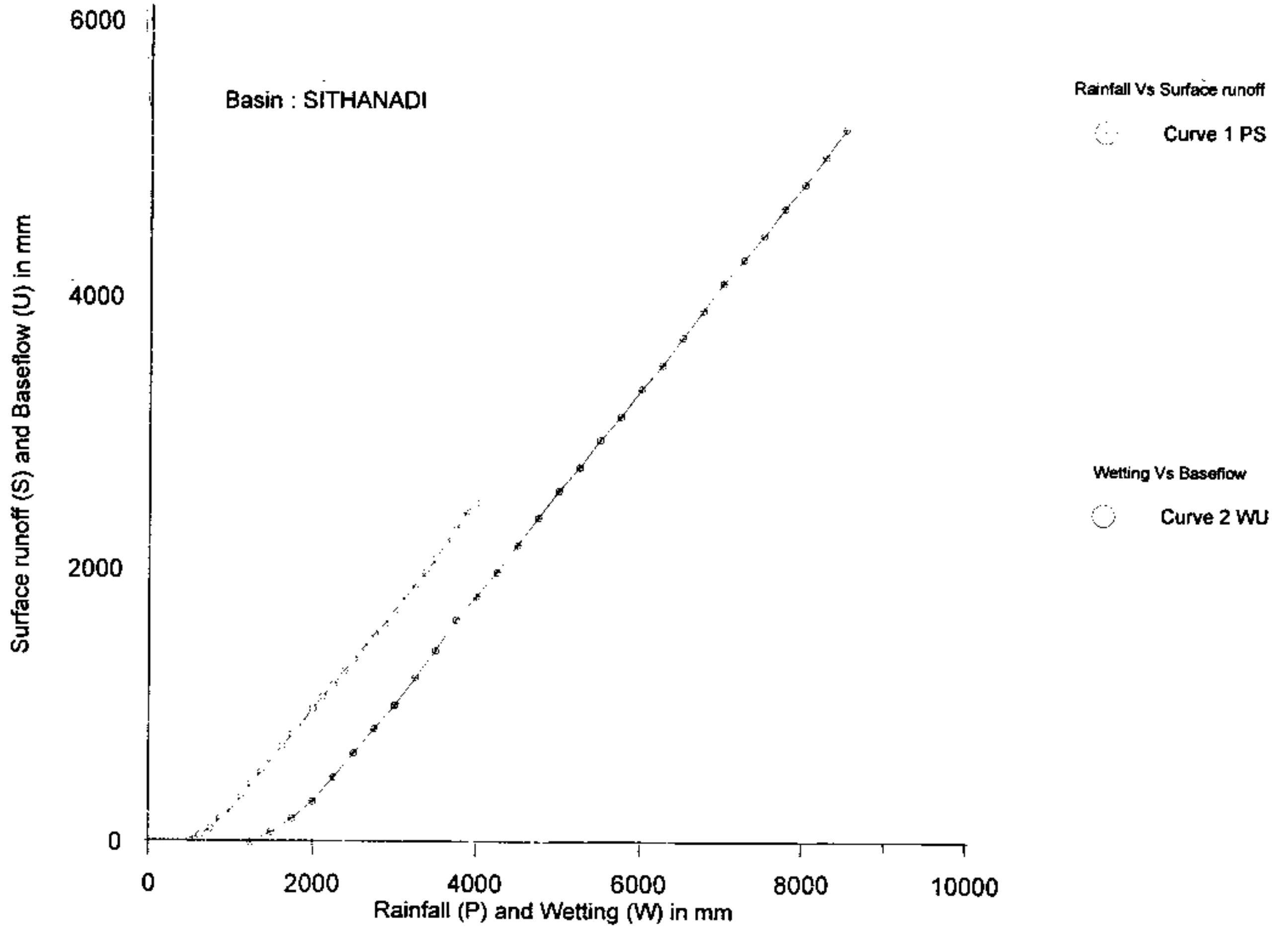


Fig : 3.1.3 Fitted proportional line [P & S] and [W & U]

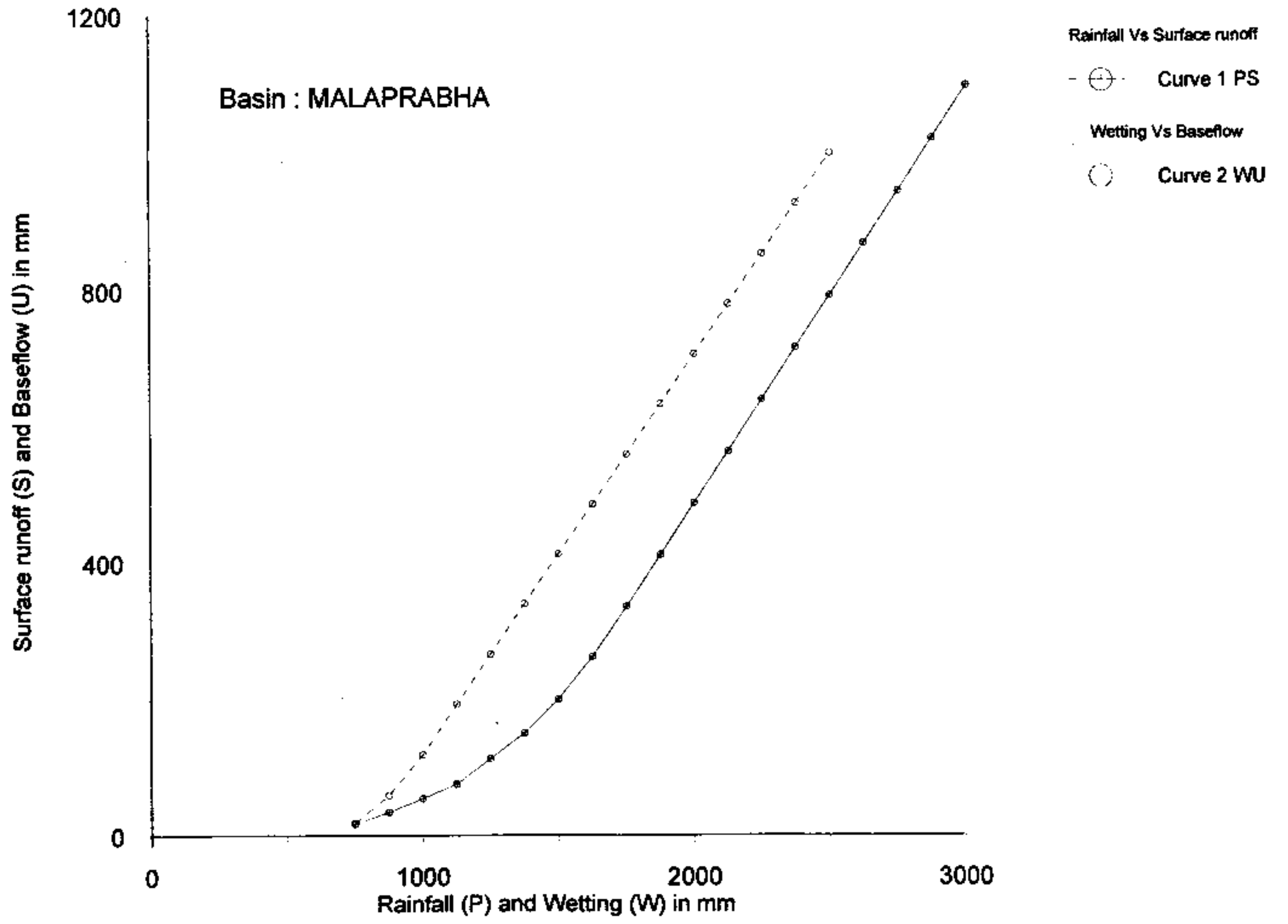


Fig : 3.1.4 Fitted proportional line [P & S] and [W & U]

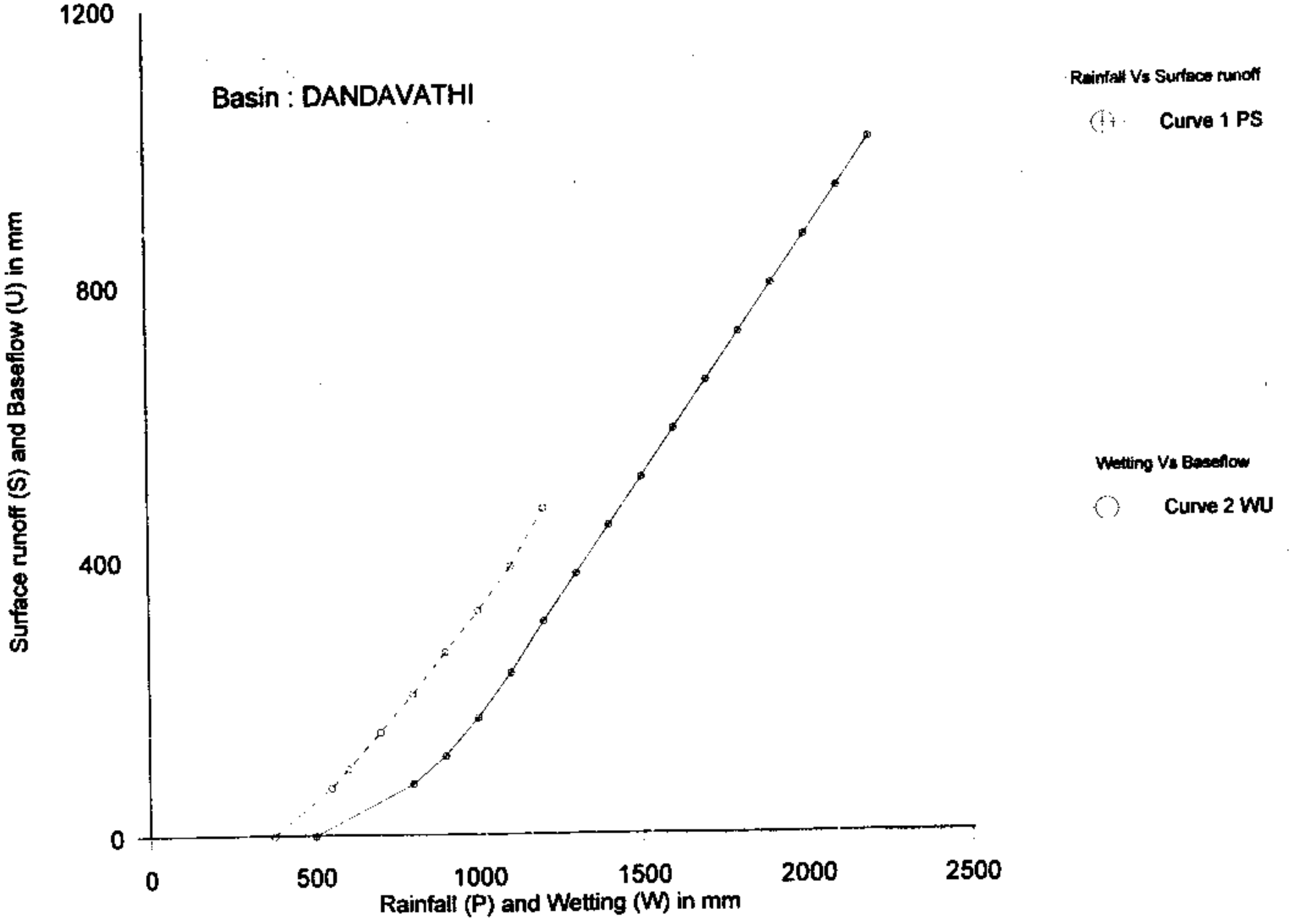
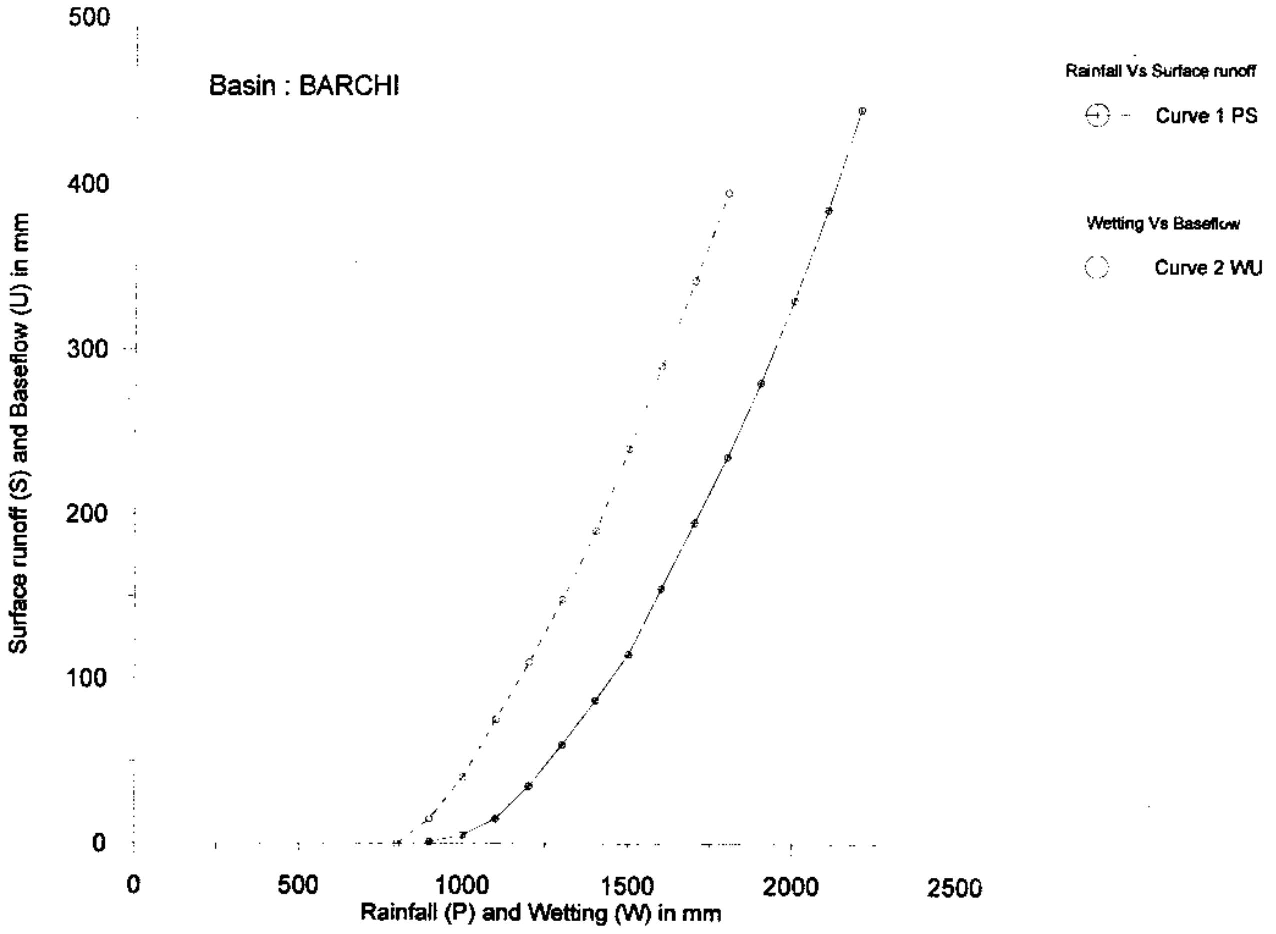


Fig : 3.1.5 Fitted proportional line [P & S] and [W & U]



been used to fit the proportional curves for precipitation and surface runoff, and wetting and baseflow. A set of paired values of precipitation and surface runoff, and wetting and baseflow has been derived from the fitted proportional curves respectively to calibrate the parameters. The calibrated parameters presented in the table 3.1.1.

Table 3.1.1. Model Parameters

Sl. No.	Name of the basin	W_p (mm)	λ_s	V_p (mm)	λ_u
1	Sithanadi	3448	0.3	1823	0.15
2	Netravathi	1838	0.33	601	0.36
3	Malaprabha	3537	0.16	2132	0.24
4	Barchi	3616	0.24	2295	0.33
5	Dandavathi	1668	0.25	1237	0.18

The water balance components such as wetting, vaporization, surface runoff, total runoff, and baseflow have been separated for Sithanadi (Shetty,1997) and Nethravathi (Shetty,1997), Malaprabha (Shetty,1994), Barchi, and Dandavathi basins and are presented in table 3.1.2 and 3.1.6 and also shown in figures 3.1.6 to 3.1.10 The runoff and baseflow coefficients for all the basins with annual rainfall is also presented in the tables 3.1.7 to 3.1.9. and shown in figures 3.1.11 to 3.1.15.

The simulated and observed total runoff has been compared and presented in figure 3.1.16 to 3.1.20. The percentage of error also estimated between observed and simulated total runoff for all catchments. There is an error of 6.44 per cent for Netravathi basin, 5.75 per cent for Sitanadi basin, 4.74 per cent for Malaprabha catchment, 9.84 per cent for Dandavathi catchment and 11.87 per cent for Barchi catchment.

Table 3.1.2. Simulated water balance components(Netravathi)

P in mm	S in mm	U in mm	V in mm	W in mm	R in mm
1000	97.8	438.8	463.4	902.2	536.6
1250	224.6	547.7	477.7	1025.4	772.3
1500	380.5	632.8	486.7	1119.5	1013.3
1750	556.2	700.8	493.0	1193.8	1257.0
2000	746.0	756.3	497.6	1254.0	1502.4
2250	946.4	802.4	501.2	1303.6	1748.8
2500	1154.7	841.4	503.9	1345.3	1996.1
2750	1369.2	874.6	506.2	1380.8	2243.8
3000	1588.6	903.4	508.0	1411.4	2492.0
3250	1812.0	928.4	509.6	1438.0	2740.4
3500	2038.6	950.5	510.9	1461.4	2989.1
3750	2267.8	970.1	512.1	1482.2	3237.9
4000	2499.3	987.6	513.1	1500.7	3486.9
4250	2732.7	1003.3	513.9	1517.3	3736.1
4500	2967.8	1017.5	514.7	1532.2	3985.3
4750	3204.2	1030.4	515.4	1545.8	4234.6
5000	3441.8	1042.2	516.0	1558.2	4484.0
5250	3680.5	1052.9	516.6	1569.5	4733.4
5500	3920.1	1062.8	517.1	1579.9	4982.9
5750	4160.5	1071.9	517.5	1589.5	5232.5
6000	4401.7	1080.3	518.0	1598.3	5482.0
6250	4643.5	1088.2	518.4	1606.5	5731.6
6500	4885.8	1095.4	518.7	1614.2	5981.3
6750	5128.7	1102.2	519.0	1621.3	6231.0
7000	5372.1	1108.6	519.4	1627.9	6480.6
7250	5615.9	1114.5	519.6	1634.1	6730.4
7500	5860.0	1120.1	519.9	1640.0	6980.1
7750	6104.5	1125.3	520.2	1645.5	7229.8

Table 3.1.3 Simulated water balance components (Sithanadi)

P in mm	S in mm	U in mm	V in mm	W in mm	R in mm
1000	0.5	231.5	768.0	999.5	232.0
1250	17.6	366.4	865.9	1232.4	384.0
1500	75.2	490.6	934.2	1424.8	565.8
1750	163.5	602.1	984.4	1586.5	765.6
2000	275.7	701.3	1022.9	1724.3	977.1
2250	407.0	789.6	1053.4	1843.0	1196.6
2500	553.5	868.4	1078.2	1946.5	1421.8
2750	712.5	938.8	1098.6	2037.5	1651.4
3000	882.0	1002.2	1115.8	2118.0	1884.2
3250	1060.1	1059.4	1130.5	2189.9	2119.5
3500	1245.6	1111.2	1143.2	2254.4	2356.8
3750	1437.4	1158.4	1154.2	2312.6	2595.8
4000	1634.6	1201.5	1163.9	2365.4	2836.1
4250	1836.5	1241.0	1172.5	2413.5	3077.5
4500	2042.4	1277.4	1180.2	2457.6	3319.8
4750	2252.0	1310.9	1187.1	2498.0	3562.9
5000	2464.8	1341.9	1193.3	2535.2	3806.7
5250	2680.3	1370.7	1199.0	2569.7	4051.0
5500	2898.4	1397.5	1204.1	2601.6	4295.9
5750	3118.6	1422.5	1208.8	2631.4	4541.2
6000	3341.0	1445.9	1213.1	2659.0	4786.9
6250	3565.1	1467.8	1217.1	2684.9	5032.9
6500	3790.8	1488.3	1220.8	2709.2	5279.2
6750	4018.0	1507.3	1224.2	2731.9	5525.8
7000	4246.7	1525.9	1227.4	2753.3	5772.6
7250	4476.6	1543.1	1230.4	2773.4	6019.6
7500	4707.5	1559.3	1233.2	2792.5	6266.8
7750	4939.6	1574.7	1235.8	2810.4	6514.2

Table 3.1.4 Simulated water balance components (Malaprabha)

P in mm	S in mm	U in mm	V in mm	W in mm	R in mm
500	1.5	0.1	498.4	498.5	1.6
600	0.4	4.5	595.1	599.6	4.9
700	5.8	18.5	675.7	694.2	24.3
800	17.1	38.9	744.0	782.9	56.0
900	33.8	63.7	802.6	866.2	97.4
1000	55.3	91.3	853.4	944.7	146.6
1100	81.4	120.8	897.8	1018.6	202.2
1200	111.5	151.4	937.1	1088.5	262.9
1300	145.4	182.6	971.9	1154.6	328.1
1400	182.8	214.0	1003.2	1217.2	396.8
1500	223.4	245.3	1031.3	1276.6	468.7
1600	267.0	276.3	1056.7	1333.0	543.3
1700	313.3	306.8	1079.9	1386.7	620.1
1800	362.2	336.8	1101.0	1437.8	699.0
1900	413.4	366.2	1120.4	1486.6	779.6
2000	466.9	395.0	1138.2	1533.1	861.8
2100	522.4	423.0	1154.6	1577.6	945.4
2200	579.8	450.3	1169.9	1620.2	1030.1
2300	639.1	476.9	1184.0	1660.9	1116.0
2400	700.0	502.7	1197.2	1700.0	1202.8
2500	762.6	527.9	1209.5	1737.4	1290.5
2600	826.6	552.3	1221.0	1773.4	1379.0
2700	892.1	576.1	1231.8	1807.9	1468.2
2800	958.9	599.2	1241.9	1841.1	1558.1
2900	1026.9	621.6	1251.5	1873.1	1648.5
3000	1096.1	643.4	1260.5	1903.9	1739.5
3100	1166.5	664.6	1269.0	1933.5	1831.0
3200	1237.9	685.1	1277.0	1962.1	1923.0
3300	1310.3	705.1	1284.6	1989.7	2015.4
3400	1383.6	724.5	1291.9	2016.4	2108.1
3500	1457.8	743.4	1298.7	2042.2	2201.3
3600	1533.0	761.8	1305.3	2067.0	2294.7
3700	1608.9	779.6	1311.5	2091.1	2388.5
3800	1685.6	797.0	1317.4	2114.4	2482.6
3900	1763.0	813.9	1323.1	2137.0	2576.9
4000	1841.2	830.3	1328.5	2158.8	2671.5

Table 3.1.5 Simulated water balance components (Dandawathi)

P in mm	S in mm	U in mm	V in mm	W in mm	R in mm
500	5.2	57.6	437.3	494.8	62.7
600	23.4	91.6	485.1	576.6	114.9
700	52.2	125.6	522.2	647.8	177.8
800	89.8	158.3	551.9	710.2	248.1
900	134.5	189.2	576.2	765.5	323.8
1000	185.3	218.2	596.5	814.7	403.5
1100	241.2	245.2	613.6	858.8	486.4
1200	301.4	270.3	628.3	898.6	571.7
1300	365.4	293.6	641.0	934.6	659.0
1400	432.5	315.3	652.1	967.5	747.9
1500	502.5	335.5	661.9	997.5	838.1
1600	575.0	354.4	670.7	1025.0	929.3
1700	649.6	371.9	678.5	1050.4	1021.5
1800	726.2	388.4	685.5	1073.8	1114.5
1900	804.4	403.8	691.8	1095.6	1208.2
2000	884.2	418.2	697.6	1115.8	1302.4
2100	965.4	431.7	702.9	1134.6	1397.1
2200	1047.8	444.5	707.7	1152.2	1492.3
2300	1131.4	456.5	712.1	1168.6	1587.9
2400	1215.9	467.8	716.2	1184.1	1683.8
2500	1301.4	478.6	720.0	1198.6	1780.0
2600	1387.7	488.7	723.6	1212.3	1876.4
2700	1474.8	498.3	726.9	1225.2	1973.1
2800	1562.7	507.4	729.9	1237.3	2070.1
2900	1651.1	516.1	732.8	1248.9	2167.2
3000	1740.2	524.3	735.5	1259.8	2264.5
3100	1829.8	532.2	738.0	1270.2	2362.0
3200	1920.0	539.7	740.4	1280.0	2459.6
3300	2010.6	546.8	742.6	1289.4	2557.4
3400	2101.6	553.7	744.7	1298.4	2655.3
3500	2193.1	560.2	746.7	1306.9	2753.3
3600	2285.0	566.4	748.6	1315.0	2851.4
3700	2377.2	572.4	750.4	1322.8	2949.6
3800	2469.7	578.2	752.1	1330.3	3047.9
3900	2562.6	583.7	753.7	1337.4	3146.3
4000	2655.7	589.0	755.3	1344.3	3244.7

Table 3.1.6 Simulated water balance components (Barchi)

P in mm	S in mm	U in mm	V in mm	W in mm	R in mm
500	0.0	0.0	500.0	500.0	0.0
600	0.0	17.9	582.1	600.0	17.9
700	10.9	3.2	685.9	689.1	14.1
800	1.7	1.1	797.2	798.3	2.8
900	0.4	12.0	887.6	899.6	12.4
1000	6.1	31.5	962.4	993.9	37.6
1100	18.1	56.6	1025.3	1081.9	74.7
1200	35.8	85.1	1079.1	1164.2	120.9
1300	58.7	115.8	1125.4	1241.3	174.6
1400	86.3	147.8	1165.9	1313.7	234.1
1500	118.2	180.3	1201.4	1381.8	298.6
1600	154.0	213.0	1233.0	1446.0	367.0
1700	193.4	245.5	1261.1	1506.6	438.9
1800	236.1	277.5	1286.4	1563.9	513.6
1900	281.8	309.0	1309.2	1618.2	590.8
2000	330.3	339.7	1329.9	1669.7	670.1
2100	381.4	369.7	1348.8	1718.6	751.2
2200	434.9	399.0	1366.1	1765.1	833.9
2300	490.7	427.4	1382.0	1809.3	918.0
2400	548.4	454.9	1396.6	1851.6	1003.4
2500	608.2	481.7	1410.2	1891.8	1089.8
2600	669.7	507.6	1422.7	1930.3	1177.3
2700	732.9	532.7	1434.4	1967.1	1265.6
2800	797.6	557.0	1445.3	2002.4	1354.7
2900	863.9	580.6	1455.5	2036.1	1444.5
3000	931.5	603.4	1465.0	2068.5	1535.0
3100	1000.4	625.6	1474.0	2099.6	1626.0
3200	1070.6	647.0	1482.4	2129.4	1717.6
3300	1141.9	667.7	1490.4	2158.1	1809.6
3400	1214.3	687.9	1497.8	2185.7	1902.2
3500	1287.7	707.4	1504.9	2212.3	1995.1
3600	1362.1	726.3	1511.6	2237.9	2088.4
3700	1437.4	744.6	1518.0	2262.6	2182.0
3800	1513.6	762.4	1524.0	2286.4	2276.0
3900	1590.6	779.4	1529.8	2309.4	2370.2
4000	1668.3	796.4	1535.2	2331.7	2464.81

Table 3.1.7. Simulated runoff and baseflow coefficients

P in mm	NETRAVATHI		SITHANADI	
	K_u	K_r	K_u	K_r
1000	0.486	0.537	0.232	0.232
1250	0.534	0.618	0.297	0.307
1500	0.565	0.676	0.344	0.377
1750	0.587	0.718	0.380	0.437
2000	0.603	0.751	0.407	0.489
2250	0.616	0.777	0.428	0.532
2500	0.625	0.798	0.446	0.569
2750	0.633	0.816	0.461	0.601
3000	0.640	0.831	0.473	0.628
3250	0.646	0.843	0.484	0.652
3500	0.650	0.854	0.493	0.673
3750	0.655	0.863	0.501	0.692
4000	0.658	0.872	0.508	0.702
4250	0.661	0.879	0.514	0.724
4500	0.664	0.886	0.520	0.738
4750	0.667	0.891	0.525	0.750
5000	0.669	0.897	0.529	0.761
5250	0.671	0.902	0.533	0.772
5500	0.673	0.906	0.537	0.781
5750	0.674	0.910	0.541	0.790
6000	0.676	0.914	0.544	0.798
6250	0.677	0.917	0.547	0.805
6500	0.679	0.920	0.549	0.812
6750	0.680	0.923	0.552	0.819
7000	0.681	0.926	0.554	0.825
7250	0.682	0.928	0.556	0.830
7500	0.683	0.931	0.558	0.836
7750	0.684	0.933	0.560	0.841

Table 3.1.8 Simulated runoff and baseflow coefficients

P in mm	DANDAVATHI		MALAPRABHA	
	K_u	K_r	K_u	K_r
500	.116	.125	.000	.003
600	.159	.192	.008	.008
700	.194	.254	.027	.035
800	.223	.310	.050	.070
900	.247	.360	.073	.108
1000	.268	.404	.097	.147
1100	.285	.442	.119	.184
1200	.301	.476	.139	.219
1300	.314	.507	.158	.252
1400	.326	.534	.176	.283
1500	.336	.559	.192	.312
1600	.346	.581	.207	.340
1700	.354	.601	.221	.365
1800	.362	.619	.234	.388
1900	.369	.636	.246	.410
2000	.375	.651	.258	.431
2100	.381	.665	.268	.450
2200	.386	.678	.278	.468
2300	.391	.690	.287	.485
2400	.395	.702	.296	.501
2500	.399	.712	.304	.516
2600	.403	.722	.311	.530
2700	.407	.731	.319	.544
2800	.410	.739	.325	.556
2900	.413	.747	.332	.568
3000	.416	.755	.338	.580
3100	.419	.762	.344	.591
3200	.422	.769	.349	.601
3300	.424	.775	.354	.611
3400	.426	.781	.359	.620
3500	.429	.787	.364	.629
3600	.431	.792	.369	.637
3700	.433	.797	.373	.646
3800	.435	.802	.377	.653
3900	.436	.807	.381	.661
4000	.438	.811	.385	.668

Table 3.1.9 Simulated runoff and baseflow coefficients

P in mm	BARCHI	
	K_u	K_r
500	.000	.000
600	.030	.030
700	.005	.020
800	.001	.003
900	.013	.014
1000	.032	.038
1100	.052	.068
1200	.073	.101
1300	.093	.134
1400	.113	.167
1500	.131	.199
1600	.147	.229
1700	.163	.258
1800	.177	.285
1900	.191	.311
2000	.203	.335
2100	.215	.358
2200	.226	.379
2300	.236	.399
2400	.246	.418
2500	.255	.436
2600	.263	.453
2700	.271	.469
2800	.278	.484
2900	.285	.498
3000	.292	.512
3100	.298	.525
3200	.304	.537
3300	.309	.548
3400	.315	.559
3500	.320	.570
3600	.325	.580
3700	.329	.590
3800	.333	.599
3900	.338	.608
4000	.342	.616

Figure 3.1.6. Relationship of Water Balance Components with Annual Rainfall

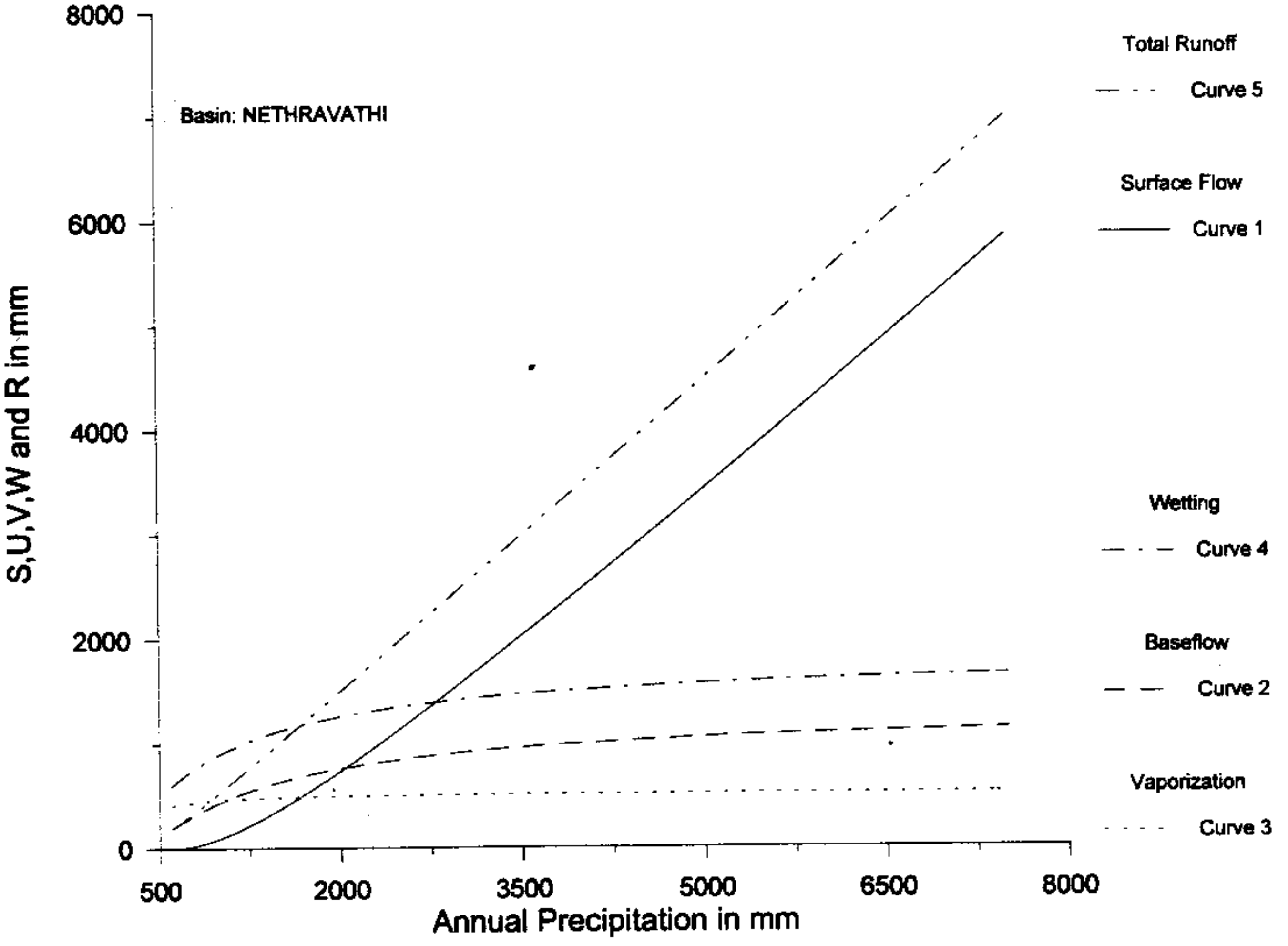


Figure 3.1.7. Relationship of Water Balance Components with Annual Rainfall

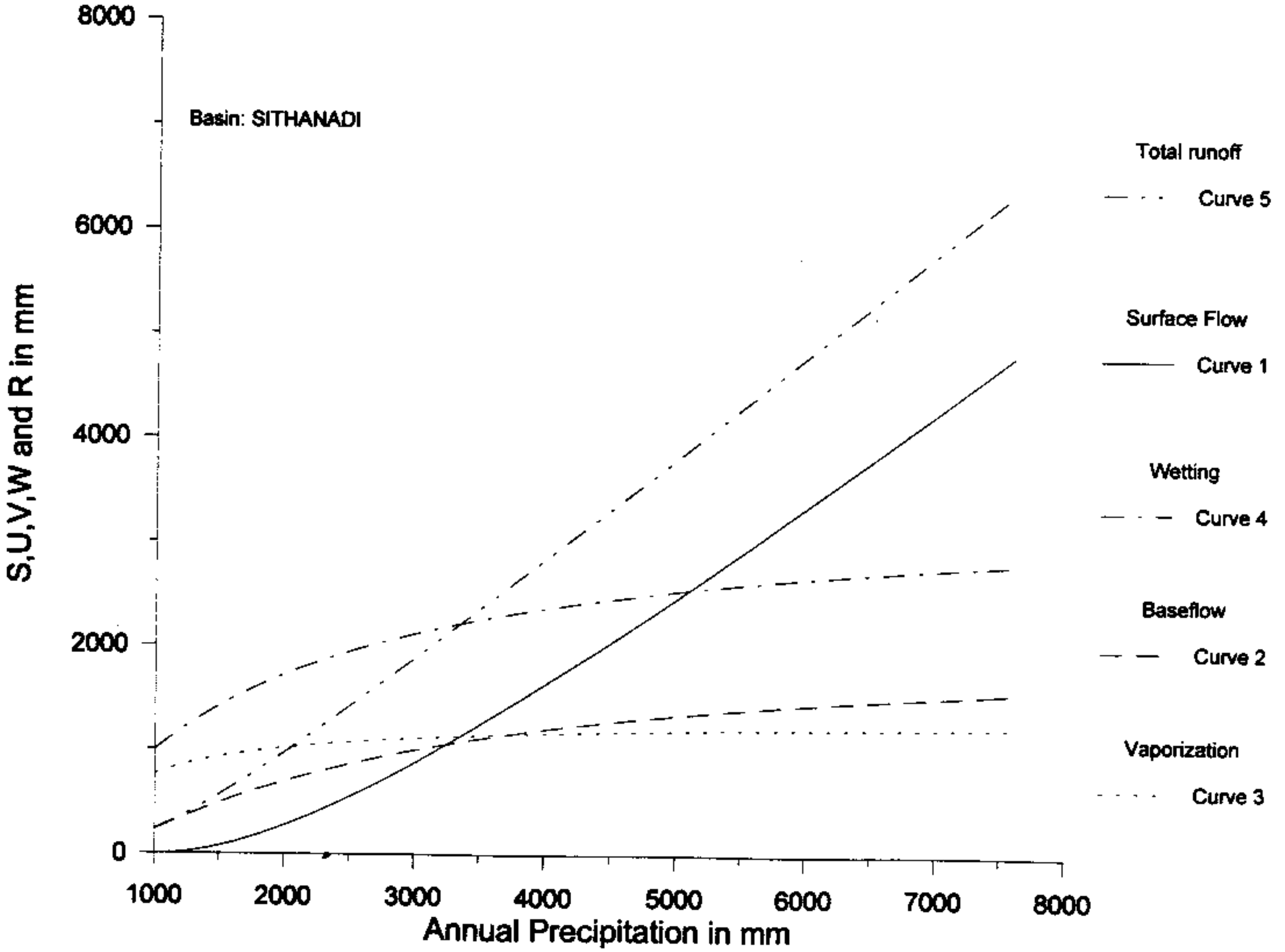


Figure 3.1.8. Relationship of Water Balance Components with Annual Rainfall

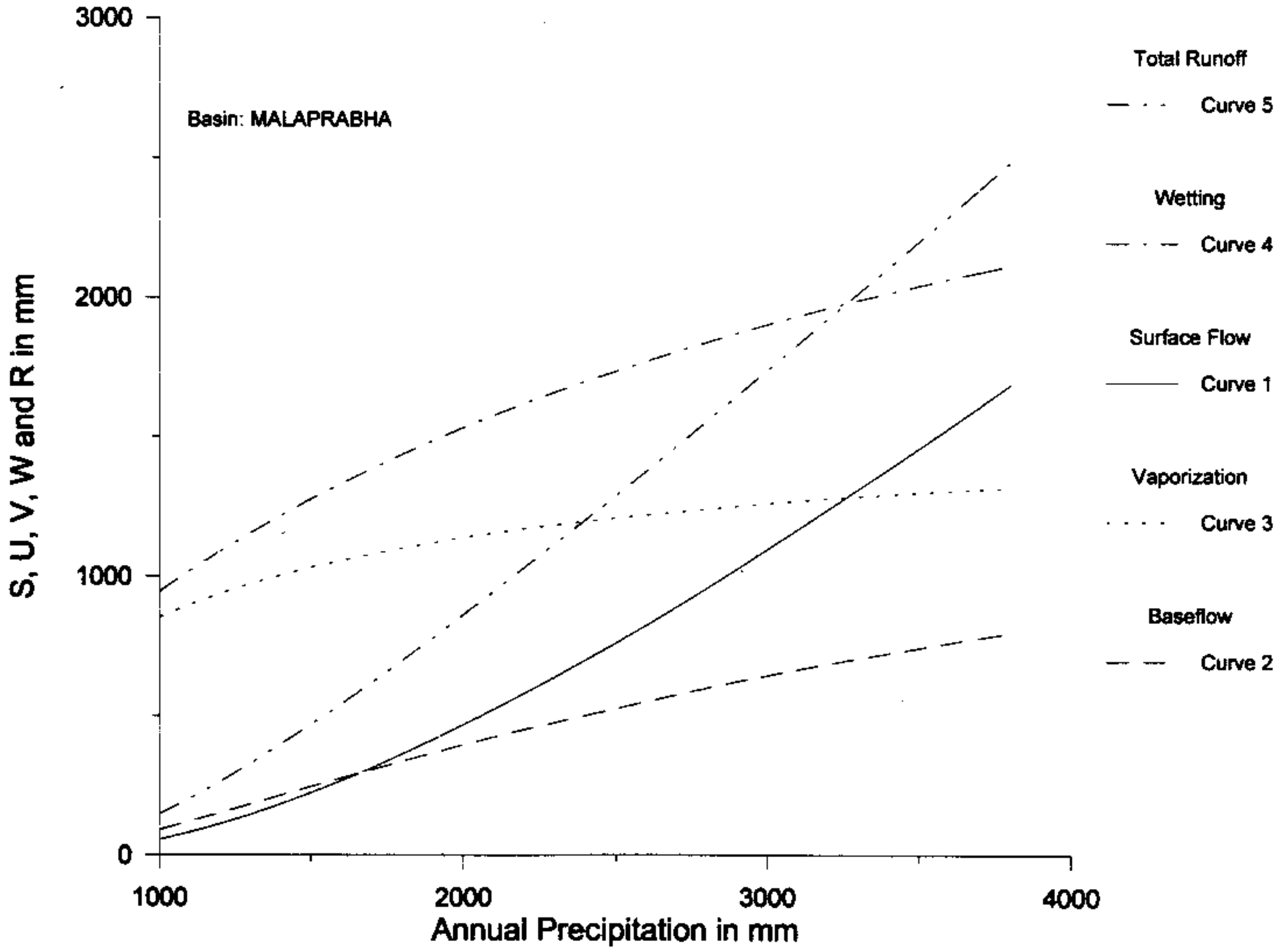


Figure 3.1.9. Relationship of Water Balance Components with Annual Rainfall

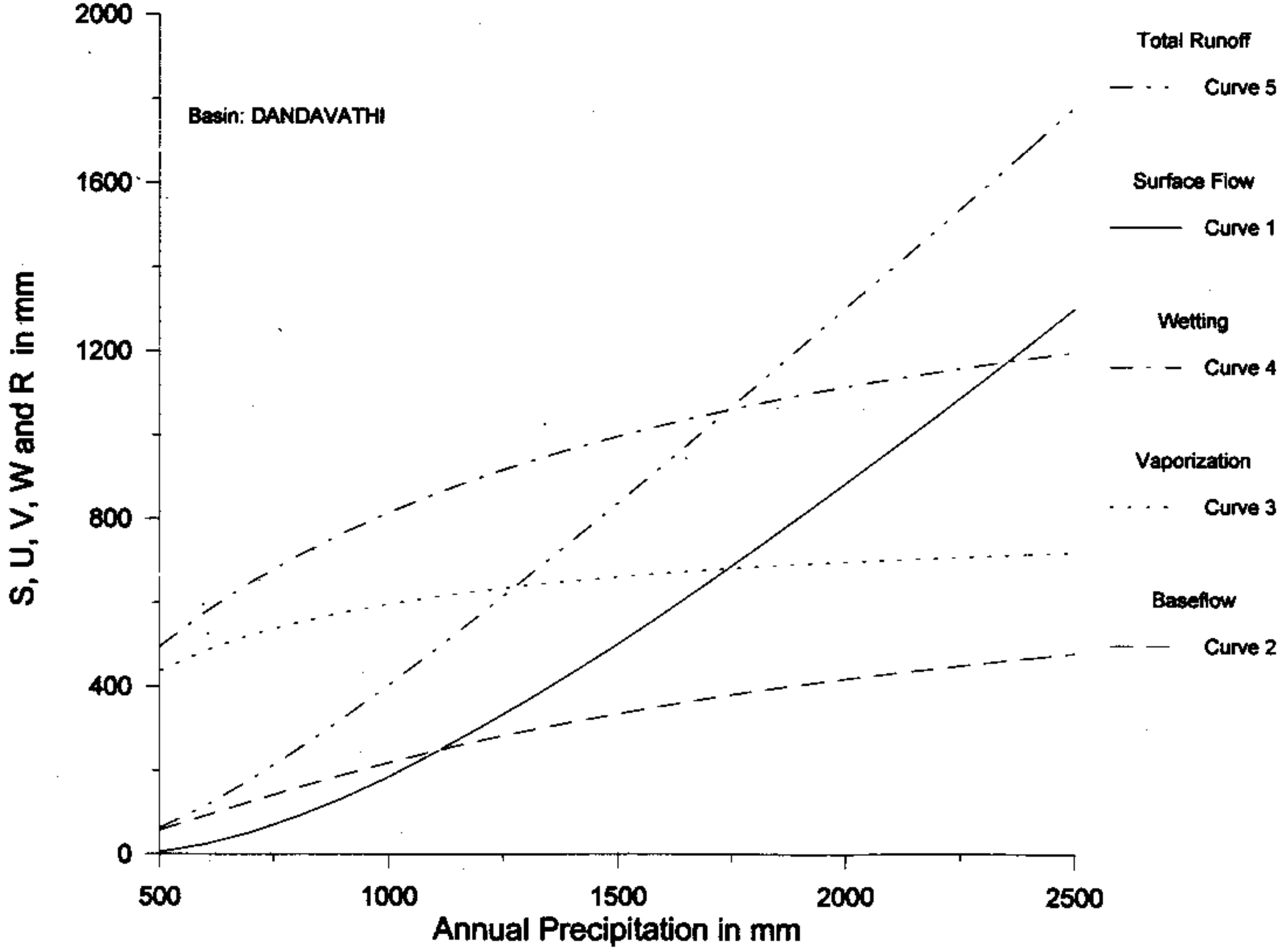


Fig : 3.1.10 Relationship of Water Balance Components With Annual Rainfall

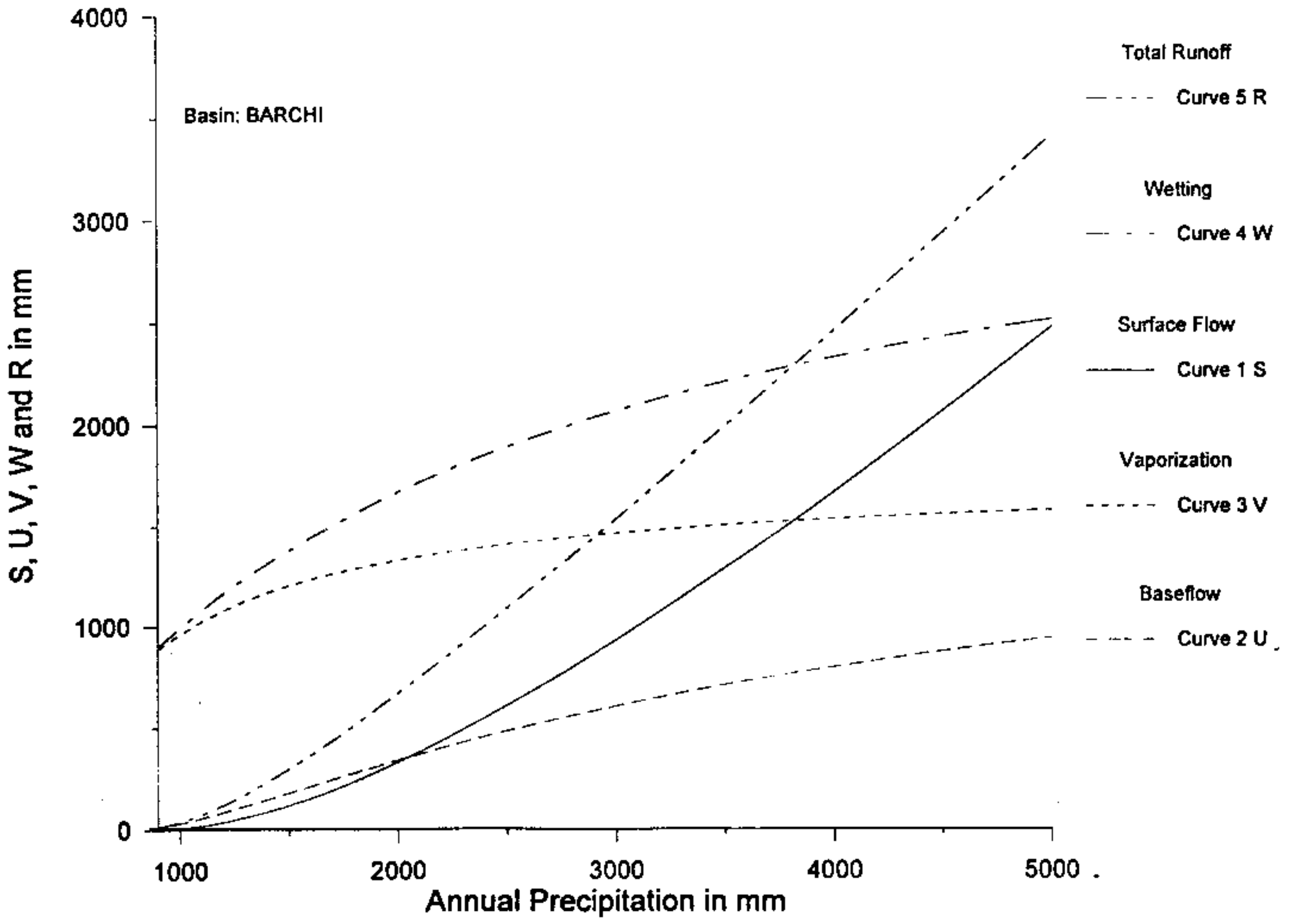


Figure 3.1.11. Variation of KU and KR with Annual Rainfall

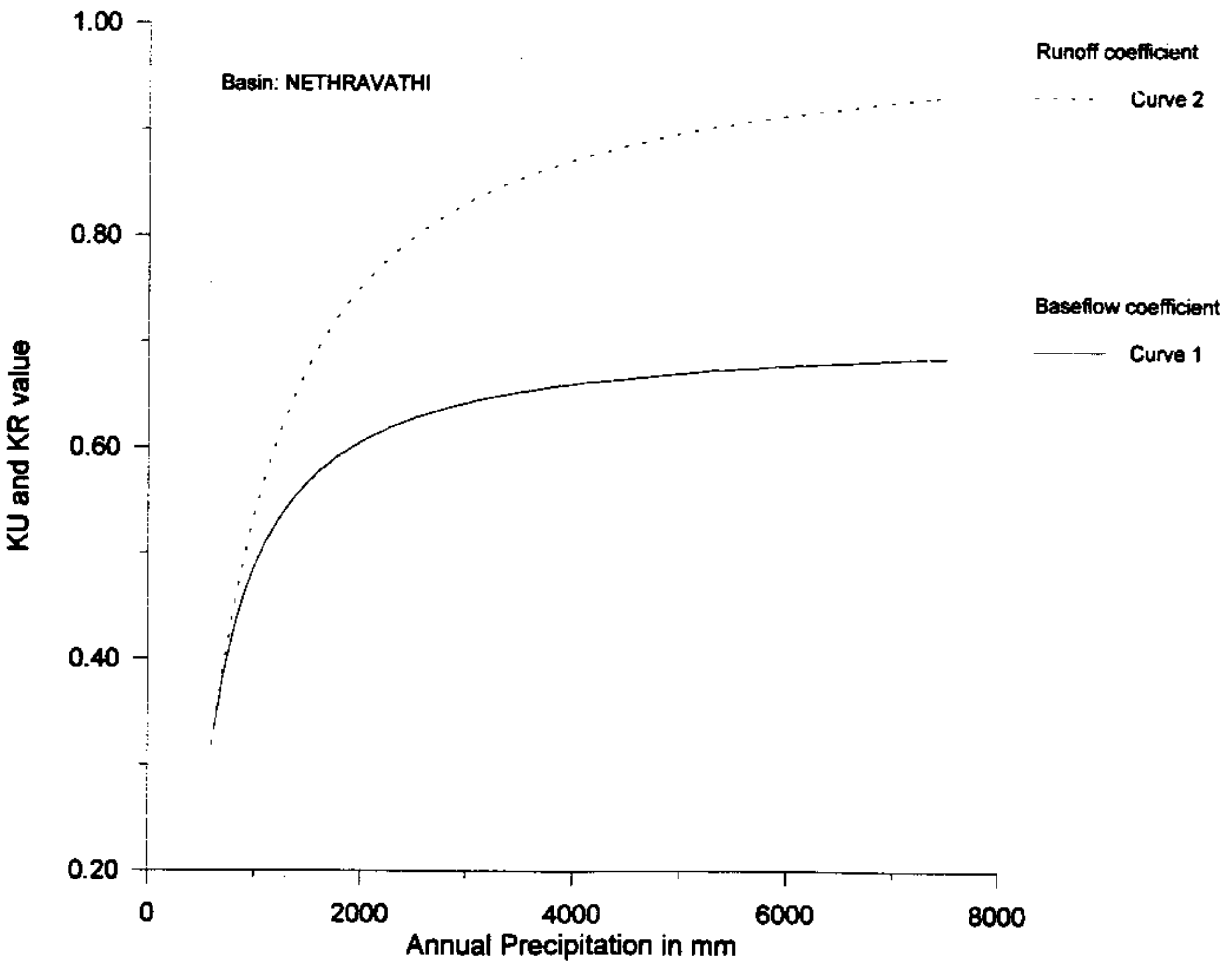


Figure 3.1.12. Variation of KU and KR with Annual Rainfall

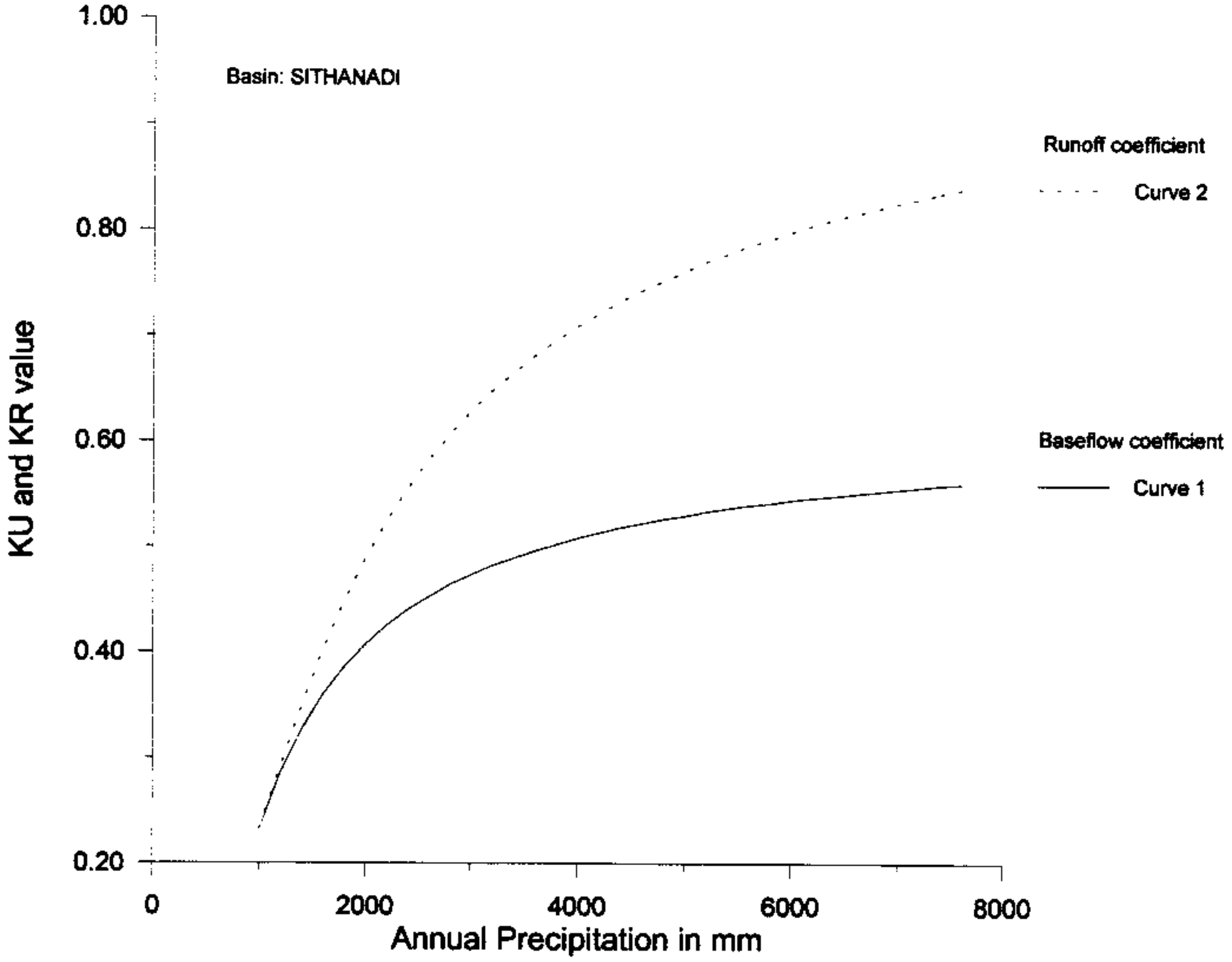


Figure 3.1.13. Variation of KU and KR with Annual Rainfall

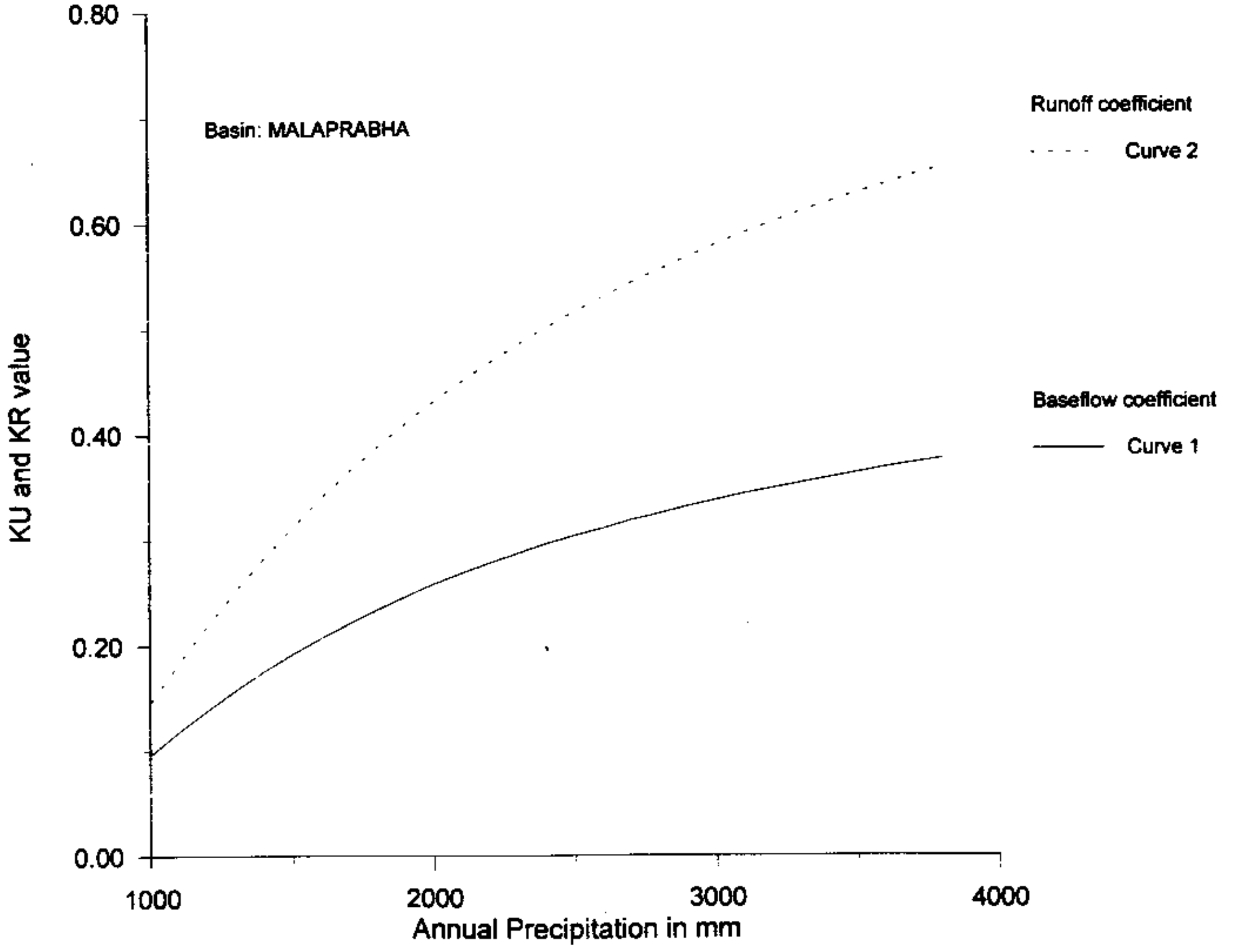


Figure 3.1.14. Variation of KU and KR with Annual Rainfall

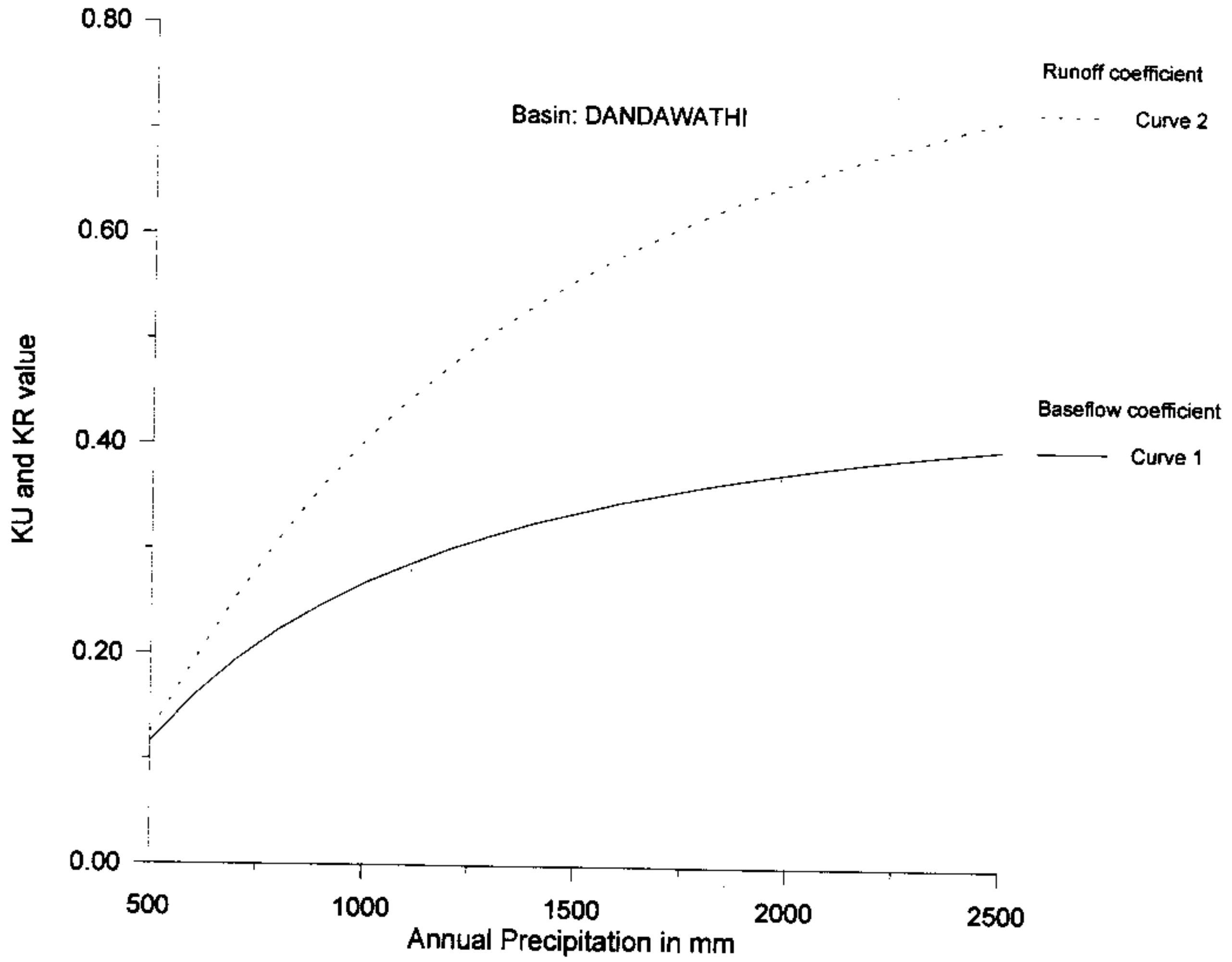


Fig : 3.1.15 Variation of KU and KR with Annual Rainfall

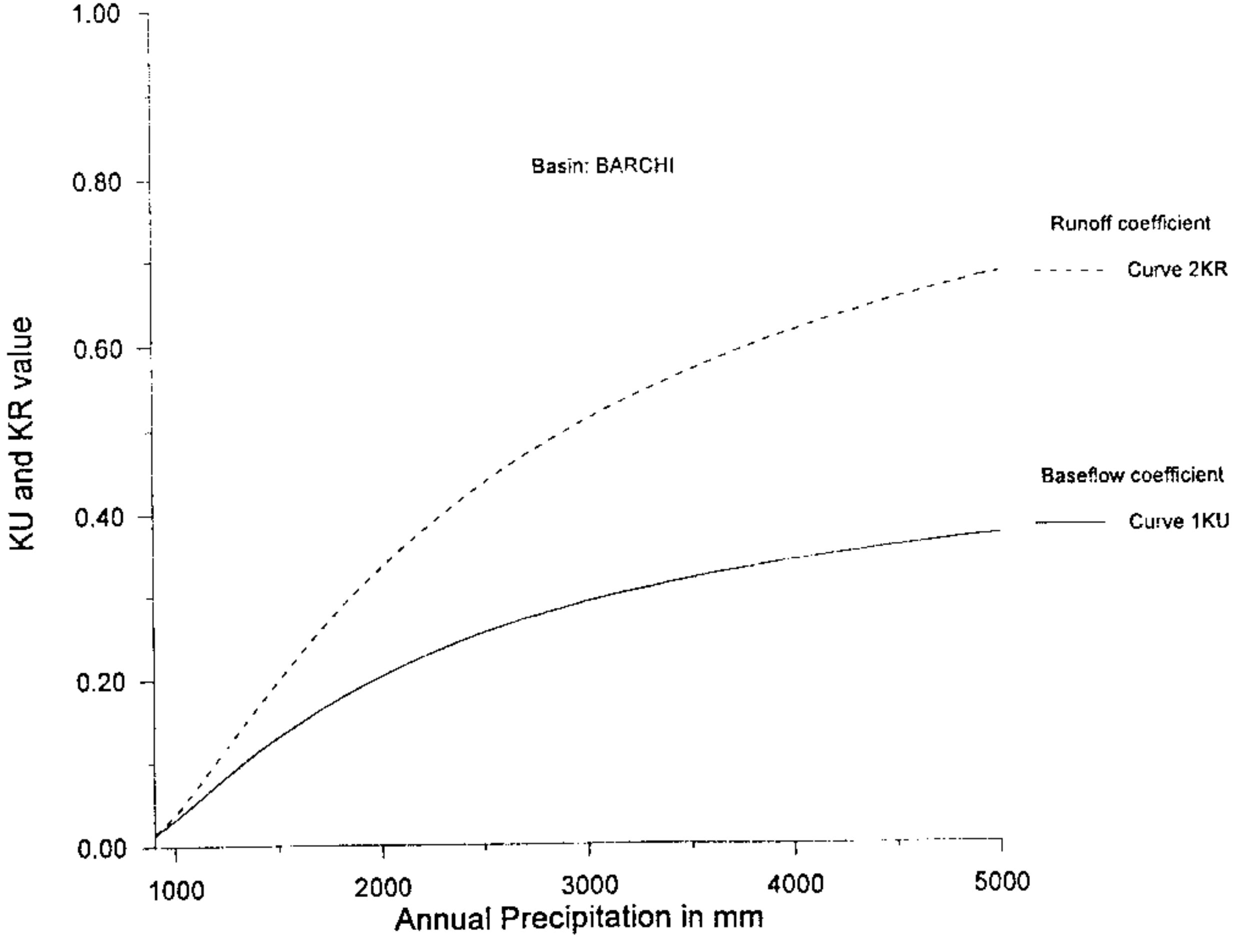


Figure 3.1.16. Observed and simulated total runoff

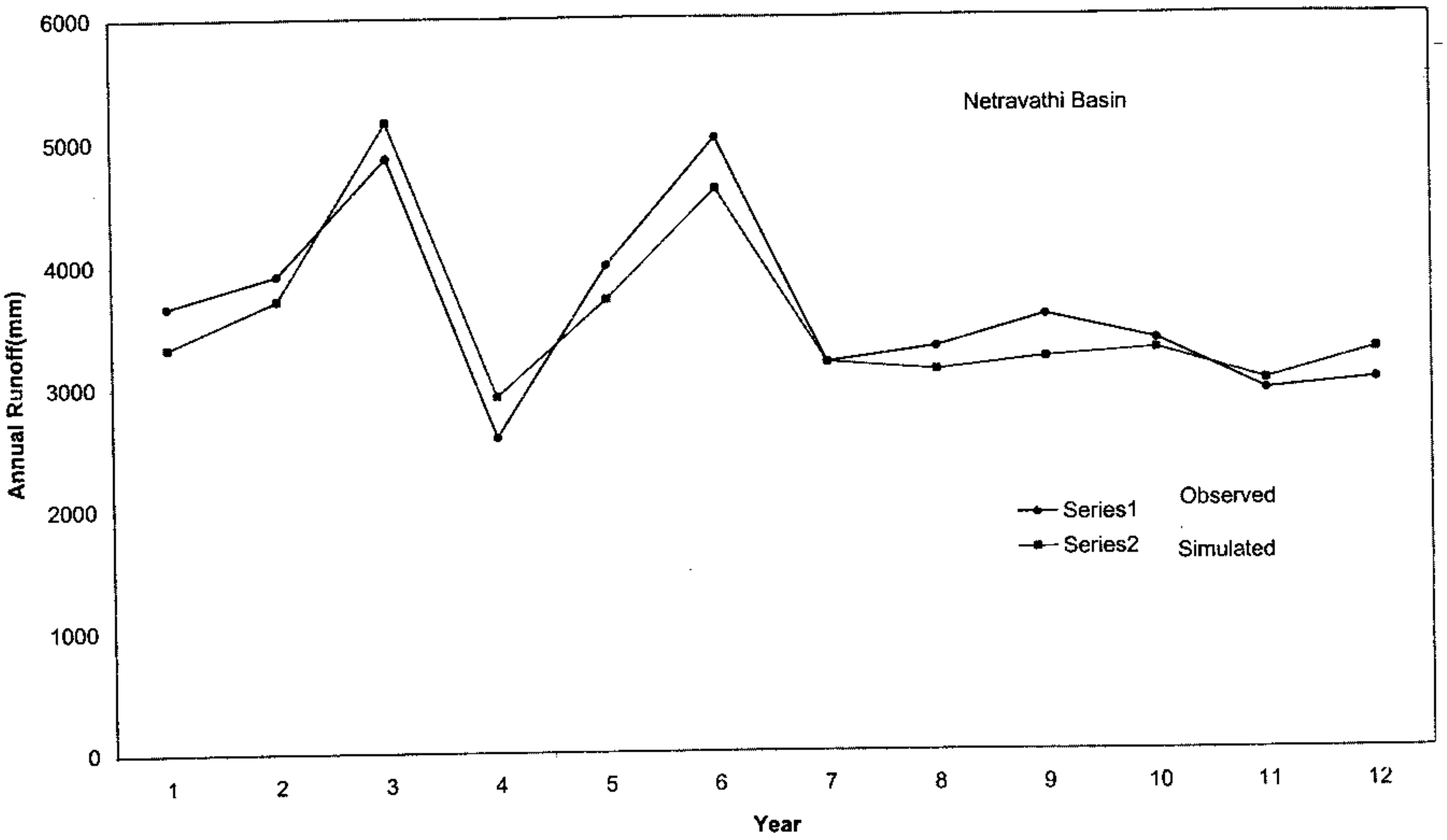


Figure 3.1.17. Observed and simulated total runoff

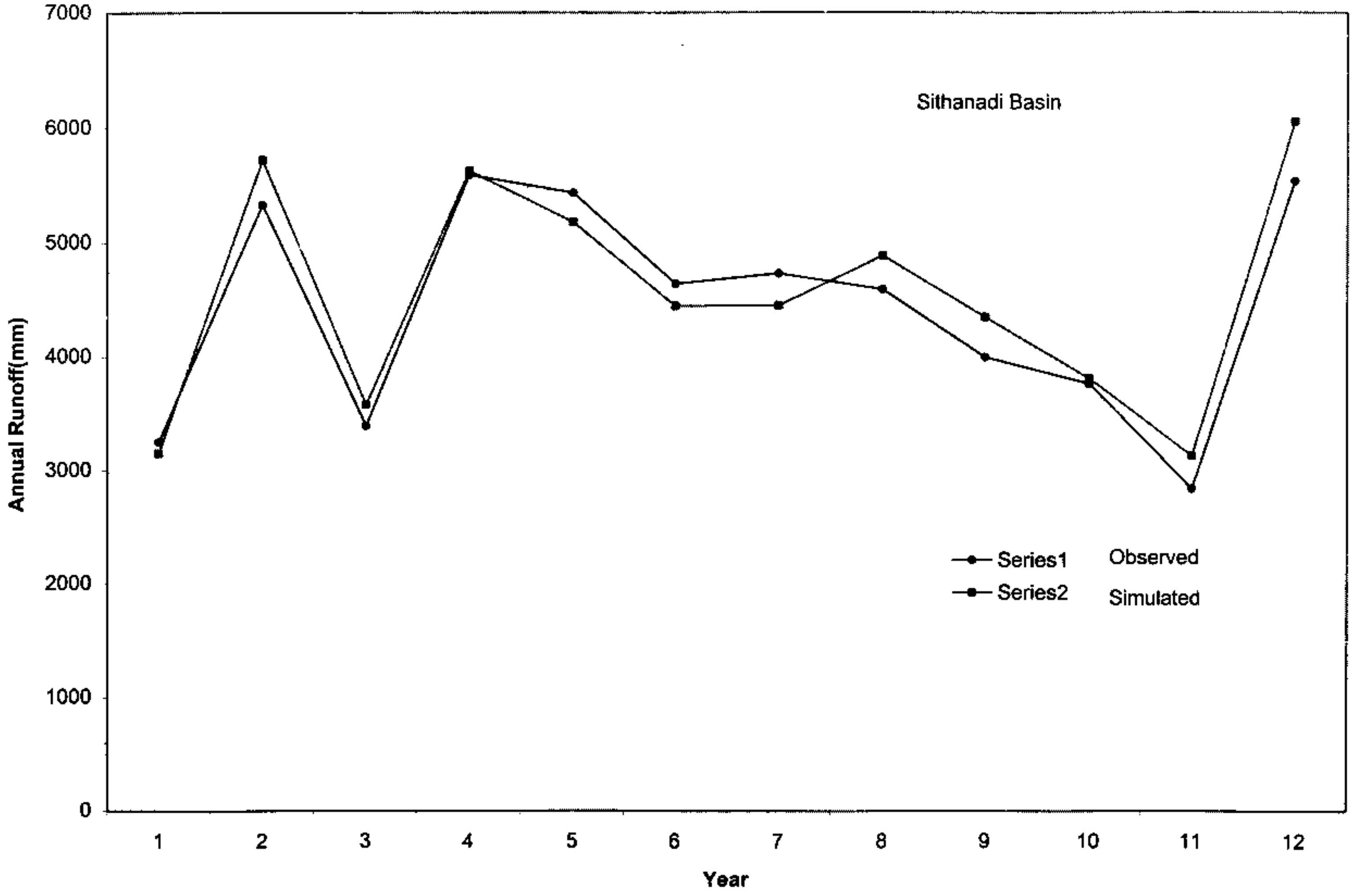


Figure 3.1.18. Observed and simulated total runoff

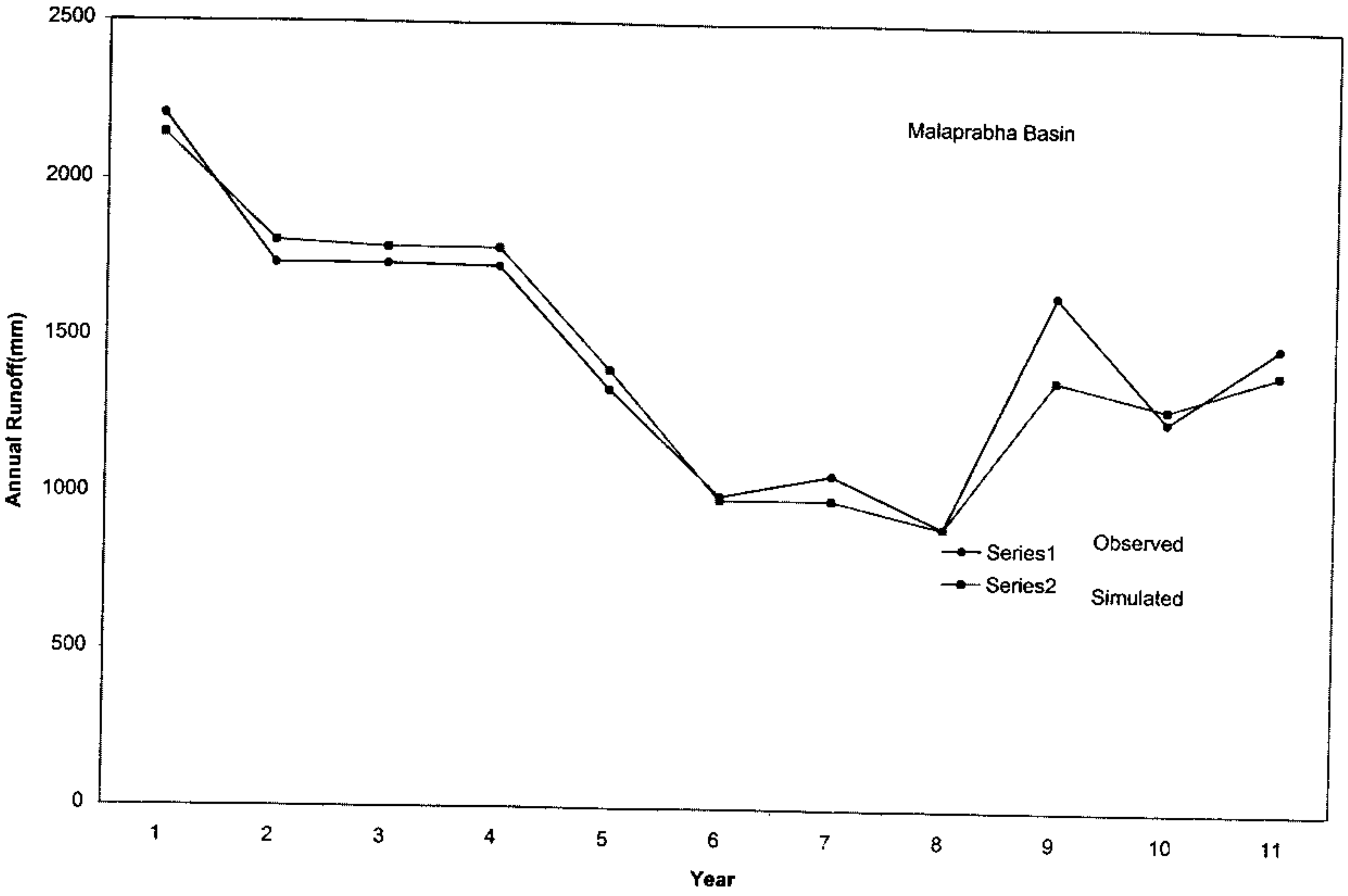


Figure 3.1.19. Observed and simulated total runoff

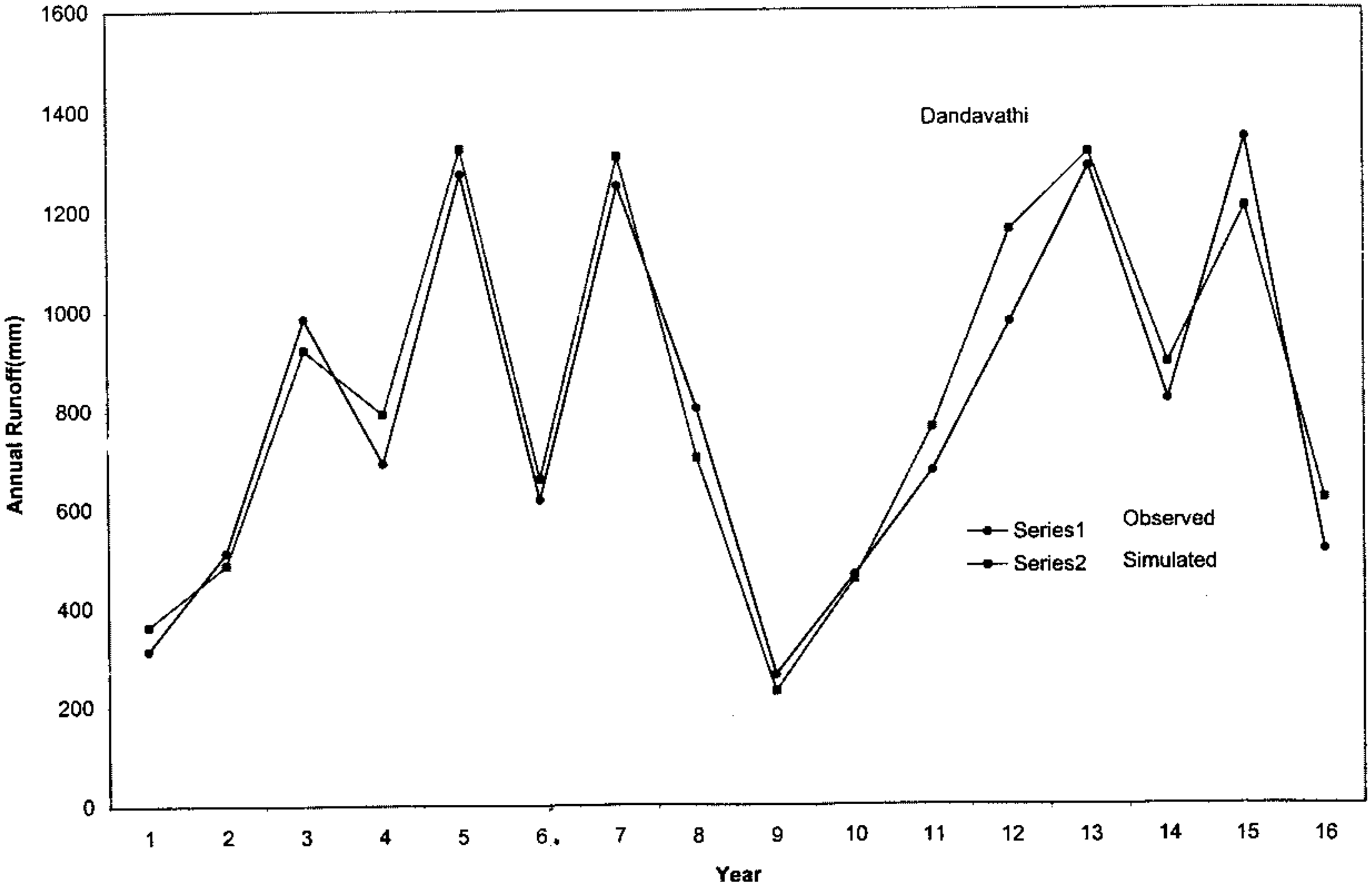
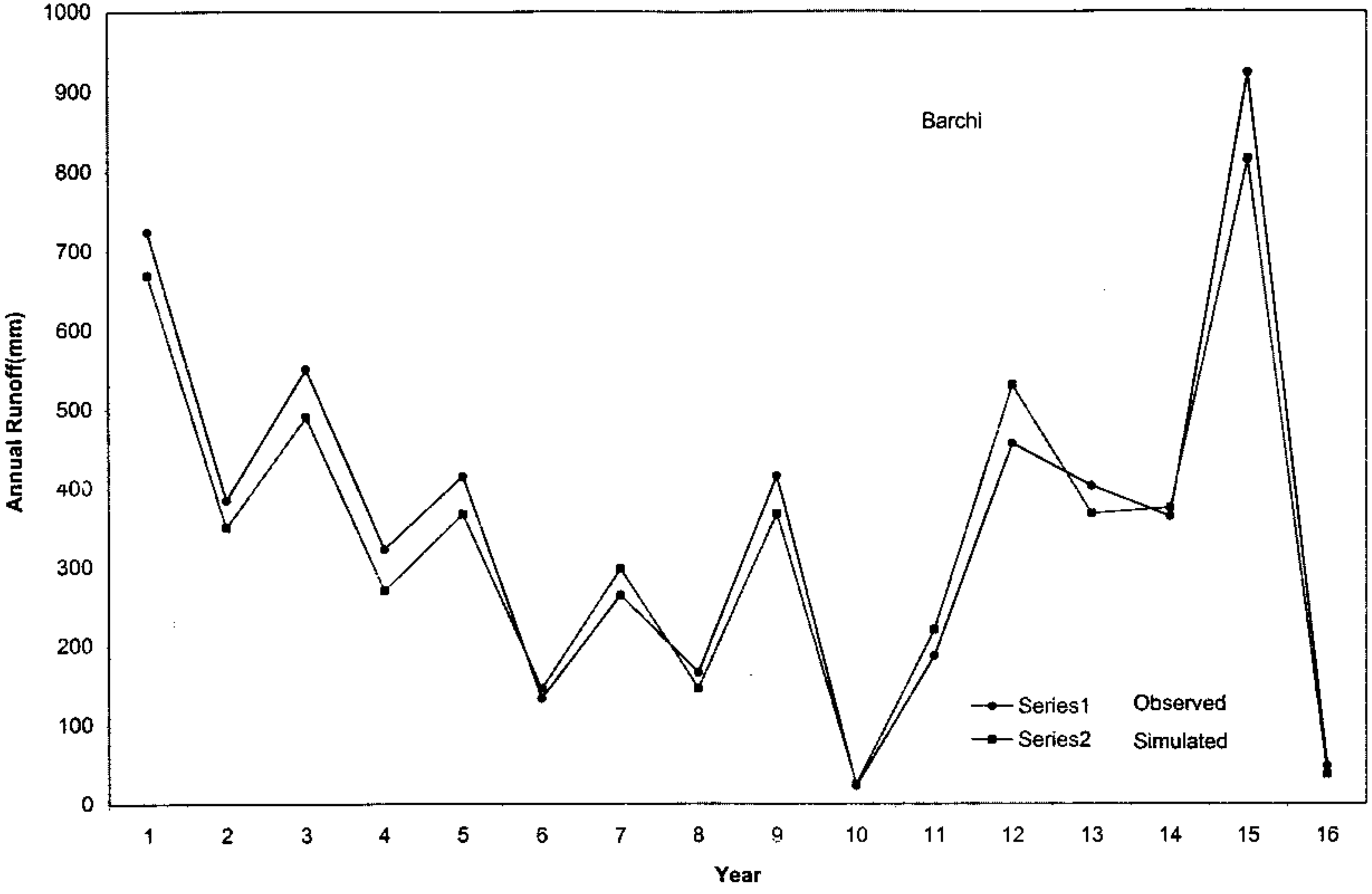


Figure 3.1.20. Observed and simulated total runoff



3.2.0 Rainfall-Runoff-Runoff coefficient Relationship

After the calibration of model parameters for selected catchments in the Western ghat region, the scenario of annual rainfall, runoff and corresponding runoff coefficients are generated. Using set of these values, the set of curves have been established to predict the yield of the catchment, depending on the annual precipitation. The established curves are shown in figures 3.2.1 to 3.2.5.

3.3.0 Regionalisation of Model Parameters

The main aim of the study, to develop a regional conceptual catchment water balance model parameters which can be used to estimate the quantity of water yield from the ungauged catchments.

The catchment water balance model (Ponce and Shetty) has parameters like wetting potential, vaporisation potential, initial abstraction coefficient of surface flow and initial abstraction coefficient of baseflow. The parameters of the model is a function of annual rainfall, vegetation covers, soil moisture, soil characteristics, surface topography and drainage density. However, in the present study, per cent of vegetation cover and annual normal rainfall of all the catchments were considered to develop the regionalised parameters. The table 3.3.1 presenting the model parameters, per cent of vegetation cover of the study areas and annual mean rainfall.

Table 3.3.1. Model Parameters, Vegetation Cover, and Annual Mean Rainfall

Sl. No.	Name of the basin	W_n (mm)	V_n (mm)	λ_s	λ_u	Iabs (mm)	Iabu (mm)	P (mm)	Veg.Cover per cent
1	Sithanadi	3448	1823	0.3	0.15	1034	273	5550	69
2	Netravathi	1838	601	0.33	0.36	606	216	4050	30
3	Malaprabha	3537	2132	0.16	0.24	566	512	3000	60
4	Barchi	3616	2295	0.24	0.33	868	757	1534	75
5	Dandavathi	1668	1237	0.25	0.18	417	222	1351	38

Figure 3.2.1. Simulated type curve of Precipitation, Runoff coefficient and Runoff

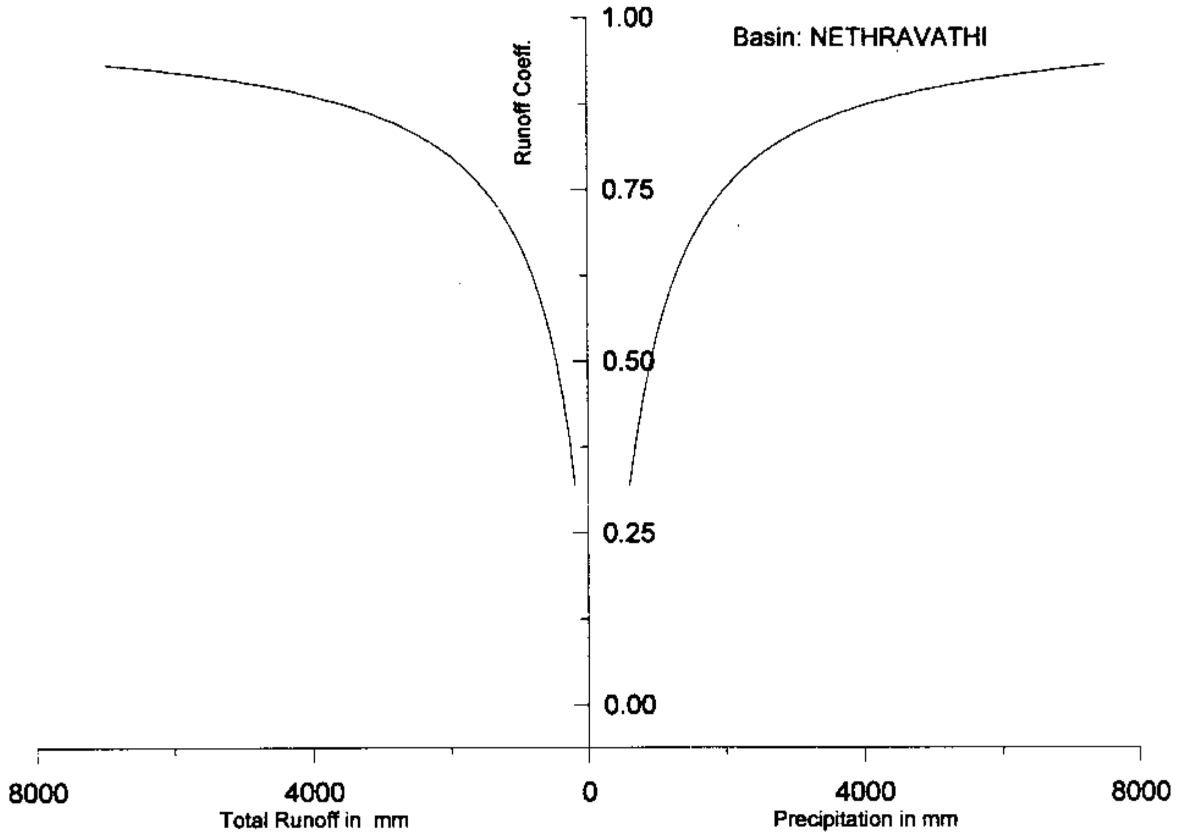


Figure 3.2.2. Simulated type curve of Precipitation, Runoff coefficient and Runoff

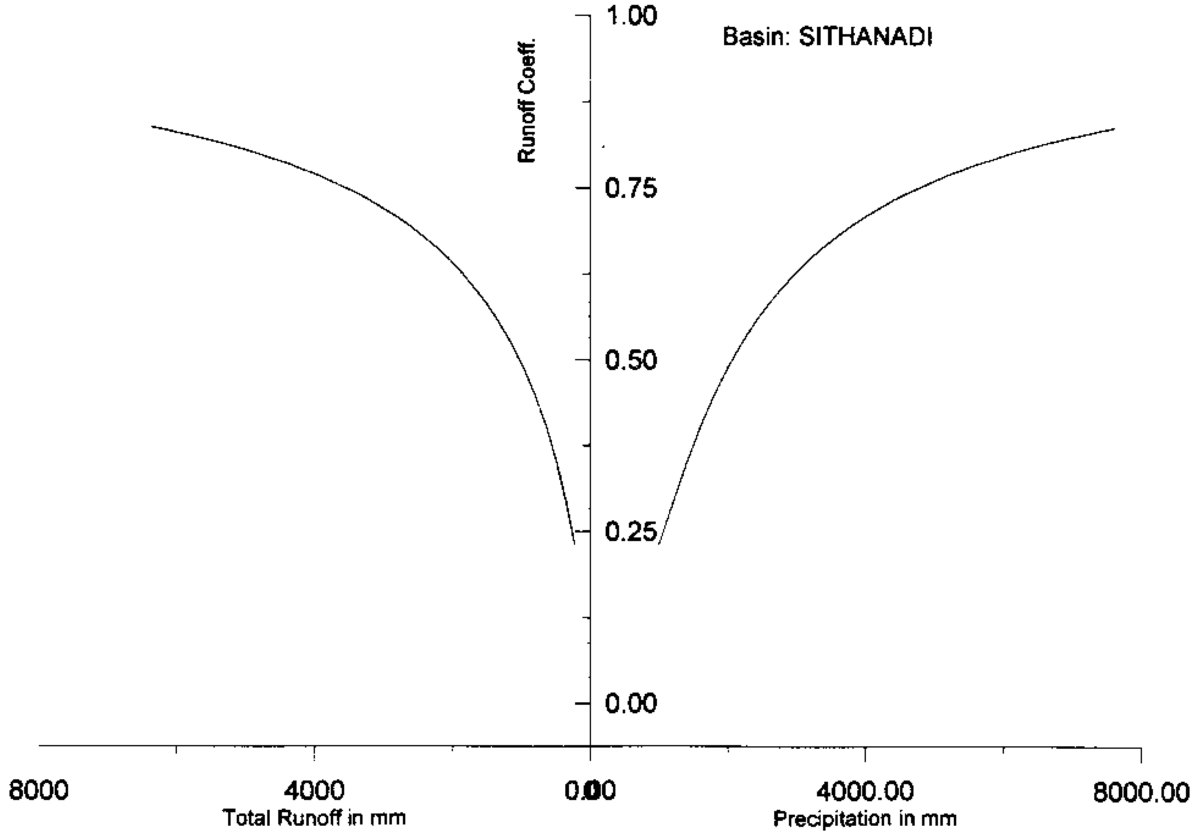


Figure 3.2 3. Simulated type curve of Precipitation, Runoff coefficient and Runoff

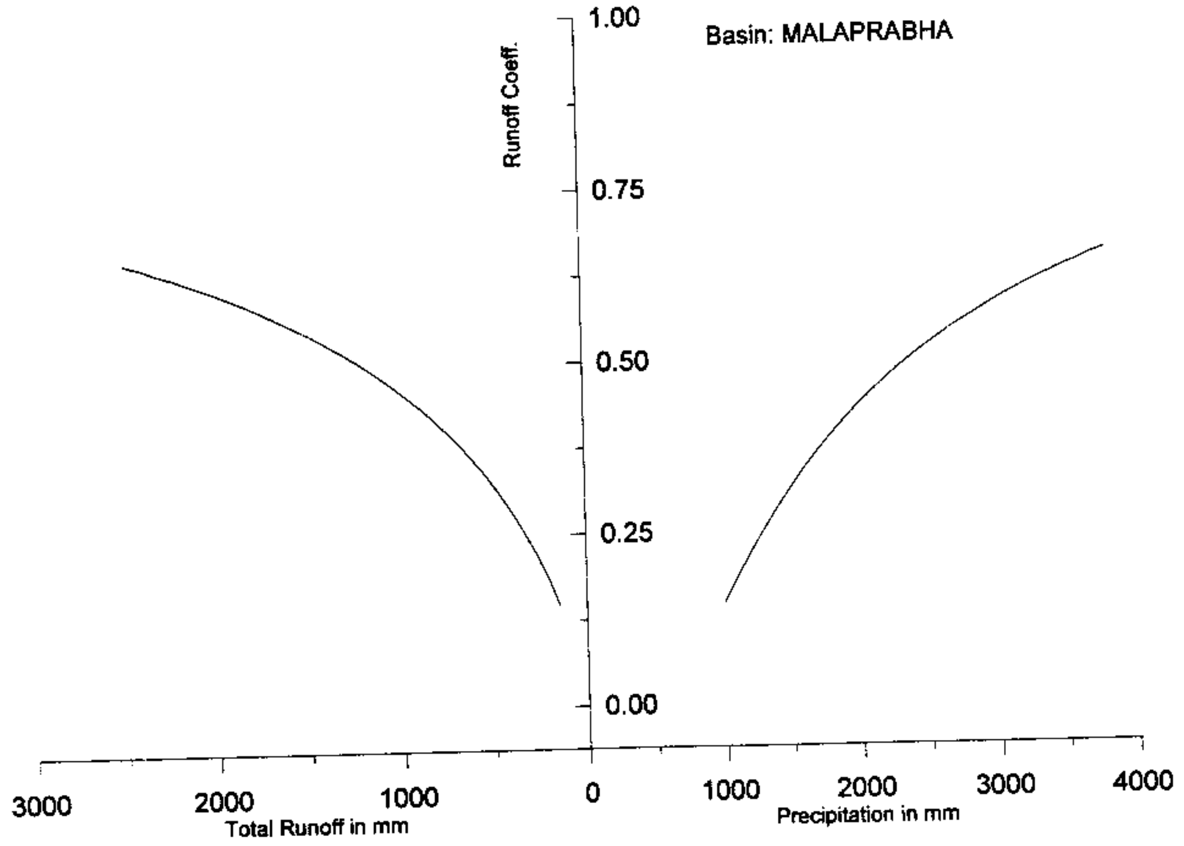


Figure 3.2.4. Simulated type curve of Precipitation, Runoff coefficient and Runoff

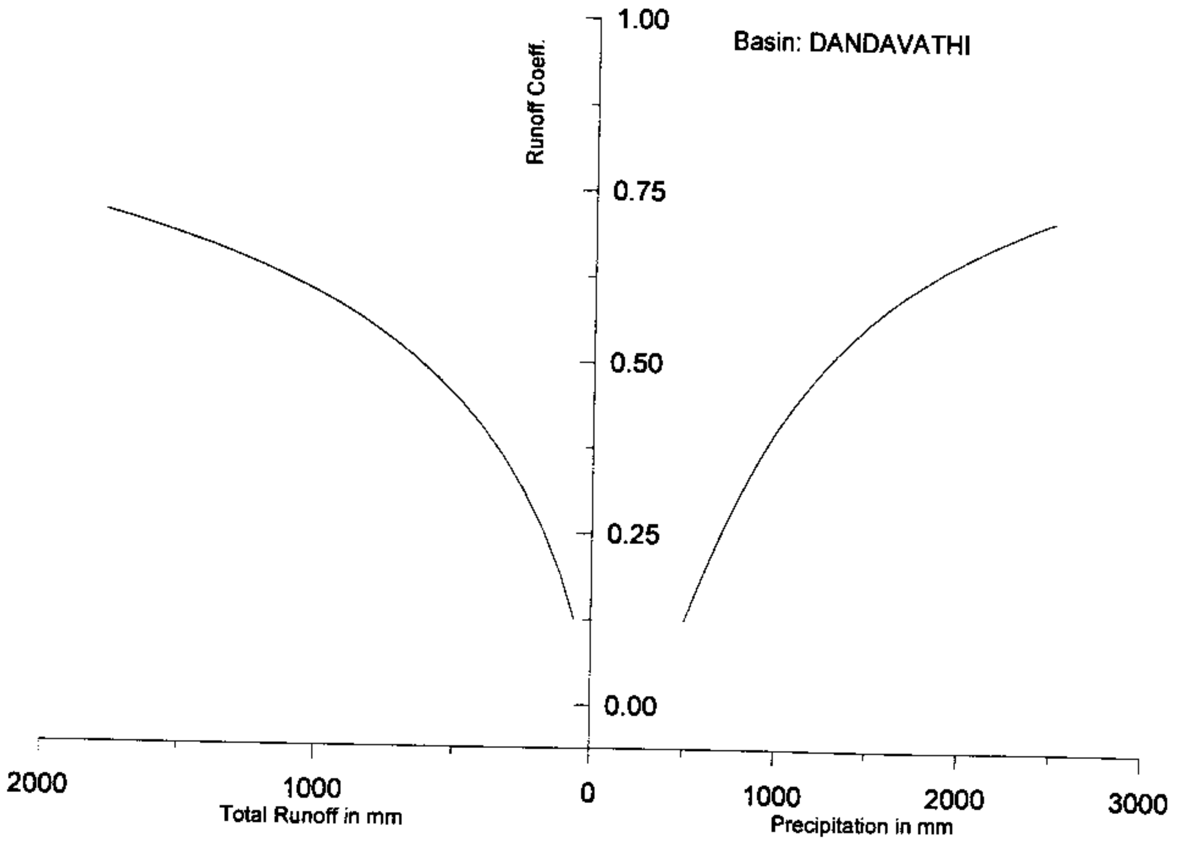
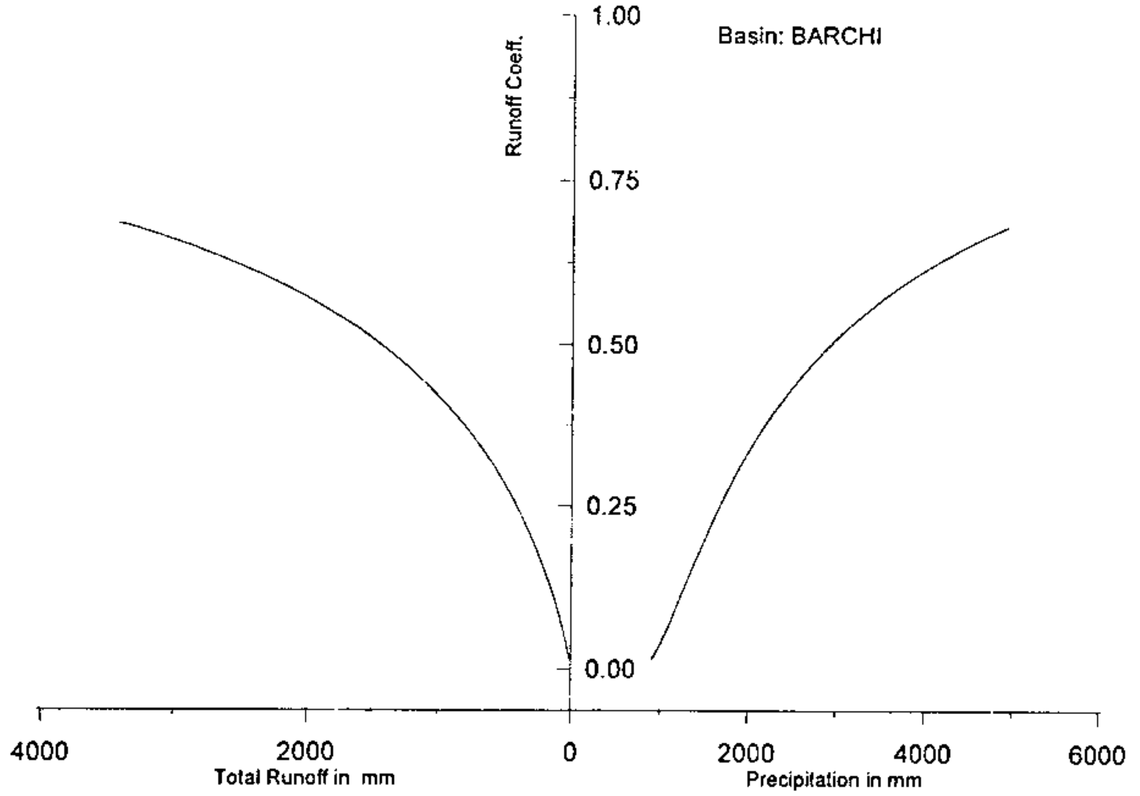


Fig : 3.2.5 Simulated type curve of Precipitation, Runoff coefficient and Runoff



The relationship is established between model parameters and factors effecting the water yield by of the catchment as follows;

The correlation between mean annual rainfall and wetting potentials of selected catchments carried out and the established relationship is,

$Wp = 0.104841P + 2496.7$ with coefficient of determination 0.35.

The correlation between mean annual rainfall and vaporisation potentials of selected catchments carried out and fitted regression in the form,

$Vp = 1844.14 - 0.0731464P$ with coefficient of determination 0.034.

The correlation between mean annual rainfall and Initial abstraction of surface flow of selected catchments carried out and relationship as follows,

$Iabs = 0.0784157P + 455.34$ with coefficient of determination 0.309

The correlation between Mean annual rainfall and Initial abstraction of baseflow of selected catchments carried out and the following realationship has been established,

$Iabu = 581.651 - 0.0599438P$ with coefficient of determination 0.201.

The correlation between the per cent of vegetation cover and wetting potentials of selected catchments carried out and the established relationship is,

$Wp = 47.2445Vc + 251.302$ coefficient of determination 0.8926.

The correlation between the per cent of vegetation cover and vaporisation potentials of selected catchments carried out and the following relationship has been established,

$Vp = 33.186Vc - 187.719$ with coefficient of determination 0.8685.

The correlation between the per cent of vegetation cover and initial abstraction of surface flow of selected catchments carried out and the relationship as follows,

$Iabs = 9.4713Vc + 182.95$ with coefficient of determination 0.557.

The correlation between the per cent of vegetation cover and initial abstraction of baseflow of selected catchments carried out and the esablished relationship is,

$Iabu = 8.82839Vc - 84.2755$ with an coefficient of determination 0.5393.

4.0 Results and Discussions

The comparison of observed and simulated total runoff shows that, they are very close each other in all the cases except for Barchi catchment where the percentage of error is 11.87. The percentage of error is within the limit and calibrated parameters of catchment water balance model can be used to simulate the runoff of the basin.

The simulation of surface runoff, baseflow, vaporisation, wetting and total runoff with respect to the annual rainfall shows an clear indication of dynamic nature of the catchment during the initial range of annual rainfall, in otherwords, very much susceptible for lower side of the annual precipitation. The dynamic range of precipitation is varies from 500mm to 3000mm. In the case of Nethravathi and Seethanadi the catchment is very sensitive upto 3000mm which are westward flowing rivers. However in the case of eastward flowing rivers are sensitive upto 2000mm. The trend of water balance components with respect to the annual rainfall shows different attitude which can be remarkably isolated from each other with westward or eastward flowing nature.

In all the cases, total runoff and surface runoff will increase monotonically and baseflow, wetting and vaporisation increases asymptotically. Westward flowing rivers are having similar trend when eastward flowing rivers has common trend with the annual precipitation. In the case of westward flowing rivers baseflow has tide over the vaporization in the total wetting where as in the case of eastward flowing rivers are other way. Hence this may be the indication of perinial nature of flow in the westward flowing rivers when compared to eastward flowing rivers. This kind of phenomenon may be a indication of high infiltration, porosity and percolation, and low soil moisture retention capacity of of the area. Hence it is justifying the existing aquifer conditions of the study area. In the case of Sithanadi basin, inspite of maximum vegetation cover baseflow takes over the vaporization when compared to the east flowing rivers. It may also be attributed to the minimum deep percolation in the study area. The failure of deep wells also quit common in this part of the area. In the case of Netravathi, baseflow takes over the vaporization around 900mm of annual rainfall where as in the case of Sithanadi, 3500mm of annual rainfall. This is also a clear indication of percentage of vegetation cover of the study area. Sithanadi is having about 60 per cent of vegetation and Nethravathi is having about 30 per cent of vegetation. Therefore Sithanadi vaporization is more than baseflow till it stabilises.

The catchments are very sensitive for the lower part of annual precipitation or otherwords rate of change of runoff and baseflow coefficients are very high with respect to the unit annual rainfall. It can also be visualised by the relationship between annual rainfall and baseflow coefficient and runoff coefficient. Westward flowing rivers having common nature of runoff and baseflow coefficient process where as eastward flowing rivers are having similar nature of trend.

The relationship between annual rainfall-runoff coefficient and runoff-runoffcoefficient has been established using calibrated parameters of the model. From which total yield of the catchment based on the annual rainfall can be obtained.

The correlation between mean annual rainfall and wetting potentials of selected catchments carried out and it shows that $W_p = 0.104841P + 2496.7$ with coefficient of determination 0.35.

The correlation between mean annual rainfall and vaporisation potentials of selected catchments carried out and fitted regression in the form,

$V_p = 1844.14 - 0.0731464P$ with coefficient of determination 0.034.

The correlation between mean annual rainfall and Initial abstraction of surface flow of selected catchments carried out and it has established,

$I_{abs} = 0.0784157P + 455.34$ with coefficient of determination 0.309

The correlation between Mean annual rainfall and Initial abstraction of baseflow of selected catchments shows that,

$I_{abb} = 581.651 - 0.0599438P$ with coefficient of determination 0.201.

Based on the coefficient of determination for the above said regression fitting one can be easily discard the relationship between the above said parameters. It clearly shows that there is no relationship between annual rainfall and other model parameters.

The correlation between the per cent of vegetation cover and wetting potentials of selected catchments having an coefficient of determination 0.8926.

The correlation between the per cent of vegetation cover and vaporisation potentials of selected catchments with coefficient of determination 0.8685.

The correlation between the per cent of vegetation cover and Initial abstraction of Surface flow of selected catchments with an coefficient of determination 0.557.

The correlation between the per cent of vegetation cover and Initial abstraction of baseflow of selected catchments with an coefficient of determination 0.5393.

The coefficient of determination vegetation cover, and wetting potential and vaporisation potential is very close to 0.90. The higher the coefficient of determination shows the clear cut relationship between vegetation cover of the catchments and wetting potential and vaporisation potential. However, in the case of initial abstraction of surface runoff and baseflow, the coefficient of determination is above 0.50. Due to nonavaialability of data, the present coefficient of determination can be accepted for the establishment of relationship between vegetation cover and initial abstraction of baseflow and surface runoff. The established relationship as given below.

$W_p = 47.2445\ V_c + 251.302$

$V_p = 33.186\ V_c - 187.719$

$I_{abs} = 9.4713\ V_c + 182.95$

$I_{abu} = 8.82839\ V_c - 84.2755$

The regionalised parameters of the model is given in the table 4.1.

Table 4.1.0 Comparison of calibrated and Regionalised parameters of the Model

Basin	Wp		Vp		λs		λu	
	Cal	Fit	Cal	Fit	Cal	Fit	Cal	Fit
Netravathi	1838	1668	601	808	0.33	0.28	0.36	0.22
Sitanadi	3448	3511	1823	2102	0.30	0.23	0.15	0.25
Malaprabha	3537	3086	2132	1803	0.16	0.24	0.24	0.25
Dandavathi	1668	2046	1237	1074	0.25	0.27	0.18	0.23
Barchi	3616	3795	2295	2301	0.24	0.24	0.33	0.25

Based on the regionalised relationship, wetting potentials, vaporisation potentials, initial abstraction of baseflow and surface runoff re-established. The regionalised parameters have been compared with the calibrated parameters from observed data. It is also compared with the simulated water balance components both from calibrated parameters and regionalised parameters. All those compared components shown in figures 4.1.1 to 4.1.15. The simulation shows some kind of discrepancy only in the case of Dandavathi. However, all other components almost coincides with regionalised parameter value and calibrated parameter value. The difference between these two value within the tolerance limit and less than 10 per cent.

Suggestion and conclusions

The results shows that relationship between catchment water balance model parametres and vegetation cover has certain kind of relationship and regional model parametres can be very well obtained. However, consistancy of the data should be verified before the calibration of the model. The range of data used for the calibration may be well distributed.

The regionalisation of the parametres may be carried out for more number of catchments so that more reliable parametres can be obtained.

As a initial effort for regionalising the model parametres, the parametres obtained from the present study could be used to estimate the water yield from the catchments of Wester Ghat region based on the vegetation cover.

Fig : 4.1.1 Comparison of fitted and calibrated water balance components [NETHRAVATHI]

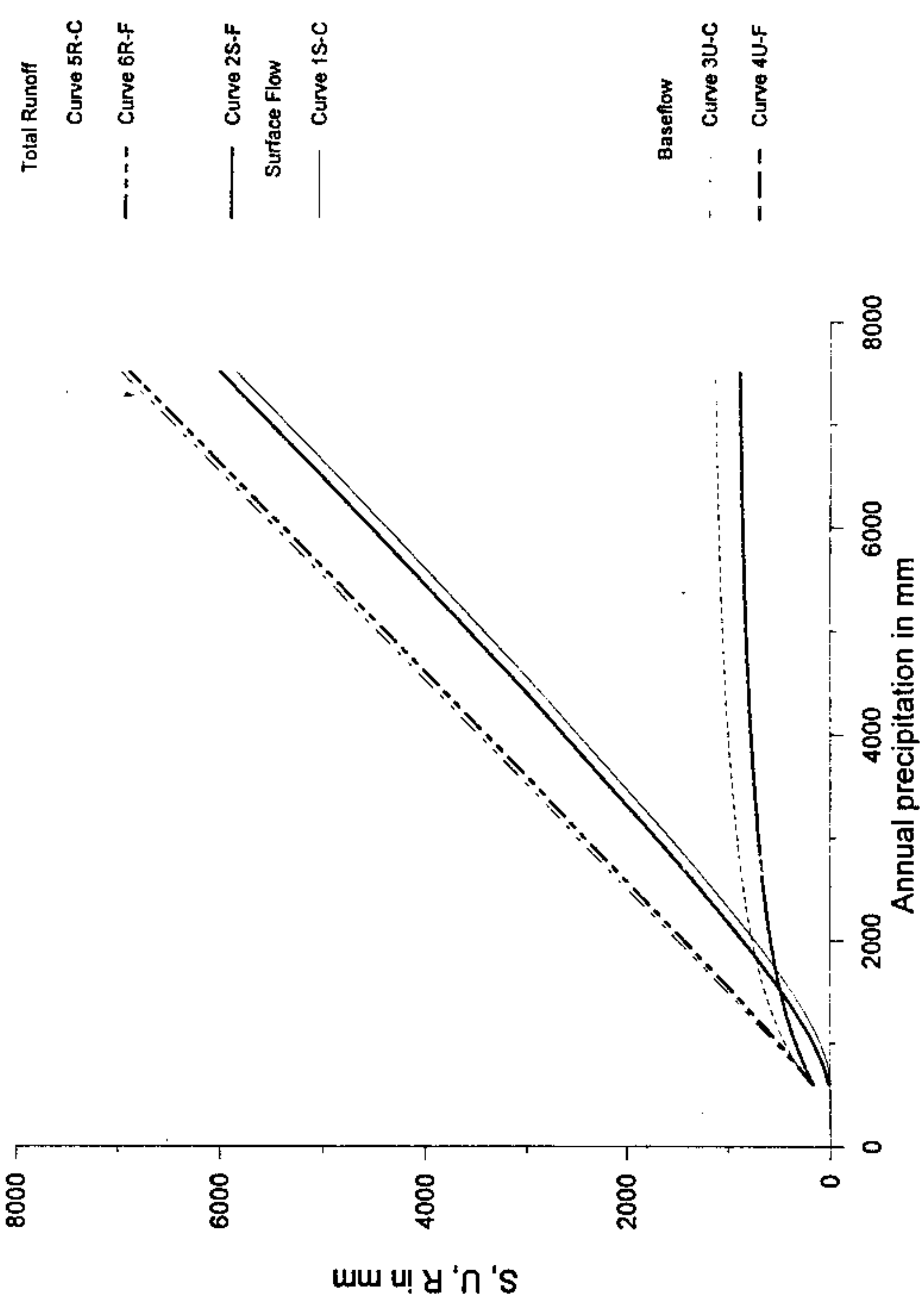


Fig : 4.1.2 Comparison of fitted and calibrated water balance components [NETHRAVATHI]

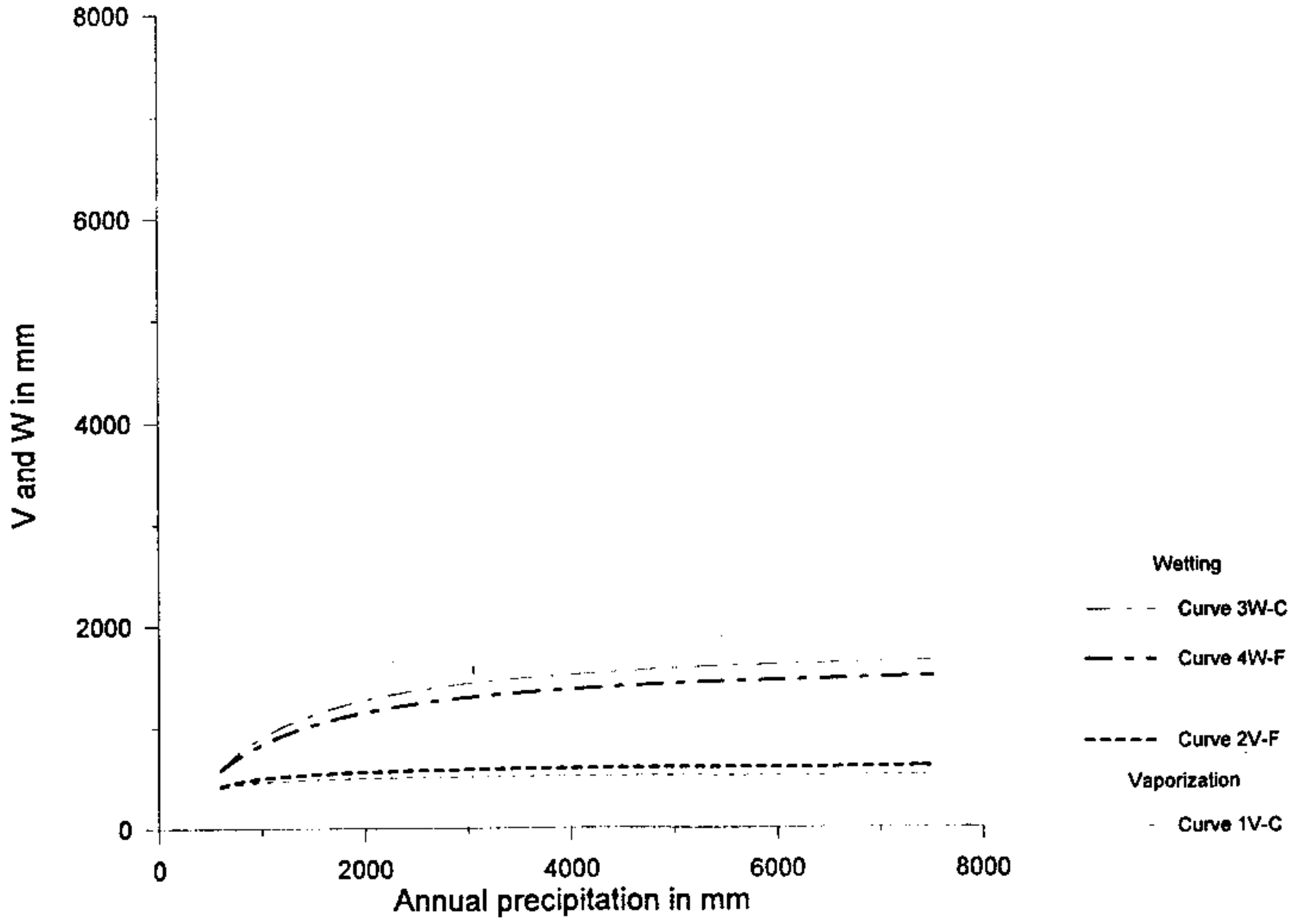
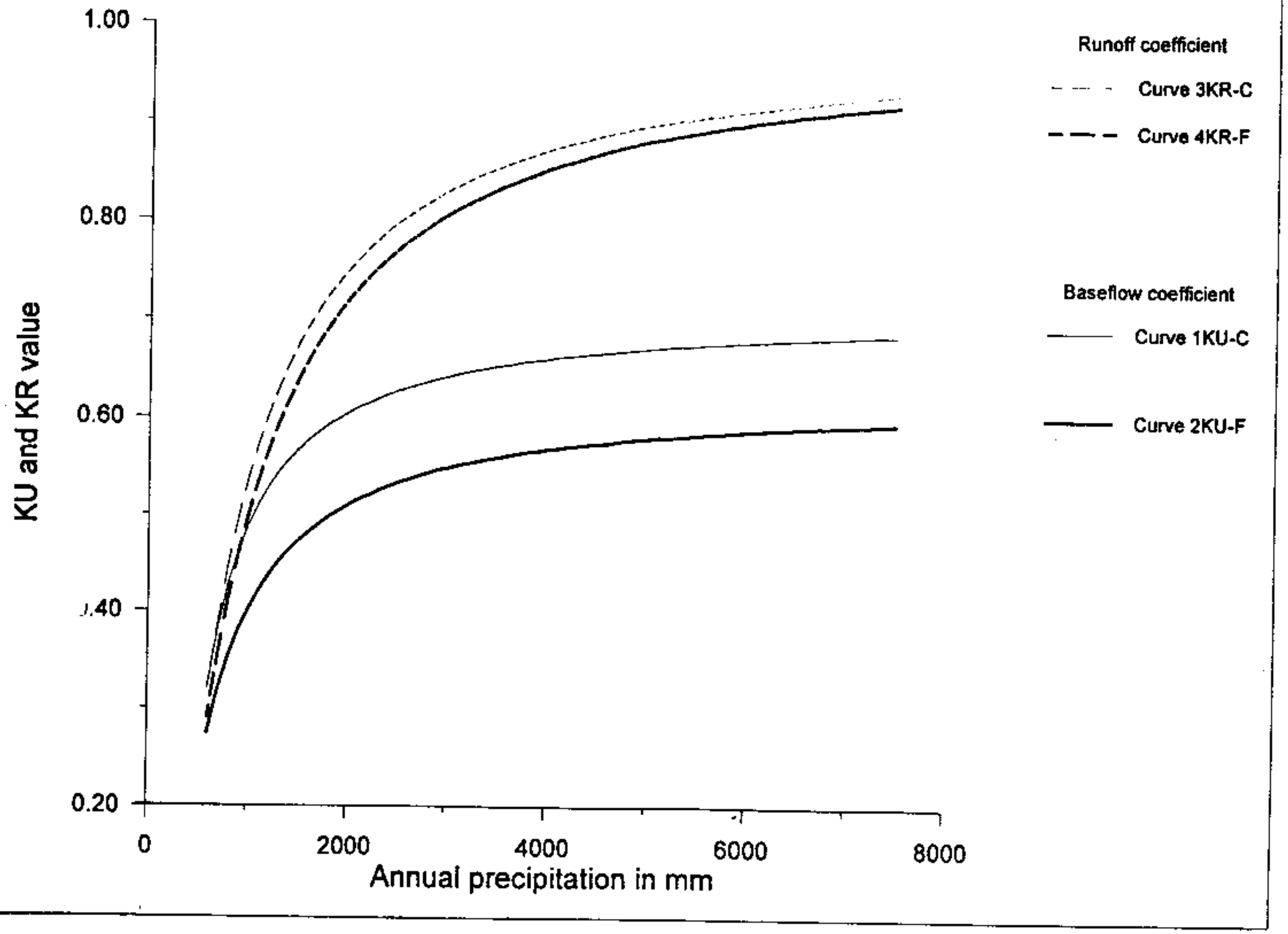


Fig : 4.1.3 Comparison of fitted and calibrated water balance components [NETHRAVATHI]



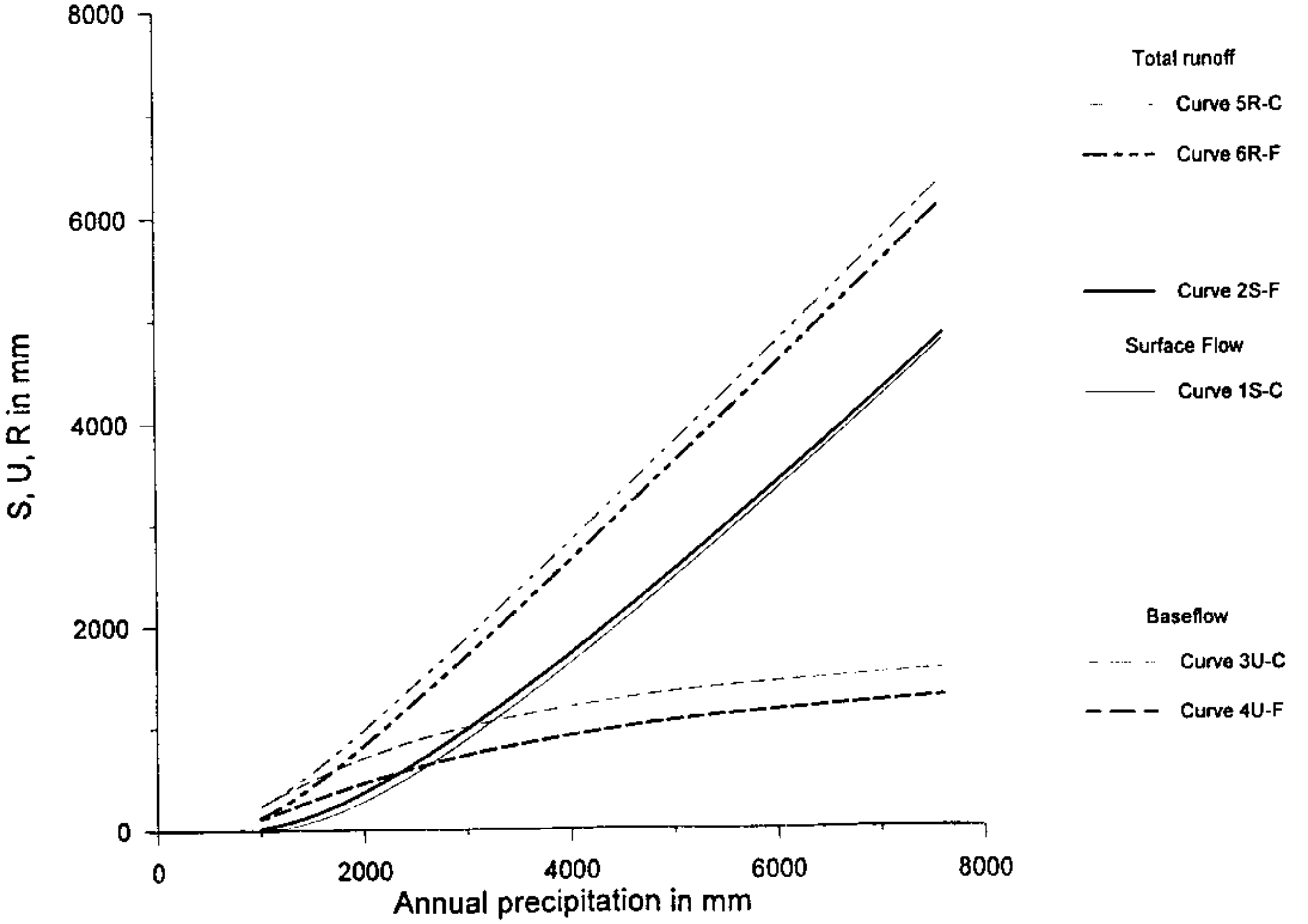


Fig : 4.1.4 Comparison of fitted and calibrated water balance components [SITHANADI]

Fig : 4.1.5 Comparison of fitted and calibrated water balance components [SITHANADI]

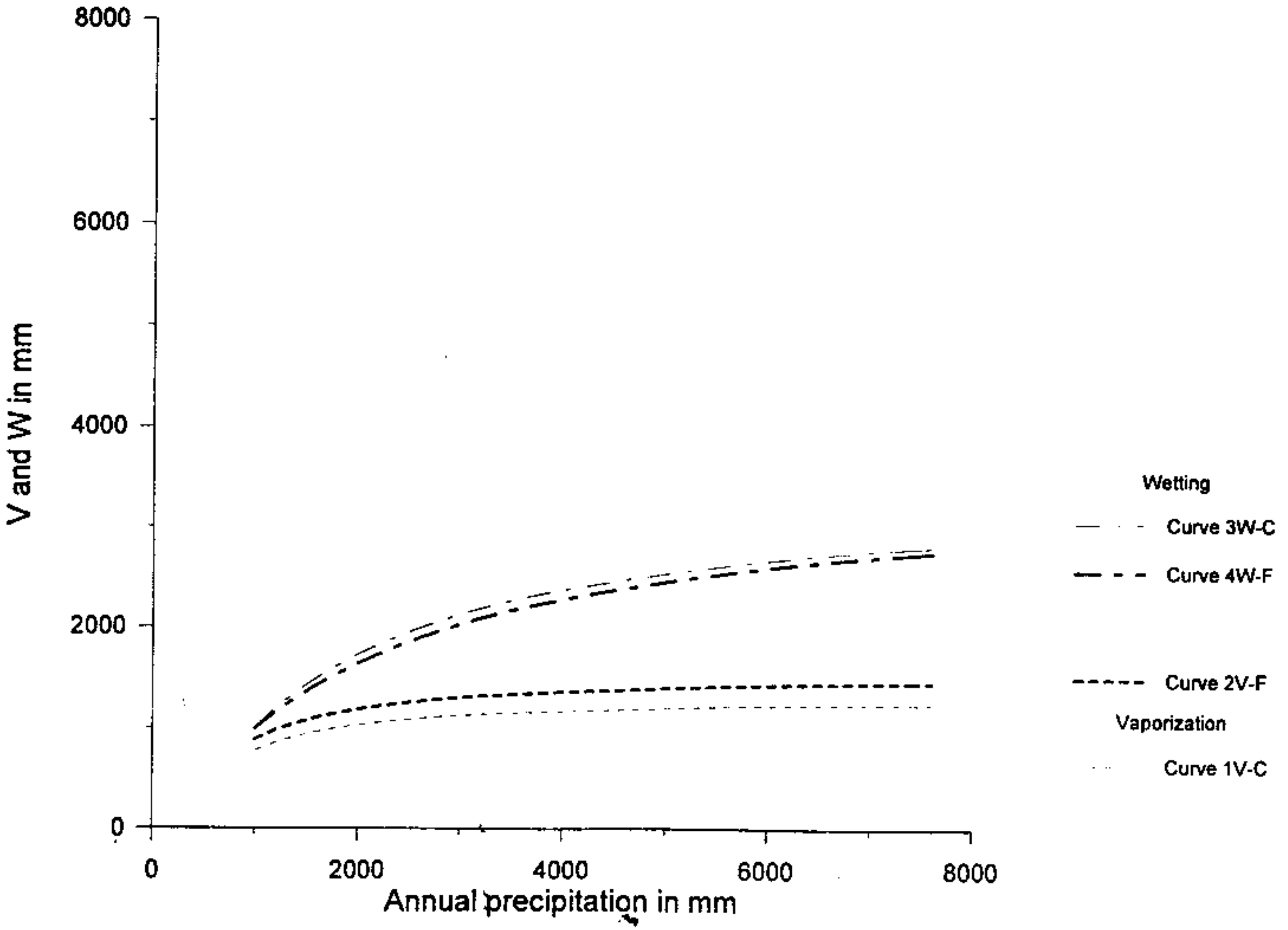


Fig : 4.1.6 Comparison of fitted and calibrated water balance components [SITHANADI]

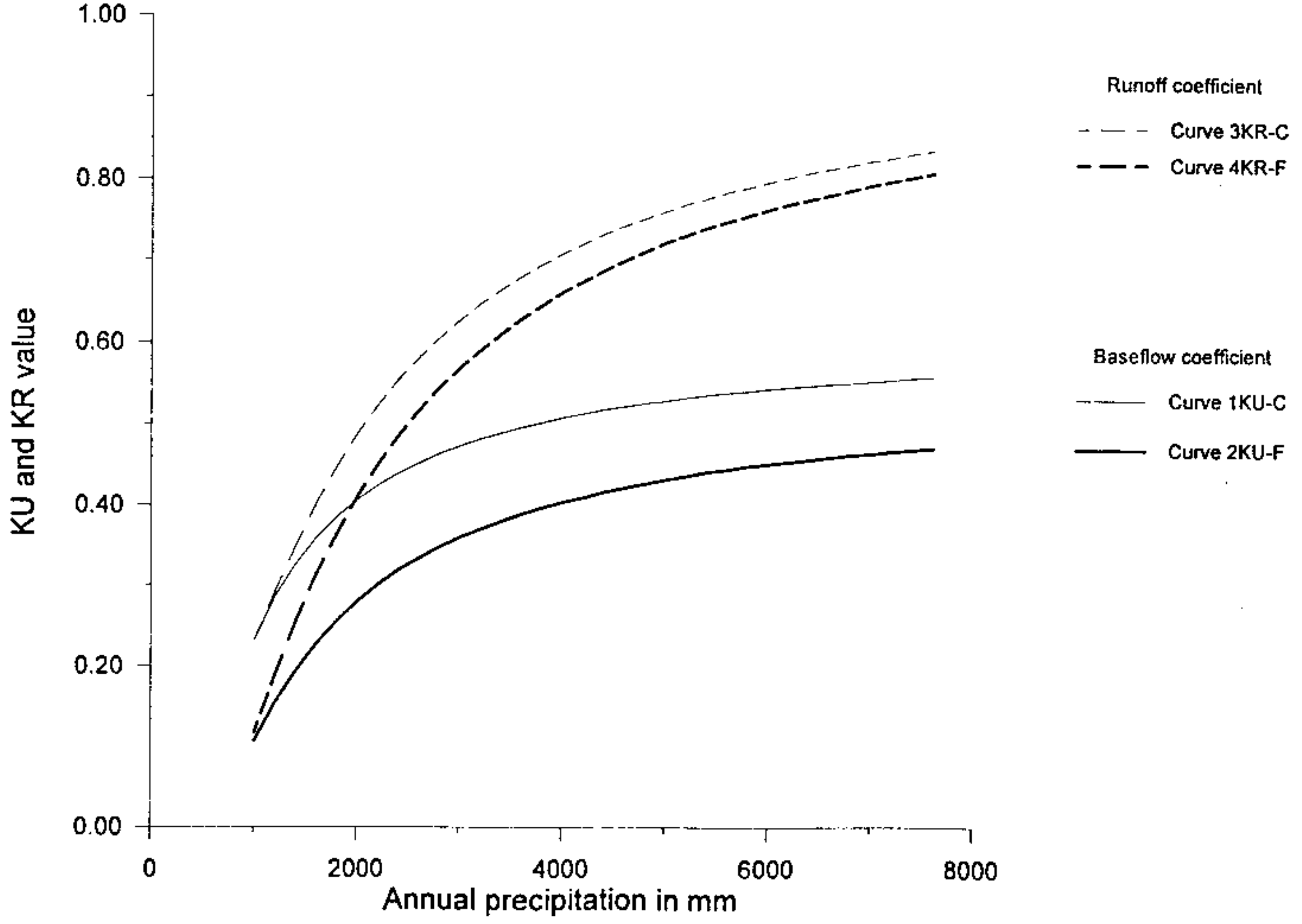


Fig : 4.1.7 Comparison of fitted and calibrated water balance components [MALAPRABHA]

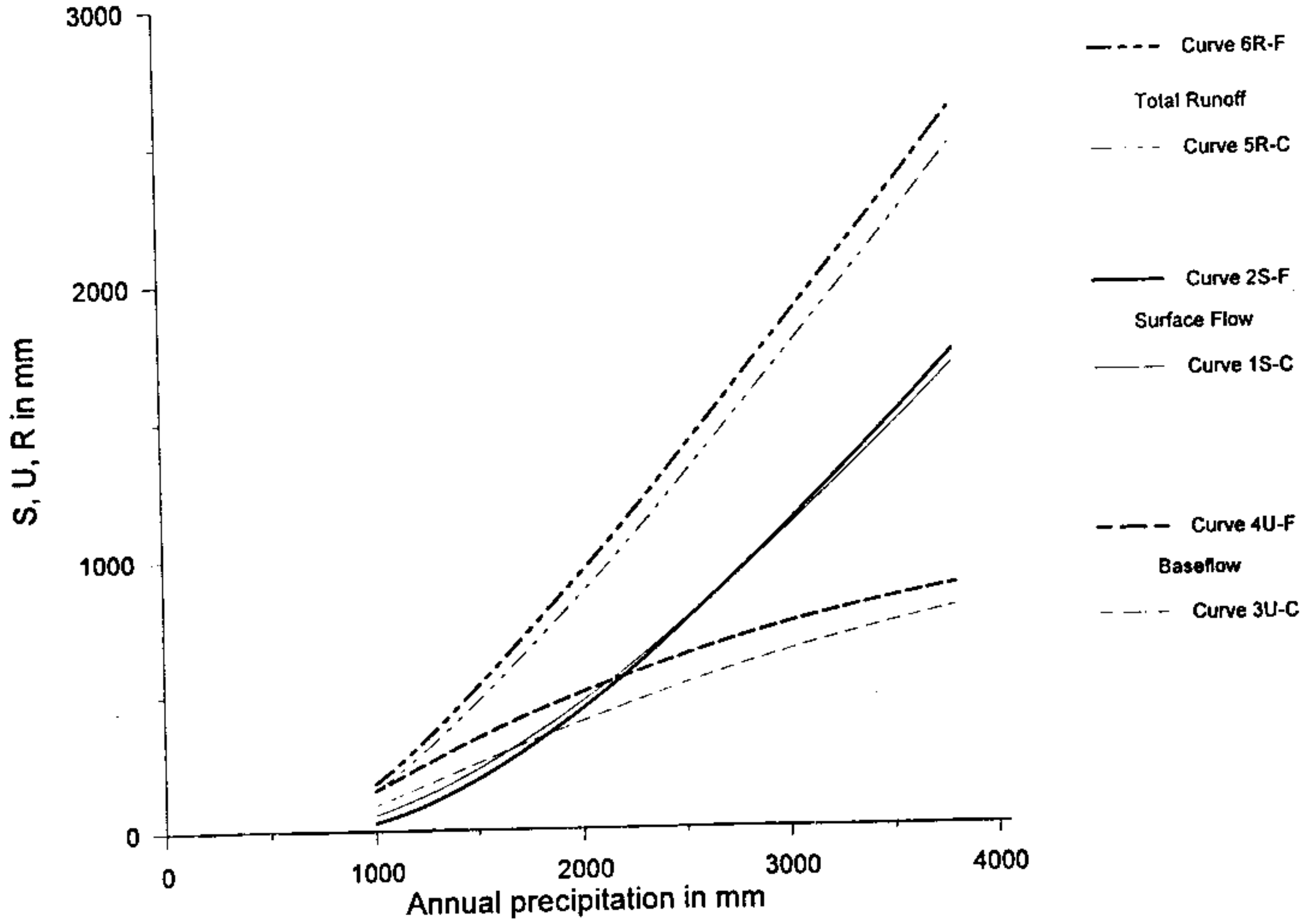


Fig : 4.1.8 Comparison of fitted and calibrated water balance components [MALAPRABHA]

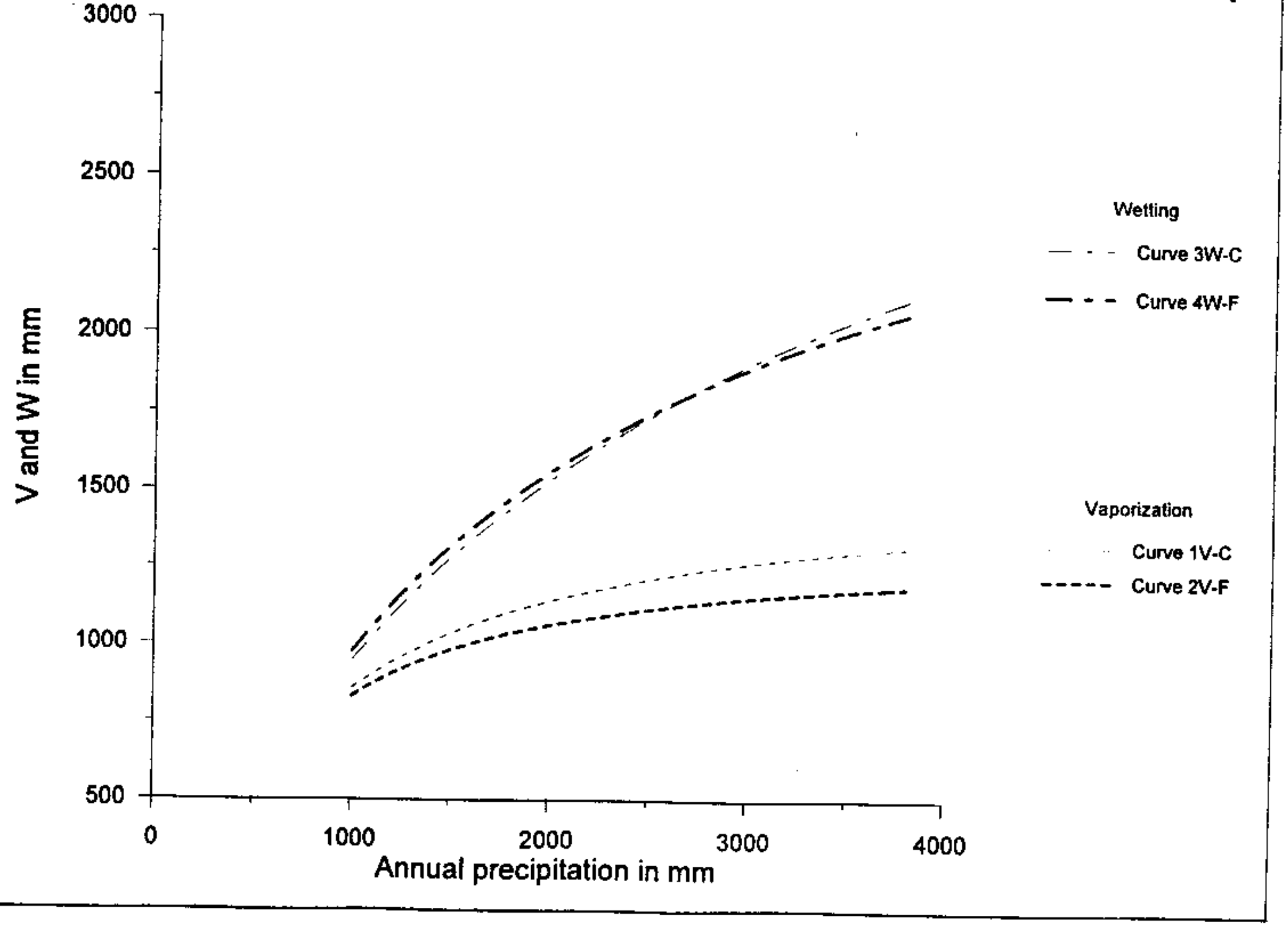


Fig : 4.1.9 Comparison of fitted and calibrated water balance components [MALAPRABHA]

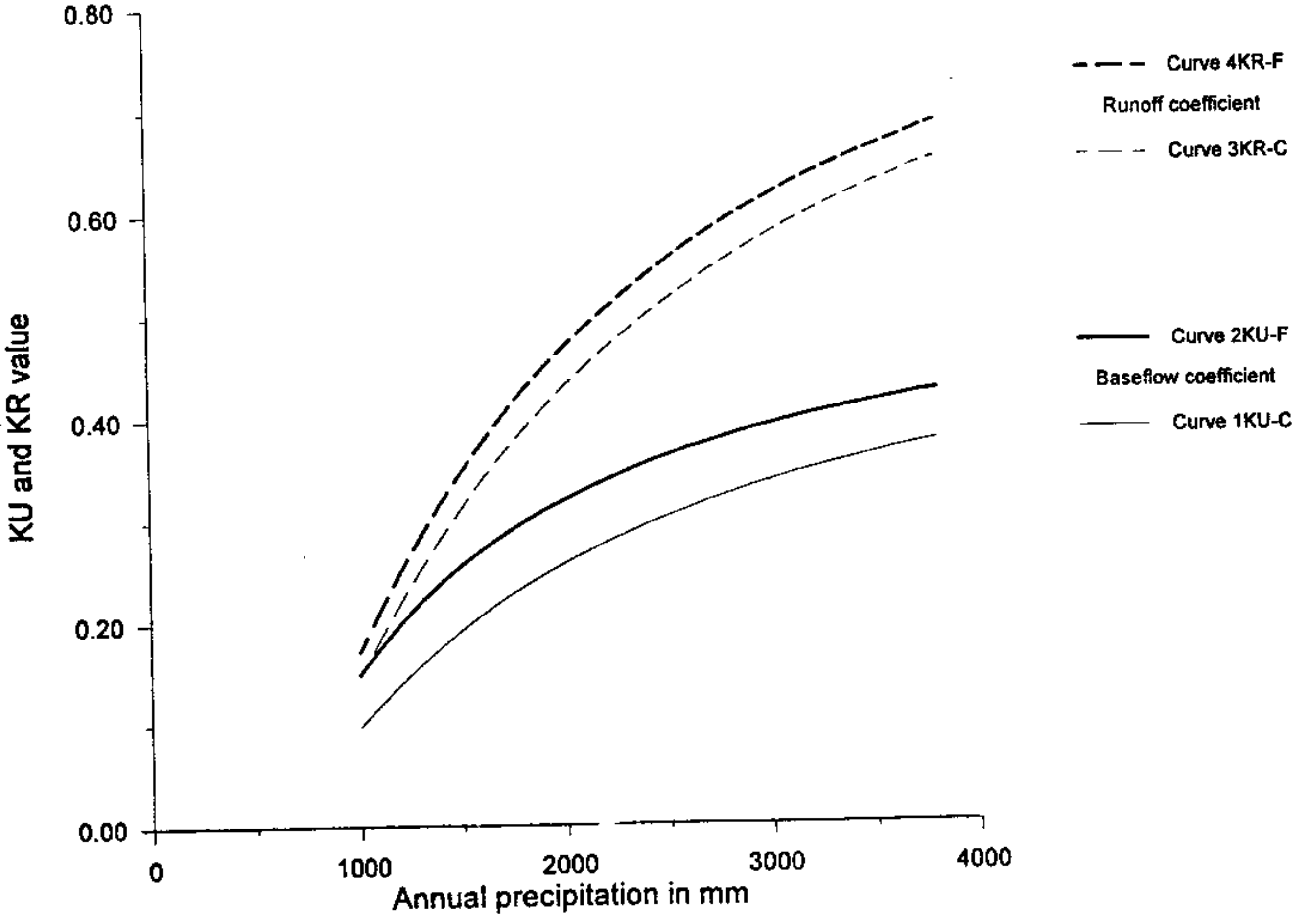


Fig : 4.1.10 Comparison of fitted and calibrated water balance components [DANDAVATHI]

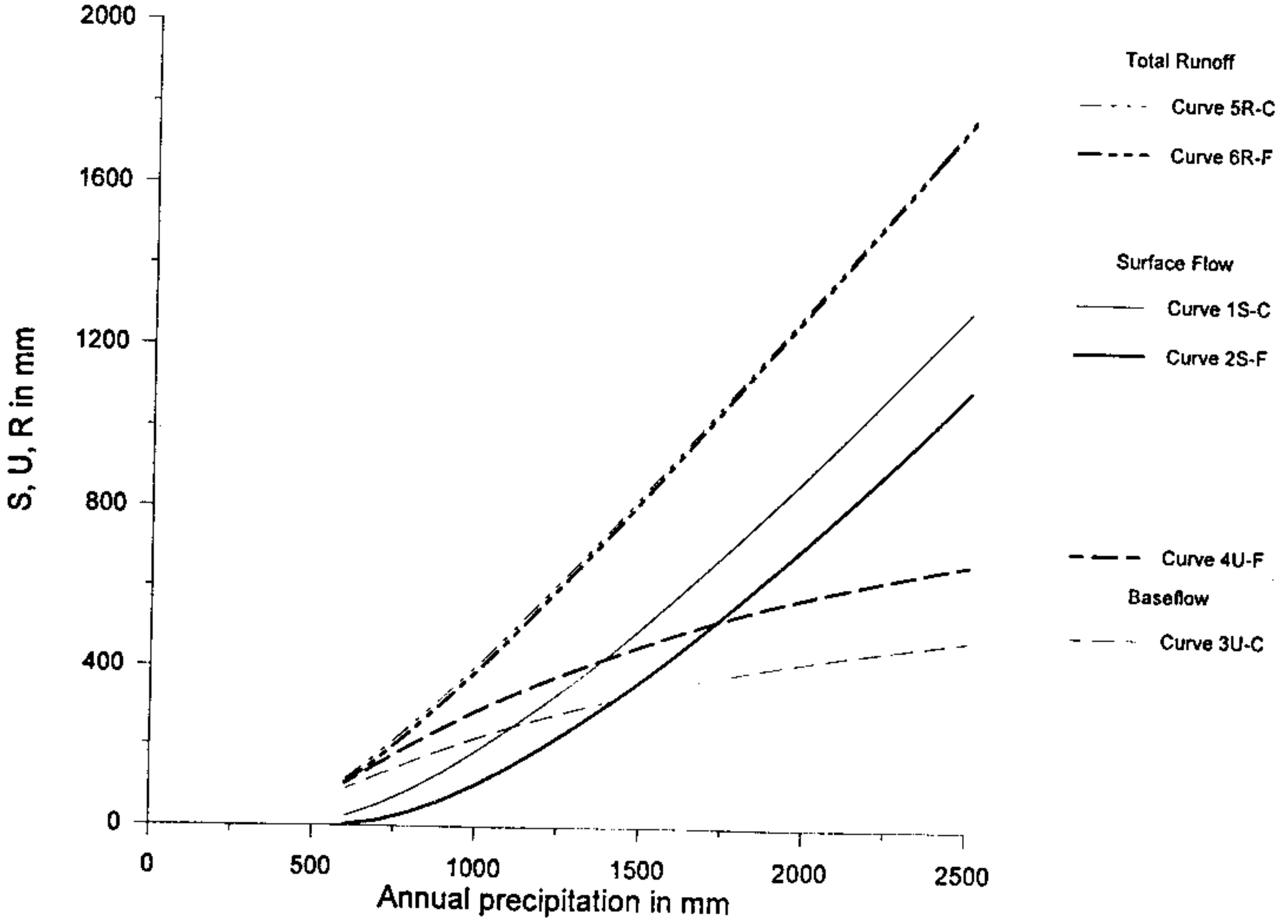


Fig : 4.1.11 Comparison of fitted and calibrated water balance components [DANDAVATHI]

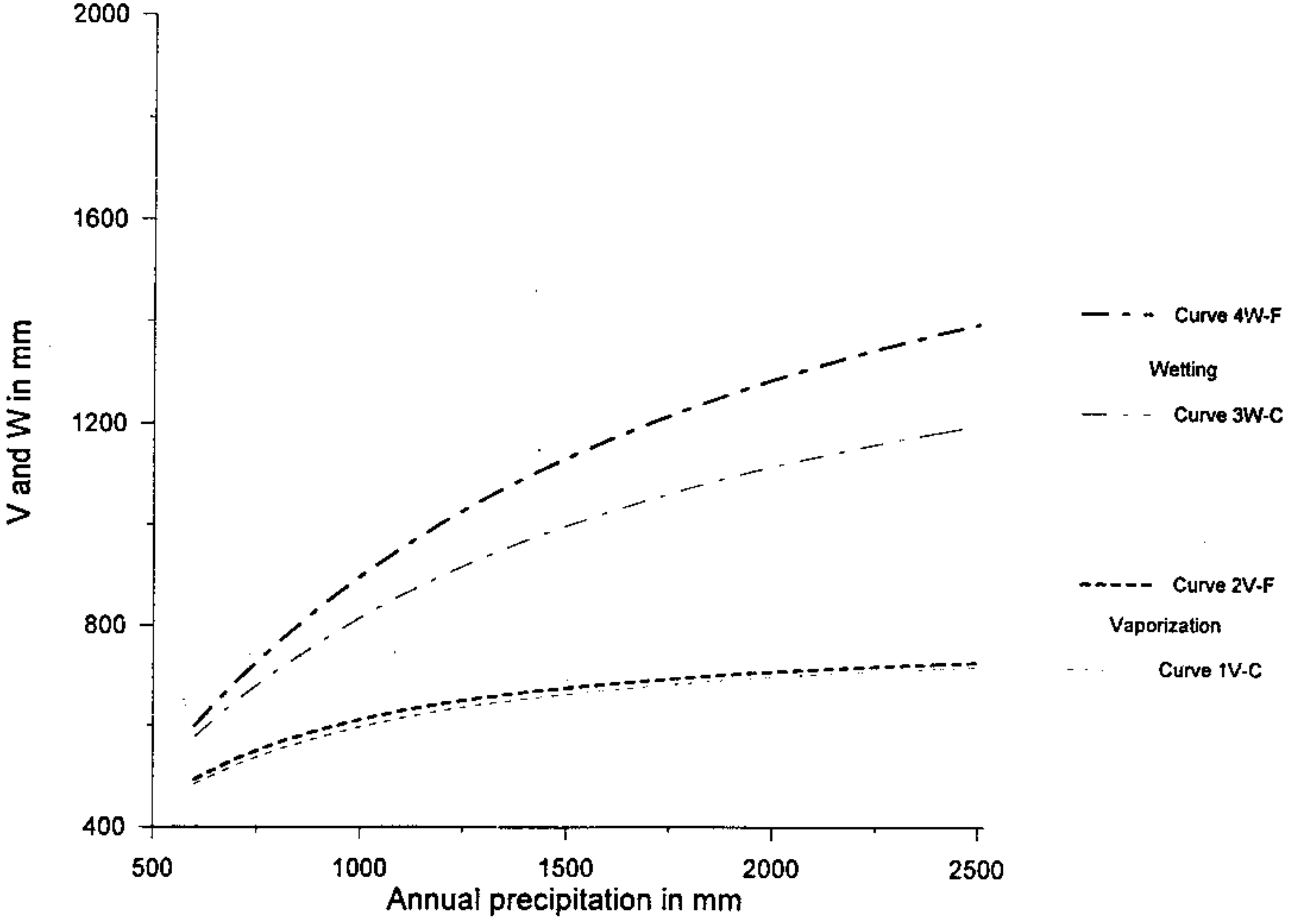


Fig : 4.1.12 Comparison of fitted and calibrated water balance components [DANDAVATHI]

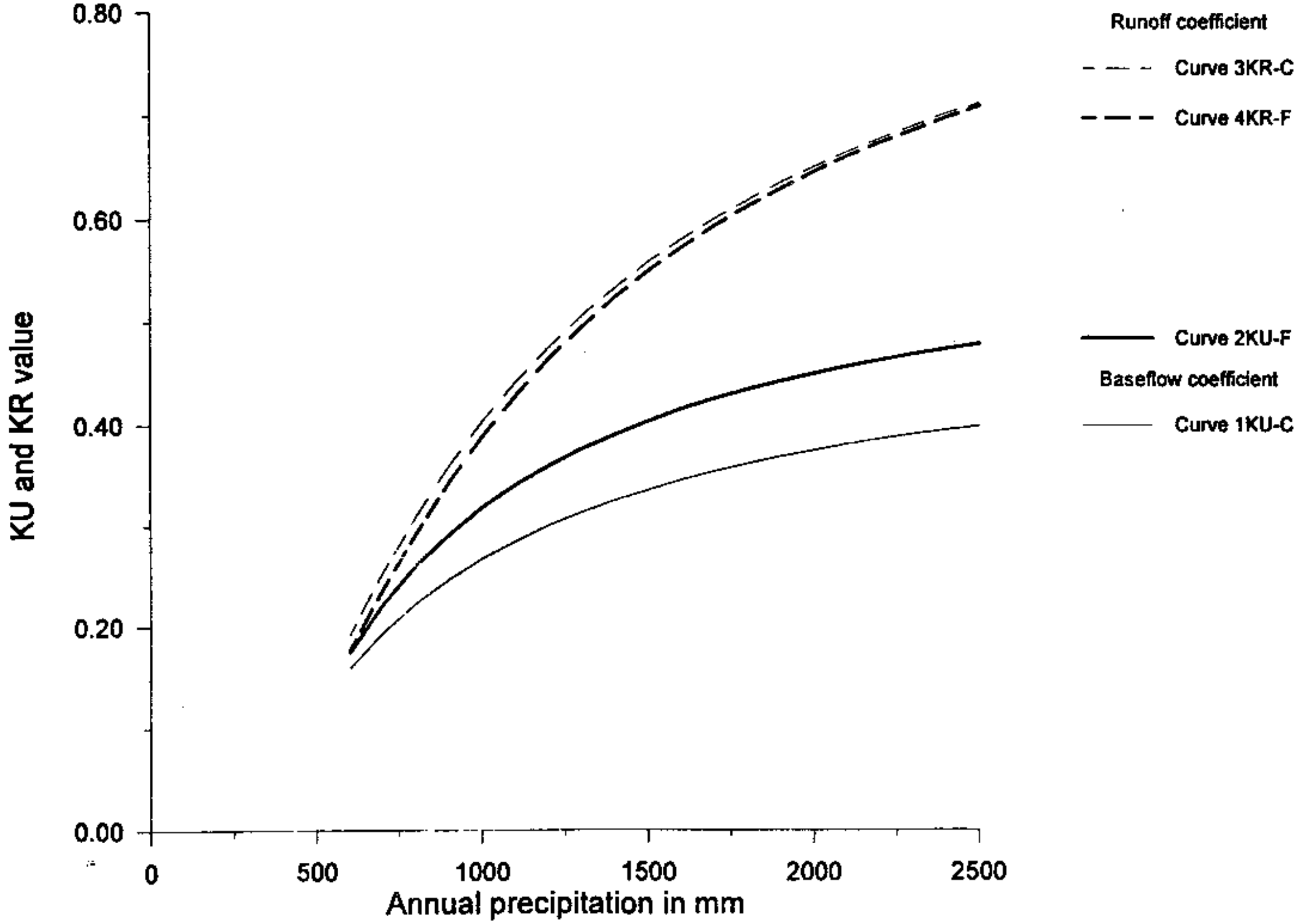


Fig : 4.1.13 Comparison of fitted and calibrated water balance components [BARCHI]

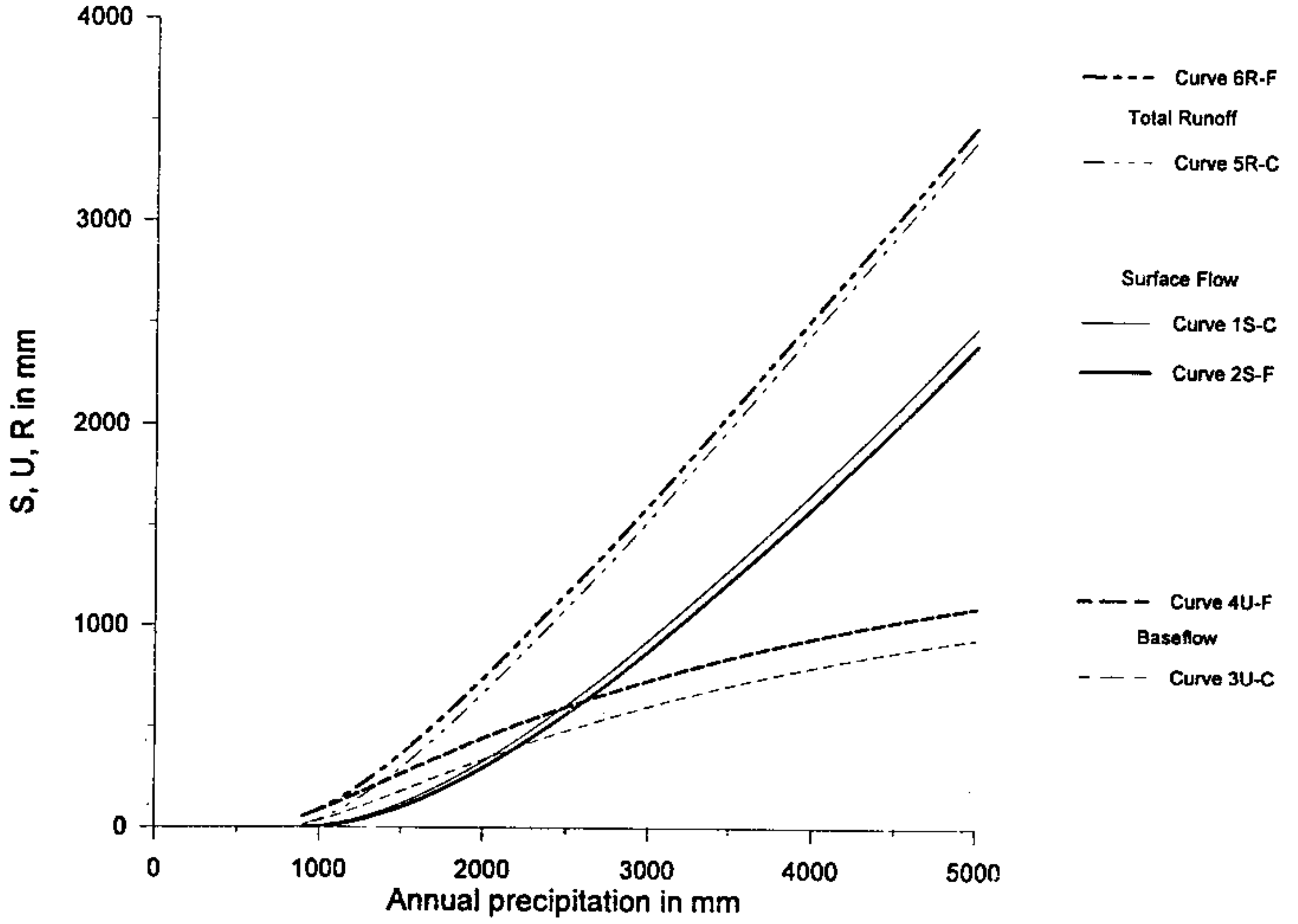


Fig : 4.1.14 Comparison of fitted and calibrated water balance components [BARCHI]

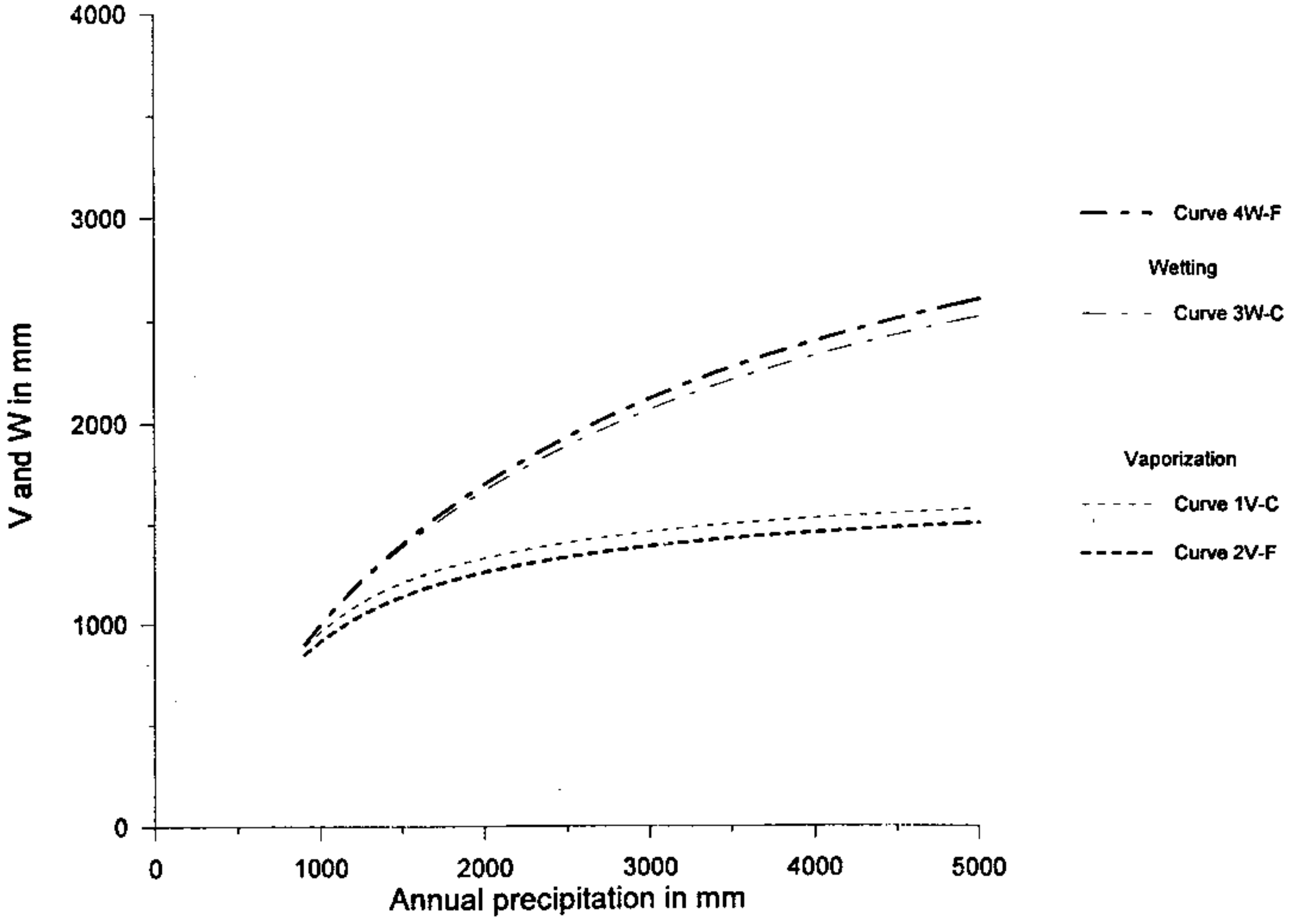
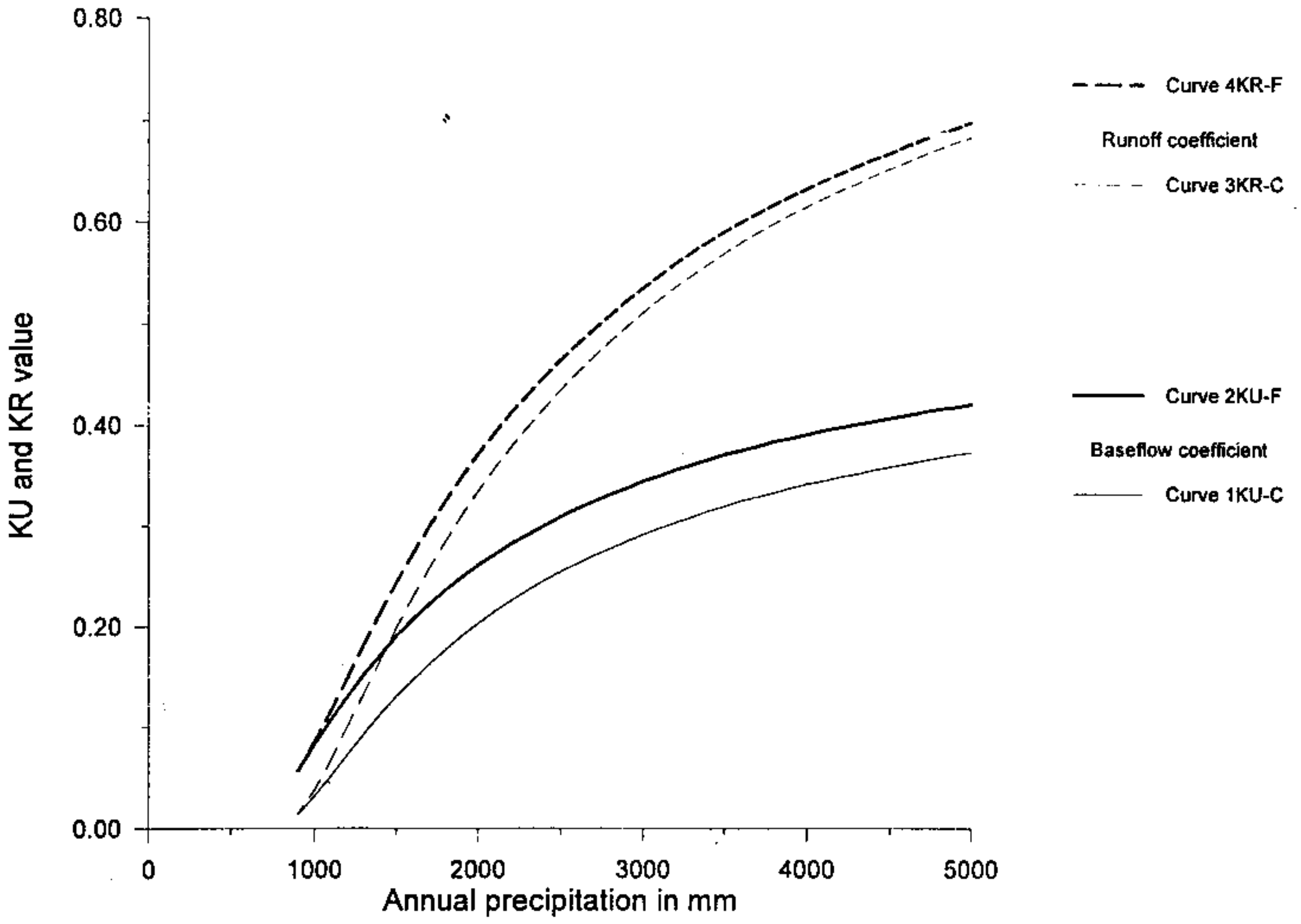


Fig : 4.1.15 Comparison of fitted and calibrated water balance components [BARCHI]



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DIRECTOR : S. M. SETH
COORDINATOR : G. C. MISHRA
HEAD : B. SONI
STUDY GROUP : A. V. SHETTY
N. K. LAKHERA