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APPLICATION OF CONCEPTUAL CATCHMENT WATER BALANCE MODEL TO THE SARADA RIVER BASIN, ANDHRA PRADESH

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PREFACE

The hydrological behaviour of catchments is a very complex phenomenon which is controlled by a large number of climatic and physiographic factors that vary in time and space. The basic problem of hydrology is the establishment of relationships between rainfall and runoff. Several approaches available for the computation of water yield at the catchment outlet over a specific period of time. The conceptual catchment water balance model is used to simulate changes in runoff and baseflow with annual precipitation in the basin. The main advantage of the model is its simplicity and less data requirement. The model can be applied to any basin by field Engineers without much knowledge of computers to understand the hydrological behaviour of the catchment.

The applicability of the conceptual catchment water balance model is being explained in this report by applying to Sarada river basin.This study is carried out by sri Y Ramji Satyaji Rao, Scientist'B' and assisted by Sri T. Vijaya, SRA. While Dr. P.V Seetapathi Sc 'F' Head & Co ordinator DRC, supervised and the overall guidance for the study was provided by Dr. V M Ponce, Professor, Civil and Environmental Engg. Dept., San Diego State University, U S A.

(S M SETH)

DIRECTOR

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The conceptual model of catchment water balance is used to simulate changes in runoff and baseflow with annual precipitation in the Sarada River Basin, Andhra Pradesh, India. The model is based on the sequential separation of annual precipitation into surface runoff and wetting, and wetting into baseflow and vaporization. Model calibration using six years of rainfall-runoff data (1981-86) was successfully accomplished using a root-mean-square minimization technique. This application shows that the model can simulate changes in runoff and baseflow with annual precipitation in a large subtropical basin (1,980 km^2) with a spatial mix of semiarid and subhumid climatic conditions.

1.0 INTRODUCTION

A catchment's water yield is a fundamental problem in hydrology, referring to the volume of water available at the catchment outlet over a specified period of time. The yield is expressed for monthly, seasonal, or annual periods. Several approaches are available for the computation of water yield. These vary in complexity from the simple empirical formulas to the complex models based on continuous simulation. While the empirical formulas have limited applicability (Sutcliffee and Rangeley, 1960; Woodruff and Hewlett, 1970), the continuous simulation models require large amounts of data for their successful operation (Crawford and Linsley, 1966). A practical alternative is represented by the Conceptual models, which use the water balance (or hydrologic budget) equation to seperate precipitation into its various components (Hamon, 1963).

Water balance techniques are a way of solving important theoretical and practical hydrological problems. Using the water balance approach it is possible to make a quantitative evaluation of water resources and to assess any changes that might occur through the influence of man's activity. The study of the water balance structure of regulated river basins permits the rational use, control and redistribution of water resources in time and space. Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes and groundwater.

Current information on the water balance of river basins for short time intervals - a season, month, week or day- is used for operational management of reservoirs and for the compilation of hydrological forecasts for water management. An understanding of the water balance is also extremely important for studies of the hydrological cycle. With water balance data it is possible to compare individual sources of water in a system, over different periods of time and to establish the extent of their effect on variations in the water regime. Water balance studies can also provide an indirect evaluation of any unknown water balance components. For example, long-term evaporation from a river basin may be computed by the difference between precipitation and runoff.

Ponce and Shetty (1995) have developed a conceptual model of annual water balance suitable for application to a wide range of climatic conditions. The model separates annual precipitation into its three major components: surface runoff, baseflow and vaporization. In this paper, the model is applied to the Sarada river basin, in the State of Andhra Pradesh, India. The basin has a total area of 2,590 km^2, it features a spatial mix of semiarid and subhumid climatic conditions, and drains to the Bay of Bengal, in the Indian Ocean.

2.0 REVIEW OF THE CONCEPTUAL CATCHMENT WATER BALANCE MODEL

The conceptual catchment water balance model separates annual precipitation into two components (Ponce and Shetty, 1995):

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

in which P = annual precipitation, S = Surface runoff, defined as the fraction of runoff originating on the land surface, and W = Catchment wetting, defined as the fraction of precipitation which does not contribute to surface runoff. In turn, wetting is separated into two components:

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

in which U = baseflow, defined as 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 vapor (Lee, 1970). The term vaporization encompasses all moisture returned to the atmosphere by evaporation, i.e., evapotranspiration from vegetated areas, evaporation from nonvegetated areas and evaporation from water bodies. Deep percolation, the portion of wetting not contributing to either baseflow or vaporization, is a very small fraction of precipitation, and is neglected here on practical grounds (L'vovich, 1979). The systematic diagram of conceptual catchment water balance model is shown in Fig 1. In which

E = evaporation

T = evapotranspiration

E_n = evaporation from non vegetated areas of the earth surface

E_w = evaporation from sizable bodies

Runoff consists of surface runoff and baseflow :

$$R = S + U \qquad (3)$$

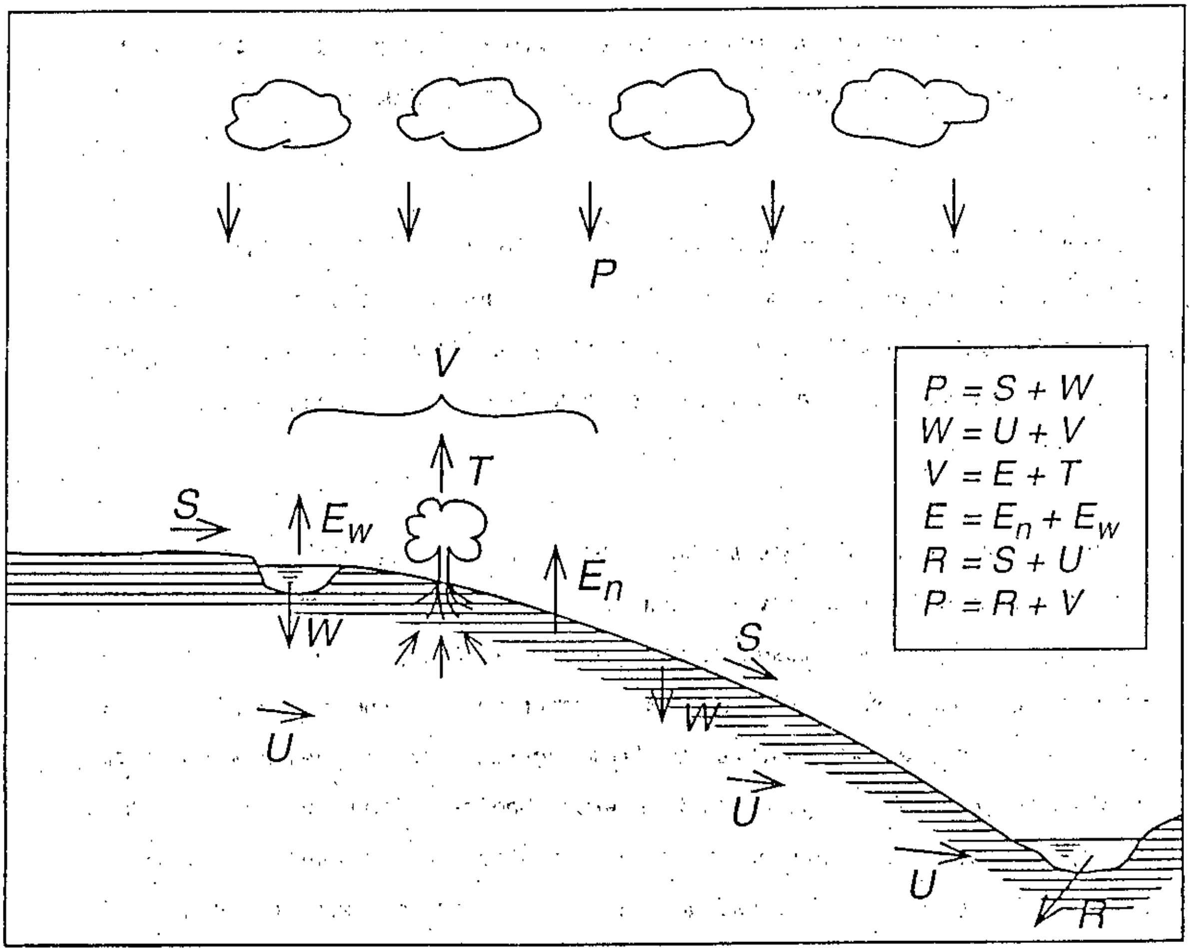


FIG. 1 Systamatic diagram of Conceptual catchment water balance model

Precipitation consists of runoff and vaporization :

$$P = R + V \tag{4}$$

Combining Eqs. 3 and 4

$$P = S + U + V \tag{5}$$

Equations 1 to 4 constitute a set of water balance equations. Equation 5 separates annual precipitation into its three major components: surface runoff, baseflow and vaporization. This equation assumes that the annual change in soil moisture storage is negligible, and assumption which is useful as a first approximation.

The runoff coefficient is :

$$K_r = \frac{R}{P} \tag{6}$$

The runoff gain is :

$$K_r = \frac{dK_r}{dP} \tag{7}$$

The baseflow coefficient is :

$$K_u = \frac{U}{W} \tag{8}$$

The baseflow gain is :

$$K'_u = \frac{dk_u}{dP} \tag{9}$$

L'Vovich (1979) has shown that Eq.1 can be modeled by a proportional relation such that wetting asymptotically reaches an upper bound ($W \rightarrow W_p$) as precipitation increase unbounded ($P \rightarrow \infty$).Likewise, Eq.2 can be modeled by the same type of relation, i.e. one where vaporization asymptotically reaches an upper bound ($V \rightarrow V_p$) as wetting increases unbounded ($W \rightarrow \infty$). In this way, the sequential two-step separation of annual precipitation into its three major components, surface runoff, baseflow, and vaporization, is accomplished.

Ponce and Shetty (1995) have used this proportional concept to formulate the equations of their water balance model. The surface runoff submodel is :

$$S = \frac{(P - \lambda_s W_p)^2}{P + (1 - 2\lambda_s) W_p}$$

subject to $P > \lambda_s W_p$ and $S = 0$ otherwise, with λ_s= surface-runoff initial abstraction ratio (dimensionless), and W_p= Wetting potential, in cm or mm.

The baseflow submodel is :

$$U = \frac{(W - \lambda_u V_p)^2}{W + (1 - 2\lambda_u) V_p}$$

subject to $W > \lambda_u V_p$; and $U=0$ otherwise, with λ_u =baseflow initial abstraction ratio (dimensionless) and V_p= vaporization potential in cm or mm

Thus, given annual precipitation and a set of initial abstraction coefficients λ_s and λ_u , and potentials W_p and V_p, Eqs.10 to 11 (together with Eq.1) are used to separate annual precipitation into surface runoff, baseflow,and vaporization. Then, runoff is calculated using Eq.3, and runoff and baseflow coefficients are calculated using Eqs. 6 and 8, respectively.

The procedure is repeated for a realistic range of annual precipitation, leading to a set of runoff and baseflow functions (runoff and baseflow coefficients vs annual precipitation). Then, runoff and baseflow gains are calculated using Eqs. 7 and 9 respectively.The generic form of the proportional relation of surface runoff submodel and baseflow submodel is expressed as:

$$Y = \frac{(X - \lambda Z_p)^2}{X + (1-2\lambda) Z_p}$$

in which X = independent variable

Y = dependent variable

λ = initial abstraction coefficient

Z_p = potential value of the difference $Z = X-Y$

The model separates annual precipitation into its three major components: Surface runoff, baseflow, and vaporization. It is based on a two step sequential application of a proportional relation linking two variables X and Y, such that the difference Z = X-Y asymptotically reaches an upper bound as X and Y grow unbounded. The proportional relation is shown in Fig. 2.

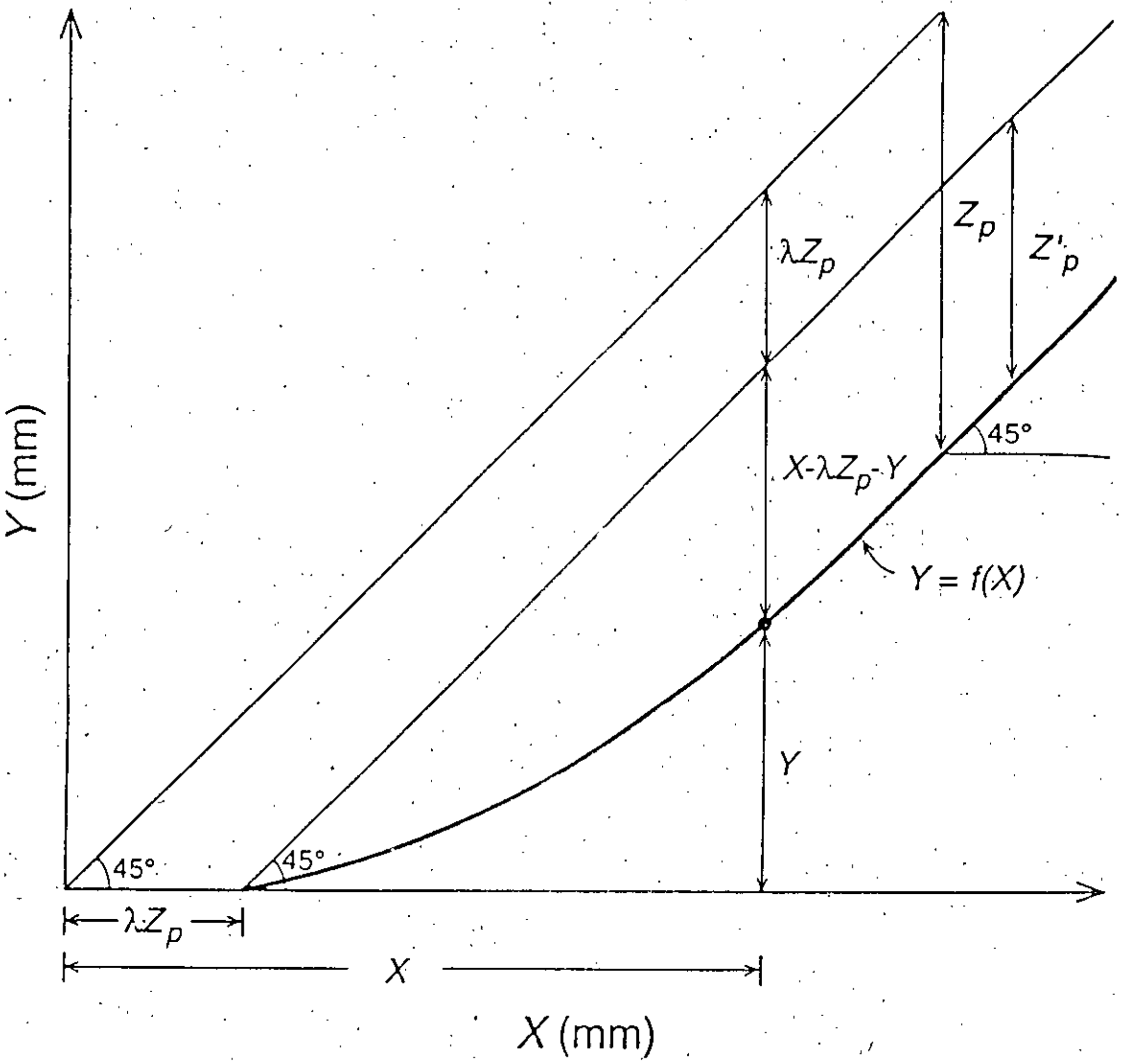


FIG. 2 Generic relation of surface runoff model and baseflow model

3.0 THE SARADA RIVER BASIN

The Sarada river basin is comprised within latitudes 17°25 to 18°15 N and longitudes 82°32 to 83°08 E (Fig.3). The total catchment area is 2,590 km^2. The catchment is positioned between the Eastern Ghats and the eastern coastline of India, with its mouth on the Bay of Bengal, on the Indian Ocean. The basin headwaters are at Anantagiri Hills, Vishakapatnam district, Andhra Pradesh state, at an altitude of 1,448 m. The Sarada river main stem flows in a predominantly north-south direction for about 140 km to reach Anakapalli, where there is a gaging station. From Anakapalli, the river flows first southwest and then south for about 60 km to reach its mouth on the Bay of Bengal (Fig.3). The principal tributaries of the Sarada river are: Bodderu, Tacheru, Paderu, Chintala Gedda, and Vedurla Gedda. The river and its tributaries are intermittent, and subject to occasional floods. The portion of the basin upstream of Anakapalli, with a catchment area of 1,980 km^2, has been considered in this study. Topographically the basin can be divided into mountains, hills and ridges and plains. The northern and northeastern parts of the basin have mountains with a maximum relief of 1620 mts. Down south the hills and ridges are at an altitudinal range of 150 to 600 mts.

3.1 Geology

The Sarada river basin presents a metamorphic succession of rocks belonging to the Khondalite suite of rocks. The arenaceous, argillaceous, calcareous and manganiferous members of the khondalite series are gradations in the sedimentary rocks which have later undergone regional metamorphism of high grade. Structurally the rock formations trend in a general NE-SW direction dipping south east with deviations in strike towards NNW- SSE, N-S and NNE-SSW. The foliation observed in these is analogous to the gneissic structure of the high grade metamorphic rocks. The eastern ghats have in general, multiple field structures with extensive faulting and consequent

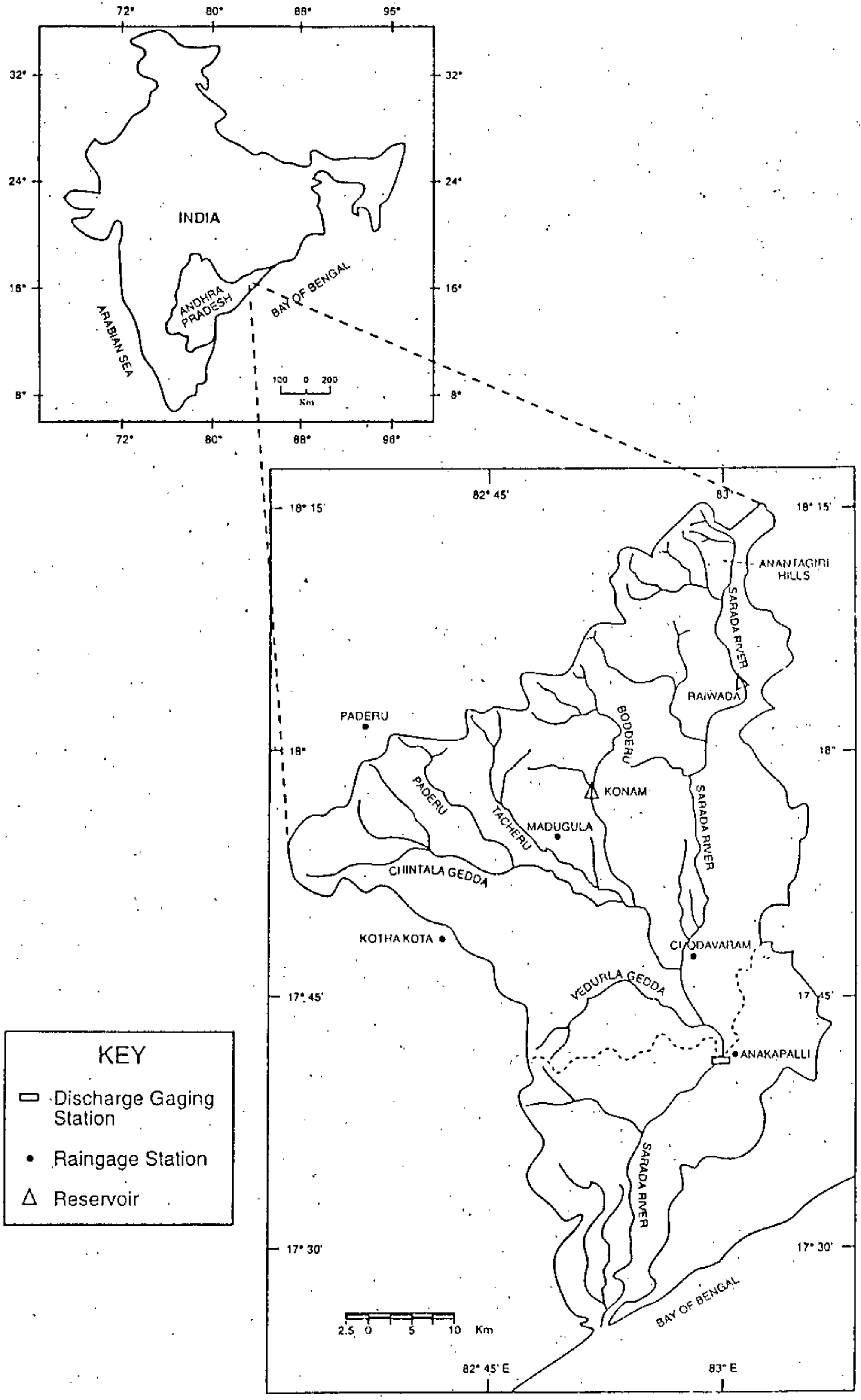


FIG. 3 Geographical location of Sarada river basin

development of fracture patterns. The geology of the basin is characterized by khondalite rocks (65 percent), granite gneiss (20 percent), charnockites (10 percent), and quartzites (5 percent) (CBI & P, 1986).

3.2 Soils

The soils are of four types (IARI, 1970): (1) sandy soils, (2) loamy soils, (3) clay loamy soils, and (4) clayey soils. Residual soils are of common occurrence on the hills whereas transported soils are present in the plains. Sandy soils characterise quartzitic terrains while clayey soils are on charnockite and gneissic regions. The sandy soils are usually brick red in colour. The clayey soils have a colour which ranges from black to grey.

3.3 Climate

The basin has two types of climate : (1) subhumid in the Upper reaches, close to the mountain range, and (2) semiarid in the lower reaches, including the alluvial valleys and near-coastal regions. The average climate of the year is characterised by four distinct seasons.

They are:

1. Winter season (December to February)
2. Hot weather season (March to May)
3. South west monsoon season (June to September)
4. Post monsoon season (October and November)

May is the hottest month with a mean monthly maximum temperature of 36.9^{o} C and mean monthly minimum temperature of 17.5^{o} C at Anakapalli. The air is generally humid throughout the year in the coastal parts of the basin. But at the upstream of river the humidity is less than in the coastal parts, especially during the summer season. The evaporation varies from 3.2 mm (January) to 7.9mm (April). The maximum evaporation has been recorded during the month of April. From May onwards evaporation gradually decreases with the onset of monsoon.The basin is subject to the southwest monsoon, with 90 percent of annual precipitation occurring during the monsoon season (June to November). During the month of May the basin received about 6% of the average annual rainfall due to summer showers. The balance amount of rainfall was received during the period ranging from Feb to April.

3.4 Geomorphology

The geomorphology of the Sarada river basin is studied from aerial photographs with supporting ground information (Prudviraj and Vaidyanadham, 1981). The following geomorphic features have been identified in the basin, they are, paleo-channels, flood plain, pediment fans, tidal flats, residual hills, creep build plains, wash plains, river terraces and sediments.

River built plains/ flood plains are the constructional land forms resulting from the fluvial deposition. The river built plain/flood plains are the two features which are recorded in the basin. The plain which occupies a large portion of the basin on both sides of the Sarada river as well as its tributaries in built plain. An extensive network of abandoned (buried) channels in the plain suggests intensive fluvial action and extensive meandering of the river. So these alluvial deposits making up the plain are due to the essentially migrating meander belts.

3.5 Runoff - Land use/Cover

Runoff computations for the Sarada river basin show that most of the runoff is produced by the Upper sub basin, which consists of dense forest with steep gradients (Subbaramayya et al, 1979). For the year 1983-84, the land use was the following : (1) forest land, 25.3 percent; (2) cropland (rice, jowar, sugar cane, etc.), 42.6 percent, (3) plantations (banana, cashew, etc.), 1.6 percent; (2) barren land, including non agricultural lands, 21.7 percent, and (5) fallow land, 8.8 percent (CBI&P, 1986).

The distribution of land cover over the Sarada river basin was determined from satellite imagery by the(Y.R.S.RAO, 1992). The upper reaches are hilly and covered with dense forests. The middle reaches and flood plains are covered with cropland. Fallow land ,rock outcroppings are scattered throughout the basin. The Raiwada and Konam reservoirs located in the upper reaches exercise some control over the basin's runoff.

4.0 MODEL APPLICATION

Rainfall-runoff records for the 1981-86 period is used to apply the conceptual water balance model. Daily rainfall data at Anakapalli, Chodavaram, Kothakota, Madugula, and Paderu stations (Fig. 3) were used to calculate annual precipitation at each station (Table 1), from which the spatially-averaged annual precipitation (P) was calculated using the Thiessen polygon method. The variation of rainfall is found to be very much significant in the study area. The mean annual rainfall during the study period is found to be between 77 cm and 121.1 cm (Table 2). Daily discharge data at Anakapalli station were used to calculate the annual runoff (R) in cm. Yearly runoff has been calculated by integrating the daily hydrograph over a year. The daily hydrograph is drawn for the year 1986 at Anakapalli gauging station is shown in Fig 4. Annual runoff was separated into surface runoff (S) and baseflow (U) using an appropriate baseflow separation procedure. The baseflow separation line has been drawn as shown in Fig.4. Equation 2 was used to calculate catchment wetting (W), and Eq.4 was used to calculate vaporization (V). These values are shown in Table 2.

4.1 Model Parameters

The calibration procedure sought to minimize the root mean square (RMS) of the difference between calculated and measured values of surface runoff (Eq.10) and baseflow (Eq.11). For this purpose, λ_s was varied at 0.01 intervals in the range $0 \leq \lambda_s \leq 1$ and W_p was varied at 1 cm intervals in the range $0 \leq W_p \leq 1200$cm. The selected surface-runoff submodel parameters (λ_s,W_p) were those corresponding to the minimum root mean square of the differences between calculated (Eq.10) and measured surface runoff (Table 2). Likewise, was varied at 0.01 intervals in the range 1, and V_p was varied at 1 cm intervals in the range $0 \leq V_p \leq 1200$cm. The selected baseflow submodel parameters (λ_u,V_p) were those corresponding to the minimum root mean square

FIG.4 DAILY HYDROGRAPH YEAR 1986

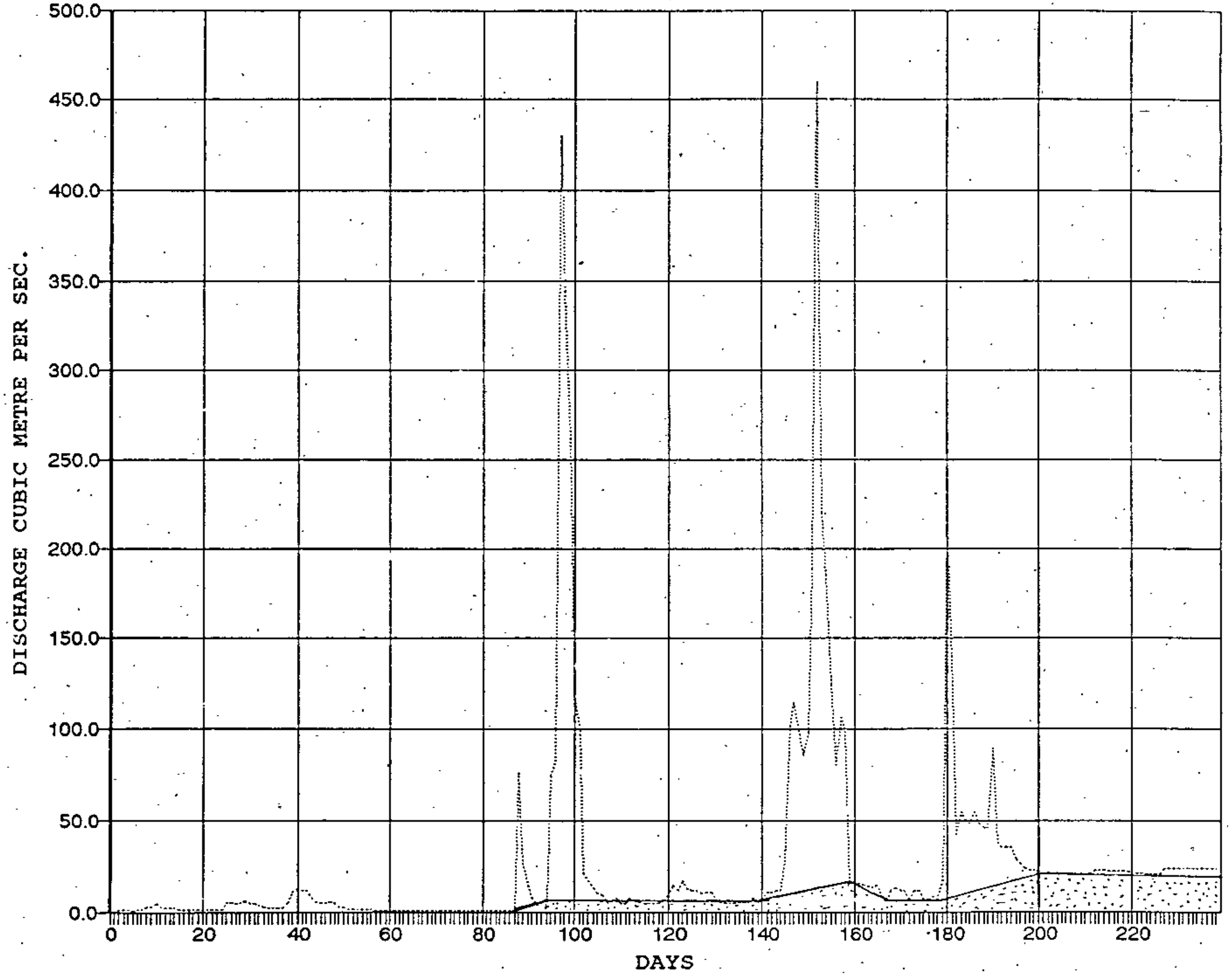


Table 1. Sarada River Basin: Annual precipitation at gaging stations.

Year	Anakapalli	Chodavaram	Kothakota	Madugula	Paderu
Thiessen weighting factor	0.049	0.288	0.198	0.375	0.090
1981	70.2	79.3	82.7	104.9	111.6
1982	96.6	100.9	83.5	106.9	124.3
1983	132.8	126.4	100.0	128.2	158.8
1984	79.4	71.8	55.0	85.5	105.0
1985	98.9	90.0	76.1	98.5	97.3
1986	130.5	135.0	78.0	134.7	136.5

All units are in cm yr^{-1}.

Table 2. Sarada River Basin: Observed water balance data set.

Year	Precipitation	Surface Runoff	Wetting	Baseflow	Vaporization	Runoff
1981	92.0	6.1	85.9	2.6	83.3	8.7
1982	101.6	9.6	92.0	4.5	87.51	4.1
1983	125.1	26.6	98.5	11.1	87.43	7.7
1984	77.0	5.0	72.0	2.1	69.9	7.1
1985	91.5	5.3	86.2	1.6	84.6	6.9
1986	123.5	19.9	103.6	8.2	95.4	28.1

All units are in cm yr^{-1}.

of the differences between calculated (Eq.11) and measured baseflow (Table 2). The high upper limit on W_p and V_p (1,200 cm) was necessary to guarantee attainment of the stated objective (minimum RMS). The computer programme has been developed to attain minimum RMS value to find the corresponding (λ_s, W_p) and (λ_u, V_p) values. The programme and its results are given in Annexure I.

4.2 Methodology

The methodology is as follows:

1. Use the root mean square minimization procedure to calculate λ_s and W_p.
2. Use the root mean square minimization procedure to calculate λ_u and V_p.
3. Use Eq.10 to calculate a set of surface runoff values corresponding to precipitation values in the range $1 \leq P \leq 200$cm, at 1-cm intervals.
4. Use Eq.11 to calculate a set of baseflow values corresponding to wetting values in the range $1 \leq W \leq 200$ cm, at 1-cm intervals.
5. Use Eq.1 and the S-P data calculated in step 3 to determine a set of corresponding wetting (W) values.
6. Use Eq.11 with the wetting values calculated in step 5 to determine a set of corresponding baseflow (U) values.
7. Use Eq.3 to calculate a set of corresponding runoff R values, based on S values (step 3) and U values (step 6).
8. Use Eq.6 to calculate a set of runoff coefficients K_r , based on corresponding runoff (step 7) and precipitation (step 3) values.
9. Use Eq.8 to calculate a set of baseflow coefficients K_u, based on corresponding baseflow (step 6) and wetting (step 5) values.
10. Use Eq.7 to calculate a set of runoff gains K_r, based on the runoff coefficients vs precipitation relation developed in step 8.
11. Use Eq.9 to calculate a set of baseflow gains K_u, based on the baseflow coefficients vs precipitation relation developed in step 9.

The calibrated model parameters are $\lambda_s = 0.36$ and $W_p = 171$ cm, with $RMS_{min} = 2.205$ cm; $\lambda_u = 0.39$ and $V_p = 170$ cm, with $RMS_{min} = 1.896$ cm. The fitted P-S and W-U relations are shown in Fig.5. The runoff and baseflow coefficient functions are shown in Fig.6. The runoff and baseflow gain functions are shown in Fig.7.

The mean annual precipitation for the study period (1981-86) is $P_a = 102$ cm. From Fig. 7 the runoff threshold precipitation is $P_{rt} = 94$ cm; the peak runoff gain is $K'_p = 0.005 \text{ cm}^{-1}$; the baseflow threshold precipitation is $P_{ut} = 92$ cm; and the peak baseflow gain is $K'_{up} = 0.0018 \text{ cm}^{-1}$. Thus, the ratio $P_{rt}/P_a = 0.92$, and the ratio $P_{ut}/P_a = 0.90$.

Table 3 shows a comparison of the Sarada basin calibration with those obtained earlier by Ponce and Shetty (1995) for a semiarid and a subhumid basin in Africa. It is seen that the Sarada basin parameters depict a predominantly semiarid region, although somewhat affected by its subhumid portion. Thus, the study results confirm that the conceptual water balance model can characterize the runoff and baseflow regimes in a wide range of geographical regions.

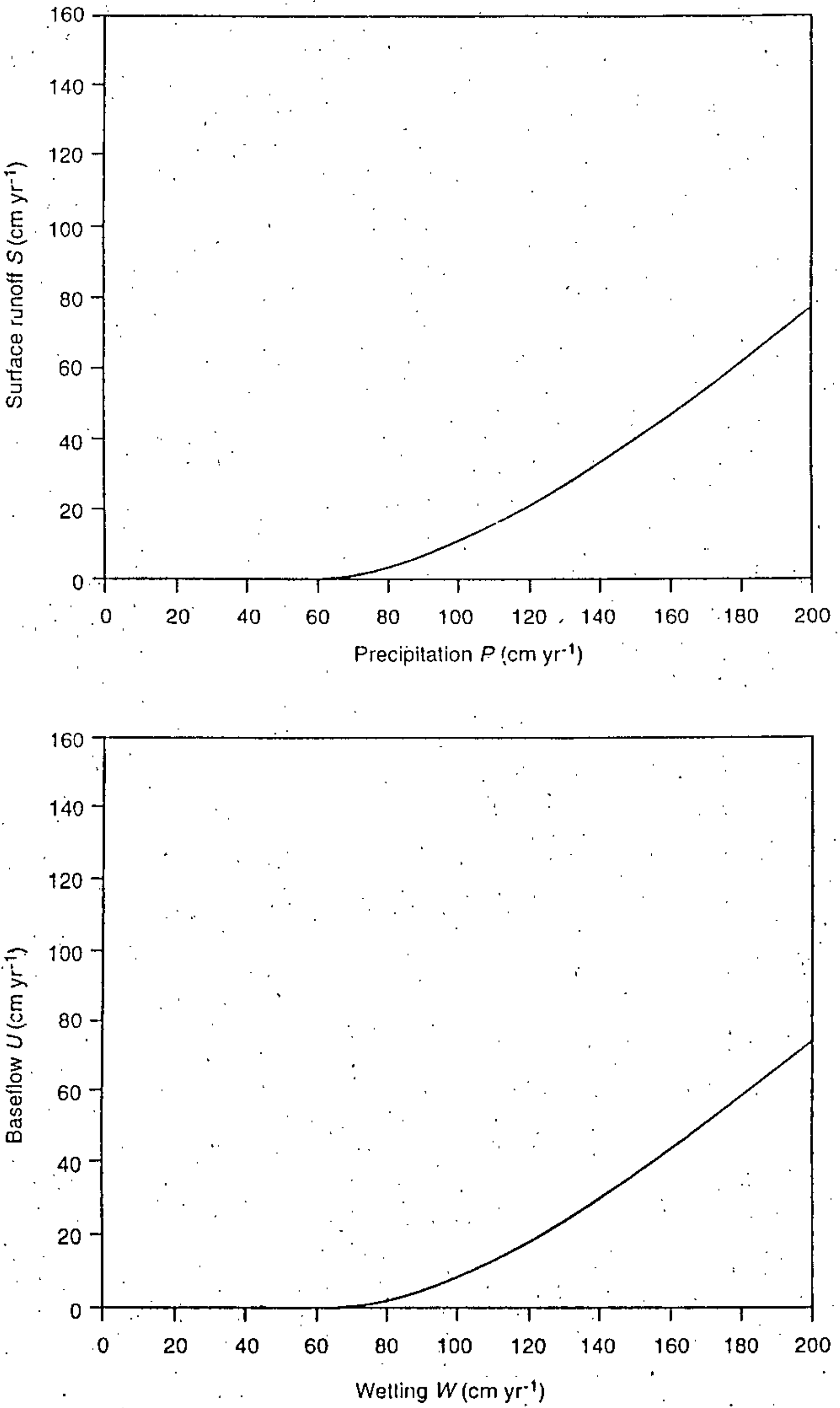
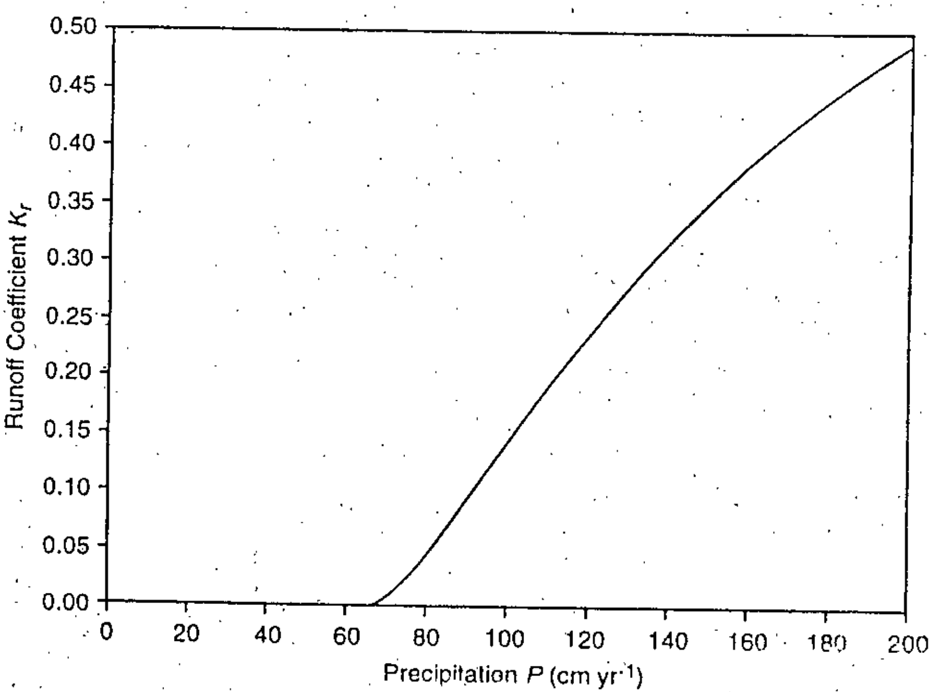


FIG. 5 Precipitation-Surface runoff and wetting-baseflow relations for Sarada river basin



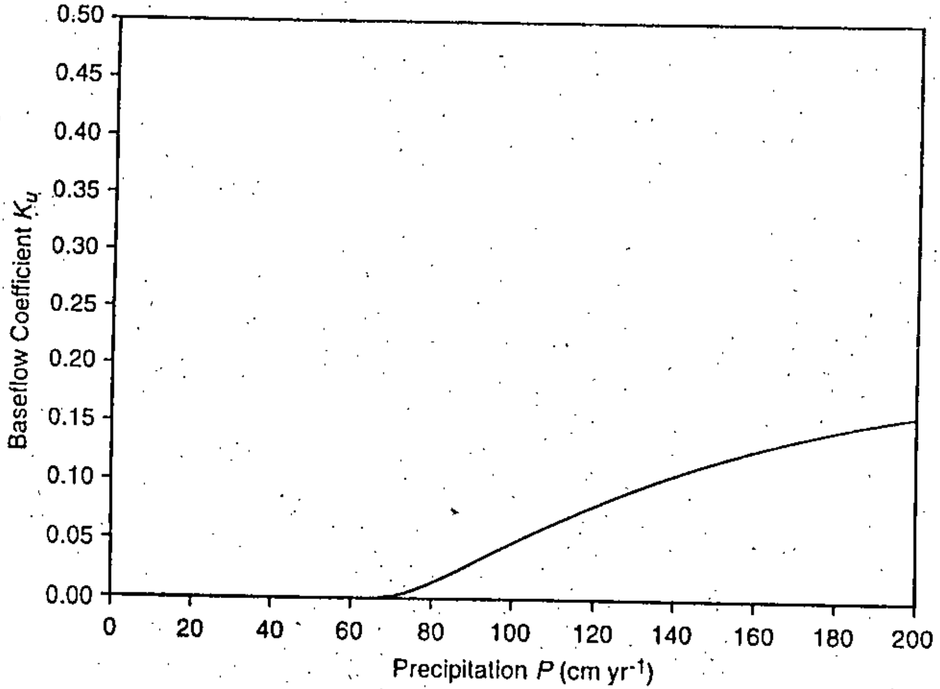


FIG. 6 Runoff and baseflow coefficient functions for Sarada river basin

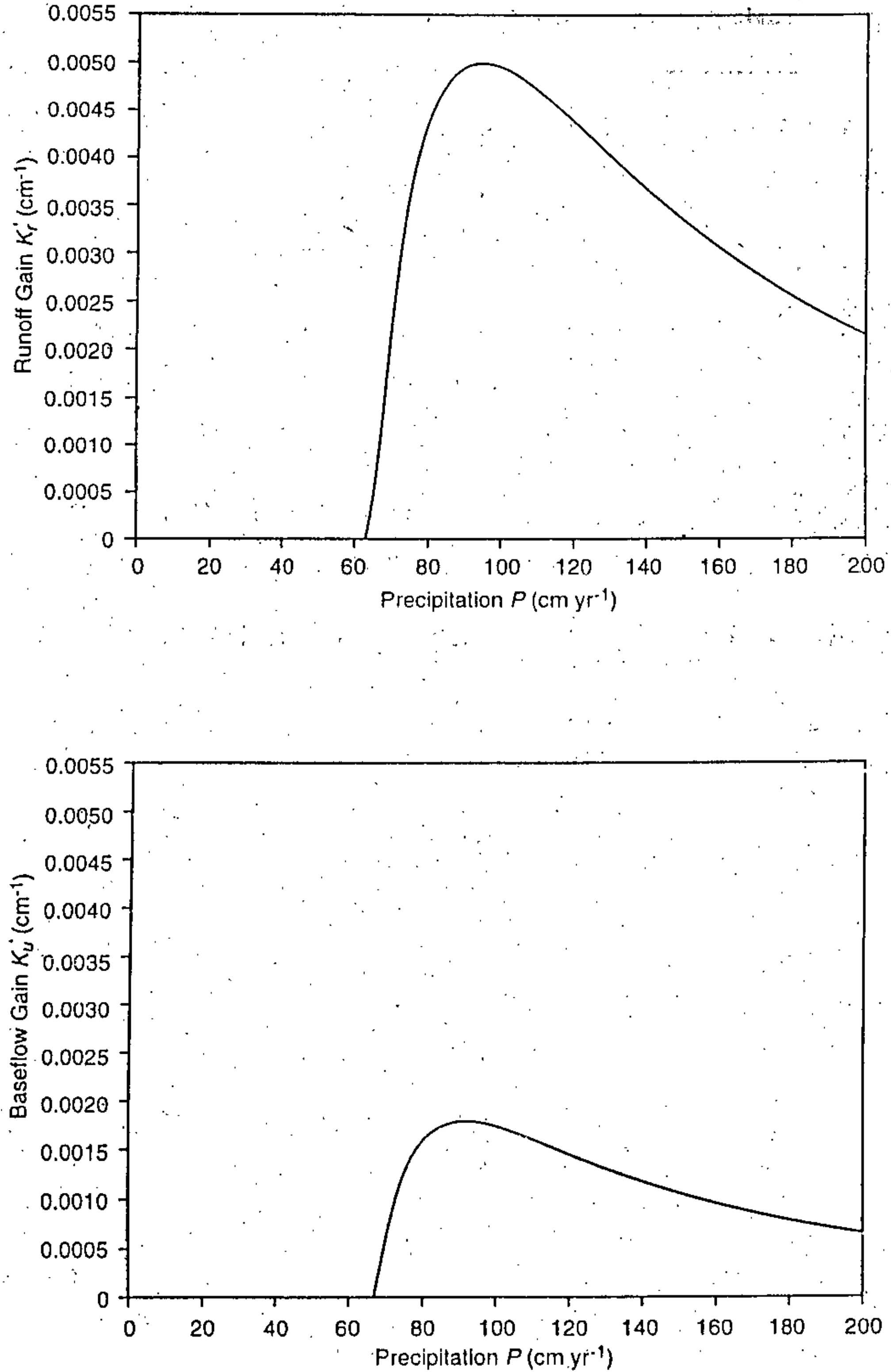


FIG. 7 Runoff and baseflow gain functions for Sarada river basin

Table 3. Comparison of model parameters of Sarada river basin with other semiarid and subhumid basins.

Basin(climate)	P_a (cm)	λ_s	W_p (cm)	P_{rt} (cm)	P_{rt}/P_a	K'_{rp} (cm^{-1})
Sarada (India) (semiarid/ subhumid)	102	0.39	170	92.0	0.90	0.00180
Africa (semiarid)	75	0.37	140	82.5	1.10	0.00186
Africa (subhumid)	75	0.35	90	57.5	0.77	0.00142

[1] Values for African basins were obtained from Ponce and Shetty (1995).

5.0 CONCLUSIONS

The conceptual water balance model has been applied to 1,980 km2 of the Sarada river basin, in Andhra Pradesh, India. The water balance components have been estimated for the period of six years(1981-86). The basin has both subhumid and semiarid conditions, and a mix of land use ranging from forest, agricultural, plantation, fallow, and barren land. The calibrated model parameters are :$\lambda_s = 0.36$; W_p=171 cm;$\lambda_u = 0.39$; and $V_p = 170$ cm. The peak runoff gain is $K'_{rp} = 0.005\ cm^{-1}$; the peak baseflow gain is $K'_{up} = 0.0018\ cm^{-1}$. The ratio $P_{rt}/P_a = 0.92$; the ratio $P_{ut}/P_a = 0.90$. These values are comparable to those obtained previously for semiarid and subhumid climatic conditions in Africa. This confirms the applicability of the conceptual water balance model to a wide range of geographical regions.

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ANNEXURE I

```
C-----THIS PROGRAM COMPUTES RMS VALUES FOR FITTING RETENTION CURVE NUMBERS
C-----DEVELOPED FEBRUARY 8, 1995
      PARAMETER (NX=100,NZ=1000,NV=6)
      DOUBLE PRECISION Z(NZ),X(NV),Y(NV)
      DOUBLE PRECISION YC(NZ,NV),RMS(NZ)
      DOUBLE PRECISION XNUM,XDEN
      CHARACTER*60 ID
      OPEN(5,FILE='SYS96.DAT',STATUS='UNKNOWN')
      OPEN(7,FILE='SYS96.OUT',STATUS='UNKNOWN')
      READ(5,*) ID,N
      DO 10 J=1,N
      READ(5,*) LDUMMY,X(J),Y(J)
   10 ENDDO
      RMSMIN= 1000000.
      DO 40 K= 1,NX
      XLAMBDA= K*0.01
      RMSMINJ= 1000000.
      DO 30 J= 1,NZ
      SUM= 0.
      Z(J)= FLOAT(J)
      DO 20 L= 1,N
      XNUM= (X(L) - XLAMBDA*Z(J))**2
      XDEN= X(L) + (1. - 2.*XLAMBDA)*Z(J)
      IF(XNUM.LE.0.OR.XDEN.LE.0.) THEN
      YC(J,L)= 0.
      ELSE
      YC(J,L)= XNUM/XDEN
      ENDIF
      DIFFSQ= (YC(J,L) - Y(L))**2
      SUM= SUM + DIFFSQ
   20 ENDDO
      RMS(J)= SQRT(SUM/N)
      IF(RMS(J).LT.RMSMINJ) THEN
      RMSMINJ= RMS(J)
      ZOUTJ= FLOAT(J)
      XLAMBDAOUTJ= XLAMBDA
      ENDIF
      IF(RMS(J).LT.RMSMIN) THEN
      RMSMIN= RMS(J)
      ZOUT= FLOAT(J)
      XLAMBDAOUT= XLAMBDA
      ENDIF
   30 ENDDO
      WRITE(6,'(1X,F10.2,I10,F10.3,F10.2,I10,F10.3)') XLAMBDA,
     1INT(ZOUTJ),RMSMINJ,XLAMBDAOUT,INT(ZOUT),RMSMIN
      WRITE(7,'(1X,F10.2,I10,F10.3,F10.2,I10,F10.3)') XLAMBDA,
     1INT(ZOUTJ),RMSMINJ,XLAMBDAOUT,INT(ZOUT),RMSMIN
   40 ENDDO
      WRITE(6,'(1X,A)')        'TEST:                    ',ID
      WRITE(6,'(1X,A,F8.2)')   'LAMBDA=                  ',XLAMBDAOUT
      WRITE(6,'(1X,A,I5,A)')   'Z POTENTIAL=             ',INT(ZOUT),' CM'
      WRITE(6,'(1X,A,F8.3)')   'RMSMIN=                  ',RMSMIN
      WRITE(7,'(1X,A)')        'TEST:                    ',ID
      WRITE(7,'(1X,A,F8.2)')   'LAMBDA=                  ',XLAMBDAOUT
      WRITE(7,'(1X,A,I5,A)')   'Z POTENTIAL=             ',INT(ZOUT),' CM'
      WRITE(7,'(1X,A,F8.3)')   'RMSMIN=                  ',RMSMIN
      END
```

```
'SARADA P-S FIT' 6
01 92.0 6.1
02 101.6 9.6
03 125.1 26.6
04 77.0 5.0
05 91.5 5.3
06 123.5 19.9
```

0.01	625	4.396	0.01	625	4.396
0.02	566	4.221	0.02	566	4.221
0.03	519	4.064	0.03	519	4.064
0.04	481	3.921	0.04	481	3.921
0.05	449	3.791	0.05	449	3.791
0.06	421	3.669	0.06	421	3.669
0.07	398	3.557	0.07	398	3.557
0.08	377	3.451	0.08	377	3.451
0.09	359	3.353	0.09	359	3.353
0.10	342	3.260	0.10	342	3.260
0.11	328	3.172	0.11	328	3.172
0.12	315	3.090	0.12	315	3.090
0.13	303	3.012	0.13	303	3.012
0.14	292	2.939	0.14	292	2.939
0.15	281	2.869	0.15	281	2.869
0.16	272	2.804	0.16	272	2.804
0.17	264	2.742	0.17	264	2.742
0.18	256	2.685	0.18	256	2.685
0.19	248	2.630	0.19	248	2.630
0.20	241	2.579	0.20	241	2.579
0.21	235	2.532	0.21	235	2.532
0.22	229	2.488	0.22	229	2.488
0.23	223	2.447	0.23	223	2.447
0.24	218	2.410	0.24	218	2.410
0.25	213	2.376	0.25	213	2.376
0.26	208	2.345	0.26	208	2.345
0.27	203	2.317	0.27	203	2.317
0.28	199	2.292	0.28	199	2.292
0.29	195	2.271	0.29	195	2.271
0.30	191	2.253	0.30	191	2.253
0.31	187	2.237	0.31	187	2.237
0.32	184	2.226	0.32	184	2.226
0.33	180	2.216	0.33	180	2.216
0.34	177	2.209	0.34	177	2.209
0.35	174	2.206	0.35	174	2.206
0.36	171	2.205	0.36	171	2.205
0.37	168	2.208	0.36	171	2.205
0.38	165	2.214	0.36	171	2.205
0.39	163	2.221	0.36	171	2.205
0.40	160	2.231	0.36	171	2.205
0.41	158	2.243	0.36	171	2.205
0.42	156	2.261	0.36	171	2.205
0.43	153	2.275	0.36	171	2.205
0.44	151	2.294	0.36	171	2.205
0.45	149	2.315	0.36	171	2.205
0.46	147	2.338	0.36	171	2.205
0.47	145	2.363	0.36	171	2.205
0.48	143	2.391	0.36	171	2.205
0.49	141	2.421	0.36	171	2.205
0.50	140	2.450	0.36	171	2.205
0.51	138	2.480	0.36	171	2.205
0.52	136	2.515	0.36	171	2.205
0.53	135	2.547	0.36	171	2.205
0.54	133	2.582	0.36	171	2.205
0.55	132	2.618	0.36	171	2.205
0.56	130	2.656	0.36	171	2.205
0.57	129	2.690	0.36	171	2.205
0.58	128	2.731	0.36	171	2.205
0.59	126	2.769	0.36	171	2.205
0.60	125	2.804	0.36	171	2.205
0.61	124	2.842	0.36	171	2.205
0.62	123	2.882	0.36	171	2.205
0.63	122	2.921	0.36	171	2.205
0.64	121	2.959	0.36	171	2.205
0.65	119	2.994	0.36	171	2.205
0.66	118	3.027	0.36	171	2.205

```
     0.67        117      3.060       0.36        171      2.205
     0.68        117      3.088       0.36        171      2.205
     0.69        116      3.112       0.36        171      2.205
     0.70        115      3.133       0.36        171      2.205
     0.71        114      3.150       0.36        171      2.205
     0.72        113      3.164       0.36        171      2.205
     0.73        112      3.175       0.36        171      2.205
     0.74        112      3.182       0.36        171      2.205
     0.75        111      3.176       0.36        171      2.205
     0.76        110      3.170       0.36        171      2.205
     0.77        109      3.167       0.36        171      2.205
     0.78        108      3.172       0.36        171      2.205
     0.79        107      3.192       0.36        171      2.205
     0.80        106      3.238       0.36        171      2.205
     0.81        105      3.325       0.36        171      2.205
     0.82        104      3.478       0.36        171      2.205
     0.83        102      3.664       0.36        171      2.205
     0.84        101      3.918       0.36        171      2.205
     0.85         99      4.271       0.36        171      2.205
     0.86         98      4.633       0.36        171      2.205
     0.87        105      4.668       0.36        171      2.205
     0.88        102      4.508       0.36        171      2.205
     0.89        101      4.580       0.36        171      2.205
     0.90        106      4.660       0.36        171      2.205
     0.91        106      4.412       0.36        171      2.205
     0.92        104      4.143       0.36        171      2.205
     0.93        103      3.927       0.36        171      2.205
     0.94        101      3.866       0.36        171      2.205
     0.95        100      3.861       0.36        171      2.205
     0.96         98      4.051       0.36        171      2.205
     0.97         96      4.902       0.36        171      2.205
     0.98         95      5.040       0.36        171      2.205
     0.99         98      5.104       0.36        171      2.205
     1.00         98      5.130       0.36        171      2.205
TEST:
SARADA P-S FIT
LAMBDA=                 0.36
Z POTENTIAL=          171 CM
RMSMIN=                2.205
```

```
'SARADA W-U FIT' 6
1 85.9 2.6
2 92.0 4.5
3 98.4 11.1
4 72.0 2.1
5 86.2 1.6
6 103.6 8.2
```

0.01	1107	2.587	0.01	1107	2.587
0.02	920	2.514	0.02	920	2.514
0.03	793	2.453	0.03	793	2.453
0.04	701	2.401	0.04	701	2.401
0.05	631	2.355	0.05	631	2.355
0.06	575	2.314	0.06	575	2.314
0.07	529	2.278	0.07	529	2.278
0.08	490	2.244	0.08	490	2.244
0.09	458	2.214	0.09	458	2.214
0.10	430	2.186	0.10	430	2.186
0.11	405	2.160	0.11	405	2.160
0.12	384	2.136	0.12	384	2.136
0.13	365	2.114	0.13	365	2.114
0.14	348	2.094	0.14	348	2.094
0.15	332	2.075	0.15	332	2.075
0.16	319	2.058	0.16	319	2.058
0.17	306	2.042	0.17	306	2.042
0.18	294	2.027	0.18	294	2.027
0.19	284	2.013	0.19	284	2.013
0.20	274	2.000	0.20	274	2.000
0.21	265	1.988	0.21	265	1.988
0.22	256	1.977	0.22	256	1.977
0.23	248	1.967	0.23	248	1.967
0.24	241	1.957	0.24	241	1.957
0.25	234	1.949	0.25	234	1.949
0.26	228	1.941	0.26	228	1.941
0.27	222	1.934	0.27	222	1.934
0.28	216	1.928	0.28	216	1.928
0.29	211	1.923	0.29	211	1.923
0.30	206	1.918	0.30	206	1.918
0.31	201	1.913	0.31	201	1.913
0.32	196	1.909	0.32	196	1.909
0.33	192	1.906	0.33	192	1.906
0.34	188	1.903	0.34	188	1.903
0.35	184	1.901	0.35	184	1.901
0.36	180	1.899	0.36	180	1.899
0.37	177	1.899	0.37	177	1.899
0.38	173	1.897	0.38	173	1.897
0.39	170	1.896	0.39	170	1.896
0.40	167	1.896	0.39	170	1.896
0.41	164	1.896	0.39	170	1.896
0.42	161	1.897	0.39	170	1.896
0.43	158	1.898	0.39	170	1.896
0.44	156	1.900	0.39	170	1.896
0.45	153	1.900	0.39	170	1.896
0.46	151	1.903	0.39	170	1.896
0.47	148	1.903	0.39	170	1.896
0.48	146	1.905	0.39	170	1.896
0.49	144	1.907	0.39	170	1.896
0.50	142	1.910	0.39	170	1.896
0.51	140	1.912	0.39	170	1.896
0.52	138	1.914	0.39	170	1.896
0.53	136	1.915	0.39	170	1.896
0.54	134	1.916	0.39	170	1.896
0.55	132	1.918	0.39	170	1.896
0.56	131	1.923	0.39	170	1.896
0.57	129	1.920	0.39	170	1.896
0.58	127	1.921	0.39	170	1.896
0.59	126	1.922	0.39	170	1.896
0.60	124	1.921	0.39	170	1.896
0.61	123	1.921	0.39	170	1.896
0.62	121	1.921	0.39	170	1.896
0.63	120	1.917	0.39	170	1.896
0.64	119	1.918	0.39	170	1.896
0.65	117	1.914	0.39	170	1.896
0.66	116	1.909	0.39	170	1.896

```
          0.67         115       1.907        0.39         170        1.896
          0.68         114       1.909        0.39         170        1.896
          0.69         112       1.905        0.39         170        1.896
          0.70         111       1.901        0.39         170        1.896
          0.71         110       1.902        0.39         170        1.896
          0.72         109       1.910        0.39         170        1.896
          0.73         108       1.927        0.39         170        1.896
          0.74         106       1.955        0.39         170        1.896
          0.75         105       1.980        0.39         170        1.896
          0.76         104       2.022        0.39         170        1.896
          0.77         103       2.088        0.39         170        1.896
          0.78         102       2.186        0.39         170        1.896
          0.79         100       2.307        0.39         170        1.896
          0.80          99       2.439        0.39         170        1.896
          0.81          98       2.619        0.39         170        1.896
          0.82          97       2.864        0.39         170        1.896
          0.83          95       3.094        0.39         170        1.896
          0.84          94       3.385        0.39         170        1.896
          0.85         103       3.379        0.39         170        1.896
          0.86         101       3.131        0.39         170        1.896
          0.87          98       2.725        0.39         170        1.896
          0.88          95       2.567        0.39         170        1.896
          0.89          94       2.624        0.39         170        1.896
          0.90          94       2.661        0.39         170        1.896
          0.91          93       2.718        0.39         170        1.896
          0.92          93       2.754        0.39         170        1.896
          0.93          93       2.782        0.39         170        1.896
          0.94          94       2.732        0.39         170        1.896
          0.95          93       2.674        0.39         170        1.896
          0.96          91       2.747        0.39         170        1.896
          0.97          90       2.792        0.39         170        1.896
          0.98          89       2.951        0.39         170        1.896
          0.99          90       3.043        0.39         170        1.896
          1.00          90       3.067        0.39         170        1.896
TEST:
SARADA W-U FIT
LAMBDA=                 0.39
Z POTENTIAL=          170 CM
RMSMIN=                1.896
```

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STUDY GROUP

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