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A MODIFIED SCS-CN-BASED HYDROLOGIC MODEL

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PREFACE

Long-term hydrologic simulation studies provide a useful input to the water resources planning and watershed management studies. The most widely used event-based method of runoff computation the Soil Conservation Service Curve Number (SCS-CN) method is employed in the development of a long-term hydrologic model. The present study differs from the earlier study in the computation of SCS-CN parameter using evapotranspiration as well as antecedent moisture condition (AMC) whereas the earlier study depended only on AMC for S-variation.

The model presented in this report has been applied to two large catchments falling in sub-humid regions of India and its performance is evaluated. The variation of the curve number is examined and discussed and a critical evaluation of the employment of single linear reservoir routing technique and linear regression technique presented.

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ABSTRACT

Long-term hydrologic simulation studies provide a useful and important input to water resources planning and watershed management practices. The Soil Conservation Service (SCS, 1956) Curve Number (SCS-CN) method is a widely used event based rainfall-runoff method. In this report, the SCS-CN method is used for simulating daily rainfall-runoff data of two catchments, viz., Hemavati (area=600 sq. km) and Ramganga (area=3134 sq. km) catchments falling in sub-humid regions of India. The model formulation is based on the conversion of precipitation to rainfall excess using SCS-CN method and its routing by single linear reservoir and linear regression techniques. The baseflow that is assumed to be a fraction of the infiltration amount is routed using the lag and route method. The variation of SCS-CN parameter potential maximum retention S is governed by evapotranspiration and antecedent moisture condition. This model when applied to Hemavati has shown efficiency of 75.31% and 82.03% in calibration and validation, respectively, and when applied to Ramganga, these are 58.34 and 67.20% respectively in calibration and validation. The stability of the computed parameters is examined by reversing the data sets of calibration and validation and it is found that a greater length of data will be required to stabilise the model parameters. The application of single linear reservoir technique to Hemavati data is found to conserve the mass successfully in Hemavati application whereas the application of linear regression fails to conserve the mass of Ramganga runoff. The computed values of the initial abstractions, rainfall excess, infiltration, and baseflow are also presented in tabular form along with their annual and seasonal statistics. Initial abstraction values are found to be much higher in non-monsoon season than those in monsoon season.

1.0 INTRODUCTION

The existing Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956) is the combination of the universal water balance equation and two hypotheses described, respectively, as

$$P = I_a + F + Q \tag{1}$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

where, P=total precipitation; I_a=initial abstraction; F=cumulative infiltration; Q=direct runoff; S=potential maximum retention or infiltration; λ is the initial abstraction coefficient. λ is taken equal to 0.2 (a standard value) in usual practical applications. Mishra (1998a) defined S as the maximum amount of space available in the soil profile under given antecedent moisture and Mishra and Singh (1999c) described the hypothesis of Eq. 2 as a proportionality concept. An overview of the SCS-CN method is provided by Ponce and Hawkins (1996).

The popular form of the SCS-CN method can be derived by combining Eqs. 1 and 2 as

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{4}$$

Here, $P > I_a$ and Q=0 otherwise. Mishra and Singh (1999a, 1999b) explained the functional behaviour of the SCS-CN method (EQ. 4) using I_a as a key descriptor and derived C-I_a*-λ spectrum, where C is the runoff factor (=Q/P) and I_a* is the non-dimensional initial abstraction (=I_a/P).

The relation between S and CN is expressed as

$$S = \frac{1000}{CN} - 10 \tag{5}$$

Eq. 5 is empirical one, supposedly based on field experience and scaling. It is not, however, entirely clear as to the extent to which S could assume a value that is practically meaningful. Mishra and Singh (1999c) revisited this relation and showed that though the CN varied from 1 to 100, resulting in the range of S (0,990) inches and described the practical range of CN variation as (50,100). Furthermore, the relation assumes a value of 10 inches as the absolute maximum retention (S_{abs}). They suggested a general form of Eq. 5 as follows:

$$\frac{S}{S_{abs}} = \frac{100}{CN} - 1 \tag{6}$$

where S varies between 0 and S_{abs} inches (or any other unit). The importance of such a manipulation can be found in Williams and LaSuer (1976), Rallison and Miller (1982), and Ponce (1989).

Long-Term Hydrologic Simulation

Several models are available for hydrologic simulation varying in degree of complexity of inputs, number of parameters to be determined, time interval used, and output. Some models like Stanford Watershed Model, USDAHL (Holtan and Lope, 1971) and its versions, System Hydrologique Europien (SHE), HEC-1, etc. have many parameters, usually use a short time interval, and output hydrographs as well as water yield. These models are designed for detailed hydrologic studies. Furthermore, the Stanford Watershed Model and SHE models are not applicable to ungauged watersheds because of parameter calibration reasons. The USDAHL model can however be used for ungauged watersheds, but prediction accuracy is not high considering input detail.

The curve number method is an infiltration loss model and, therefore, its applicability is restricted to modelling storm losses (Ponce and Hawkins, 1996). The method has, however, been used in long-term hydrologic simulation and several models have been developed in the past two decades. The models of Williams and LaSuer (1976), Huber et al. (1976), Knisel (1980), Soni and Mishra (1985) applied with varying degree of success (Woodward and Gburek, 1992) are notable among others. The models of Williams and LaSuer (1976), Hawkins (1978), Soni and Mishra (1985), and Mishra (1998b) are described below for emphasising the importance and need for the development of the SCS-CN-based long-term hydrologic models.

(i) Williams-LaSuer model

The William-LaSuer model is based on SCS-CN equations (Eqs. 4 and 5). It has only one parameter, uses a 1-day time interval, has simple inputs, and only outputs runoff volume. The input requirements are: (1) an estimate of the curve number (for AMC-II condition) for the watershed; (2) measured monthly runoff; (3) daily rainfall; and (4) average monthly lake evaporation. The model computes a soil moisture index depletion parameter that forces agreement between measured and predicted average annual runoff. Other optimisation schemes, like optimising on monthly or annual runoff, were not used because these did not predict consistently the proper average annual runoff and thus, did not provide a good estimate of average curve number. This model has the advantage that when it is used on nearby ungauged watersheds, the curve number corresponding to AMC-II condition is adjusted for the ungauged watershed in proportion to the ratio of the AMC-II curve number to the average predicted curve number for the calibrated watershed.

The above model, however, utilises an arbitrarily assigned value of 20 for S_{abs}; assumes a decay pattern for the soil moisture as a function of lake evaporation; and simulates the runoff on monthly and annual bases though the runoff is computed daily, treating the rainfall of a day as a storm. It is worth noting that the model efficiencies for a greater time interval are usually higher than those derived using a shorter time interval. Furthermore, daily average values of evaporation were derived from monthly lake evaporation and used in model calibration and validation.

(ii) Hawkins (1978) model

Hawkins (1978) developed a continuous soil-moisture accounting model. The accounting of soil moisture was based on the variation of AMC conditions with time and the AMC-based curve numbers were derived using Eq. 5. The S-value was also varied with the evapotranspiration, which is a significant feature of the model as evapotranspiration plays a significant role in long-term hydrologic simulation. However, the model assumes a total storage of 1.2S that varies with time according to the evaporation and infiltration. It is worth noting that the assumed total soil storage of 1.2 S is not a realistic assumption because 0.2S part of the storage does not contribute to storage for infiltration, rather only S takes part in storing the infiltrated part of surface water. In the (I_a+S) scheme followed by the existing SCS-CN method, only S takes an active part in apportioning runoff and infiltration, as shown in Eq. 2. Furthermore, it does not prescribe any boundary for the 1.2 S to deplete. Hawkins, however, suggested an upper limit of (S_{abs}) equal to 20 in accordance with Williams and LaSuer.

(iii) Soni and Mishra (1985) model

Soni and Mishra (1985) applied the Hawkins model to 1-year daily data of Hemavati watershed located in the sub-humid region of India with the Nash and Sutcliffe (1970) efficiency equal to about 85%. They used a root zone depth of 1.2 m for the computation of S varying with the evapotranspiration. In an attempt to apply this model to a large set of daily data, Mishra (1998b) found the model to be performing unsatisfactorily, with much low efficiencies, and consequently, developed another model.

(iv) Mishra (1998b) model

Mishra (1998b) developed an SCS-CN-based long-term hydrologic model that relied on the following:

1. The variation of parameter S was governed by the antecedent moisture condition.
2. The excess rainfall was routed to the outlet using a linear regression scheme, following unit hydrograph theory.
3. The baseflow was assumed to be a fraction of the infiltration amount.
4. The baseflow is routed to the outlet of the basin using lag and route method.
5. The routed rainfall excess and the baseflow is the total flow at the outlet of the basin.
6. The parameters of the model were computed using non-linear Marquardt algorithm.

The developed model was applied to a large set of daily rainfall-runoff data of three large catchments varying significantly in their geologic and meteorologic character with a reasonable amount of success. Since the curve number was varied with only antecedent moisture and evapotranspiration was not accounted for, it did not warrant the reasonableness and completeness of the model formulation. Additionally, due to using regression for employing unit hydrograph and computing parameters using optimisation, the model was unable to conserve the mass, a matter of serious concern. Therefore, it is necessary to devise a model eliminating these deficiencies.

2.0 SOIL-MOISTURE ACCOUNTING LONG-TERM HYDROLOGIC MODEL

2.1 Computation of Rainfall Excess

Replacing Q by RO (runoff) in Eq. 4 for avoiding confusion, Eq. 4 can be re-written for daily runoff with time as subscript t as

$$RO_t = \frac{P_{e_t}^2}{P_{e_t} + S_t} \tag{7}$$

Where

$$P_{e(t)} = P_{(t)} - I_{a(t)} \tag{8}$$

$$I_{a(t)} = \lambda S_t \tag{9}$$

$$S_t = \frac{25400}{CN_t} - 254 \tag{10}$$

Here, λ=0.2, $P_{e(t)} \geq 0$ else $RO_t = 0$, CN_t is the curve number and S_t is the corresponding maximum potential retention (in mm) at the end of the day t, computed as below taking into account the previous day balance moisture:

$$S_t = S_{t-1} - (1-b_f)\, F_{t-1} + EV_{t-1} \tag{11}$$

where S_{t-1} is the previous day potential maximum retention (mm), F_{t-1} is the previous day infiltration (mm), computed using water balance equation:

$$F_{t-1} = P_{t-1} - I_{a(t-1)} - RO_{t-1} \tag{12}$$

It is worth mentioning that for $P_{e(t)} \geq 0$, $F \geq 0$. In Eq. 12, EV_{t-1} is the previous day evapotranspiration (mm), computed using Penman coefficient method. In this study, Penman coefficients are taken as 0.8 for the period June-Sept., 0.6 for the period Oct.-Jan., and 0.7 for the period Feb.-May. In Eq. 11, b_f is a factor used to compute baseflow (q_b), as follows:

$$q_{b(t\text{-}NLAG)} = b_f F_t \tag{13}$$

Eq. 13 represents the baseflow routed to the outlet of the basin using lag and route method with the NLAG representing the lag parameter.

2.2 CN Variation with AMC

CN_t computed using Eqs. 10 and 11 are accounted for the antecedent moisture conditions (AMC) (Table 1) as (Hawkins et al., 1985)

TABLE 1. ANTECEDENT SOIL MOISTURE CONDITIONS (AMC)

AMC	5-day antecedent rainfall (mm)	
	Dormant season	Growing season
I	Less than 13	Less than 36
II	13 to 28	36 to 53
III	More than 28	More than 53

$$CN_t = \frac{CN_{t-1}}{2.3 - 0.013\,CN_{t-1}} \tag{14a}$$

or

$$CN_t = \frac{CN_{t-1}}{0.43 - 0.0057\,CN_{t-1}} \tag{14b}$$

which are valid for AMC I or AMC III. It is worth noting that the initial value of CN (=CN_o) at the start of simulation corresponds to AMC II. In this study, June 1–Oct. 31 is taken as dormant season and the remaining period of the year as growing season.

India being a tropical country, most part of the annual rainfall in the country occurs during the period of monsoon. The pre-monsoon period experiences hot summer and consequently, high temperature leading to higher evapotranspiration. In the present study, June 1 is the beginning day for simulation. In the month of May-June, the summer is at its peak, and consequently, maximum evapotranspiration takes place. Thus, dry soils contain minimum moisture in their pores, leading to availability for maximum pore space for moisture retention. Therefore, the minimum CN-values are likely during this period and hence it is not far from reality to assume a CN value that is minimum of the year on June 1, which is designated as CN_0. Thus,

$$S_t = S_o \qquad \text{for } S_t \geq S_o \tag{15}$$

where S_0 corresponds to CN_0.

2.3 Routing of Rainfall Excess

After computing RO from Eq. 7, which represents the rainfall excess amount corresponding to P_e, it is necessary to transform it to direct runoff that is produced at the outlet of the basin. It is carried out using

a) Single Linear Reservoir method

$$q_t = C0\,RO_t + C1\,RO_{t-1} + C2\,q_{t-1} \tag{16}$$

where

$$C0 = \frac{COUR}{2 + COUR} \tag{17a}$$

$$C1 = C0 \tag{17b}$$

$$C2 = \frac{2 - COUR}{2 + COUR} \tag{17c}$$

$$COUR = 1/K \tag{17d}$$

In Eq. 17d, K represents the single linear reservoir storage coefficient.

b) Linear Regression

$$q_t = d_1 RO_t + d_2 RO_{t-1} + d_3 RO_{t-2} + \ldots\ldots\quad (18)$$

where d_1, d_2, d_3,... are the non-dimensional regression coefficients.

2.4 Computation of Total Runoff

The total flow on a day t, Q_t, is computed by summing q_t (Eq. 16 or 18) and q_b (Eq. 13). Thus,

$$Q_t = q_t + q_{b(t)}\quad (19)$$

where $q_{b(t)}$ is the t th day baseflow.

It is worth indicative that in the above model formulation, the mass remains conserved during both processes of routing: the single linear reservoir routing and lag and route method. However, in linear regression, if the sum of d_1, d_2, d_3, etc. is equal to 1, the mass is conserved. The infiltration component $(1-b_f)$ F is assumed to be a part of evaporation and used to balance the soil storage for moisture retention.

The developed model has only four parameters: b_f, CN_0, K (1/day), and NLAG (day) if single linear reservoir routing is used and these are bf, CN0, NLAG, d_1, d_2, d_3, etc. if linear regression for routing is used. The parameters are determined using non-linear Marquardt algorithm utilising the objective function of minimising the errors between the computed and observed data or maximising model efficiency, in what follows.

2.5 Model Efficiency

The model efficiency (Nash and Sutcliffe, 1970) is computed using

$$\text{Efficiency} = [\ 1 - RV/IV]\quad (20a)$$

Where

$$RV = \sum_{i=1}^{n}(Q_i - \hat{Q}_i)^2 \tag{20b}$$

and

$$IV = \sum_{i=1}^{n}(Q_i - \overline{Q}_i)^2 \tag{20c}$$

Here, RV is the remaining variance; IV is the initial variance; Q_i is the observed runoff for ith day; $\hat{Q}_i$ is the computed runoff for ith day; n is the total number of observations; and $\overline{Q}$ is the overall mean daily runoff. Efficiency is used for evaluating the model performance in cal and validation periods.

3.0 STUDY AREAS

3.1 Hemavati Catchment

River Hemavati is one of the tributaries of River Cauvery. It rises in Ballaiarayanadurga in the western ghats in Mundgiri taluk of Chikmanglur district in Karnataka State (Fig. 1). Hemavati river, in its early reaches, passes through a very heavy rainfall region in the vicinity of Kotigehara and Mudigere. The river is joined by Yagachi and Algur. It drains an area of 600 sq. km. up to Sakleshpur, lying between 12°55' and 13°11' north latitude and 75°20' and 75°51' east longitude. The area is a typical monsoon type of climate. It is a hilly catchment with steep to moderate slopes. Agriculture and plantation are the major industries of the basin. The land use can be characterised by forests (12%), coffee plantations (29%), and agricultural lands (59%). The principal soil types are red loamy soil (67%) and red sandy soil (33%). Soils in the forest area and coffee plantations are greyish due to high humus content. The data of rainfall, runoff, and evaporation were available for 5 years (1974-75 to 1979-80) and these are used in the present study.

3.2 Ramganga Catchment

The Upper Ramganga Catchment (Fig. 2) lies in the foothills of Himalayas in the northern part of Uttar Pradesh, India. River Ramganga is a major tributary of River Ganga with origin at Diwali Khel. It emerges out of the hills at Kalagarh (District Almora) where, for harnessing the waters of Ramganga catchment, a major multi-purpose dam, also known as Ramganga dam, is situated. The river traverses approximately 158 km before it meets the reservoir and then continues its journey in the downstream plains for 370 km before joining River Ganga at Farrukhabad (Uttar Pradesh). During its travel up to Ramganga dam, the river is joined by main tributaries: Ganges, Binoo, Khatraun, Nair, Badangad, Mandal, Helgad, and Sona Nadi. Its catchment (area= 3134 sq. km) lies between elevation 262 and 2926 m above mean sea level, and is considerably below the perpetual snow line of the Himalayas. About 50% of the drainage basin is covered with forest and 30% is under cultivation on terraced fields.

The Ramganga valley experiences approximately an annual precipitation of 1550 mm. The raingauge network consists of Ranikhet, Chaukhatia, Naula, Marchulla, Lansdowne and Kalagarh besides the other existing stations. The present study utilises a continuous rainfall

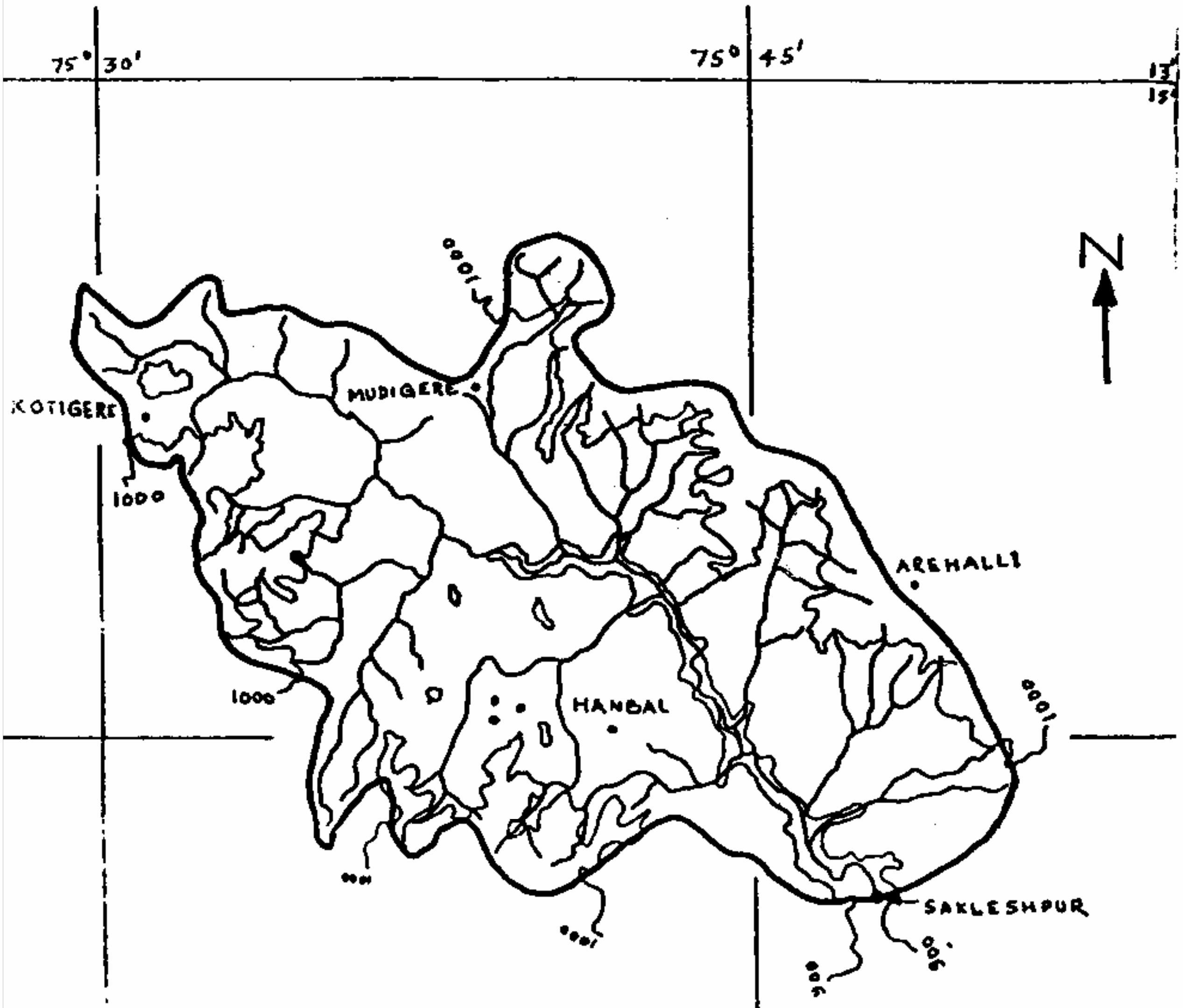

FIG. ~~3~~ 1-HEMAVATI UPTO SAKLESHPUR BASIN

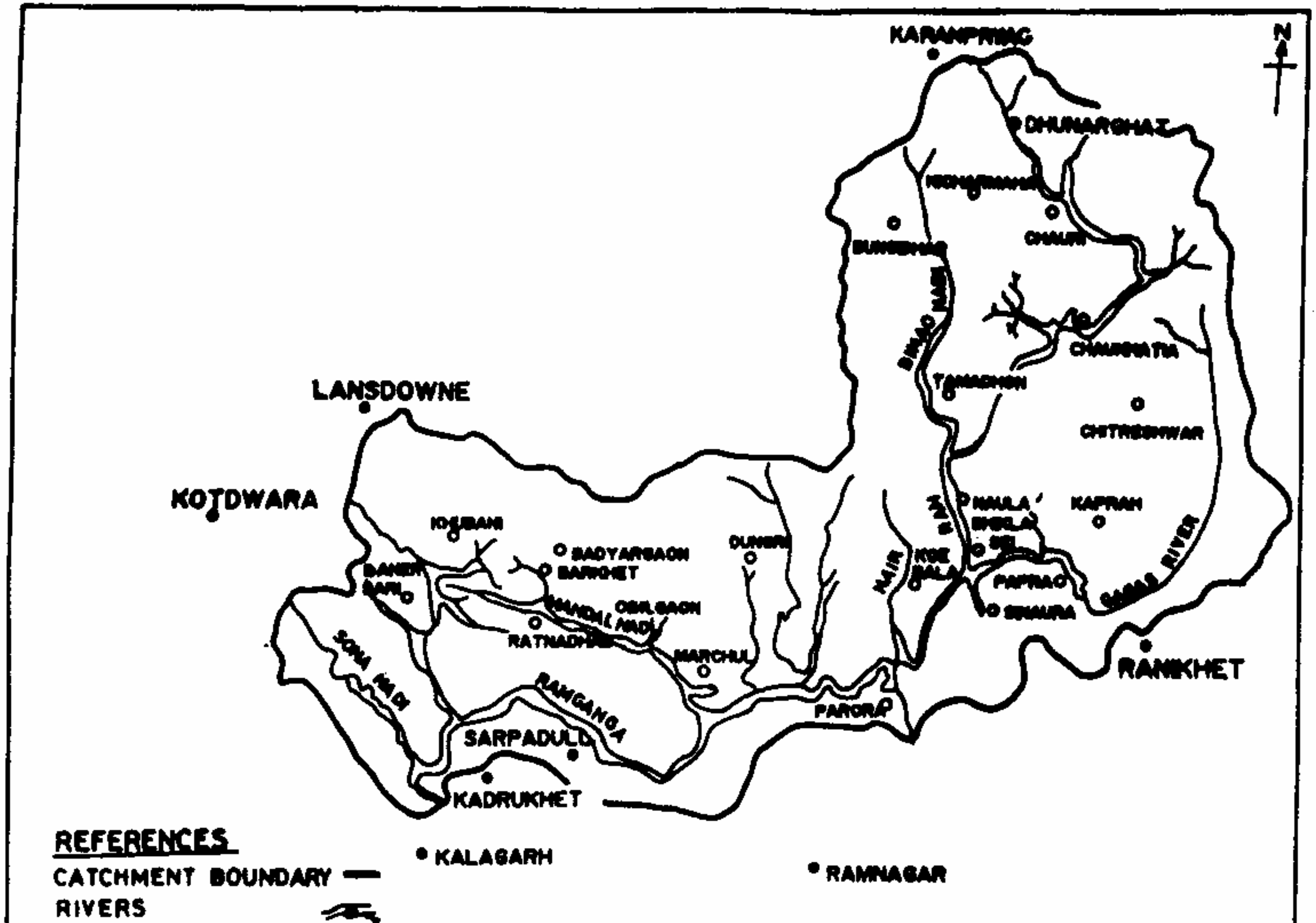

FIG. 2 RAMGANGA CATCHMENT

record that was available at the first six stations. The Theissen weights computed for these stations are 0.088, 0.298, 0.190, 0.251, 0.092, 0.081, respectively. Streamflow record of the Ramganga river including river stages, instantaneous as well as monthly, are available at Kalagarh from the year 1958. At this site various high floods were recorded in the years 1963, 1966, 1969, and 1978. It is worth mentioning that after the commencement of the operation of Ramganga dam in Dec. 1974, the available later discharges have been computed using the mass balance approach-- for the computations of inflows to Ramganga dam-- assuming a linear variation in monthly evaporation computed using Rowher's formula. The pan evaporation data observed at Kalagarh were available for only 6 years (1978-79 and 1985-86 to 1989-90) and hence the corresponding data of rainfall and runoff have been used in this study. Even though the quality of runoff data is not indubitable, it is used as such without any modification.

The data availability of both the above catchments is shown in Table 2. In this table,

- Case A represents the case when the model is calibrated on the data set obtained from former period and validated on the latter period.
- Case B represents the case when the model is calibrated on the data set obtained from latter period and validated on the former period.
- Case C represents the case when the model is calibrated only on 1-year data and not validated.

The last column of Table 2 represents the 5-day antecedent moisture condition (AMC).

TABLE 2. DATA USED FOR MODEL CALIBRATION AND VALAIDATION

Catchment	Area (sq. km)	Region	Data Length (Years) Calibration	Validation	AMC (Day)
Hemavati	600	Sub-humid	Case A: 3 Case B: 2	Case A: 2 Case B: 3	5
Ramganga	3134	Sub-humid	Case A: 4 Case B: 2 Case C: 1	Case A: 2 Case B: 4 Case C: 0	5

4.0 ANALYSIS

4.1 Parameter Estimation

The earlier described model parameters are determined using Marquardt algorithm of constrained least squares. The algorithm has the advantage of offering unique set of parameters irrespective of initially supplied values of the parameters given the range of parameters' variation. However, for the purpose of using the algorithm one needs to supply their initial values along with their range of variation. In the present study, the initial values of the parameters were decided by trial and error. Several runs were made before these were finally accepted. The range of CN variation is taken as 1-100 and b_f can vary between 0 and 1. In the case of the other two parameters, if the computed value of a parameter assumed a value equal to the prescribed upper or lower limit, the range was extended accordingly. In the event that efficiency of the simulation assumed a lower value due to the extension of range, the final range corresponded to the higher efficiency. It was particularly noticed in Hemavati application for which NLAG was taken equal to 1. The derived initial and final estimates of the parameters are given in Table 3.

4.2 Single Linear Reservoir Vs. Linear Regression

In Hemavati application, single linear reservoir (SLR) routing was employed whereas in the Ramganga application, the linear regression approach was adopted. The former approach is supposed to be superior to the latter since the former balances the mass whereas the latter does not, as seen from the computed values of the parameters d_1, d_2, d_3, and d_4. Here, the sum of these parameters does not equal 1 implying that there is a loss of mass that remains unaccounted. Consequently, these errors affect the parameter computation. Efforts were also made to employ the SLR technique to route the rainfall excess of Ramganga catchment. However, the application yielded undesirable negative efficiency in validation though it was greater than 50% in calibration. The poor efficiency in Ramganga application shows that

1. The SLR technique may not be suitable for this catchment.
2. The model structure may not be sufficient to describe fully the rainfall-runoff processes of the large catchment.
3. The evaporation data collected at Kalagarh that is the outlet of the 3000 sq. km cacthment may not be representative of the whole catchment.

TABLE 3. MODEL CALIBRATION AND VALIDATION

Catchment	Parameter Estimation								Calibration	Validation
	CN	b_f	K	NLAG	d_1	d_2	d_3	d_4	Efficiency (%)	Efficiency (%)
Hemavati	Initial estimates									
	10	0.1	3	1	-	-	-	-		
Range	(0.1-100)	(0-1)	(1-15)	(0-30)						
Case A	Final estimates									
Case B	19.34	0.6688	3.14	1	-	-	-	-	75.31	82.03
	10.00	0.4480	1.99	1					83.71	73.16
Ramganga	Initial estimates									
	70	0.1	-	-	0.5	0.5	0.5	0.5		
Range	(0.1-100)	(0-1)			(0-1)	(0-1)	(0-1)	(0-1)		
Case A	Final estimates									
Case B	67.62	0.2636	-	-	0.1033	0.1420	0.0515	0.0516	58.34	67.20
Case C	64.46	0.1193			0.1188	0.1022	0.0818	0.0396	69.15	54.96
	10.00	0.1552			0.3952	0.5720	0.0853	0.0364	67.18	-

Note: Case A represents the case when the model is calibrated on the data set obtained from former period and validated on the latter period.

Case B represents the case when the model is calibrated on the data set obtained from latter period and validated on the former period.

Case C represents the case when the model is calibrated only 1-year period and not validated.

Range represents the range of parameter variation in Marquardt application.

4. The data may be of poor quality; as discussed in the catchment description of Ramganga, the flow data are collected from the mass balance approach of the reservoir content that inheres all the errors of elevation-capacity curve and other measurement errors. Thus, the data are not indubitable.

The last can also be asserted from the Hemavati application to which the model has performed more than satisfactorily, as explained later.

4.3 Model Calibration and Validation

The model is calibrated and validated for data sets of Hemavati and Ramganga catchments. In Hemavati application, two cases are examined:

1. Case A: Data used in calibration belong to 1974-75 to 1977-78 and those in validation belong to 1979-80 to 1980-81 period.
2. Case B: Data used in calibration belong to 1979-80 to 1980-81 and those in validation belong to 1974-75 to 1977-78 period.

In Ramganga application, three cases are examined:

1. Case A: Data used in calibration belong to 1985-86 to 1989-90 and those in validation belong to 1990-91 to 1991-92 period.
2. Case B: Data used in calibration belong to 1990-91 to 1991-92 and those in validation belong to 1985-86 to 1989-90 period.
3. Case C: Model is calibration is performed on 1978-79 data only without validation.

Here, it is in order to describe the possible implications of reversing data sets on the computed values of the parameters. As apparent from Table 3, the final estimates of the model parameters change significantly as the data set changes. CN changes to 10 from 19.34, b_f to 0.4480 from 0.6688, K to 1.99 from 3.14 as the data length changes to 2 years from 4 years in calibration on Hemavati data. A similar variation is apparent in the calibration on Ramganga data. It implies that a sufficiently longer set of data is required for the stability of model parameters in calibration.

The earlier described model is calibrated and validated on the data sets of the above described two catchments. The model efficiencies showing its performance in both the applications are given in Table 3. It is apparent from this table that the efficiencies in calibration and validation on Ramganga data are poorer than those on Hemavati data. It is for the most part attributed to the dubious quality of Ramganga flow data, as above. The performance of the model in Hemavati application is more than satisfactory as the efficiencies in calibration in both the cases (Cases A & B) are much higher, viz., 75.31% and 83.71% in Case A and Case B, respectively. In Case A, the validation efficiency is higher than that in calibration, contrasting the general notion. The models usually show better performance in calibration than in validation because of optimality reasons of the parameter estimates. This, however, might be attributed to the length of the data set. In Case A of Hemavati application, 3 years data are utilised in calibration and 2 years data in validation. Since the data length is insufficient, it is possible to encounter such a phenomenal aberration. It is worth noting that as the data sets of calibration and validation are reversed, which corresponds to Case B, the resulting efficiencies that are of the same order (83.71% in calibration and 73.16% in validation) also get reversed. Based on these results, it can be inferred that given the data length, the model performs more than satisfactorily on the Hemavati data set.

The model efficiencies in calibration on Ramganga data are 58.34, 69.15 and 67.18% in Cases A thorugh C, respectively and in validation, these are 67.20% and 54.96% respectively in Case A and Case B. The above shown impact of the data length is also visible in Ramganga application. The efficiencies of calibration and validation that are of the same order in Cases A and B for the same, but reversed data sets. It also supports the inadequacy of the data for calibration, which is in consistent with Mishra (1998a) and Mishra et al. (1998). For this reason, the model was also calibrated on 1978-79 data (Case C). It is visible that the model efficiency varies with the length of the data, and so are the parameters.

The calibration and validation results of the above two applications depicted graphically in Figs. 3 through 13. From these figures it is apparent that the runoff hydrographs both Hemavati and Ramganga are closely followed by the model generated runoff values. Peaks are closely simulated as shown in figures, for example, Figs. 3, 4, 5, and 7 in Hemavati application and in Ramganga application, this is visible in Fig. 11. The most important aspect here to visualise is that the trends of computed runoff with the precipitation are more consistent than the observed, which specially holds in Ramganga application (see Fig. 9).

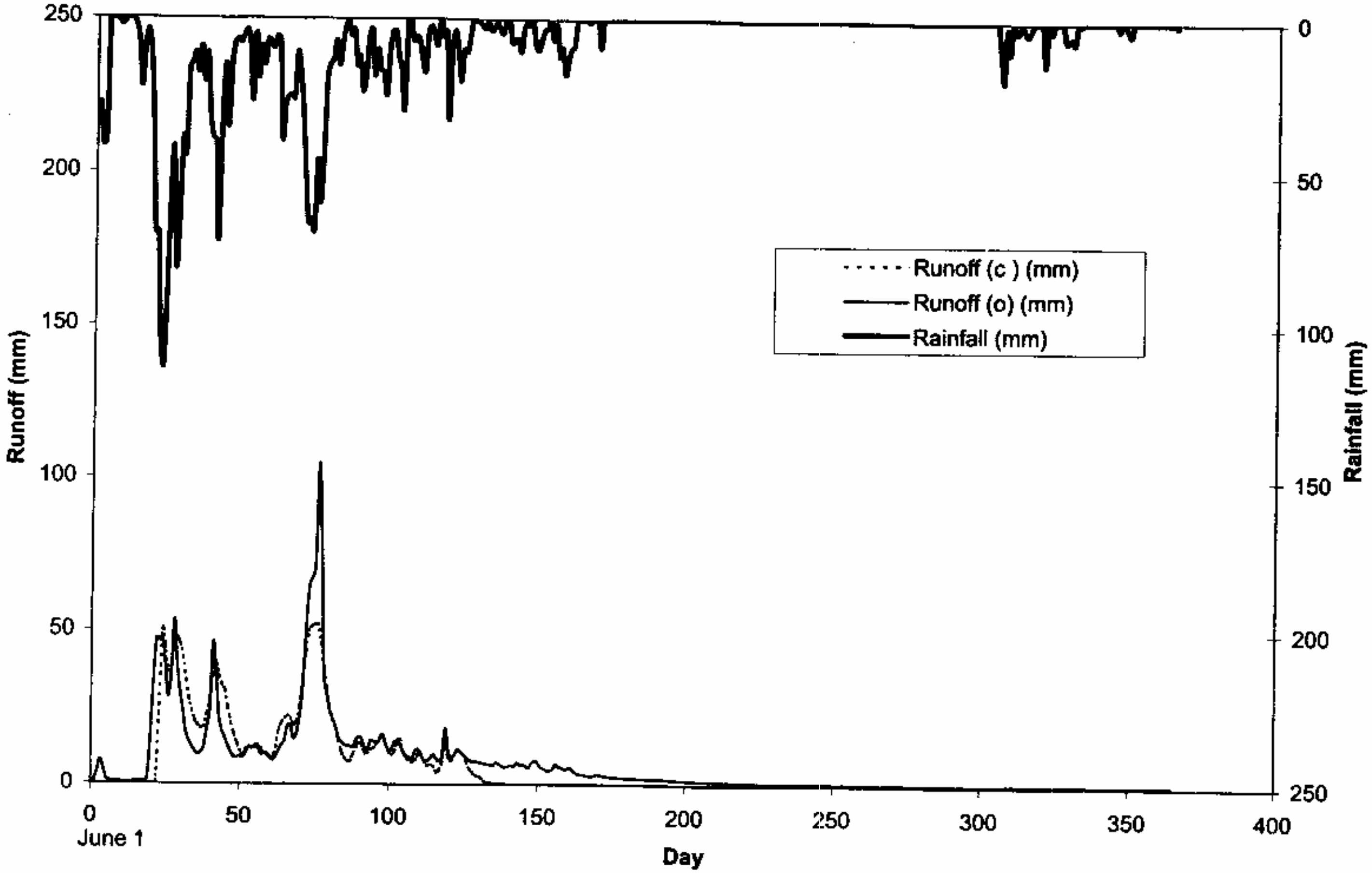

Fig. 3. Calibration of SCS-CN-based hydrologic model using Hemavati data of 1974-75.

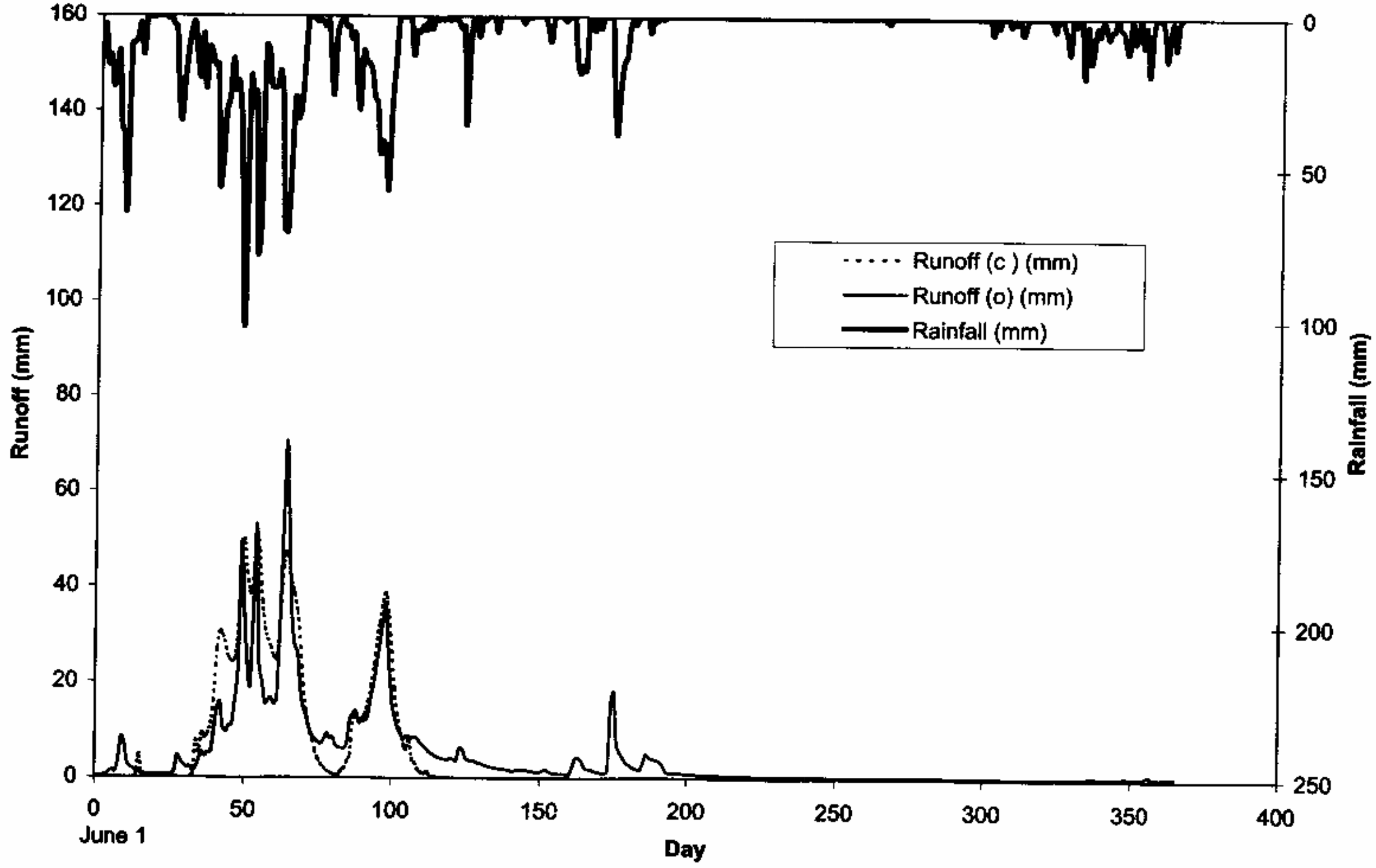

Fig. 4. Calibration of SCS-CN-based hydrologic model using Hemavati data of 1975-76.

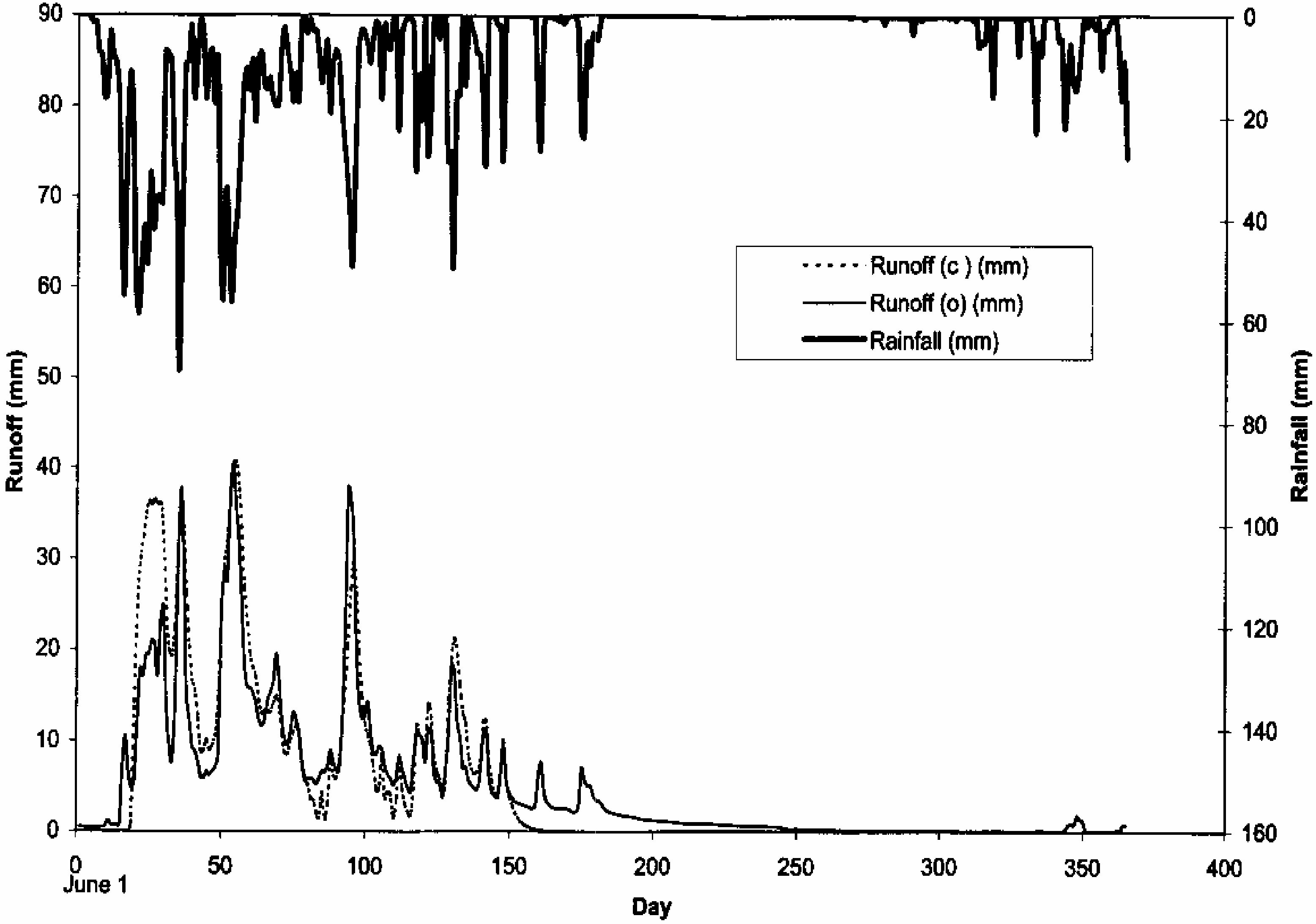

Fig. 5. Calibration of SCS-CN-based hydrologic model using Hemavati data of 1976-77.

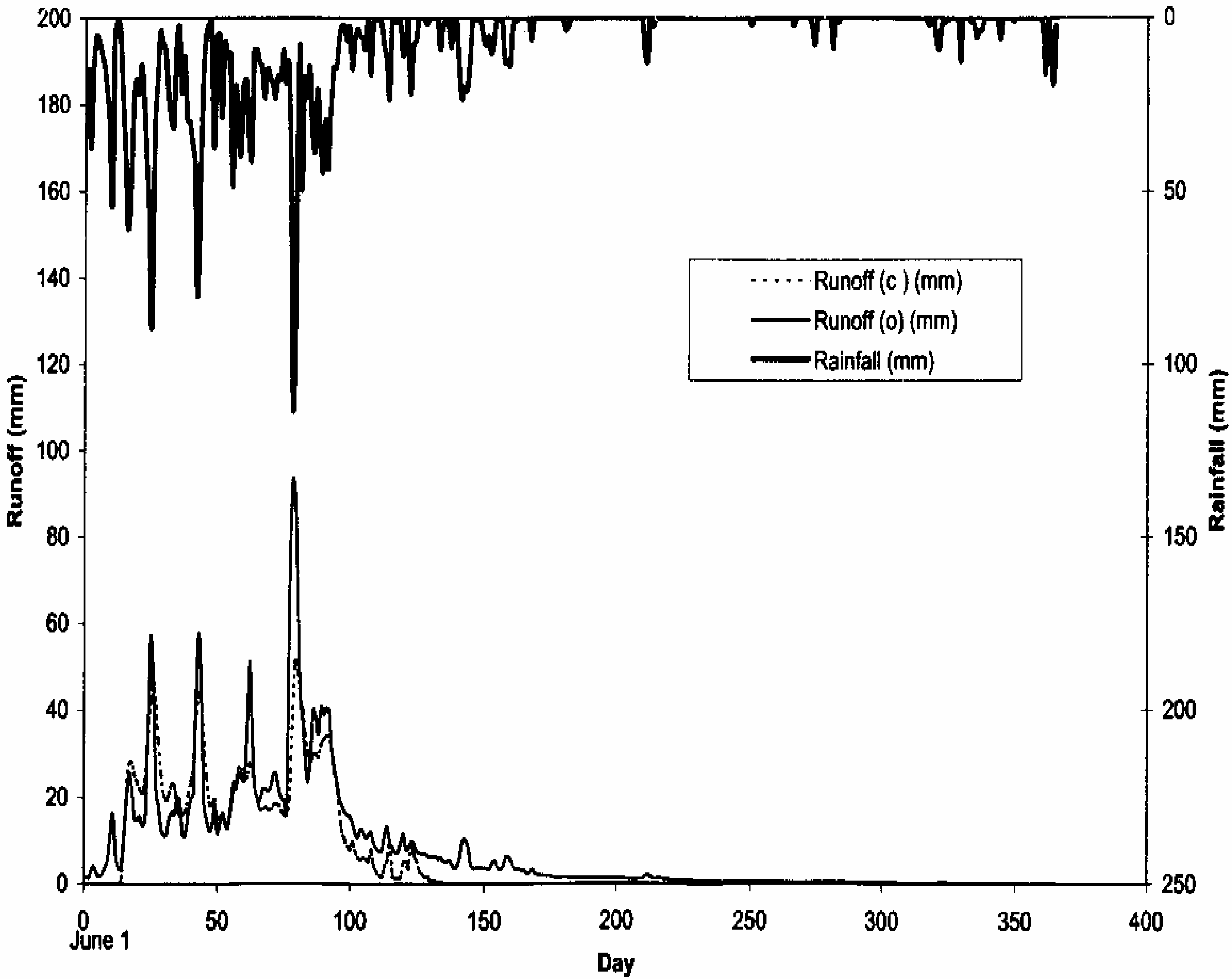

Fig. 6. Validation of SCS-CN-based hydrologic model using Hemavati data of 1977-78.

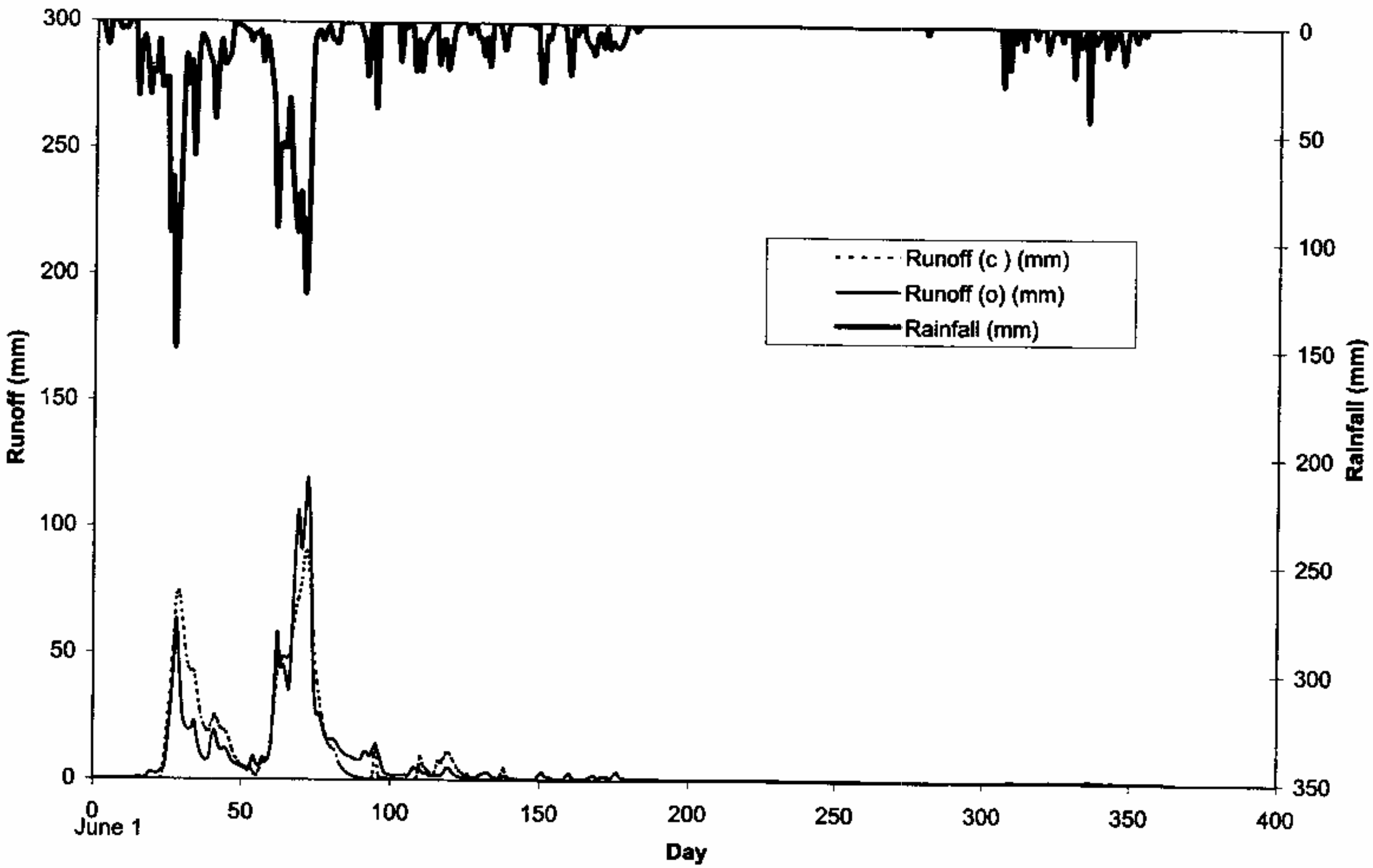

Fig. 7. Validation of SCS-CN-based hydrologic model using Hemavati data of 1978-79.

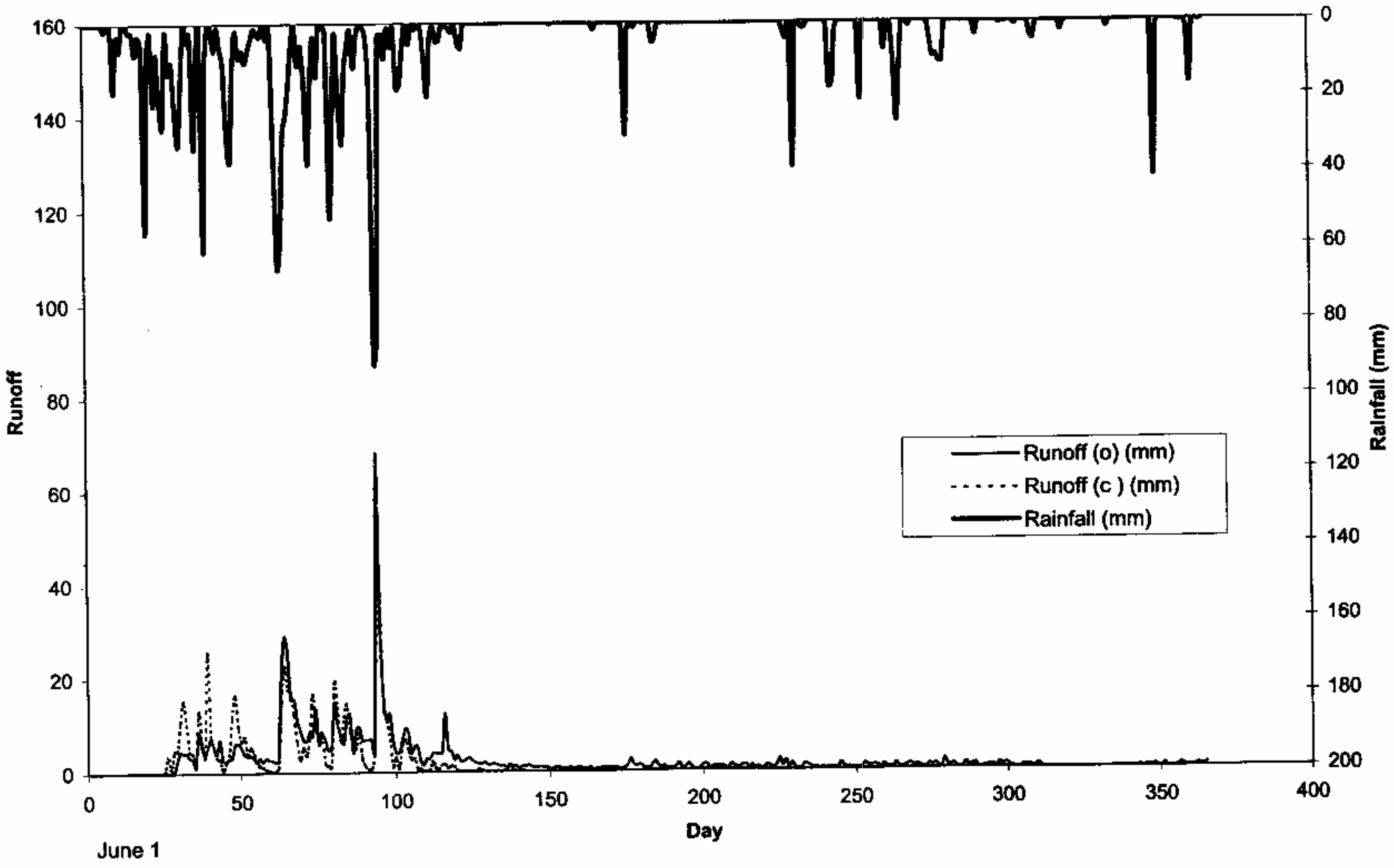

Fig. 8. Calibration of SCS-CN-based hydrologic model using Ramganga data of 1978-79 .

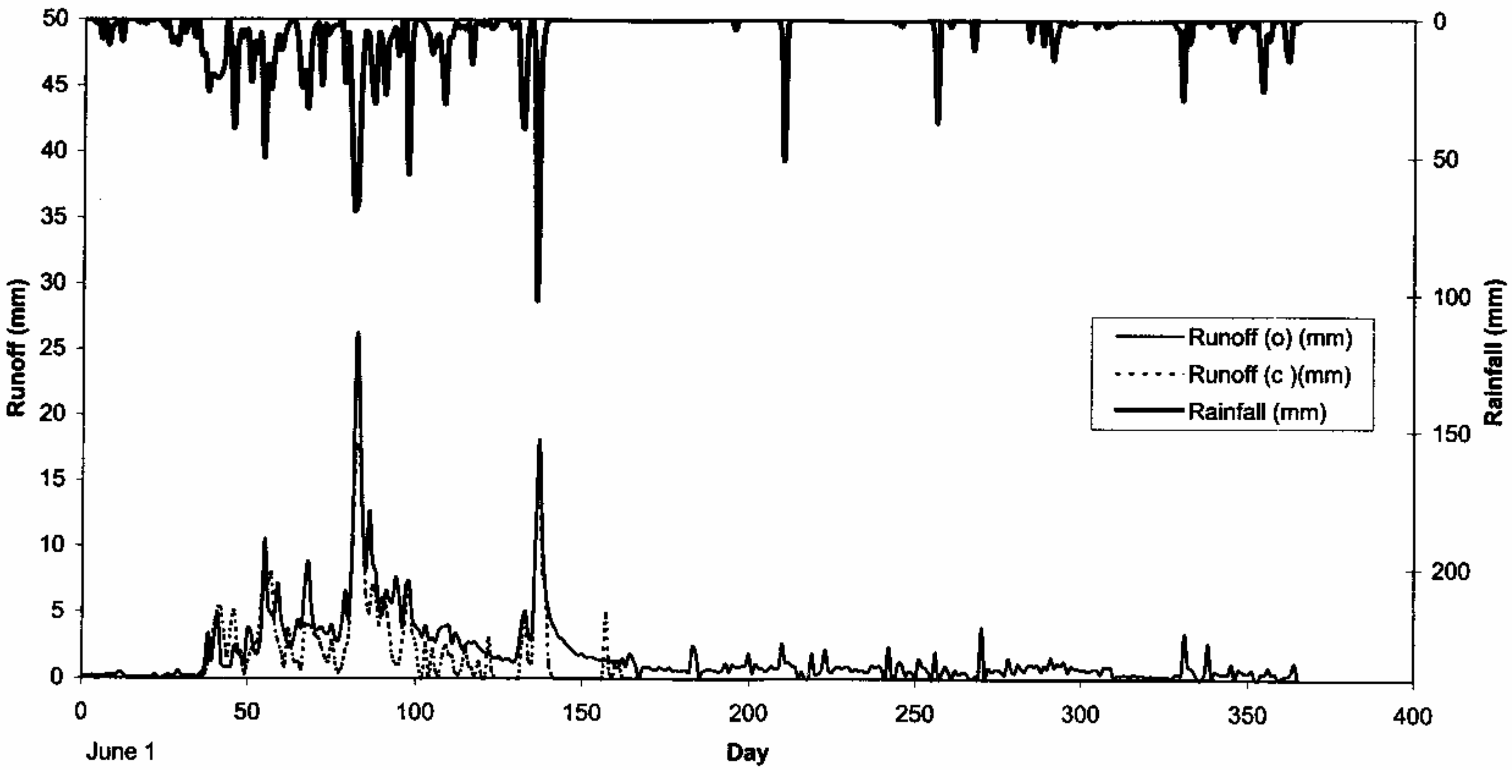

Fig. 9. Calibration of SCS-CN-based hydrologic model using Ramganga data of 1985-86.

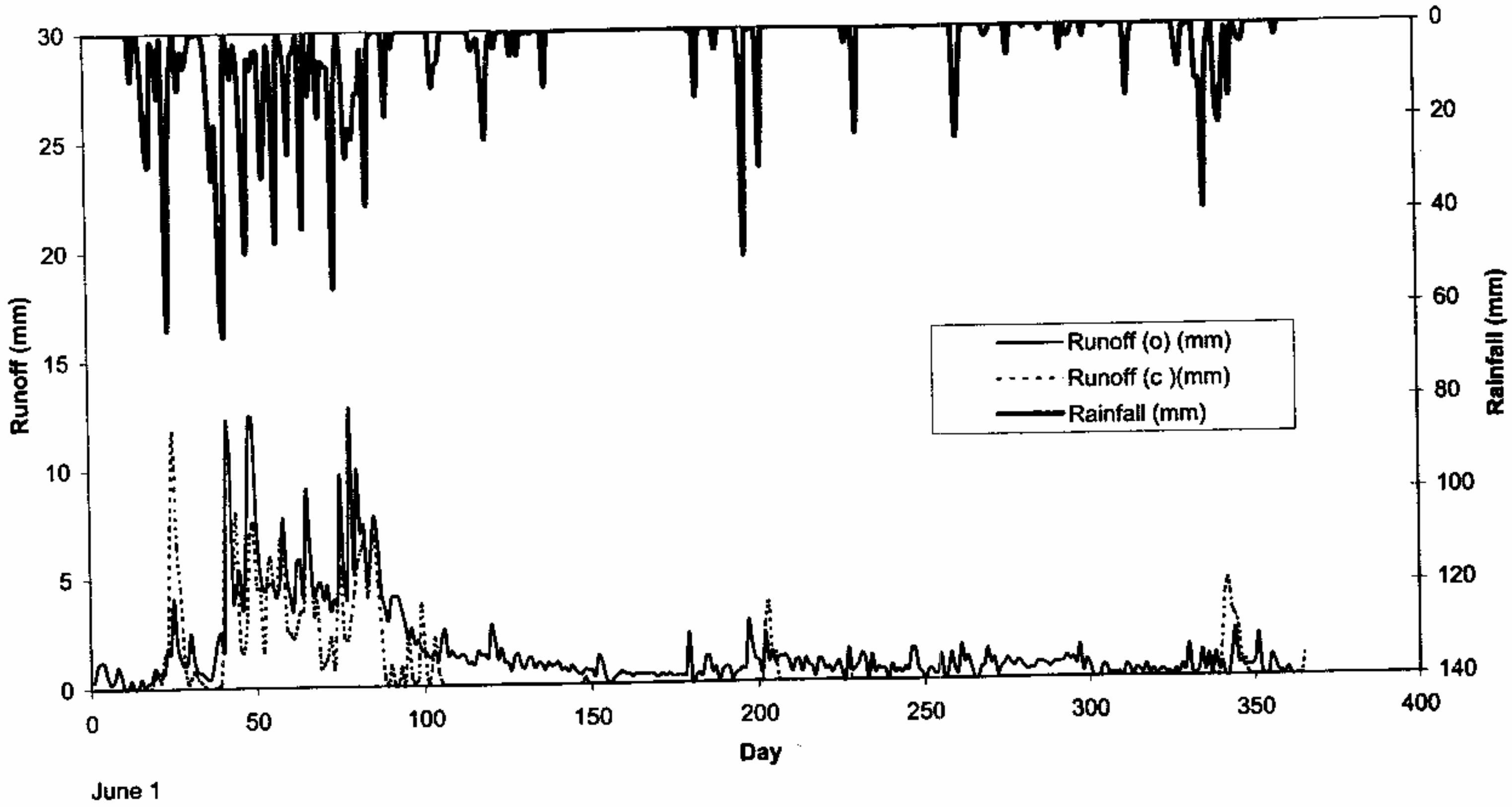

Fig. 10. Calibration of SCS-CN-based hydrologic model using Ramganga data of 1986-87.

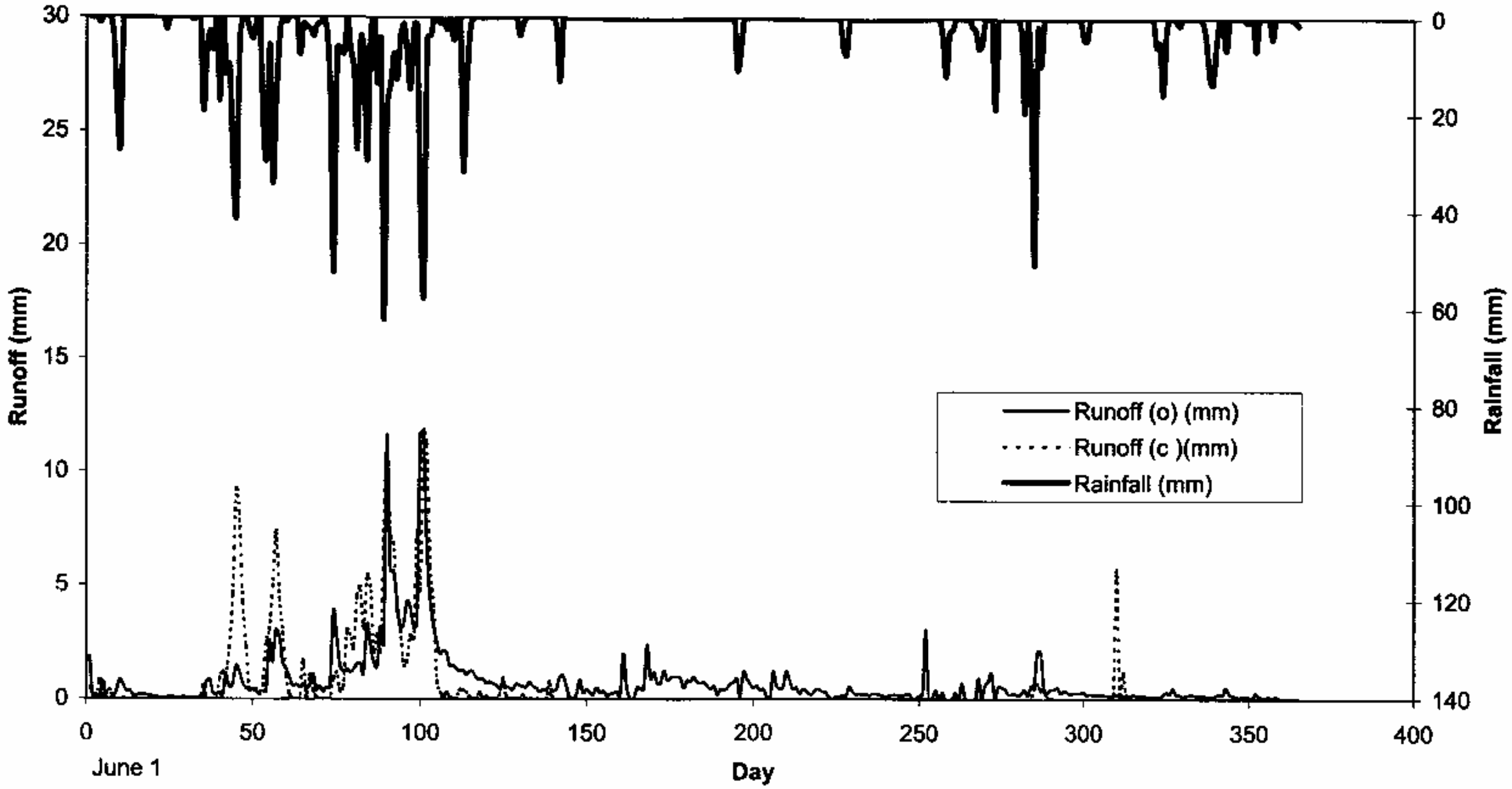

Fig. 11. Calibration of SCS-CN-based hydrologic model using Ramganga data of 1987-88.

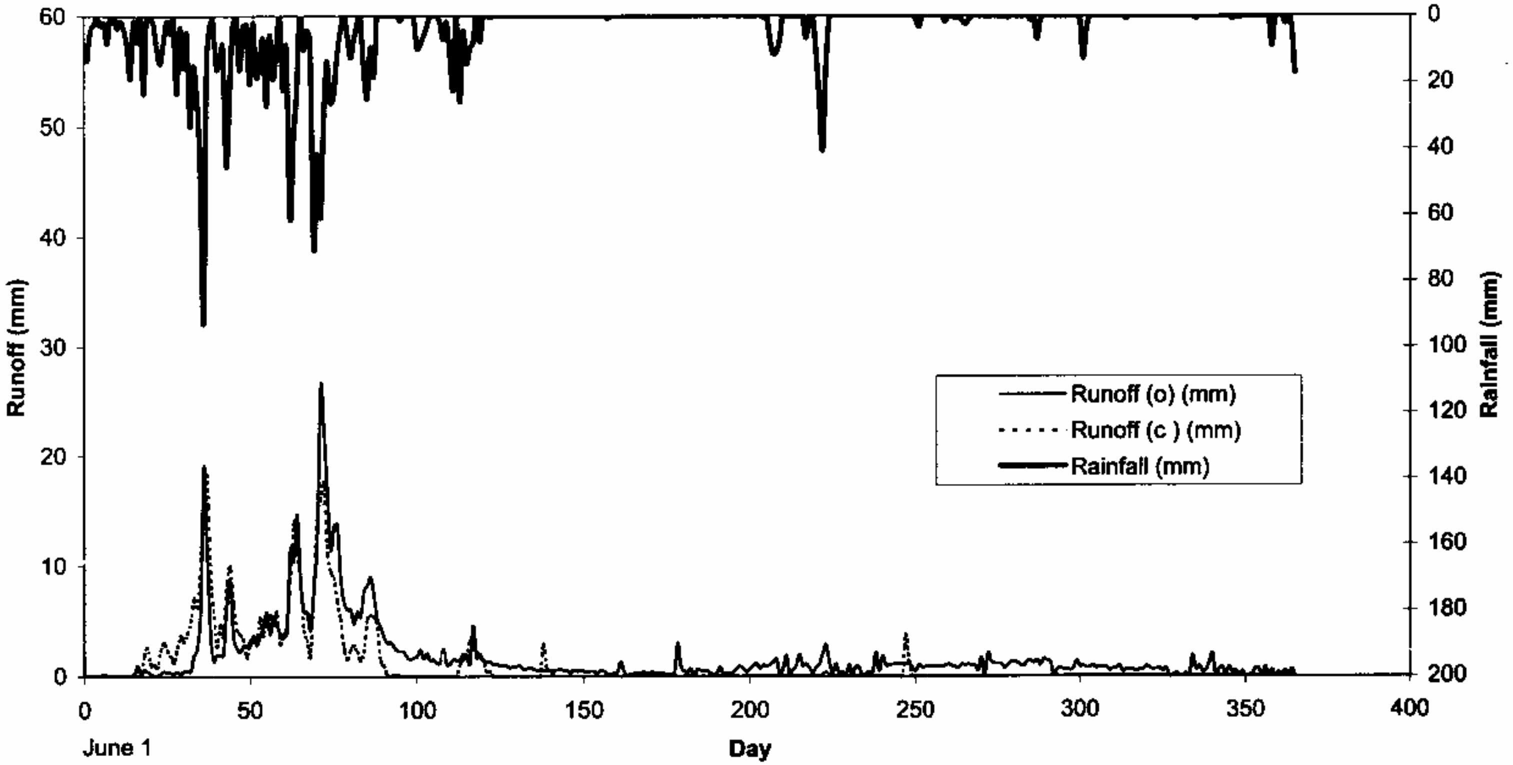

Fig. 12. Validation of SCS-CN-based hydrologic model using Ramganga data of 1988-89.

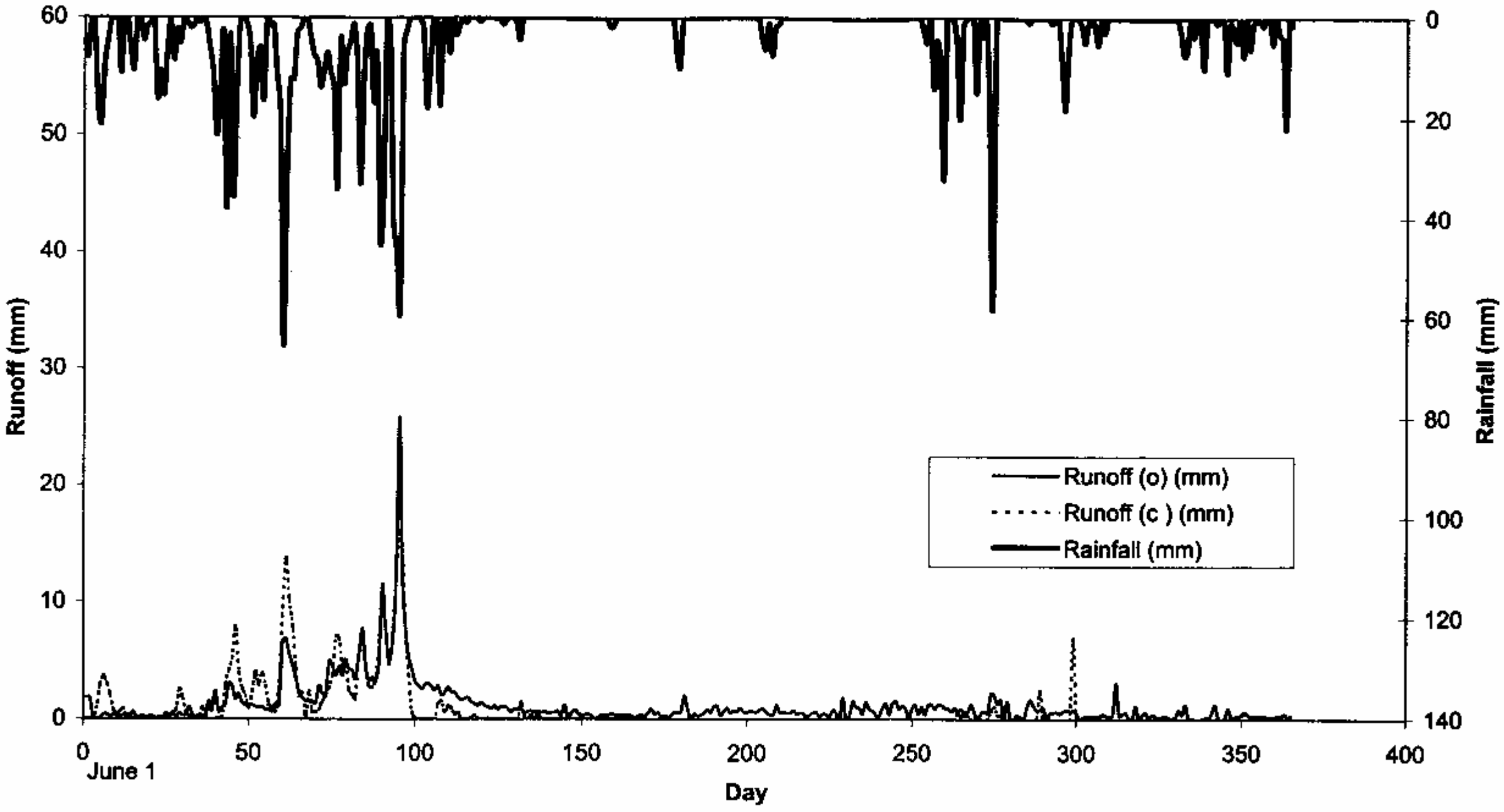

Fig. 13. Validation of SCS-CN-based hydrologic model using Ramganga data of 1989-90.

4.4 Variation of Parameter CN

In the application of SCS-CN method, its only parameter S or CN needs to be computed satisfactorily. Here, it is important to note that the model requires an initial value of CN (=CN_0) that varies continuously with the daily evapotranspiration and antecedent precipitation. For given initial set of CN-values (Table 3), the daily variation of CN is shown in Figs. 14 through 17 for both the calibration and validation periods of Hemavati data and calibration period of 1978-79 (Case C) of Ramganga data, respectively. It is visible from these figures that in the beginning of the year (i.e. June 1) CN assumes a value that is close to almost 0 and increases continuously with the precipitation amount. As the rainfall ceases and evapotranspiration dominates, CN decreases. In this study, Panman coefficients are used to compute evapotranspiration from pan evaporation. These values are 0.8 for the period June-Sept., 0.6 for the period Oct.-Jan., and 0.7 for the period Feb.-May. More important to emphasise here is that in the monsoon period, CN-values are close to 100 and in the non-monsoon period, these values are close to 0. It implies that CN is a variable quantity and antecedent moisture condition plays a significant role in its determination. It is also supported by physical behaviour of soils. As the soil gets saturated with time, the infiltration amount reduces and resulting runoff increases.

4.5 Computation of Initial Abstraction, Infiltration, Rainfall Excess, Baseflow

Initial abstraction, Infiltration, rainfall excess, and baseflow form the essential components of resulting hydrographs observed in field. Their computation is necessary to signify the importance of their contribution to the whole rainfall-runoff process. All these components were computed and these are shown in Fig. 19 for Ramganga catchment and in Table 4 for Hemavati catchment. Since λ is assumed equal to 0.2 in this study, the initial abstraction is computed as 0.2 times S (Eq. 3). It is important to note that λ, however, can take any value between 0 and infinity depending on the value of initial abstraction and S.

The annual and seasonal statistics of the above Table 4 are given and Tables 5 and 6, respectively. The actual amount of initial abstraction is computed as follows. If precipitation exceeds initial abstraction (=0.2S from Eq. 3), the computed value of initial abstraction represents the actual amount whereas if the precipitation is less than the initial abstraction

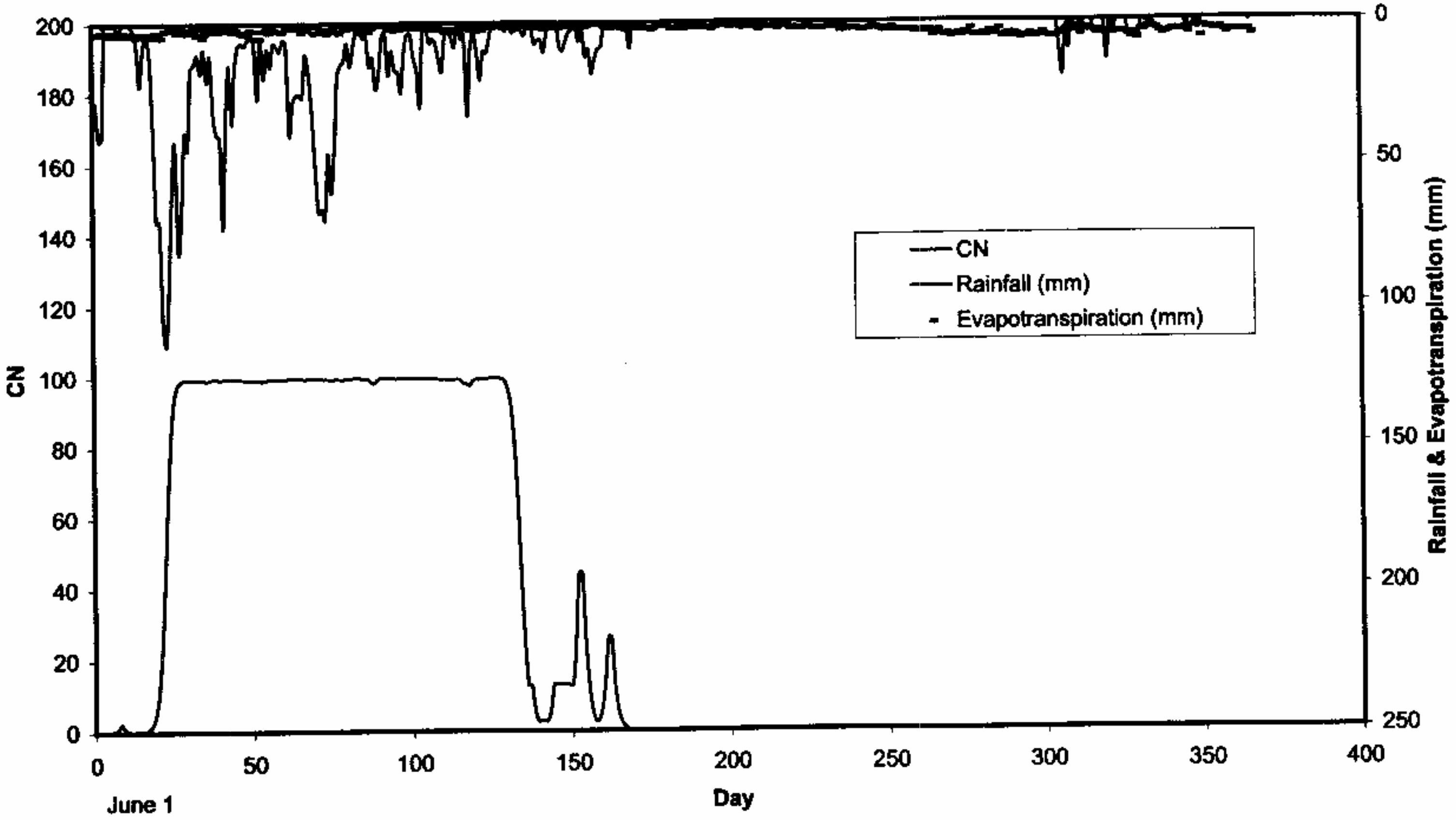

Fig. 14. Daily variation of CN with precipitation and evapotranspiration of Hemavati basin (1974-75).

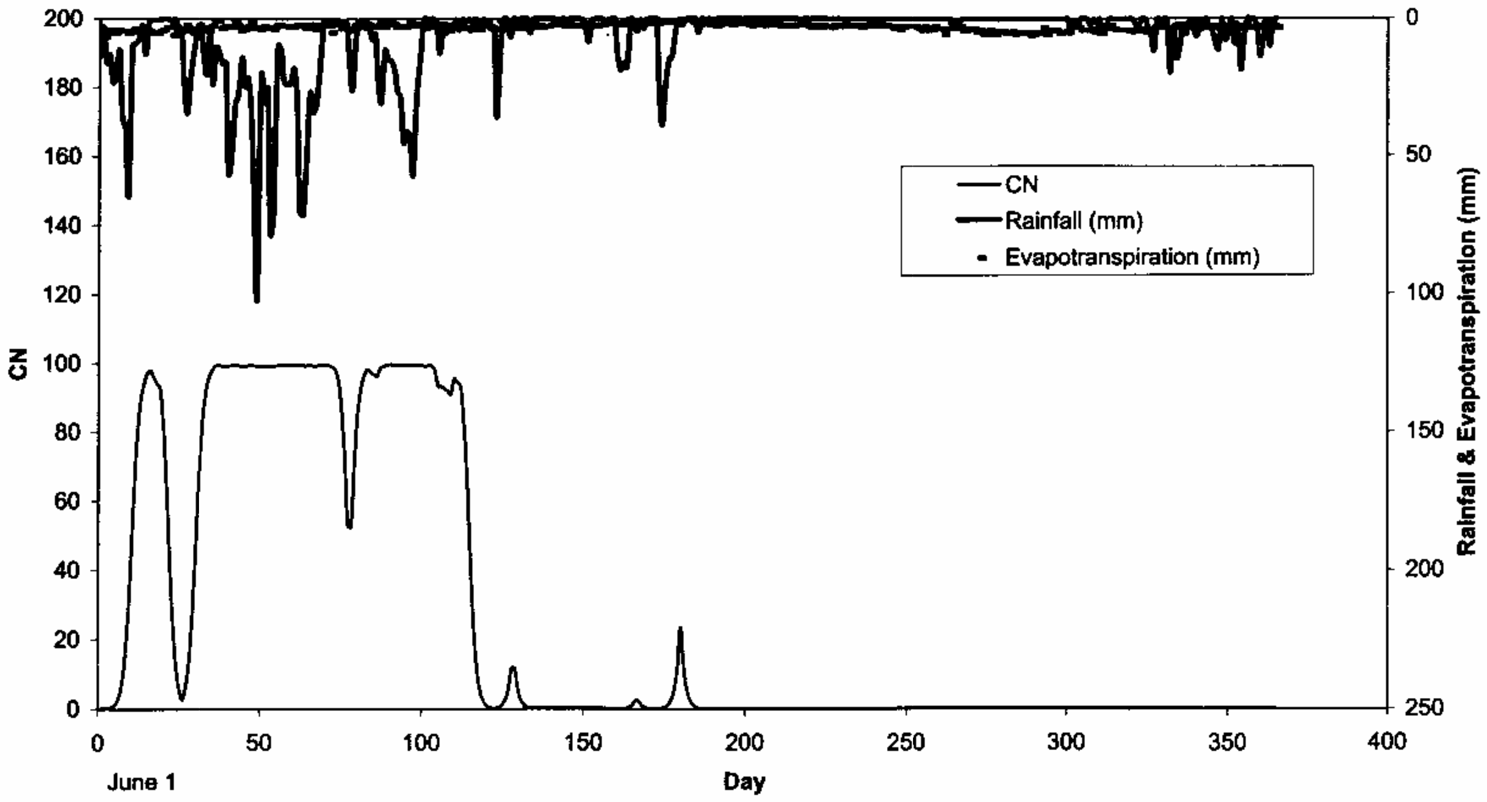

Fig. 15. Daily variation of CN with precipitation and evapotranspiration of Hemavati basin (1975-76).

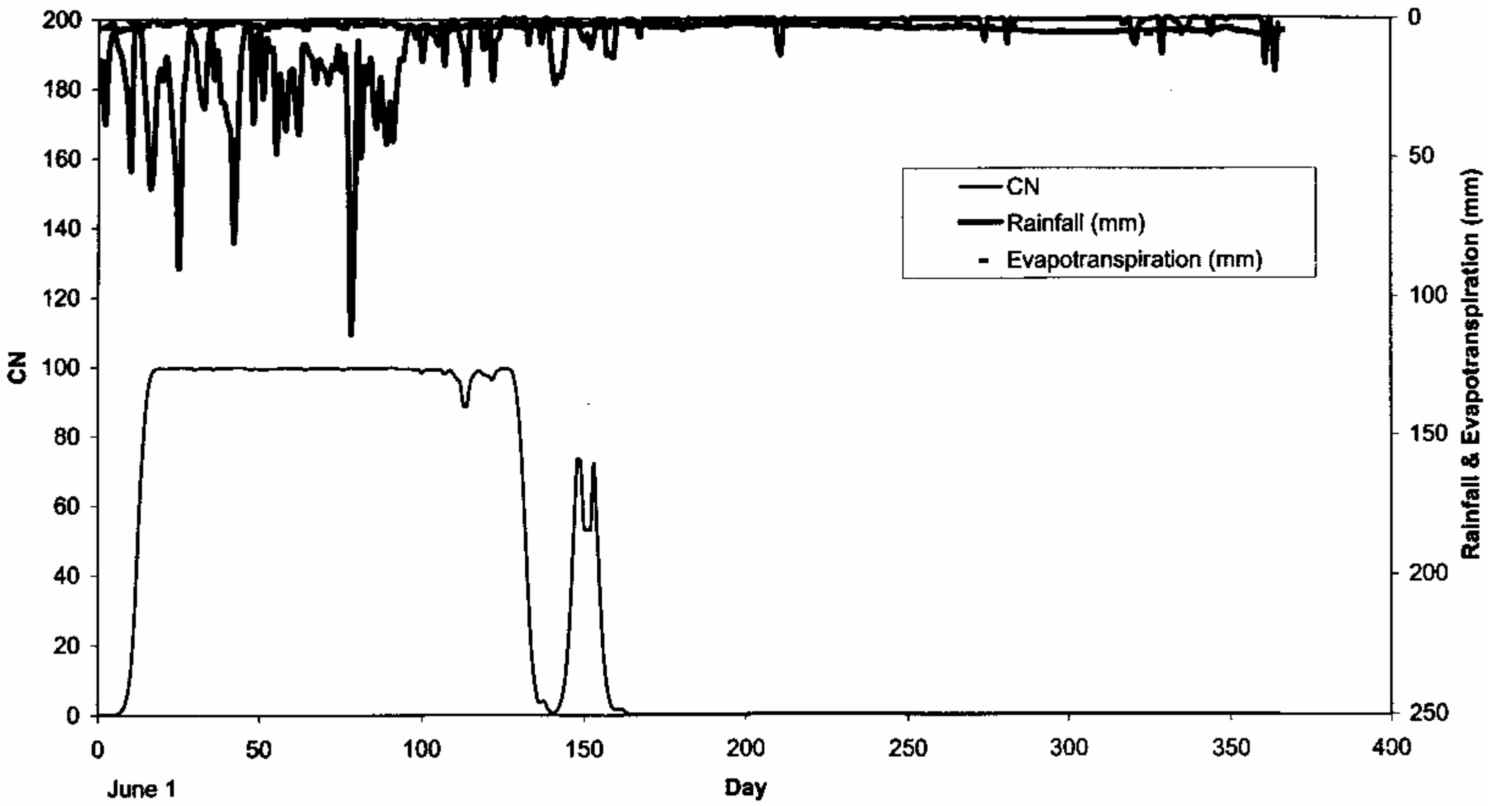

Fig. 16. Daily variation of CN with precipitation and evapotranspiration of Hemavati basin (1977-78).

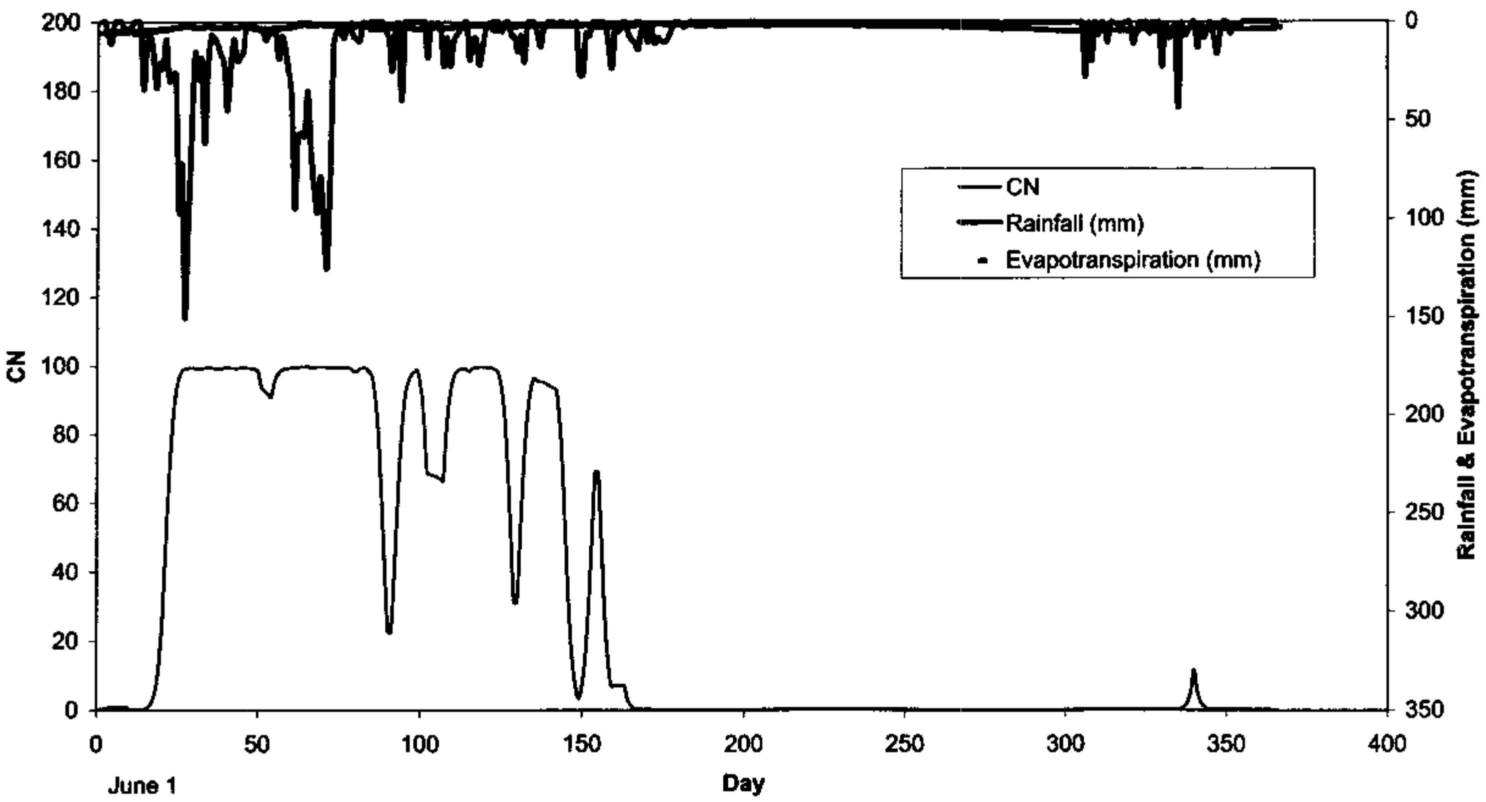

Fig. 17. Daily variation of CN with precipitation and evapotranspiration of Hemavati basin (1978-79).

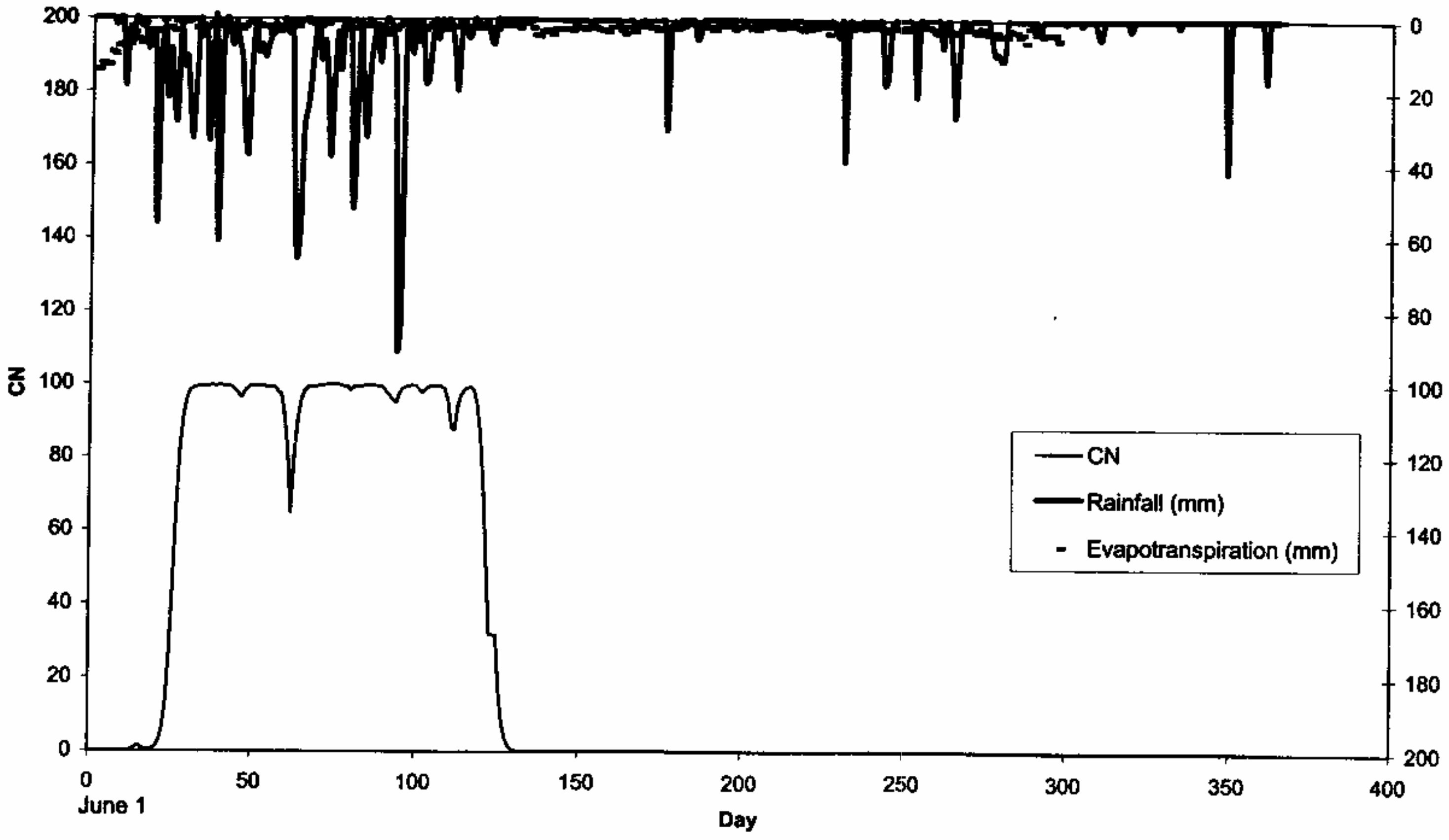

Fig.18. Daily variation of CN with precipitation and evapotranspiration of Ramganga catchment (1978-79).

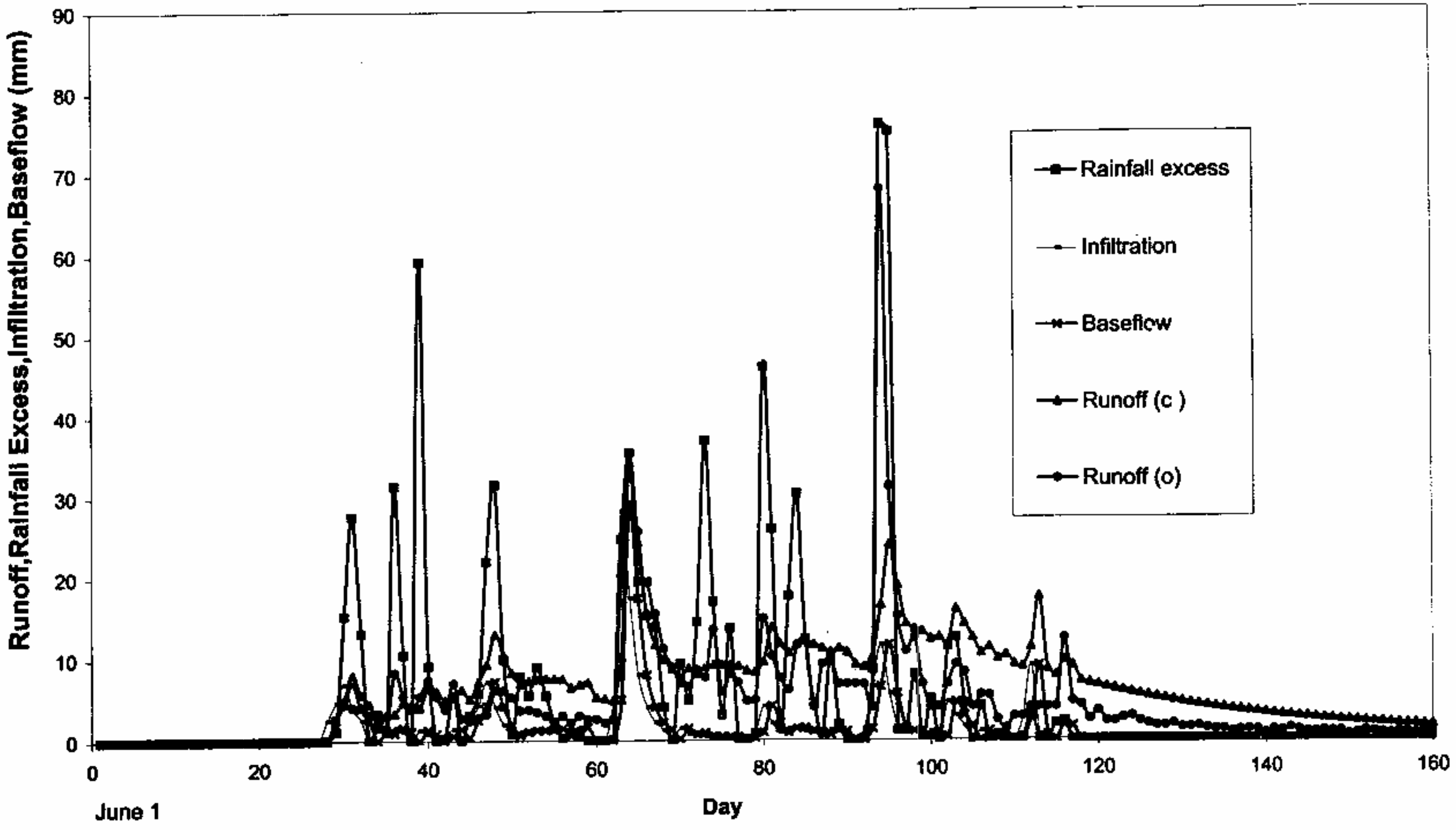

Fig. 19. Computation of rainfall excess, infiltration, base flow, and runoff using SCS-CN-based long term hydrologic model for the year 1978.

Table 4. Computational details of the hydrologic simulation using Hemavati data. (Period: June 1-Oct. 31, 1974) (Contd..)

Day	Rainfall (mm)	Evapotranspiration (mm)	CN	Initial abstraction (mm)	Infiltration (mm)	Rainfall excess (mm)	Baseflow (mm)	Runoff (c) (mm)	Runoff (o) (mm)
1	27.63	3.68	0.19	27.63	0	0	0	0	0.81
2	41.34	2.96	0.19	41.34	0	0	0	0	3.72
3	40.23	0.40	0.19	40.23	0	0	0	0	7.66
4	0.20	3.20	0.19	0.20	0	0	0	0	5.56
5	0.43	4.00	0.19	0.43	0	0	0	0	1.79
6	0.52	3.04	0.45	0.52	0	0	0	0	0.95
7	0.45	3.04	1.04	0.45	0	0	0	0	0.76
8	2.41	4.00	2.38	2.41	0	0	0	0	0.63
9	1.57	3.20	1.05	1.57	0	0	0	0	0.6
10	0.14	4.00	0.46	0.14	0	0	0	0	0.53
11	0.22	3.36	0.20	0.22	0	0	0	0	0.52
12	0.64	3.52	0.19	0.64	0	0	0	0	0.5
13	2.33	4.64	0.19	2.33	0	0	0	0	0.5
14	7.95	3.76	0.19	7.95	0	0	0	0	0.49
15	22.13	4.32	0.19	22.13	0	0	0	0	0.56
16	9.62	3.52	0.45	9.62	0	0	0	0	0.76
17	3.69	4.00	1.04	3.69	0	0	0	0	0.98
18	10.05	4.80	2.38	10.05	0	0	0	0	0.75
19	33.40	3.20	5.36	33.40	0	0	0	0	1.09
20	69.92	3.20	11.63	69.92	0	0	0	0	11.65
21	69.60	4.80	23.40	69.60	0	0	0	0	31.98
22	105.31	2.40	41.40	0.48	30.56	2.84	0	0.39	47.35
23	113.91	2.24	62.67	0.45	53.87	29.79	20.44	25.21	46.44
24	92.31	1.12	81.32	0.22	33.85	46.79	36.03	50.01	47.38
25	58.70	1.36	92.45	0.27	15.03	39.52	22.64	44.64	39.1
26	42.35	3.04	97.18	0.61	6.24	34.64	10.05	36.2	28.3
27	80.81	1.36	98.61	0.27	3.43	76.66	4.17	38.43	34.66
28	68.08	2.08	99.36	0.42	1.6	66.15	2.3	46.77	53.63
29	38.73	3.20	99.46	0.64	1.32	37.13	1.07	47.51	39.2
30	44.47	2.00	99.30	0.40	1.71	42.41	0.89	45.49	30.15
31	16.34	2.48	99.46	0.50	1.27	14.79	1.14	41.35	24.24
32	14.34	3.84	99.42	0.77	1.34	12.71	0.85	33.78	17.18
33	11.06	1.52	99.18	0.30	1.75	8.89	0.89	27.74	14.03
34	17.69	4.80	99.49	0.96	1.21	16.21	1.17	24.09	12.3
35	9.11	3.20	99.04	0.64	1.91	6.71	0.81	20.58	10.51
36	20.67	1.52	99.16	0.30	1.95	18.29	1.28	19.05	9.62
37	11.45	1.12	99.49	0.22	1.17	10.02	1.3	18.08	10.17
38	31.56	2.64	99.65	0.53	0.85	30.53	0.78	18.52	11.51
39	39.11	2.72	99.46	0.54	1.34	37.49	0.57	22.78	17.58
40	40.20	1.60	99.38	0.32	1.52	38.37	0.9	27.43	23.85
41	72.51	2.24	99.55	0.45	1.13	71.15	1.01	35.31	45.99

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