CS (AR) 134

# Daily Runoff Simulation of Hemavati at Sakleshpur using 4 X 4 TANK Model

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1993-94

# Preface

Continuous simulation of runoff from a watershed is an important component for water resources planning and design. Numerous models are available and are being used for this purpose. Tank model is one of the important model used extensively for daily runoff simulation in humid as well as non-humid basins. The main advantage of using Tank model for daily runoff simulation is its simplicity and less data requirement. Also, with its simple model structure it is capable of representing some of the complex hydrological processes while simulating rainfall-runoff response.

Applicability of Tank model is being investigated in this report by applying it to Hemavati basin at gauging site at Sakleshpur. This study is conducted by Shri Manoj Kumar Jain, Scientist B, Mountain hydrology division, National Institute of Hydrology, Roorkee.

(S. M. Seth)
Director

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# Abstract

Calibration and testing of 4X4 Tank model structure for daily rainfall runoff analysis of Hemavati at Sakleshpur is carried out. The methodology suggested by Prof. Sugawara for non-humid basins was adopted for calibration and testing of Tank model. The model was found to be capable of simulating daily runoff of Hemavati basin at Sakleshpur both for dry and wet periods except for few high peaks.

# 1.0 INTRODUCTION

For derivation of flood hydrographs, a lot of models of different types are in use. Among them are simple conceptual models or others are complex models and need a lot of hydrological and meteorological data. There are certain advantages and disadvantages with both type of models. But simple models are easier to use and are mostly recommended for practical applications.

TANK model is a simple conceptual rainfall-runoff model. The model was developed by Prof. Sugawara in Japan. The model can be applied to both humid and non humid basins. For humid basins, simple tank model where 4 tanks are laid vertically can be used. But in case of non-humid basins, 4 x 4 Tank model structure can be used because it takes into account the variability of soil moisture within the basin by dividing the whole basin into different zones.

Daily runoff analysis of runoff for Hemavati upto Sakleshpur basin is being carried out by employing a 4x4 Tank model. This report is aimed at finding out the suitability of Tank model in Western Ghats by analyzing Hemavati basin at Sakleshpur.

## 2.0 THE 4X4 TANK MODEL

The 4x4 tank model is used for daily analysis of rainfall and runoff of river basins situated in non-humid regions or the basins which experience long dry spells. In such basins some part of the basin is dry while other parts, usually along the river flat lands, may be wet, and, if it rains, discharge will occur only from the wet areas. In the dry season, the percentage of dry area in the whole basin increases with time, and accordingly, evaporation from the basin will decrease with time. To approximate such a condition, we can divide the basin into zones, as shown schematically in fig. 1 where $S_1$, $S_2$, ... is the area of each zone. Each zone can be represented by a tank model as shown in fig. 2. In these conditions we can use a tank model of m x n type , shown in fig. 3 where m is the number of zones and n is the number of tanks in each model. For each zone ( m = n = 4 in fig. 3 ) four linear tanks in series are considered to represent surface flow, intermediate flow, sub-base flow and base flow. Therefore, a non humid basin generally contains 4x4 = 16 tanks in all.

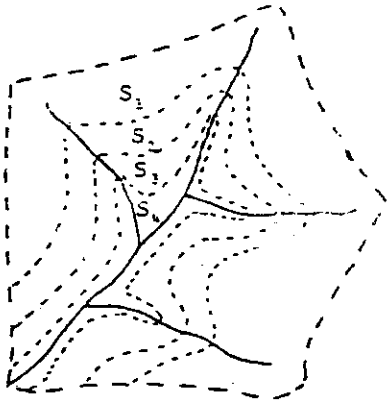


Fig. 1. A non-humid basin divided into four zones.

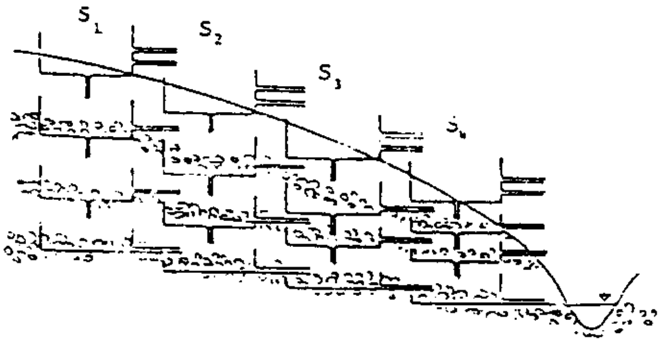


Fig. 2. 4X4 Tank model along a sloping ground of a basin.

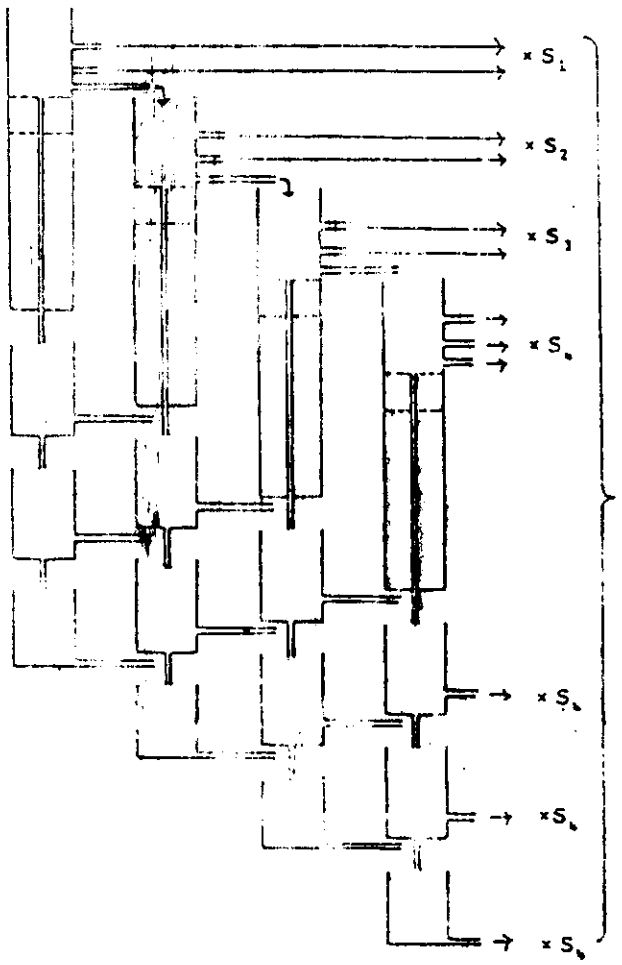


Fig. 3. 4X4 Tank model structure for non-humid basin.

In this model, water transfers in two directions, vertically and horizontally, i.e. a tank receives water from upper tank of the same zone and from the equivalent tank of the next higher zone, and supplies water to the lower tank of the same zone and to the equivalent tank of the next lower zone. The input output calculation of every tank is based on a unit of water depth, i.e. every tank is considered per unit basin area. The top tank of each zone receive rain water as input. Another water transfer is transfer to soil moisture from lower free water by capillary action.

When the dry season comes, free water of the highest zone decreases faster than that of the other zones due to water transfer to the lower zones. After depletion of free water, soil moisture begins to decrease. Due to these depletions, the highest zone becomes dry earliest and than the second zone, the third zone and fourth zone. Whereas in rainy season, the lowest (fourth) zone becomes saturated first and than the third, second and first zone.

In this model, the parameter $S_i$, the area of the Zones, are very important. If enough information and data describing the change of dry area with time are available, we can determine $S_i$ from these areas. If data are scarce, however, it is better to determine $S_i$ in the form of a geometrical progression.

## Water transfer between zones

In the Tank model, calculation of input, output and storage is done in terms of depth of water per unit area. In 4x4 Tank model water transfer take place between zones, therefore, in calculation, area of each zone must be taken into consideration. When a tank in the i th zone receives water from a similar tank of (i-1)th zone, the output of (i-1)th tank has to be multiplied by the area $S_{i-1}$ to be converted into quantity unit, and then it has to be divided by the area $S_i$ to be converted back into water depth units to serve as an input to the tank of i th zone, i.e. the output of a tank in zone (i-1) has to be multiplied by ratio $S_{i-1}/S_i$ before being used as input for a tank in i th zone, as shown in fig. 4.

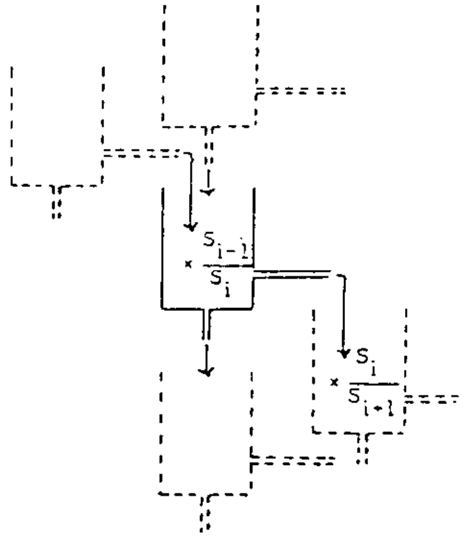


Fig. 4. Water transfer between zones.

From the same reason, for the calculation of final discharge the output of a tank in the i-th zone has to be multiplied by $S_i$, as shown in fig. 3.

## Soil moisture

The tank model as shown in Fig. 5 has a soil moisture in the top tank. When the storage XA in the top tank is not greater than S1, water can neither infiltrate nor discharge as shown in fig. 6a. In such a case XA represents primary soil moisture storage and there is no free water in the top tank i.e. when $XA \leq S1$, $XP=XA$, $XF=0$, where XP is primarily soil moisture and XF is free water. When XA is greater than S1, the excess part will infiltrate or discharge through the outlet as shown in fig. 6b. In such a case the primary soil moisture is saturated as $XP=S1$ where S1 is saturation capacity of the primary soil moisture and the free water is given by $XF=XA-S1$ i.e. when $XA>S1$, $XP=S1$, $XF=XA-S1$. To put it simply, water fill the top tank from the bottom up and lowest part form primary soil moisture storage as shown in fig. 6. There is no soil moisture structure in lower tank since they are considered to be always saturated.

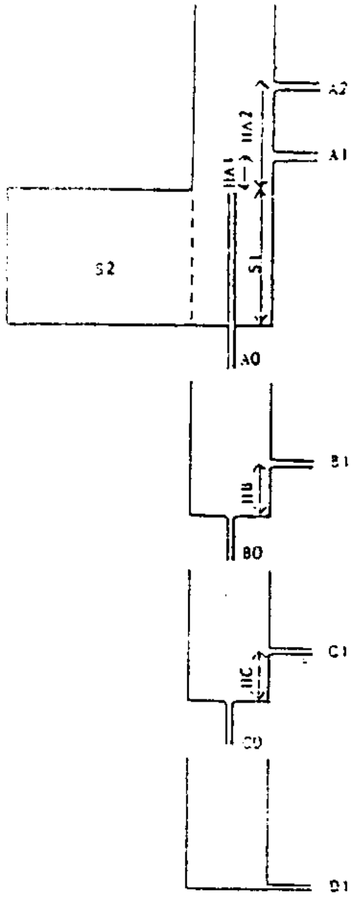
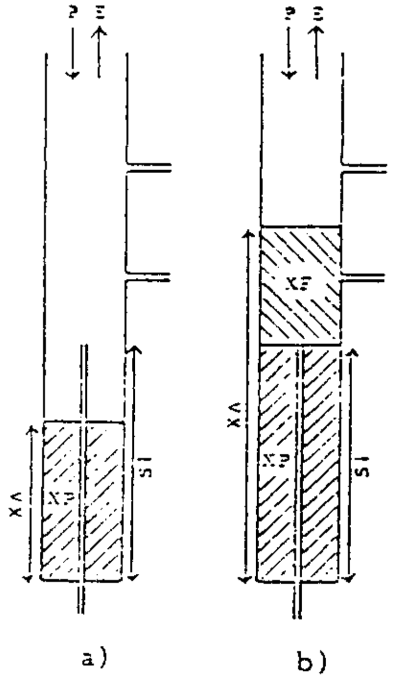


Fig. 5. Tank model structure.



a) b)

Fig. 6. Soil moisture structure for daily analysis.

Besides primary soil moisture storage, there is a secondary soil moisture storage situated alongside of primary soil moisture storage as shown in fig. 5. Input (precipitation) fills, at first, the primary soil moisture storage, and then, gradually penetrates the secondary soil moisture storage as shown in fig. 7. Evaporation, when it occurs, is subtracted from storage XA and the primary soil moisture storage becomes dry, then, gradually, water returns from secondary soil moisture storage. The volume of water exchange between primary and secondary soil moisture storage is assumed to be

$$K2 * ( XP/S1 - XS/S2 )$$

Where k2 is some constant, XP(XS) is the volume of primary (secondary) soil moisture storage and S1(S2) is the saturation capacity of primary (secondary) soil moisture storage. If this term is positive, water transfers from primary soil moisture storage to secondary soil moisture and vice versa. As XP/S1 and XS/S2 define the relative humidity of both soil moisture storage, this term also means that water transfers from the wet part to dry part of soil, with the rate proportional to the difference to then relative humidities.

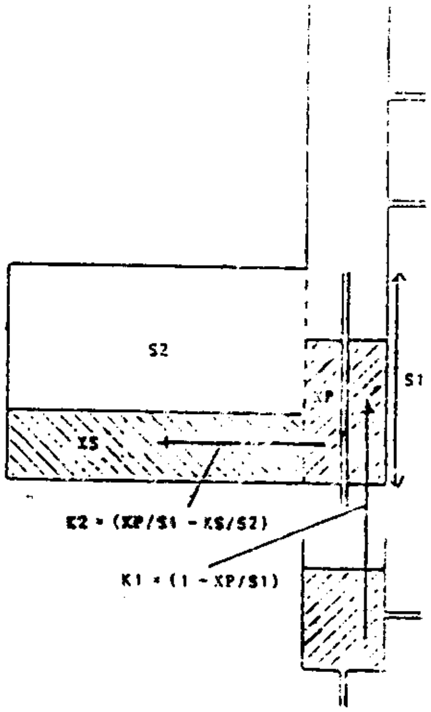


Fig. 7. Water transfer between primary and secondary soil moisture zones.

When the primary soil moisture storage is not saturated, water is supplied to this storage from the free water in the lower tank. The volume of water is given by the expression.

K1 * (1 - XP/S1)

As XP/S1 is the relative humidity of primary soil moisture storage, the above term means that the primary soil moisture structure absorbs the water from free water in the lower tank at a rate proportional to its relative dryness. The water supply to the primary soil moisture storage from free water is subtracted from the second tank, if there is some free water, and if the second tank is empty, water supply is subtracted from third tank if there is water and so on.

S1, S2 , K1 and K2 depends on basin conditions, but usually in earlier trails these values are set as follows as initial values:

S1 = 15-50 mm, S2 = 15-300 mm,
K1 = 2-5 mm/day and K2 = 10-20 mm/day

## River channel deformation

Output from the Tank model goes into river channel where its hydrograph is deformed by storage effect of the channel. Three types of channel deformation are considered.

### (a) Type I

Type I is the same as the usual tank which has two side outlets. Calculation of ratio is also the same as usual tank as shown in fig. 8.

$$\left.\begin{array}{l} Y2 = (XCH-H) * CH2 \\ Y1 = XCH * CH1 \end{array}\right\} Y = Y1+Y2$$

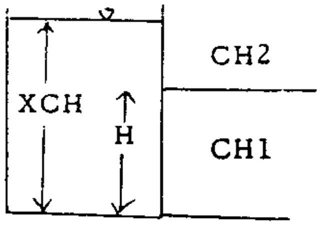


Fig. 8. Type I channel deformation.

(b) Type 2

This type is used when discharge are very small. it has a structure for initial loss at the bottom as shown in fig. 9, if necessary

$$\begin{array}{l} Y = A * (XCH-H) ** 2 \\ \qquad\qquad \text{if } (XCH-H) \text{ .LE. } XO \\ Y = 2. * A * (XCH-H) * XO-A * XO ** 2 \\ \qquad\qquad \text{if } (XCH-H) \text{ .GT. } XO \end{array}$$

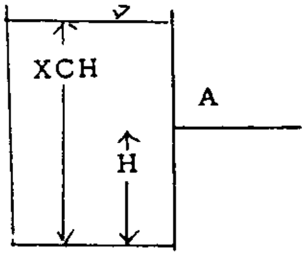


Fig. 9. Type II channel deformation.

where,

XO is set to 0.8/(2.* A), the value 0.8 may be modified between 0.5 - 0.9 if necessary.

## Type 3 (Inundation type)

This type is used in the basin in upper part of which some inundation happen. The quantity (Y) from the river channel tank of this type can be calculated as follows.

Y = ( SQRT( CX1 * CX1 + 2. * CX2 * XCH ) - CX1 ) / CX2

CX1 and CX2 are constants which must be determined by trial and error method. CX1 may be between 1 and 3 . CX2 is say, 0.2-0.4

## Data Requirement

### (a) For calibration

Following data is needed for calibration of the model.

i) Daily rainfall values of various raingauge stations lies in the catchment or situated nearby

ii) Daily discharge values at the outlet of the basin.

iii) Daily mean evaporation value for the basin. If observed evaporation values are not available for the period under consideration, monthly mean of daily evapotranspiration values may be used.

iv) Catchment area

v) Topographic and geomorphological map of the basin, if available, to ascertain roughly the upper and lower bounds of soil moisture parameter values.

vi) Ratio of zonal areas: This can be roughly ascertained by topographic, soil, vegetation and land use map of the area. If nothing is available, these can be finalized by trial and error or may be given as geometric progression.

### (b) Data required for operation of 4x4 Tank model

Once the Tank model for daily analysis is calibrated, it requires daily rainfall and daily evapotranspiration data for further periods for which daily discharge values need to be simulated.

## 3.0 THE STUDY AREA AND DATA AVAILABILITY

### 3.1 The Study Area

The Hemavati, a tributary to Cauvery, takes its origin near Darali in Mudigere taluk of Chikmangalur district in Karnataka and follows south easterly course in the study area which comprises of the 632.1 square kilometer head water catchment of the Hemavati defined by the WRDO gauging site at Sakleshpur. The Hemavati basin up to Sakleshpur lies between 12°55′ and 13°11′ north latitude and 75°20′ and 75°51′ east longitude in the south western parts of Chickmaglur and Hassan districts. The area is a typical example of monsoon type of climate. It is a hilly catchment with steep to moderate slopes. The area is covered under survey of India toposheet No.48 0 and 48 P. Fig. 10 shows the map of the study area. Detailed geomorphological properties of the study basin are given in Technical Report No. 127 (Jain, 1992) National Institute of Hydrology, Roorkee.

### 3.2 Data Availability

Following data were available and used for calibration and testing of 4x4 Tank model.

1. Daily rainfall data of five rain gauge stations. Namely Arehalli, Kotigere, Hanbal, Mudigere, Sakleshpur from June 1975 to May 1981.
2. Daily discharge data at Sakleshpur from June 1975 to December 1980.
3. Daily pan evaporation data from June1975 to December 1980.
4. Soil type and land use information
5. Topographic map of the basin

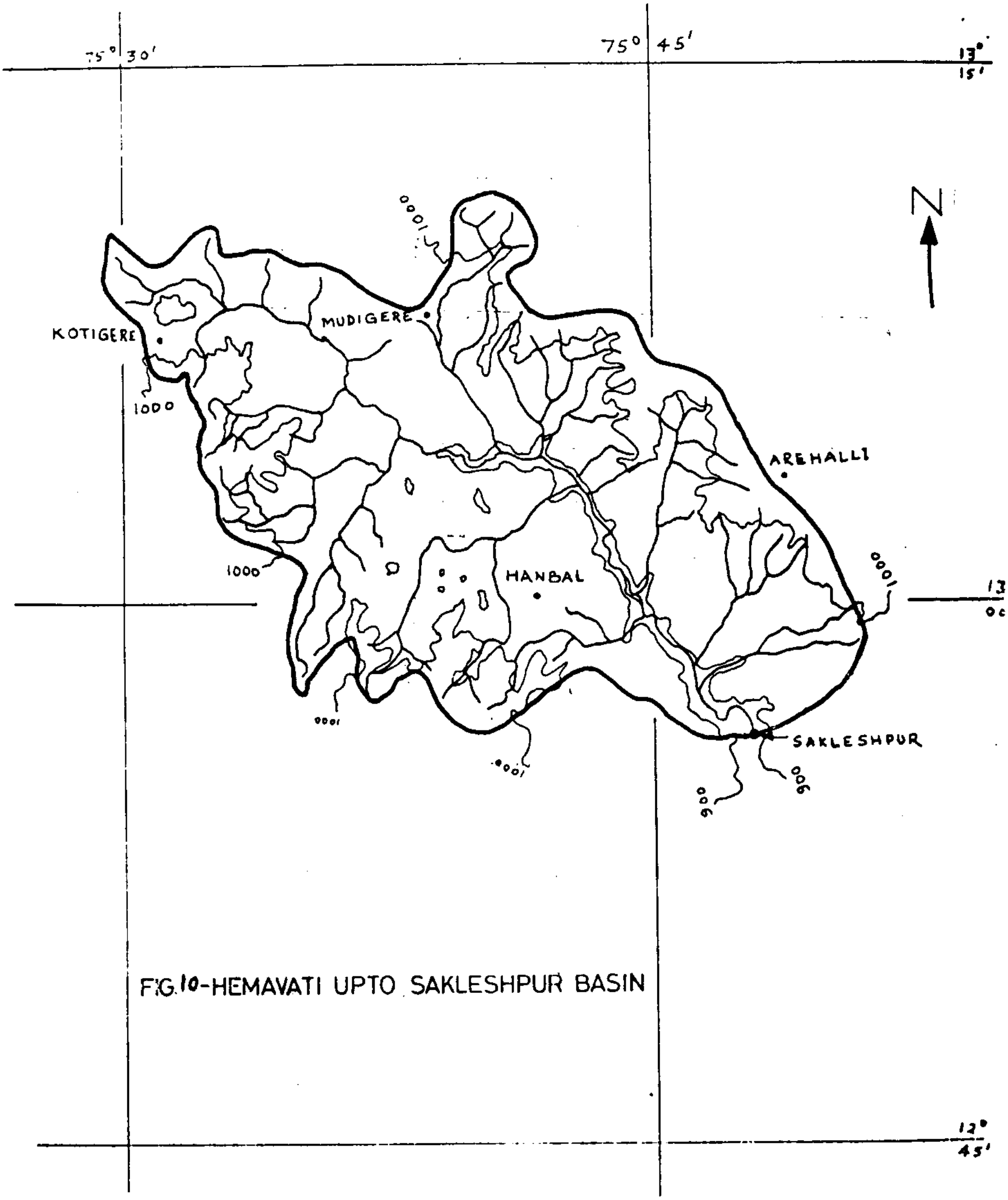


FIG.10-HEMAVATI UPTO SAKLESHPUR BASIN

## 4.0 METHODOLOGY

While calibrating the Tank model following guidelines should be kept in mind.

1. A minimum of four years of continuous daily discharge, rainfall and evaporation data are necessary. A period of ten years continuous data containing both wet and dry years is a good choice.

2. Hydrograph plotting - observed discharge data are plotted in logarithmic scale against time in natural scale. A rough estimation of time constant of runoff, TC, is made from recession slope of the flow hydrographs.

3. Initial Tank model parameters - Decreasing ratio $\alpha$ is calculated as 1/TC . From the value of $\alpha$ the discharge coefficients and initial losses are calculated all zones for top tank, second tank and third tank using the equations

$$A0 = A1 = A2 = A3 = \alpha/2$$

$$B0 = B1 = \alpha/10$$

$$C0 = C1 = \alpha/50$$

The values of initial losses are selected from the following ranges

HA1 = 0-15 (mm),
HA2 = 15-40 (mm),
HA3 = 40-60 (mm),
HB = 5-15 (mm),
HC = 5-15 (mm)

4. Input precipitation - weighted mean values of the rainfall stations for the basin are generally considered. For simplicity simple mean of rainfall stations may also be considered.

5. Time Lag (LAG) - Unit of time lag is one day. Initial time lag is considered to be zero.

6. Evapo(transpi)ration (E) - If observed evapo(transpi)ration data are available from number of stations within the basin or near the basin, then mean daily evapo(transpi)ration values are computed and used for analysis. If no such data are available for the period under consideration monthly mean of daily evapo(transpi)ration value for that region may be used.

7. Initial storage (XA, XB, XC, XD) - Initial amount of storage of the fourth tank can be decided from long duration of dry period. For first trial, initial value of storage for all tanks and all zones may be set to zero.

8. Correction Factor for Precipitation - For initial trial, the values of correction factors CP & WE are usually considered as 1.0

Main steps to be followed in calibration are as follows:

a) Observing and comparing the calculated and observed hydrographs, if it is found that nth runoff component takes the main part then the parameter of nth tank is adjusted.

b) If the parameter of side outlet is increased and that of bottom outlet is decreased of the nth tank keeping their sum unchanged then the amount of discharge increases without changing the form of the hydrograph and vice versa.

c) If both the parameters of side outlet and bottom outlet of nth tank are increased then the recession slope corresponding to nth tank becomes steeper.

d) If the parameter of top side outlet of top tank is decreased and that of lower outlet is increased then hydrograph of large flood becomes steeper whereas for smaller flood it becomes smoother.

e) The positions of the side outlets, determined by thee parameters HA1, HA2, HA3 , HB and HC, are useful for representing initial losses of surface flow, inter flow and base flow.

f) Different values of primary and secondary soil moisture may be considered for each zone depending on the situation.

g) Aerial ratio of zones S1:S2:S3:S4 is an important parameter in this model. These ratios can be determined if the detailed information, regarding drainage area, topography vegetation and soil of the basin are available. .If no such information are available, the ratio can be determined by trial and error. Usually for convenience of taking different trials, the ratios of areas are assumed to be in geometrical progression.

h) After obtaining fairly good result by adjusting the above stated parameters , calibration of the weights of rainfall station begins.

i) When there are number of rainfall stations and data of each rainfall stations are considered as a part of the input, then on comparing the simulated hydrograph with observed one suitable time lags are provided to the stations depending on the distance of rainfall stations from the observed discharge site.

j) Usually same amount of initial storage are considered . But depending on antecedent rainfall and soil moisture condition different initial storage may be considered subject to further adjustment.

k) Correction factor for the precipitation is provided when the depth of calculated discharge differs considerably from the observed one. Generally same value of correction factor is provided to all precipitation stations. But in some cases, it becomes necessary to provide different correction factors to different precipitation stations depending on its topographic location, orographic effect etc.

l) Correction factor for channel deformation is also provided depending on the situation.

m) During calibration it is very important to keep in mind that parameters are to be changed and adjusted one by one in successive trials. Usually it is better to adjust the tope tank first, then the second tank, the third tank and so on. But in case of significant difference between calculated and actual base discharge, the parameter corresponding to fourth tank requires to be adjusted first.

n) It is important to make a well balanced general outline first and then fine adjustment are to be made.

## 5.0 CALIBRATION OF THE MODEL

As reported earlier, rainfall and runoff data for six years are available. For calibration and testing of the model, the data is divided in two parts. i.e. from June 1975 to Dec 1977 and Jan. 1978 to Dec. 1980. Out of these two groups, the first group data i.e..June 1975 to Dec. 1977 were used for calibration of the model.

For calibrating the model, the methodology described in section 4.0 is used and accordingly values of different parameters for first trial run were fixed and are summarized below.

1. Observed daily discharge data were plotted on semi-log paper and from the recession slope of the plot average value of decreasing ratio $\alpha$ have been calculated as 0.20.

2. Using the value of $\alpha$ as 0.20 , initial set of parameter values for four tanks were calculated as

Top tank $A0 = A1 = A2 = A3 = 0.100$
2nd tank $B0 = B1 = 0.02$
3rd tank $C0 = C1 = 0.004$
Bottom tank $D0 = 0.00$ $D1 = 0.0001$

3. Side outlet heights as

HA1 = 8 for all zones
HA2 = 25 for all zones
HA3 = 40 for all zones
HB = 8.0

HC = 8.0

HD = 0.0

4. Initial storage for all tanks and all zones was initially assumed to be zero.

5. Primary soil moisture S1 and secondary soil moisture S2 was initially set to 50 and 250 mm for all zones.

6. Transfer rate of water K1 = 5.0 and K2 = 10.0

7. Station weights for all stations unity

8. Multiplication factor for basin precipitation = 1.0.

9. Time lag = 0.0

10. The study basin is a hilly region, as such the zoning has been done according to the slopes. The first zone consists of steep slopes with generally exposed rocks and very little vegetal cover. Second zone represents flatter slopes. Third zone consists of plain areas and fourth zone consists of almost submerged areas of river channels. The values calculated are as follows:

S1:S2:S3:S4 :: 0.60:0.25:0.10:0.05

11. Saturation height of top tank HS = 200 mm

12. Initial storage height of secondary soil moisture of each of top tank

13. Multiplication factor of basin precipitation for each month from January to December as unit.

14. Multiplication factor for basin evapotranspiration for each month from January to December was set to 0.80.

By taking above mentioned parameter values, the first trial calibration run of the model was taken with the data set of the period June 1975 to Dec. 1977. It was observed from comparison of observed and predicted plots of runoff that the model is over estimating high and low flows in initial months and under estimate high and low flows in end months of the year. Accordingly soil moisture parameters and infiltration and discharge coefficients of top, 2nd, 3rd and 4th tanks were modified in successive runs and set of parameters which given good matching of observed and computed hydrograph were obtained.

After close examination of the results, it was noticed that the model under predict overall runoff hydrograph for months of July, August and September . Accordingly multiplication factor for evapotranspiration for these months were adjusted. Thiessen weights for all the five rain gauge stations were also considered. But it was noticed that giving equal weight to all stations give better results.

The final calibrated parameters of 4x4 Tank model for study basin are given Fig. 11. Other parameters which are not shown in figure 11 are as follows:

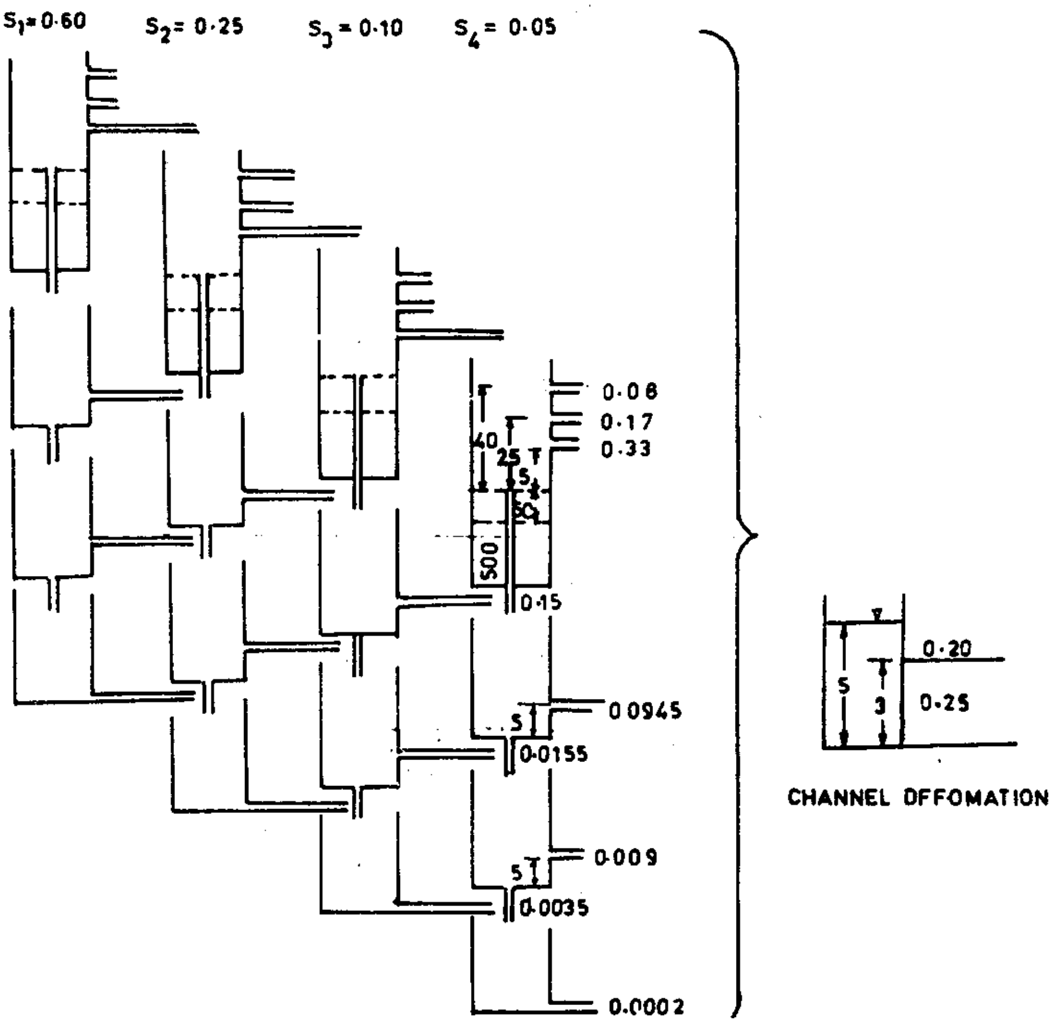


FIG.11 4x4 TANK MODEL FOR DAILY ANALYSIS OF HEMAVATI UP TO SAKLESHPUR BASIN

| zone | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| XA | 0.0 | 0.0 | 0.0 | 0.0 |
| XS | 10.0 | 10.0 | 10.0 | 10.0 |
| XB | 20.0 | 20.0 | 20.0 | 20.0 |
| XC | 50.0 | 50.0 | 50.0 | 50.0 |
| XD | 100.0 | 100.0 | 100.0 | 100.0 |

PP(I) = 1.0 for I = 1,5

PA = 1.0

PB(I) = 1.0 for I = 1,12

$K_1$ = 2 mm/day, $K_2$ = 10 mm/day

lag = 0

ED1 = ED2 = ED3 = ED4 = ED5 = ED6 = 0.80

ED7 = ED8 = ED9 = 0.40

ED10 = ED11 = ED12 = 0.80

Plot of observed and simulated hydrographs with final calibration parameters are shown in Fig. 12, 13 and 14 for year 1975, 1976 and 1977 respectively.

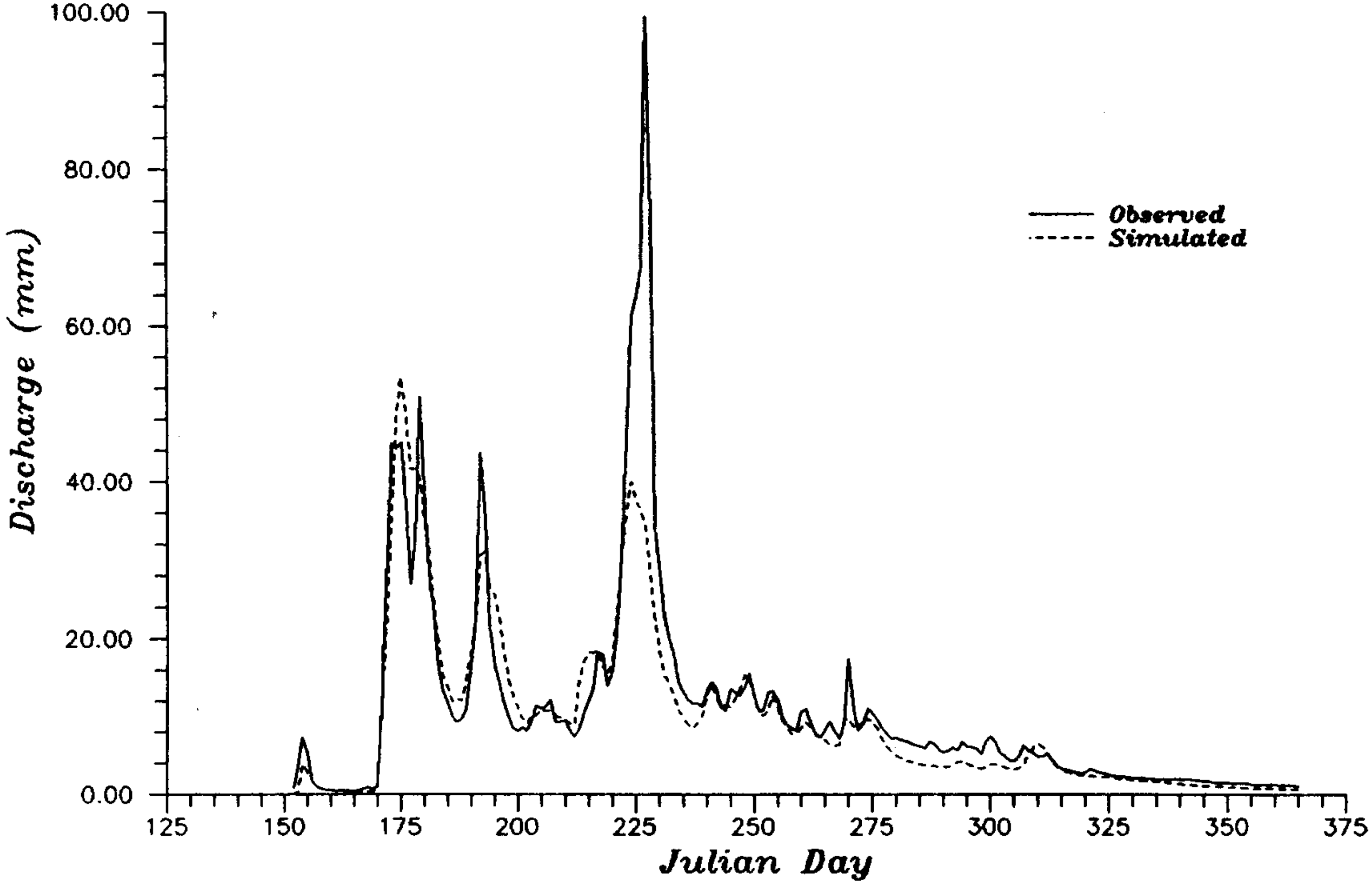


*Fig.* 12. *Observed and simulated daily discharge*
*( Year – 1975 )*

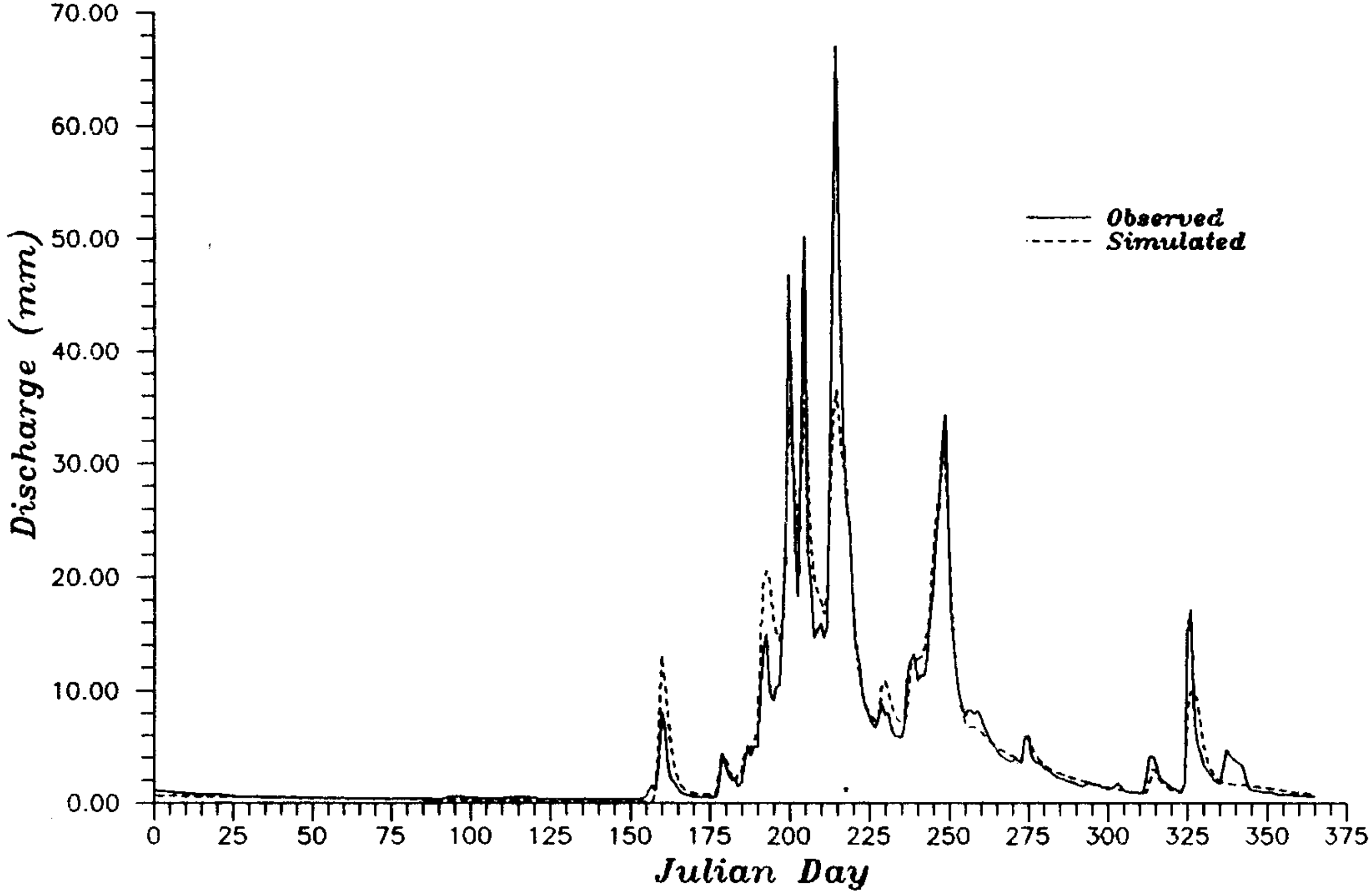


*Fig.* 13. **Observed and simulated daily discharge**
( Year – 1976 )

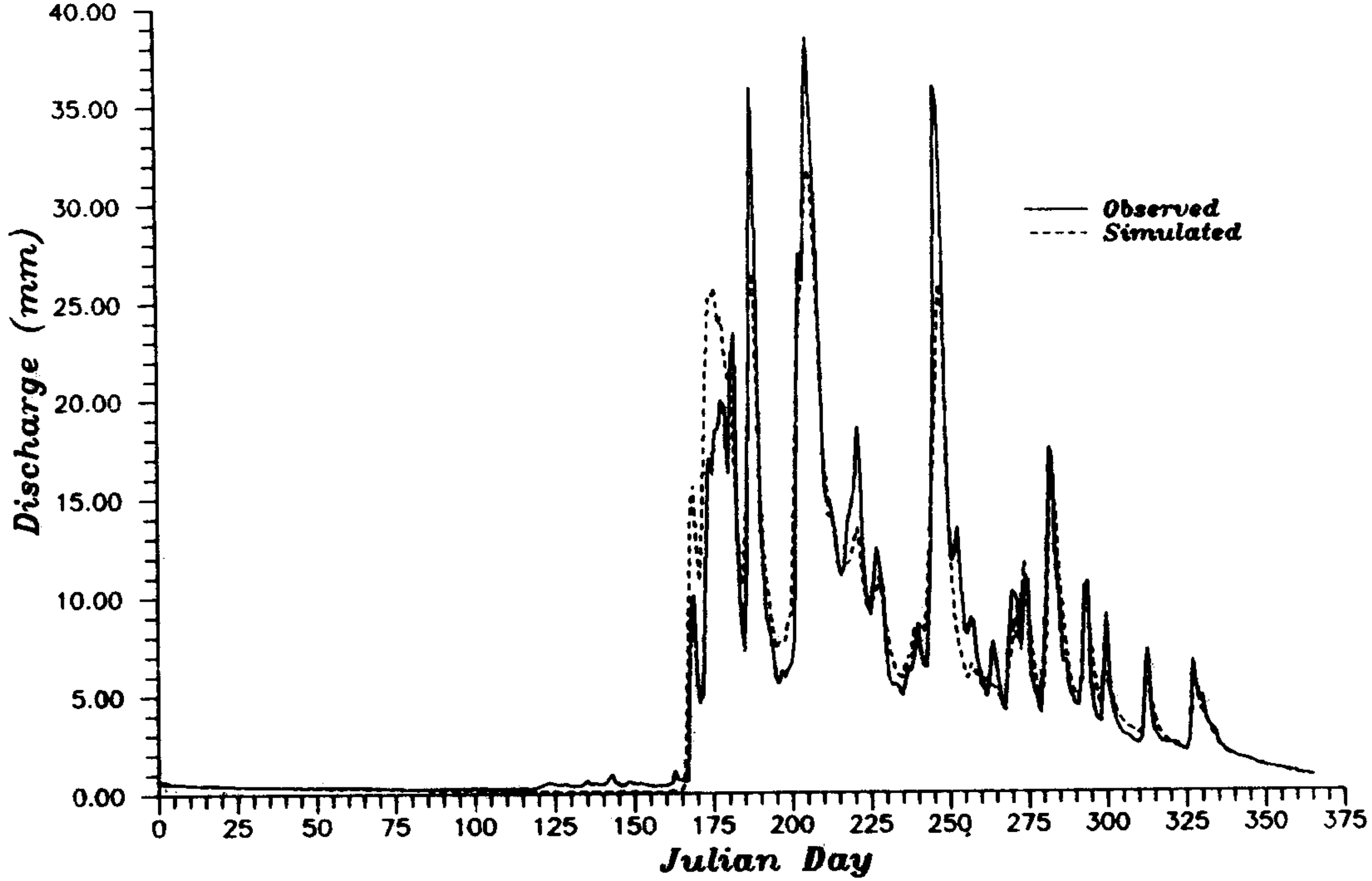


*Fig.* 14. ***Observed and simulated daily discharge* (*Year – 1977*)**

## 6.0 RESULTS AND DISCUSSION

The final calibrated model was tested with remaining three years of data i.e. data of 1978, 1979 and 1980. Plots of observed and computed hydrographs for test period are shown in fig. 15, 16 and 17 for 1978, 1979 and 1980 respectively. From the plot of hydrographs, it can be seen that the model reproduces the flow for monsoon and lean period reasonably well except for few high peaks. To evaluate the model performance, the volume of annual flows for calibration and validation period for observed and predicted flows were calculated and are tabulated in Table. 1. It can be seen from the table the observed and computed flow volume match reasonably well both for calibration and validation.

Table 1. Comparison of Observed and Simulated Annual Discharge.

| Year | Observed | Simulated | % relative error |
|---|---|---|---|
| 1975 | 2345.51 | 2050.50 | 12.57 |
| 1976 | 1648.66 | 1647.43 | 0.07 |
| 1977 | 1816.04 | 1814.57 | 0.08 |
| 1978 | 2767.83 | 2151.97 | 22.25 |
| 1979 | 1963.07 | 2014.80 | -2.63 |
| 1980 | 2622.90 | 2460.44 | 6.19 |

From the analysis it is observed that 4X4 Tank model is a suitable daily rainfall runoff model for Hemavati basin. The model, besides having simple structure is quite versatile and may have wide range of applicability.

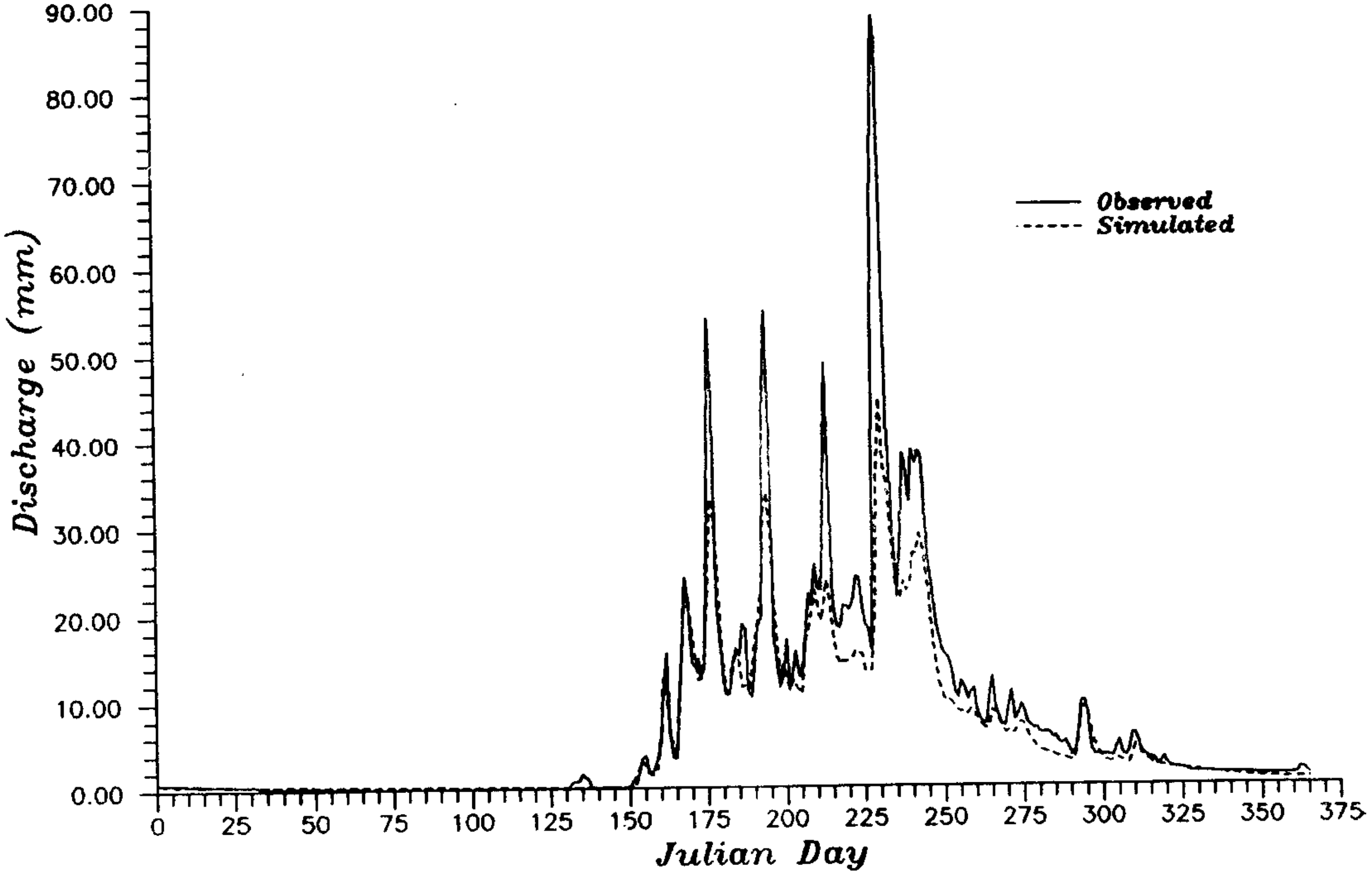


*Fig.* 15. ***Observed and simulated daily discharge***
***( Year - 1978 )***

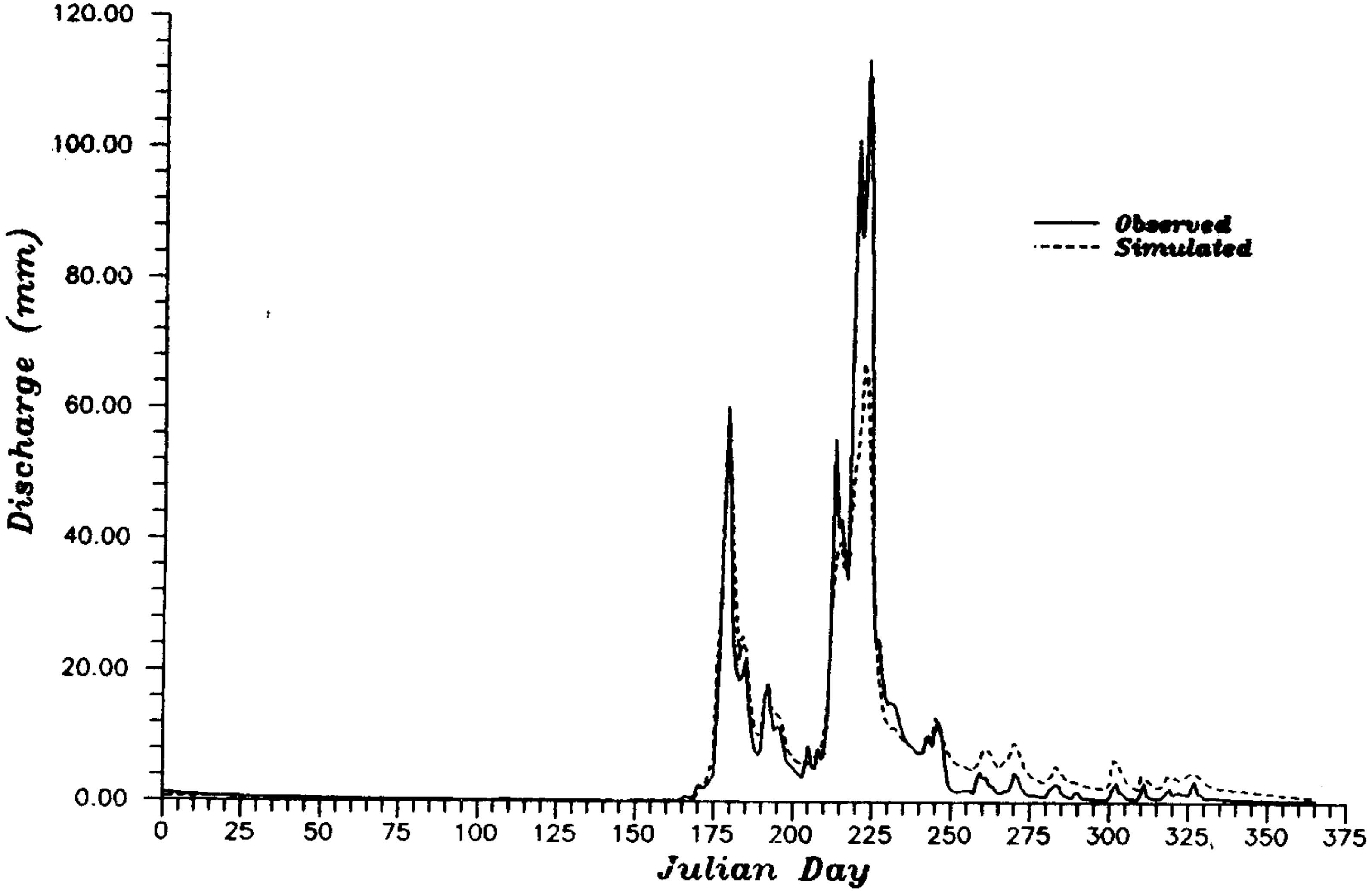


Fig. 16. *Observed and simulated daily discharge ( Year – 1979 )*

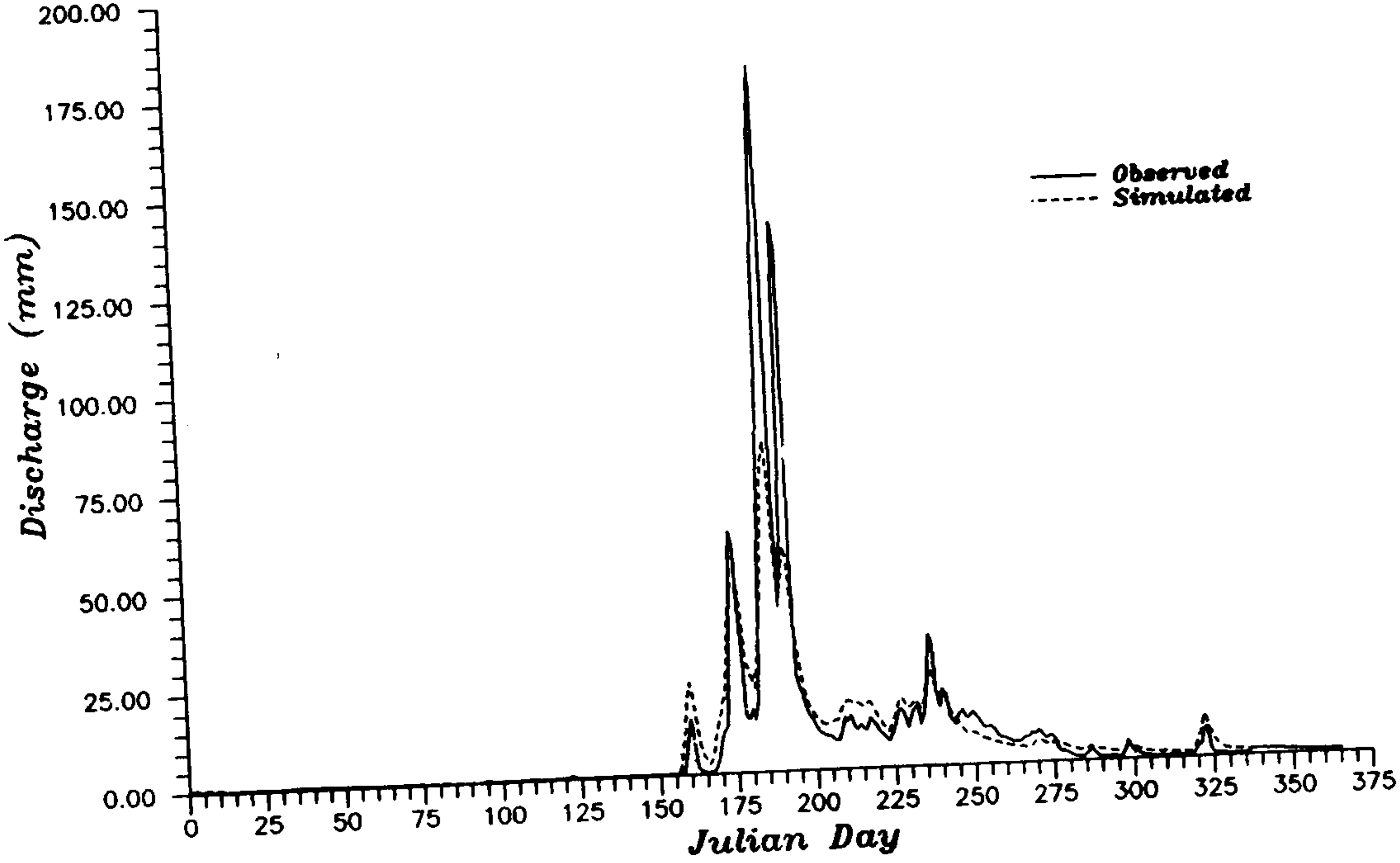


*Fig.* 17. ***Observed and simulated daily discharge***
***( Year – 1980 )***

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