CS - 5

SIMULATION OF DAILY RUNOFF OF TWO SUB-BASINS OF RIVER NARMADA USING TANK MODEL

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CONTENTS

LIST OF SYMBOLS

α	=	Decreasing ratio
T	=	Time constant
X	=	Storage
Y	=	Discharge
E	=	Evapotranspiration
Ao	=	Coefficient of discharge of bottom outlet of top tank (measure of infiltration rate from top strata)
A1,A2,A3	=	Coefficient of discharge of first second and third side outlets of top tank(measure of surface runoff rate from top tank)
Bo	=	Coefficient of discharge through bottom outlet of second tank (measure of percolation).
B1	=	Coefficient of discharge through side outlet of second tank.(measure of intermediate flow)
Co	=	Coefficient of discharge through bottom outlet of third tank (measure of deep percolation).
C1	=	Coefficient of discharge through side outlet of third tank (measure of sub-base flow)
D1	=	Coefficient of discharge through side outlet of fourth tank(measure of baseflow).
HA_1, HA_2, HA_3	=	Head for first,second and third side outlets of top tank (measure of initial losses).
PS	=	Saturation value of primary soil moisture
SS	=	Saturation value of secondary soil moisture
XP	=	Initial storage of primary soil moisture

XS	=	Initial storage of secondary soil moisture
XA,XB,XC, XD	=	Initial storage of top tank, second tank, third tank and fourth tank of each zone.
T_1	=	Transfer velocity of water from lower strata to fulfil the primary soil moisture under capillary action.
T_2	=	Transfer velocity of water from primary to secondary soil moisture.
Y_1, Y_2, Y_3, Y_4	=	Discharges respectively from top tank, second tank, third tank and fourth tank.
S_1, S_2, S_3, S_4	=	Ratio of area of different zones of the basin from mountain side zone to river side zone.
C_p	=	Weightage of precipitation
We	=	Weight of discharge

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The methodology for Tank model as developed by Sugawara (1967) for daily analysis has been used to develop 4 x 4 Tank model for two sub-basins Jamtara and Ginnore in Narmada basin. Jamtara basin is the basin of river Narmada from its source at Maikala hill range upto discharge measuring site at Jamtara having catchment area of 16575 sq.km. The basin experiences 86% of average annual rainfall in four Monsoon months from June to September. Using the available daily data of 1978 and 1979, 4 x 4 Tank model of Jamtara basin has been calibrated.

Ginnore basin is the basin of river Chhota-Tawa, a left bank tributory of river Narmada, from its source at Satpura range in the West Nimar district of Madhya Pradesh at an elevation of 600 meter to its gauging station at Ginnore having a catchment area of 4816 sq.km. The Ginnore basin is located in the lower plains zone of Narmada basin. The river Chhota-Tawa joins the river Narmada at 829 km. from its origin. Average annual rainfall of the basin is 855.0 mm and 90% of it falls during four Monsoon months from June to September. The basin contains permanent ordinary raingauge and self recording raingauge stations at Khandwa and Punasa. Punasa station is situated little outside of the basin, north of Khandwa station. Daily rainfall of Khandwa and Punasa stations, daily runoff at Ginnore and monthly mean of daily E.T.values of 1972 and 1973 have been used to calibrate the 4 x 4 Tank model. The model has been used to simulate daily runoff of the basin for 1974, to test its performance. The simulated runoff of 1974 is then compared with the observed runoff and the performance of the model is found to be good.

From the present analysis it is observed that the 4 x 4 Tank model

is a suitable daily rainfall runoff model for simulation of daily runoff for basins in India which experience nearly 75% to 90% of annual rainfall during monsoon season followed by long dry period in non-monsoon months.

1.0 INTRODUCTION

Different rainfall runoff models are in use in India for simulation of daily runoff. Tank model is a simple conceptual rainfall runoff model developed in Japan by Sugawara (1967). The model considers total rainfall as input and gives total runoff as output. The model has the capability to simulate both flood and daily runoff. He first developed Tank model for flood analysis composed of three tanks laid vertically in series. Sugawara subsequently developed daily analysis model, applicable to humid basins so as to suit Japanese conditions. In Japan rainfall is high and distributed almost throughout the year, so that the soils always remain in near saturated conditions. But in India conditions differ widely ranging from arid to very humid. Annual rainfall varies from less than 200 mm in Western desert area to more than 4000 mm in the North Eastern and in the Western ghats areas. Moreover, the rainfall is not uniformly distributed throughout the year. In major part of India southwest monsoon is responsible for 75% to 90% of annual rainfall in four monsoon months from June to September and mainly dry weather prevails in the remaining seven months. To take into account the variation of soil moisture in non-humid basins experiencing long dry period, the 4 x 4 Tank model structure developed by Sugawara could be used by considering such variations by dividing the basin generally into four zones.

Salient features of Tank model and 4 x 4 Tank model for daily analysis and its application to Jamtara, and Ginnore sub-basins in Narmada basin having catchment area of 16575 and 4816 sq.km respectively and the performance of the model have been described in the subsequent sections.

2.0 REVIEW

Sugawara (1967) has applied Tank model for flood analysis and daily analysis to number of basins in Japan and other countries. Tank model has been considered as one of the models in intercomparison of conceptual models by WMO and has been included in WMO report No.429 (1975) entitled " Inter Comparison of Conceptual models used in Operational Hydrological Forecasting". He has analysed the data of six basins as prescribed by WMO for comparison, namely Bird Creek (Oklahoma, USA, C.A = 2344 sq.km.), Wollombi Brook (New South Wales, Australia C.A = 1592 sq.km.) Bikin river (East Siberia, USSR, C A = 13100 sq.km.) Kitsu river (Kyoto, Japan, C.A.=1456 sq.km), Sanaga river (Cameron, Africa, C.A.=131500 sq.km) and Nam Mune (Thailand C.A.= 104000 sq.km). Detailed analysis of the basins has been published as Research note No.11 (1974) of the National Research Centre for Disaster Prevention, Japan. Tank model has been applied extensively in Japan. The model has also been applied to data of river basins in other countries like Malayasia, Thailand, Canada and some African countries.

Tank model can also consider snowmelt component and irrigation water applied to some part of the basin.

Application of Tank model for hydrological studies in India has been rather limited and only a few studies have been made so far. One such study is by Ekbote and Bhave (1982) who have used 4 x 3 Tank model for daily runoff analysis for venna catchment located in westernghats area having catchment area of 205 sq.km. They have used data of monsoon period of 1975 for calibration of the model and reported good comparison of observed and simulated flows. However, no attempt had been made for testing the performance with independent data.

Tank model for flood analysis has also been used by B Datta (1984) for the sub-basins of Narmada basin namely Jamtara and Belkheri. Basin Belkheri is the basin of river Sher at Belkheri having catchment area of 1508 sq.km.

3.0 STATEMENT OF THE PROBLEM

4x4 Tank model is suitable for daily analysis for semi-arid basin or basin experiencing long dry period. Most part of India experience 75% to 90% of average annual rainfall in four monsoon months from June to September. Narmada basin is located at central part of India bounded by Vindhya hill range at north and Satpura hill range at south. Two sub-basins of Narmada basin, namely Jamtara and Ginnore have been selected. Jamtara basin is comparatively large having 16575 sq.km. area and mainly mountaineous covered with thick forest, where as Ginnore basin is located at down stream of Narmada river, West of Jamtara basin, having 4816 sq.km.area and lies in lower plains of Narmada river. Both the basins experience about 90% of average annual rainfall in four monsoon months and long dry period in non-monsoon months. 4 x 4 Tank modoel has been applied to simulate daily runoff of these basins using available data.

4.0 DESCRIPTION OF STUDY AREA:

Two sub-basins of Narmada basin namely Jamtara and Ginnore have been selected as study area.

4.1 Narmada basin

Narmada river basin is the fifth largest basin of India and is the largest west flowing river of the peninsula. Total length of the river is 1312 km and catchment area is 98796 sq.km. The basin lies in the northern extremity of the Deccan plateau between east longitudes $72^{o}32'$ to 81^{o} 45', and northern latitudes 21^{o} 20' to 23^{o} 45'. The basin has an elongated shape with a maximum length of 953 km from East to West and a maximum width of 234 km. from North to South. The basin is bounded on the North by Vindhya hill ranges, on the South by Satgpura hill ranges, on the East by Maikala hill ranges and on the West by Arabian sea. The basin has five well defined physiographic zones and they are upper hilly areas, upper plains, middle plains, lower hilly areas and lower plains. The river Narmada rises from the Amar Kantak plateau of Maikala hill ranges at 22^{o} 40' north latitude and 81^{o} 45' east longitude at an elevation of 900 meter from MSL. The river has 41 tributaries of which 22 are on the left bank and 19 on the right. Narmada river basin is shown in figure 1 indicating locations of Jamtara and Ginnore sub basins.

Climate of the basin is humid and tropical although at places extremes of heat and cold are often encountered. In the year four distinct seasons occur and they are cold, hot, Southwest monsoon and post monsoon. In the cold weather the mean temperature varies from 17.5^{o}C. to 20^{o}C. and in the hot weather from 30^{o}C to 32^{o}C. In the South-west monsoon the temperature ranges from 27.5 to 30^{o}C. In the post monsoon season it varies between 25^{o} to 27.5^{o}C.

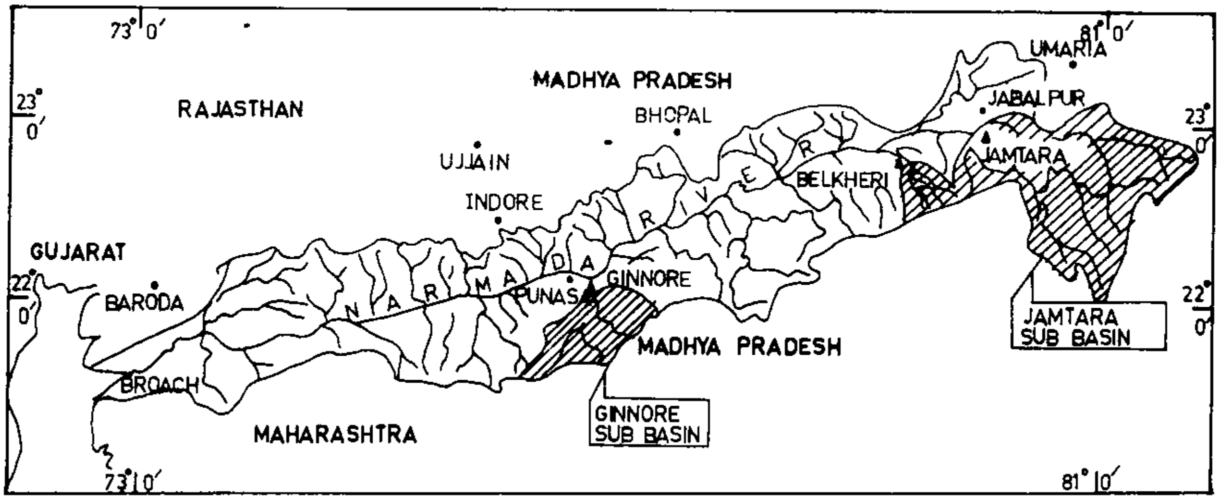

FIGURE 1 - INDEX MAP SHOWING LOCATIONS OF JAMTARA AND GINNORE SUB-BASINS IN NARMADA BASIN

Southwest monsoon from June to September is the principal rainy season and accounts for about 90% of the annual rainfall. During this period a series of tropical storms originating in Bay of Bengal move in West Northwest direction towards the basin and sometimes move parallel along the length of the basin and emerge into Arabian Sea. The average annual rainfall over the Narmada basin is 1230 mm. Annual rainfall varies from over 1550 mm in the Eastern part to 750 mm in the Western part.

4.2 Jamtara Sub-basin

Jamtara basin is a part of Narmada river basin containing 399 km of the main river Narmada from its source upto discharge measuring site Jamtara at an elevation of 360 meters. Details of the basin are shown in figure 2.

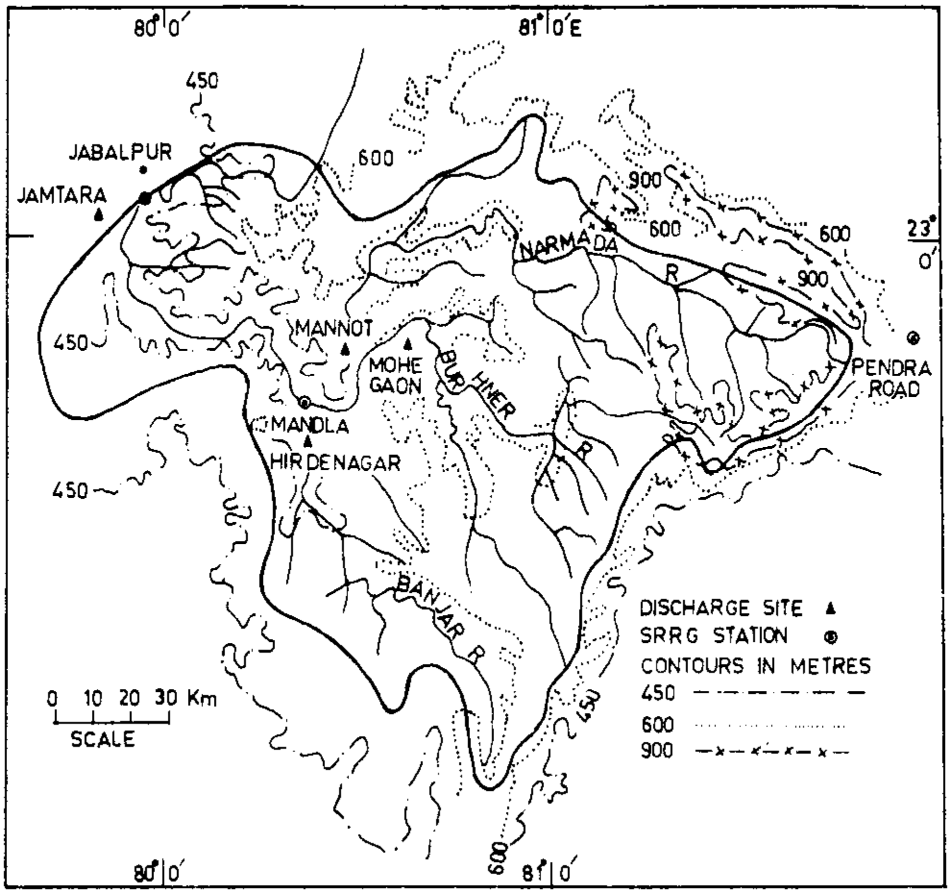

FIGURE 2 - MAP OF JAMTARA BASIN

The basin falls in the upper hilly zones of Narmada basin. The catchment area of the basin upto Jamtara discharge site is 16575 sq.km. The basin lies between east longitudes 79° 45' to 81° 45' and north latitudes 21°20' to 23°45'.

The river has number of falls in its head reaches. Two major tributaries Burhner and Banjar joins the river Narmada from left at 248 km and 287 km near Mannote and Mandla respectively within Jamtara basin. The upper reaches of Jamtara sub-basin is well forested and covered with good quality Sal and Teak woods; North, East, Central part of the basin is mainly covered with Sal wood forest whereas Southern and Western part is covered with Teak woods. The soil of Jamtara basin is loamy clay, in general with about 60% area having red and yellow variety, about 25% area having deep black variety and

and rest portion having medium black variety.

Maximum and minimum temperatures of Mandla and Jabalpur towns are given in table 1.

Table 1: Maximum and Minimum Temperatures for Mandla and Jabalpur Stations, in ^{o}C.

Station	Jan.-Mar.		April-June		July-Sept		Oct.- Dec.	
	Max.	Min.	Max.	Min	Max.	Min	Max.	Min
Mandla	34.9	9.0	40.2	19.6	29.1	21.7	29.4	6.8
Jabalpur	36.2	10.1	42.1	21.0	30.6	23.1	30.5	7.7

4.3 Ginnore Sub-basin

Ginnore basin is the basin of river Chotta-Tawa from its source upto discharge measuring site at Ginnore. Catchment area of the basin is 4816 sq.km. The basin lies between East longitudes 85^{o} 50' to 77^{o}11' and North latitude 21^{o} 27' to 22^{o} 11'. The river Chhota-Tawa, a left bank tributary of river Narmada, rises in the Satpura range in the west Nimar district of Madhya Pradesh near Kakora village at north latitude 21^{o} 31' and east longitude 75^{o}50' and flows for a total length of 169 km. in a north eastern direction to join the Narmada river at its 829 km.reach from source, north of Purni village. The river Chhota-Tawa is next in size to the Tawa among the left bank tributaries of Narmada river. The basin falls in the lower plains (Zone-3) of Narmada basin. Southern border of the basin is the water divide line of Satpura mountain range. The basin gradually slopes down in the north-northeast direction. R.L. of gauging station Ginnore is 218 m. Average slope of river is 1:400. Details of the basin are shown in figure 3.

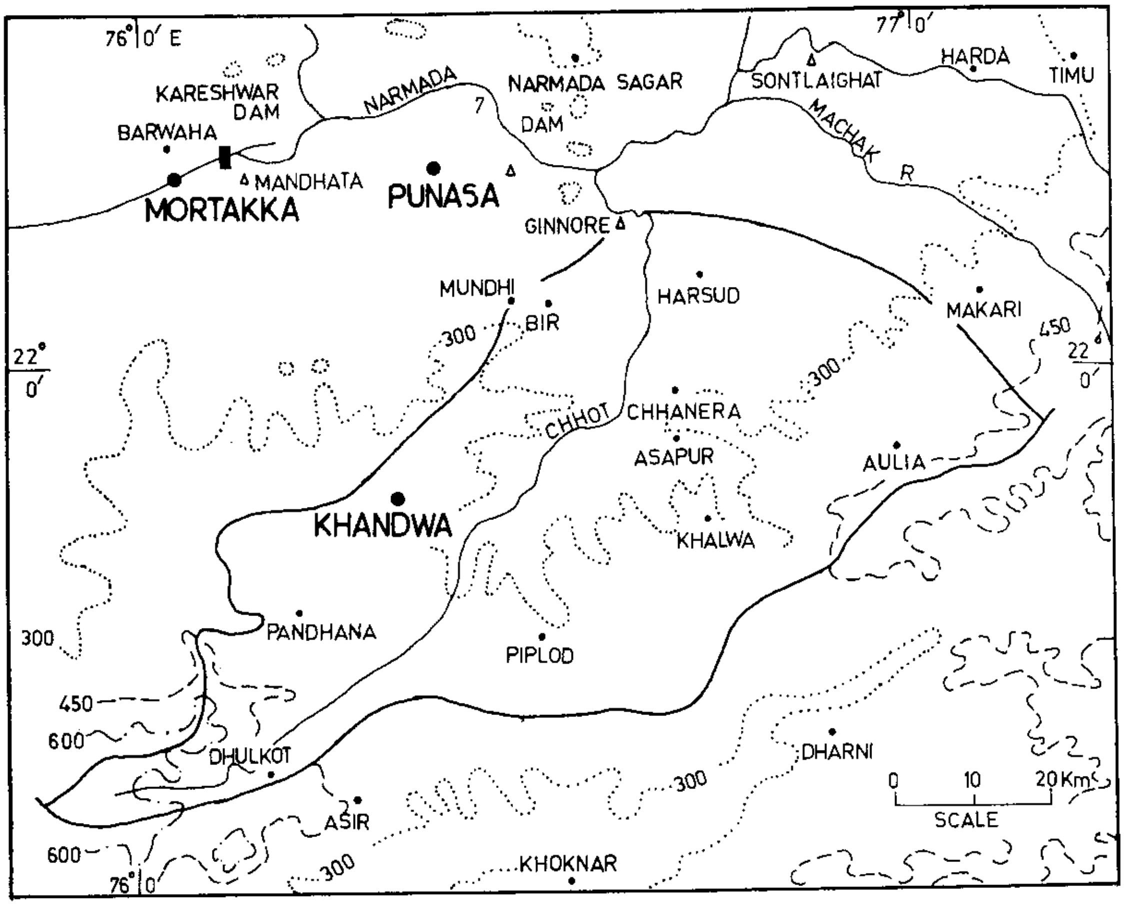

FIGURE 3 - DETAILED MAP OF GINNORE BASIN

The basin has two types of soil. Soil in the main part of the basin covering central and lower reaches is of medium black variety. Texture of the soil is silty clay loam and soil cover varies from 50 to 100 cm. Soil reaction is slightly alkaline. Soil of the upper reach of the catchment is shallow black variety. Texture of the soil is clay loam and soil cover varies from 25 to 50 50 cm.

Upper and some part of the central region is under forest cover amounting to about 32% of the basin area. About 60% area is culturable and remaining part is under shrub, suitable for grazing. Good quality Teak woods grow in upper reaches of the basin. Main crops under agriculture in the basin are wheat, pulses (mainly Arhar), Linsead, Sesame and rice. Large quantity of cotton also grows in the basin. Groundnuts is another cash crop that grows in the basin. Only 4.5% of cultivated area is under irrigation. Wheat is the most important crop in the basin.

Climate of the basin is humid and tropical. In a year, four distinct seasons occur and they are cold, hot, southwest monsoon and post monsoon. Maximum and minimum temperatures at Khandwa and Punasa towns in the four quarters of the year are given in table 2.

Table 2: Maximum and Minimum Temperatures of Khandwa and Punasa Stations, in ^{o}C

Station	Jan. - Mar.		Apr.- Jun		July - Sept		Oct.- Dec	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Khandwa	38.0	11.8	41.5	24.3	30.5	22.6	31.3	11.1
Punasa	38.8	11.9	42.9	24.2	31.1	22.9	33.1	12.0

Salient features of Jamtara and Ginnore basins have been given in table 3.

4.4 Hydrometeorology of the Basins

Average annual rainfall of Jamtara and Ginnore sub basins are 1480 mm and 855 mm respectively. Southwest monsoon from June to September accounts 86% and 87.6% of the average annual rainfall respectively for Jamtara and Ginnore sub-basins. July and August are the two most rainy months. Details of average annual, average monsoon and monthly average rainfall of two basins Jamtara and Ginnore are given in table 4.

Table 3 : Salient Features of Jamtara and Ginnore sub-basins in Narmada basin.

Sl.No.	Features	Jamtara sub-basin	Ginnore sub-basin
1.	Name of river	Narmada	Chhota-tawa
2.	Gauging Station	Jamtara	Ginnore
4.	Location of sub-basin in Narmada basin	Upper hilly area	Middle plains
5.	Source of river	Maikala hill range	Satpura hill range
6.	RL of river at source	900 meter	600 meter
7.	RL of Gauging station	360 meter	218 meter
8.	Length of river from source to gauging station	399 km.	155 km.
9.	Average river bed slope	1:740	1:400
10.	Soil	Loamy clay	Silty clay loam

Table 4: Annual and Monthly Average Rainfall of the Two Sub-basins Jamtara and Ginnore in mm.

	Jamtara sub-basin	Ginnore sub-basin
January	33.5	5.5
February	35.0	3.5
March	24.0	3.5
April	18.0	1.5
May	15.5	9.0
June	190.0	135.5
July	440.0	274.0
August	420.5	190.0
September	221.0	169.5
October	57.0	35.5
November	18.0	21.0
December	7.5	6.5
Annual Average Rainfall	1480.00	855.00
Average Monsoon Rainfall (June to September)	1271.5	769.0
Percentage of annual rainfall	86%	89.9%
July rainfall in percentage to annual rainfall	29.7%	32.0%
August rainfall in percentage to annual rainfall	28.4%	22.2%

5.0 AVAILABILITY OF DATA

Following data of two basins were available and used for calibration and testing of the 4 x 4 Tank model and simulation of daily runoff.

5.1 Jamtara Basin

(i) Daily rainfall data of stations Jamtara and Mandla for 1978 and 1979.

(ii) Daily discharge data of river Narmada at Jamtara for the monsoon period 1st June to 15th October of 1978 and 1979.

(iii) Daily evaporation value at Station Jabalpur (outside the basin) for 1978 and 1979.

(iv) Monthly mean of daily evapotranspiration values of Jamtara basin for twelve months taken from IMD published report (Rao et al 1971).

(v) Topographic map, soil map, forest map and Geologic map.

5.2 Ginnore Basin

(i) Daily rainfall data of station Khandwa and Punasa for 1972, 1973 and 1974.

(ii) Daily discharge data of river Chhota-Tawa at Ginnore for 1972, 1973 and 1974.

(iii) Monthly mean of daily evapotranspirations of Ginnore basin for twelve months taken from I M D report (Rao et al 1971).

(iv) Topographic map, soil map and forest map.

6.0 METHODOLOGY

6.1 The Tank Model

The Tank model and its different forms are simple conceptual rainfall runoff models developed by Sugawara (1967) for simulation of flood and daily runoff of a basin. The model.deals with overall rainfall runoff process and considers total rainfall as input and gives total runoff as output

6.1.1 The model structure

The model structure is composed of several tanks laid vertically in series representing soil moisture and ground water in different soil strata of the basin. Generally the daily rainfall runoff analysis model applicable to humid basins consists of four tanks laid vertically in series as shown in figure 4.

Each tank has one side outlet and one bottom outlet except the top tank which has one or more additional side outlets and the bottom tank which does not have any bottom outlet. The top tank corresponds to the sturcture of ground surface and the discharge through side outlets (Y_1) represents the surface flow while the discharge through bottom outlet represents infiltration. Similarly, discharges through side outlets of second, third and fourth tanks represent interflow (Y_2), sub-base flow (Y_3) and baseflow (Y_4) respectively. Discharges through bottom outlets of second and third tanks represent percolation and deep percolation respectively. The sum of outflows through side outlets of four tanks ($Y = Y_1+Y_2+Y_3+Y_4$) represent total runoff from the basin. The H_{A1} and H_{A2} represent the heads (threshold levels) of two side outlets of top tank and are measures of initial losses. Similarly, H_B and H_C are heads (threshold levels) of side outlets of second and third tanks respectively. A_1, A_2, B_1,C_1

and D_1 are discharge coefficients of side outlets of four tanks, and A_o, B_o and C_o are the discharge coefficients of bottom outlets of top, second and third tanks respectively, as shown in figure 4.

Rainfall is the input to the top tank. Water in all the three tanks from top moves both horizontally and vertically. Discharges through bottom outlet of the top tank is the inflow to the second tank. Similarly discharge through bottom outlets of second and third tanks are the inflows to the third and fou rth tanks respectively. The model is based on the hypothesis that the runoff at any instant from each tank depends on the storage in the tank at that instant and follows an exponential function.

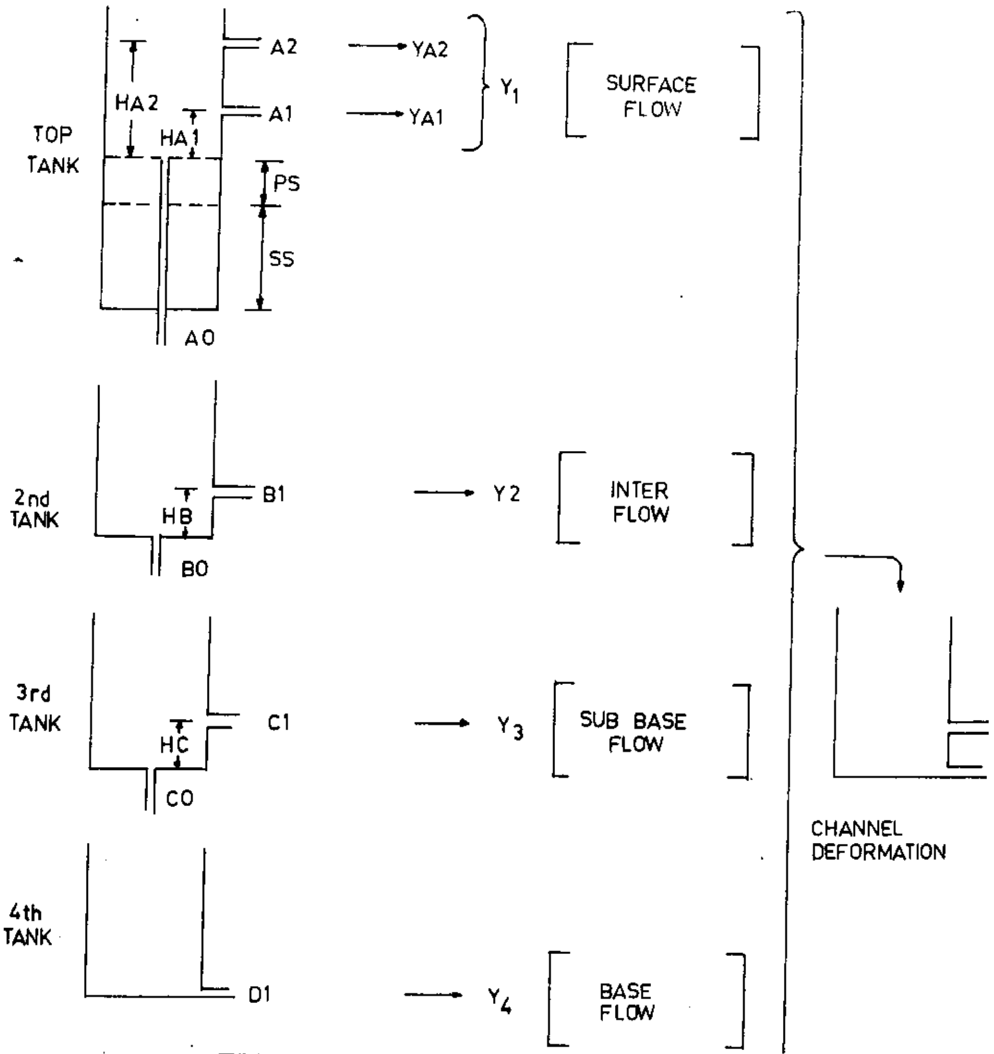

FIGURE 4 - TANK MODEL STRUCTURE

The model is non-linear in character and as such it is very difficult to find optimum parameter values using analytical techniques of optimisation. Only way of calibration is therefore by trial and error method or by using numerical techniques for optimisation.

Tank model for daily discharge analysis consists of four tanks laid vertically in series as shown in figure 4. The daily analysis model also includes a structure of soil moisture at the bottom of the top tank. Details of the soil moisture structure are shown in figure 5.

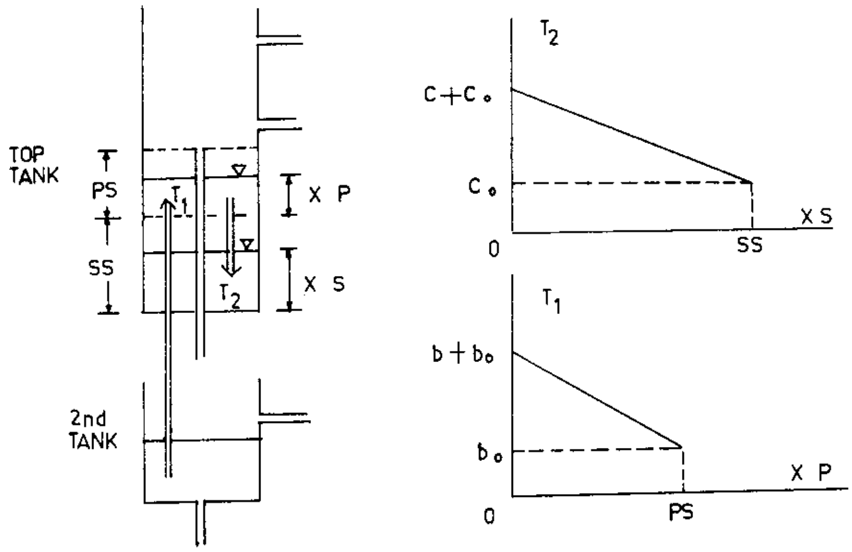

FIGURE 5 - SOIL MOISTURE STRUCTURE OF TANK MODEL FOR DAILY ANALYSIS

When rain starts after a long dry period, value of primary soil structure (XP) goes on increasing till it reaches saturation value (PS), after this water becomes free water in the top tank. This free water partly infiltrates to the lower tank and partly discharges as surface runoff. Water gradually goes from primary soil moisture to secondary soil moisture at a transfer velocity T_2 which can be given as:

$$T_2 = C_o + C\,(1 - XS/SS) \qquad \ldots(1)$$

where

C_o and C = Constants

XS = Secondary soil moisture

SS = Saturation capacity of secondary soil moisture

When dry season starts, evaporation first takes place from free water, at a certain stage free water of the top tank becomes zero and evaporation starts to take place from primary soil moisture. When primary soil moisture is not in saturated condition and free water is available in the lower tank, water goes up by capillary action at a transfer velocity T_1 which can be given as:

$$T_1 = b_o + b\,(1 - XP/PS) \qquad \ldots \qquad (2)$$

where

b_o and b = Constants

XP = Primary soil moisture

PS = Saturation capacity of primary soil moisture.

The ratios (XP/PS) and (XS/SS) represent moisture status and can be regarded as relative humidity of primary and secondary soil moisture.

6.1.2 The 4 x 4 Tank model:

The 4 x 4 Tank model is used for daily analysis of rainfall and runoff of river basins which is situated in non-humid regions or the basins which experience long dry periods. Some part of such basins remain dry while the area near the river remains wet. Percentage of dry area and wet area of such basins do not remain constant all throughout the year. As the dry season continues, the percentage of dry area to the whole basins area continues to increase. When the rainy season begins, the wet area that remained near the river courses at the end of dry period starts to increase and continues to grow till the rainy season continues. Surface runoff occurs only in wet area while in dry area all the rainfall gets absorbed as soil moisture. Evaporation from the basin also varies depending on the variation of wet area. To take into account such variations, the basin is divided into number of zones and variation is accounted in steps. Generally the basin is divided into four zones S_1, S_2, S_3 and S_4 as shown in figure 6.

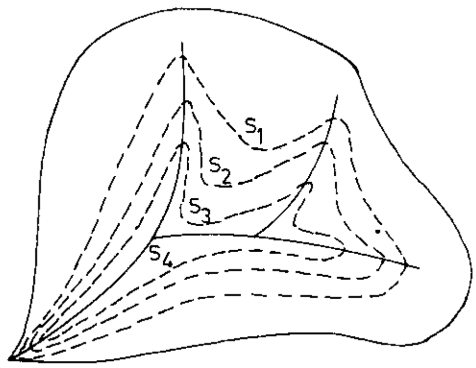

FIGURE 6 - A NON-HUMID BASIN DIVIDED INTO FOUR ZONES

For each zone four linear tanks in series are considered to represent surface flow, intermediate flow, sub-base flow and base flow. Therefore, a non humid basin contains 4 x 4 = 16 tanks in all. Schematically 4 x 4 Tank model structure along a sloping ground of a basin is shown in figure 7.

Left side is the mountain side and right side is the river side. Details of 4 4 x 4 Tank model structure are shown in figure 8. Each zone is represented for simulation by series of four tanks laid vertically with soil moisture at the bottom of top tank. Series of four tanks of first zone S_1 is in parallel with that of the other three zones S_2, S_3 and S_4 . The top tanks of four zones are of identical structure, similarly structure of all second tanks, structure of all third tanks, structure of all fourth tanks are identical. The only difference

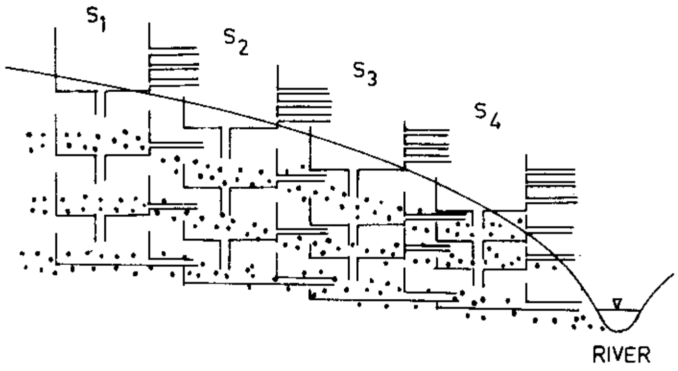

FIGURE 7 - 4 x 4 TANK MODEL ALONG A SLOPPING GROUND OF BASIN

in the structure of four zones that may occur is in the structure of soil moisture (PS and SS values may be different and zonal areas.

In this model free water moves in two directions, horizontally and vertically. Each tank receives water from the top tank of the same zone or from the mountain side tank of the same strata and transfers water to the lower tank of the same zone or to the river side tank of the same strata. The top tank of each zone receives rain water as input. Another important 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 lower zones. After depletion of free water, soil moisture begins to decrease. Due to these depletions, the highest zone becomes dry earliest and then the second zone, the third zone and the fourth zone. When rainy season comes in the opposite way the lowest zone (fourth) becomes saturated first and then the third zone, the second zone and the first zone.

Arieal ratio of zones S_1; S_2 ; S_3; S_4, is an important parameter in this model. These ratios can be determined if the detailed informations regarding

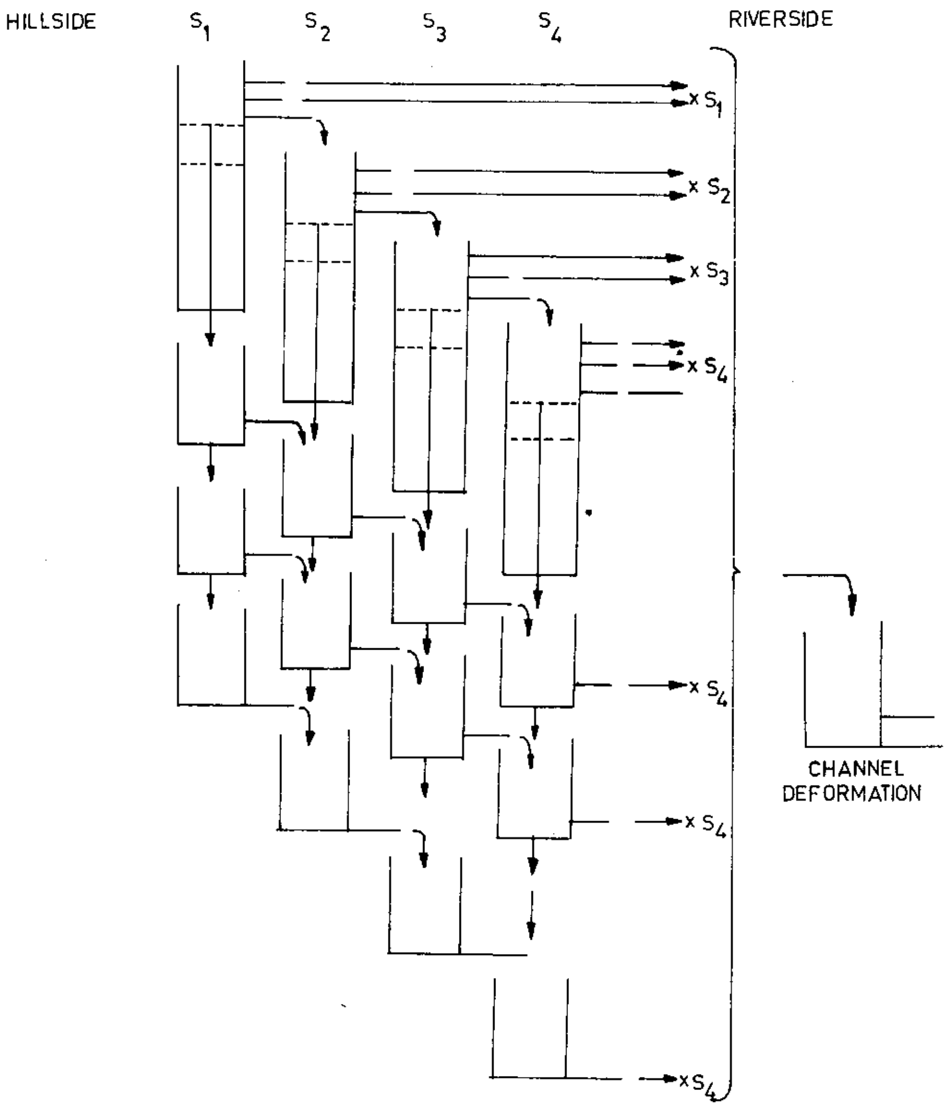

FIGURE 8 - 4 x 4 TANK MODEL STRUCTURE FOR NON-HUMID BASIN

hydrological, topographical and geological characteristics of the basin are available. If no such information is available, the ratios can be determined by trial and error.

6.1.3 Deformation in river channel

Output from the Tank model goes into the river channel where its hydrograph is deformed by storage effect of the channel. To consider such deformation two types of models, type A and type B, are considered as shown in figure 9.

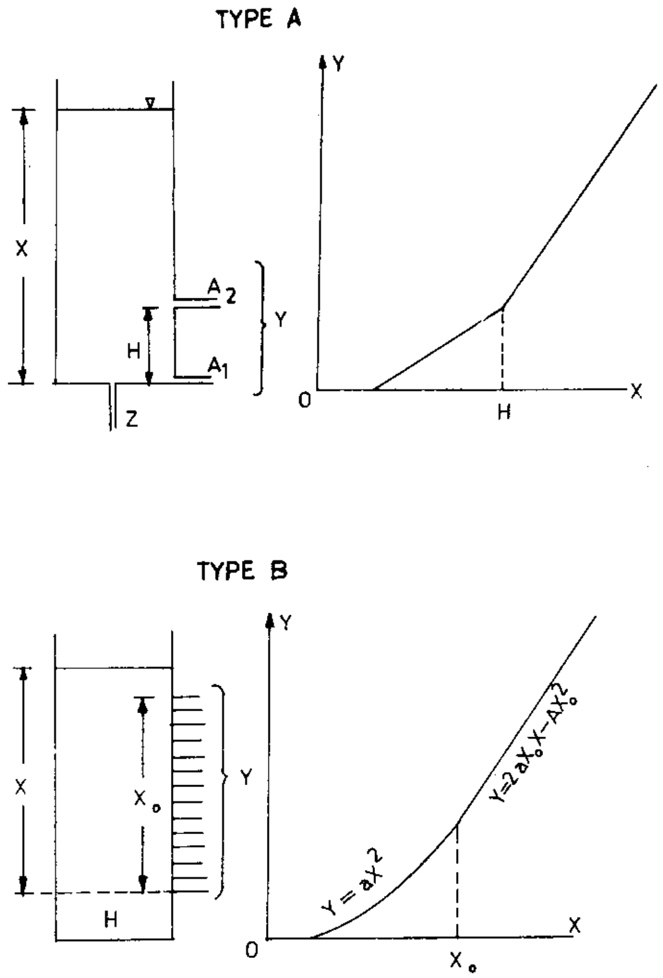

FIGURE 9 - DEFORMATION MODELS IN RIVER CHANNEL

The type A model is a sort of delayed first order system where time constant T_c varies as follows:

(i) When storage is small, X H

$$T_c = \frac{1}{A_1} \quad \text{.. (3)}$$

(ii) When storage is large

$$T_c = \frac{1}{(A_1 + A_2)} \quad \text{...(4)}$$

Type B:

This type of model is used when discharges are very small. It has a structure for initial loss at the bottom and the relation between outflow Y and storage amount X is given by

(i) $Y = aX^2$ when 0 x x_o .. (5)

where, a = a constant

X = storage measured above the confined storage

If local approximation of this model is made by delayed first order system, its time constant varies reciprocally to storage.

(ii) $Y = 2a\ X_o X - a\,X_o^2$ when x x_o ... (6)

In this type of model effect of precipitation and evapotranspiration on or from the river channel are also considered. The effect of evapotranspiration from river channel is significant when the river discharge is very small.

6.1.4 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 4 x 4 Tank model water transfer takes place between zones, therefore in calculation, area of each zone must be taken into consideration. When transfer between zones of 4 x 4 Tank model is shown in figure 10. When output from its zone enters as input to (i + 1)th zone, the depth of water of ith zone is to be multiplied by area of ith zone, S_{i+1}. Therefore, the multiplying factors is $R_i = (S_i/S_{i+1})$ when water transfer

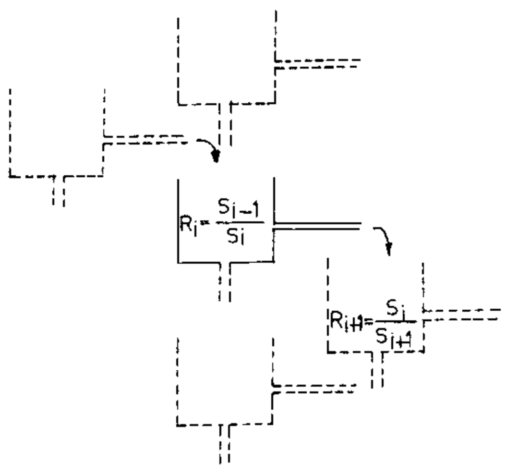

FIGURE 10 - WATER TRANSFER BETWEEN ZONE

takes place from the i th zone to (i + 1)th zone.

6.2 Main Advantages of the Tank Model

(i) It is simple in its form and to some extent it has reasonable physical meaning corresponding to the zonal structure of groundwater, (ii) it can represent the non-linear character of surface runoff, (iii) it can represent several components of runoff, each of the components having its own half life but from non linear character of this modoel the values of the half periods are not definite, (iv) input (rainfall) is distributed to each of the components automatically by this non-linear structure, (v) runoff components from lower tanks are smoothened in shape and the time-lags are given to them automatically (vi) data requirements are comparatively small, and (vii) the model can also suitably be applied to basins experiencing snowmelt runoff.

6.3 Data Requirement

6.3.1 Data requirement for calaibration of the 4 x 4 tank model

(i) Daily rainfall values of number of rainfall stations within and near the basin.

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

(iii) Daily mean evaporation value for the basin computed from number of stations. If observed evaporation values are not available for the period under consideration, monthly mean of daily evapotranspiration values maya be considered from the tables provided by I M D.

(iv) Catchment area

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

(vi) Ratio of Zonal areas

This can roughly be ascertained if topographic, soil, vegetation and land use maps are available. If nothing is available in details parameters are to be finalised by trial and error.

6.3.2 Data required for operation of the 4 x 4 Tank model

Once the Tank model for daily analysis is calibrated it requires daily rainfall and daily evaporation values as stated in (i) and (iii) of para 3.2.1 for further period for which daily discharge values require to be simulated.

6.4 Steps to Follow to Implement the Models

Following steps are to follow to implement the Tank modoel for a particular basin.

(a) Selection of length of data

A minimum of three to four years continuous daily discharge, rainfall and evapotranspiration data are selected for the purpose. A period of ten years continuous data containing both wet year and dry year is a good choice.

(b) Observed discharge data are plotted in logarithmic scale by unit of water depth per day. Rough estimation of time constant of runoff is made from recession part of the hydrographs.

(c) The value of decreasing ratio is calculated as reciprocal of time constant. Then the initial set of parameter values of the Tank model is decided for the first run. The discharge coefficients of tank second tank and third tank are selected as

$$A_o = A_1 = A_2 \ \ldots\ldots = \ /2$$

$$B_o = B_1 = \ /10$$

$$C_o = C_1 = \ /50$$

The values of initial losses are selected from the following ranges

$$HA_1 = 0 - 15 \text{ mm}$$

$$HA_2 = 15 - 40 \text{ mm}$$

$$HB = 0 - 15 \text{ mm}$$

$$HC = 0 - 15 \text{ mm}$$

(d) Precipitation as input

It is desirable that the basin should have several rainfall stations scattered over the catchment. For simplicity the simple mean of the rainfall data at each of the raingauges may be assuamed as input precipitation into the tank model. Weighted mean of the rainfall data may also be used. To get better result, rainfall at each station is termed into discharge by the tank model individually which are summed up by weighted mean to give the total discharge.

(e) Time lag

Time lag may be determined by rough estimation. The first trial is generally done without considering any time lag.

(f) Evapotranspiration

Monthly mean of daily evapotranspiration value may be considered for simplicity instead of considering daily E.T.values.

(g) Initial Storage:

Initial storage(XS) of the fourth tank can be decided from the long duration of dry period. The initial amount of the other tanks may be determined by rough estimation. Initially zero storage for top tank and second tank are considered.

(h) Soil moisture

For initial trial primary soil moisture (PS) and secondary soil moisture (SS) are assumed depending on the type of soil.

(i) Base discharge

Base discharge is assumed to be constant in each of the flood. The value of base discharge is determined from the stationary discharge before each flood.

(j) Channel deformation

Output from the Tank model goes into the river channel. Sometime it is observed that the hydrograph is deformed by storage effect of the channel and thereby it requires to consider chanel deformation also. In earlier trials this effect is usually disregarded.

6.5 Basic Procedure for Calibration

First initial set of parameter values of the model is finalised and the model is run. The model simulates outflow hydrographs. Six hydrographs are plotted simulatenously and they are observed discharge and simulated discharges Q_o, Y_4, $(Y_3 + Y_4)$, $(Y_2 + Y_3 + Y_4)$, $(Y_1 + Y_2 + Y_3 + Y_4)$ and final simulated discharge QE in logarithmic scale against time in natural scale. These five simulated discharges give information about runoff components from each tank. These hydrographs are compared with observed hydrograph to find which runoff component takes main part in the period. Calibration of parameters are done by trial and error in the method. Value of each parameters are successively changed and from comparison of fit of simulated hydrograph with observed one, best fit parameter value is ascertained. In this way parameters are calibrated leading to final model structure. Comparison are done by human judgement. Three main characteristics that are mainly looked into for comparison are

(a) peak flow value

(b) time to peak

(c) recession slopes of the hydrograph.

But importance is to be given in overall fit of the simulated hydrograph with observed one for the full period under consideration. Main steps to be followed in calibration are as folows:

(i) 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.

(ii) 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.

(iii) 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.

(iv) 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 small flood it becomes smoother.

(v) The positions of the side outlets determined by the parameters HA_1, HA_2, HA_3, H_B and H_C are useful for representing initial losses of surface flow, interflow and baseflow.

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

(vii) 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.

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

(ix) 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.

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

(xi) 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 top 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.

(xii) It is important to make a well balanced general outline first and then the fine adjustments are to be made.

7.0 ANALYSIS

7.1 Simulation of Daily Runoff of Jamtara Basin using 4 x 4 Tank Model

7.1.1 Data used

Following available daily data of Jamtara basin for 1978 and 1979 have been used for analysis.

(i) Daily available rainfall data of stations Jamtara and Mandla continuously for two years.

(ii) Available daily observed discharge of river Narmada at Jamtara for monsoon periods of 1978 and 1979.

(iii) Monthly mean of daily evapotranspiration values of Jamtara basin for twelve months from January to December.

(iv) Topographic map, soil map and vegetation map.

Average daily rainfall values of the basin have been calculated from observed daily rainfall values of two stations.

7.1.2 Calibration of 4 x 4 Tank modoel for Jamtara basin

(i) Observed daily discharge data available for two monsoon periods have been plotted in semilog paper.

(ii) From recession slopes of number of peak floods, average value of decreasing coefficient have been calculated as 0.23.

(iii) Using this value of α ,initial set of parameter values of four tanks have been selected as.

For Top tank $A_o = A_1 = A_2 = 0.115$

$H_{A1} = 15, H_{A2} = 40$

2nd tank $B_o = B_1 = 0.023, H_B = 15$

3rd tank $C_o = C_1 = 0.0046, H_C = 15$

(iv) Primary and secondary soil moisture PS= 50 mm, SS= 250 mm.

(v) Transfer velocity of water $T_1 = 2.0$ and $T_2 = 20.0$

(vi) CP = 1.0, WE = 1.0 and LAG = 0.0

(vii) Monthly mean of daily evapotranspiration values considered for different months (in mm/day) are as follows:

Jan. = 2.3	May = 6.6	Sept. = 3.5
Feb.= 3.3	Jun.= 5.5	Oct. = 3.5
Mar. = 4.5	Jul. = 3.3	Nov. = 2.6
Apr. = 5.6	Aug.= 3.3	Dec. = 2.1

(viii) Initial storage of four tanks XA = 0, XB = 0, XC= 0 and XD = 0

(i) $S_1 : S_2 : S_3 : S_4 = 0.675 : 0.225 : 0.075 : 0.025$

(ii) Initial storage height of secondary soil moisture of each of the top tank, SC = 5 mm.

(iii) Saturation height of HS = 600 mm

(iv) Multiplying factor of basin precipitation for each month from January to December as unity.

From the result of the first trial run, it is observed that the higher flows have matched reasonably well and the low flows at the initial stage has been underestimated. So the initial storage value has been considered as 75% of storage that remained at the end of May'79. All the parameter values have been adjusted in the successive trials till an overall good fit is obtained. The final 4 x 4 Tank model for Jamtara basin with channel deformation model has been obtained after 16 trials.

7.2 Simulation of Daily Runoff of Ginnore Basin Using 4 x 4 Tank Model

7.2.1 Data used

Daily data of Ginnore basin for the year 1972 and 1973 have been used for calibration of the model and independent data of 1974 have been used for testing the performance of the model. Following data of 1972, 1973 and 1974 have been used:

(i) Daily rainfall data of two stations Khandwa and Punansa.

(ii) Daily discharge data of river Chhota-Tawa at Ginnore available continuously for three years.

(iii) Monthly mean of daily evapotranspiration values for twelve months taken from Rao (1971).

(iv) Catchment map, soil map and vegetation map.

Average daily rainfall values of the basin have been calculated using Thiessen weightage for Khandwa and Punansa which have been calculated to be 0.78 and 0.22 respectively.

7.2.2 Calibration of the 4 x 4 Tank model for Ginnore basin

The 4 x 4 Tank model for Ginnore basin is considered by dividing the basin into four zones. Three side outlet model for top tank of each zone is considered. Structure of top tank of each zone is considered to be similar. Calibration of the model is done using daily data of calender year 1972 and 1973. Following steps have been followed for calibration.

(i) Observed daily discharge data of two calender years have been plotted in semilog paper

(ii) From recession slopes of number of peak floods, average value of decreasing coefficient α = 0.6 have been calculated

(iii) Based on the value of α , initial set of parameter values have been selected and the model has been run to simulated daily runoff. Observed and simulated hydrographs are then compared and value of α = 0.52

has been obtained by trial and error which gives proper fit in recession slopes at peak flow parts.

(iv) Initial storage values have been provided as 75% of the storage that stood at the end of May '72.

(v) Then in the next few trials the value of discharge coefficients and height of initial losses of top tanks, second tanks and third tanks are adjusted. A small value of D_1 = 0.001 of the fourth tanks has been provided.

(vi) Starting forom the Thiessen weightage value, weightage of rainfall stations Khandwa and Punansa have been found to be 0.8 and 0.2 respectively by trial and error.

(vii) It is observed that most of the simulated peak discharge are underestimated. The value of multiplying constant for basin precipitation PA = 1.2, obtained by trial and error, gives good fit. This may be due to the reason that the raingauges are located in plains where as rainfall may be high in upper hilly regions

(viii) PS and SS values are adjusted by trial and error and it is found that PS = 40 and SS= 200 give overall good fit.

(ix) Different ratios of zonal areas are tested and it is observed that ratio $S_1:S_2:S_3:S_4$ = 0,675 : 0.225 : 0.075 : 0.025 gives good result.

7.2.3 Testing of the model

The 4 x 4 Tank model as calibrated above has been tested with independent data of 1974. The same set of monthly mean of daily evapotranspiration values for each month have been considered.

8.0 RESULTS AND DISCUSSION

8.1 Jamtara Basin

Most of the calibrated parameter values for 4 x 4 Tank model for Jamtara basin are shown in figure 11. Other parameter values which are not shown in the figure as follows:

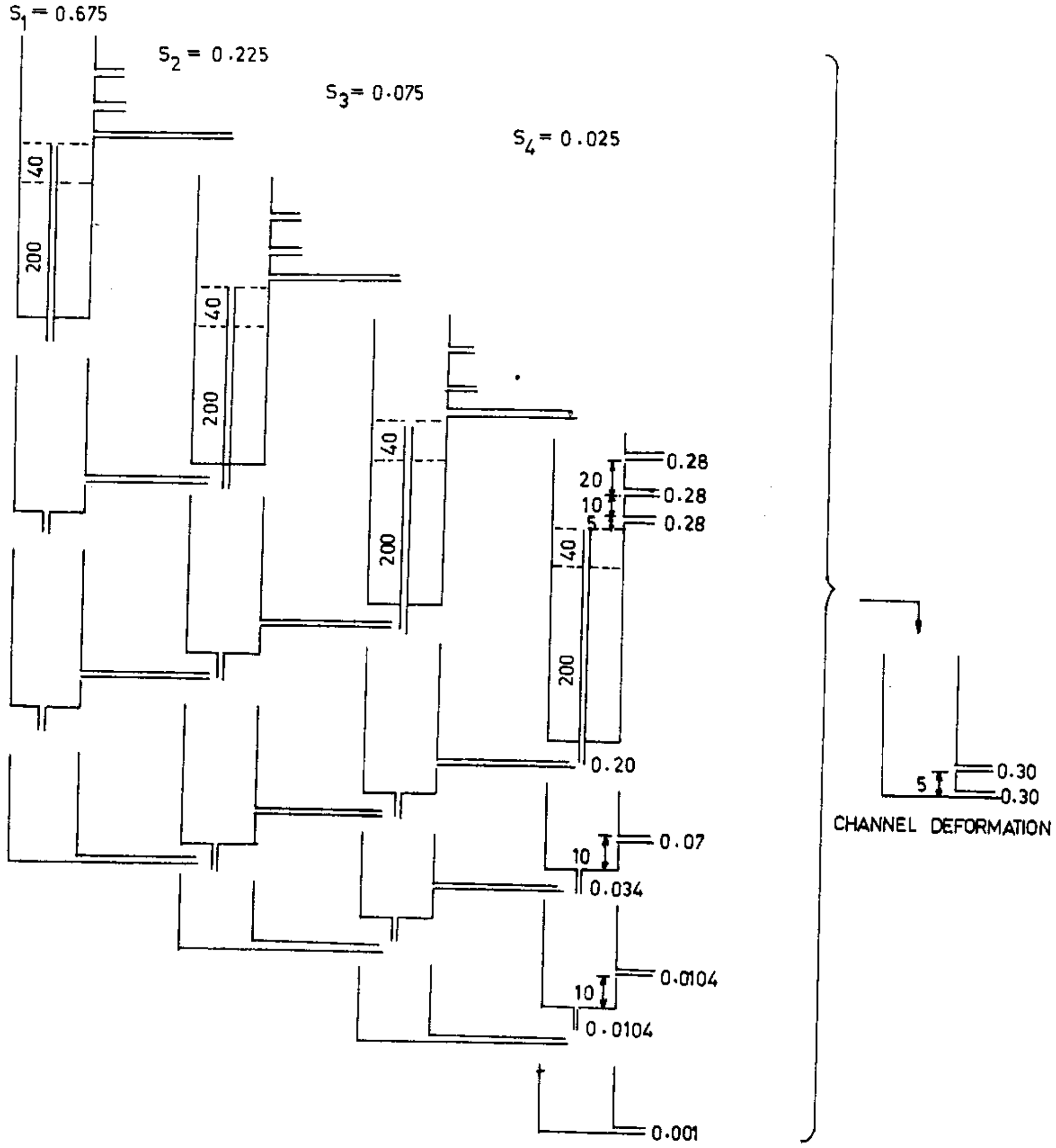

FIGURE 11- 4x4 TANK MODEL FOR DAILY ANALYSIS OF JAMTARA BASIN

Zones	1	2	3	4
XA	0.0	0.0	0.0	0.0
XS	6.0	6.0	7.0	7.0
XB	0.0	0.0	0.0	0.0
XC	0.0	9.0	120.0	360.0
XD	0.0	120.0	390.0	840.0
HS	500.0	500.0	500.0	500.0

and WE (PP) = 1.0, CP (PA) = 1.2

PB (N) = 1.0 for N = 1 to 12

T_1 = 2.0 mm/Day

T_2 = 20.0mm/Day

LAG = 0.0

The simulated hydrograph by the final calibrated Tank model for the period from June '78 to December '79 is plotted alongwith the observed hydrograp as shown in figure 12. The overall fit of the computed hydrograph with observed one is good. Peak flows of the monsoon periods of 1978 and 1979 and recession slopes of the two major peak flows of 1979 have matched well. Overall fit of the computed hydrographs of the monsoon periods of 1978 and 1979 are good. The response to rainfall during low flow periods are smooth. This justifies the fact that when some light rainfall occurs during continuation of low flows, initial part of the rainfall gets absorbed in the dry part of the basin. The model has also simulated a steady base flow for long dry season of seven months from November '78 to May'79.

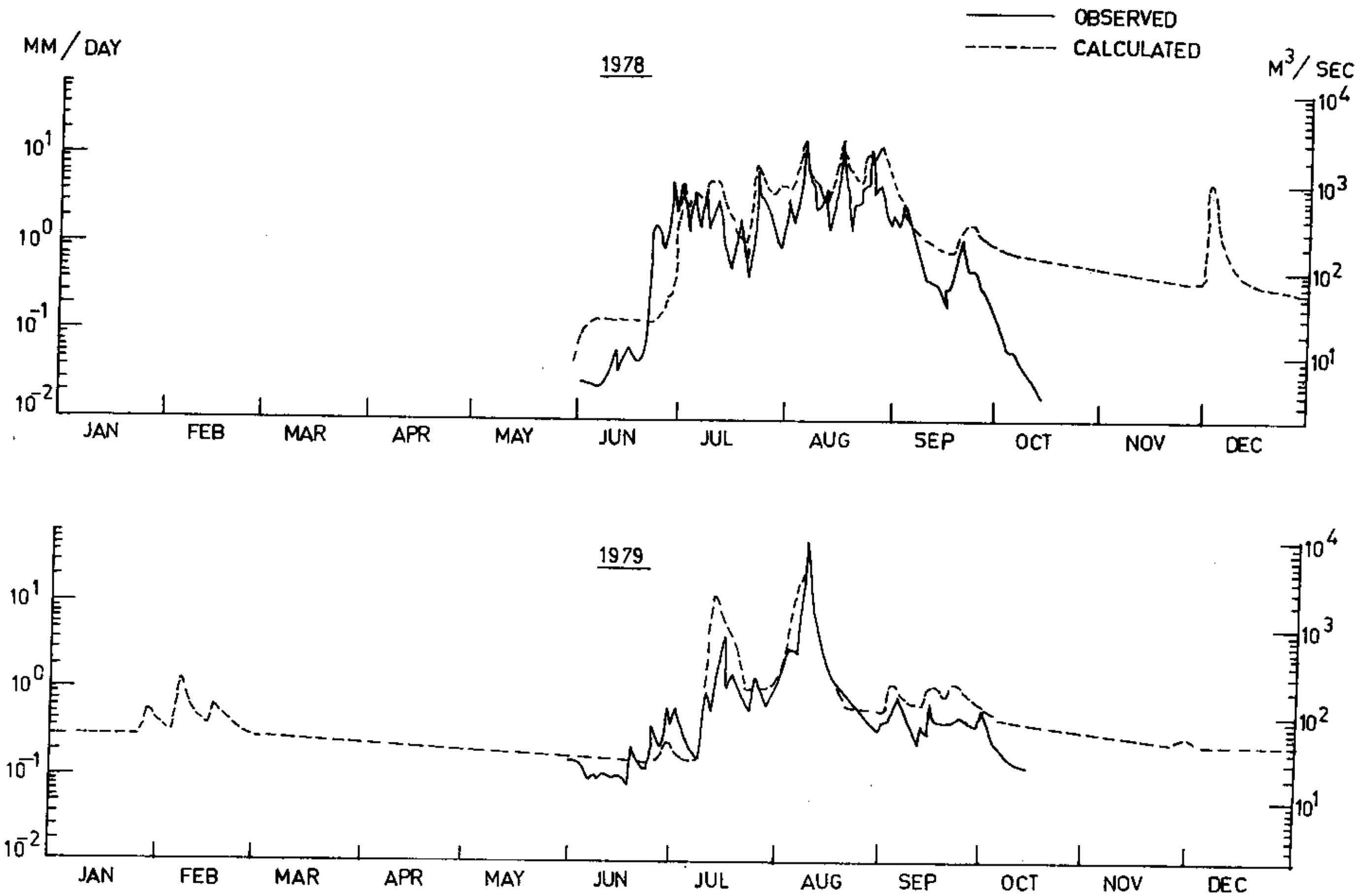

FIGURE 12 - DAILY FLOW HYDROGRAPHS OF JAMTARA BASIN FOR 1978

8.2 Ginnore Basin

The calibrated 4 x 4 Tank model for Ginnore basin is shown in figure 13.

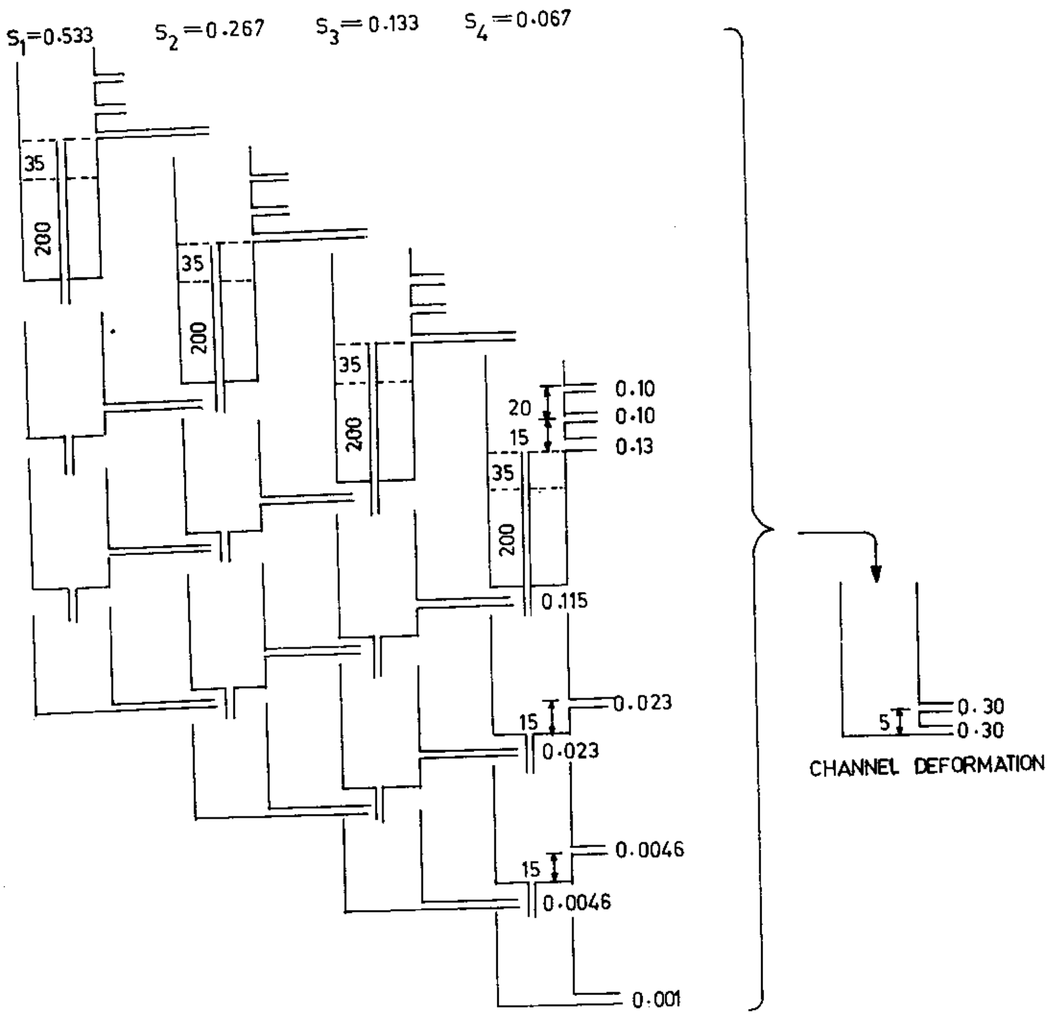

FIGURE 13 - 4x4 TANK MODEL FOR DAILY ANALYSIS OF GINNORE BASIN

Observed daily runoff hydrographs for 1972 and 1973 and corresponding simulated hydrographs by the calibrated model are shown in figures 14a,14b, and 14d. Only a few peak flows are overestimated and a few peak flows are underestimated but most of the peak flows and the overall fit of the simulated runoff with observed one is good. Recession slopes of peak floods have also matched satisfactorily. The observed and simulated daily runoff for independent data set of 1974 are shown in figure 15a and 15b. Overall fit of the simulated daily flows with observed one is good except for a short period in the month of July '74. Daily recorded rainfall data seems to be not well representative for the catchment rainfall for that period because both of the recording stations are located in the plains where as heavy rainfall might have occured in the mountainous region of the basin. In order to evaluate model performance in reproduction of floods, three typical flood periods in year 1972, 1973 and 1974 have been identified from hydrographs and volume of total flow and base flow for both observed and simulated hydrographs have been calculated as given in table 5.

Table 5 - Comparison of Observed and Simulated Runoff Volumes for Typical Floods for Ginnore Basin

S.No.	Period	Total Runoff Volumes in 10^6 m^3		Base flow			
				Volume in 10^6 m^3		Percentage of total volume	
		Obs.=	Sim.	Obs.	Sim.	Obs.	Sim.
A.	For Calibration						
1.	129 days from 15.8.72 to 31.12.72	1763.84	1766.88	60.25	63.34	3.41	3.58
2.	184 days from 1.7.73 to 31.12.73	3842.99	3143.52	221.54	183.56	5.76	5.84
B.	For Testing						
3.	116 days from 27.7.74 to 19.11.74	1038.78	1259.48	44.69	51.84	4.30	4.12

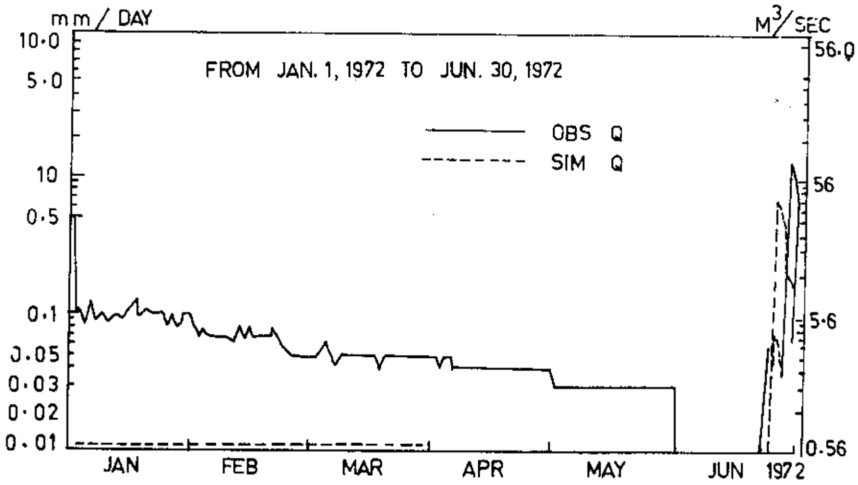

FIGURE 14a - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JANUARY TO JUNE 1972

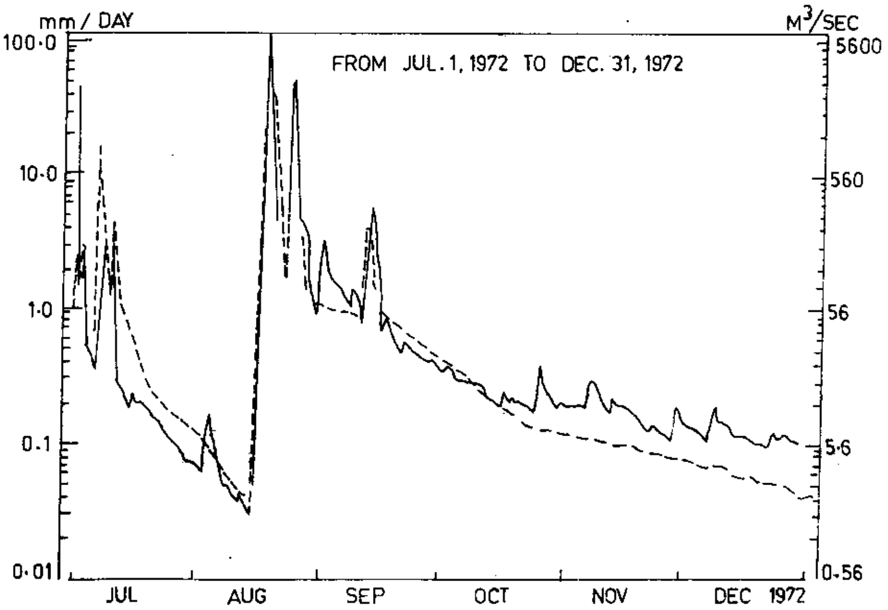

FIGURE 14b - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JULY TO DECEMBER 1972

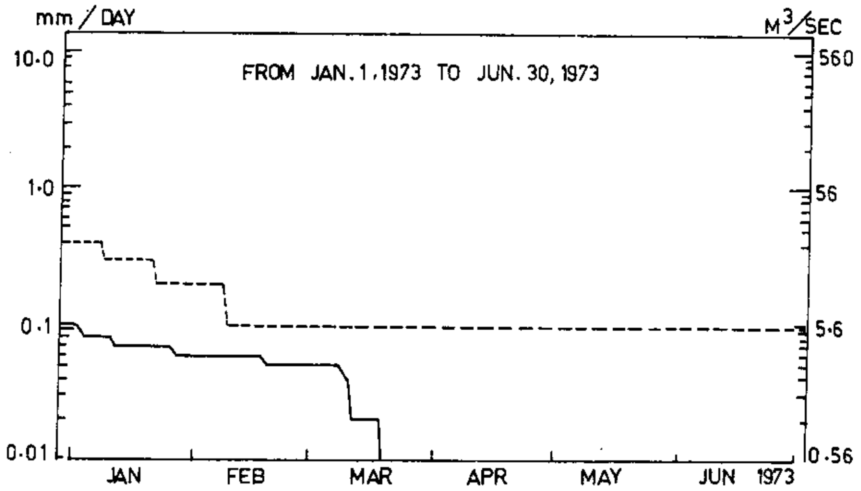

FIGURE 14c - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JANUARY TO JUNE 1973

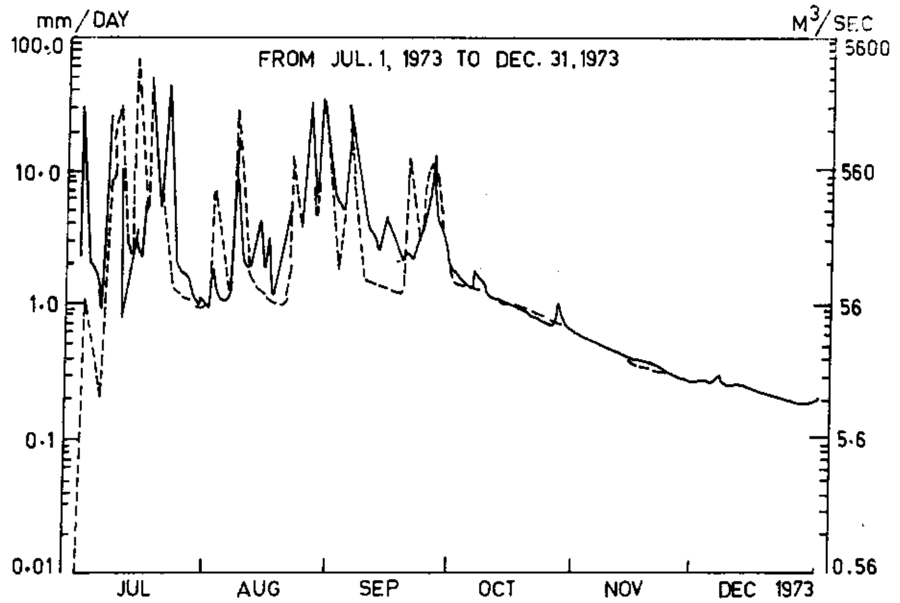

FIGURE 14d - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JANUARY TO JUNE 1973.

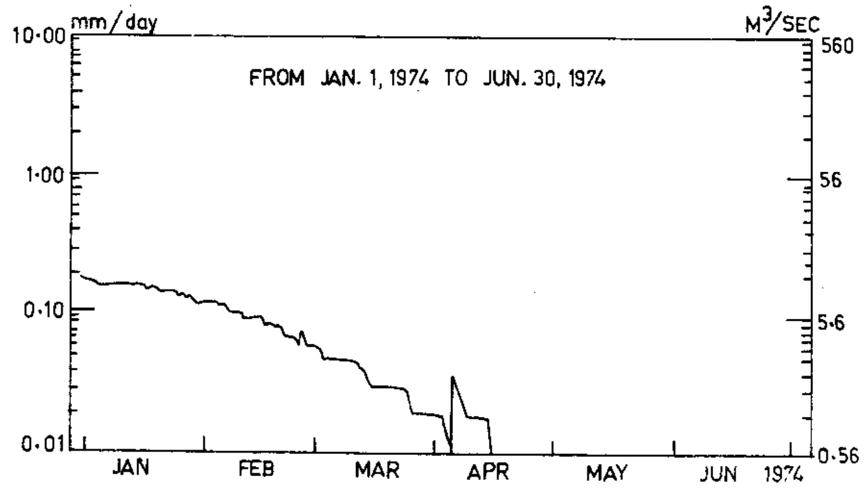

FIGURE 15a - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JANUARY TO JUNE 1974

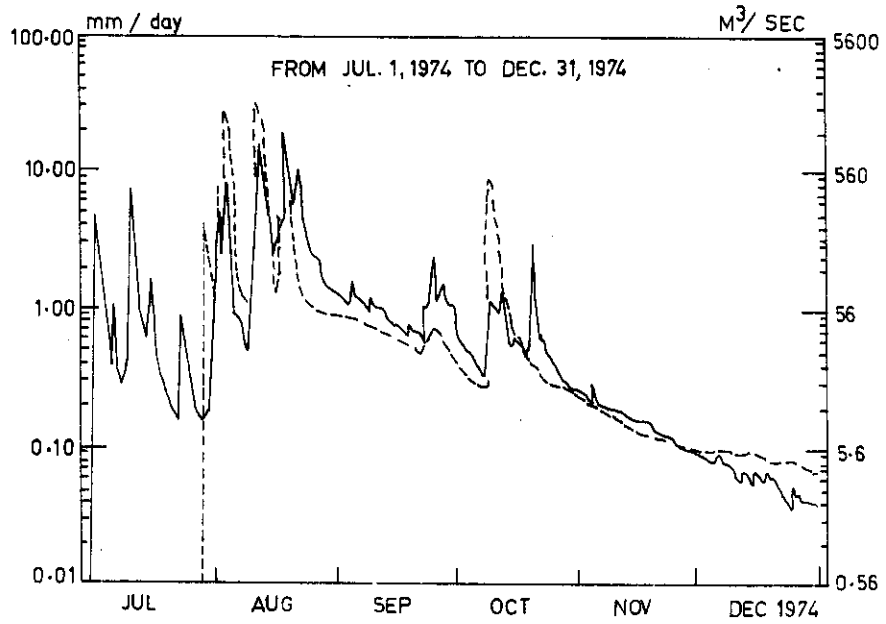

FIGURE 15b - DAILY FLOW HYDROGRAPHS OF GINNORE BASIN FROM JULY TO DECEMBER 1974

It is observed from the table that the total runoff volume and base flow volume for both observed and simulated daily flow has matched sufficiently well both for data used in calibration (data of 1972, 1973) and independent data used for testing (data of 1974).

9.0 CONCLUSIONS

It is observed that overall performance of the 4 x 4 Tank model is satisfactorily both for high flows and low flows for basins like Jamtara and Ginnore which experience most of the rainfall during monsoon period followed by long dry period in non-monsoon period. The 4 x 4 Tank model for Ginnore basin also showed good performance when tested with independent data. Datta (1984) and Datta and Seth (1985) have discussed elsewhere in detail the application of daily analysis models to these basins.

From the analysis it is observed that the 4 x 4 Tank model is a suitable daily rainfall runoff model for simulation of daily runoff since most of basins in India experience nearly 75% to 90% of annual rainfall during monsoon season followed by long dry period in non-monsoon period. The Tank model besides have simple structure is quite versatile with wide range of applicability. Moreover data requirement is less compared to other models and as such the tank model is better suited for data generally available for most of the Indian catchments. Only a few studies have so far been done in India on application of Tank model. The results of studies described in this paper are quite encouraging. Further studies are however warrnated for basins of different sizes spread over various hydroclimatic regions of the country.

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