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RAINFALL RUNOFF MODELLING OF RAMGANGA AT CHAUKHUTIA USING RAINFLO MODEL

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PREFACE

RAINFLO is a comprehensive hydrologic computer software system to model the rainfall runoff process in complex watersheds and river basins. It can be used to predict the temporal and spatial variations of a flood wave as it traverse a river reach or reservoir, or can be employed to predict the outflow hydrograph from a watershed subjected to a known amount of precipitation.

The Rainflo model was transferred to NIH under the ongoing UNDP project entitled "Developing Capabilities in Hydrological Studies".

This report has been prepared by Shri M.K. Jain, Scientist B, Surface Water Analysis and Modelling Division, NIH, Roorkee. The report is aimed to test the applicability of the Rainflo model in steep Himalayan catchment.

(S.M. Seth)

DIRECTOR

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ABSTRACT

In present study, suitability of RAINFLO model for rainfall runoff simulation of Ramganga at Chaukhutia has been studied. Runoff event simulation and model parameter sensitivity was carriedout. The study shows that, the parameters such as SCS curve number, antecedent moisture conditions, velocity, and Manning's "n" has its role in the discharge estimation. The RAINFLO model is less sensitive to the velocity of the flow. However, the model is very sensitive to runoff curve number and antecedent moisture conditions. Also it is observed that lower value of Manning's "n" results in higher peak discharge and lower time to peak. Higher values of Manning's "n" results in more diffusion of flow hydrograph resulting in lower peak discharge and increase in time to peak in all the events. Therefore, selection of curve number, initial moisture conditions, and Manning's "n" should choosen carefully and thoughtfully otherwise, it may give unreliable results.

From the simulation results it is concluded that the model can simulate the runoff hydrographs reasonably well for Ramganga at Chaukhutia. The errors in peak discharge, time to peak and overall runoff volume are within $\pm 12\%$.

1.0 INTRODUCTION

Runoff estimates are needed for planning and design of various hydrologic systems. There are several models available to simulate rainfall runoff process of a watershed. RAINFLO is a comprehensive hydrologic computer software system to model the rainfall runoff process in complex watersheds and river basins. It can also be used for real time flood forecasting. To setup the model for a watershed, you specify the stream channel network in terms of a set of topologic numbers. Using these topologic numbers , RAINFLO orders the sequence of computations to enable the subwatershed hydrograph generation and the routing the flows through the specified network of stream channels and reservoirs if exist.

RAINFLO accepts rainfall input to the watershed or basin and converts it into stream flow. Flows are expressed at the basin outlet, and optionally, at any or all network confluences. The total basin area is divided into two types of subwatershed units:

1. upland subwatersheds, neighbouring the basin perimeter, which generate upland inflow hydrographs to the stream network; and
2. reach subwatersheds , adjacent to the stream channel reaches and generating lateral inflow to them.

Rainfall can be specified distinctly for each subwatershed. Storm can be input discretely in time or as a total amount for a given duration. In the latter case , you can supply a temporal storm pattern, or alternatively, choose among several builtin SCS dimensionless storm patterns.

Present study is aimed at finding the suitability of RAINFLO model for Ramganga at Chaukhutia for rainfall runoff simulation

2.0 MODEL DESCRIPTION

RAINFLO is a comprehensive hydrologic computer software system to model the rainfall runoff process in complex watersheds and river basins. To setup the model for a watershed the user, has to specify the stream channel network in terms of a set of topological numbers. Using these topological numbers, RAINFLO orders the sequence of computations to enable the subwatershed hydrograph generation and the routing of flows through the specified network of stream channels and reservoirs. RAINFLO accepts rainfall input to the watershed or basin and converts it into streamflow. Flows are expressed at the basin outlet, and optionally, at any or all network confluences.

RAINFLO consists of four major modules:

1. Network topology;
2. Subwatershed hydrograph generation;
3. Stream channel routing; and
4. Reservoir routing.

2.1 Network Topology

In RAINFLO, the basic unit of network simulation is the stream reach. The total number of stream reaches forms the channel network. The channel network is specified by a set of topological numbers. Each stream is assigned a topological number consisting of order-branch-channel information. The array of the topological numbers determines the connectivity of the stream network, enabling the routing of flows in time and space. A topological number has five digits. The first digit is the order, varying from 1 to 9; the Second and third digits are the branch numbers varying from 1 to 99; and the fourth and fifth digits are the channel number, from 1 to 99.

To determine the topological number, the following steps are to be carried out;

1. develop tree-like schematic of the stream network;
2. delineate all broaches;
3. assign steam orders to the various branches following RAINFLO procedures;

4. number the branches following RAINFLO procedures;
5. number the channels following RAINFLO procedures; and
6. combine order-branch-channel information for each stream reach into a five-digit topological(NTOPO) number.

All stream reaches with 01 as the last two digits of the NTOPO number are upland stream reaches, and consequently, accept upland subwatershed hydrograph inflow. Number all upland subwatersheds sequentially, in order of increasing upland stream reach NTOPO number, from 1 to number of upland watersheds. In RAINFLO, confluence is the location where two stream reaches meet and join their flows. Multiple confluences can be configured in RAINFLO by using null reaches. RAINFLO stream reaches can be sub-divided in number of subreach-per stream reach to account for cross sectional nonuniformity. Within each stream reach, one subreach at most can be considered a reservoir subreach, and therefore, subject to reservoir routing.

2.2. Subwatershed Hydrograph Generation

The subwatershed unit hydrograph calculation is based on current SCS practice. For watershed areas equal to or less than 6.2 square miles, the lag is estimated by the curve number method, provided the input (AMC 2.0) runoff curve number is within the range 50-95. Otherwise, the lag is estimated as a percentage of the time of concentration. The latter is calculated based on the hydraulic length of the subwatershed and an estimation of the average velocity along the hydraulic length. The duration of the unit hydrograph is estimated as the percentage of the lag. The unit hydrograph time to peak is estimated as a multiple of the unit hydrograph duration. The peak flow is calculated based on the subwatershed area and unit hydrograph time to peak. Based on peak flow and time to peak, the SCS dimensionless unit hydrograph is used to calculate the ordinates of the subwatershed unit hydrograph. The calculated unit hydrograph is convoluted with the effective storm pattern to generate the composite outflow hydrograph at each watershed outlet. RAINFLO uses established SCS practices for subwatershed hydrograph generation, including the runoff curve number procedure for abstraction of flows, dimensionless storm distribution patterns, and the dimensionless unit hydrograph. The SCS unit hydrograph is the dimensionless unit hydrograph developed by Victor Mockus in the 1950s. The hydrograph was developed based on the analysis of a large number of natural unit hydrographs from a wide range of catchment sizes and geographic locations. This method has been recognized as the SCS synthetic unit hydrograph and has been applied to mid size catchment-throughout the world. The SCS method uses constant rates of actual time base to time to peak, and also uses a dimensionless hydrograph function to provide a standard unit hydrograph shape. The following two methods has been used to find out the catchment lag (i) The curve number method (ii) The velocity method.

2.2.1 Curve number method

The curve number method is limited to catchment of areas less than 8 km, but recent evidence suggests that it may be used up to the catchment area 16 square km. The subwatershed unit hydrograph calculation is based on current SCS practice. For watershed areas equal to or less than 6.2 square miles, the lag is estimated by the curve number method, provided the input (AMC 2.0) runoff curve number is within the range 50-95.

2.2.2 Velocity Method

In the velocity method, the main stream divided into reaches and the two year flood or the bankfull discharge is to be estimated. It is also suggested for certain cases to use discharges corresponding to 10 year frequencies or more. The mean velocity is computed and the reach concentration time is calculated by using the reach valley length (straight distance). The sum of the concentration time for all reaches is the concentration time for the catchment.

2.3.0 Stream Channel Routing

The stream channel routing refers to a specific length of stream channel possessing certain translation and storage properties. The hydrograph at the upstream end of the reach is the inflow hydrograph at downstream end is the outflow hydrograph. Lateral contributions consists of point tributary inflow and distributed inflows. The stream channel routing is attributed for the application such as flood flow analysis, flood control design or flood forecasting. The hydrologic and hydraulic approaches has been recognised in the stream channel routing. The hydraulic stream channel routing is based on the storage concept. Where as in the case of hydraulic stream channel routing is based on the principles of conservation of mass and momentum. The Muskingum-Cunge method is an alternative approach to hydraulic and hydrologic routing has emerged in recent years. The approach is similar in nature to the hydrologic routing method, yet contains sufficient physical information to compare favourably with the more complex hydraulic routing techniques. The Muskingum-Cunge method has been adopted for the stream channel flow routing mode in the RAINFLO model. The Muskingum-Cunge method is a physically based alternative to the Muskingum method. In this method the parameters are calculated based on flow and channel characteristics. It also limited to diffusion waves and is based on a single value rating and does not take into account strong flow non uniformity or unsteady flows exhibiting substantial loops in discharge stage rating. The Muskingum-Cunge method has been calibrated using physical characteristics such as rating curve, cross sectional data, and channel slope.

2.4 Reservoir Routing

The RAINFLO reservoir routing model is based on the storage indication technique. The system accepts sets of elevation-storage-outflow values for each reservoir channel exponent and user the information together with starting reservoir elevation, to calculate the outflow hydrograph for the reservoir subreach. The storage indication method of routing a hydrograph through a reservoir is also called the modified Plus method. A flood wave passing through a storage reservoir is both delayed and attenuated as it enters and spreads over the pool surface. Water stored in the reservoir is gradually released through turbines outlet works called principal spillways or in extreme floods over an emergency spillway. Flow over an ungated emergency spillway weir section or flow through a free outlet discharge pipe or some other may be estimated using proper flow equations. Storage value for various pool elevation in a reservoir are readily determined from computations of volume confined between various pool areas measured from topographic maps. Since storage and outflow both depend only on pool elevation, the resulting storage-elevation curve and the out flow and outflow-elevation relationship can be easily combined to for a storage outflow graph.

3.0 DESCRIPTION OF THE STUDY AREA

The Chaukhutia sub-watershed comprising an area of 452.25 sq. km. of Ramganga reservoir catchment lies between 29°46′15″ to 30°6′ N latitude and 79°12′15″ to 79°31 longitude in the Shivalik range of the Himalayas was selected for the present study. The climate of the region is Himalayan sub-temperate having mean annual temperature of about 21°C. The average annual total precipitation in the area is 1466.76 mm, which varies from 1208.5 mm to 1773.76 mm at different locations. The maximum elevation of the watershed is 3114.14 metre above the mean sea level and the minimum elevation at Chaukhutia is 929 metre. Fig. 1 shows the catchment map of the study area along with location of gauging stations.

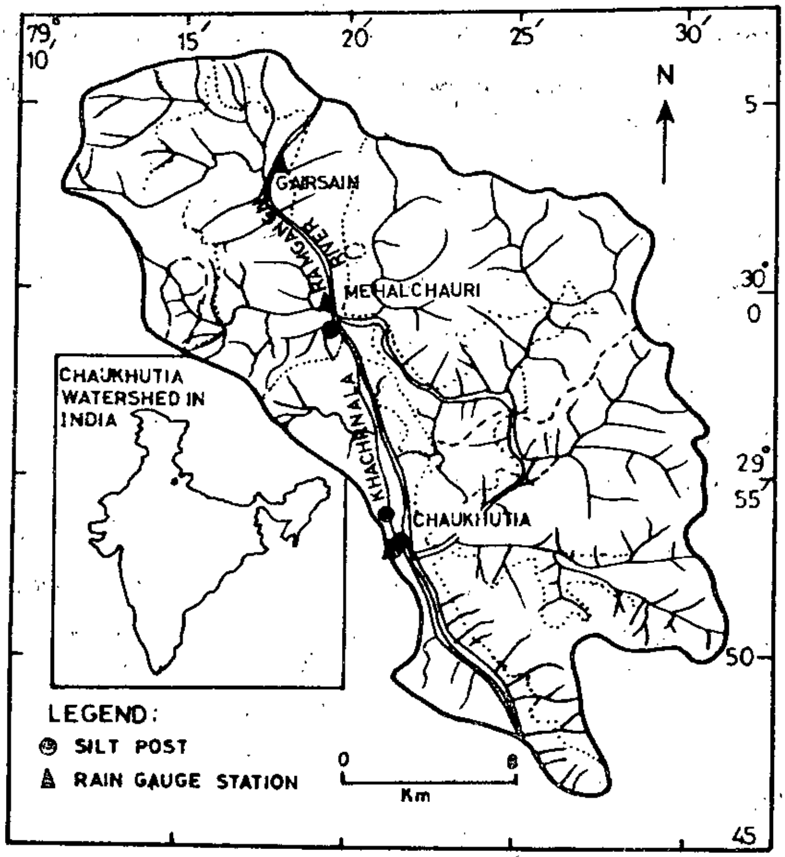


FIG.1. RAMGANGA RIVER BASIN WITH LOCATION OF GAUGING STATIONS.

4.0 MODEL SETUP ON RAMGANGA AT CHAUKHUTIA

The RAINFLO model has been tested as an initial application to the Ramganga at Chaukhutia. The following data were collected and assembled in suitable form for computer utilization.

1. Precipitation
2. Runoff curve number based on hydrologic soil type and land use/land cover derived from remote sensing data.
3. Assumed trapezoidal stream cross-sections.
4. Manning's 'n' for stream reaches.
5. Discharge hydrograph at Chaukhutia.

The Ramganga basin upstream of Chaukhutia was descritized into 7 subcatchments and 13 stream reaches and set of RAINFLO topological numbers were developed.

4.1 Topology

The total basin area is sub divided into upland and reach watershed units. To the extent possible the watershed units should be of the same order of magnitude in such a way that non of them should be too big and too small. The Ramganga basin upstream of Chaukhutia was discretised into 7 subcatchments and 13 stream reaches as shown in the Fig. 2. A set of RAINFLO topological numbers developed in which five digit number containing information on order-branch-channel. First digit indicates order of the Stream, next two digits for the branch and last two digits which indicates the channel.

4.2 Soil and Landuse Details

In this subwatershed the croplands consists of 27.28% of the total area, 42.76% is under hay and grazing land, 19.87% is under forest and wood land, and the balance of about 10% is otherwise covered or used.

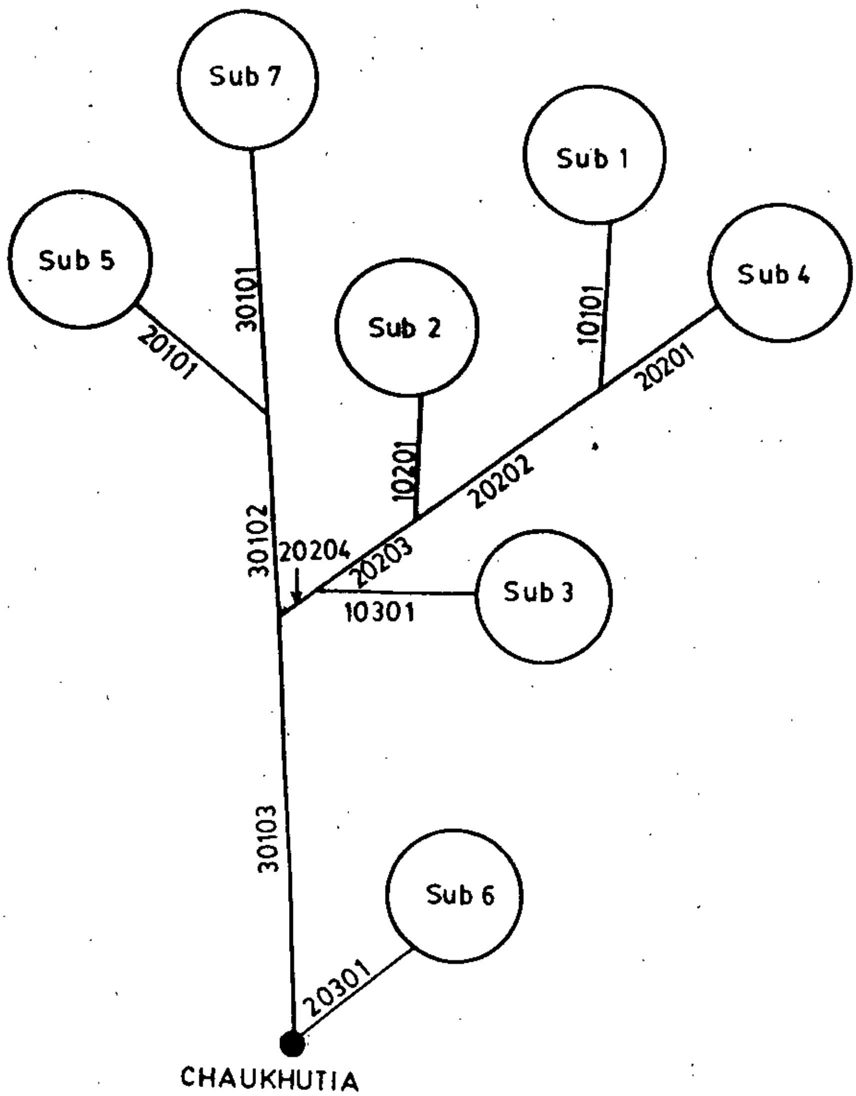


FIG. 2. STREAM NETWORK TOPOLOGY FOR RAMGANGA AT CHAUKHUTIA.

The soils in most areas of the watershed have resulted from washing away of top soils aided by continuous biotic interference. The watershed has shallow soils on hill slopes and considerably deep soils in the valleys. The properties of the soils of the watershed exhibit large variations depending upon their parent materials, local vegetation, landuse, altitude, and land management practice. Soils under reserved forests are good, medium to deep and rich in organic matters. Soils under pastures, waste lands and poorly managed panchayat and civil forests are severely grazed and eroded. Soils under cultivation shows large variation in their soil properties governed by the process of management of terraces. The eroded soils of poorly managed terraces are dominated by coarse fragments.

4.3 Land Slope

The elevation of the land surface lies in the range of 929 to 3144 m above mean sea level. slopes in the valley vary from 8 to 10% in the lower reaches, 10 to 50% in the intermediate higher reaches and almost vertical hills at the highest point.

5.0 RESULTS AND DISCUSSION

As described in section 4.0, the RAINFLO model was setup for Ramganga at Chaukhutia. For calculation of excess rainfall, SCS procedure (SCS, 1972) is followed. From the soil type and landuse present in the basin, preliminary estimates of the curve numbers for different sub-basins were made. The curve numbers were found in the range of 69 to 74 for various sub-basins depending upon soil type and landuse in a sub-basin. For Indian conditions antecedent moisture condition AMC-III is recommended (Malhotra, 1995) and used in present model setup for initial runs.

Besides runoff curve number, the RAINFLO requires Manning's "n" value for routing the runoff hydrograph using Muskingum-Cunge routing technique. Chow (1964) has recommended a value of 0.035 for Manning's "n" for natural rivers. Therefore, for initial runs of the model, Manning's "n" was taken as 0.035. Trial model runs were made and velocity for calculating basin lag time for computation of SCS unit hydrograph and antecedent moisture conditions in SCS runoff curve number method were adjusted in successive runs of the model in such a way that observed and computed runoff volume and time to peak match closely. Above procedure of calibration of the model was repeated for all three events observed in the basin. It was observed from trial runs of the model that the velocity of the order of 0.8 m/sec give a good match in time to peak of the observed and computed flood hydrographs in all the events. For further calibration runs, the velocity parameter was assigned a value of 0.8 m/sec. It was also observed from initial calibration runs of the model that the runoff volume is sensitive to antecedent moisture conditions (AMC) and runoff curve numbers. Different values of initial abstractions were assigned to different events to get close volume match of the observed and computed runoff keeping the curve numbers same as calculated previously. Event dependent AMC conditions fall between AMC-II and AMC-III.

After assigning event dependent AMC values and velocity parameter as discussed above, the model sensitivity to Manning's "n" was carried out. Manning's "n" was varied from 0.030 to 0.050 in successive trial runs for all the events. Sensitivity of Manning's "n" on peak, time to peak and runoff volume is given in Table 1. It can be seen from Table 1 that lower value of Manning's "n" results in higher peak discharge and lower time to peak. Higher values of Manning's "n" results in more diffusion of flow hydrograph resulting in lower peak discharge and increase in time to peak in all the events. Based on the observations of Table 1, a value of 0.035 for Manning's "n" was adopted for the basin. The results of simulation of observed and predicted hydrographs are shown in Figs. 3 to 5 for events dated 24.07.1973, 17.08.1983 and 01.09.1984 respectively. Simulation results suggests that present modelling approach cab very well predict peak, time to peak and overall runoff volume as well as shape of hydrograph.

Table-1. Sensitivity Analysis of Manning's "n".

Date of event	Manning's "n"	Peak runoff (cumec)		Time to peak runoff (hr)		Equivalent depth (mm)	
		Observed	Simulated	Observed	Simulated	Observed	Simulated
24.07.73	0.030	102.0	101.0	14.0	14.50	2.896	2.881
	0.035	102.0	101.0	14.0	14.55	2.896	2.883
	0.040	102.0	100.0	14.0	14.75	2.896	2.880
	0.045	102.0	98.0	14.0	14.75	2.896	2.871
	0.050	102.0	97.0	14.0	15.00	2.896	2.868
17.08.83	0.030	104.0	117.0	5.0	4.75	2.694	2.667
	0.035	104.0	115.0	5.0	4.75	2.694	2.668
	0.040	104.0	111.0	5.0	4.75	2.694	2.670
	0.045	104.0	109.0	5.0	5.00	2.694	2.676
	0.050	104.0	106.0	5.0	5.25	2.694	2.666
01.09.84	0.030	100.0	103.0	5.0	5.50	2.195	2.202
	0.035	100.0	99.0	5.0	5.50	2.195	2.201
	0.040	100.0	96.0	5.0	5.50	2.195	2.200
	0.045	100.0	94.0	5.0	5.75	2.195	2.200
	0.050	100.0	92.0	5.0	6.00	2.195	2.196

Fig. 3. Observed and computed runoff for event dated 24.07.1973

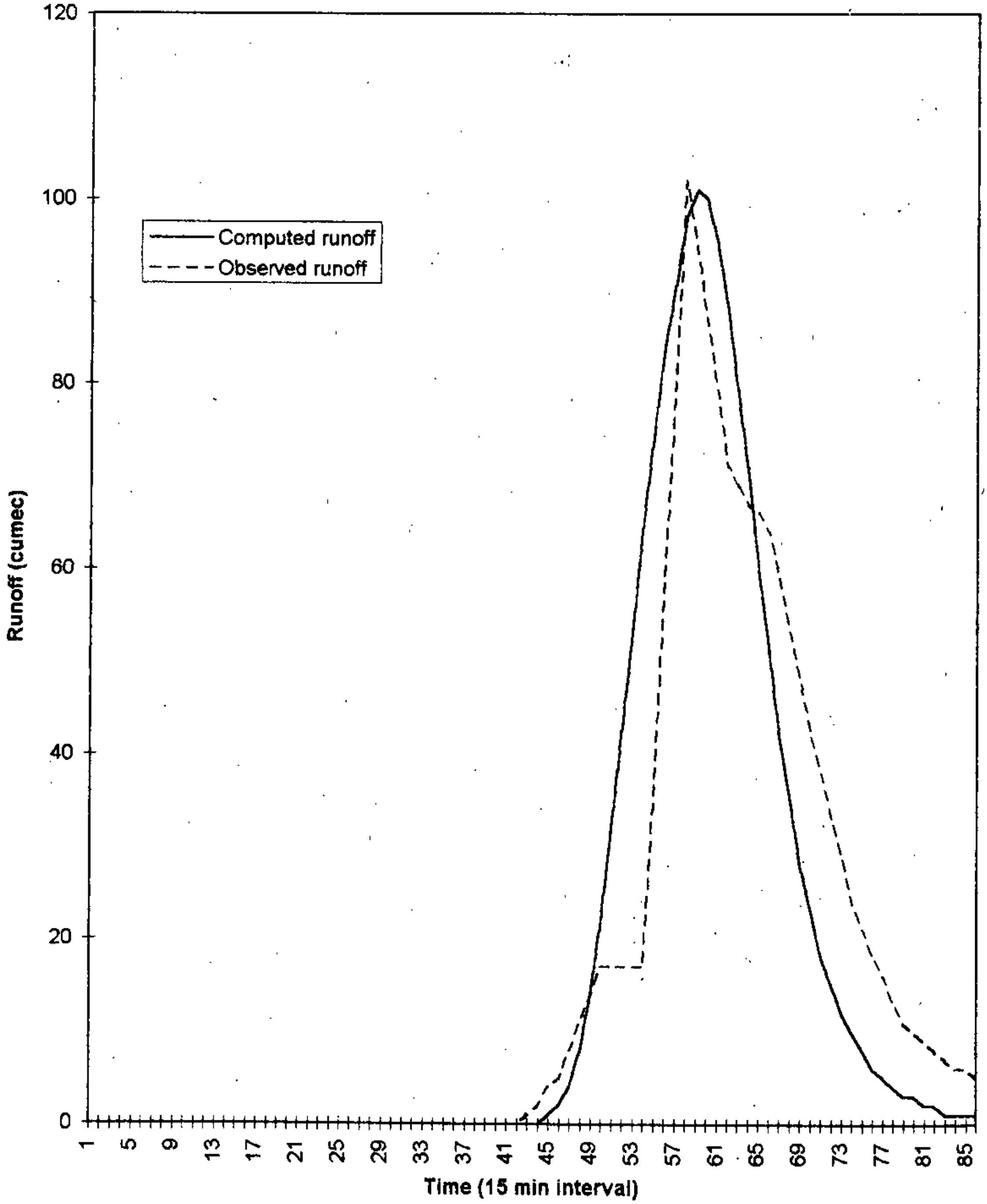


Fig. 4. Observed and computed runoff for event dated 17.08.1983

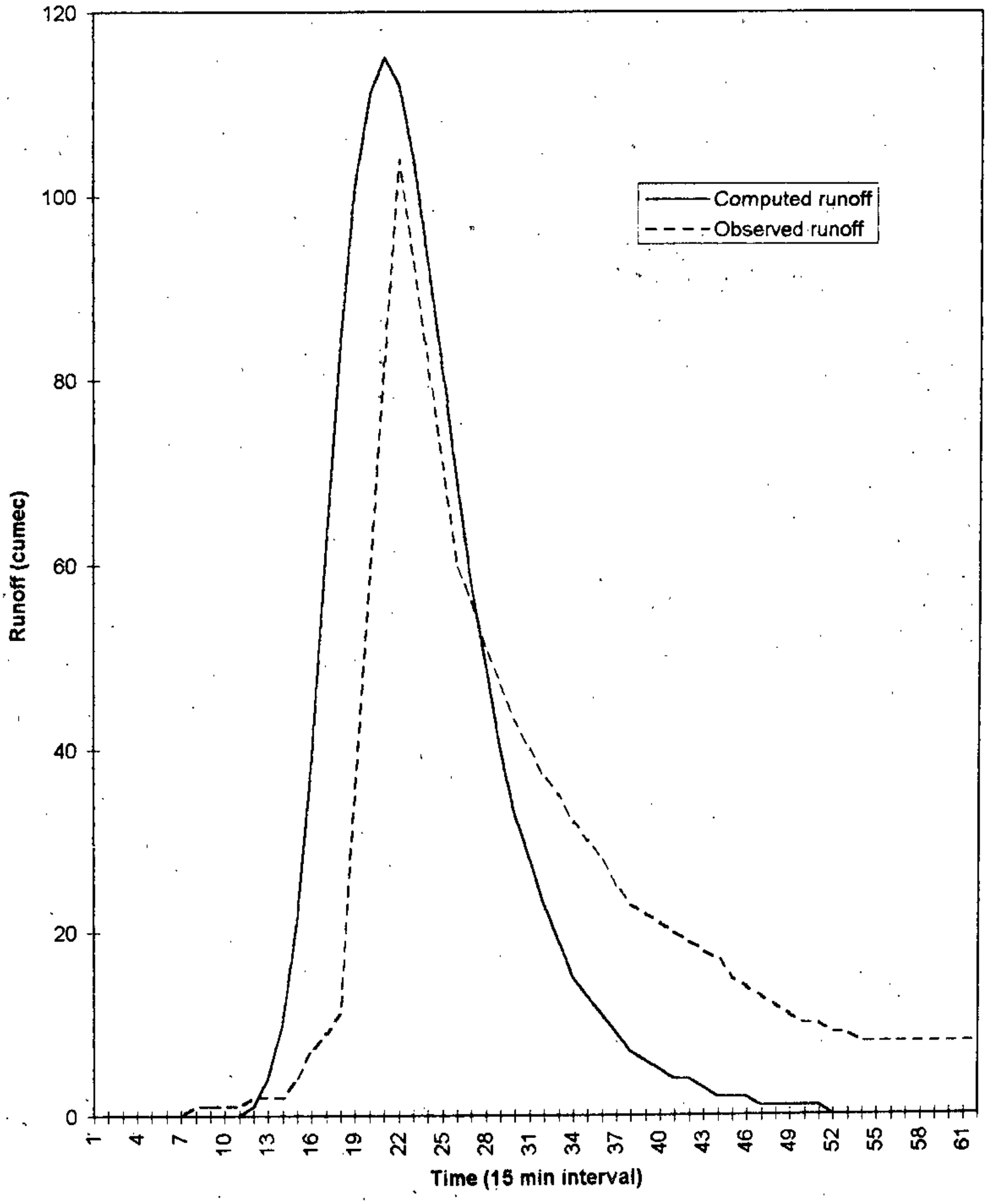
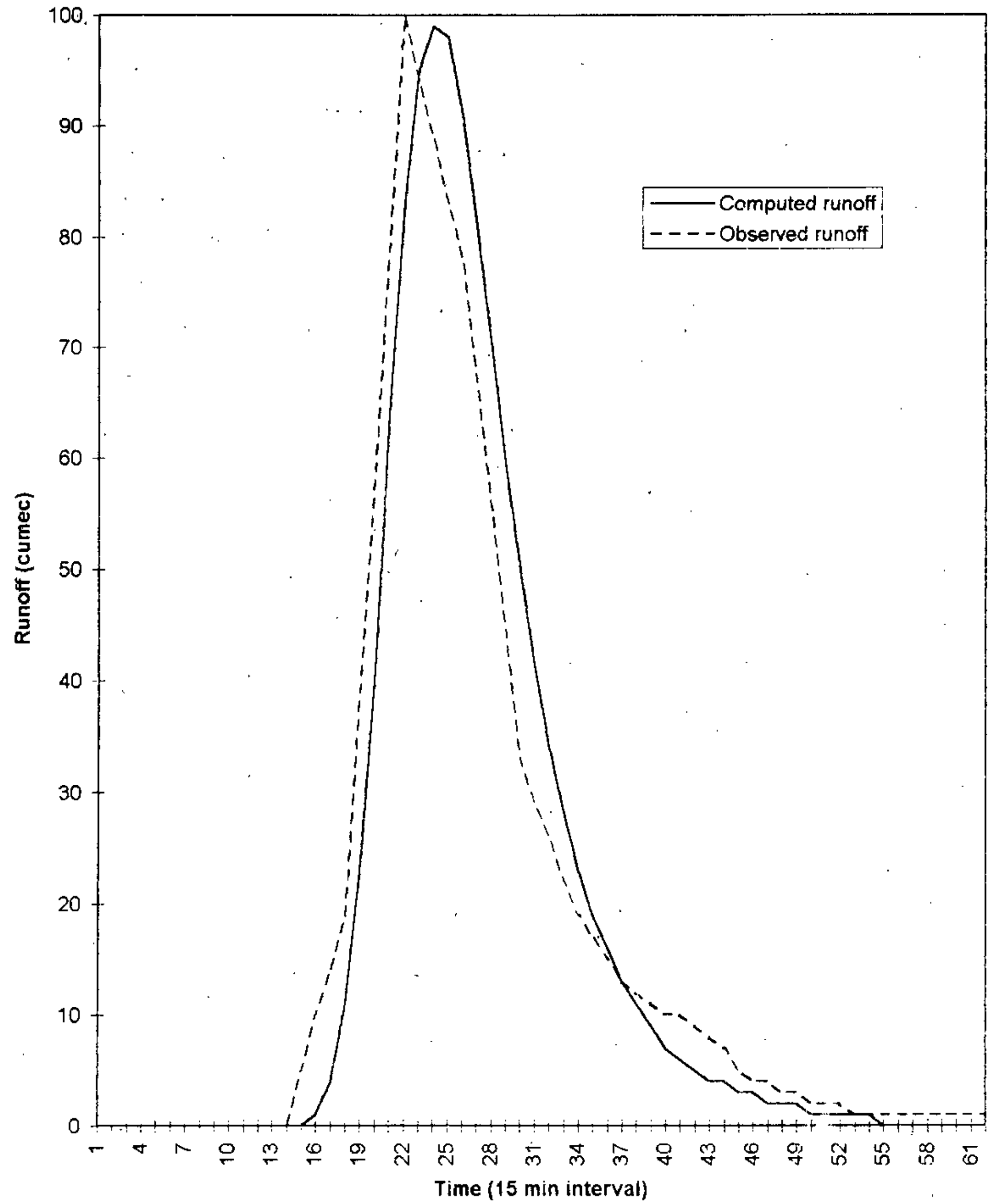


Fig. 5. Observed and computed runoff for event dated 01.09.1984



6.0 CONCLUSIONS

The above discussions shows that, the parameters such as SCS curve number, antecedent moisture conditions, velocity, and Manning's "n" has its role in the discharge estimation. The RAINFLO model is less sensitive to the velocity of the flow. However, the model is very sensitive to runoff curve number and antecedent moisture conditions. It can be seen from Table 1 that lower value of Manning's "n" results in higher peak discharge and lower time to peak. Higher values of Manning's "n" results in more diffusion of flow hydrograph resulting in lower peak discharge and increase in time to peak in all the events. Therefore, selection of curve number, initial moisture conditions, and Manning's "n" should choosen carefully and thoughtfully otherwise, it may give unreliable results.

From the simulation results it is concluded that the model can simulate the runoff hydrographs reasonably well for Ramganga at Chaukhutia. The errors in peak discjharge, time to peak and overall runoff volume are within the tolerance limit.

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