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RAINFALL RUNOFF MODELLING OF UPPER NARMADA BASINS USING A GEOMORPHOLOGIC TECHNIQUE

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PREFACE

The research in the field of fluvial geomorphology has recently picked up and offers some great opportunities in solving many of the problems facing the hydrologists today. The concept of Geomorphological Instantaneous Unit Hydrograph (GIUH) has first been introduced by Rodriguez-Iturbe and Valdes in 1979, since then lot of refinements have taken place in their original theory. However, inspite of refinements, the original basic framework of GIUH remains the same. A very complicated analysis is requires for accurate interference based on the geomorphological theory. Many investigators have simplified its application to different levels. Also, there have been attempts to relate the parameters of conventional conceptual models of instantaneous unit hydrograph to the geomorphological instantaneous unit hydrograph.

In this report, a methodology to derive the gamma pdf parameters is proposed using dimensionless Horton numbers, and characteristic stream flow velocity which in turn is estimated from basin lag calculated from basin area. The applicability of the proposed method has been tested by simulation runs using data for four sub-basins of river Narmada namely Narmada at Manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri. The results of simulation are in reasonable agreement with observed records. This study has been carried out by Shri M. K. Jain, Scientist 'B' under the guidance of Shri R. D. Singh, Scientist 'E' of the Surface Water Analysis and Modelling Division of the National Institute of Hydrology, Roorkee.

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ABSTRACT

Two parameter gamma probability density function (pdf) is one of the most commonly used representation of instantaneous unit hydrograph (IUH) of a basin. Parameter estimation is a major constraint for its application on ungauged catchments or catchments with limited data. When sufficient records are not available, one of the possibilities is the development of a relationship between characteristics of quantitative geomorphology of drainage basins and channel networks and parameters of an IUH. Recent advances in geomorphological parameterization and their linking to the parameters of existing conceptual hydrological models provides a good basis for application of these models to ungauged catchments. In this report, a methodology to derive the gamma pdf parameters is proposed using dimensionless Horton numbers, and characteristic stream flow velocity which in turn is estimated from basin lag calculated from basin area. The applicability of the proposed method has been tested by simulation runs using data for four sub-basins of river Narmada namely Narmada at Manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri. The results of simulation are in reasonable agreement with observed records.

1.0 INTRODUCTION

Quantitative understanding and prediction of the process of runoff generation and its transmission to the outlet represent one of the most basic and challanging areas of scientific hydrology. To explain the world of hydrologic phenomina it will be necessary to develop scientific theories of a general character. In respect to the structure of the hydrologic response these theories, by necessity, will have to be linked to the geomorphologic structure of the basin.

The concept of Geomorphologic Instantaneous Unit Hydrograph was first introduced by Rodriguez-Iturbe and Valdes (1979). They used a state-transition approach, defining the presence of a drop of water in an interior link as a 'state' and assuming an exponential form for the probability dendity function (pdf) of the holding time in each state. The derived distribution of total travel time to the outlet is taken as the instantaneous unit hydrograph (IUH) of the basin and is termed as geomorphologic unit hydrograph. Using the same basic framework of Rodriguez-Iturbe and Valdes, Gupta Waymier and Wang (1980) were able to work with any distribution for the waiting time mechanism as well as to get rid of the Markovian hypothesis. An excellent review on GIUH studies can be found out in Technical Note no. 95 of National Institute of Hydrology, Roorkee.

Recent studies had sugested several forms of GIUH representation. On the basis of multiple regression of Nash model and GIUH model given by Rodriguez-Iturbe et al., Rosso (1984) suggested Nash model formulation through basin geomorphology. In the present study, a methodology to derive the gamma pdf parameters is proposed using dimensionless Horton numbers, and characteristic stream flow velocity which in turn is estimated from basin lag calculated from basin area. The applicability of the proposed method has been tested by simulation runs using data for four sub-basins of river Narmada namely Narmada at Manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri. The results of simulation are in reasonable agreement with observed records.

2.0 METHODOLOGY

In this methodology a relation between GIUH and Nash IUH is proposed using dimensionless Horton numbers, and characteristics stream flow velocity which in turn is estimated from basin lag estimated from basin area.

Under the assumption of equality of dimensionless product of peak and time to peak of Nash's IUH and GIUH, Rosso (1984) provided a Nash model formulation of GIUH based on multiple correlation. Thus Nash model parameters "N" and "k" are given as;

$$\left.\begin{aligned} N &= 3.29\left(\frac{R_B}{R_A}\right)^{0.78} R_L^{0.07} \\ \text{and} \qquad k &= 0.70\left(\frac{R_A}{R_B R_L}\right)^{0.48} V^{-1} L_\Omega \end{aligned}\right\} \tag{1}$$

For two parameter gamma pdf, the time to peak is the mode of the gamma function shape, or;

$$t_p = k(N-1) \tag{2}$$

and the scale parameter is;

$$k = \frac{t_l}{N} \tag{3}$$

where t_l is the lag time estimated as the difference between the rainfall excess hyetograph and the flood hydrograph centre of gravity.

The assumption of equality of t_p of Nash IUH and GIUH allows the estimation of mean stream flow velocity as;

$$v = 1.584\left(\frac{R_B}{R_A}\right)^{0.55} R_L^{-0.38} \frac{L_\Omega N}{(N-1)\, t_l} \tag{4}$$

The lag time (t_l) is an unknown value in above equation and can be estimated from basin area (Body, 1978; Body et al., 1979; Panu and Singh, 1981; Singh, 1983).

$$t_l = bA^{0.38} \tag{5}$$

The parameter b in Eq. 5 is unknown and can be computed by optimization if observed rainfall runoff records are available. For estimation of parameter b, modified Rosenbrock-Palmer optimization algorithm (Rosenbrock, 1960; Palmer, 1969; Himmelblau, 1972) is used such that the objective functions defined below by Eqs. 6 and 7 refered hereafter as objective function 1 and objective function 2 respectively, are minimum. Two objective functions are choosen to study the effect of choice of objective function on simulated results.

$$F = W_1 \sum_{j=1}^{M} \left[\frac{Q_{po}(j) - Q_{pc}(j)}{Q_{po}(j)} \right]^2 + (1 - W_1) \sum_{j=1}^{M} \left[\frac{t_{po}(j) - t_{pc}(j)}{t_{po}(j)} \right]^2 \tag{6}$$

$$F = \sum_{i=1}^{N_i} [Q_o(i) - Q_c(i)]^2 \tag{7}$$

where, Q_{po} is the observed peak flow, Q_{pc} is the computed peak flow, t_{po} is the observed time to peak, t_{pc} is the computed time to peak, W_1 is an arbitrary weight ($0 \leq W_1 \leq 1$), $Q_o(i)$ is the i-th ordinate of observed runoff, $Q_c(i)$ is the i-th ordinate of computed runoff, N_i is number of ordinate in the event and M is the number of events.

3.0 THE STUDY AREA AND DATA AVAILABILITY

The Narmada is a major west flowing river in central India traversing through Madhya Pradesh, Gujarat and Maharastra and finally meets Arabian Sea. It rises in the Amarkantak plateau of Maikala range in the Shahdol district of Madhya Pradesh at an elevation of 1057 metres above mean sea level. Upper Narmada lies in sub zone 3(c) defined by Central Water Commission. It comprises of about twelve tributaries of river Narmada meeting to left or right banks. For the present study, four sub basins of upper Narmada are selected. They are Narmada upto Manot, Burhner upto Mohegaon, Banjar upto Hridenagar and Sher upto Belkheri.

Narmada upto Manot lies between east longitude 80°24′ to 81°47′ and north latitudes 22°26′ to 23°18′ in Mandla and Shahdol districts of Madhya Pradesh. The river rises in Maikala range near Amarkantak in the Shahdol district of Madhya Pradesh at an elevation of 1057 metres.

Burhner rises in the Maikala ranges, southeast of Gwara village in Mandala district of Madhya Pradesh at an elevation of about 900 metres, at north latitude 21°42′ and east longitude 80°50′ and flows generally in north-westly direction for a total length of 184 kilometres to join Narmada near Manot.

The Banjar rises in the Satpura range in the Durg district of Madhya Pradesh near Rampur village at an elevation of about 600 metres at north latitude 21°42′ and east longitude 80°50′ and flows generally in north-westerly direction for a total length of 184 kilometres to join Narmada from left bank near Mandala.

The Sher rises in the Satpura ranges near Patan in Seoni district of Madhya Pradesh at an elevation of 600 metres at north latitude 22°31′ and east longitude 79°25′ and flows in north-westerly direction for a total length of 129 kilometres to its confluence with Narmada from left near Brahmand.

The Upper Narmada has a complex relief. High ranges of above 900 metre exist over a small area near the source of Narmada river. Areas varying in height between 600 and 900 metre lies along eastern and middle portions of the boundary. The Upper Narmada has a continental type of climate. It is very hot in summer and cold in winters and receives most of the rainfall from South-West monsoon from June to October. Mean annual rainfall varies approximately from 800 to 1600 mm. Fig 1 shows the index map of the study basins. Figs. 2 to 5 shows maps of Narmada at

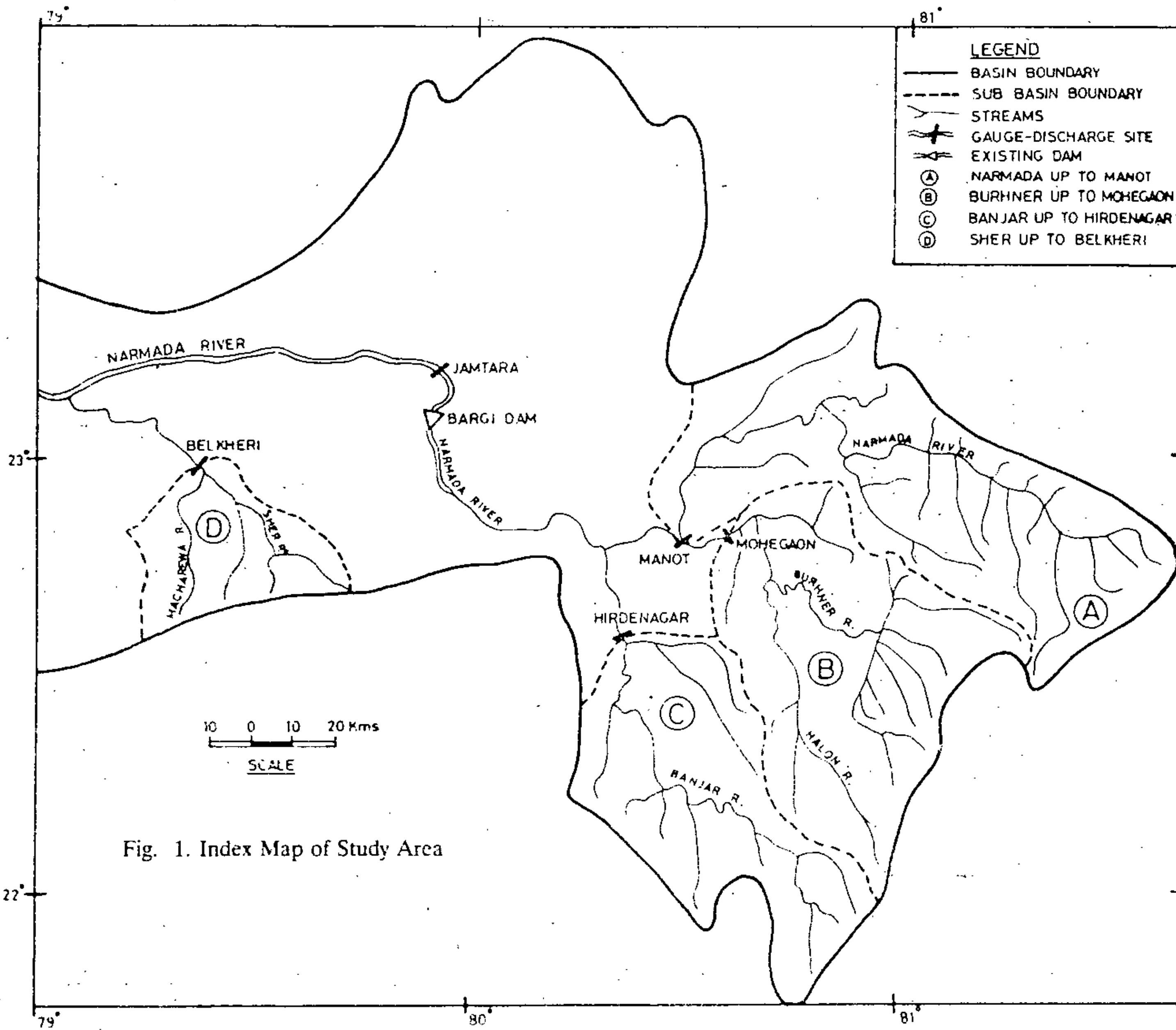


Fig. 1. Index Map of Study Area

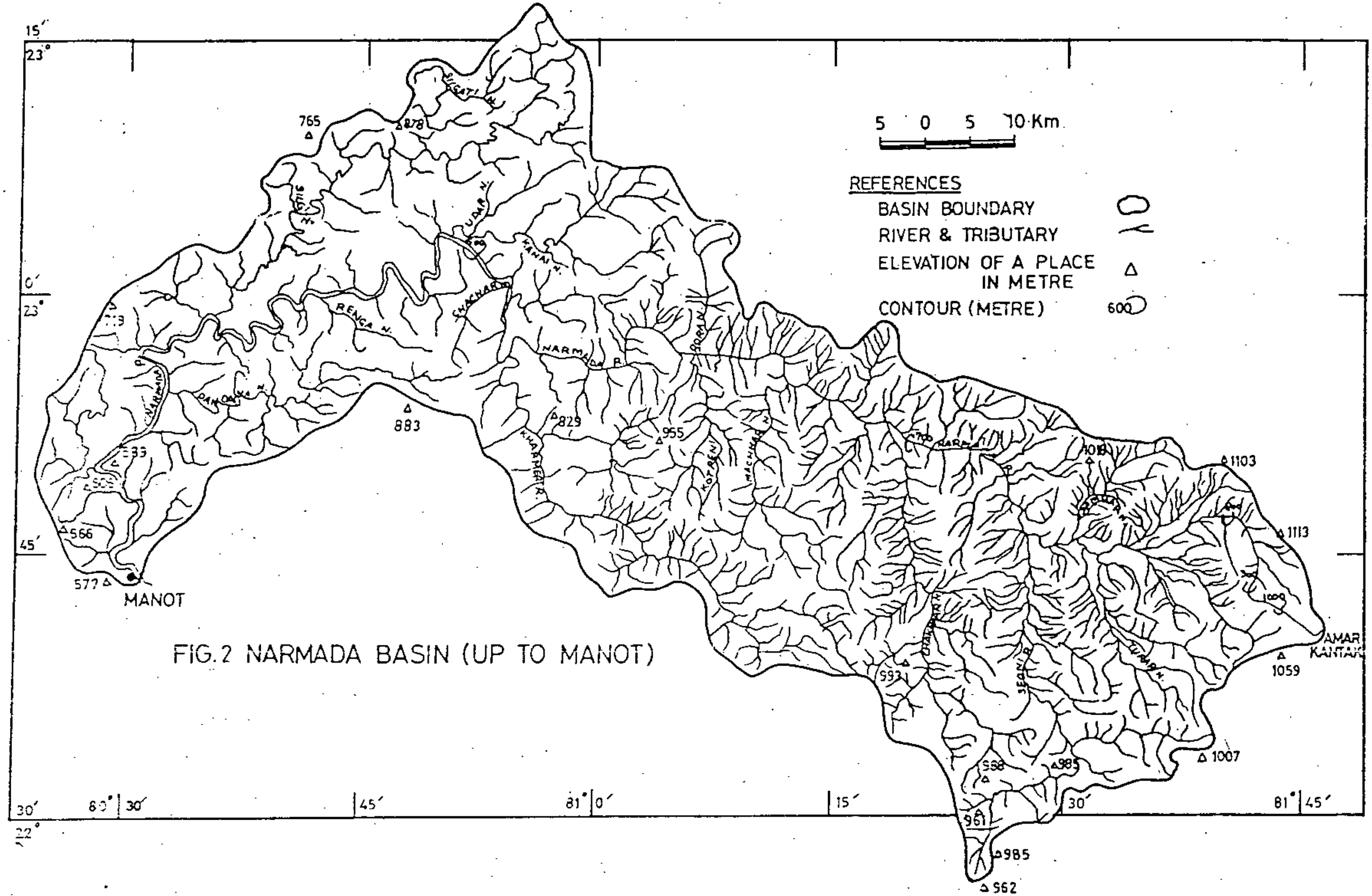


FIG.2 NARMADA BASIN (UP TO MANOT)

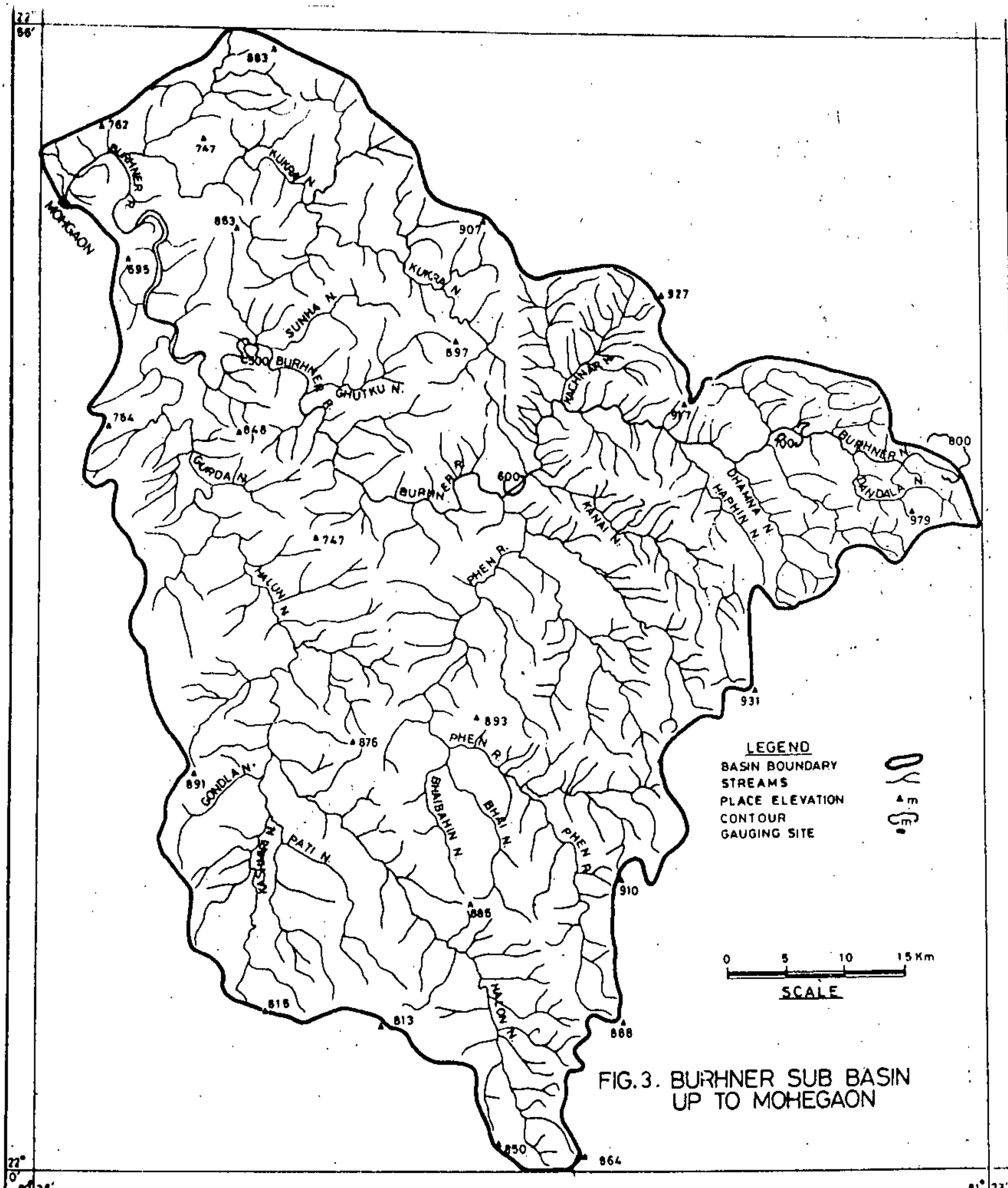


FIG. 3. BURHNER SUB BASIN UP TO MOHEGAON

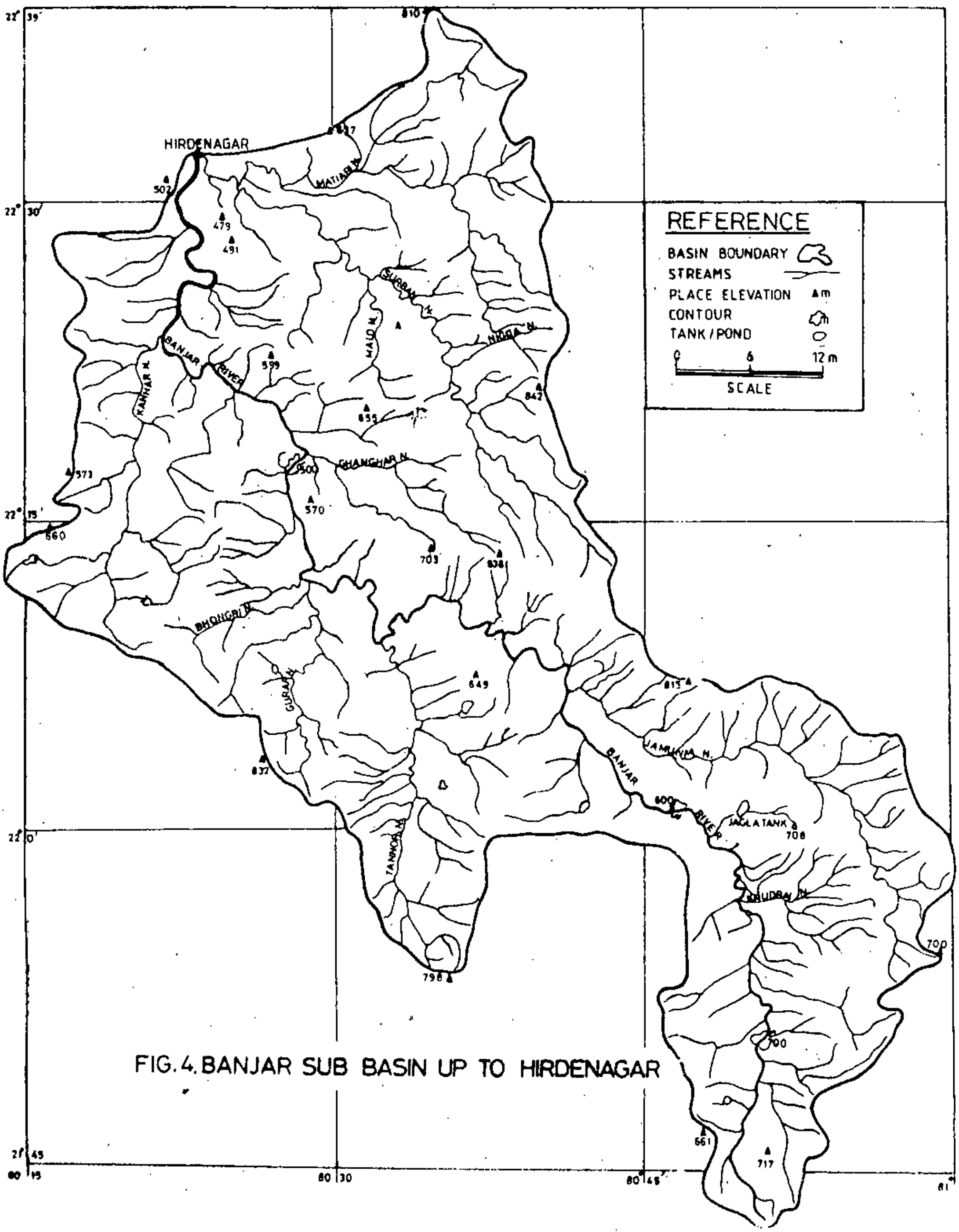


FIG. 4. BANJAR SUB BASIN UP TO HIRDENAGAR

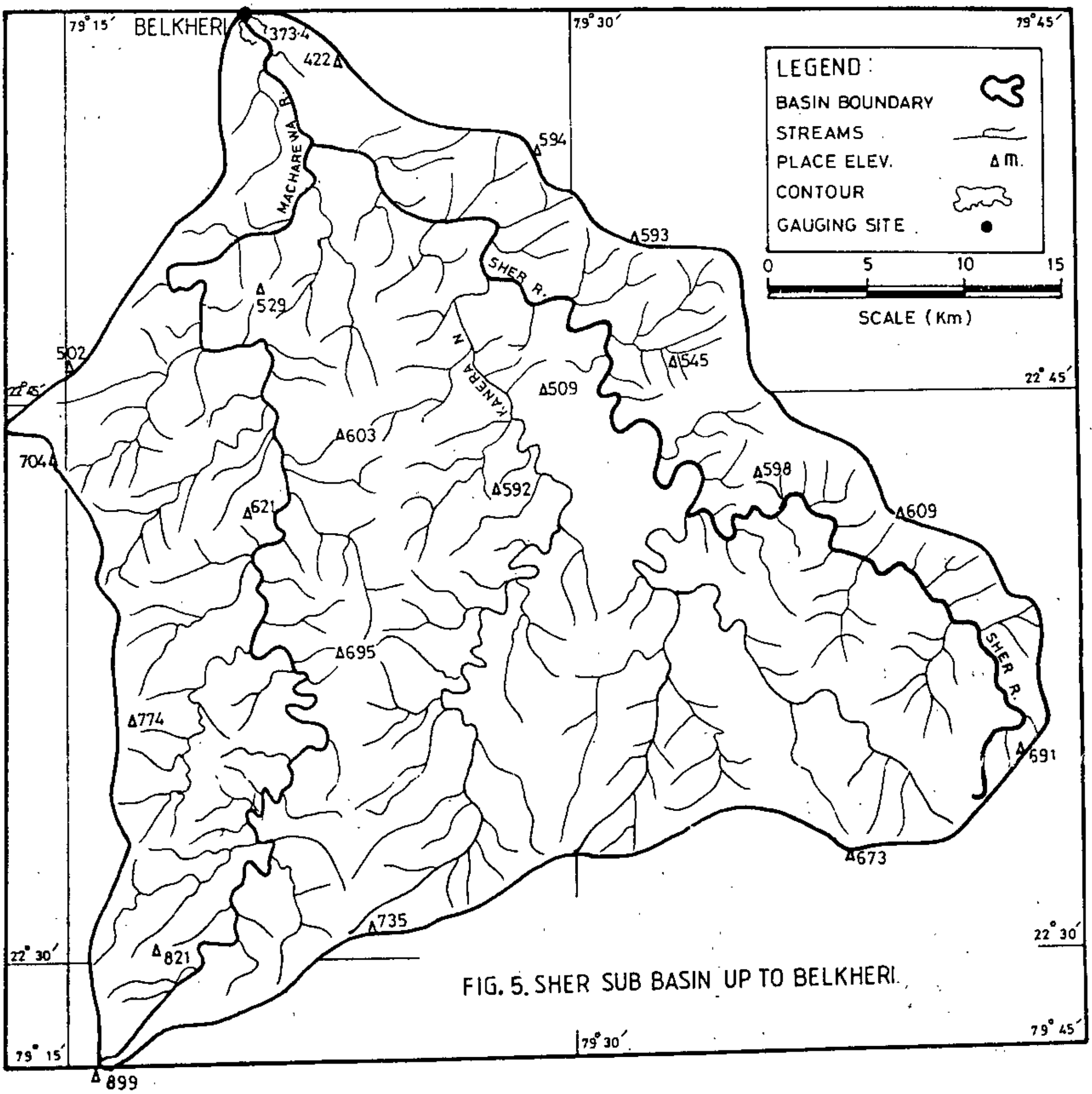


FIG. 5. SHER SUB BASIN UP TO BELKHERI.

Manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri basins respectively.

Table 1: Main geomorphological parameters of selected basins

Name of Basin	Area (km^2)	R_A	R_B	R_L	L_Ω (km)	S_Ω
Narmada at Manot	4980.0	4.198	3.981	2.148	239.0	0.00069
Burhner at Mohegaon	4103.0	3.936	3.524	1.786	138.0	0.00210
Banjar at Hridenagar	3472.0	4.797	4.446	2.393	185.0	0.00130
Sher at Belkheri	1457.0	4.786	4.074	1.514	77.0	0.00330

3.1 Rainfall runoff data

Limited rainfall runoff data for all the basins were available form reference 21 (Seth et al.). Direct surface runoff (DSRO) was calculated by subtracting baseflow using straight line method (McCuen, 1989) for all the events for all four basins. Average weighted rainfall was calculated by employing Thiessen polygon method. Since SRRG network in all the four basins studied is poor, the available ORG records were distributed into hourly values based on the observed rainfall pattern of nearest SRRS station. Main characteristics of various selected flood events are listed in Tables 2 through 5 for Narmada at manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri basins respectively.

Table 2: Main characteristics of the selected flood events of the Narmada at Manot

Date	DSRO volume (cm)	Peak discharge (m^3s^{-1})	Time to Peak (hr)
04.08.78	2.73	1470.0	20
08.08.79	5.32	3906.0	16
02.08.80	2.79	3320.0	13

Table 3: Main characteristics of the selected flood events of the Burhner at Mohegaon

Date	DSRO volume (cm)	Peak discharge (m^3s^{-1})	Time to Peak (hr)
04.08.78	1.34	529.0	18
16.08.78	0.63	494.0	13

Table 4: Main characteristics of the selected flood events of the Banjar at Hridenagar

Date	DSRO volume (cm)	Peak discharge (m^3s^{-1})	Time to Peak (hr)
04.08.78	1.02	368.0	30
16.08.78	0.41	247.0	15
15.07.80	3.00	1622.0	15

Table 5: Main characteristics of the selected flood events of the Sher at Belkheri

Date	DSRO volume (cm)8	Peak discharge (m^3s^{-1})	Time to Peak (hr)
05.08.78	1.21	506.0	9
15.08.78	4.17	811.6	15
03.08.79	3.88	1830.0	13

4.0 ANALYSIS AND DISCUSSION OF RESULTS

4.1 Determination of effective rainfall

Since for the present study, limited number of SRRG's were available within or near to the basin, therefore, the ORG records for various representative rainfall stations were distributed into hourly records based on available SRRG station for various selected storm events. Thiessen weights for each raingauge station were calculated and weighted average hourly precipitation was calculated for all the basins. Infiltration for each rainfall-runoff event was determined using two methods namely ϕ-index method and Philip two term infiltration model (Philip 1957).

By definition the phi index (ϕ) equals the average rainfall intensity (or depth) above which the the volume of rainfall excess equals the volume of direct surface runoff. Thus the value of ϕ is adjusted such that the volume of rainfall excess and direct runoff are equal.

The Philip two term infiltration model can be written as

$$f = A + \frac{1}{2} S t^{-\frac{1}{2}} \qquad (8)$$

where f is infiltration rate (cm h^{-1}), A is a parameter dependent on soil characteristics that, as a first approximation is equivalent to saturated hydraulic conductivity (cm h^{-1}), S is sorptivity (cm $h^{-1/2}$), depending on soil characteristics and initial moisture content, and t is time in hours. Both parameters are estimated from measured direct runoff, apart from surface runoff computation. They are considered constant in space, but sorptivity is computed for each event independently with a view to take into account initial conditions of humidity.

4.2 Determination of GIUH based Nash model Parameters

Basin lag time varies not only between basins but also within a basin. The lag time also varies within a basin for different events. This variation may be explained by reference to the dynamics of flood events which, in turn can be characterized by velocity of flow. It is known that the basin lag time is a function of flow velocity (Taylor and Schwarz, 1952; p. 239). Since information on measured velocity or lag time for various rainfall runoff events were not available, therefore, the only parameter "b" in lag time relation in Eq. 5 was optimized for each rainfall runoff event for all the basins using modified Rosenbrock-Palmer optimization algorithm such that the objective function defined by Eq. 6 and 7 is minimum. Equal weighteg was given to peak and time to peak discharge, therefore, parameter W_1 (Eq. 6) was fixed at 0.5. After each optimization run, optimized values were introduced as initial values, to check the stability of results.

4.3 Discussion of Results

The methodology discussed has been applied to simulate the flood events for various sub basins, namely Narmada at Manot, Burhner at Mohegaon, Banjar at Hridenagar and Sher at Belkheri. The GIUH based Nash model parameters for the catchment of Narmada at Manot are given in Table 6 and 7 with objective function 1 and 2 respectively. Observed peak, time to peak and computed peak and time to peak alongwith per cent error are also given in Tables 6 and 7. As discussed earlier the excess rainfall has been computed by two methods viz. ϕ index and Philip two term infiltration model and Tables 6 and 7 provide all the above discussed parameters and flood peak characteristics with both the methods. It may be observed from Tables 6 and 7 that the two methods of excess rainfall computation results in almost identical simulation results. It can also be seen from these tabes that for flood events dated 08.081979 and 02.08.1980, the velocity comes out to be more than 7 m/s. These unrealistic estimates may be attributed to the inadequate network of self recording raingauge (SRRG) network for Manot catchment as well as errors associated with the observed peak and time to peak. Out of three events, two events viz. event of dated 4.8.1978 and 8.8.1979 have shown shift in computed time to peak. This shift may be due to consideration of only one SRRG for distributing the ORG records at hourly interval. However, the actual storm pattern may be totally different than that was observed at the SRRG. Simulation results for these three events dated 4.8.1978, 8.8.1979 and 2.8.1980 are shown in Figures 6 through 8 respectively.

Fig. 6 **Narmada at Manot (event 04.08.1978)**

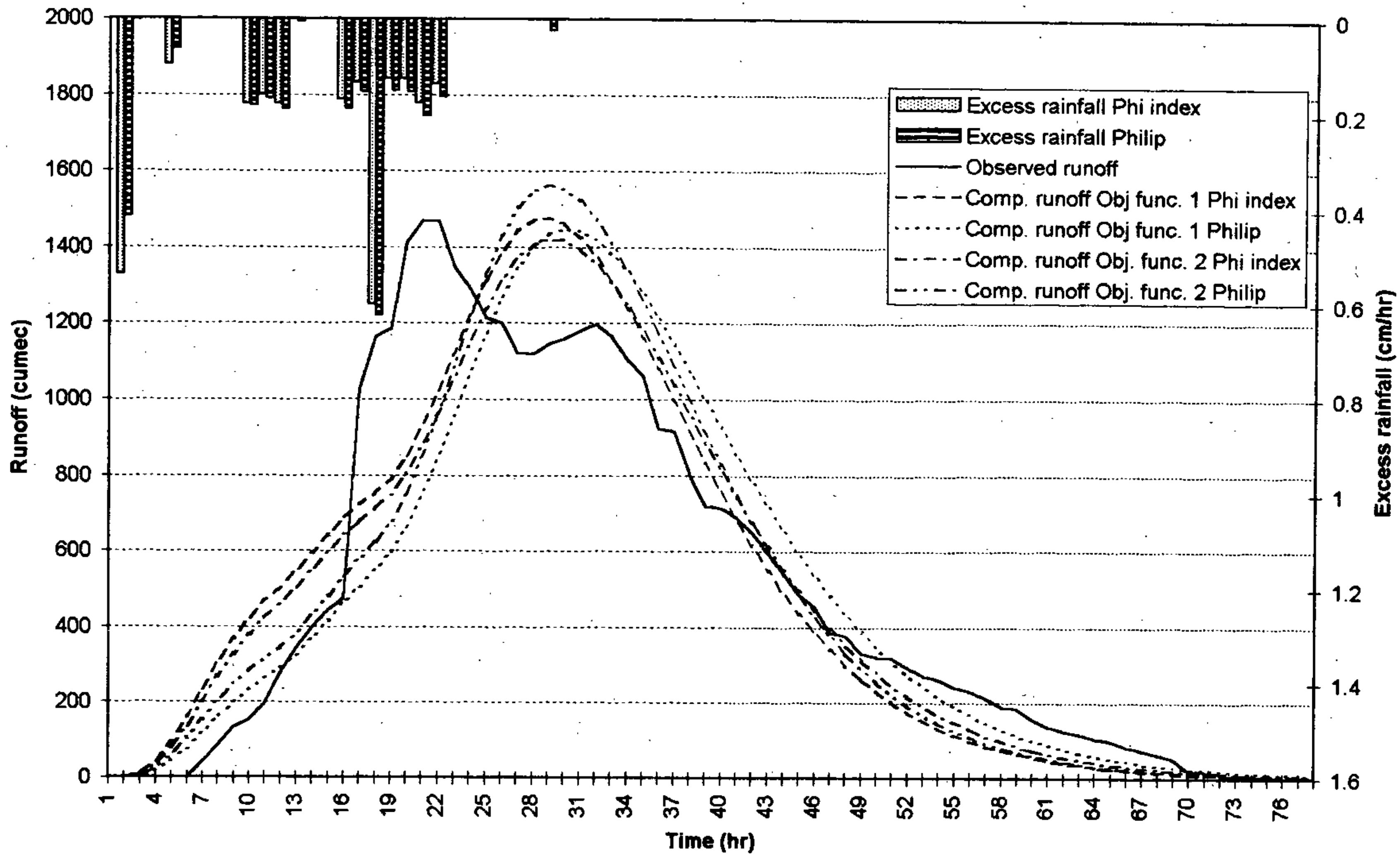


Fig. 7 Narmada at Manot (event 08.08.1979)

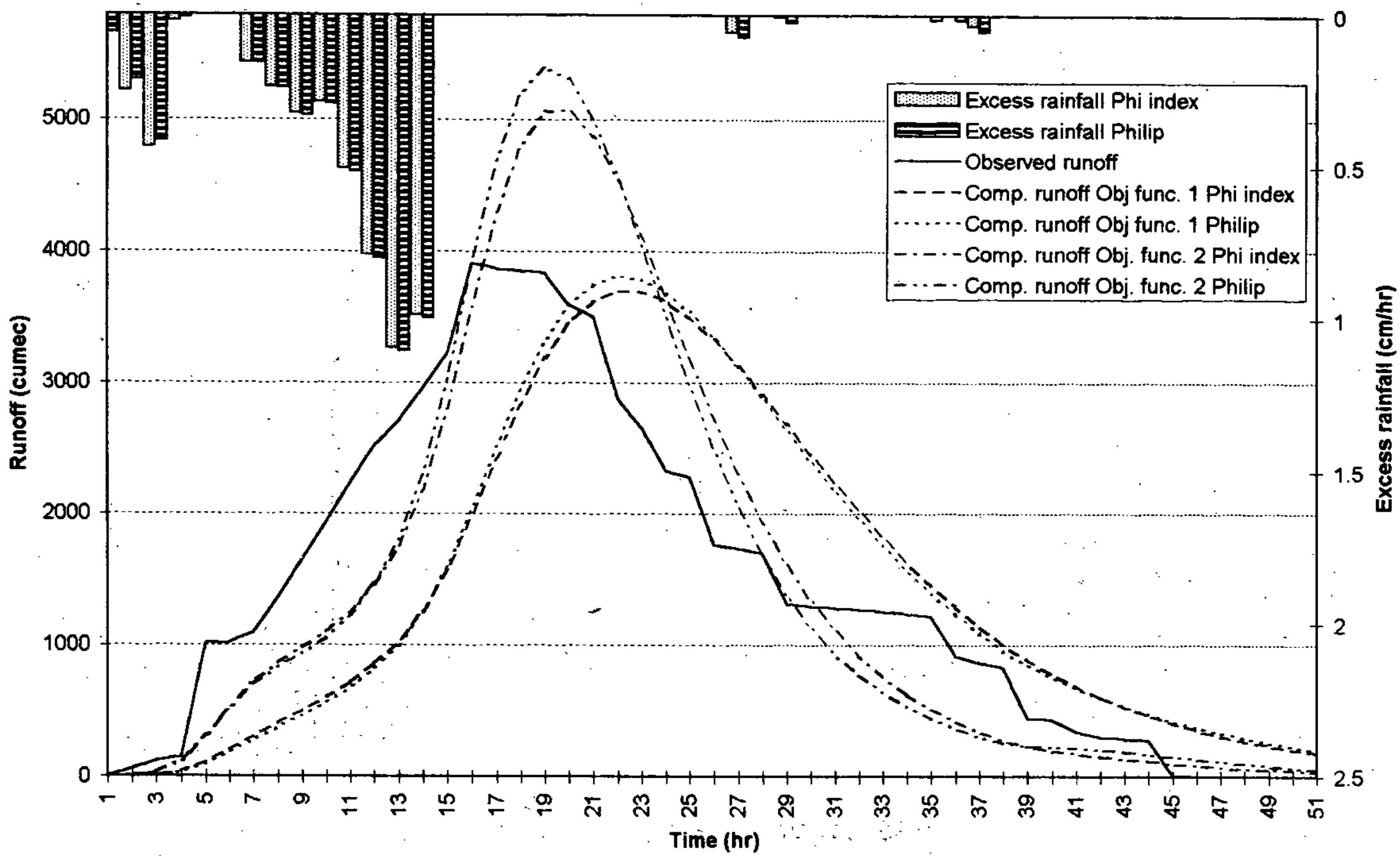
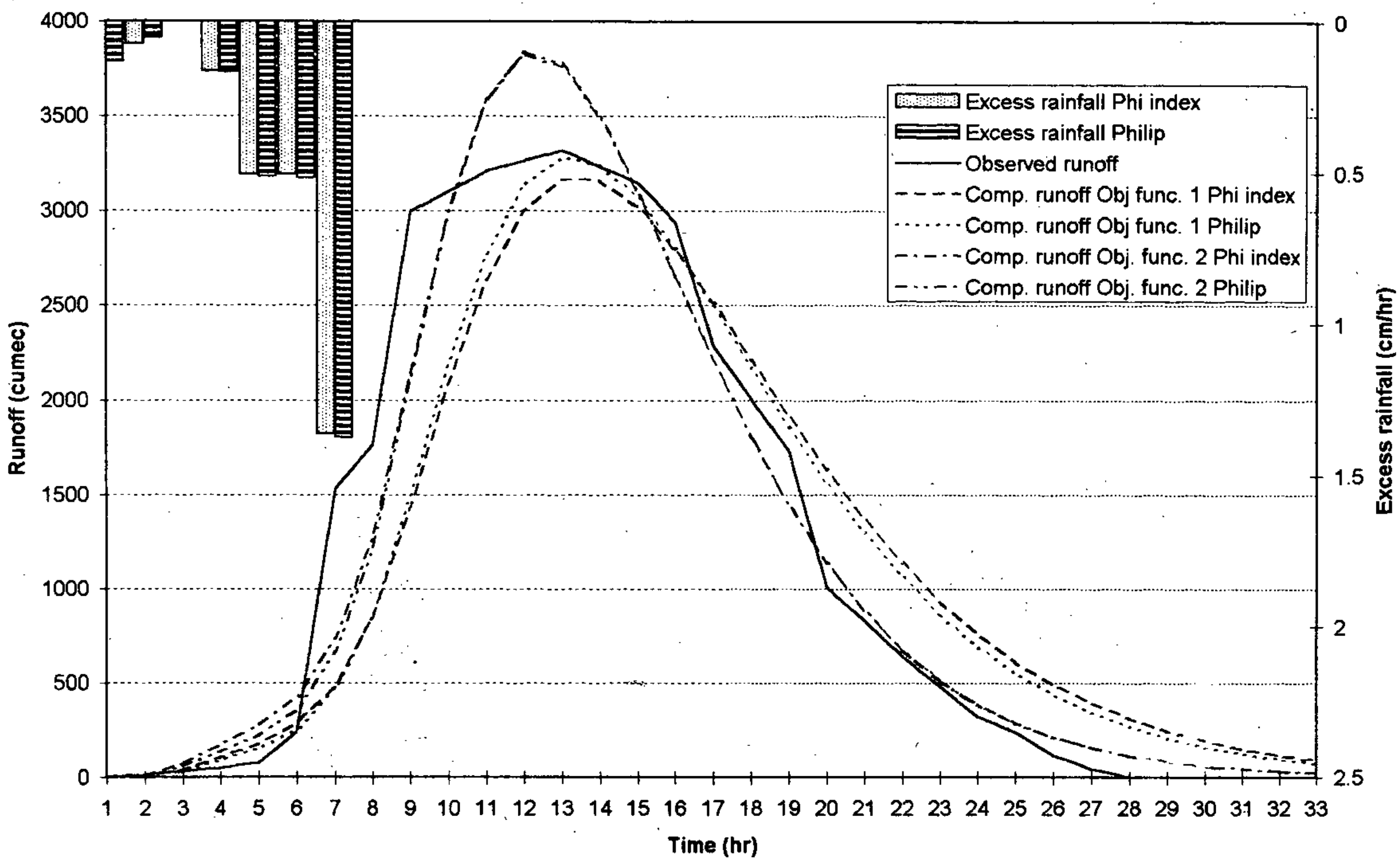


Fig. 8 Narmada at Manot (event 02.08.1980)



Tables 8 and 9 shows summary results for Burhner at Moheaon sub basin with objective function 1 and 2 respectively. It can be seen from these tables that simulation results are good. However, shift in computed time to peak is there. This shift may be due to consideration of only one SRRG for distributing the ORG records at hourly interval. However, the actual storm pattern may be totally different than that was observed at the SRRG. Simulation results for these two events dated 4.8.1978 and 16.8.1978 are shown in Figures 9 and 10 respectively.

Simulation results for Banjar at Hridenagar are give in Tables 10 and 11 with objective function 1 and 2 respectively. It can be seen from these tables that the proposed methodology has simulated both peak and time to peak reasonably well for all three events. It can also be seen from Tables 10 and 11 that the choice of excess rainfall calculation method have little effect on simulation results. The results of simulation for events dated 4.8.1978, 16.8.1978 and 15.7.1980 are shown in Figures 10 through 13 respectively.

For Sher basin at Belkheri, the summary results are presented in Tables 12 and 13 with objective function 1 and 2 respectively. In this case also the choice of excess rainfall calculation method do not significantly affect the computed results. It can be seen from Tables 10 and 11 that the model has simulated both peak and time to peak reasonably well. Simulation results are give in Figures 14 through 16 for events dated 5.8.1978, 15.8.1978 and 3.8.1979 respectively.

The results suggest that in general the model has simulated the flood hydrograph reasonably well for most of the cases on all the basins. However, simulated time to peak matching is not so good. This could be attributed to the inadequate raingauge network in the catchments and uneven distribution of rainfall in time and space. Also looking at the size of the basins, it is quite possible that the rain event may have traversed during the storm duration and the distribution of daily rainfall to hourly rainfall largely depends on only one SRRG. These result in shift in the shape of observed and computed hydrograph. Table 14 presents intercomparison of results for all four basins with both the objective functions. It can be seen from Table 14 that choice of the objective function significantly affect the simulated peak. It may be concluded from Table 14 that if correct peak flow simulation is the objective of the study then the objective function 1 which is based on peak and time to peak should be used in optimization. However, if complete shape of hydrograph is of importance then objective function 2 should be prefered.

Fig. 9 Burhner at Mohegaon (event 04.08.1978)

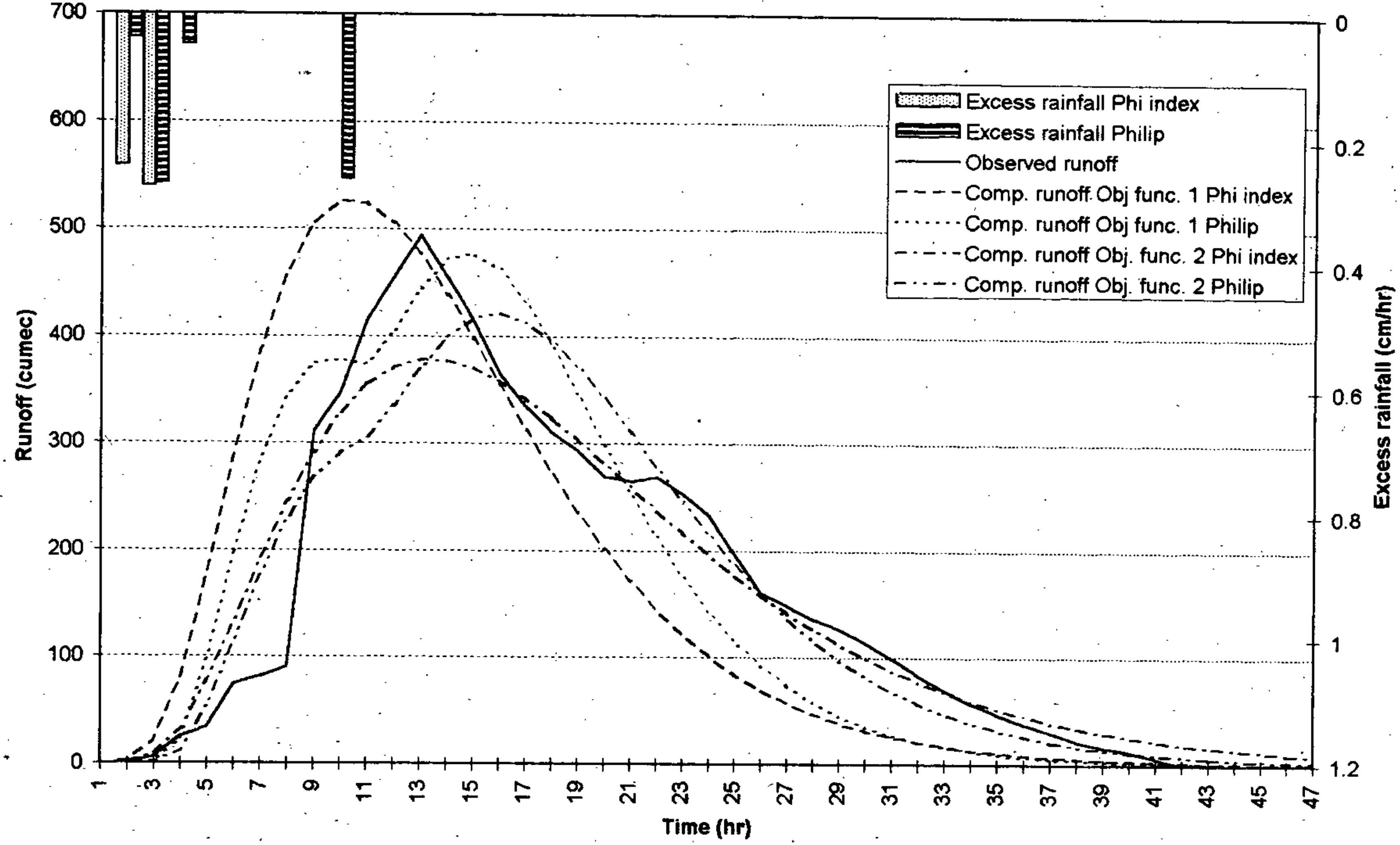


Fig. 10 Burhner at Mohegaon (event 16.08.1978)

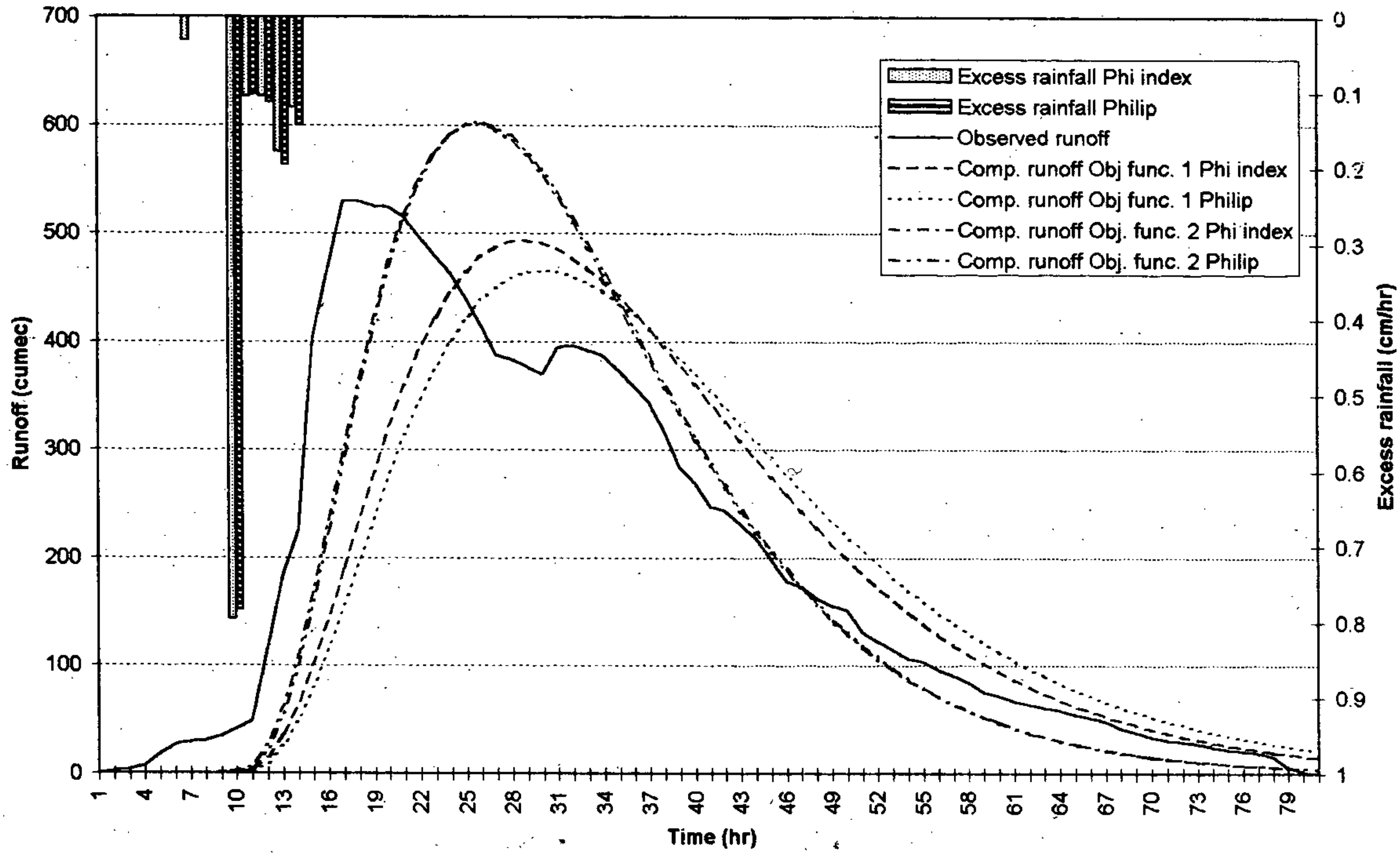


Fig. 11 Banjar at Hridenagar (event 04.08.1978)

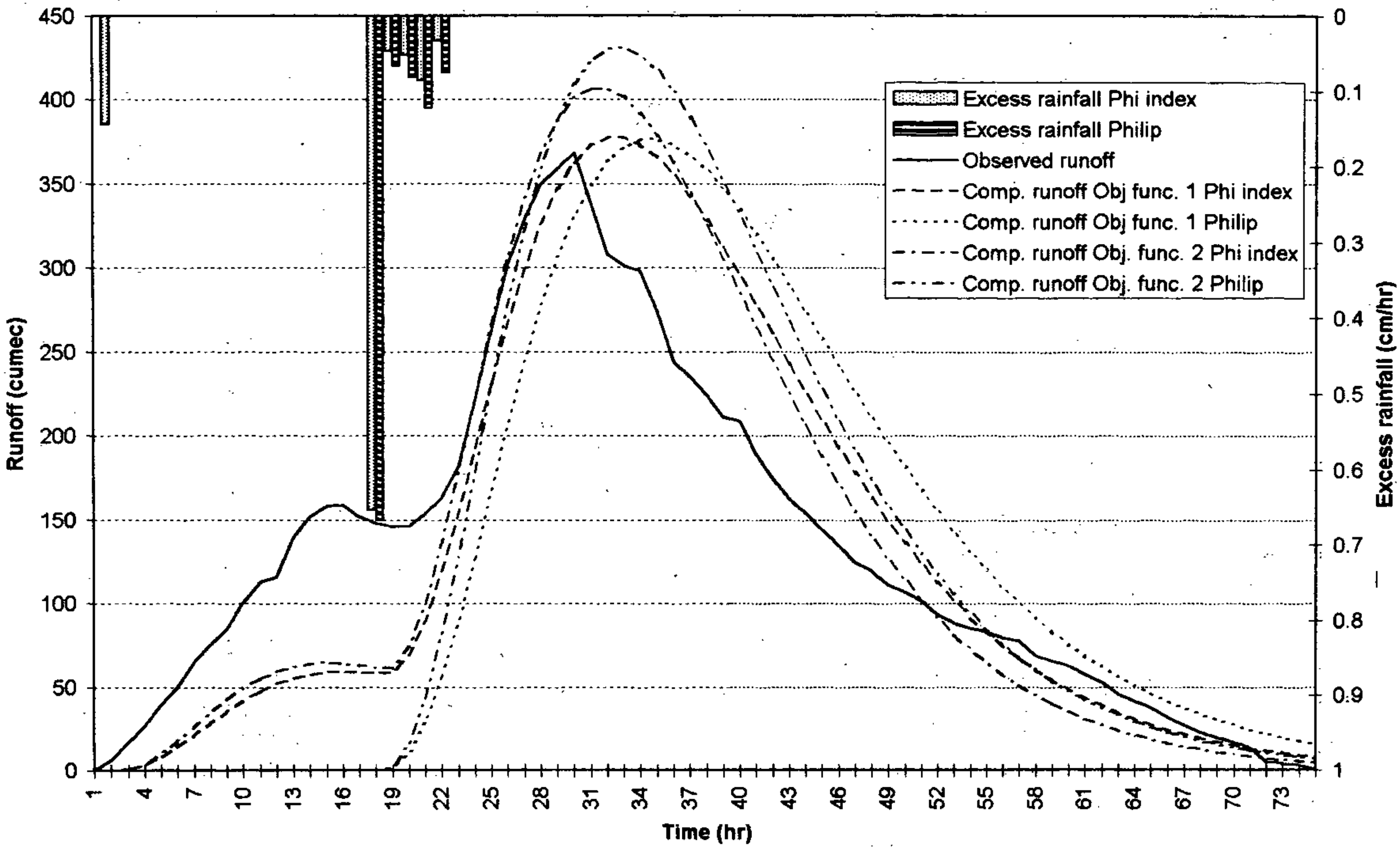


Fig. 12 Banjar at Hridenagar (event 16.08.1978)

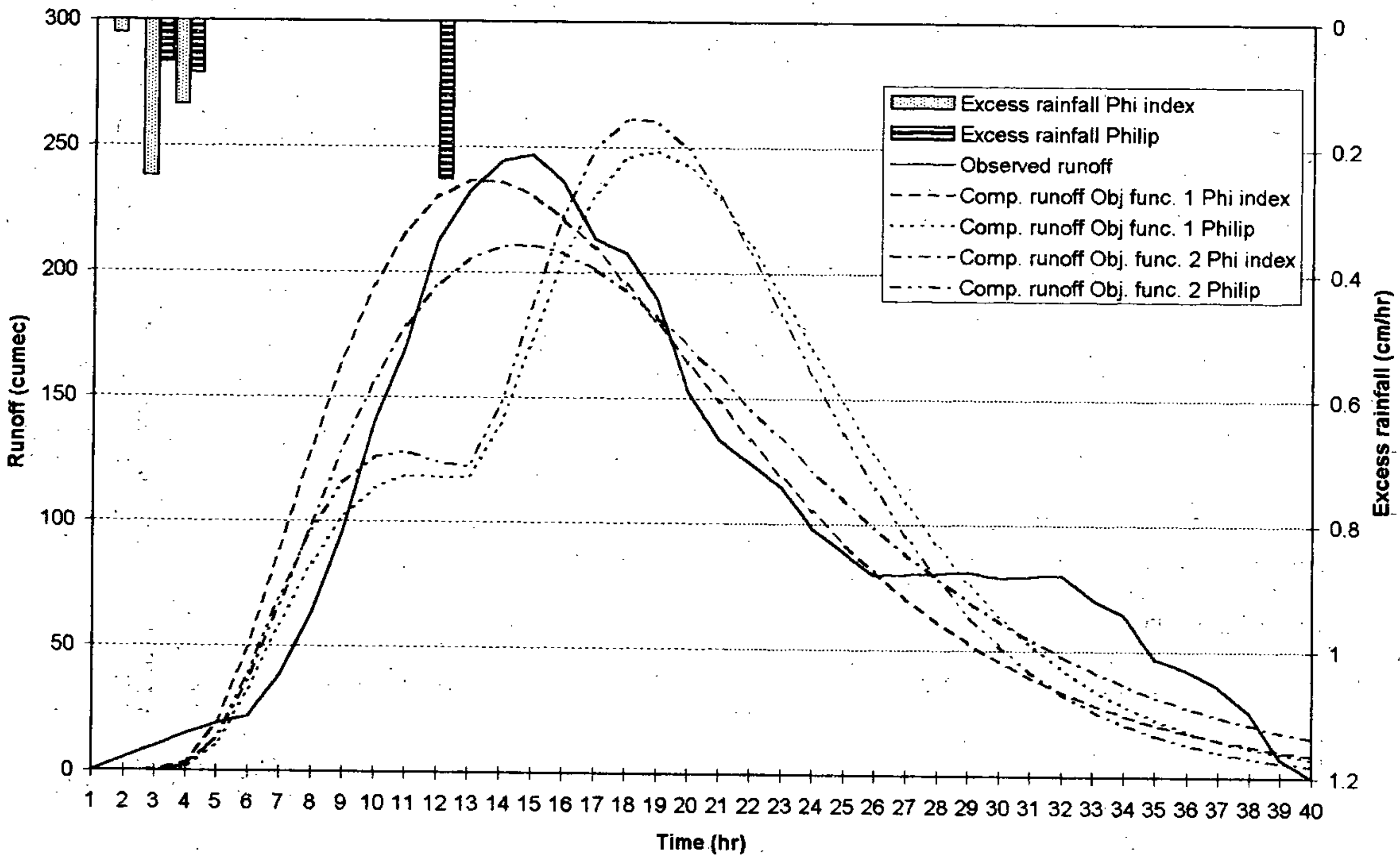


Fig. 13 Banjar at Hridenagar (event 15.07.1980)

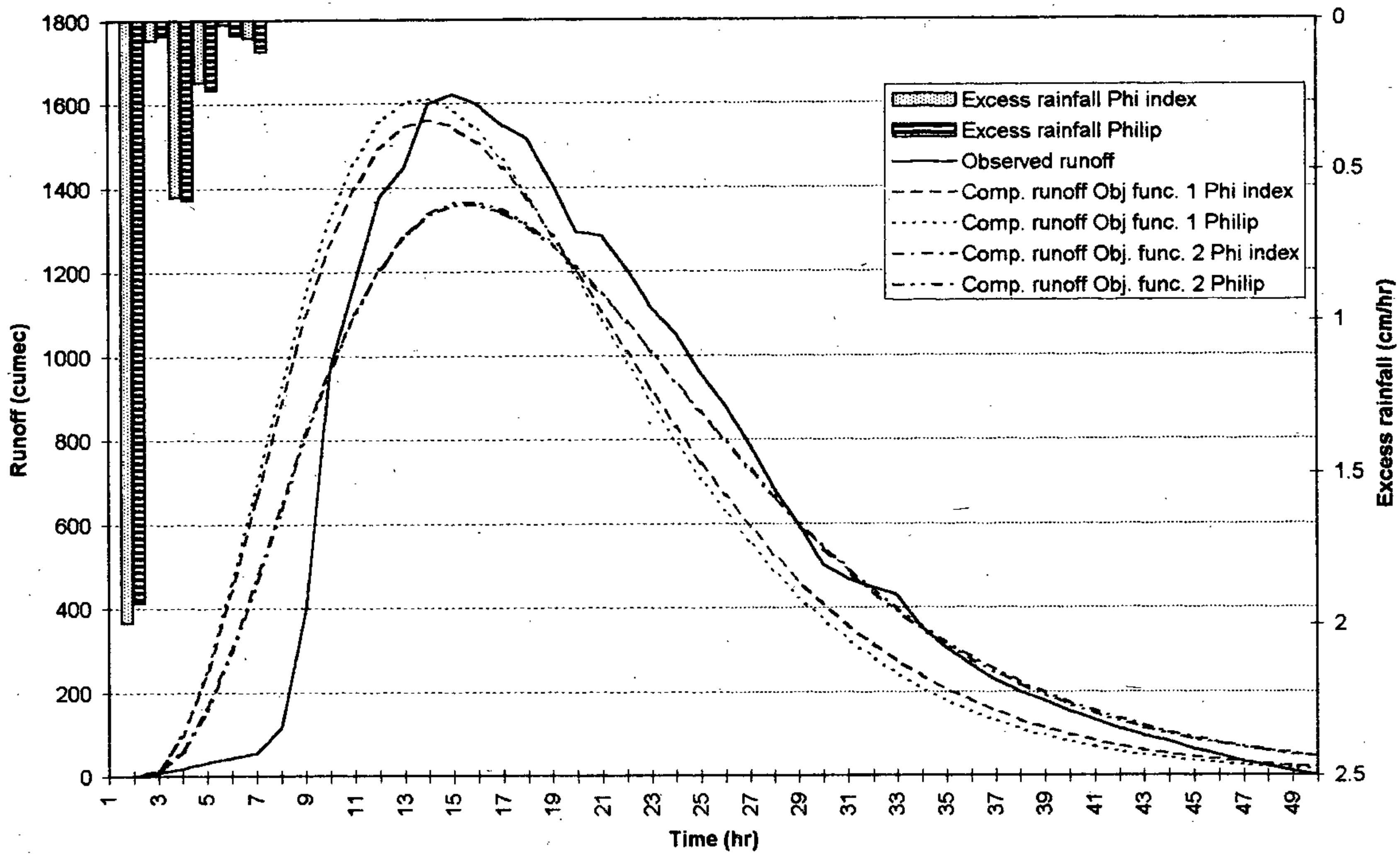


Fig. 14 Sher at Belkheri (event 05.08.1978)

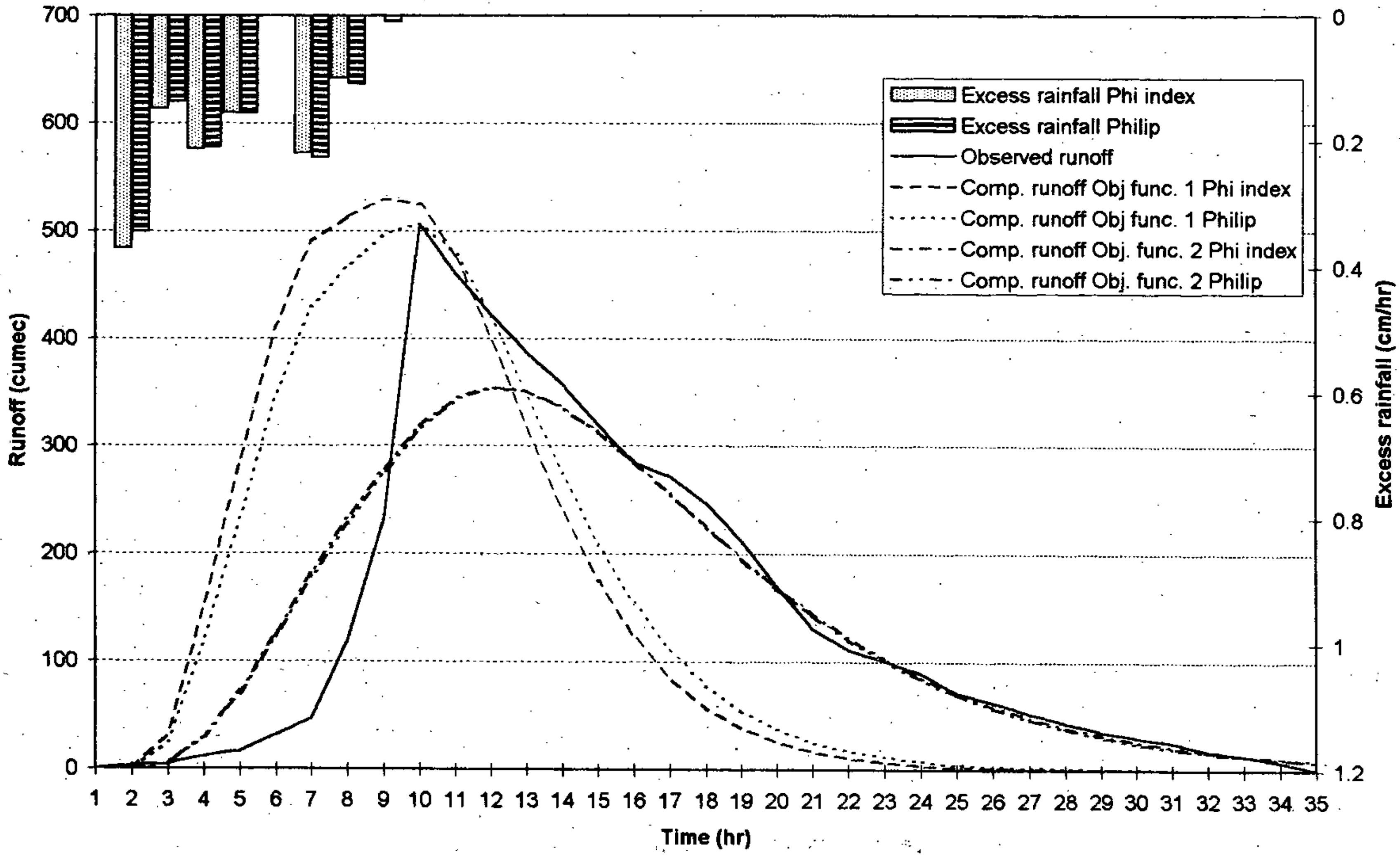


Fig. 15 Sher at Belkheri (event 15.08.1978)

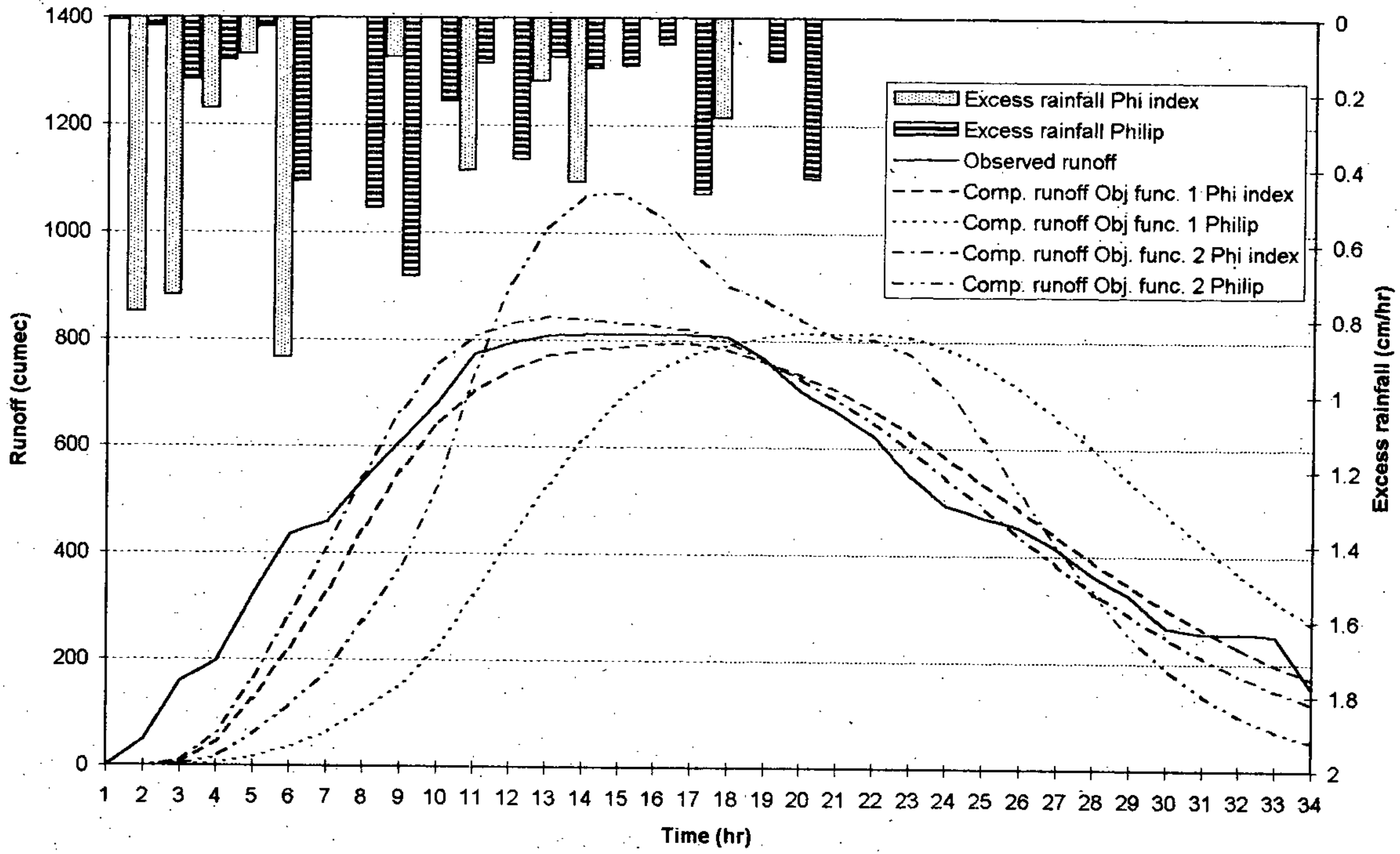


Fig. 16 Sher at Belkheri (event 03.08.1979)

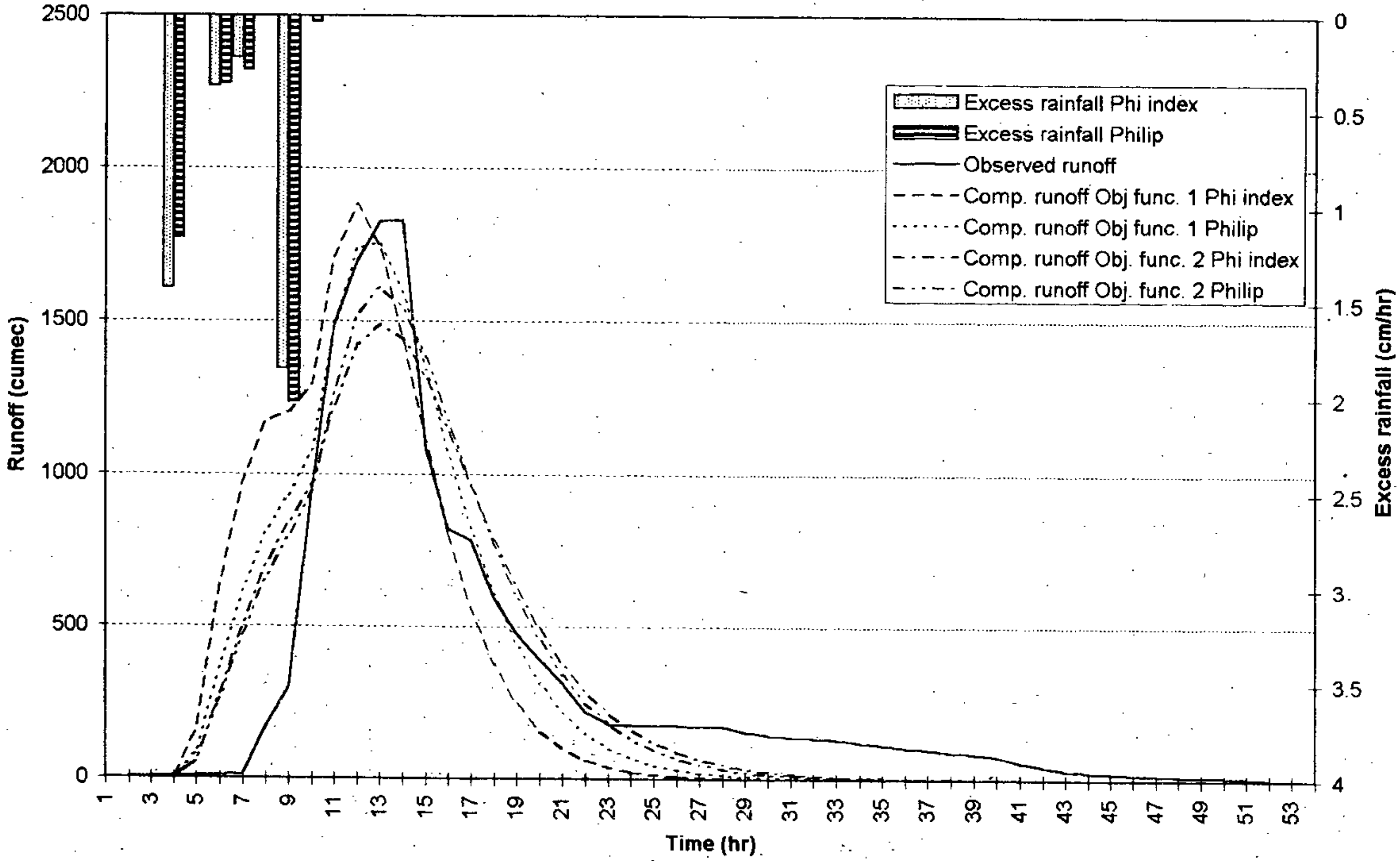


Table 6. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Narmada at Manot (with objective function 1)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
04.08.78	ϕ index	0.63	6.8	3.33	4.82	1470.0	1476.1	-0.4	20	28	-40.0
	Philip model	0.69	6.2	3.33	5.30	1470.0	1447.8	1.5	20	29	-45.0
08.08.79	ϕ index	0.57	7.5	3.33	4.40	3906.0	3695.9	5.4	15	21	-40.0
	Philip model	0.55	7.7	3.33	4.24	3906.0	3810.3	2.4	15	21	-40.0
02.08.80	ϕ index	0.38	11.3	3.33	2.90	3320.0	3167.1	4.6	12	12	0.0
	Philip model	0.36	11.8	3.33	2.79	3320.0	3218.1	1.2	12	12	0.0

Table 7. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Narmada at Manot (with objective function 2)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
04.08.78	ϕ index	0.67	6.4	3.33	5.12	1470.0	1422.2	3.3	20	28	-40.0
	Philip model	0.62	6.9	3.33	4.76	1470.0	1561.7	-6.2	20	28	-40.0
08.08.79	ϕ index	0.38	11.2	3.33	2.94	3906.0	5063.5	-29.6	15	19	-26.7
	Philip model	0.35	12.0	3.33	2.73	3906.0	5401.2	-38.3	15	18	-20.0
02.08.80	ϕ index	0.31	14.0	3.33	2.35	3320.0	3826.8	-15.3	12	11	8.3
	Philip model	0.31	14.0	3.33	2.35	3320.0	3836.8	-15.6	12	11	8.3

Table 8. **Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Burhner at Mohegaon (with objective function 1)**

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
04.08.78	ϕ index	1.07	2.6	3.14	8.05	529.0	493.4	6.7	17	28	-64.7
	Philip model	1.13	2.5	3.14	8.56	529.0	465.4	12.0	17	29	-70.6
16.08.78	ϕ index	0.46	6.0	3.14	3.52	494.0	525.8	-6.4	12	9	25.0
	Philip model	0.37	7.5	3.14	2.82	494.0	477.2	3.4	12	14	-16.7

Table 9. **Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Burhner at Mohegaon (with objective function 2)**

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
04.08.78	ϕ index	0.87	3.2	3.14	6.58	529.0	601.2	-13.6	17	25	-47.1
	Philip model	0.87	3.2	3.14	6.57	529.0	602.9	-14.0	17	25	-47.1
16.08.78	ϕ index	0.65	4.3	3.14	4.94	494.0	377.7	23.5	12	12	0.0
	Philip model	0.47	5.9	3.14	3.58	494.0	421.2	14.7	12	15	-25.0

Table 10. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Banjar at Hridenagar (with objective function 1)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr.	Comp. time to peak hr	% error
04.08.78	ϕ index	0.88	4.1	3.29	5.98	368.0	377.5	-2.6	29	32	-10.3
	Philip model	0.97	3.7	3.29	6.55	368.0	376.5	-2.3	29	34	-17.2
16.08.78	ϕ index	0.62	5.8	3.29	4.20	247.0	236.2	4.4	14	12	14.3
	Philip model	0.46	7.7	3.29	3.15	247.0	248.6	-0.7	14	18	-28.6
15.07.80	ϕ index	0.68	5.3	3.29	4.62	1622.0	1560.6	3.8	14	13	7.1
	Philip model	0.65	5.5	3.29	4.41	1622.0	1610.7	0.7	14	13	7.1

Table 11. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Banjar at Hridenagar (with objective function 2)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
04.08.78	ϕ index	0.81	4.4	3.29	5.50	368.0	406.4	-10.5	29	30	-3.4
	Philip model	0.84	4.3	3.29	5.70	368.0	431.0	-17.1	29	30	-10.3
16.08.78	ϕ index	0.69	5.2	3.29	4.71	247.0	210.8	14.6	14	14	0.0
	Philip model	0.43	8.3	3.29	2.92	247.0	261.0	-5.7	14	17	-21.4
15.07.80	ϕ index	0.79	4.6	3.29	5.32	1622.0	1359.0	16.2	14	15	-7.1
	Philip model	0.77	4.6	3.29	5.24	1622.0	1365.4	15.8	14	15	7.1

Table 12. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Sher at Belkheri (with objective function 1)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
05.08.78	ϕ index	0.32	7.6	2.98	1.73	506.0	529.4	-4.6	9	8	11.1
	Philip model	0.34	7.0	2.98	1.87	506.0	507.2	-0.2	9	9	0.0
15.08.78	ϕ index	0.74	3.3	2.98	3.99	811.6	793.8	2.2	15	16	-6.7
	Philip model	0.68	3.6	2.98	3.68	811.6	813.4	-0.2	15	21	-40.0
03.08.79	ϕ index	0.29	8.3	2.98	1.58	1830.0	1883.4	-2.9	13	11	15.4
	Philip model	0.34	7.0	2.98	1.87	1830.0	1757.8	3.9	13	12	7.7

Table 13. Summary of the GIUH based Nash model parameters and comparison of historical and simulated flood peak characteristics for Sher at Belkheri (with objective function 2)

Date of event	Excess rainfall method	b	velocity m/sec	N	k	obs. peak cumec	comp. peak cumec	% error	Obs. time to peak hr	Comp. time to peak hr	% error
05.08.78	ϕ index	0.63	3.9	2.98	3.40	506.0	354.1	30.0	9	11	-22.2
	Philip model	0.62	3.9	2.98	3.34	506.0	353.4	30.1	9	11	-22.2
15.08.78	ϕ index	0.66	3.7	2.98	3.57	811.6	841.4	-3.7	15	12	20.0
	Philip model	0.39	6.2	2.98	2.12	811.6	1073.9	-32.2	15	14	6.7
03.08.79	ϕ index	0.43	5.6	2.98	2.33	1830.0	1492.5	18.4	13	12	7.7
	Philip model	0.40	6.1	2.98	2.17	1830.0	1611.2	12.0	13	12	7.7

Table 14. Intercomparison of results (all basins)

Date of event	Excess rainfall method	Obs. peak	Obs. time to peak	k with		Predicted peak		% error		Predicted time to peak		% error	
				Obj. 1	Obj. 2	Obj. 1	Obj. 2	Obj. 1	Obj. 2	Obj. 1	Obj. 2	Obj. 1	Obj. 2
Narmda at Manot (N = 3.33)													
04.08.78	ϕ index	1470.0	20	4.82	5.12	1476.1	1422.2	-0.4	3.3	28	28	-40.0	-60.0
	Philip	1470.0	20	5.30	4.76	1447.8	1561.7	1.5	-6.2	29	28	-45.0	-40.0
08.08.79	ϕ index	3906.0	15	4.40	2.94	3695.9	5063.5	5.4	-29.6	21	19	-40.0	-26.7
	Philip	3906.0	15	4.24	2.73	3810.3	5401.2	2.4	-38.3	21	18	-40.0	-20.0
02.08.80	ϕ index	3320.0	12	2.90	2.35	3167.1	3826.8	4.6	-15.3	12	11	0.0	8.3
	Philip	3320.0	12	2.97	2.35	3218.1	3836.8	1.2	-15.6	12	11	0.0	8.3
Burhner at Mohegaon (N = 3.14)													
04.08.78	ϕ index	529.0	17	8.05	6.56	493.4	601.2	6.7	-13.6	28	25	-64.7	-47.1
	Philip	529.0	17	8.56	6.57	465.4	602.9	12.0	-14.0	29	25	-70.6	-47.1
16.08.78	ϕ index	494.0	12	3.52	4.94	525.8	377.7	-6.4	23.5	9	12	25.0	0
	Philip	494.0	12	2.82	3.58	477.2	421.2	3.4	14.7	14	15	-16.7	-25.0

... Table continued on next page

... Table 14. continued

Banjar at Hridenagar (N = 3.29)													
04.08.78	ϕ index	368.0	29	5.98	5.50	377.5	406.4	-2.6	-10.5	32	30	-10.3	-3.4
	Philip	368.0	29	6.55	5.70	376.5	431.0	-2.3	-17.1	34	30	-17.2	-10.3
16.08.78	ϕ index	247.0	14	4.20	4.71	236.2	210.8	4.4	14.6	12	14	14.3	0.0
	Philip	247.0	14	3.15	2.92	248.6	261.0	-0.7	-5.7	18	17	-28.6	-21.4
15.07.80	ϕ index	1622.0	14	4.62	5.32	1560.6	1359.0	3.8	16.2	13	15	7.1	-7.1
	Philip	1622.0	14	4.41	5.24	1610.7	1365.4	0.7	15.8	13	15	7.1	7.1
Sher at Belkheri (N = 2.98)													
05.08.78	ϕ index	506.0	9	1.73	3.40	529.4	354.1	-4.6	30.0	8	11	11.1	-22.2
	Philip	506.0	9	1.87	3.34	507.2	353.4	-0.2	30.1	9	11	0.0	-22.2
15.08.78	ϕ index	811.6	15	3.99	3.57	793.8	841.4	2.2	-3.7	16	12	-6.7	20.0
	Philip	811.6	15	3.68	2.12	813.4	1073.9	-0.2	-32.2	21	14	-40.0	6.7
03.08.79	ϕ index	1830.0	13	1.58	2.33	1833.4	1492.5	-2.9	18.4	11	12	15.4	7.7
	Philip	1830.0	13	1.87	2.17	1757.8	1611.2	3.9	12.0	12	12	7.7	7.7

6.0 CONCLUSION

Gamma IUH parameters for Nash model for four sub-basins of river Narmada were derived using basin geomorphological characteristics. In general the proposed methodology simulated flood hydrographs reasonably well for all four basins. The results of simulation from the model can be rated as reasonably good particularly in view of the fact that only one parameter of the model was optimized and all other information was estimated from geomorphological characteristics and other hydrological data of the basin.

The results suggest that in general the model has simulated the flood hydrograph reasonably well for most of the cases on all the basins. However, simulated time to peak matching is not so good. This could be attributed to the inadequate raingauge network in the catchments and uneven distribution of rainfall in time and space. Also looking at the size of the basins, it is quite possible that the rain event may have traversed during the storm duration and the distribution of daily rainfall to hourly rainfall largely depends on only one SRRG. These result in shift in the shape of observed and computed hydrograph. Intercomparison of results for all four basins with both the objective functions suggest that choice of the objective function significantly affect the simulated peak. It may be concluded that if correct peak flow simulation is the objective of the study than the objective function 1 which is based on peak and time to peak should be used in optimization. However, if complete shape of hydrograph is of importance then objective function 2 should be prefered. Some times unrealistic estimates of velocities have been obtained which may be due to improper representation of the rainfall-runoff events.

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List of Notations:

$\bar{L}_i$ = Mean length of channel of order i (km)

L_Ω = Length of main channel (km)

L_b = Basin length (km)

R_L = Stream length ratio

R_B = Bifurcation ratio

A = Area of watershed (km^2)

$\bar{A}_i$ = Mean drainage area of order i (km^2)

R_A = Area ratio

S_m = Main channel slope.

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