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APPLICATION OF WAHS MODEL TO KOLAR SUB-BASIN

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PREFACE

The estimation of flood from a watershed is a very important component of the water resources planning and design. Different methods for estimation of design floods invariably need some observed data of discharge, rainfall etc. Even the conventional techniques for derivation of the unit hydrograph need observed rainfall and runoff data. However, the observed data are not available at all the points along the river reach. This is more so in the case of smaller river systems or the tributaries. Even in the case of gauged rivers, the observed data may not be available at the desired interval or may not be representative of the conditions which are essential for derivation of the unit hydrograph or the instantaneous unit hydrograph. If runoff data are inadequate or not available, it becomes necessary to adopt techniques in which geomorphological characteristics of the basin, the hydrometeorological features of the region and other factors are used to derive the unit hydrograph. Such unit hydrographs are termed as regional unit hydrographs or synthetic unit hydrograph or geomorphological unit hydrograph. The geomorphological characteristics can be easily derived from maps/toposheets having details of stream network as well as contours. Such maps/toposheets are readily available and are very reliable.

In this report an attempt has been made to apply geomorphology based WAHS model to Kolar Sub-Basin upto Satrana to simulate flood events recorded in the basin. This study has been carried out by Sri M K Jain, Scientist B, in the Mountain Hydrology Division, National Institute of Hydrology, Roorkee.

(S. M. Seth)
Director

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1.0 INTRODUCTION

The estimation of flood from a watershed is a very important component of the water resources planning and design. Different methods for estimation of design floods invariably need some observed data of discharge, rainfall etc. Even the conventional techniques for derivation of the unit hydrograph need observed rainfall and runoff data. However, the observed data are not available at all the points along the river reach. This is more so in the case of smaller river systems or the tributaries. Even in the case of gauged rivers, the observed data may not be available at the desired interval or may not be representative of the conditions which are essential for derivation of the unit hydrograph or the instantaneous unit hydrograph. If runoff data are inadequate or not available, it becomes necessary to adopt techniques in which geomorphological characteristics of the basin, the hydrometeorological features of the region and other factors are used to derive the unit hydrograph. Such unit hydrographs are termed as regional unit hydrograph or synthetic unit hydrograph or geomorphological unit hydrograph. The geomorphological characteristics can be easily derived from maps/toposheets having details of stream network as well as contours. Such maps/toposheets are readily available and are very reliable.

Efforts have been made since very beginning for the derivation of unit hydrograph with the help of the physical characteristics of the basin. The first systematic analysis was reported by Synder in 1938 who suggested a synthetic unit hydrograph which could be derived with the help of length of the main channel and the distance of centroid of the basin from the outlet.

Geomorphological techniques have recently been advanced for hydrograph synthesis (Body 1978; Body, Pilgrim, and Cordery 1979; Rodriguez-Iturbe and Valdes 1979; Rodriguez-Iturbe, Devoto and Valdes 1979; Gupta, Waymire, and Wang 1980; Wang, Gupta, and Waymire 1981;' Rodriguez-Iturbe 1982). Rodriguez-Itubbe et al. (1979) had made pioneering attempt in the direction of coupling of quantitative geomorphological analysis with the most important hydrological variable namely the stream flow response to the surface runoff of the basin. The structure of the hydrological response is found to be intimately linked to the geomorphological parameters of the basin when the hydrological response is represented by a unit hydrograph. The geomorphological parameters have also been found to have very good relationship with the parameters representing the Instantaneous Unit Hydrograph. This theory was subsequently generalized by Gupta et al. (1980). These techniques have added a new dimension to application of geomorphology to the effective rainfall direct runoff relationship. However, they remain to be tested to a wide variety of gauged basins and have yet to be applied to ungauged basins.

Consequently Singh and his associates developed a quasi conceptual model which employed geomorphologic techniques given by Valdes, Rodriguez- Iturbe et al. and modern hydrologic system analysis and synthesis approach to synthesis stream flow hydrographs. The model developed by Singh and his associates is referred in literature as WAHS (or watershed Hydrology Simulation Model). In this report suitability of WAHS model is being evaluated by applying it to Kolar sub-basin in Narmada river system in central India.

2.0 MODEL DESCRIPTION

2.1 General

The Watershed Hydrology Simulation (WAHS) model, developed by Singh (1983, 1987), is designed for prediction of DRH for a specified rainfall event from an ungauged watershed. Rainfall hyetograph, observed at one or more points, constitutes input to the model. In addition, soil vegetation-land use and geomorphic characteristics are needed to estimate model parameters. It is a two parameter linear model, wherein the watershed unit hydrograph is determined using geomorphologic concepts involving one parameter the watershed lag (Singh and Aninian 1984, 1985) estimated simply from watershed area. The DR amount is obtained from SCS curve number method. Then the Effective Rainfall Hyetograph is estimated using Philip two term infiltration equation, where the steady infiltration parameter is obtained from soil characteristics and the sorptivity term comes from satisfying the continuity equation. If stream flow observations are available, then the DR amount is obtained by base flow separation. If needed information on soil characteristics is not available, the Rosenbrock Palmer algorithm is provided to optimize model parameters based on minimizing the sum of squares of the deviations between observed and computed peaks over a number of rainfall-runoff events.

2.2 Theoretical Description of the Model

The model is designed to principally compute,

1. Volume of direct runoff
2. Infiltration
3. The effective rainfall hydrograph (ERH),
4. The instantaneous unit hydrograph (IUH),
5. The direct runoff hydrograph (DRH), and
6. Optimal parameters, if necessary

A brief description of each term is given below:

2.2.1 Volume of direct runoff

The volume of direct runoff VQ resulting from a specified rainfall of volume VP is computed by SCS curve number method which is based on the assumption:

$$\frac{F}{S} = \frac{VQ}{VP - IA}$$

In which IA is initial abstraction; S is potential maximum retention; and F is actual retention excluding IA. and can be expressed as

$$F = VP - VA - IA$$

From the above two equations

$$VQ = \frac{(VP - IA)^2}{VP - IA + S}$$

The initial abstraction depends upon antecedent soil moisture, soil vegetation, land use complex, and interception and can be expressed as

$$IA = a . S$$

Where a is normally been taken between 0.1 and 0.2 . and S is calculated empirically from curve number (CN) by

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

Where CN denotes curve number which has been determined by the soil conservation service for various hydrologic soil cover complexes corresponding to these antecedent soil moisture conditions with a = 0.2

In case where discharge measurements are available, the DSRO volume may be calculated by hydrograph separation method.

2.2.2 Effective rainfall hyetograph (ERH)

The effective rainfall hyetograph was computed by subtracting infiltration rate from the rainfall hyetograph such that the residual rainfall volume is the same as volume of direct runoff. The infiltration for each rainfall runoff event is computed by Philip two term infiltration model (Philip 1969),

$$f = A\ t + 0.5\ S\ t^{-0.5}$$

where

f = rate of infiltration at time t(cm/hr)

A = steady state infiltration, approximately equal to saturated hydraulic conductivity (cm/hr)

S = Sorptivity, depends on antecedent soil moisture conditions and soil properties (cm/sqrt hr.) , and

t = time (hr)

2.2.3 The instantaneous unit hydrograph (IUH)

The IUH is derived by an approach developed by Rodriguez-Iturbe and Valdes (1979) and generalized by Gupta, Waymier and Wang (1980) by employing empirical laws of geomorphology and techniques of linear hydrologic systems.

A basin of order w contains streams of order from one to W (following Horton Strahler ordering system). The network of these streams and their drainage area determine the paths to be followed by rainwater from the point of its landing to the watershed outlet. The number of paths specified by basin geomorphology will be less then or equal to, 2^{W-1}. Each path is composed of an overland region (r) and one or more channels (c) and is, in turn, represented by a cascade of unequal linear elements. The travel time of a particle must therefore be specified by the particular path it takes to reach the outlet. The travel time T_s is the sum of the times spent by the particle in the various states forming its path.

$$T_S = T_{x1} + T_{x2} + \dots + T_{xM} , \ M > 1 \qquad \dots(1)$$

where T_x is the time a particle spends in the state x ($x = r_i$ or C_i for some i) and M is the number of states. T_x is assumed to be a random variable. T_x can have an arbitrary probability density function (PDF), and for different states x and y, T_x and T_y can have different PDF's. However, T_x and T_y are assumed to be independent for $x \neq y$. If T_B denotes the random time that a particle spends in the basin, then

$$T_B = \sum_{s \in S} I_s \, T_s \qquad \dots(2)$$

where I_s is the indicator function for the path s; that is, $I_s = 1$ if the particle follows the path s, and $I_s = 0$ otherwise. The PDF of T_B, denoted by $f_B(t)$, is obtained as follows.

Let A_{ri} be the ratio of the area of r_i to the basin area A_W, and $P_{ci,cj}$ the proportion of channels of order i merging into channels of order j, $j > i$, $2 < j \leq W + 1$. Obviously $P_{cW,cW+1} = 1$; this is not strictly true since a basin of any given order may outlet into a stream several orders higher. However, this is convenient and does not affect the model. Similarly, $P_{ri,ci} = 1$. Then for a path $s \in S$ of the form $s = \{x_1, x_2, \ldots, x_k\}$ where $x_1, x_2, \ldots, x_k \in \{C_1, C_2, \ldots, C_W; r_1, r_2, \ldots, r_W\}$.
The path probability function is defined as

$$p(s) = A_{x1} \cdot P_{x1,x2} \cdots P_{xk-1,xk} \qquad \ldots(3)$$

It should be emphasized that the paths are all distinct, therefore, the probability of $T_B < t$ is

$$P(T_B < t) = \sum_{s \in S} P(T_s < t) \cdot p(s)$$

$$= \sum_{s \in S} F_{x1} * F_{x2} * \ldots * F_{xk}(t) \cdot p(s), \qquad \ldots(4)$$

$$s = \{x_1, x_2, \ldots, x_k\}$$

where

t = specific time

F_x = cumulative density function of T_x

$*$ = convolution operation

Differentiation with respect to t on both sides yields

$$f_B(t) = \sum_{s \in S} f_{x1} * f_{x2} * \ldots * f_{xk} \cdot p(s) \qquad \ldots(5)$$

where f_x denotes the PDF of T_x . Gupta, Waymire, and Wang (1980) have established the equivalence of $f_B(t)$ and the IUH, h(t). Therefore,

$$h(t) = \sum_{s \in S} f_{x1} * f_{x2} * \ldots * f_{xk} \cdot p(s) \qquad \ldots(6)$$

where h(t) is the result of an instantaneous burst of effective rainfall of unit volume.

Thus, the direct runoff hydrograph synthesis reduces to synthesis of h(t) using Equation 6. In Equation 6 the path probability function p(s) can be specified completely from the drainage network morphometry. However, specification of f_{xi} cannot be entirely based on physical considerations. For simplicity, f_{xi} is assumed to be exponentially distributed with some parameter $K_{xi} > 0$. This is consistent with the assumption of basin linearity. Then $f_{x1} * f_{x2} * \ldots * f_{xk}$ in Equation 6 become the k-fold convolution of independent but nonidentically distributed exponential random variables. That is,

$$f_{x1} * f_{x2} * \ldots * f_{xk}(t) = \sum_{i=1}^{k} C_{ik} \exp(-K_{xi}\, t) \qquad \ldots(8)$$

Where the coefficients C_{ik} are given by Feller (1971) as

$$C_{ik} = K_{x1} K_{x2} \dots K_{xk-1} \Big[(K_{x1} - K_{xi}) \cdot (K_{xi-1} - K_{xi}) \dots (K_{xi+1} - K_{xi}) \dots (K_{xk} - K_{xi}) \Big]^{-1} \qquad \dots(9)$$

in which $K_{xi} \neq K_{xk}$ unless $i = k$. Therefore, the IUH is given as

$$h(t) = \sum_{s \in S} \sum_{i=1}^{k} C_{ik} \exp(-K_{xi}\, t) \cdot p(s), \qquad \dots(10)$$

$$s = \{ x_1, x_2, \dots, x_k \}$$

To apply equation 10, the parameters K_{xi} must be determined. Following Gupta, Waymier and Wang (1980), the mean holding time of an ith order Strahler channel (state) is given as

$$\frac{1}{K_{ci}} = \gamma \left(\bar{L}_i \right)^{1/3}, \quad 1 \leq i \leq W \qquad \dots(11)$$

where γ is an empirical constant and L_i is the average channel length of order i. Likewise, the mean holding time $1/K_{ri}$ of an ith order overland region can be given by

$$\frac{1}{K_{ri}} = \gamma \left(\frac{A_{ri}\, A_W}{2N_i\, \bar{L}_i} \right)^{1/3}, \quad 1 \leq i \leq w \qquad \dots(12)$$

The constant γ is determined empirically and plausibly may remain more or less constant from one state to another within a given basin. To use Equations 11 and 12 the constant γ must be specified. The first moment of the IUH, h(t), being equal to the mean holding time of the basin, K_B, can be written as

$$K_B = \int_0^{\infty} t\ h(t)\ dt \qquad \ldots(13)$$

From equation 10 and 13 it can be shown that

$$K_B = \sum_{s \in S} p(s) \left[\frac{1}{K_{x1}} + \frac{1}{K_{x2}} + \ldots + \frac{1}{K_{xk}} \right], \qquad \ldots(14)$$

$$s = \{ x_1, x_2, x_3, \ldots, x_k \}$$

If Equation 11 and 12 are substituted in Equation 14 the only unknown is γ . However, K_B is estimated following Body (1978) as

$$K_b = b \left[A_w \right]^{0.38} \qquad \ldots(15)$$

where K_B is in hours and A_W is in square kilometers. The parameter b must be determined empirically. Thus, for a specific value of K_B, γ can be determined. Thus the IUH can be completely specified by watershed geomorphology.

2.2.4 Computation of Direct Runoff Hydrograph (DRH)

The DRH Q(t) is computed by

$$Q(t) = \int_0^{t} h(t-s)\ I(s)\ ds$$

where I(t) is the ERH, and h(t) is the IUH. In discrete form,

$$Q_j = \sum_{i=0}^{j} h_{j-1} \, l_j \, \Delta t \quad , \quad j = 0, 1, 2, \ldots\ldots$$

where Δt is the discretization time interval used for discretizing the ERH and IUH.

2.3 Model Structure

The Watershed Hydrology Simulation Model (WASH) consists of a number of component models. The arrangement of these components is shown in Figure 1, and depends on whether or not optimization of model parameters is required. A flow chart of the model is given in Figure 2. A brief discussion of the subroutines is given below.

The program MAIN provides general information on the WASH model, sets its objectives and specifies inputs required by subsequent routines. It also monitors whether optimization of model parameters is required or not.

The rainfall-runoff data are processed by a subroutine PRECIP. These data are properly arranged and their units are specified. The rainfall is partitioned into (1) the effective rainfall, and (2) the portion not contributing to direct runoff. This requires a two-step computation. First, the volume of the effective rainfall, which by virtue of continuity equals the volume of direct runoff, is to be computed. Second, the ERH is determined. To that end, a subroutine CURVE is designed which employs such basin surfacial characteristics as vegetation cover, land use, and soil type. This computes an integrated curve number

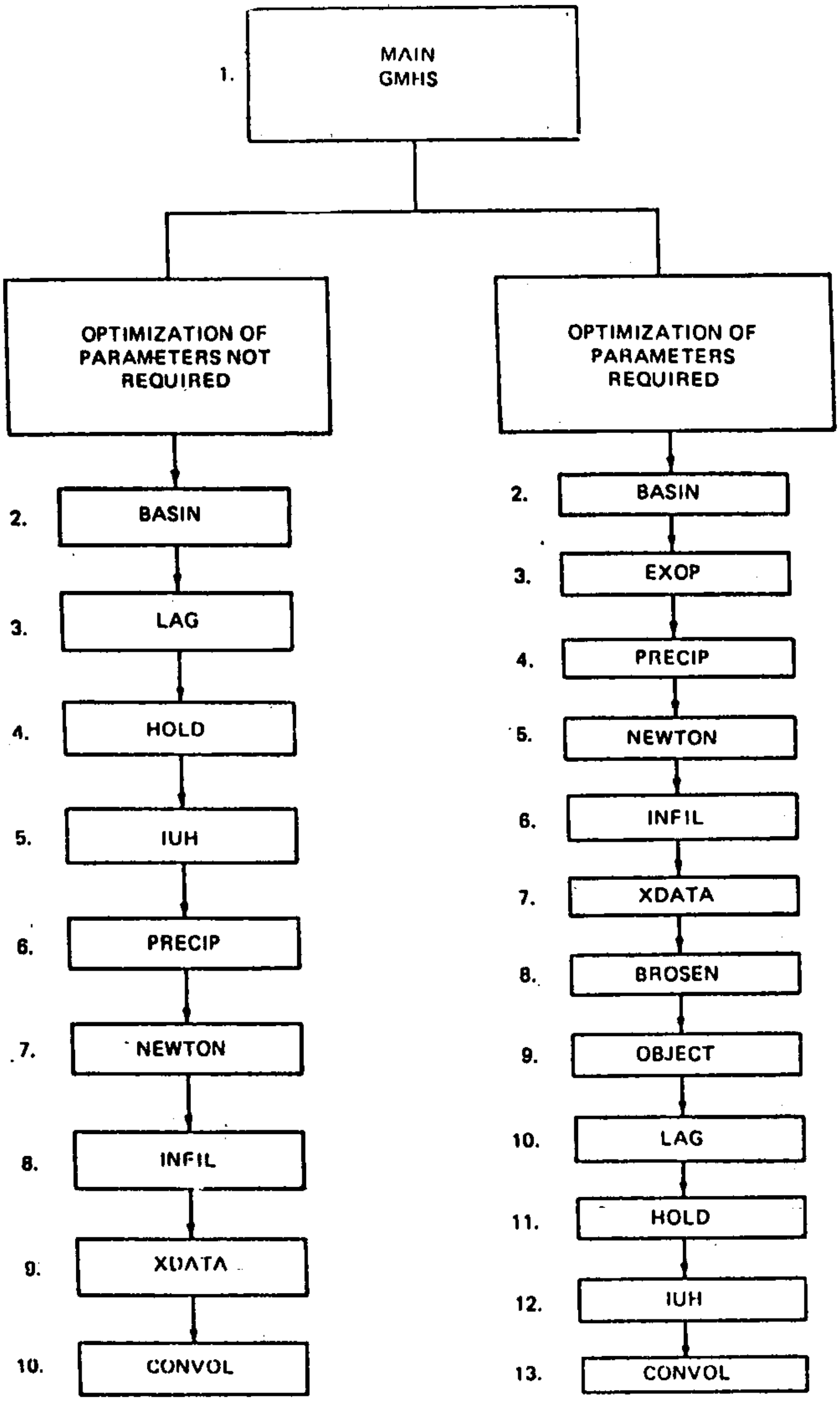

Figure 1. Components of Watershed Hydrology Simulation Model

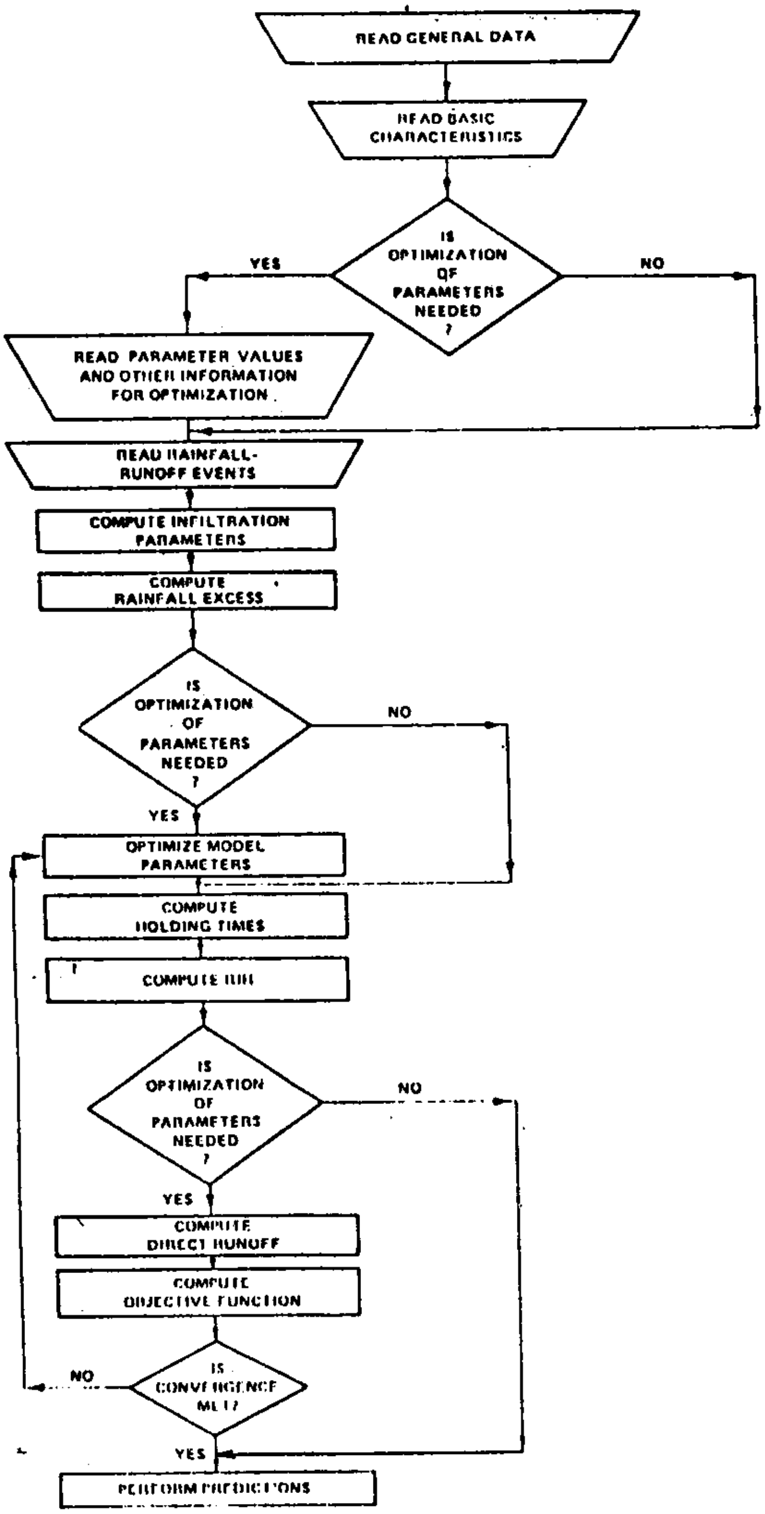

Figure 2. Computer flow chart of WAHS model

for the entire basin which is an indicator of its runoff producing efficiency. This number is then included in another subroutine RUNOFF which actually computes the volume of direct runoff by employing the SCS hypothesis. On the other hand, the stream flow hydrograph is separated into direct runoff and base flow by a subroutine HSEP. This also then computes the volume of direct runoff. Thus, in this manner, the volume of direct runoff is obtained in two ways: (1) by the SCS method, and (2) by the hydrograph separation.

The effective rainfall is computed by utilizing the subroutine INFIL. The time difference between the start of the effective rainfall and that of the direct runoff is noted. To represent the portion of rainfall not contributing to direct runoff, a subroutine INFIL is included. This computes infiltration capacity as a function of time using the two-term Philip infiltration model. The infiltration model has two parameters: sorptivity and saturated hydraulic conductivity. The former is determined for each rainfall-runoff event by a volume balance technique. The latter is specified for each watershed and is assumed constant from one event to another. These computations are carried out in the subroutine NEWTON.

The basin characteristics are analyzed by a subroutine BASIN. The principal geomorphologic characteristics are: (1) basin area, (2) drainage area of channels, (3) channel lengths, and (4) number of channels of a specified order. This subroutine estimates mean lengths of and areas required by channels of a given order. Another subroutine LAG computes the basin lag utilizing basin area.

The mean holding times of overland flow and channel flow are computed by a subroutine HOLD. The instantaneous unit hydrograph is computed by a subroutine IUH. The IUH is then convoluted with the ERH obtained from the subroutine PRECIP by the subroutine CONVOL to obtain the direct runoff hydrograph. This subroutine also compares computed runoff hydrograph with the corresponding observed hydrograph and computes error of prediction.

The subroutine EXOP provides pertinent information required by the optimization algorithm, including specification of initial guesses, upper and lower bounds on parameter values, number of stage searches, and convergence limit. The subroutine OBJECT specifies the objective function to be used in optimization of model parameters. The objective function is defined as the sum of squares of deviations between observed and computed discharge peaks and their times of occurrence. Optimization of parameters is performed by subroutine BROSEN which combines the original Rosenbrock method, the Palmer version and the penalty function constrained minimization problem requiring the vector always to be an interior point of the feasible set.

2.4 Important Features of the Model

The most important feature of the model is that it takes into account the drainage network properties. This feature suggests that the model may be applicable to ungauged basins with relative ease and produce superior results. This feature also makes it possible to carry out flood hydrograph computations and can be extended to frequency estimation without making unrealistic assumptions about basin representation.

With the use of the various parameters representing the drainage network properties, only a few parameters are left to be decided by trial & error or by optimization techniques. Therefore, the model can be applied to a new catchment with relatively more confidence if certain basic information is available.

2.5 Data requirement

The data requirement of the model can be classified into two broad groups .

1. hydrological data and
2. data based on geomorphology of the basin

Under hydrological data, the data required include rainfall hyetograph, saturated hydraulic conductivity, observed runoff hydrograph for calculating volume of direct runoff or soil cover complex data to calculate volume of direct runoff by SCS method.

The rainfall data can be supplied in units such as mm, cm or inches and runoff data can be supplied in cusecs or cumecs or cm or inch. A suitable control is also supplied to the model to understand the proper units of data supplied.

The principal geomorphological characteristics needed are basin area, areas of overland regions, channel length, number of channels, basin order, and path matrix of the basin. The length parameters are given in kilometer and area in square kilometer respectively.

3.0 THE STUDY AREA

The Kolar river is a tributary of Narmada river. It originates in the Vindhyanchal mountain ranges at an elevation of 550 metres in Sehore district of Madhya Pradesh, India. The river Kolar during its 100 kilometer course flows towards east and then towards south before its confluence with Narmada near Neelkanth. During its course the river Kolar drains an area of about 1350 square kilometers. In the present study the catchment area upto Satrana gauging site only is modeled. The study basin lies between north latitude 22°40′ to 23°08′ and east longitude 77°01′ to 77°29′. The index map of the basin showing location of raingauge stations and gauge-discharge stations and other hydraulic stations is given in Fig. 3.

Topographically, the Kolar sub-basin can be divided in two zones. The upper four-fifth part having elevations ranging from 300 to 600 metres is predominantly covered by deciduous forests. The boundaries of the catchment are mild sloped at the northern end of the basin. The river debauches to plains from this area upstream of Jholiapur through ramp shaped topography. The soils are skeleton to shallow except near canals where it is relatively deep. In this area the rocks are weathered and deep fissures can be seen. The channel beds are rocky or graveled. Thin soils gets saturated even during low intensity rains and water moves through fissures rapidly. General response of this upper part of the basin to rains appears to be quick.

The lower one-fifth part of the basin consists of flat bottomed valley narrowed towards outlet and having elevations ranging from 300 to 350 meters. The area is predominantly

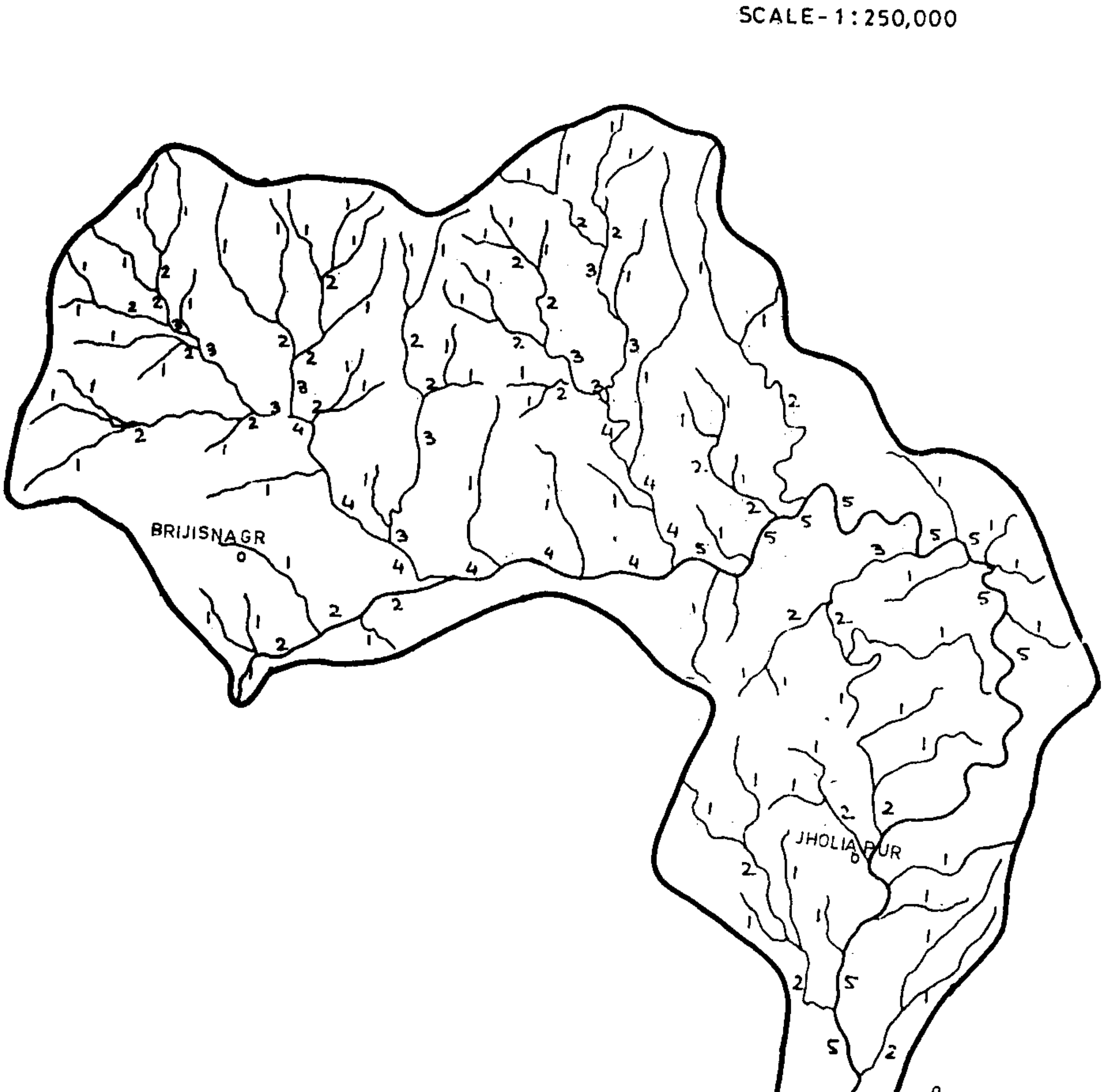

FIG. 3-RIVER CHANNEL NETWORK OF KOLAR SUB-BASIN UP TO SATRANA GAUGING SITE

cultivatable. The soils are deep and have flat slopes. The response of this area to rainfall is likely to be quite slow.

3.1 Data Availability

The topographic map of the area was prepared from Survey of India toposheets in 1:2,50,000 scale. This map is used for the preparation of catchment map along with river system. Geomorphological properties of the basin were derived from this map using modern measuring aids. Drainage network properties are given in Table 3.1. Overland-channel flow path structure of the basin is shown in Fig. 4.

Rainfall and runoff data from 1983 to 1987 were available and used for present study. Six events were selected form this data set. Hourly rainfall values at four rainfall stations namely Rehti, Jholiapur, Birpue and Brijeshnagar were obtained from the records.

The Satrana gauging site located at the outlet of this basin was established in 1983. The gauge-discharge measurements are made at a bridge on Rehti-Nasrullaganj road where an automatic gauge recorder (AGR) has been installed. At this gauging site hourly gauge observations and daily discharge measurements were available for the monsoon months during 1983-87. Based on the rating curves for this period, the hourly discharge were calculated and the values pertaining to six events were taken for analysis.

Table 3.1: Drainage Network Properties of Kolar upto Satrana Basin.
(Watershed Drainage Area = 903.88 Sq. Km.)

Serial Number	Channel length Kilometers	Contributing Area Square Kilometers
Order 1		
1	0.90	2.50
2	1.00	2.10
3	1.50	2.10
4	1.10	3.10
5	2.60	20.60
6	2.10	10.40
7	1.10	4.60
8	2.20	13.60
9	1.70	4.60
10	1.60	4.60
11	1.00	4.40
12	2.00	6.30
13	0.70	4.10
14	1.10	4.10
15	1.70	6.90
16	1.50	7.00
17	1.90	5.30
18	1.20	5.80
19	2.70	13.60
20	2.10	9.10
21	1.80	6.50
22	1.60	5.00
23	1.40	3.80
24	2.00	6.30
25	1.10	4.40
26	1.00	3.80
27	1.20	3.10
28	1.30	5.00
29	2.00	5.00
30	1.10	2.80
31	0.60	3.10
32	3.30	13.60
33	2.60	12.50
34	1.50	5.60
35	0.70	2.50
36	0.70	3.10
37	1.20	1.30
38	1.20	3.10

39	1.00	1.90
40	0.90	2.50
41	0.80	4.00
42	1.20	5.00
43	1.10	3.50
45	1.50	3.40
46	1.60	5.10
47	5.80	21.80
48	3.70	16.00
49	1.20	5.60
50	1.30	5.30
51	1.10	2.80
52	0.50	2.90
53	1.50	4.00
54	2.20	10.00
55	1.20	2.50
56	0.80	3.10
57	0.50	2.50
58	2.10	7.10
59	3.80	11.00
60	1.70	6.90
61	1.90	9.00
62	1.10	3.60
63	1.00	3.00
64	1.20	3.60
65	2.60	12.30
66	2.20	8.40
67	1.30	8.00
68	1.00	4.40
69	2.60	7.80
70	1.90	3.00
71	1.00	3.80
72	1.80	13.10
73	2.10	12.00
74	1.30	12.40
75	1.00	7.60
76	3.10	7.10
77	2.50	6.00

Order 2

1	3.70	13.50
2	2.20	13.10
3	0.30	3.10
4	1.30	3.10
5	1.20	3.80
6	0.60	3.80

7	1.70	3.50
8	0.50	1.90
9	1.60	10.00
10	0.40	5.00
11	1.00	3.80
12	1.80	9.40
13	0.40	2.50
14	1.30	5.00
15	0.60	1.90
16	2.00	6.90
17	3.90	33.10
18	1.60	10.60
19	0.90	3.60
20	1.30	4.40
21	0.80	3.80
22	1.60	13.10
23	1.50	8.10
Order 3		
1	3.10	16.90
2	1.00	8.80
3	2.70	15.00
4	1.40	6.90
5	2.60	15.00
6	2.10	9.40
Order 4		
1	8.00	63.80
2	3.30	17.50
Order 5		
1	23.50	100.78

Path S_1 : $r_1 \longrightarrow C_1 \longrightarrow C_2 \longrightarrow C_3 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_2 : $r_1 \longrightarrow C_1 \longrightarrow C_2 \longrightarrow C_3 \longrightarrow C_5 \longrightarrow C_6$

Path S_3 : $r_1 \longrightarrow C_1 \longrightarrow C_2 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_4 : $r_1 \longrightarrow C_1 \longrightarrow C_2 \longrightarrow C_5 \longrightarrow C_6$

Path S_5 : $r_1 \longrightarrow C_1 \longrightarrow C_3 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_6 : $r_1 \longrightarrow C_1 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_7 : $r_1 \longrightarrow C_1 \longrightarrow C_5 \longrightarrow C_6$

Path S_8 : $r_2 \longrightarrow C_2 \longrightarrow C_3 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_9 : $r_2 \longrightarrow C_2 \longrightarrow C_3 \longrightarrow C_5 \longrightarrow C_6$

Path S_{10}: $r_2 \longrightarrow C_2 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_{11}: $r_2 \longrightarrow C_2 \longrightarrow C_5 \longrightarrow C_6$

Path S_{12}: $r_3 \longrightarrow C_3 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_{13}: $r_3 \longrightarrow C_3 \longrightarrow C_5 \longrightarrow C_6$

Path S_{14}: $r_4 \longrightarrow C_4 \longrightarrow C_5 \longrightarrow C_6$

Path S_{15}: $r_5 \longrightarrow C_5 \longrightarrow C_6$

C_6 denotes trapping state

r_i denotes overland region

C_i denotes channel element

Fig. 4 Overland-channel flow path structure of the basin.

4.0 PROCESSING AND PREPARATION OF DATA

4.1 Selection of the Events

The rainfall runoff records of the catchment from 1983 to 1987 were available and analyzed. Six well shaped flood events were identified by plotting discharge vs. time on simple graph paper. The different identified flood events along with observed peaks are given in table 4.1.

Table 4.1 Selected Flood Events at Gauging Site at Satrana

Event No.	Date of event	Observed DSRO peak (cumecs)
1	28 Aug. 1983	4843.606
2	10 Aug. 1984	2022.105
3	31 July 1985	1369.871
4	13 Aug. 1985	872.542
5	15 Aug. 1986	1270.479
6	27 Aug. 1987	1946.389

4.2 Processing of Rainfall Data

The rainfall data observed at Rehti, Jholiapur, Birpur and Brajeshnagar are being used for the study. The Thiessen weights for each raingauge station were calculated and weighted average hourly rainfall for the catchment is calculated by employing Thiessen method. Table 4.2 shows the thiessen weights for the raingauges and fig. 3 shows the location of raingauges.

Table 4.2 Thiessen Weights of Various Rain Gauge Stations

Name of Station	Weight
Rehti	0.04
Jholiapur	0.24
Birpur	0.38
Brajeshnagar	0.33

4.3 Preparation of Data File

The data file was prepared according to the input requirement of the WAHS model. The input data file can be divided in to three sections. I st section contains details about Geomorphological properties of the basin. This section also contain details about optimization switch and land use and soil type information in case if volume of direct runoff is to be computed by SCS method.

The second section of the data file read information about parameter optimization, If optimization of parameters is desired then it need information about number of parameters to be optimized, their initial values, upper and lower limit of the parameter value, convergence criterion, weighing factor used for optimization. If optimization of the parameters is not needed then value of the parameter is read in this section. This section also read information about how many events are to be used for optimization of the model parameters.

The third section of the data file contains details of rainfall runoff events. It reads information about unit of measurements, number of rainfall readings. Before reading runoff reading it read information about whether base flow Separation is required or not, method to compute volume of direct runoff, if direct runoff is to be computed by SCS method then antecedent soil moisture conditions for each event are to be specified. This part contains details about all the events used in the study sequentially.

5.0 ANALYSIS AND DISCUSSION OF RESULTS

The model has the capability to compute the volume of direct runoff by two methods, the SCS method and hydrograph separation method. In this study, second method i.e. hydrograph separation method was employed to compute the volume of direct runoff. Infiltration for each rainfall runoff event was determined by using Philip two term infiltration model (Philip 1968). The parameter "A" depends on the soil type and therefore fixed for a given basin. The value of "A" was taken as 0.254 cm/hr for this study. By employing this technique, we test the shape, peak and time to peak predicted by the model by comparing it with the observed hydrographs.

In all a total of 6 events have been identified for model calibration and testing (validation). Out of these 6 events listed in table 4.1, events no. 1 to 3 were used for calibration of the model and remaining 3 events were used for testing the model performance. The only parameter "b" in the lag-area relation was optimized using Rosenbrock Palmer optimization algorithm available in the model. The other parameter which is exponent in the lag-area relationship was fixed as 0.38 as proposed by Body (1979). After successful execution of the model, the value of the parameter "b" was found to be 0.350. Using these parameters value, the IUH was determined for the study basin. The ordinates of IUH are given in table 5.1 and IUH is shown in fig. 5. Table 5.2 gives the value of observed and computed peak discharge and their relative error for calibration.

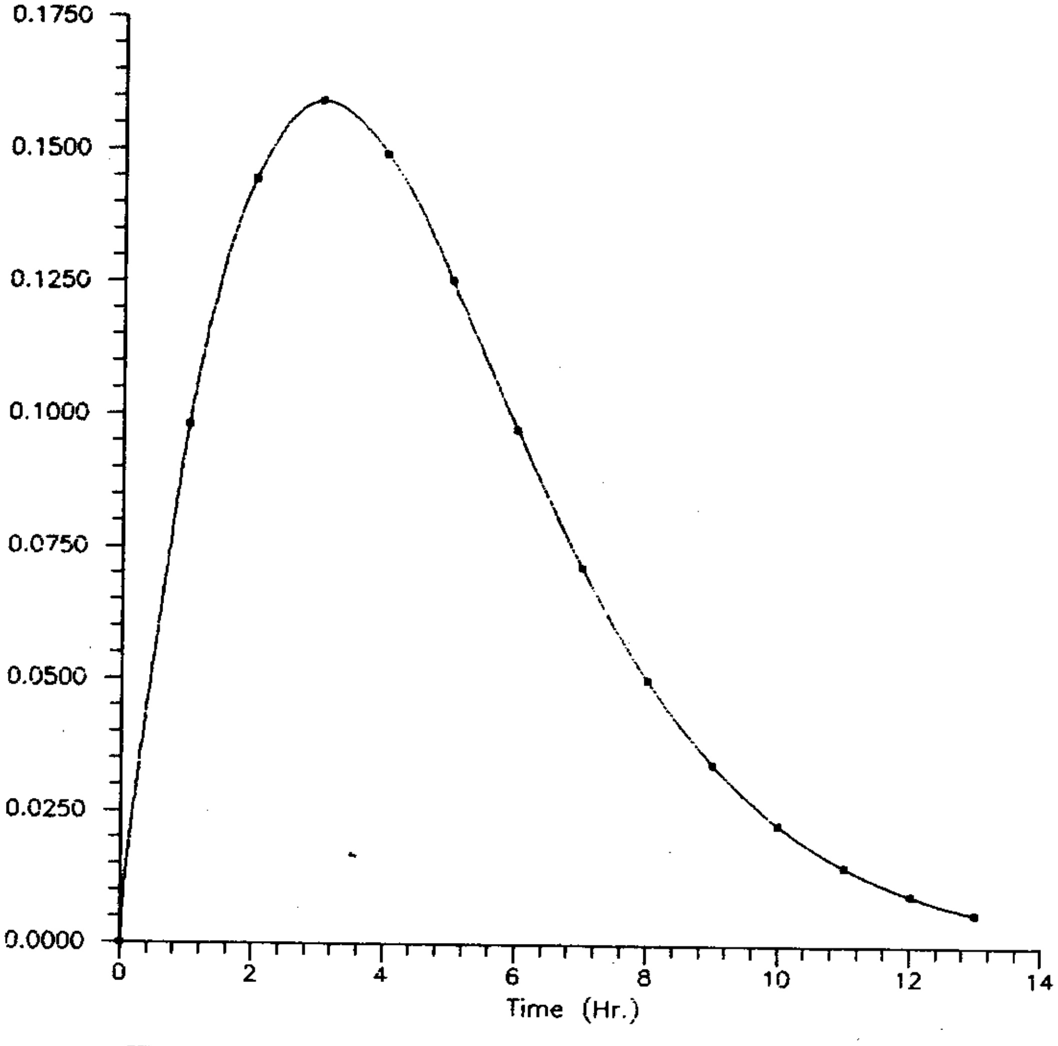

Fig. 5 *IUH of Kolar Basin*

Table 5.1 IUH of Kolar at Satrana

Time HR	h(t) 1/HR	Time HR	h(t) 1/HR	Time HR	h(t) 1/HR	Time HR	h(t) 1/HR
0	0.0000	1	0.0981	2	0.1444	3	0.1592
4	0.1492	5	0.1253	6	0.0973	7	0.0714
8	0.0502	9	0.0343	10	0.0229	11	0.0151
12	0.0098	13	0.0063				

Table 5.2 Relative errors in peak discharge for calibration

Event No.	Observed (cumecs)	Computed (cumecs)	Relative error
1	4843.606	4915.808	-0.01
2	2022.105	1943.342	0.04
3	1369.871	1436.164	-0.05

It may be seen that the computed and observed values of the peak discharge match reasonably well in most of the events. The relative errors in the time of occurrence for the peak is illustrated in table 5.3. Fig. 6 to 8 show the observed and computed flood hydrographs for different events for calibration.

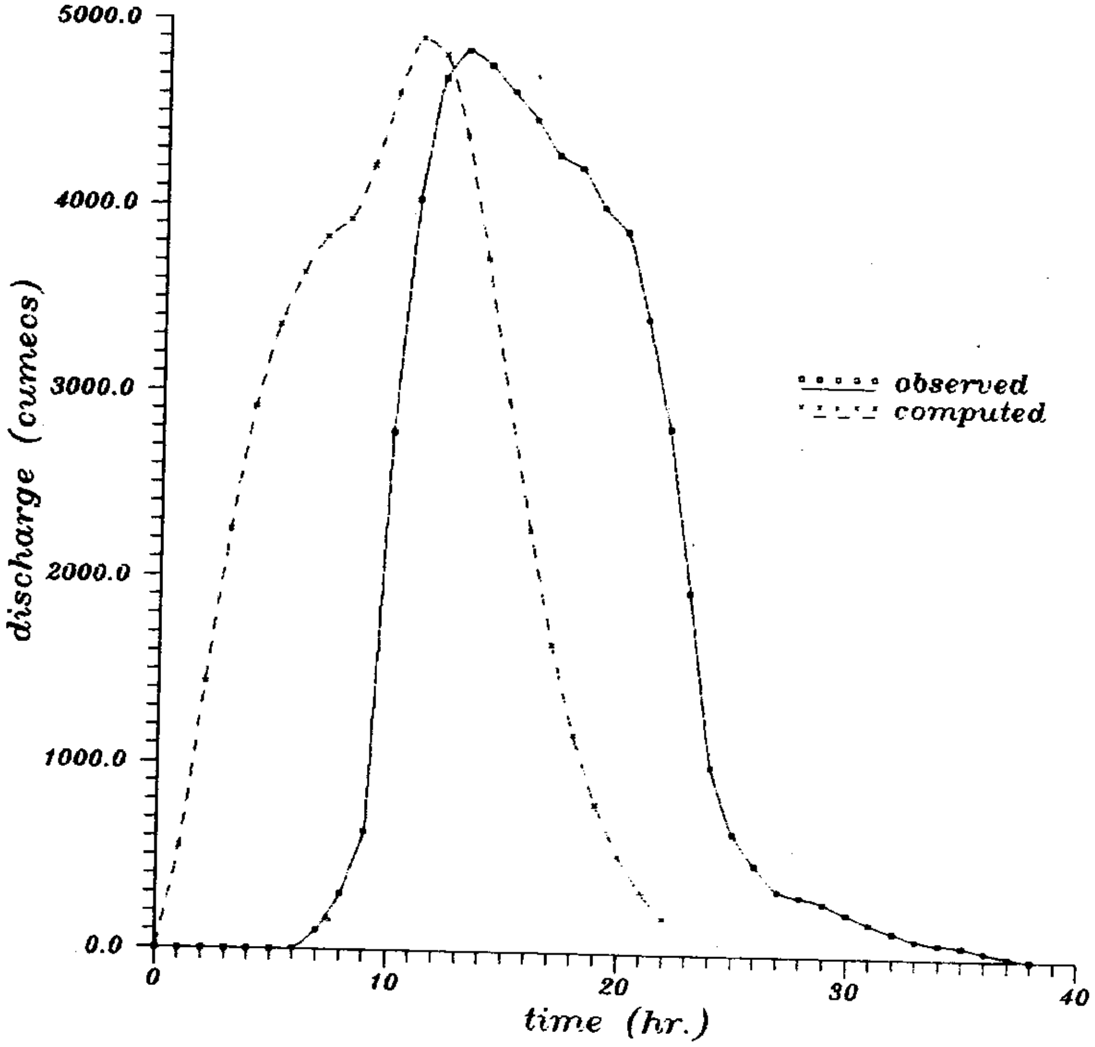

Fig 6. Observed and computed hydrograph
(event no. 1)

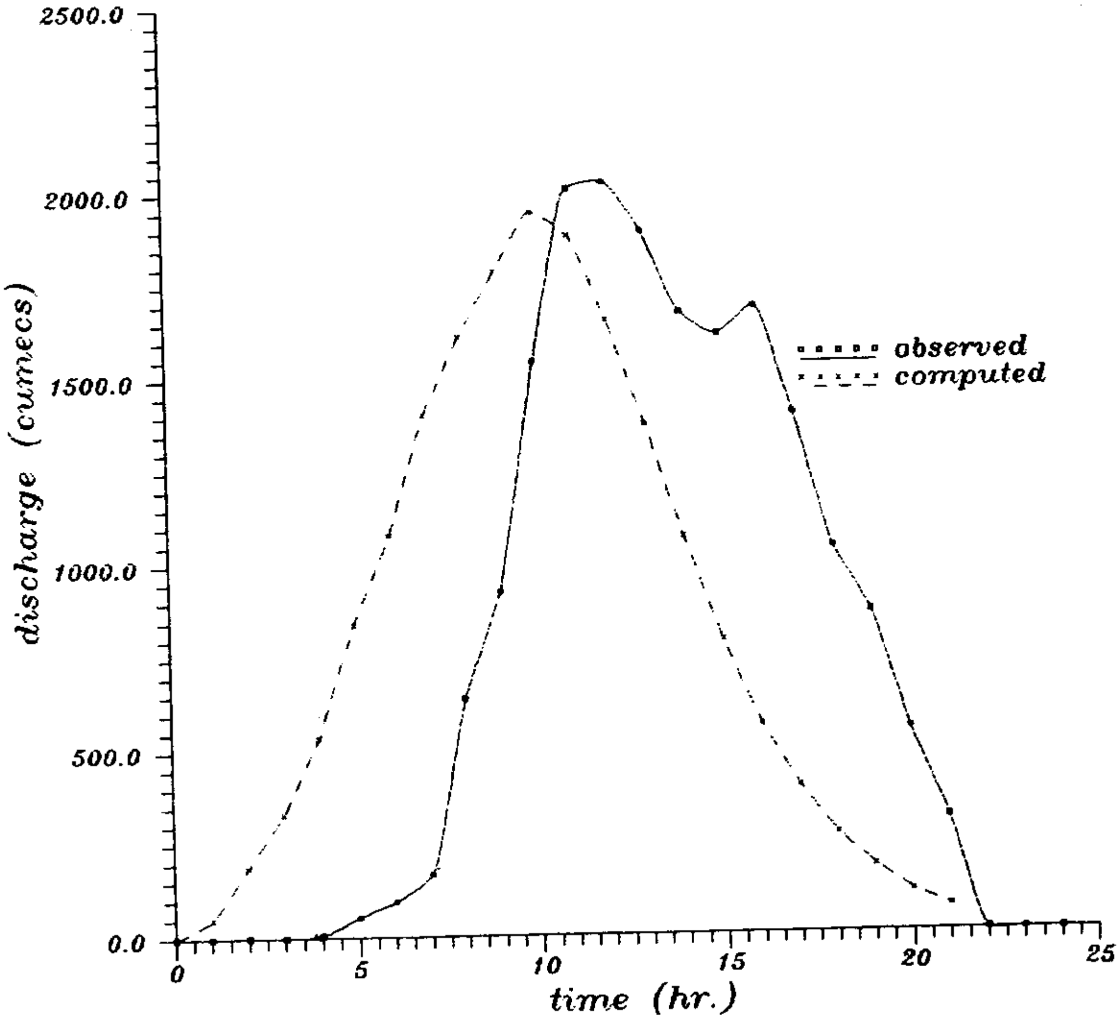

Fig. 7 . Observed and computed hydrograph (event no. 2)

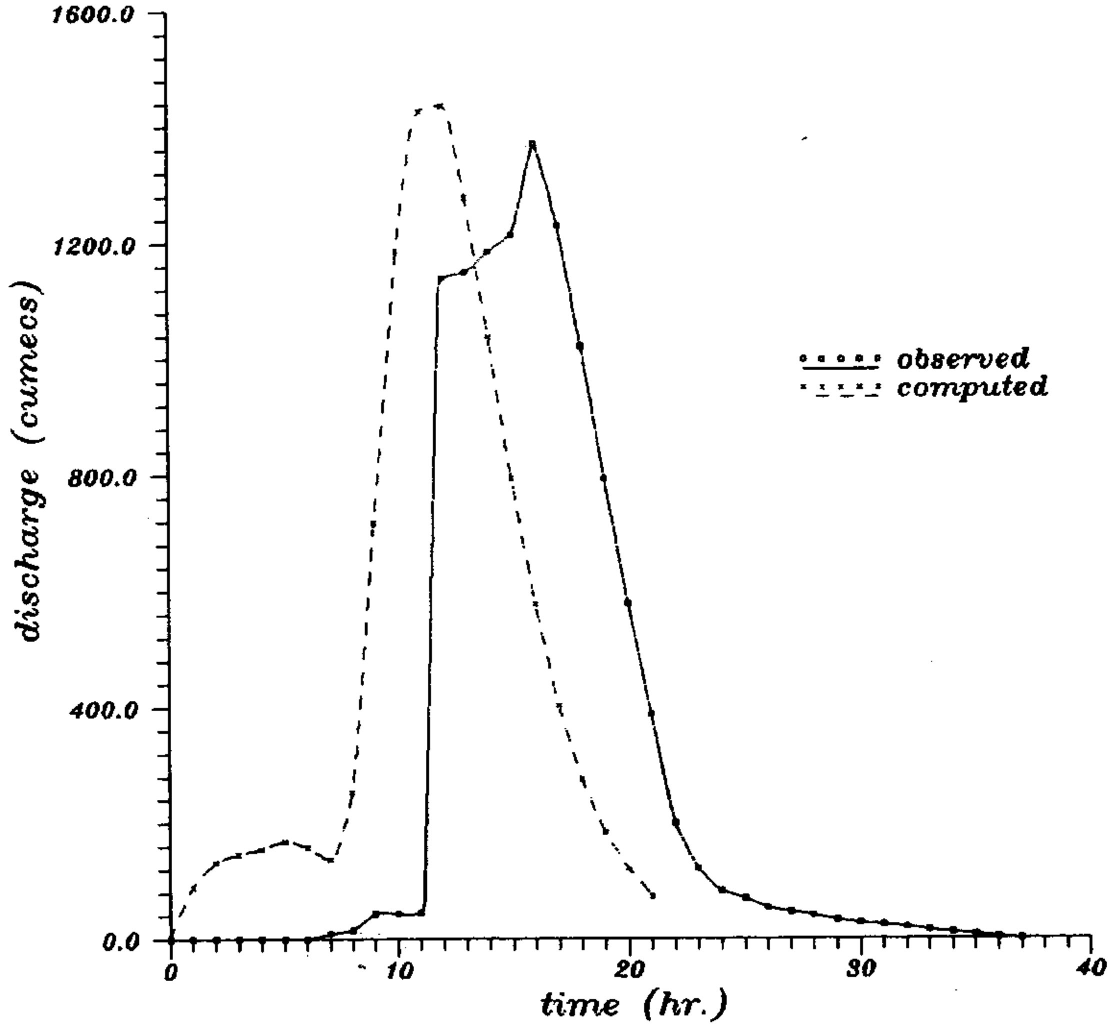

Fig. 8 . Observed and computed hydrograph
(event no. 3)

Table 5.3 Relative errors in time to peak discharge for calibration

Event No.	Observed (hour)	Computed (hour)	Relative error
1	13.00	11.00	0.15
2	12.00	10.00	0.17
3	16.00	12.00	0.25

The calibrated model has been used to simulate the flood hydrograph for remaining events (events no. 4 to 6, table 4.1). The values of relative errors in the computed rates of peak discharges for various test events is summarized in table 5.4 .

Table 5.4 Relative errors in peak discharge for validation

Event No.	Observed (cumecs)	Computed (cumecs)	Relative error
4	872.542	669.122	0.23
5	1270.479	1749.007	-0.38
6	1946.389	1757.042	0.10

Fig. 9 to 11 show the observed and computed flood hydrographs for different events. It may be seen that computed and observed values of the peak discharges match reasonably well in most of the events. The relative errors in the time of occurrence of peak is illustrated in table 5.5 .

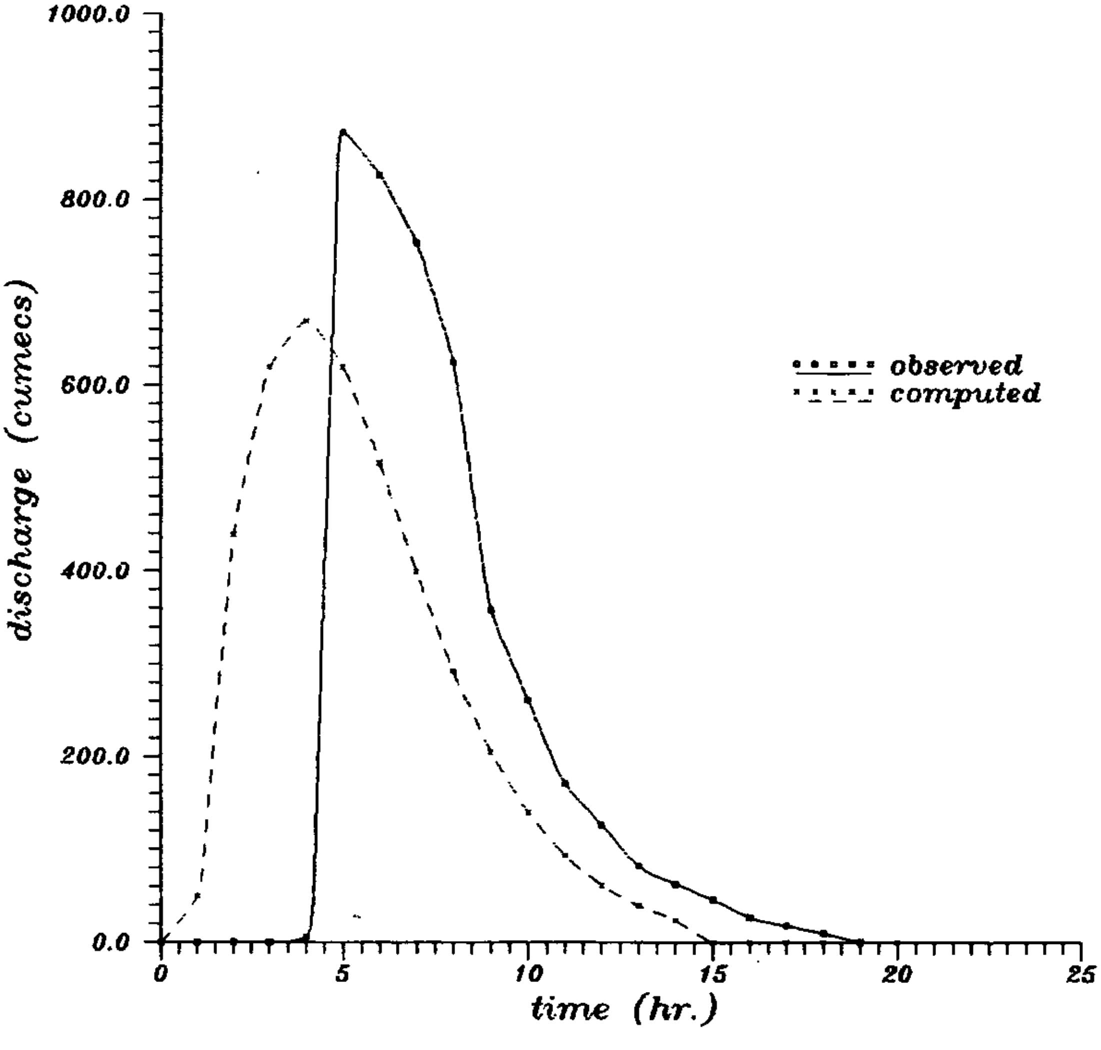

Fig. 9 . Observed and computed hydrograph (event no. 4) .

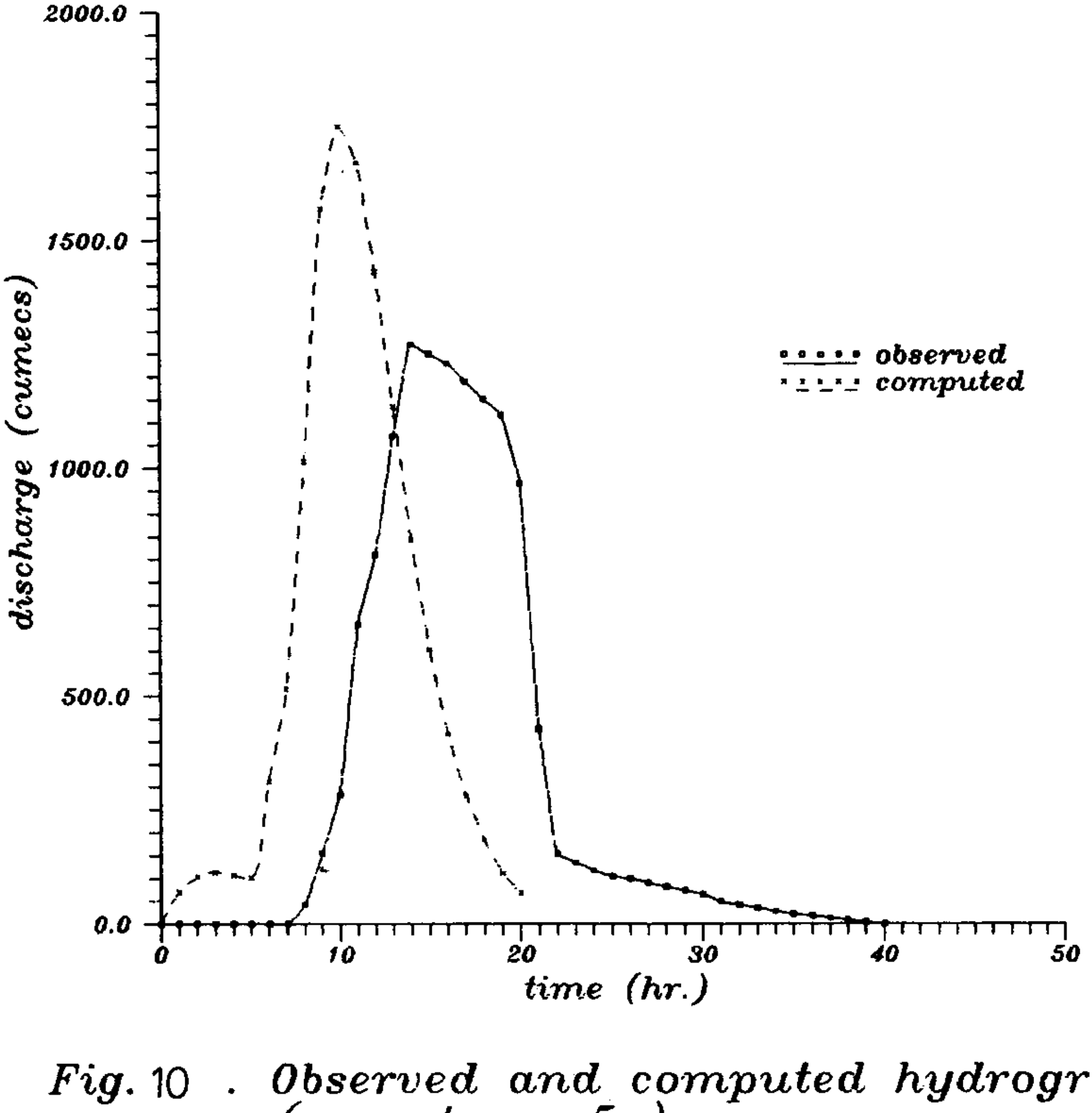

Fig. 10 . *Observed and computed hydrograph (event no. 5)*

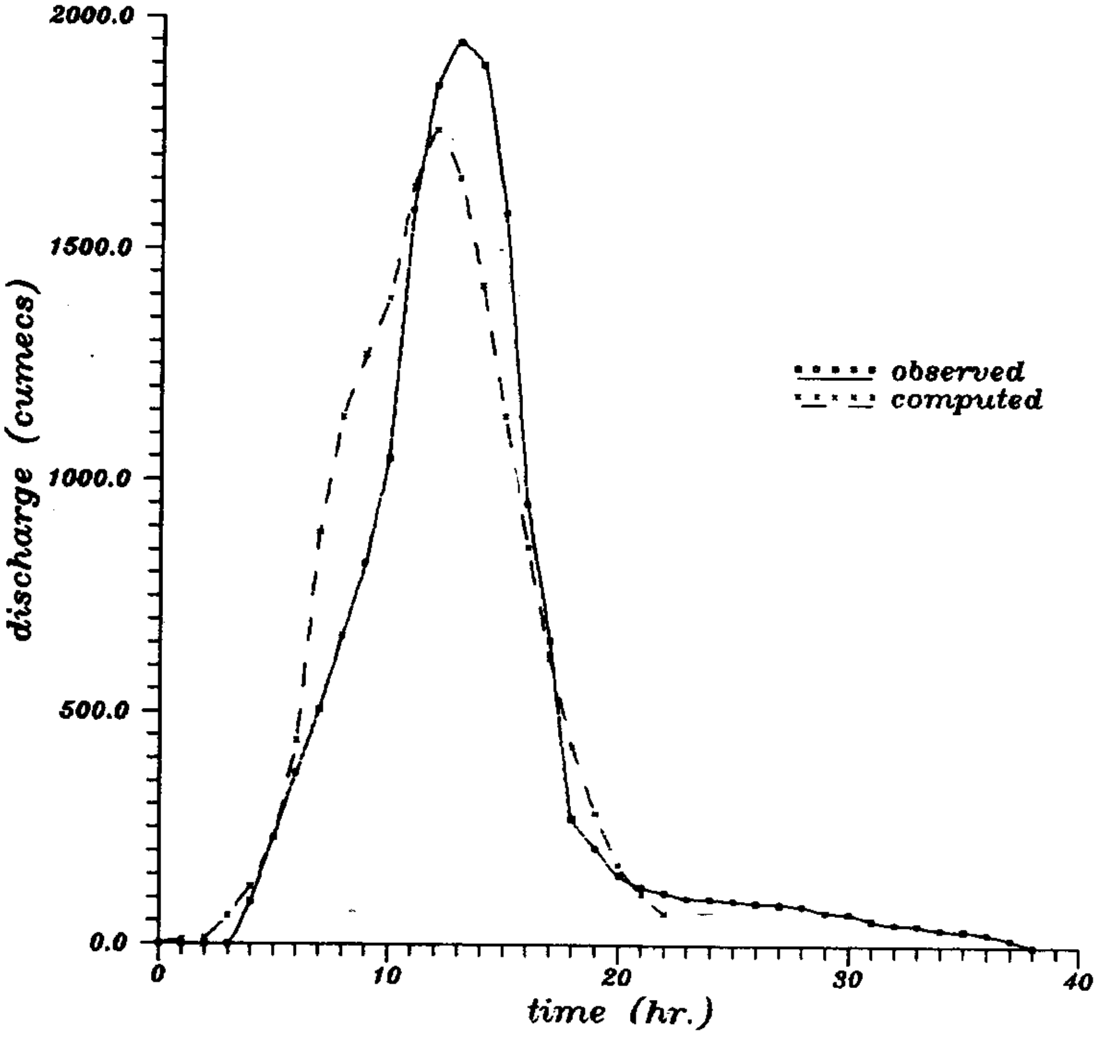

Fig. 11 . Observed and computed hydrograph
(event no. 6)

Table 5.5 Relative errors in time to peak discharge for validation

Event No.	Observed (hour)	Computed (hour)	Relative error
4	5.00	4.00	0.20
5	14.00	10.00	0.29
6	13.00	12.00	0.08

The results indicate that in general the model has simulated the flood hydrograph reasonably well except for shifting in the timing of the hydrographs. Even in case of complex hydrograph, the model has been found to be capable of predicting the shape of the hydrograph reasonably well.

6.0 Summary and Concluding Remarks

The Watershed Hydrology Simulation (WAHS) model which primarily uses the geomorphological characteristics of the basin for derivation of the IUH of the basin was successfully applied for simulation of flood events of river Kolar at Satrana. The results of the simulation of the flood events indicate that the model can be very effectively used for estimation of peak floods as well as complete flood hydrograph. However, shifting of simulated hydrograph was noticed in most of the events. One of the reasons may be attributed to the fact that the rainfall variations within the basin are quite significant. Further, sufficient number of flood events having the observed record of rainfall and discharge data were not available and the model calibration was done with relatively few events.

Keeping in view the above facts, 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 were estimated from geomorphological characteristics and other hydrological data of the basin.

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