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APPLICATION OF KINEMATIC CASCADE MODEL 'KINGEN' FOR FLOW COMPUTATION IN A HILLY CATCHMENT

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Estimation of Runoff in mountainous areas is required for the design, development and management of water resources projects. Runoff in mountainous areas result from precipitation in the form of rainfall or snowfall. The response of watershed to the precipitation may be conceptualised into three components; viz. infiltration into the soil; overland flow and channel flow; collectively called as surface runoff.

Surface runoff from a small catchment is predominantly overland flow with channel flow being comparatively less significant. The overland flow from mountainous areas is generally recognised as non-linear process. Among the two approaches of modelling non-linear processes viz. system approach and hydro-dynamic approaoch; it is usually the later one which has mostly been used for modelling overland flows.

Based on hydrodynamic approach, a kinematic cascade model namely KINGEN has been developed at Colorado State University. The model incorporates infiltration model to compute excess rainfall. The model requires simplification of the watershed into a cascade of planes and channel elements. The input data to the model include details of various elements; such as length, width, slope, etc. roughness parameters, in the form of Chezy's C or Manning's n and soil related data for infiltration calculations. Computed excess rainfall is routed over the planes and in the channels upto the outlet of the catchment to yield surface runoff hydrograph. The rainfall is assumed to be uniformly distributed over the entire catchment for the purpose.

For the present study, the catchment of Malaprabha upto Khanapur in Western Ghats region has been selected. The watershed geometry has been represented by a cascade of fourteen elements. Infiltration losses were computed using Smith's theory of soil water flow. The kinematic cascade model KINGEN based on kinematic wave equation has been used to simulate overland flow and channel flow.

Using data of some storm spells in the catchment, the model has been calibrated. The calibrated model was varified with data for the other storm events. The direct-surface runoff hydrograph simulated by the model was compared with the observed runoff after seperating base-flow. Peak flow and time to peak were simulated fairly accurately. The volume of the simulated hydrograph was found to be in agreement with the observed flow volume.

1.0 INTRODUCTION

Much of the water resources of our country are generated from rainfall and melting of snow from mountainous areas. Development of water resources require the estimation of water availability and peak magnitude of flood at the project sites. Estimation of Stream Flows from mountainous catchments requires a thorough understanding of runoff process in these areas. Runoff process in mountainous areas are the result of complex interaction among precipitation, infiltration, evaporation and storage effects. A complete mathematical description of flow phenomenon is possible in principle, but will be extremely time consuming and sophisticated with respect to numerical treatment.

Runoff in mountainous areas consists of surface runoff, subsurface runoff and groundwater runoff. The surface runoff comprises of two components viz. overland flow and channel flow. Overland flow is that part of the surface runoff which flows directly over the land surface towards the stream channel. Hydrological modelling of overland flow and stream runoff in mountainous watersheds is either based on system approach or hydrodynamic approach. In hydrodynamic approach, the watershed needs to be replaced by a number of geometric elements such as combination of planes and channels of various dimensions or linearly converging and diverging sections. The form of resistance law and infiltration equation is then decided and hydrodynamic equations or their (kinematic wave) approximations solved to simulate the overland flows.

For the purpose of simulation of overland flows, a model named as KINGEN75 developed at Colorado State University has been used in the present study. The watershed is represented by kinematic cascade of planes and channels. A parametric infiltration model has been incorporated with a surface routing model. The main input to the model is the simplified catchment geometry in the form of overland flow planes and channels, their dimensions, slopes etc. infiltration parameters and resistance parameters. The input consists of the discharge calculated over the desired time-interval; which can be compared with the observed discharge at the outlet.

2.0 REVIEW

2.1 General

Surface runoff in mountainous areas which consists of overland flows and channels flows result from precipitation. There is a complex interaction regarding precipitation, infiltration, evaporation and storage effects before overland flows are generated. One should consider the interaction between overland flow and infiltration as both the processes occur simultaneously. The infiltration capacity is affected by many factors such as vegetation cover, land use, slope, rainfall intensity etc, and varies with time.

The overland flow is generated when the rainfall intensity exceeds the infiltration capacity of the soil so that excess rainfall appears as overland flow (Horton, 1933). However, according to Dunne (1978), overland flow is generated when precipitation rate is less than the saturated hydraulic conductivity of the soil and initial water table is shallow. In this case, surface saturation occurs because of rising water table.

The overland flow is both unsteady and spatially varied as it is mainly fed by rain and depleted by infiltration neither of which are constant in time and space. The flow may be either laminar or turbulent or a combination of these two conditions and the depth of flow may be either below or above critical or the depth may change from sub-critical to super-critical.

Several researchers have developed physical and mathematical models to represent overland flow. Mathematical models are generally more useful in hydrologic studies

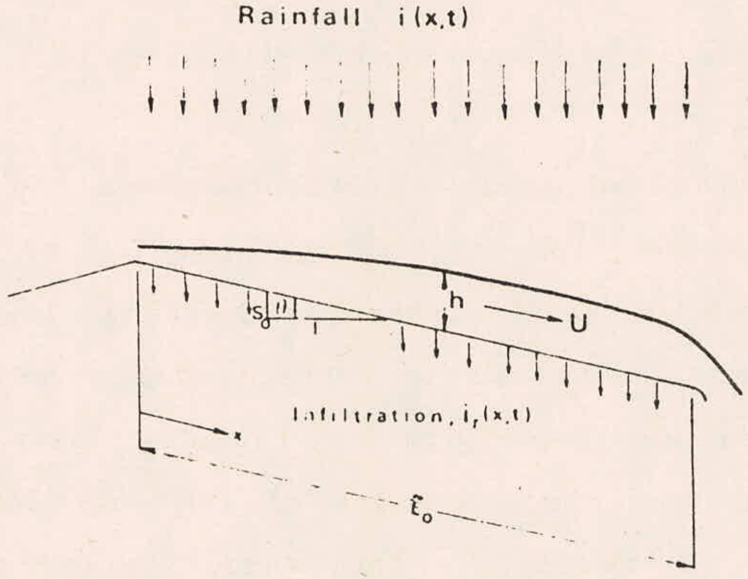

Fig 1 : Description of Overland flow on a plane compared with physical models. The relationship between watershed response and its parameters can be studied easily with the help of mathematical models.

There are four important phases in the mathematical modelling of overland flow:

i) To determine equations and appropriate boundry conditions describing the physical proces. Also to consider possible simplification.

2) To develop an efficient and accurate method to solve the set of equations.

3) To estimate the model parameters using rainfall and runoff records, topographic and soil related data.

4) To predict the watershed response for known inputs.

2.2 Kinematic Wave Theory

The equations of motion viz. continuity and momentum equation for spatially varied unsteady overland flows are derived from the principles of conservation of mass and of momentum and were developed by St.Venant in 1871 (Yevjevich, 1960). The one dimensional continuity equation with lateral flow for unit width of cross-section (see Fig.1) is given as

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) = q\,(x,t) \qquad \ldots(1)$$

and momentum equation, as:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial u}{\partial x} = (S_o - S_f) - \frac{u}{h}\,q\,(x,t) \qquad \ldots(2)$$

where,

$h = h(x,t)$ = Depth of overland flow (L)

$u = u(x,t)$ = Flow Velocity (L/T)

$q = q(x,t)$ = The net rate of lateral inflow (L/T)

$= i(x,t) - i_r(x,t)$

g = Acceleration due to gravity (L/T^2)

S_f = friction slope (L/L)

These equations of hydraulics of overland flow are the one in which non-linear effects are quite marked. Therefore kineamatic wave approximations are used to solve the hydrodynamic equations. The review has indicated that kinematic wave approximation to the hydraulics of overland flow is better for rough and steep slope.

Kinematic wave occurs whenever a balance between gravitational and frictional forces is achieved. Under such conditions, the dynamic terms in the momentum equation (terms $\frac{\partial u}{\partial t}$, $\frac{\partial u}{\partial x}$, $g \frac{\partial h}{\partial x}$ and $\frac{u}{h} q(x,t)$ in equation 2) reduces to the following form:

$$S_o = S_f \qquad \ldots(3)$$

With kinematic wave approximation, the mechanism of flow is now described by Equation 1(continuity eq.) and equation 3(KInematic wave approximation to momentum equation). Assuming the flow to be sheet flow so that width of plane $B \gg h$, and combining the two equations, the following equation is obtained;

$$\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = (x,t) \qquad \ldots(4)$$

$$\text{Here } Q = \alpha h^N \qquad \ldots(5)$$

α and N are parameters related to surface roughness and geometry.

2.3 Numerical Solutions of Overland flow equations

The overland flow equations that have been formulated have been solved by a variety of finite difference methods. The finite difference methods are either implicit or explicit.

In general, the numerical schemes that have been used by investigators to solve kinematic wave equations are:

i) Upstream Finite differencing scheme

ii) Crank-Nicholson scheme

iii) Brakensick's four point implicit scheme

iv) Single step Lax-Wendroff scheme

Lax-Wendroff scheme is comparatively more popular since this scheme has second order accuracy and will have the smallest errors of approximation for given x and t. But, in case of Law-Wendroff scheme, the stability criteria needs to be respected. Singh (1976) has developed the step error of these schemes and found that step error of Lax-Wendroff scheme is least and that of Brakensick four point implicit scheme is highest. However, Brakensick's four point scheme is unconditionally stable.

Thus, stability and step error of a scheme must be considered simultaneously while selecting a numerical scheme to approximate kinematic wave equation.

2.4 General Procedure of Overland Flow Modelling

For hydrological modelling of overland flow, the complex geometry and topography of natural watershed is replaced by large number of simple elements. One geometrical abstraction that has been used by several investigators is to represent the watershed by a network of overland flow planes and channels (Henderson and Wooding, 1964; Harley et al, 1970; Singh, 1974; Smith and Woolhiser, 1971a and 1971b; Lane et al, 1975 and Rovey et al, 1977).

The other approaches for simplifying the geometric complexities that have been used by some investigators are to represent the catchment by converging section (Woolhiser 1969 and Kibler and Woolhiser 1970) and Diverging Section (Singh and Agiralioglue 1981 a and 1981 b). But these abstractions have usually been made in case where the natural catchments either converge or diverge in shape.

After the decision regarding spatial representation of the watershed has been made, the user has to decide on the form of infiltration law and resistance law and to estimate several key parameters. In most of the cases, as it has been found, the roughness is described by Chezy's C or Manning's n. Effect of raindrop impact has also been studied by some investigators.

Once the parameters of the models have been established, the numerical scheme is selected to solve kinematic wave equations.

The overland flow study for Godavari basin has been carried out by Jayaseelan (1984). He used KINGEN75 developed by Rovey et al (1977) to convert rain fall into surface runoff. The catchment was discretised into 1 4 elements comprising of 8 planes and 6 channels. The model uses four point implicit scheme to solve kinematic equations of flow over planes and into the channels.

3.0 Statement of the Problem

Surface Runoff from small mountainous catchments results predominently due to overland flows since channel flows are comparatively less significant. Overland flows from mountainous watersheds are difficult to be measured. However they can be estimated using mathematical models based on some assumptions and approximations. Since the measured surface runoff at the catchment outlet in hilly areas consists of overland flows and channel flows, the models need to have the capability of routing overland flow and channel flow.

The present study has been carried out with the objective to simulate the surface runoff by applying a kinematic cascade model to a small catchment in Malaprabha subbasin of Krishna basin. Since the measured surface runoff at Khanapur gauging site consists of overland and channel flows, the catchment is descritised into elements such as overland planes and channels. The kinematic cascade model namely KINGEN developed at Colorado State University has been selected. The model has capability of routing flows over planes and in the channels.

4.0 METHODOLOGY

A computer program for computing the runoff hydrograph from a complex configuration of impervious planes and channels was written by D.A.Woolhiser in 1969. Later, Rovey et al (1977) added an infiltration subroutine (developed by R.E.Smith) to the model, and a routine to handle unsteady flow in a circular conduits; and presented the model what they called as 'KINGEN model.

4.1 Mathematical Model-KINGEN75

KINGEN75 model is classified as non-linear, deterministic and distributed. Input to the model are:

i) The hyetograph of precipitation as measured on the watershed and is assumed constant over the watershed.

ii) Geometry and topography as determined from a map of the area.

iii) Two parameters, which relate to the surface roughness characteristics and the regime of flow (laminar or turbulent) and,

iv) Infiltration characteristics for pervious areas.

The catchment is represented by cascade of planes and channels as shown in fig.2. The planes may be discharging on to other planes or connected with other planes by channels. The planes and channels may be either impervious indicating no infiltration from them or pervious with some infiltration. The channels may be assumed either

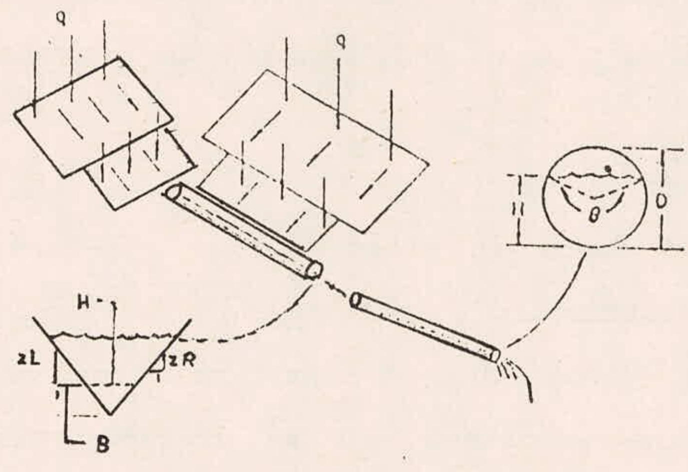

Fig. 2
Watershed Represented as a Kinematic Cascade

trapezoidal in section or may be assumed to have circular cross-section. The options for surface routing over an overland plane, trapezoidal channel and circular channel are available in the model.

4.2 Surface Water Routing

4.2.1 Kinematic Equations for a plane

The Kinematic wave approximation to the governing equations of motion for spatially varied flow (following equations, ie. eq; nos.6 to 8) have been used to compute the entire hydrograph for a single plane segment from constant inflow rate q.

$$\frac{dx}{dt} = N\, h^{N-1} \qquad \ldots(6)$$

$$h = h_o + q\,(t - t_o) \qquad \ldots(7)$$

and $$Q = h^N \qquad \ldots(8)$$

The symbols appearing in these equations have already been defined under section 2.0

KINGEN75 uses four point implicit scheme for solving the equations of flow over a plane. The scheme uses a weighing factor for space derivative at current and past time steps. For detailed information regarding four point implicit scheme and weighing factor, reader is referred to Rovey et al (1977).

For the solution of equations for the entire length of flow on a cascade of planes and channels, initial and boundry conditions must be specified. The intial conditions must be specified as:

$$h\,(x,o) \left[\begin{array}{l} = 0 \\ \text{or, for all } x \\ 0 \end{array} \right. \qquad \ldots(9)$$

The upstream boundary depth depends on the position of the plane in a cascade. The boundary conditions are given as:

$$h(o,t)_i = \begin{cases} 0 & \text{if } i=1 \\ f[h(l,t)_{i-1}, W_{i-1}, W_i] & \text{if } i > 1 \end{cases} \qquad \ldots(10)$$

Where i is the order of the plane in the cascade (for upper most plane i=1); l is the length of the plane and w is the width.

The discharge from an upper plane is assumed to be modified as the ratio of upper width to the lower width. The upstream boundary depth for the ith plane which receives inflow from $(i-1)^{th}$ plane is found by

$$h(o,t)_i = \left[(Q(l,t)_{i-1} \cdot \frac{W_i}{W_{i-1}} \cdot \frac{1}{\alpha_i}\right]^{1/N_i} \qquad \ldots(11)$$

where α and N are the parameters in Equation $Q = \alpha h^N$, and l is the length of the plane.

Using the above initial and boundary conditions Rovey et al (1977) established the expressions for flow rate at the downstream point. For detailed information, Rovey et al (1977) may be referred to.

4.3 Channel Routing

Free surface flow in channels is computed using the kinematic approximation to the equations of unsteady gradually varied flow. The difference between routing runoff over plane and thro' channels is that upstream inflow to a plane is given as discharge per foot of the width of the plane while upstream inflow to a channel is the total discharge from the previous segment. For the purpose of computation of watershed area, it is assumed that channel is of negligible width so that no rainfall falls directly on to the channel. The adjacent plane is therefore assumed to provide lateral inflow to a channel.

KINGEN75 has two options for representing the channel shape in the watershed; viz. trapezoidal and circular cross-section.

In routing kinematic waves thro' circular conduits, it is assumed that free surface conditions are maintained at all times. The equation of continuity for a closed conduit is

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad \ldots(12)$$

This differs from open channel equation because lateral inflow is zero for a closed conduit. The input to the channel is at the upstream and either in the form of an outflow hydrograph from a previous channel conduit or the inlet hydrograph from overland flow. The kinematic approximation is found by using Darcy-Weisback formula for flow in pipes.

These equations are also solved by four point implicit scheme. Implicit schemes are unconditionally stable and require an iterative process for solution. In the present model, Newton-Rapson iteration scheme has been incorporated to solve a general non-linear equation of motion.

4.4 Infiltration

Overland flow is said to occur when rainfall rate exceeds infiltration rate. Hence Watershed models simulating runoff, must have a means of estimating infiltration so that rainfall excess (Rainfall rate minus infiltration rate) may be converted into direct surface runoff. Rovey et al (1977) have used infiltration model developed by Smith (1972) in KINGEN75 where rainfall excess for each time increment is calculated.

Smith (1972) reported the infiltration model as shown in fig.3 which resulted from analysis or simulation using a uniform rainfall rate for six soil. Initially the infiltration rate is limited by the rainfall rate i. Then soil surface capillary potential goes to zero and surface runoff begins, at times denoted as t_p in fig.3. This time marks the beginning of infiltration decay type function that has the form

$$f = \begin{cases} f_\infty + A(t-t_o)^{-\alpha} & \text{for } t > t_p \\ i & \text{for } t < t_p \end{cases} \qquad \ldots(13)$$

where f_∞ is infiltration rate

f is steady state infiltration rate;

t is time

t_o is the vertical asymptota of infiltration decay function and

A and α are parameters unique to a soil, initial moisture and rainfall rate.

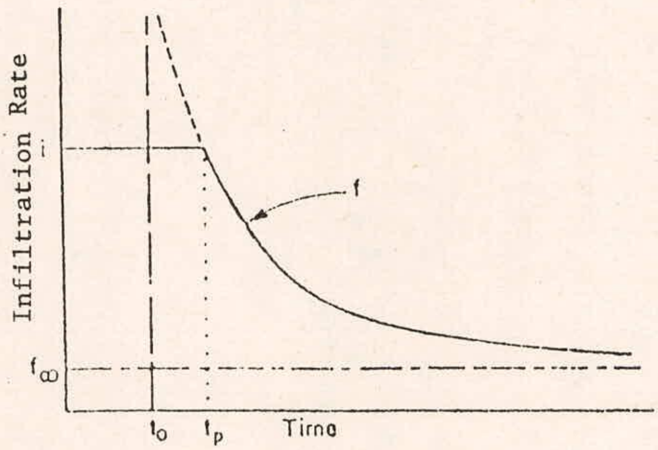

Fig. 3
General Infiltration Response Curve
(after smith, 1972)

Table 1 : Infiltration Model Parameters (Re - produced from Rovey et. al.)

Infiltration Parameter	Computer Program Symbol	Definitions	Units	Initi- ating values
	AL	Exponent parameter for decay curve	none	0 < < 1
B_p	BP	Ponding time parameter	none	$0 < B_p$
C_1	C	Infiltration scaling parameter	min.	$0 < C_1$
S_i	SI	Initial volumetric relative water content	----	$0<S_i<<S$
S_o	SMAX	Maximum volumetric water con - tent under imbition	----	$.5 <S_o < 1$
V_r	ROC	Volumetric relative rock content	----	$0<V_r<<1$

Table 2 : RESISTANCE PARAMETERS FOR OVERLAND FLOW

Sl. No:	Bed Surface	Laminar Flow K_o	Turbulant Flow Manning's 'n'	Turbulant Flow Chazy's 'c'	Sources
1.	Smooth Im - pervious surface	14	0.02	-	Kerby (1965)
2.	Concrete/ Asphalt	14 - 108	.01 -.013	73 - 38	Woolhiser (1975)
3.	Bare sand	20 - 65	.01 -.10	65 - 33	Linsley et. al. (1966) & (Morgali) (1970)
4.	Gravelled Surface	90 - 400	.012 -.03	38 - 18	- do -
5.	Bare clay Loam soil	100 - 500	.012 -.033	36 - 16	- do -
6.	Sparce vegetation	1000 - 4000	.053 -.13	11 - 5	- do -
7.	Short Grass Prairie or Turf	3000 - 14000	.1 -.2	6.5 - 3.6	- do -
8.	Blue grass Sod	7000 - 40000	.17 -.48	4.2 - 1.8	- do -
9.	Lawn	--	.2 - .3	4.2 - 1.8	- do -
10.	Pasture or Av. Grass	--	.3 - .4	--	- do -
11.	Deciduous Timber Land	--	.4 - .6	--	- do -
12.	Timber land with Deep Forest Litter or Dense Grass	--	.6 - .8	--	- do -

Smith (1972) developed infiltration equation containing dimensionless variable; which has been modelled in the present model. For more information regarding dimensionless equation of infiltration curve; paper by Rovey et al (1977) can be referred to.

The dimensionless equation of infiltration has been modified using a parameter to account for rock if total available pore volume has been reduced by large rock. In the present model, four parameters f_∞, α, B and C have been used to determine infiltration from any watershed. Table 1 may be used as helping guide in selecting the values of various parameters of infiltration model.

4.5 Resistance to Overland flow

Several Researchers have worked on problem of resistance to overland flow. The values of laminar resistance parameter K, Maning's n and Chezy's C for typical surface suggested by various researchers have been shown in table 2.

KINGEN 75 allows considerable freedom in choosing the hydraulic resistance law to be used. The following four choices are available.

1) Manning Law
2) Laminar law used the Reynold's number exceeds a certain value, then Manning Law would be used.
3) Laminar Law used until the Reynolds number exceeds a certain values, then Chezy law would be used.

4) Chezy law

4.6 Flow Chart of KINGEN75

The program namely KINGEN, compiled by Rovey et al (1977) has been used in the present study for simulation of overland flows. The program is based upon the mathematical model described in the present chapter. The model used is a Kinematic cascade model as it converts rainfall into runoff through a cascade of overland flow planes and channels using kinematic wave theory. It is a non-linear distribution deterministic model.

The catchment plan of the watershed is represented by combination of overland flow planes and channels. Geometrical parameters of the model are estimated from topomap of the area. There are four options for representing the resistance under laminar and turbulent flow conditions. The infiltration parameters are determined from the soil characteristics of the watershed.

The model computes the runoff for the combination of following geometrical segments:

1) Overland flow over a rectangular impervious surface
2) Overland flow over a rectangular pervious surface.
3) Flow in a trapezoidal channel, and
4) Free surface flow in a circular conduit.

Input data are utilized by the computed model to sequentially compute outflow hydrograph from each segment. The runoff computation begins on the segment at the highest elevation of the watershed and continues downslope to the lowest point on the watershed. The program KINGEN consists of a main program and 19 subroutines. Fig.4 is a flow chart of KINGEN and provides a brief outline of the computational logic utilized in the model.

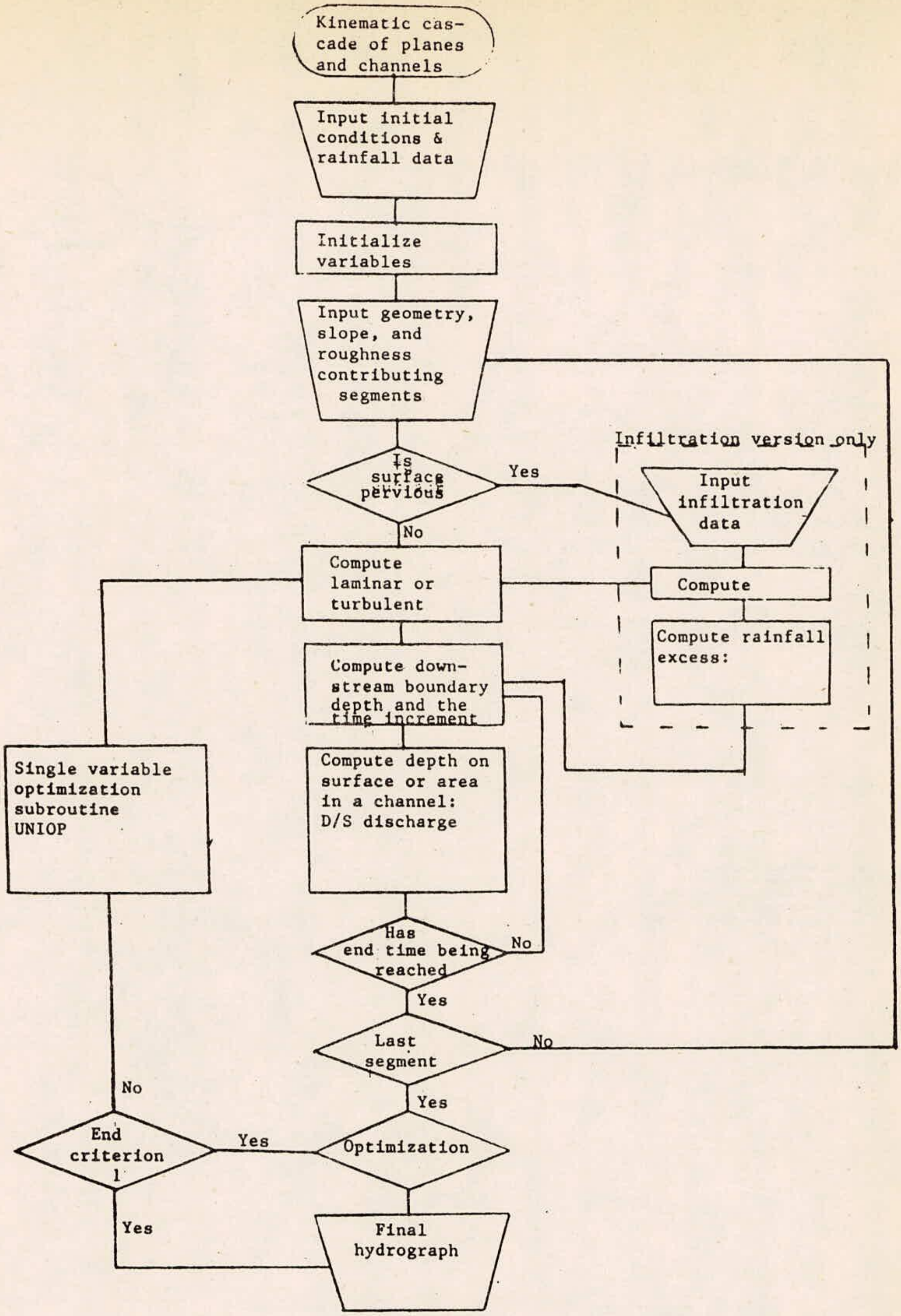

Fig. 4 : FLOW CHART OF PROGRAM KINGEN

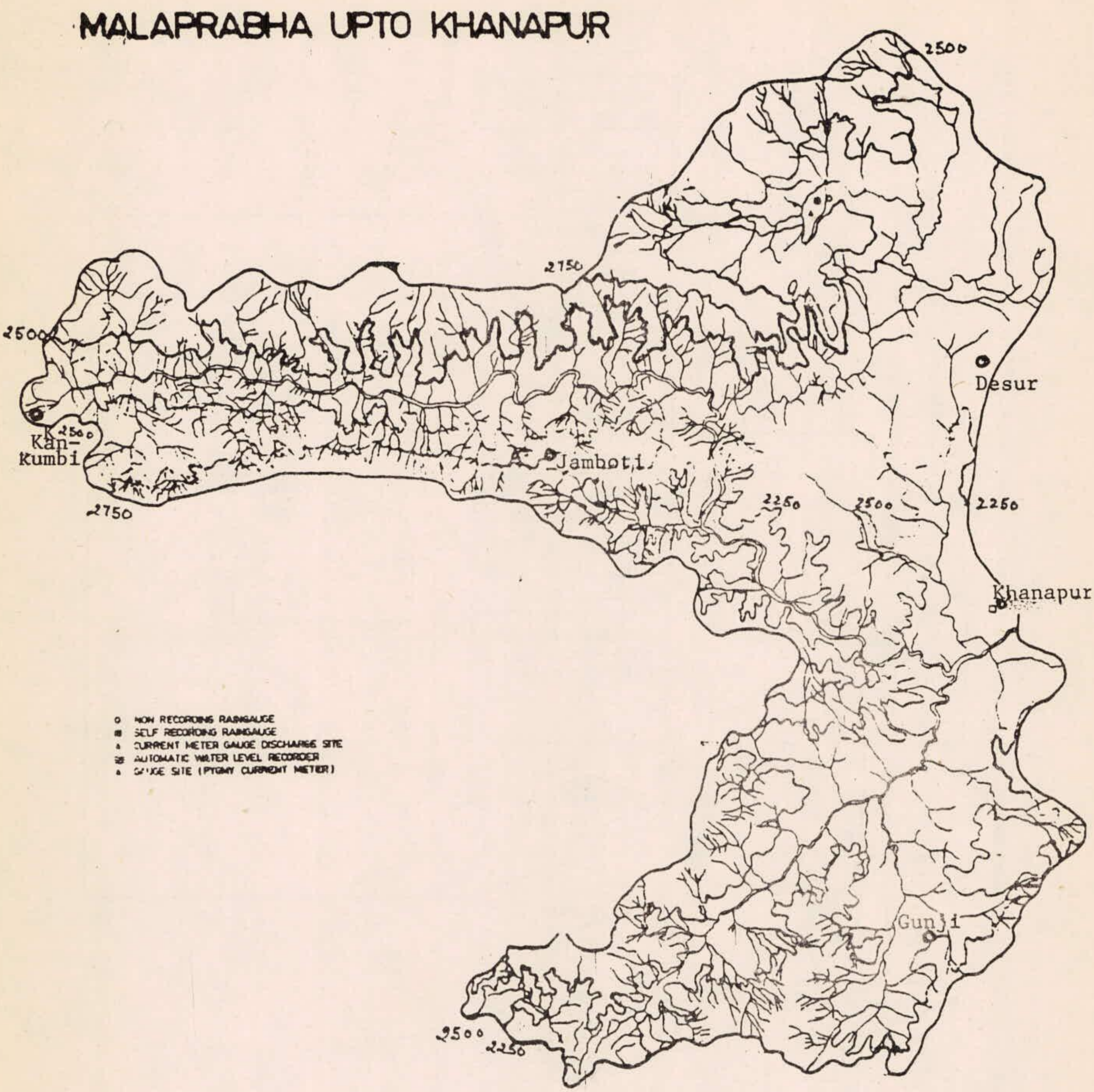

Fig. 5 : Catchment plan of Malaprabha upto Khanapur

5.0 APPLICATION

5.1 General

The Kinematic Cascase model KINGEN, developed by Rovey et al (1977) has been applied to a catchment in Malaprabha Sub-basin at Khanapur gauging site with the objectives to simulate the surface runoff. The complex geometry of the watershed is simplified by cascade of planes and channels. The lateral inflow to the plane is rainfall excess (rainfall less infiltration) and that to the channel is the discharge from the adjacent plane(s)

The study of simulation of runoff from the catchment at Khanapur has been carried out for the events only because the data for more events could not be made readily available. The input parameters have been obtained from topographic sheets of the area.

5.2 Description of the Watershed

The Malaprabha is an important tributary of river Krishna. The catchment area of Malaprabha upto Khanapur is 326.0 Sq.Km. Geographically, the catchment is located between 74°14' and 74°33' east longitudes and 15°30' and 15°47' north latitutdes. The shape of the catchment upto Khanapur, which is shown in Fig.5 is irregular. The altitude of the watershed varies from 2500 ft at the origin to 2147 ft at Khanapur. The topographical details of the catchment are shown in Table 3.

The basin soil is classified as medium black soil from the soil classification map. The basin belongs to Deccan Hard rock region. The average annual rainfall is about 750-800 mm. The watershed has humid type of climate with moderate winters and summers. The basin receives most of the rainfall from South West monsoon. The monsoon rainfall consistutes nearly 90.0% of the total annual rainfall.

Table 3: Topographical details of the Malaprabha upto Khanapur.

S.No.	Particulars	Units
1.	Catchment Area	326.0 Sq.Km.
2.	Shape of the catchment	Irregular
3.	Name of the Main River	MALAPRABHA
4.	Total length of the two rivers upto Khanapur	41.76 Km
5.	Type of Soil	Medium black Soil
6.	No. of Raingauge locations	Four
7.	No. of Discharge location	One
8.	Climate	humid

5.3 Data Used

The topographic details of the catchment are collected from the Survey of India topographic sheets no.s48I/6 and 48 I/10 From the topographic sheets, the boundaries of the catchment have been delineated. The catchment with boundary, elevation contours and channel network is shown in Fig.5.

Rainfall for the basin was recorded at five raingauge stations. One of the raingauge station at Khanapur is a self recording raingauge station and hourly data is available at this gauging station. However, the other four raingauge stations at places viz. Kamkumbi, Jamboti, Gunji and Desur are ordinary raingauge stations. Only daily rainfall values are available at these ordinary raingauge stations. The rainfall measurement is done by Water Resources Development Organisation(WRDO) Irrigation Deptt. Karnataka.

The rainfall and gauge discharge data has been collected from the sub-division office at Bagalkot, Bijapur District.

5.4 Input to the model

5.4.1 Watershed Geometry

The boundaries of Malaprabha upto Khanapur have been traced using the topographic maps. The catchment with its boundaries, contours and channel network is shown in Fig.5.

The catchment has been discretised into 14 elements consisting of 8 planes and 6 channels. The planes are so dimensioned that total area of the catchment may be preserved. The length of the channel is so fixed that total length of main river (two main tributaries in case of this catchment) may be preserved. The dimensions of the planes and channels are measured from the map and average slope of the planes and channels are estimated from the contour lines. The planes and channels are numbered according to sequence of flow. The slope, length, width and sequence of flow has been listed in Table 4 and shown in Fig.6.

5.4.2 Rainfall Analysis

In the catchment of Malaprabha upto Khanapur there are four ordinary raingauge stations at Kankumbi, Jamboti, Gunji and Desur recording rainfall daily. There is only one self recording raingauge station situated at Khanapur.

Two storm events, one on 27 June 1983 and the other on 21 July 1983 were identified for the purpose of runoff simulation. In case of both the events the daily rainfall values at Jamboti and Kankumbi were not available.

Table 4: Model Geometry of the Catchment upto Khanapur

Element No.	Type	Length* in feet	Width in feet	Slope	Lateral flow from
1	Plane (P1)	9965	43069	0.025	Rainfall (RF)
2	Plane (P2)	10471	43069	0.030	Rainfall
3	Channel	43069	0.0	0.002	P1,P2
4.	Plane	38002	23139	0.025	RF
5.	Channel	23139	0.0	.002	P4,C3
6.	Plane	18073	11653	0.02	RF

7.	Channel	11653	0.0	0.002	P6
8.	Plane	24988	21111	0.025	RF
9.	Plane	5911	21111	0.025	RF
10.	Channel	21111	0.0	0.02	P8,P9,C3&C7
11.	Plane	16720	32766	0.035	RF
12.	Plane	16720	32766	0.035	RF
13.	Channel	32766	0.0	0.002	P11 & P12
14.	Channel	99532	0.0	0.02	C10 & C13

* Length is measured in the direction of flow on the plane.

Initially, the observed rainfall values at Gunji, Khanapur and Desur only were used for the purpose of catchment runoff simulation. The total simulated surface runoff volume was found to be much less as compared to the observed one. Comparative study of observed rainfall and runoff volume indicated that the volume of observed runoff was much more than the corresponding rainfall volume. When daily rainfall measurement at Kankumbi and Jamboti of later period (June-Aug. 1986 and July 1987) was compared with that of Khanapur, Gunji and Desur, the daily rainfall values at Kankumbi and Jamboti were found to be much more than the rainfall values at later stations (i.e. Khanapur, Gunji and Desur) indicating that there was pattern in the rainfall recorded at the two sets of raingauge. The raingauges at Kankumbi and Jamboti recorded comparatively higher rainfall as compared to ones at Gunji, Khanapur and Desur.

This pattern in the data had to be incorporated into the input before working with the model. So, the miss-

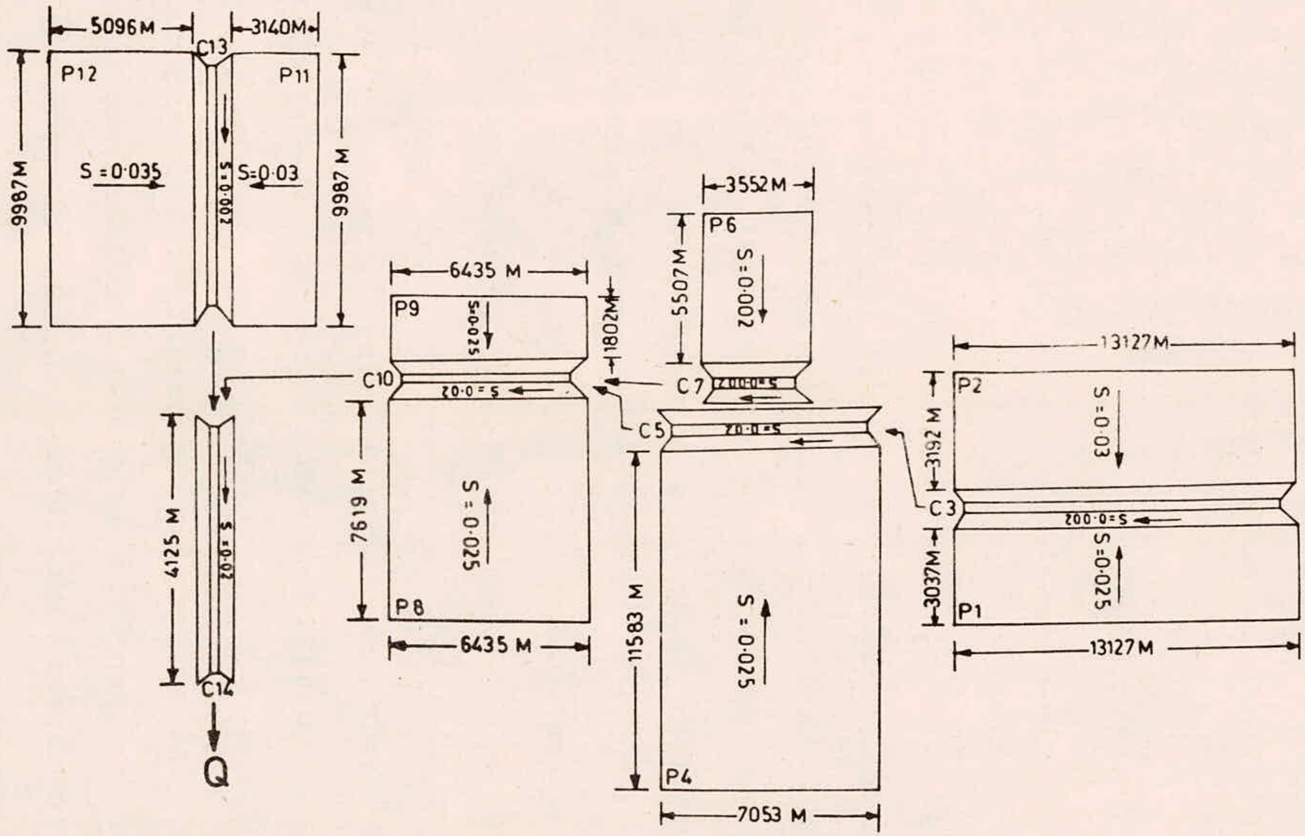

FIG. 6 MODEL GEOMETRY OF KHANAPUR WATERSHED

ing rainfall data at Kankumbi and Jamboti was filled up using regression analysis with the help of daily records at Khanapur for some dates during June 1986 to Aug.1986. The following types of regression equation was obtained:

$$J = 1.35\ (Kh) + 13.98$$

$$K = 2.26\ (Kh) + 46.76$$

where J and K are dependent variables giving the generated values of daily rainfall at Jamboti and Kankumbi respectively and Kh is the daily records at Khanapur used as independent variable.

With the above regression equation the daily rainfall values were calculated at Jamboti and Kankumbi and used in the analysis.

The model utilises the hourly records of rainfall to compute runoff at hourly or desired interval. In order to convert the daily rainfall at Kankumbi, Jamboti, Gunji, and Desur into hourly values; the hourly records of self recording raingauge station at Khanapur were utilised. The ratio of hourly rainfall to the daily rainfall was found for Khanapur. These ratios were multiplied by the daily rainfall values at O.R.Gs to distribute the daily rainfall recorded at CRGs into hourly.

The arithmetic average of rainfall at all the five raingauge station were then used to represent as the areal rainfall and used as input to the model.

5.4.3 Roughness Parameters

As already discussed in previous sections, the kinematic wave equation for the computation of flow is dependent on the roughness coefficient. The roughness coefficient for different surfaces as estimated by various researches has been given in tabular form in section 4.0. On the basis of information available for surface condition of the catchment, it was though appropriate to use Chezy's equation with Chezy constant equal to 7 $ft^{1/2}$/sec for overland flow on planes and 50 $ft^{1/2}$/sec for channel elements. Since the channels are usually irregularly shaped for which the model can not be applied, it is assumed that all the channels considered are trapezoidal in cross-section. The side slope of channel is assumed as 1:1 and the bed width is taken as 1.8 m.

5.4.4 Infiltration Parameters

Infiltration parameters are provided to estimate rainfall excess which is converted into surface runoff. The present study uses Smith's (1972) four parameters soil moisture storage infiltration model to compute the infiltration in the catchment based on soil type. The details of the infiltration parameters have been given in section 4.0.

5.5 Runoff Simulation

Kinematic cascade model KINGEN is applied to the catchment of Malaprabha sub-basin upto Khanapur. The complex geometry of the catchment is simplified to 14 elements of planes and rectangular channels. Event of 27th June '83 was used for the calibration of the model. The parameters viz. α , f_∞ and S_o are taken as characteristics of the watershed soil type whereas the parameters viz. B, C and SI are the calibrated ones. Using these parameters, the hydrographs for other events were simulated.

The two hourly discharge data is used as observed runoff hydrograph. The base-flow is seperated from the observed hydrograph to get the direct surface runoff hydrograph. The surface runoff hydrograph thus arrived at is used for the comparison between the observed hydrograph and the simulated hydrograph using Kinematic Cascade model, KINGEN.

6.0 RESULTS

Runoff hydrographs for the events recorded in the basin have been simulated using KINGEN75. The observed and computed surface runoff hydrograph, corresponding rainfall and the infiltration curve have been presented in Fig.7 & 8.

The rainfall and corresponding observed runoff hydrograph for event dated 21st July 83 as shown in Fig.8 has been used for calibrating the model parameters SI, C and B. The values of the model parameters SI, C and B for which the simulated and observed hydrographs match are 0.5, 12 and 1.0 respectively. Using the calibrated parameters the runoff hydrographs for other events are simulated. The following error criteria is then used to test the model performance.

i) percentage error in peak

$$E_{QP} \quad \frac{Q_{po} - Q_{pc}}{Q_{po}}$$

ii) percentage error in time to peak

$$E_{TP} = \frac{T_{p,o} - T_{p,C}}{T_{p,o}}$$

where

$E_{T,p}$ = error in time to peak

$T_{p,o}$ = observed time to peak

$T_{p,c}$ = computed time to peak

iii) percentage error in volume

$$E_V = \frac{V_O - V_C}{V_O}$$

where

E_V = Error in volume

V_O = Volume of observed hydrograph

V_C = Volume of computed hydrograph.

iv) Integral Square Error

$$ISE = \sqrt{\frac{\Sigma(Q_O - Q_C)^2}{\Sigma Q_O}}$$

where,

ISE = Integral Square Error.

These error criterian for various events have been calculated and tabulated in Table 5.

Table 5 : Error Criteria for the events

Storm Date	E_{Qp} (%)	E_{Tp} (%)	E_V (%)	ISE (%)
27 June 1983	17.44%	6.25%	2.6%	11.0%
21 July 1983	1.32%	7.14%	6.38%	7.29%

Runoff hydrograph for event dated 27 June 1983 is simulated using calibrated parameters (Fig.7). The magnitude of peak and time of the occurrence for the observed hydrograph is 1192 cumecs and 1800 hrs on 27th June respectively. The corresponding value on predicted hydrograph are 1400 cumecs and 1700 hours on 27th June. The percentage error in peak and time to peak are 17.44% and

6.25% respectively. The volume under the observed hydrograph is 360.70 mm and that under simulated hydrograph is 370.10 mm the error being 2.6 percent.

In case of both the events, magnitude of peak discharge, time of its occurrence and volume of DSRO is computed fairly well but computed hourly ordinates on rising and recession limbs do not match with those of observed hydrograph.

The disagreement between the hourly ordinates of computed and observed surface runoff hydrograph may be due to the following two reasons:

i) Assumptions involved in distributing the daily records of ordinary raingauges on the basis of hourly records of self Recording Raingauge at Khanapur, and

ii) Applying linear regression to obtain missing values at Jamboti and Kankumbi raingauge stations.

The daily rainfall records of ORGS have been distributed into hourly based on the assumptions that the pattern of hourly rainfall at ORGs would be the same as that of SRRG at Khanapur. Consequently, if the rainfall at a given time (hour) at Khanapur is 0.0; the rainfall at other ORGS at the corresponding time would also be 0.0; which may not be the case in reality. Similarly if rainfall is maximum at Khanapur at any time (hour), the distributed rainfall at other ORGs at that time would be maximum. This hourly rainfall value at ORGs may be either underestimated or overestimated. Because of this

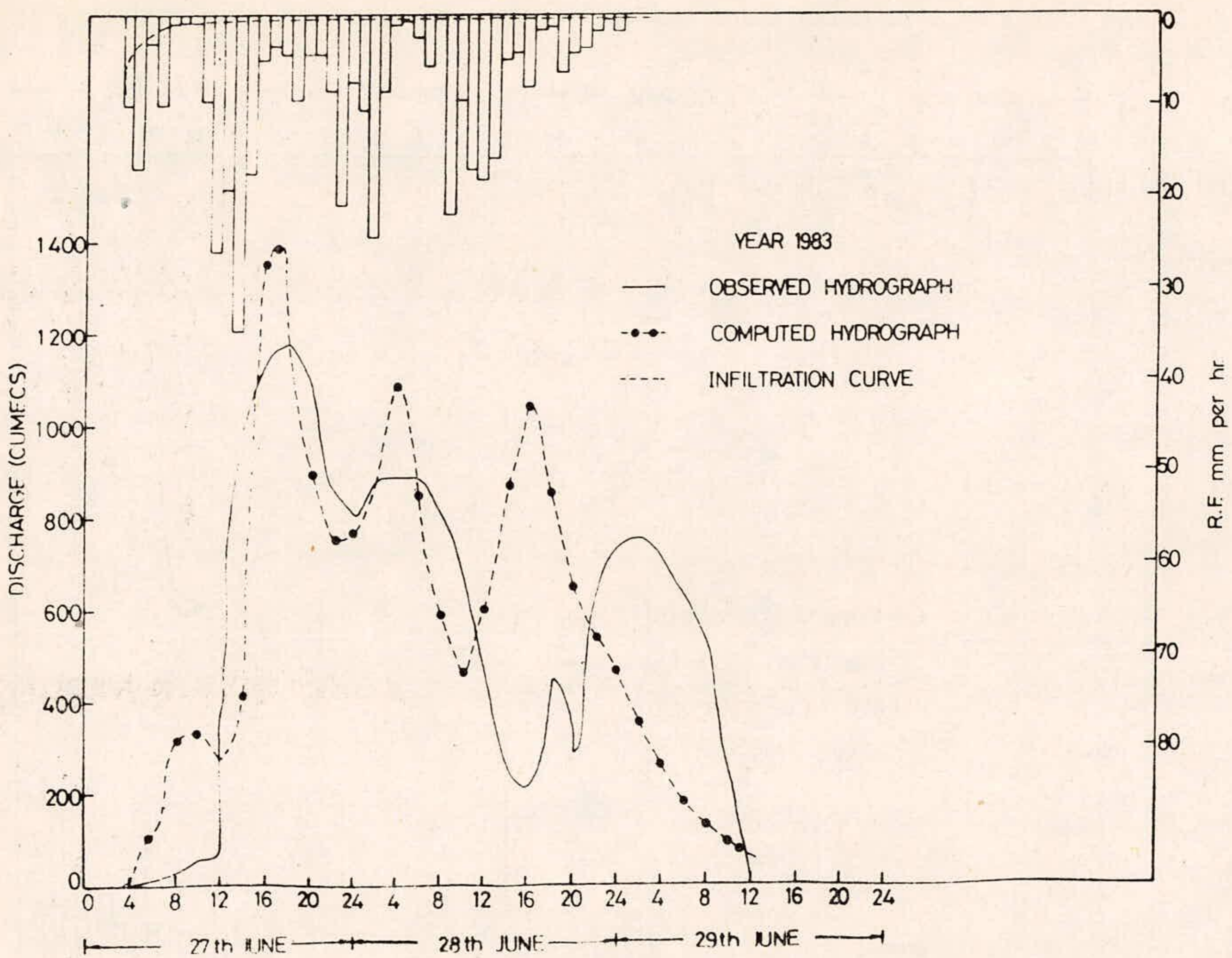

FIG. 7 : OBSERVED AND SIMULATED HYDROGRAPHS FOR EVENT DATED 27TH JUNE 1983

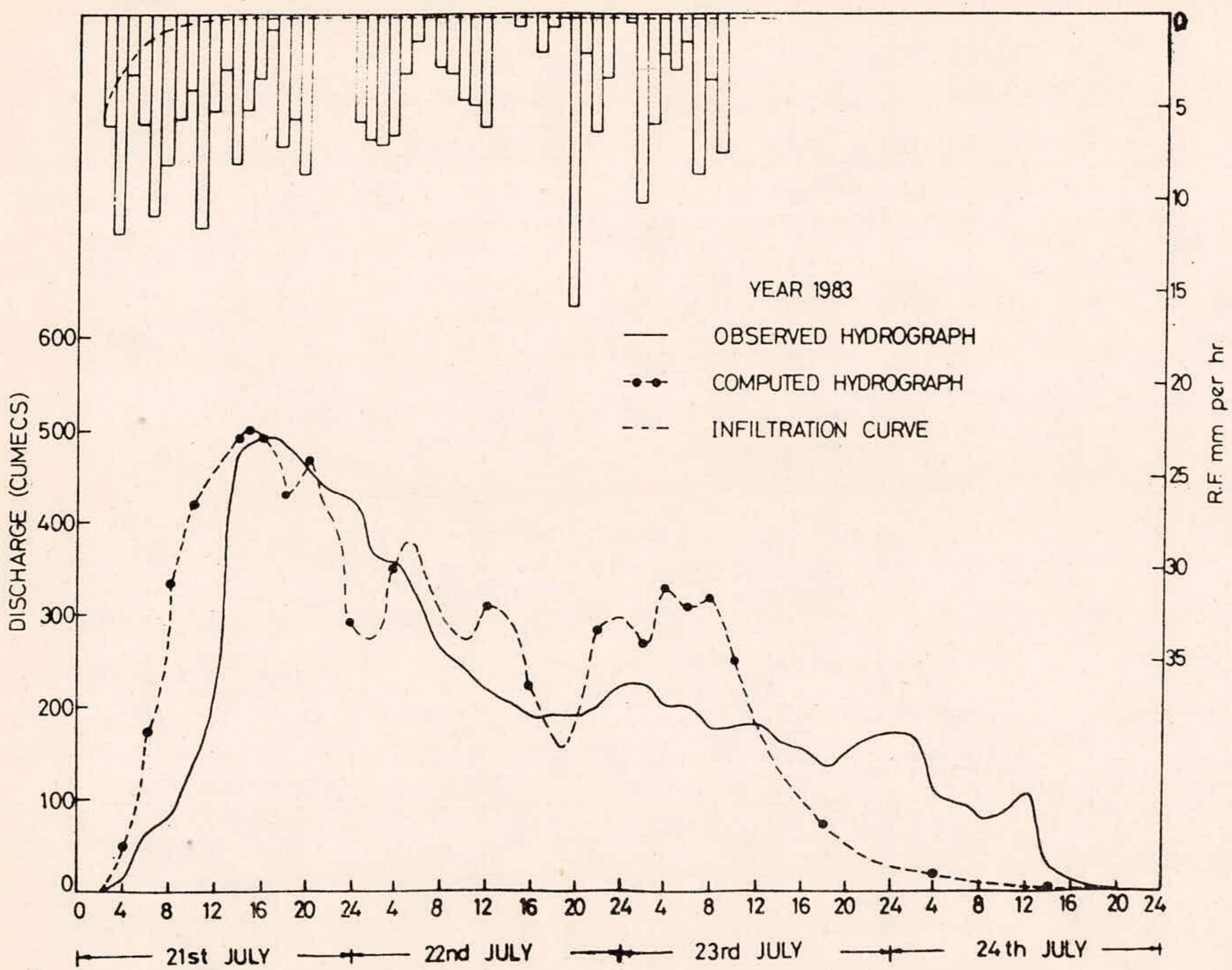

FIG. 8 : OBSERVED AND SIMULATED HYDROGRAPHS FOR EVENT DATED 21ST JULY 1983

reason, the hourly ordinates of computed hydrograph may not match well with that of the observed hydrograph.

For computation of volume of simulated direct surface runoff also, hourly rainfall records are used. But hourly rainfall values spread over 2 to 3 days in case of all the events accumulates to a value which is equal to the sum of daily rainfall values for that period spread uniformly over the entire catchment. This may be the reason why the volume of simulated hydrograph matches well with the observed hydrograph. Since the error is expected in hourly rainfall values, because of distribution of daily rainfall into hourly, the hourly ordinates of computed hydrograph may not match well. But since daily records are not associated with such errors; the simulated volume matches well with the observed volume.

Linear Regression analysis for computation of missing daily records at raingauge stations namely Jamboti and Kankumbi would either overestimate or underestimate the rainfall values which in association with the assumptions involved in distribution of daily records into hourly at ORGs may again cause the bad simulation of hourly ordinates of the hydrograph.

7.0 CONCLUSIONS

The flood events in the catchment in upper part of Krishna Basin upto Khanapur have been simulated using Kinematic cascade model. The model parameters have been determined making use of rainfall event and the corresponding observed runoff hydrograph. Using the calibrated parameters, other independent storm events are also simulated.

The simulation of the flood events indicated that the volume of surface runoff, magnitude of peak discharge and time to peak is predicted fairly well. However, the rising and recession limbs of the simulated hydrographs do not match with those of observed hydrographs.

7.1 Limitations

The possible reason for the rising and recession limbs being not predicted well may be due to the assumptions involved in distributing daily records of rainfall into hourly based on the hourly rainfall distribution at a single SRRG, Khanapur. Also, due to the application of regression analysis for estimation of missing daily rainfall values at some of the raingauge station, the catchment rainfall estimated might not have been truly representative.

Some errors could also be due to assumptions of some parameter values. The infiltration parameters which are used to calibrate the model need to be determined from the infiltrometer test. As such infiltrometer study needs to be taken up for the soil in the study area for finding out the values of infiltration parameters.

The study is based on only a limited number of flood events. Data on flows over short duration was not available for more flood events. Further studies are in progress for applying the model to estimate flood from catchment in western ghats.

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