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Real-Time Flood Forecasting - A Case Study for a Small Basin

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ABSTRACT

Reliable forecast of flood is required for a number of purposes, e.g., flood control, flood damage reduction, and reservoir operation. Significant improvements in management of water resources systems can be achieved if reliable forecasts are available with sufficient lead time. Real-time flood forecasting involves an element of urgency and hence simple models should be used to save computer time. The results of application of a non-linear routing algorithm for flood forecasting in a small basin are presented in this paper. The forecasts are updated in real-time using the Kalman Filter algorithm.

INTRODUCTION

Reliable forecast of flood is required for a number of purposes, e.g., flood control, flood damage reduction, and reservoir operation. Significant improvements in operation of water resources systems can be achieved if reliable forecasts are available with sufficient lead time. Real-time flood forecasting involves an element of urgency and hence simple models should be used to save computer time.

In spite of the fact that a large number of techniques are available for real time flood forecasting, this activity in India is still carried out using very crude methods, for example, gauge-to-gauge correlation. There is a urgent need for use of better methods so that improved forecasts can be issued and the existing water resources can be managed in a better way.

The work presented in this paper deals with application of a conceptual model for flood forecasting. The model is based on the kinematic wave model of flood routing. However, the Kinematic wave routing equations have been converted into nonlinear storage routing model and linkages have been established between parameters of the two approaches.

In the model, the forecasts are updated in real-time using the Kalman Filter algorithm. The software of the model was developed in Japan where it has been found to be very useful. The model is capable of providing forecasts up to several hours of lead time which can be varied by modifying the software.

RELATIONSHIP BETWEEN KINEMATIC AND STORAGE ROUTING MODELS

The equations of continuity and momentum for the kinematic wave theory for a single overland plane are :

$$\partial h/\partial t + \partial q/\partial x = r_e \tag{1}$$

$$q = \alpha\, h^m \tag{2}$$

$$h(x,0) = 0; \qquad h(0,t) = 0 \tag{3}$$

where, t is the time, x is the distance from the top of the plane, h is the water depth, q is the discharge per unit width, r_e is the rate of rainfall excess, and α and m are the parameters dependent on the friction law. Integrating equation (1) from x=0 to x = L (length of the plane) when r_e is a function of time only,

$$d/dt\int_0^L h(x,t)\, dx = Lr_e - q(L,t) \tag{4}$$

The left hand side of the above equation (4) represents change of storage which can also be written as

$$S = \int_0^L h(x,t)\, dx$$

$$= \int_0^L [q(x,t)/\alpha]^{1/m}\, dx \qquad (5)$$

where S is the storage per unit width.

The equations (1) to (3) can be analytically solved for the case of pulse rainfall input, Eagleson(1970), and the outflow hydrograph at the downstream end can be determined.

In the storage routing methods, the outflow is assumed to be a function of storage. The form of this relation depends on the assumptions made, for example, linear relation, or non-linear. In the present case the following form of storage routing is assumed:

$$s = k_1 q^{p1} + k_2 d/dt(q^{p2}) \qquad (6)$$

$$ds/dt = r_e - q = fr - q \qquad (7)$$

where s is the storage (mm), q is the direct runoff, expressed as depth (mm.h), r is the rate of total rainfall (mm/h), f is the runoff coefficient, and k_1, k_2, p1 and p2 are the model parameters. For a pulse rainfall input, the relationship between kinematic and storage routing parameters is given by

$$\left.\begin{aligned} k_1 &= m/\ (m+1)\ (10^{3m-6}/3.6)^{1/m}\ (L/\alpha)^{1/m} \\ k_2 &= m^{1/5}\ [(m+1)/m]^2\ k_1^2\ r_e^{2/m-1-p2} \\ p1 &= 1/m \\ p2 &= 1/m^{1.5} \end{aligned}\right\} \qquad (8)$$

Assuming Manning's law to be the governing law for friction on the overland plane, the kinematic wave parameters are given by

$$\alpha = \sqrt{i}\,/n, \quad m = 5/3 \tag{9}$$

where i the slope and n is the Manning's roughness coefficient. Substitution of eq. (9) into eq. (8) yields

$$\left.\begin{aligned} k_1 &= 2.823\, f_c A^{0.24} \\ k_2 &= 0.2835\, k_1^{2}\, \bar{r}_e^{-0.2648} \\ p_1 &= 0.6 \\ p_2 &= 0.4648 \\ f_c &= (n/\sqrt{i})^{0.6} \end{aligned}\right\} \tag{10}$$

While deriving the equations, it is assumed that the watershed is open-book shaped, comprising of two planes and a channel. It is assumed that the main channel length and the drainage area follow the Hack's law according to which, the drainage length $L_s = 1.35A^{0.6}$. Further, the longest plane length (L) and the basin width (W) are related as L =0.6W.

The system under study is highly non-linear. The Extended Kalman filter has been used to solve the problem. To apply the Extended Kalman Filter, the following substitution is made :

$$x_1 = q^{p_2} \tag{11}$$

$$x_2 = d(q^{p_2})/dt \tag{12}$$

Equations (6) and (7) are replaced by

$$d(x_1/dt = x_2 \tag{13}$$

$$d(x_2/dt = -(k_1 p_1/k_2 p_2 x^{p_1/p_2 - 1} x_2 - x_1^{1/p_2} /k_2 + rf/k_2 \tag{14}$$

These equations is expressed in matrix form as

$$dX/dt = F(X) \tag{15}$$

Expanding eq. (14) using Taylors series

$$F(X) = F(X^*) + A(X^*)\ (X - X^*) \tag{16}$$

where A() is the Jacobian matrix. Substituting above in eq. (17), one gets,

$$dX/dt = A(X^*)X + F(X^*) - A(X^*)X^* \tag{17}$$

To obtain the solution, the above eq. (17) is first expressed in discrete form. The Extended Kalman Filter algorithm is then used for the purpose of forecasting. The detailed description of the model is available in the report by Hokkaido Development Bureau(1990).

DETERMINATION OF MODEL PARAMETERS

In the eq. (10), the parameter k_1 is independent of storm parameters while k_2 depends on both the watershed and storm characteristics. These parameters can be determined once f_c is known. The runoff coefficient f depends upon the basin characteristics and can be initially set on the basis of data of past observed storms. The final values of K_1 and f are chosen by trial and error or optimization technique such that the best match between observed and simulated hydrograph is obtained.

APPLICATION STUDY

The results of application of this model for flood forecasting in a small basin are presented in this paper. The

Kolar subbasin located in Narmada basin was adopted for this purpose. The area of this basin is 820 sq. km. Hourly rainfall data at four rainfall stations and hourly discharge data at one GD site at the basin outlet was available for six years and used in the study. An index map of the catchment is given in Fig. 1.

For the Kolar basin, the parameter k_1 and f were found to be 60.0 and 0.7 respectively. The model was used to forecast discharge for the catchment. At any given time, the rainfall and discharge data are available and are used for this purpose. After one hour, a new set of rainfall and discharge data becomes available and the forecasts are revised in light of these. The model was used for continuous period of several days. The observed and forecasted flows (1-hr, 2-hr and 3-hr ahead) for the highest an event in 1983 are shown in Fig. 2 and the same for an event in the year 1984 are shown in Fig. 3. The event in 1983 corresponds to the highest observed discharge for this basin and the model forecast are satisfactory. Similarly the graph for 1984 also shows a good match between the observed and forecasted flow for both years. It may be mentioned that the coverage of this basin in terms of rainfall stations is not uniform and the model performance could be improved if raingauge stations were available in the upper area of the catchment.

CONCLUSIONS

A flood forecasting model using non-linear storage routing coupled with kinematic theory has been implemented. This model has been developed in Japan and is being extensively used there. The model was tested using data of an Indian catchment. The results of the study are very encouraging. Further studies are required to be carried out for a few more typical basins and the results of this model may be compared with those using other approaches like unit hydrograph etc. before the model is recommended for wider use.

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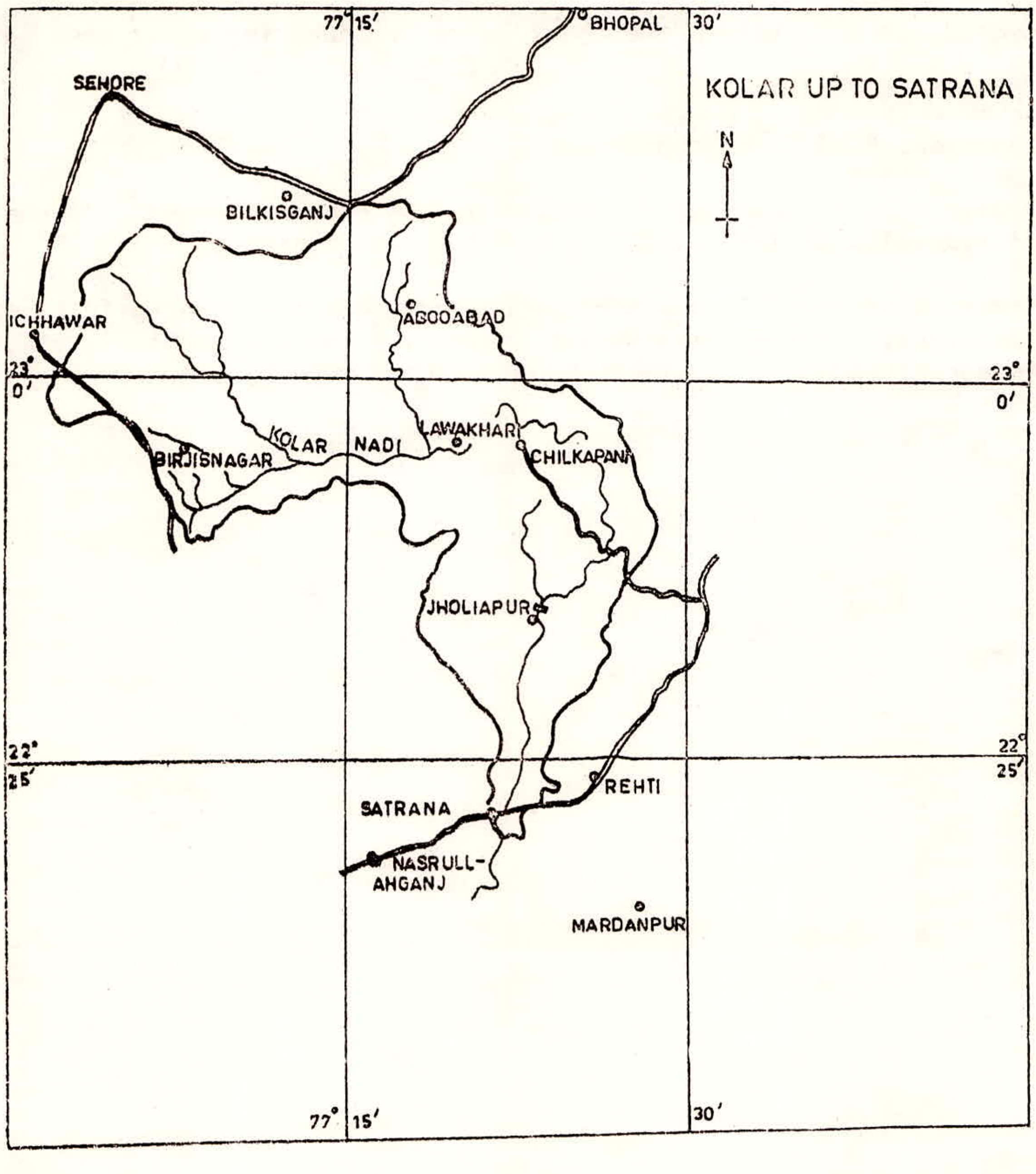

Fig. 1 : The Kolar basin upto Satrana gauging site. Also shown are the locations of hydrometeorological sites and important towns.

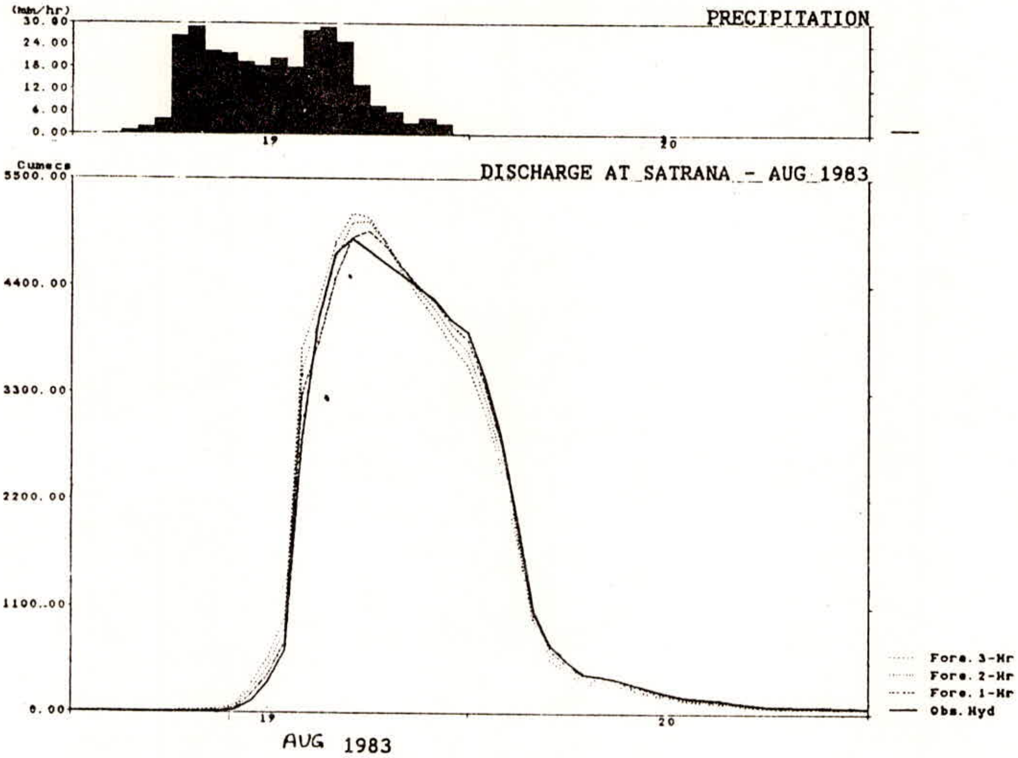

Fig. 2 Observed and forecasted discharges for an event in 1983.

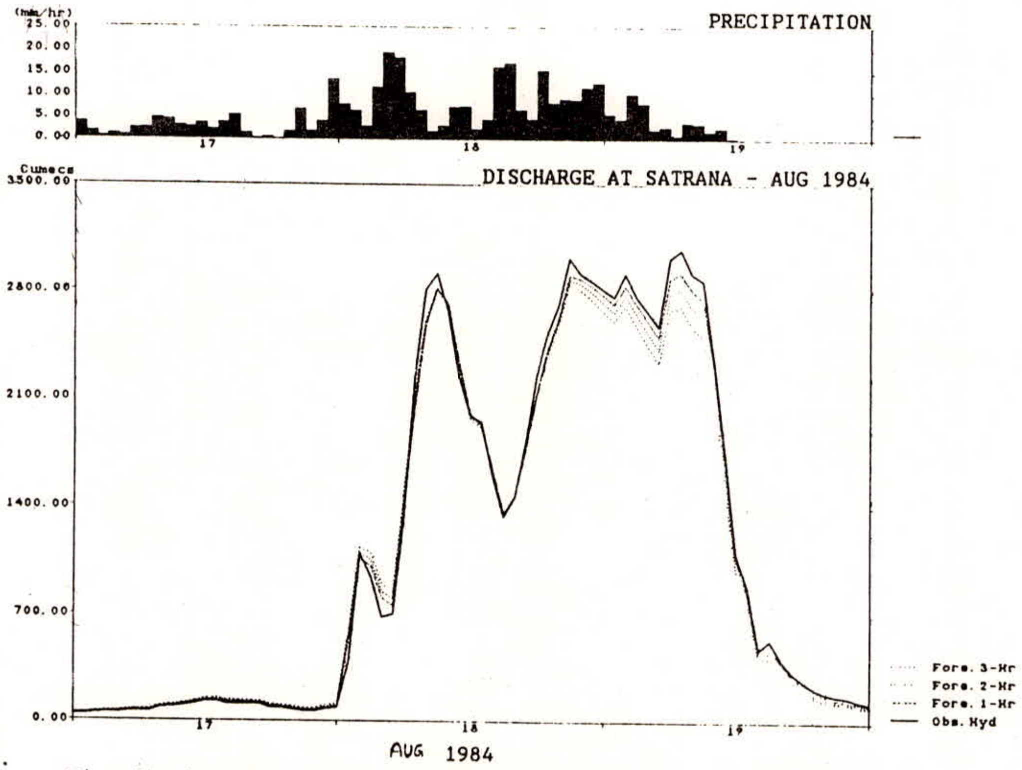

Fig. 3 Observed and forecasted discharges for an event in 1984.