FLOOD FORECASTING AND WARNING SYSTEMS

Sharad Kumar Jain
Scientist F

1.0 INTRODUCTION

The term *forecasting* denotes the estimation of some variable at a specific future time or over a specified future time interval. It is distinguished from *prediction*, which is the estimation of future conditions, without reference to a specific time. The stage of a river at 1200 hours tomorrow is forecasted, as is the next 5 months' reservoir inflow. Conversely, the 100-year flood is predicted, as is the 10-year, 7-day low flow. The time (interval) over which a forecast is made is termed as *lead time*. The reliability of a forecast usually decreases with increase in lead time. For very long lead times, the distinction between forecasts and predictions is blurred, and most forecasts are no more accurate than those made by using the long-term statistical mean.

The timeliness of a forecast is very important. If the forecast is available just as the actual event takes place, its utility is nil. In general, longer the forecast lead time, greater will be its utility. However, as the errors in forecasts increase progressively with increase in the lead time, there is need for proper balance between the accuracy and the lead time. A certain minimum lead time is necessary to organize remedial measures. For a forecast in proper time, the transmission of information and processing of data has to be done very quickly. This is possible only with the help of a computer. In India, a lead time of at least 10 to 12 hours is necessary to organize meaningful flood fighting measures.

The term *real-time forecasting* denotes the forecasting mode in which the forecasts for a future time are made based on the current conditions. After a certain (known) time interval, the new information about the system becomes available and the forecasts are updated. The real-time forecasting is specially suitable during floods where the catchment response changes very fast and decisions have to be taken quickly and adapted frequently. The forecast lead time proves useful in mitigating some of the adverse effects of flooding. The forecasts are an effective tool of reducing flood damages, particularly of life and movable property.

Hydrological forecasting is one of the most important aspect of applied hydrology. The benefits from management of water resources projects can be substantially increased if good forecasts are available. The main components involved in forecasting are weather forecasting and catchment modeling.

The forecasting is one of the most useful and difficult problem of hydrology. The main reason behind this difficulty is the hydrologic systems are complex and consist of many inter-related elements. The inputs to this system vary spatially and temporally and this variation is not precisely known. The response of the system to inputs also changes with respect to space and time.

1.1 PURPOSES OF FORECASTING

The forecasting of the hydrological variables is made for a variety of purposes. The following list gives the major purposes of forecasting in developing countries :

Objective	Percent of Cases	Objective	Percent of Cases
Flood Protection	43%	Energy Generation	19%
Navigation	12%	Water Supply and Sanitation	12%
Irrigation	6%	Others	8%

The other objective of forecasts include contingency planning, especially related to droughts and crop planning. The river stage is the variable which the hydrologists attempt to forecast in maximum cases (43%). This is followed by discharge(36%) and volume(12%). Since flood protection is one of the main objectives of forecasting, most of the forecasts are made for a lead-time of up to 24 hours or up to a week as the following table shows:

Lead-Time	Percentage of Cases
Up to 24 hrs ahead	33.5%
1 day to 1 week	37.5%
Medium-term	15.0%
Long-term	14.0%

1.2 WORTH OF A FORECAST

Forecast worth is the economic or other value that results from a forecast, that is, the net benefits that accrue if a forecast is available, less those that occur in the absence of a forecast. In some cases, the baseline or no-forecast case can be evaluated by using information derivable from past conditions, for instance, long-term streamflow records. A forecast has positive worth if, over the long-term, it results in better resource utilization or less severe damages, than would otherwise occur.

1.3 FORECAST ACCURACY

The models used for forecasting should have a simple structure; they should not require elaborate computer resources and should not have excessive input requirements. It should be possible for a trained person in the field to prepare input for the model, run the model, interpret the output and fix minor problems arising during the usage.

The utility of a forecast depends upon two factors: accuracy and timeliness. Regarding accuracy, over-prediction of a hydrologic phenomenon, e.g., flood event may result in avoidable and unnecessary high release of water form the dam, evacuation of people from the area likely to be affected by the floods, flood fighting measures and panic among the people. Under-prediction of an event can lead economic losses. Further, people in the affected area will loose confidence in forecasts.

A number of measures of forecast error are available. The accuracy of a forecast is best assessed by comparison of forecasts actually made or that might have been made and the values observed during the forecast period. Let $q_f(i)$ and $q_o(i)$ be the forecasted and observed streamflow for period i, i=1,2...n. Let $\square_f$ and $\square_o$ be the means of the forecasted and observed flows for the same period. Some widely used measures of forecast error are:

Bias $$B = \square_f - \square_o \qquad ...(1a)$$

Mean square error $$MSE = \frac{1}{n} \sum_{i=1}^{n} [\ q_f(i) - q_o(i)\ ]^2 \qquad ...(1b)$$

Mean absolute error $$MAE = \frac{1}{n} \sum_{i=1}^{n} [\_ q_f(i) \_ - \_ q_o(i) \_] \qquad ...(1c)$$

1.4 CLASSIFICATION OF FORECASTS

There are several ways in which the forecast can be classified. Depending upon the lead times, the forecasts are termed either as short-term forecast (those with lead times less than 7 days) and long-term forecast (those with lead times more than 7 days). Short term forecast are generally used for flood warning purposes and for real-time operation for water resources systems. Long-term forecast are often used for purposes such as allocation of irrigation water and management of drought.

2.0 SHORT-TERM FORECASTS

There are two basic types of short-term forecasting models : those based on channel routing and those based on rainfall-runoff modeling. For any particular application, one may base a forecast on channel routing models, rainfall-runoff models, or a combination depending on the problem classification. The classification of short-term forecasting problems depends on two criteria. The first relates the required forecast lead time T_f to the time of concentration of the catchment at the forecast point. This includes both the hydrologic response time of the catchment, T_c (often measured by the time of concentration, which is the time of travel from the farthest point in the catchment to the forecast point), and the travel time through the channel/river system, T_r. The second criterion is the ratio of the spatial scale of the meteorological event to the spatial scale of the catchment above the forecast point. This ratio R_s is the spatial scale of the forecast problem.

Lattenmaier and Wood (1993) have given the following criteria to choose the model type to be used for forecasting.

Case 1. $T_f > T_c + T_r$: if the required forecast lead time is larger than the time of concentration, then forecast of precipitation is required. This is because some of the water which is included in the flow forecast has yet to fall as precipitation on the watershed at the time the forecast is made. In such cases, a forecast procedure that includes both precipitation forecasting and hydrologic (precipitation-runoff) forecasting is needed.

Case 2. $T_f < T_c + T_r$ and $T_c << T_r$: if the forecast lead time is shorter than the time of concentration, and the total time of concentration is dominated by the routing time of the flood wave through the channel system, then streamflow forecasts can be based on observed flows at upstream gauge locations. For such applications, the upstream observed flows must be transmitted to a forecast control centre as the flows occur. For such systems, stream-flow forecasts can be based on channel routing models alone.

Case 3. $T_f < T_c + T_r$ and $T_r << T_c$: if the forecast lead time is shorter than the time of concentration, and the time of concentration of the catchment is dominated by the hydrologic response time of the catchment, then streamflow forecasts should be based on observed rainfall from a network of rain gauges whose data are transmitted to the forecast centre. This is the situation for small catchments and urban areas. Such forecasts must incorporate a rainfall-runoff model.

Case 4. R_s □ 0.7 : when the ratio of the spatial scale of the meteorological event to the spatial scale of the catchment is less than 0.7, there is partial coverage of the catchment of the rain event. This problem arises in the case of large catchment. In these situations the catchment should be sub-divided into sub-basins to prepare the forecast.

2.1 FORECASTS BASED ON CHANNEL ROUTING

The flood routing through channel can be performed through a large number of methods. One of the most widely used and simple method is the Muskingum method. It requires two parameters that can be estimated using the data of inflow and outflow from a river reach. This method was modified and the new method known as Muskingum-Cunge method makes use of channel properties also. The complete description of movement of a flood wave down a river channel is by one- dimensional equation of unsteady flow known as the St. Venant equations. The solution of these equations is complex task. Many times, simplified representations of these equations are used, for example, the diffusion wave method and the kinematic wave method. The other channel routing method include the Kalinin and Milyukov method and Cascade of Linear reservoirs.

2.2 FORECASTS BASED ON RAINFALL-RUNOFF MODELING

The catchment is a complex system where various physical, chemical, and biological processes take place continuously and govern the movement of water. In practice it is not feasible to model all these processes. Some simplifications have to be made either in the representation of the system or in the processes involved or both. The rainfall-runoff models simulate the hydrologic response of a catchment to input rainfall. These models can be broadly divided in three categories : Black box models, Conceptual models, and Physically based models.

The black box models are based on transfer functions which relate inputs with outputs. These models, as the name suggests, generally do not have any physical basis. Some commonly used black box models include the unit hydrograph based approaches, regression analysis, and time series models. These models have been in use for a long time. The parameters of these models are obtained either by analytical solution or through numerical optimization. The success of these models can be attributed mainly to simple mathematics, minimal computational requirements and acceptable results. However, it is not advisable to use these models for the input data which falls outside the calibration range. This is because in such cases the implicit understanding of the physical system and assumptions made, such as of linearity, may not remain valid and the modelling relies only on the mathematical equations. Due to this serious drawback, the use of these models for extreme events should always be made with utmost caution.

The term 'Physically Based' is used to denote that class of models which tend to use the known physical laws of various processes to model the catchment response. Due to their complexity and huge data and computer requirements, these models are not used in forecasting.

2.3 CONCEPTUAL MODELS

The conceptual model approach to rainfall runoff modelling lies intermediate between the physically based models and the black box models. Generally the term *conceptual* is used to describe models which rely on simple arrangement of a relatively small number of interlinked conceptual elements, each representing a segment of land phase of hydrologic cycle. The most commonly used element in a conceptual model is the storage. Each of these unequal sized storage usually has one input and one or more outputs and represents a catchment storage like detention, soil moisture etc. The linear reservoirs and channels are used for routing purposes. The modelling basically consists of a set of rules which govern moisture flow from one element to another. Since this is a non-iterative accounting procedure, these models are computationally very efficient.

The conceptual models were initially developed to model small homogeneous areas. However, they have been successfully applied to basins having wide variations in topography and vegetation and catchment area of the order of thousands of sq. km. The input data requirements for these models are quite modest and can be easily met with. Ciriani et al

(1977) and Blackie & Eeles (1985) provide excellent discussion on philosophy and applications of these models. Some aspects of calibration of these models have been discussed by Jain (1993).

The main advantages of using a lumped conceptual model are: a) The CPU time requirement of conceptual models are quite small and the forecast using these can be prepared in a short time. b) The requirement of other computer resources for these models are also very small and hence most of these can be used on micro computers. c) In the hydrological forecasting studies, normally only one variable, i.e., discharge at outlet, is of interest which is the major output from most of such models.

In the context of forecasting, there are two modes in which a rainfall-runoff model can operate:

a) Simulation mode: here the model output is based on previous model inputs (e.g. rainfall, evaporation, etc.) and also possibly on previous model outputs, depending on the form of the model. No use is made of previously observed output in calculating current model output, although for calibration purpose use will frequently be made of observed output.

b) Adaptive mode: here the model output may also be based on previous model inputs, but will also utilize previous observed outputs in calculating current model output. This can be done in either of two ways: i) by expressing current model output as a function of previous observed outputs as well as model inputs; ii) by using the discrepancy between the latest observed and model outputs as feedback in calculating future model outputs. The term *optimal forecast* denotes a forecast that minimizes the forecast error variance.

The ultimate success of a forecasting model lies in its ability to produce good forecasts. For forecasting, it is necessary to have a model that can operate within the adaptive mode. This implies the model should have some feedback mechanism through which the outputs at the current time step are related to previously observed outputs.

2.4 TIME SERIES MODELS

A ***time series*** is a set of observations generated sequentially in time. Let z_1, z_2.....z_N be N successive values of a discrete series observed at equidistant time intervals $_0 + h$, $_0 +$ 2h,.... $_0 +$ Nh. A model which is extremely useful in the representation of certain practically occurring series is the autoregressive model in which the current value of the process is expressed as a linear aggregate of p previous values of the process and a shock a_t. Another kind of model is the moving average model. Here the current value is assumed to be linearly dependent on q previous a's. Usually it is better to include both autoregressive and moving average terms in the model leading to the mixed autoregressive-moving average (ARMA) model. Let the values of a process at equally spaced times t, t-1, t-2,.... be Y_t, Y_{t-1}, Y_{t-2},.... Now let Z_t, Z_{t-1}, Z_{t-2} .... be deviations from the mean μ ($Z_t = Y_t - \mu$.). Then

$$Z_t = \square_1 Z_{t-1} + ..., + \;_p Z_{t-p} + a_t - \;_1 a_{t-1} - .... - \square_q a_{t-q} \qquad ...(2)$$

represents an ARMA(p,q) model. It employs p+q+2 parameters $, \;_1,..., \;_p, \;_1 ..., \;_q, \;_a^2,$ that are estimated from the data. An adequate representation of stationary time series can be obtained with ARMA models in which p & q are often less than 2. The ARMA models are a class of frequently used black-box rainfall runoff models. The text by Box & Jenkins (1976) is a well-known reference for time series models. The hydrological literature contains a number of applications of time series models. Weeks & Boughton (1987) list several applications of these models to hydrology.

3.0 LONG-TERM FORECASTING METHODS

Long-term forecasting models fall into three general classes: index-variable, storage accounting and conceptual simulation. Index-variable methods are the simplest and oldest methods of forecasting long-term runoff. They relate forecast period runoff to one or more index variables that are likely to affect stream flow during the forecast period, such as accumulated precipitation prior to the time of forecast and soil moisture at the time of forecast. Storage accounting models estimate the amount of water stored in the catchment (either as surface, subsurface, or snowpack storage) that is available to contribute to future runoff; the forecast is then some function (usually linear) of the storage estimate. The conceptual simulation approach uses precipitation-runoff simulation whose input data up to the time of forecast are the observed meteorology, and during the forecast period are estimates (e.g. forecasts) of the relevant meteorological variables.

Errors in long-term forecasts arise from three sources: model error, an incorrect conceptualization of the relationship between future runoff and the controlling variables such as precipitation; data error, or errors in the forecast model inputs such as precipitation due, for instance, to sparseness of precipitation gauge coverage; and meteorological forecast error, such as the error in forecast precipitation or error temperature. Meteorological forecasts are only marginally more accurate than climatological averages for forecast lead times of more than a few days, so for practical purposes, accurate long-term runoff forecasts are possible only in situations where the future runoff is more strongly affected by catchment water storage at the time of the forecast than by meteorological conditions (especially precipitation) during the forecast period. Except in cases where forecast period runoff is controlled by initial catchment water storage, long-term streamflow forecasts cannot be expected to be much better than a climatological average, and there is little to distinguish a long-term forecast from a prediction.

4.0 FORECAST UPDATING

Since the forecasting model is a simplification of the reality and the data used may not be representative, the forecasted behaviour deviates from the observed behaviour. Some model use current and past measured rainfall and stream flows when making the forecast. This is referred to as updating because the forecast is adjusted as new measurements become available. These measurements allow estimation of the forecast error, which is the difference between the true and the forecasted value. Updating increases the complexity of forecasting, but can significantly improve forecasts. The updating of short-term forecasts is most effective when the forecast errors are highly autocorrelated.

A time series of forecast errors is constructed and a model is fitted to this series. When an operational forecast for time t is being made, the streamflow for the previous period has been measured and the forecast error calculated. With the measured inputs an initial hydrologic model based forecast is made. Using the calculated forecast errors from the previous time periods, a forecast error for time t is predicted. The final forecast for time t is the sum of the hydrologic model based forecast and the forecast error prediction.

4.1 THE KALMAN FILTER

A technique known as **Kalman Filtering** has been found to be particularly suitable for use in the real-time hydrological forecasting. To use the Kalman Filter, the model of the process must be formulated in the state-space representation which consists of i) a system equation which represents a process in terms of known quantities and a system error which reflects the imperfect representation of the system by the model, and ii) a measurement equation which can be used to represent measurements of model inputs and outputs as subject to measurement error. The computational requirements of the Kalman filter are minimal and a typical algorithm can be easily programmed on a mini-computer.

The Kalman filter is a way to combine information from a deterministic model with uncertain measurements and uncertain parameters to provide optimal estimates of the system state. The model of the system must be represented using the state-space formulation. This formulation consists of a state equation expressing the propagation of the system state with respect to time and a measurement equation representing observations of the state. Given the state measurements up to and including the time t, the problem of estimating the system state x at time □ is a filtering problem when □ = t. For a discretetime linear model, the **system equation** and the **measurement equation** are:

$$x_{t+1} = F_t x_t + B_t u_t + \Box_t w_t \qquad \text{...(3a)}$$

$$y_t = H_t x_t + v_t \qquad \text{...(3b)}$$

where x_t is a (nx1) vector of state variables, F_t is a (nxn) state transition matrix, u_t is (mx1) vector of inputs, B_t and $\Box_t$ are weighting matrices, w_t is a (nx1) vector of system noise, y_t is a (kx1) vector of systems output at time t, H_t is a (kxn) measurement matrix and v_t is a (kx1) vector of measurement noise. The means and variance-covariance matrices of the noise terms w_t and v_t may be written as:

$$E\{w_t\} = 0; \qquad Q = \mathrm{var}(w_t) = E\{w_t w_t^T\} \qquad \text{...(4a)}$$

$$E\{v_t\} = 0; \qquad R = \mathrm{var}(v_t) = E\{v_t v_t^T\} \qquad \text{...(4b)}$$

where E{.} is the expectation operator. It is normally assumed that the noises w_t and v_t have Gaussian distributions. At time (t-1), the true value of state x_{t-1} is not known because of measurement noise; only the measurements $y_1,\dots,y_{t-1}$ will be available from which x_{t-1} can be estimated. Let $\hat{x}_{t|t-1}$ denote the estimate of x made at time t using the information available up to time t-1. When a new measurement y_t becomes available, this in itself constitutes an estimate of x_t but is subject to noise. To obtain the best unbiased linear estimate of x_t, a weighted linear sum of the two available estimates is formed to yield

$$\hat{x}_{t|t} = \hat{x}_{t|t-1} + K_t \;{}_t \qquad \text{...(5)}$$

where the weighting matrix K_t is referred to as *the Kalman gain* and the quantity

$$\Box_t = y_t - H_t \hat{x}_{t|t-1} \qquad \text{...(6)}$$

is the *filter innovation.* The Kalman gain plays a crucial role in filtering, and an optimum choice of K_t is necessary for minimum variance estimate of the state x_t. A necessary condition for optimal Kalman filter is that the innovation sequence is zero mean and white. The Kalman filter has been widely applied in hydrology.

5.0 CASE STUDY

The results of application of a conceptual model and time series model to a basin are presented here. The data of the Kolar sub-basin were used in this study. The Kolar sub-basin falls under the catchment of the Narmada basin, in central India. This basin is located in the latitude range of 22□ 40' to 23□ 08' and longitude77□ 01' to 77□ 29'. The catchment has elevation varying from 600m to 300m. The data pertaining to the catchment area of 820 sq. km. up to Satrana gauge & discharge measurement site were used. The Kolar basin has two distinct topographic zones. The upper four-fifth part is predominantly covered by deciduous forest. The soils are skeleton to shallow in depth except near stream channels. The outcrops of weathered rocks are visible at many places. Crops are grown in large pockets in the north western part and in small pockets elsewhere. The general response of this part of basin appears to be quick. The lower part of the basin consisting of flat bottomed narrowing valley is predominantly cultivated area. The soils are deep, ground slopes flat and the response of this part is slow.

The hourly rainfall data at four stations were available for the period 1983-88 and were used to get weighted average hourly rainfall for the basin. The hourly gauge data for monsoon season only was available at Satrana. Rating curves were used to obtain hourly discharge values from hourly stages. The pan evaporation data at a station located near the basin in agricultural area were used.

5.1 MODELLING OF KOLAR CATCHMENT USING THE CONCEPTUAL MODEL

The data for the period 1983-85 was chosen for model calibration. The length of computational time step was one hour. Several criteria are available in the literature to test the efficiency of a rainfall-runoff model, ref. Nash & Sutcliffe (1970) and Garrick et al (1978). However, most of these suffer from one or other deficiency. Hence in this study, the volume of the simulated discharge was compared with the volume of the observed discharge on monthly basis followed by visual comparison of observed and simulated hydrographs. This criteria also allows the modeller to view the results in light of the objectives of his study, e.g., whether peak flow modelling is more important or low flow modelling. The automatic calibration approach using the Rosenbrock method, which is a search technique, was used. The objective function was

$$\text{Min } Z = \square \ (VQ - VS_t)^2 \qquad ...(7)$$

where,

VO_t = Volume of observed hydrograph in mm for month t,

VS_t = Volume of simulated hydrograph in mm for month t.

A plot of observed and simulated hydrographs for the monsoon months during 1983-85 is given in Fig. 1. The results of final calibration show a good match between the observed and simulated hydrographs. It is seen from Fig. 1 that the hydrograph peaks, recession and base flow are also simulated reasonably well. The peaks are moderately over simulated in some cases and under simulated in some others. It is not possible to further improve the match for one peak without deteriorating it for others.

The data for the period 1986-87 were used for model validation. The parameter values arrived at after calibration were used to simulate basin response. The observed and simulated hydrographs for the validation period show acceptable match in shapes. It may be pointed out that the input data is subject to uncertainties in view of inadequate coverage. The results of the simulation are therefore acceptable particularly in view of spatial lumping.

5.2 TIME SERIES MODELLING OF RESIDUALS OF CONCEPTUAL MODEL

Once the response of the Kolar basin was satisfactorily simulated with the conceptual model, the difference between the observed and simulated discharge for each period was determined and a time series of residuals was formed. A plot of the time series of residuals is shown in Fig. 2. It is seen from this plot that this series does not show any trend. The mean of the residuals was close to zero. The residuals are larger during the high flow season which may be due to possible errors in the input data. The hydrologists have used two approaches for catchment modelling : using the physical laws and using the statistical laws. The main argument of the modellers using the physical laws is that the knowledge about the physical processes should be used in modelling while the proponents of statistical modelling claim that the knowledge of the physical laws and parameters is inadequate for satisfactory modelling. In the present work, a combination of the two approaches has been used to arrive at better results.

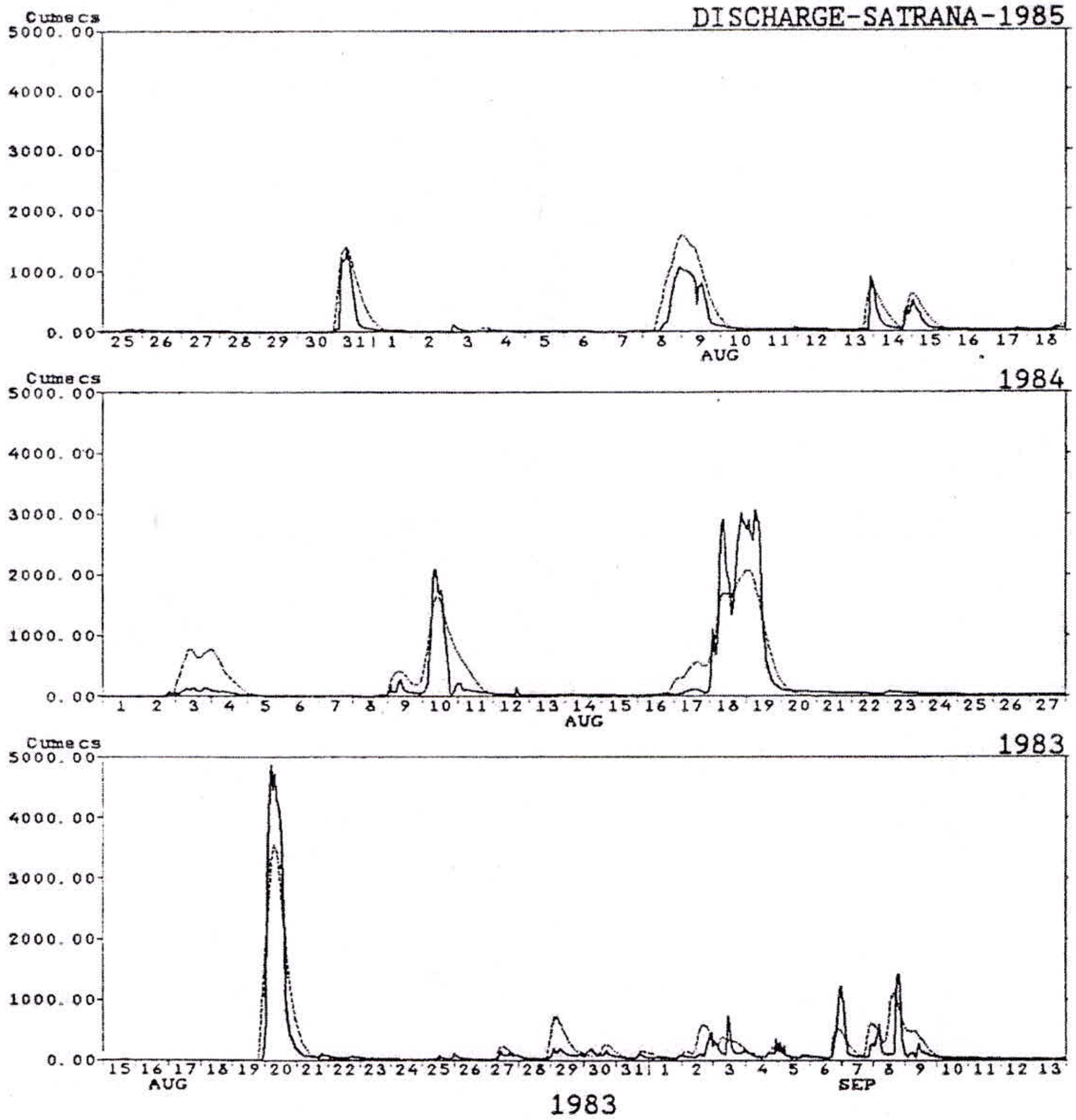

Fig. 1: Plot of observed and simulated hydrographs for the monsoon months during 1983-85.

Several ARMA models were considered for modelling the error series. For each of the model, the Akike Information Criterion (AIC) was determined as follows:

$$AIC(p,q) = N \ln(\hat{\sigma}^2_{\varepsilon}) + 2(p+q) \qquad ...(8)$$

where, N is the sample size and $\hat{\sigma}^2_\varepsilon$ is the maximum likelihood estimate of the residual variance, Salas et al (1980). According to this criterion, the model which gives the minimum AIC is the one to be selected. In addition of the AIC, the statistics of the residuals of each time series model were also determined.

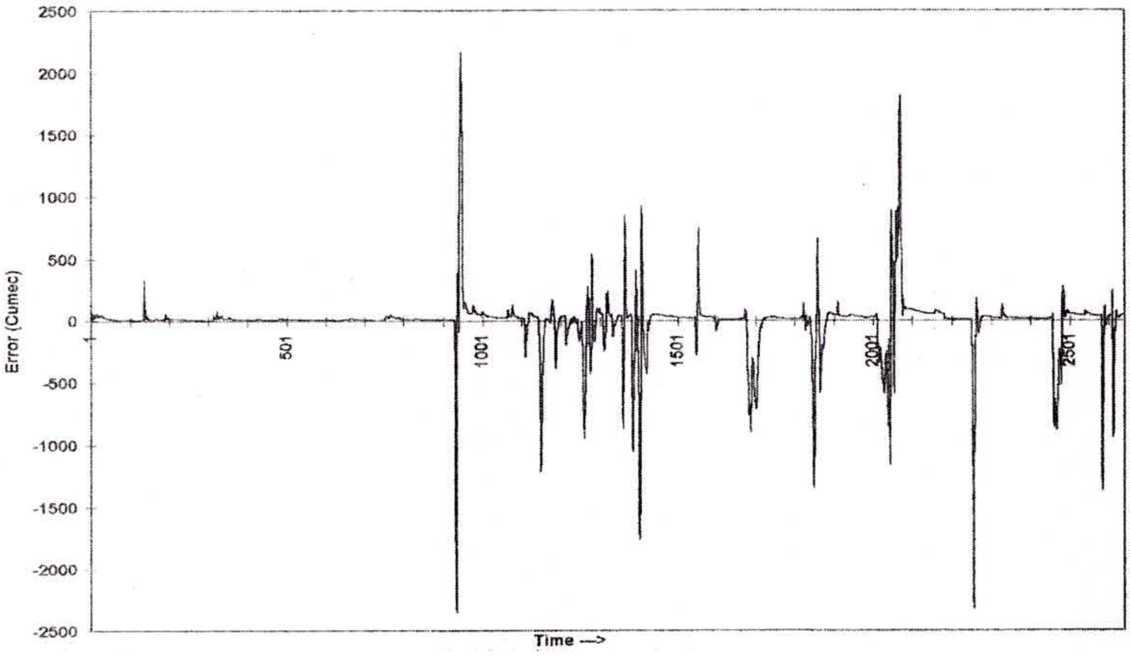

Fig. 2: Plot of the time series of residuals.

In the present case, a number of models, for example, pure AR models, pure MA models, and mixed ARMA models were tested. The AIC and residual statistics for some of these is given below:

Model	AIC	Residual Variance	Residual Mean
ARMA(1,0)	18049	8296	0.0147
ARMA(2,0)	17203	5431	0.0058
ARMA(0,1)	19503	17163	0.0113
ARMA(1,1)	17382	5937	0.010
ARMA(2,2)	17204	5422	0.0053

It is seen from this table that the ARMA(2,0) model gives the minimum AIC. The

ARMA(2,2) model also gives AIC very close to this. Further, residual mean and variance corresponding to ARMA(2,2) model is slightly smaller than that for ARMA(2,0) model. However, the minor improvement in residual statistics and higher AIC by adding two more model parameters does not look very attractive. Based on these considerations, the ARMA(2,0) or AR(2) model was finally adopted.

5.3 DISCUSSION ON FLOW FORECASTING RESULTS

For the purpose of flow forecasting, the data for 1983 and 1984 were used. The various statistics were computed for a period of one month in each instance. The statistics were computed for one-step ahead forecasts only for the months of August '83, September '83, and August '84. In all the cases, the models were run continuously. The behaviour for higher-lag forecasts is likely to follow the similar trend. The following three modelling combinations were used:

- Using only conceptual model,
- Using conceptual and time series models,
- Using conceptual and time series models and Kalman filter updating.

5.3.1 Flow Forecasting Using Only Conceptual Model

In this case, only the conceptual model was used to forecast the flows. At a certain time, the information about the current and past rainfall was used. The flow at the current time is obtained by model. Now the model is further run for a period of forecast lead-time with the initial conditions at the end of last time step. Two rainfall scenarios were examined: a) the rainfall continues at the current rate, and b) rainfall is zero after the current time. The results of the forecasting are summarized in the following table.

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	Mean Square Error (MSE)	Mean Absolute Error (MAE)
Future Rainfall at Current Rates					
Aug. '83	111.8	118.2	6.4	58641.5	62.0

Sep. '83	78.5	96.9	18.4	37766.0	73.0
Aug. '84	181.2	197.3	16.1	63298.0	121.0
Future Rainfall Zero					
Aug. '83	111.8	107.4	-4.4	49088.0	58.0
Sep. '83	78.5	88.8	10.3	29556.0	65.0
Aug. '84	181.2	179.8	-1.4	59048.0	114.8

The bias is an indicator of systematic errors. Here, the bias is quite large for the case when the rainfall is assumed at the current rate. When the future rain is assumed zero, the bias show some reduction but is still large for the month of Sept. '83. Further, The Mean Square Error (MSE) and the Mean Absolute Error (MAE) include both the random as well as systematic error terms. The large errors get magnified in MSE. In this case, the MSE is quite large in all the cases though the MAE is not that large. This shows that the MSE is dominated by a small number of large-magnitude errors. Some of these errors could be due to errors in the input data. The overall results show that the quality of forecasts issued using only conceptual model is not acceptable.

5.3.2 Flow Forecasting Using Conceptual and Time Series Model

In this case, the combination of conceptual and time series models was used to forecast the flows. At a certain time, the information about the current and past rainfall and past flows was used. The flow at the current time is obtained by adding the flow from the conceptual model and a correction term obtained from the time series model. The same procedure is used at the time of preparing the forecast. In view of the results obtained in the previous section 5.3.1, the rainfall was assumed to be zero after the current time. The results of the forecasting are summarized here:

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	MSE	MAE
Aug. '83	111.8	109.8	-2.0	7395.3	18.0

Sep. '83	78.5	79.2	0.7	4859.8	23.6
Aug. '84	181.2	180.7	-0.5	6169.5	30.0

It is seen from the above table that by including the time series model with the conceptual model, there has been significant improvement in the various statistics. The bias in the results has been substantially reduced. The MSE and MAE are also quite small now. Particularly a small value of MAE shows that the major cause of errors is a small number of bigger errors.

5.3.3 Forecasting Using Conceptual & Time Series Models with Updating

In this case, in addition to the combination of conceptual and time series models, an updating algorithm based on Kalman filter was used to forecast the flows. At a certain time, the information about the current and past rainfall and current and past flows was used. The forecast consists of: a) The flow obtained from the conceptual model, and b) and a correction term. The correction term, obtained from the time series model was updated using the Kalman filter. The same procedure is used at the time of preparing the forecast. In view of the results obtained in the previous section 5.3.1, the rainfall was assumed to be zero after the current time. The results of the forecasting are summarized in Table below.

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	MSE	MAE
Aug. '83	111.8	110.7	-1.1	5806.7	17.5
Sep. '83	78.5	79.0	0.5	1405.4	15.9
Aug. '84	181.2	180.4	-0.8	3219.0	24.2

The results in the above table show that the bias is now negligible. The changing sign in bias indicates that the bias is probably not present due to the deficiency in modelling. The values of MAE and MSE also appear to be in the acceptable range. Overall the results are acceptable. It may be added that the performance of the updating algorithm is dependent on the noise statistics which will not be the same for all the cases. Some investigators have suggested various algorithms for updating of these statistics. No such algorithm was used in the present work.

The plot of observed and one-step ahead forecasted flows for the month August and Sept. 1983 are shown in Fig. 3. This graph shows a reasonably good match between the observed and the one-step ahead forecasted hydrograph.

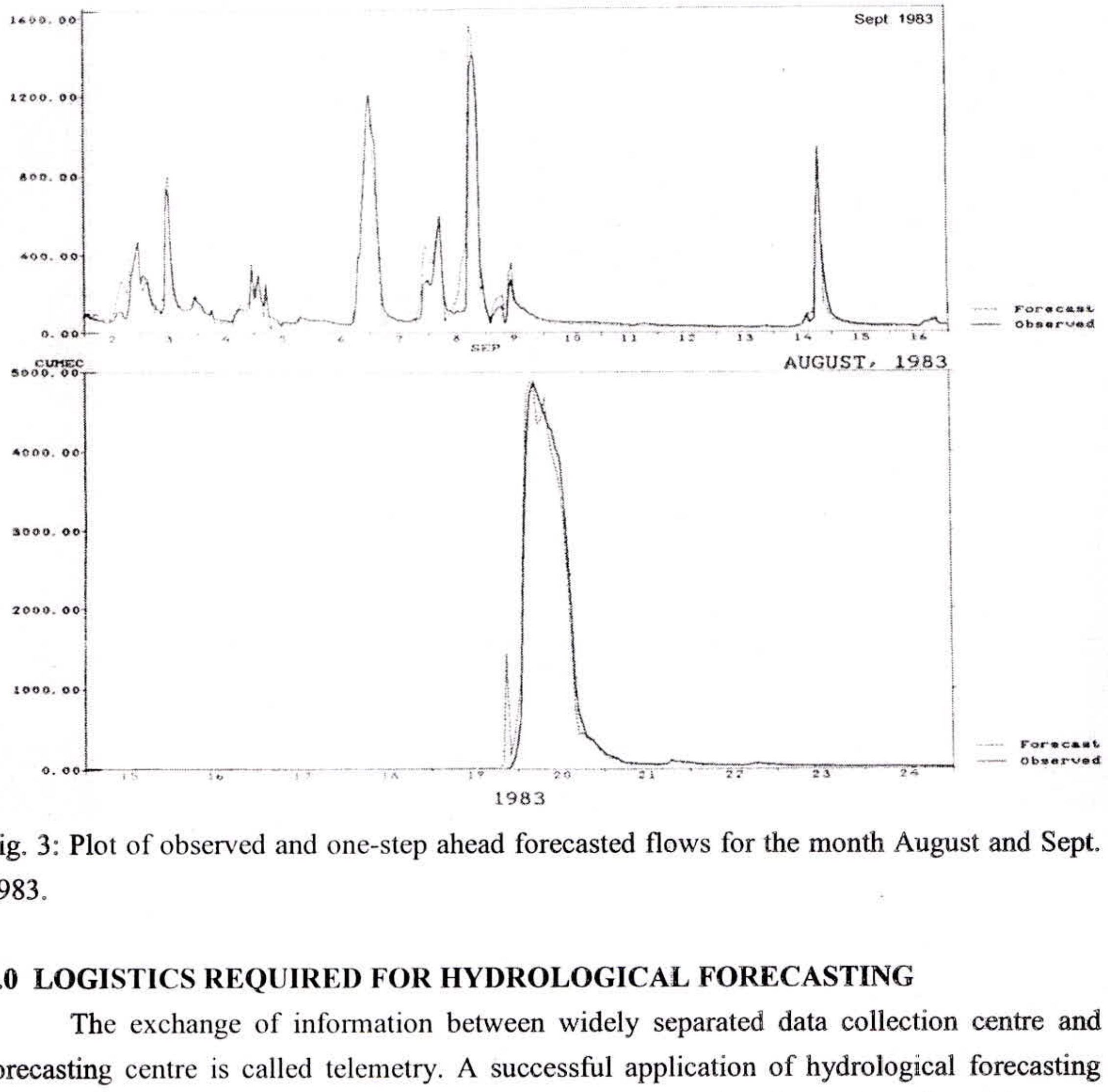

Fig. 3: Plot of observed and one-step ahead forecasted flows for the month August and Sept. 1983.

6.0 LOGISTICS REQUIRED FOR HYDROLOGICAL FORECASTING

The exchange of information between widely separated data collection centre and forecasting centre is called telemetry. A successful application of hydrological forecasting requires a good telemetry system through which data can be observed on-line. The term *on-line* implies that the data are collected, transmitted, fed to a model, the model's output is obtained and used in one uninterrupted sequence of activities. Due to increasing prevalence of high capability and low cost computers, all this is technically and economically feasible now. A typical system of forecasting consists of:

a) Observation and collection of data,
b) Transmission of data to forecasting centre, and
c) Formation of forecast.

The various hydro-meteorological data acquisition systems in use in India are :

i) Manual observation/transmission and forecasting

The rainfall data, river levels and flows are observed at fixed hours and are transmitted to the control room by telephone, telegrams, or VHF/UHF voice transmission. Delay in data transmission due to bad weather or transmission link failure is likely.

ii) Automatic sensing, transmission and computer system for forecasting

The specified river gauge, rainfall, temperature and other hydrological parameters are measured with automatic recorders and are transmitted with the help of repeater stations via VHF transmission. The master teleprocessor at the forecasting station coordinates the data collection and proper storage.

6.1 FORMATION OF FORECAST

The computer at the forecasting station coordinates the data collection and proper storage. The mathematical model for formulating forecasts is also loaded on this computer. The observed data is processed and fed to the model and the forecast is formulated. Usually, this computer is also used for various housekeeping jobs like data storage etc.

7.0 DISSEMINATION OF FORECAST

The information dissemination is an important aspect of forecasting. Due to rapid developments in the tele-communication facilities, a number of alternatives are now available to send to information to the desired destination. The forecasts are disseminated through special messengers and also on telephone/fax to the authorities. The network of wireless transmission for collection of data can also be used for dissemination of forecast. The forecast is communicated to concerned authorities through special messengers or phone/fax. In addition, these forecasts are also disseminated by the network of state and inter-state police wireless for the beneficiaries who are located at far away places.

7.1 FORECAST BULLETINS

The organizations responsible for disaster control and mitigation should be informed about the incoming danger as early as possible so that the required action is planned and activities set into operation with least possible delay. They should also be kept informed of the development of the event and of any change in the present as well as anticipated future situation. These informations are supplied by the flood forecasting authorities in the form of *Flood Forecast Bulletins*. These bulletins must be very clear and should include all necessary details so that a realistic picture is available. There should be arrangement to double-check the information supplied with well-defined responsibility in every office authorized to issue forecasts. This is necessary to avoid dissemination of wrong information including even the inadvertent mistakes because hardly any time is left for review between receipt of forecasts and triggering a chain of follow up activities.

At present, short-term forecasts, giving an advance warning of few hours to about 2 days are issued by the flood forecasting centres. Most of the flood forecasting centres issue a daily bulletin in the morning hours indicating the present position (generally the water level and rainfall data) at various stations and the forecast with respect to water level and expected time of its occurrence for specified station known as forecasting station. This is also accompanied by a descriptive bulletin indicating the anticipated flood situation in the river. The bulletin also includes a brief description about the weather condition and qualitative weather forecast in the river catchment.

In addition, special bulletins, if needed, are issued depending upon the situation. Such 6-hourly bulletins were issued when a large flood peak passed in river Yamuna at Delhi.

7.2 DISTRIBUTION OF FORECAST BULLETINS

The forecast bulletins are generally issued to a number of agencies who are responsible for providing relief or follow up action.

Civil Authorities: These authorities are responsible for the issue of disaster warning to the public and for organizing relief measures including evacuation operation from the areas likely to be affected. The civil authorities also assist the engineering authorities in patrolling of embankments etc. Sometimes, temporary control centers are set up by these authorities to coordinate disaster fighting measures.

Engineering Authorities: The forecast are issued to all the concerned officers who are responsible for operation, maintenance and safety of various structures.

Military Authorities: A continuous contact is made with these authorities so that they take care of their own establishment as well as are in a position to help the civil authorities at a short notice. In India, help of army/para-military forces is frequently taken to evacuate people from the affected areas and to provide them food and medical assistance.

Electronic Media: The different centres of All India Radio and Doordarshan broadcast special bulletins prepared by the forecasting units. In addition, they also summarize the situation and forecasts in their regular news bulletins.

Print Media: These agencies publish the forecasts highlighting the important warnings in the news papers. Usually, a press bulletin is issued in the evening to news agencies.

Other Agencies : Apart from the above mentioned authorities, the forecasts are also issued to several other organization depending upon the requirement. These include the railways and highway authorities, industries and important establishments located in the affected areas and non-governmental organizations etc.

7.3 FLOOD WARNING

Flood warning in India is primarily the responsibility of civil authorities. They have to adopt suitable media to warn the people and then to take up measure for evacuation and subsequent flood fighting operations. The flood forecasting centres are directly not issuing the warning to public except covered under the 'flood news' broadcast of All India Radio. However, the various methods of communicating warning to people are discussed below in brief.

7.3.1 Communication of Flood Warning to the Target Population

There are several methods of communicating the warning to the people such as radio, visual signals, sirens, local emergency communication etc. However the suitability of particular method to be used for warning the people of an area will depend on following factors:

i) vulnerability of the area

ii) available communication facilities, and

iii) social awareness

The methods which have been used with success in various countries are:

a) Radio During the flood season, radio stations should issue flood bulletins in addition to their usual news bulletins with the frequency of these bulletins increasing as the possibility of flood increase. When an actual flood situation develops, flood warning can be broadcast. These can indicate the areas likely to be flooded, the approximate depth of flooding and the approximate time of flooding. Instructions can be issued regarding evacuation and flood fighting operations. This is an excellent method for giving flood warning; it is inexpensive, easy and reliable.

b) Visual Signals Yellow, red and green lights may be displayed from towers erected on high spots where they can be seen from all points in the locality. If there is no electric power, the lights can be replaced by flags and lanterns mounted on the top of high poles. The red signal tells people to evacuate to higher ground with their livestock and such personal belongings as can be carried, in accordance with a previously arranged plan. The yellow signal indicates likelihood of a flood so that the people can take necessary precautionary measures for evacuation and flood fighting and be alerted for the red signal. The green signal indicates that the flood danger is over. Such an arrangement exists for North Bengal rivers system. This is a very good arrangement for flashy river where warning time is very less. It is most important that the people be educated in the meanings of the three signals.

c) Sirens In addition to the visual signals, sirens can be used effectively. Where electric power is available, electric sirens can be used; otherwise hand operated sirens can be used. The sounding of sirens in different manners can indicate flood danger and all clear situations as is being done in many places for civil defense.

8.0 PREPARATORY ASPECTS

As is true for all natural or man-made disasters, preparedness is very crucial for water related disasters. A few important preparedness steps are discussed in the following:

Education of the Public Along with the establishment of a warning system, the community should go with a programme for educating the public on the significance of the different types of warning and the action to be taken by them. People are generally reluctant to leave their homes and villages, and it is sometimes necessary that they be forced to leave by civil authorities. Also there is often a tendency for people to return while there is still flood danger, and they may be lost. Education can be accomplished by meetings and classes, by distribution of information pamphlets, and by the placing of large size posters in prominent places. The pamphlets and posters should be in the local languages. They should make use of pictorial illustration as far as possible.

Disaster-Prone Area Mapping The area likely to be affected by the disaster should be demarcated so that the warning can be made in more specific term. The main purpose is to give a realistic picture of the incoming danger.

Regular Testing of Warning Systems An extensive testing exercise for the disaster warning system should be carried out at regular intervals. This exercise will help in detecting any fault with the system and its timely rectification. It will also ensure that the various components of the system are in good working condition at the time of need and will also remind the concerned officials about the system.

In many organizations, there is frequent shifting of officers due to transfer/ promotion etc. and the exercises will make the new staff familiar with the procedures. Further, there should also be provision for training of key personnel through a real-life mock exercise so that there is no panic at the time of the actual event.

9.0 EPILOGUE

The interaction of man and machines and the involvement of human element is too critical to be ignored. There appears to be considerable gap between the researchers and the field staff which needs to be removed.

REFERENCES

Blackie, J.R, and C.W.O. Eeles, "Lumped catchment models", in Hydrological Forecasting, M.G. Anderson and T.P. Burt (ed), John Wiley and Sons, New York, 1985.

Box,G.E.P., and G.M. Jenkins, Time Series Analysis, Forecasting and Control, Holden-Day, San Francisco, 1976.

Chiu,C.L.(ed) (1978) *Applications of Kalman Filtering Theory and Techniques to Hydrology,* *Hydraulics, and Water Resources*, Proceedings of AGU Chapman Conference.

IAHS, Symposium on Hydrological Forecasting, IAHS-AISH Publication No. 129, 1990.

Jain,S.K., (1993) Calibration of conceptual models for rainfall-runoff simulation. *Hydrol. Sci. J.* **38**, 5, 431-441.

Jain,S.K., Real-time Flow Forecasting, Report No. TR(BR)-131, National Institute of Hydrology, Roorkee, 1995.

O'Connell, P.E.(ed), Real-time Hydrological Forecasting and Control, Proceedings of 1st International Workshop Held at Institute of Hydrology, 1980.

Wood,E.F., and P.E. O'Connell (1985). Real-Time Forecasting, in Hydrological Forecasting, Edited by M.G. Anderson, and T.P. Burt, John Wiley and Sons.

WMO (1975). Hydrological Forecasting Practices, Operational Forecasting Report No. 6, WMO No. 425.

WMO (2008). Guide to Hydrological Practices. Volume I: Hydrology – From Measurement to Hydrological Information. WMO No. 168. World Meteorological Organization, Geneva.

***

FLOOD FORECASTING, ESTIMATION AND EARLY WARNING SYSTEM

Forecasting: estimation of some variable at a specific future time or
over a specified future time interval
Prediction: estimation of future conditions, without reference to a specific time
Real-time forecasting: forecasts are made based on the current conditions
Lead time: time (interval) over which a forecast is made

Reliability of a forecast usually decreases with increase in lead time
Longer the forecast lead time, greater will be its utility
Need for proper balance between accuracy and lead time

Certain minimum lead time necessary to organize remedial measures
In India, a lead time of at least 10 to 12 hours needed
Higher benefits if good forecasts are available
Forecasting is one of the most useful and difficult problem of hydrology

PURPOSES OF FORECASTING

Objective	Percent of Cases
Flood Protection	43%
Energy Generation	19%
Navigation	12%
Water Supply and Sanitation	12%
Irrigation	6%
Others	8%

Forecast of	River stage	43% cases
	Discharge	36%
	Volume	12%

Lead-Time	Percentage of Cases
Up to 24 hrs ahead	33.5%
1 day to 1 week	37.5%
Medium-term	15.0%

Long-term	14.0%

WORTH OF A FORECAST

Economic or other value that results from a forecast

Net benefits that accrue if a forecast is available

Good forecast has positive worth

Better resource utilization in long-term or
less severe damages, than would otherwise occur.

Over-prediction -- avoidable and unnecessary high release form dam

Evacuation of people from area likely to be affected

Flood fighting measures

Under-prediction -- economic losses

Loss of faith of people and decision-makers

FORECAST ACCURACY

Best assessed by comparing forecasts made and observed values

$q_f(i)$ and $q_o(i)$ forecasted and observed streamflow for period i, i=1,2...n
$_f$ and $_o$ means of forecasted and observed flows

Bias $B = {}_f - {}_o$

Mean square error MSE = $$\frac{1}{n}\sum_{i=1}^{n}[\ q_f(i) - q_o(i)\ ]^2$$

Mean absolute error MAE = $$\frac{1}{n}\sum_{i=1}^{n}[\_q_f(i)\_ - \_q_o(i)\_]$$

CLASSIFICATION OF FORECASTS

Short-term forecast lead times less than 7 days

flood warning purposes, real-time operation of WRS

long-term forecast lead times more than 7 days

allocation of irrigation water and management of drought

MODELS FOR SHORT-TERM FORECASTS

Based on channel routing

Based on rainfall-runoff modeling
combination

Criteria to choose model type to be used for forecasting

Forecast lead time T_f
Time of concentration T_c
Travel time through channel/river system T_r
Ratio of spatial scale of meteorological event to spatial scale of
catchment above forecast point - R_s - spatial scale of forecast

Case 1. $T_f > T_c + T_r$
Forecast of precipitation is required
Some of the water which is included in forecast has yet to fall

Case 2. $T_f < T_c + T_r$ and $T_c << T_r$
Forecasts can be based on observed flows at u/s gauge locations
Stream-flow forecasts can be based on channel routing models alone

Case 3. $T_f < T_c + T_r$ and $T_r << T_c$
Streamflow forecasts should be based on observed
Applicable for small catchments and urban areas
Forecasts must incorporate a rainfall-runoff model

Case 4. R_s □ 0.7
Partial coverage of catchment by rain event
Large catchment
Sub-divide catchment to prepare forecast

FORECASTS BASED ON CHANNEL ROUTING

Muskingum method - two parameters
Muskingum-Cunge - use of channel properties
St. Venant equations
Kalinin - Milyukov method, Cascade of Linear reservoirs

FORECASTS BASED ON RAINFALL-RUNOFF MODELING

Black box models	transfer functions, relate inputs with outputs
Conceptual models	
Physically based models	use known physical laws

THE CONCEPTUAL MODELS

Simulation mode

Model output is based on previous model inputs (rainfall, evaporation) and also possibly on previous model outputs

Adaptive mode

Model output may be based on previous model inputs
also utilize previous observed outputs to calculate current model output
Current model output = f(previous observed outputs, model inputs)
Use discrepancy between latest observed and model outputs
as *feedback* to calculate future model outputs

TIME SERIES MODELS

A a set of observations generated sequentially in time
Equidistant time intervals
Autoregressive model - current value of the process is expressed as a linear aggregate of p previous values of process and a shock a_t
Moving average model - current value is assumed to be linearly dependent on q previous a's
Mixed autoregressive-moving average (ARMA) model
Values of a process at times t, t-1, t-2,.... be Y_t, Y_{t-1}, Y_{t-2},....
Z_t, Z_{t-1}, Z_{t-2} ... are deviations from the mean μ ($Z_t = Y_t - \mu$)

ARMA(p,q)

$$Z_t = \;{}_1Z_{t-1} + \ldots\ldots + \;{}_pZ_{t-p} + a_t - \;{}_1a_{t-1} - \ldots. - \;{}_qa_{t-q}$$

p+q+2 parameters $\;,\; {}_1,\ldots,\; {}_p,\; {}_1\ldots,\; {}_q,\; {}_a^2$
Estimated from data

FORECAST UPDATING

Forecast is adjusted as new measurements become available
Measurements allow estimation of forecast error
Updating increases complexity of forecasting
Can significantly improve forecasts

KALMAN FILTER

Combine information from a deterministic model with uncertain measurements and uncertain parameters to give optimal estimates of system state

Computational requirements are minimal
Process model must be formulated in state-space representation
system equation
measurement equation

$$x_{t+1} = F_t x_t + B_t u_t + \square_t w_t$$
$$y_t = H_t x_t + v_t$$

x_t is a (nx1) vector of state variables, F_t is a (nxn) state transition matrix
u_t is (mx1) vector of inputs, B_t and $\square_t$ are weighting matrices
w_t is a (nx1) vector of system noise
y_t is a (kx1) vector of systems output at time t, H_t is a (kxn) measurement matrix and v_t is a (kx1) vector of measurement noise

$$E\{w_t\} = 0; \qquad Q = \text{var}(w_t) = E\{w_t w_t^T\}$$
$$E\{v_t\} = 0; \qquad R = \text{var}(v_t) = E\{v_t v_t^T\}$$

E{.} is the expectation operator
Assumed that noises w_t and v_t have Gaussian distributions
$\hat{x}_{t|t-1}$ denote estimate of x made at time t using data available up to time t-1
Best unbiased linear estimate of x_t = weighted linear sum of two available estimates

$$\hat{x}_{t|t} = \hat{x}_{t|t-1} + K_t \square_t$$

K_t = *Kalman gain* and the quantity

filter innovation $\qquad {}_t = y_t - H_t \hat{x}_{t|t-1}$

Optimum choice of K_t is necessary for minimum variance estimate of state x_t

For optimal Kalman filter, innovation sequence is zero mean and white

TIME SERIES MODELLING OF RESIDUALS

Time series of model residuals formed

Akike Information Criterion (AIC)

$$AIC(p,q) = N \ln(\hat{\sigma}^2_\varepsilon) + 2(p+q)$$

N is sample size, $\hat{\sigma}^2_\varepsilon$ is maximum likelihood estimate of residual variance
Model which gives minimum AIC is selected

	Model	AIC	Residual Variance	Residual Mean
	ARMA(1,0)	18049	8296	0.0147
⇒	**ARMA(2,0)**	**17203**	**5431**	**0.0058**
	ARMA(0,1)	19503	17163	0.0113
	ARMA(1,1)	17382	5937	0.010
	ARMA(2,2)	17204	5422	0.0053

DISCUSSION ON FLOW FORECASTING RESULTS

Three modelling combinations used

Flow Forecasting Using Only Conceptual Model

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	Mean Square Error (MSE)	Mean Absolute Error (MAE)
Future Rainfall at Current Rates					
Aug. '83	111.8	118.2	6.4	58641.5	62.0
Sep. '83	78.5	96.9	18.4	37766.0	73.0
Aug. '84	181.2	197.3	16.1	63298.0	121.0
Future Rainfall Zero					
Aug. '83	111.8	107.4	-4.4	49088.0	58.0
Sep. '83	78.5	88.8	10.3	29556.0	65.0
Aug. '84	181.2	179.8	-1.4	59048.0	114.8

Bias is quite large when rainfall is assumed at current rate
MSE is quite large in all cases, MAE is not that large
MSE is dominated by a small number of large-magnitude errors

Flow Forecasting Using Conceptual and Time Series Model

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	MSE	MAE
Aug. '83	111.8	109.8	-2.0	7395.3	18.0
Sep. '83	78.5	79.2	0.7	4859.8	23.6
Aug. '84	181.2	180.7	-0.5	6169.5	30.0

Significant improvement in various statistics
Bias substantially reduced
MSE and MAE are also quite small now

Forecasting Using Conceptual & Time Series Models with Updating

Event	Mean of Observed Flows	Mean of Forecasted Flows	Bias	MSE	MAE
Aug. '83	111.8	110.7	-1.1	5806.7	17.5
Sep. '83	78.5	79.0	0.5	1405.4	15.9
Aug. '84	181.2	180.4	-0.8	3219.0	24.2

Bias is now negligible
MAE and MSE also in acceptable range

LOGISTICS REQUIRED FOR HYDROLOGICAL FORECASTING

Typical system of forecasting consists of:

a) Observation and collection of data,
b) Transmission of data to forecasting centre, and
d) Formation of forecast.

Good telemetry system to observe data on-line is necessary

FORMATION OF FORECAST

Computer at forecasting station coordinates data collection
Mathematical model for formulating forecasts

DISSEMINATION OF FORECAST

Special messengers
Telephone/fax, Cell phones
Wireless network - police wireless
Internet

FORECAST BULLETINS

Forecast are provided through *Flood Forecast Bulletins*
Must be very clear and include all necessary details
Double-check information supplied
Well-defined responsibility in offices authorized to issue forecasts
Avoid dissemination of wrong information

At present, daily bulletin issued in morning
Present position and forecast
Special bulletins issued depending upon situation

DISTRIBUTION OF FORECAST BULLETINS

Civil Authorities

Responsible for issue of disaster warning to public
Organizing relief measures
Assist engineering authorities in patrolling of embankments etc.
Control centers set up to coordinate disaster fighting measures

Engineering Authorities

All concerned responsible for operation, maintenance, safety of structures

Military Authorities

Help civil authorities at a short notice
Take care of their own establishment

All India Radio / Doordarshan

Broadcast special bulletins prepared by forecasting units
Summarize status and forecasts in regular news bulletins

News Agencies

Publish forecasts and warnings in news papers

Other Agencies

Railways and highway authorities
Industries and important establishments
Non-governmental organizations

FLOOD WARNING

Primarily responsibility of civil authorities
Flood forecasting centres directly do not issue warning to public

Communication of Flood Warning to Target Population

Many methods depending on:

- vulnerability of the area
- available communication facilities, and
- social awareness

Commonly used methods

a) Radio
Special flood bulletins
Clearly indicate areas likely to be flooded, depth and time of flooding
Excellent, inexpensive, easy and reliable method

b) Visual Signals
Yellow, red and green lights may be displayed from high towers
Being followed for North Bengal rivers system
Very effective for flash floods

c) Sirens

PREPARATORY ASPECTS

Preparedness is very crucial for water related disasters

Education of the Public

Significance/implications of different types of warning
Action to be taken by them
Generally reluctance to leave homes and villages
Tendency to return while there is still flood danger

Can be accomplished by meetings and classes
Distribution of information pamphlets **in local languages**
Placing large size posters in prominent places
Pictorial illustration as far as possible

Disaster-Prone Area Mapping

Routine Testing of Warning Systems

Testing exercise for the warning system at regular intervals
Will help in detecting faults and timely rectification
Refresh concerned officials about the system
Shifting of officers due to transfer/ promotion
Make the new staff familiar with the procedures

EPILOGUE

Interaction of man and machines, involvement of human element is critical
Gap between researchers and field staff needs to be removed