Jal Vigyan Sameeksha—a publication of
High Level Technical Committee on Hydrology
Vol. I, No. 2, December 1986

Real Time Forecasting-Response System

By

Subhash Chander
Professor of Civil Engineering
Indian Institute of Technology
Hauz Khas, New Delhi - 110016

Abstract : *Real time forecasting in hydrology assumes considerable importance for disaster management such as floods and low flows, water quality control, operation and management of water resources systems. The development realised in computer technology, data acquisition and transmission system have added new dimension in the development of reliable forecast models. This paper discusses about the available forecasting models and identifies the most suitable among them for real time forecasting. A brief description of each of the categories of these model is presented. Various data acquisition and transmission systems which are in current use have also been discussed. The paper also gives the requirements and uses of the response systems with reference to the warning of population likely to be flooded and discusses the trend of the future development of real time forecasting models.*

1. Introduction

Hydrological forecasting has become a major component in the operation and management of water resources systems. For example, real-time flood forecasting is an important non-structural method for reducing flood damages. An accurate flood forecast well in advance can help the water managers in taking emergent actions to mitigate some of the adverse effects of flooding. Likewise daily, weekly or monthly forecasts are quite helpful in the rational regulation of runoff, hydroelectric power generation, irrigation and water supply management, etc. Similarly, during low flow periods, forecasting that the volume of water available in a reach of a river is sufficient to dilute the agents causing pollution is important for the effective control of water quality.

Real time forecasting of hydrological variables require hydrometeorological and hydrometric data in real time and forecasting model. The forecasts can be coupled with the dissemination systems and a decision model to provide protection. All these components and their interaction are shown in Fig. 1. The dissemination system and the decision model are a function of the objectives for which the forecasts are made and will naturally vary from situation to situation.

This paper attempts to recapitulate the present status and the likely advances in the various subsystems .

2 Hydrological/Hydrometeorological Data Acquisition and Transmission Systems

Availability of real-time data of hydrological and hydrometeorological variables at discrete

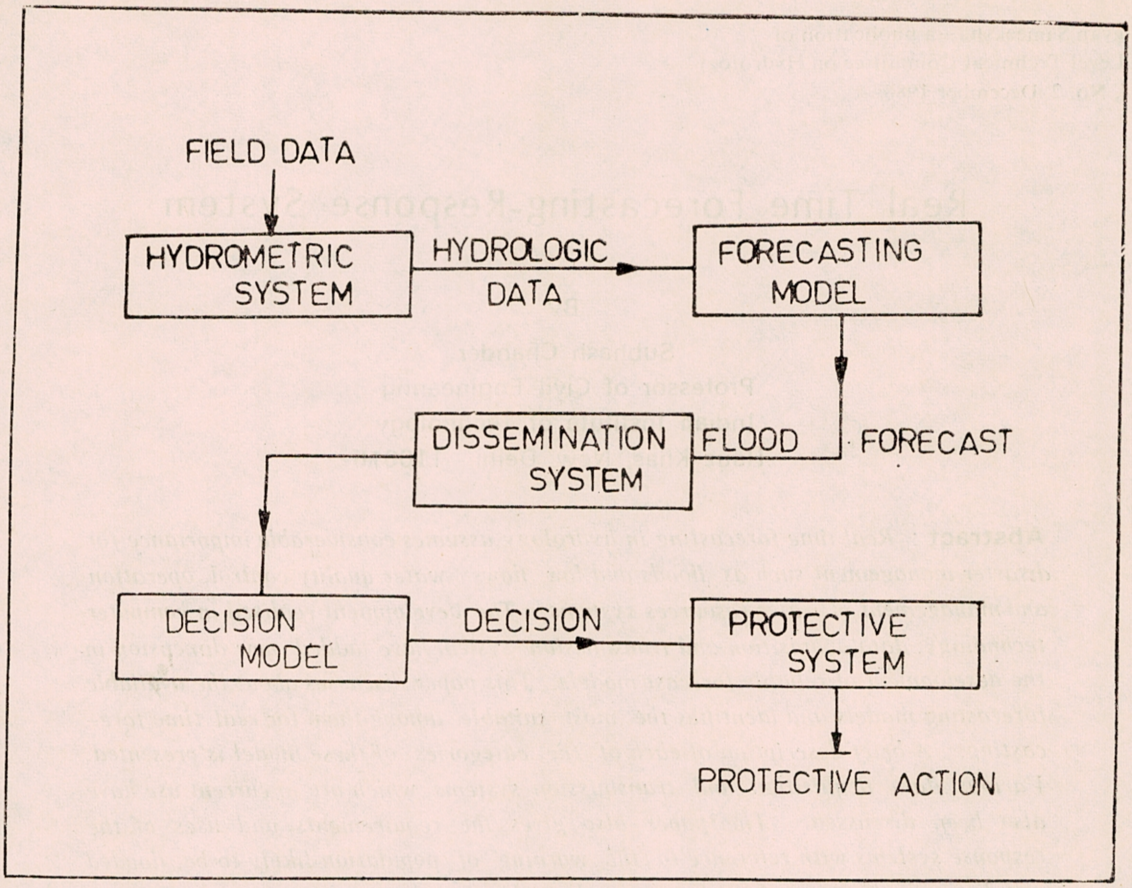


Fig. 1 : Flowchart for Forecasting Response System
(Sniedovich, et. al, 1977)

intervals is an essential prerequisite of a real-time forecast response system. Ghanekar et. al (1984) categorise these systems as

a) Manual observation/transmission system

b) Automatic sensing, transmission by land based V.H.F. transmitters/repeaters

c) Automatic sensing and link by satellite.

The comparison of various data acquisition systems is listed in Table 1.

The above mentioned systems are used to collect and transmit data such as precipitation from various points on the catchment. This data is then used to estimate the average input to the catchment. However, it is possible now to collect data on areal distribution of rainfall using radars. Nemec (1984) discusses the relative merits of radar and raingauge network and recommends the use of radar for inaccessible parts of the basin and in coastal regions where installation of gauges on the path of the inshore coming storm is not possible. Further radar provides information on quantitative precipitation forecasts. These forecasts are a boon in extending the lead time of the forecast thus making weather radars more useful in the future real-time forcecast systems.

3. Forecasting Models

In real-time forecasting it is necessary to have a forecasting model that can express current model output as a function of previously observed inputs. It is preferable that the model is able to update its parameters by using the

Table 1 : Comparison of Data Acquisition Systems (Ghanekar et. al 1984)

Sl. No.	Description	Mode of Data Acquisition	Limitations
1.	Manual observation and transmission	1. Manual observation 2. P&T channels Telegrams, telex 3. VHF/UHF 4. Telephone	1. Delay in transmission due to faults 2. Interference due to bad weather
2.	Automatic data Acquisition system using terrestrial repeaters.	1. Automatic sensing of data 2. Transmission and reception by VHF/repeater links	1. Delay in data transmission in the chain of stations in upper catchment fail 2. Failure of repeater 3. Delay in reception of data in case of failure
3.	Automatic Sensing and link by Satellite Scheme I VHF-DCP Satellite Link (Fig. 2)	1. Automatic sensing of data 2. Transmission and reception by VHF-DCP satellite links	1. Loss of data from an individual station because of local failure 2. Loss of Data due to link failure
4.	Scheme II DCP Satellite link (Fig. 3)	1. Automatic sensing 2. Transmission and reception by DCP satellite links	1. Loss of data from individual DCP sites only

discrepancy between the last observed and computed outputs. Three categories of models are able to meet the first requirement while only the first two can meet the requirement of updating of parameters. The three categories are :

1. Correlation models
2. System models
3. Conceptual models

3.1 Correlation Models

They are deterministic models in which 'T' hours ahead output is a function of the past output, Input (s) and a parameter representing the status of catchment. It is possible to represent these models in a graphic form (Fig. 4). Chander (1987) has shown that these models can be written in an equation form and their parameters can be updated. A review of such model is reported in Manual of Flood Forecasting (1980).

3.2 System Models

These models identify a relationship between rainfall input and output discharge and do not attempt to describe any of the internal mechanisms whereby this transformation takes place. These can be deterministic or stochastic. A classical example of the deterministic type is a unit hydrograph model (Chander et al 1984) which can be written in a discrete form as :

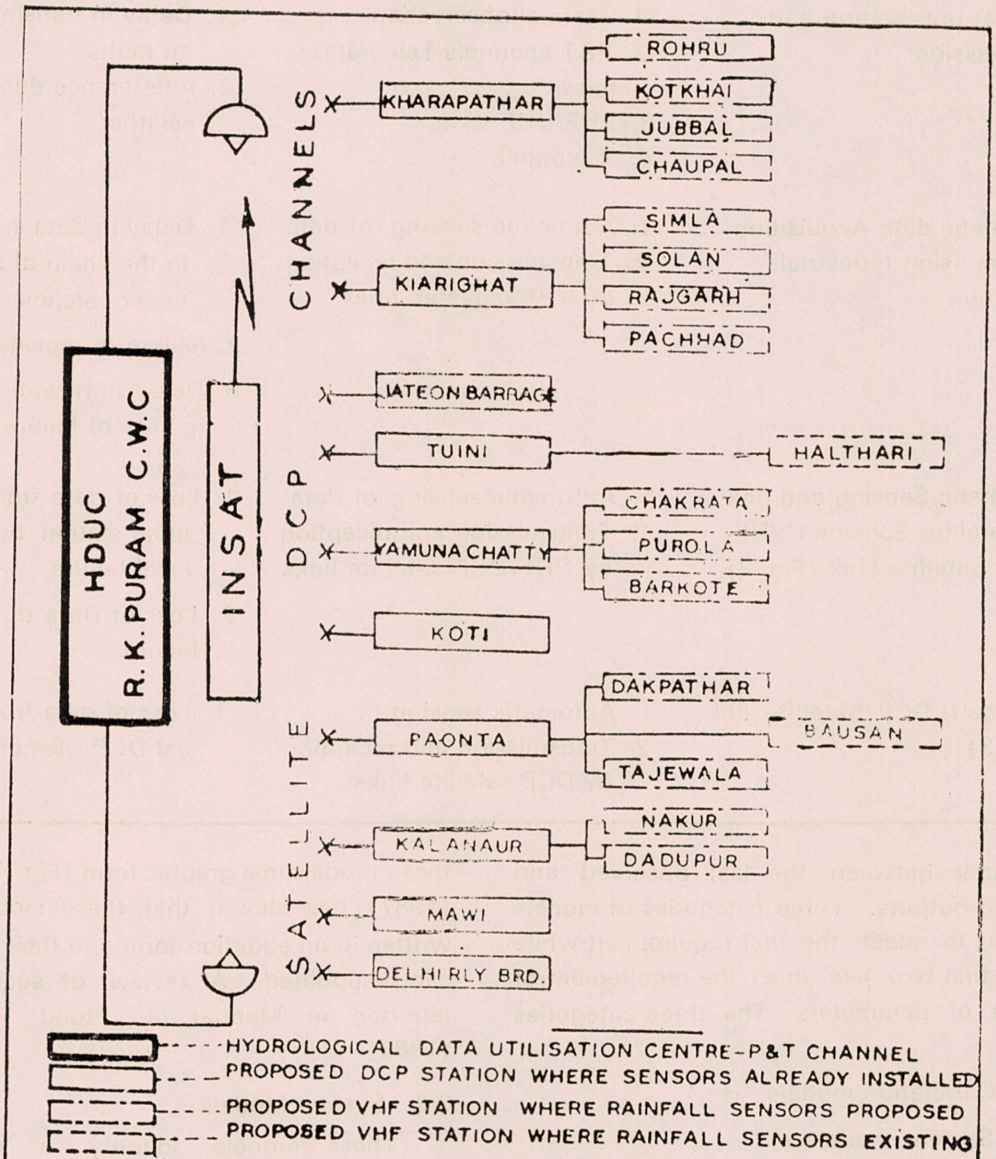


FIG. 2 - COMMUNICATION CHANNELS FOR SATELLITE DCP-VHF-LINK FOR HDUC LOCATED AT R. K. PURAM

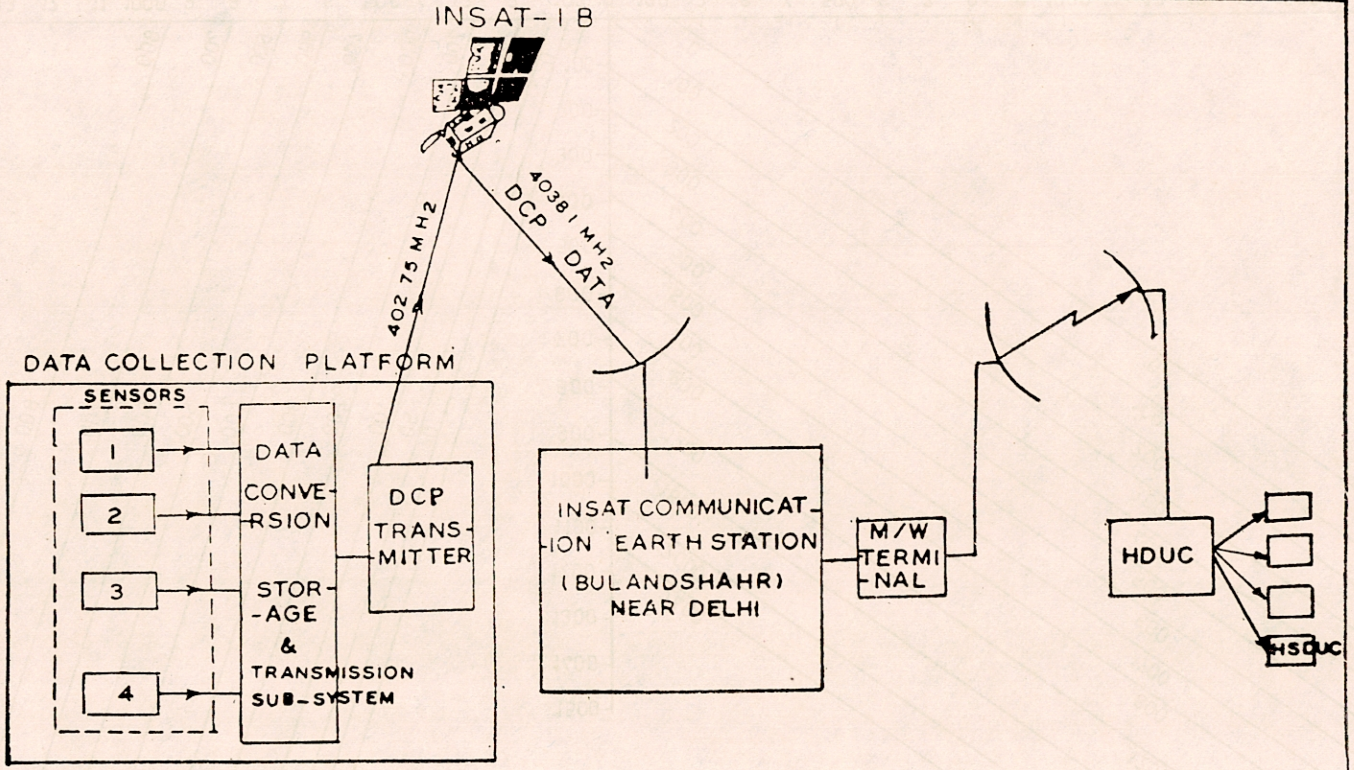
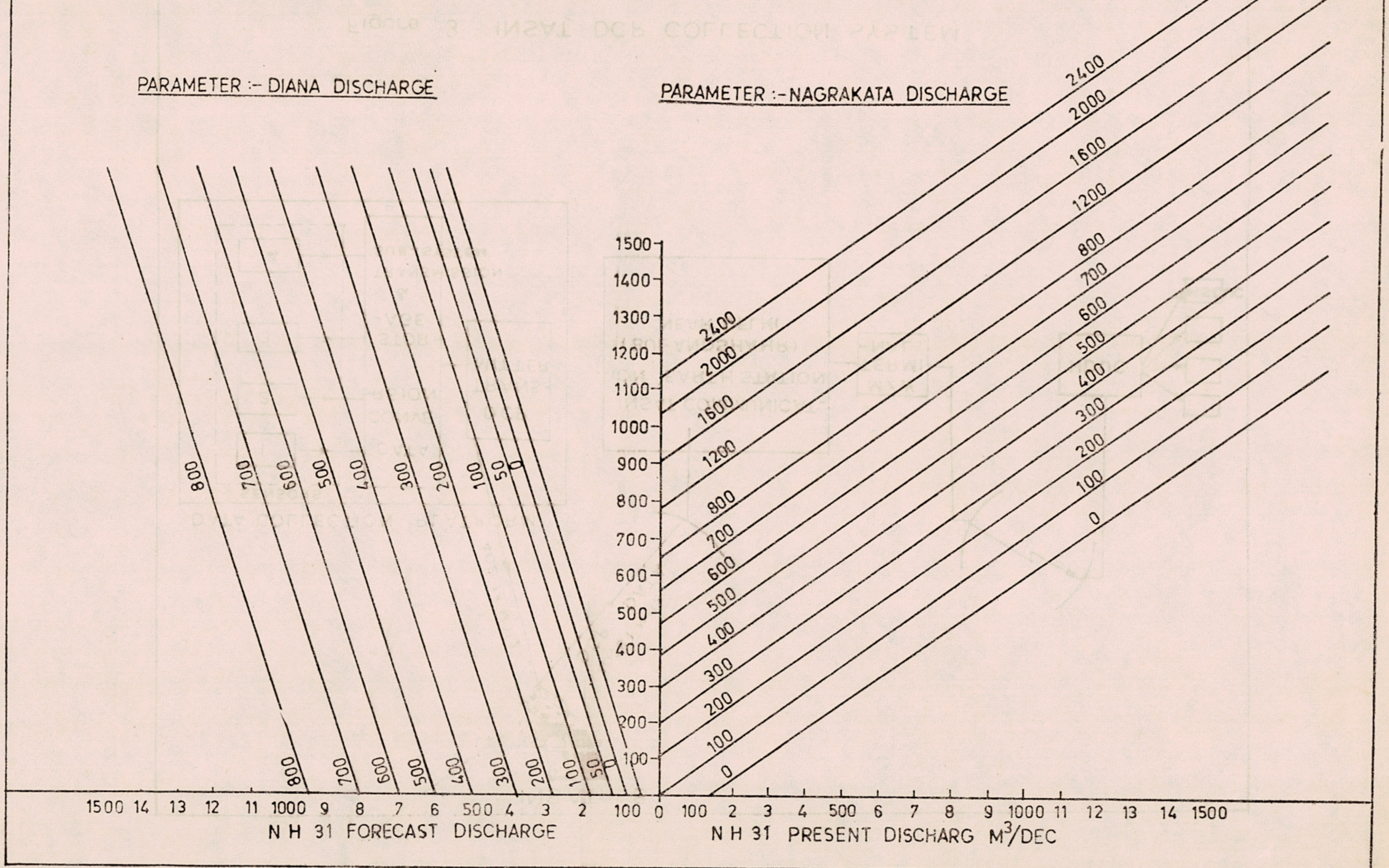


Figure : 3 **INSAT DCP COLLECTION SYSTEM**

FIG. 4
DISCHARGE CO-RELATION CURVE BETWEEN
NAGRAKATA DIANA & NH 31
TRAVEL TIME : NAGRAKATA TO NH-31=6hrs



$$Q_i = \sum_{j=1}^{i \leqslant m} R_{i-j+1} U_j \qquad (1)$$

where Q_i = runoff at time i

R_i = rainfall excess

U_j = T-hour U.H. ordinate

m = number of unit hydrograph ordinates

T = the time step of the discrete interval

The rainfall excess is computed using an average value of abstraction which is computed using equation 2.

$$F_K = \frac{\sum_{j=1}^{K} \left(Q_{j+L} - \sum_{i=1}^{j} (P_{j-i+1} U_i)\right) \left(\sum_{i=1}^{j} U_i\right)}{\sum_{j=1}^{K} \left(\sum_{i=1}^{j} U_i\right)^2} \qquad (2)$$

where F_K is the average abstraction rate.

Fig. 5 illustrates the use of the model in real-time. A stochastic representation of a system model is

$$y(t) = \frac{w(B)}{\delta(B)} x_{t-b} + \frac{\theta(B)}{\phi(B)} a_t$$

where y (t) = output at time t

B = backward shift operator

a_t = random variable

x_{t-b} = input b time units earlier

Gosain et. al (1984) have used this category of models for real-time forecasting on River Yamuna. Wood and O' Connel (1985) and O' Connell (1980) have clearly brought out the statistical and system theory aspects of these models. Fig. (6) illustrates the results of forecasting.

In larger basins where input cannot be considered to be uniformly distributed arealy, system models coupled with routing models are used for real-time forecasting. HEC 1-F and I.I.T. FORMO are two such packages which can be used for real-time forecasting. Both these packages use unit hydrograph for transforming rainfall excess to runoff. A river basin is sub-divided into interconnected system of sub-basins and streams. Each sub-basin in this system is intended to represent an area which, on an average has the same hydraulic/hydrologic characteristics. Both the packages enable the determination of the parameters for the gauged sub-basins from the observed data and other parameters by systematically altering the values of the parameters until the square root of weighted squared difference between the observed and computed hydrograph is minimized.

HEC 1-F minimizes the objective function defined earlier for 'T' hours prior to the forecast time and refines the parameters for the gauged head-water sub-basins.

I.I.T. FORMO uses equation (2) and updates the constant loss rate for each gauged basin and formulates the forecast with the newly computed values of the rainfall excess. The other parameters including the unit hydrograph ordinates are not changed during the flood.

Long term forecasts better than the average value are computed using time series models of ARMA and ARIMA category in case significant serial correlation or dependence is exhibited by the time series. Chander et, al (1980) used ARIMA models for monthly forecasts of the Krishna and Godavari rivers. (Fig. 7).

3·3 Conceptual Models

These are deterministic models. Their structure is a simplified representation of physical processes as represented by the hydrological cycle of the catchment. They are based on water balance accounting procedure. Gosain

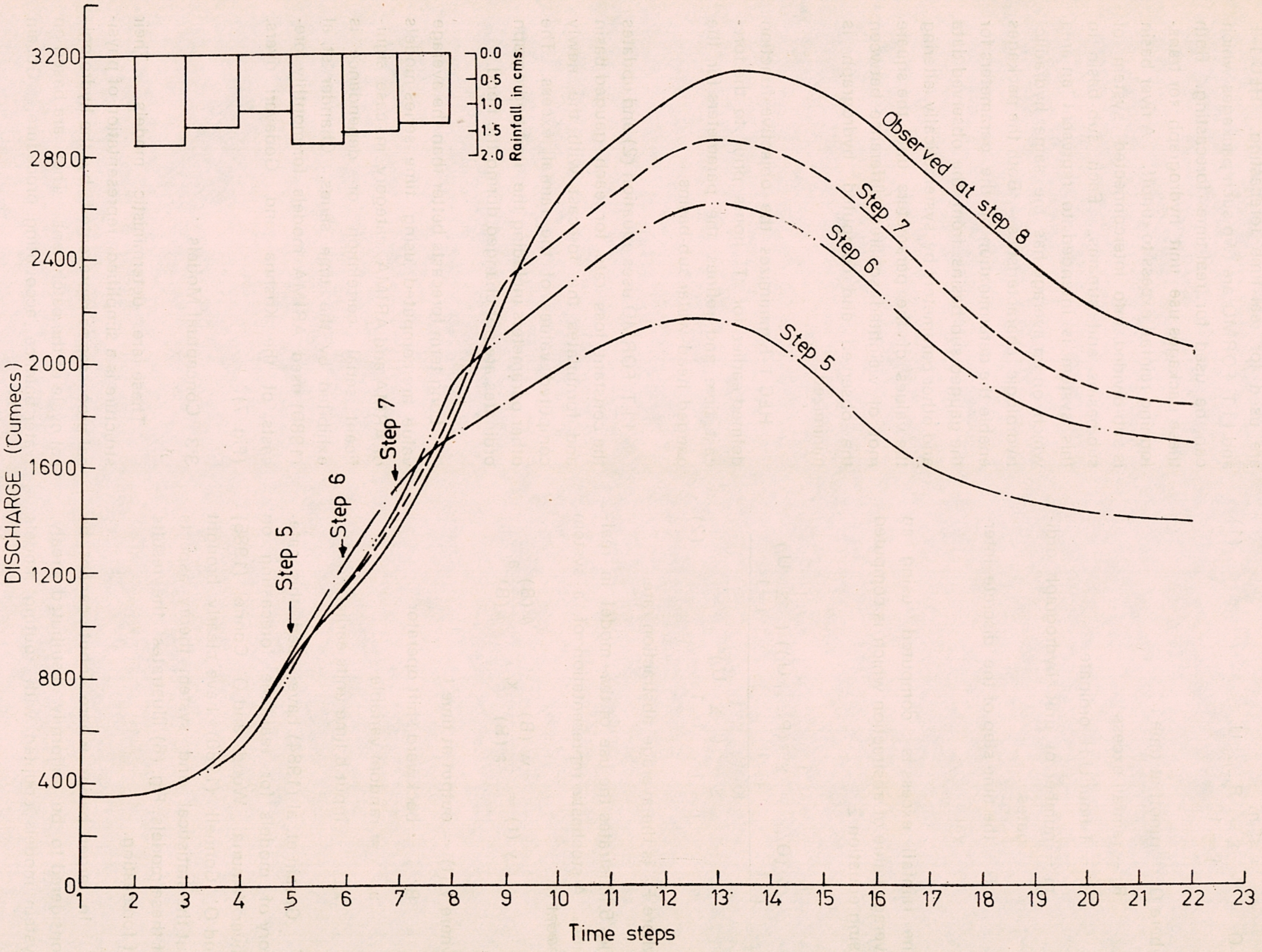


Fig. 5 : Real Time Forecasts at Time Steps 5, 6 and 7 at Point 3

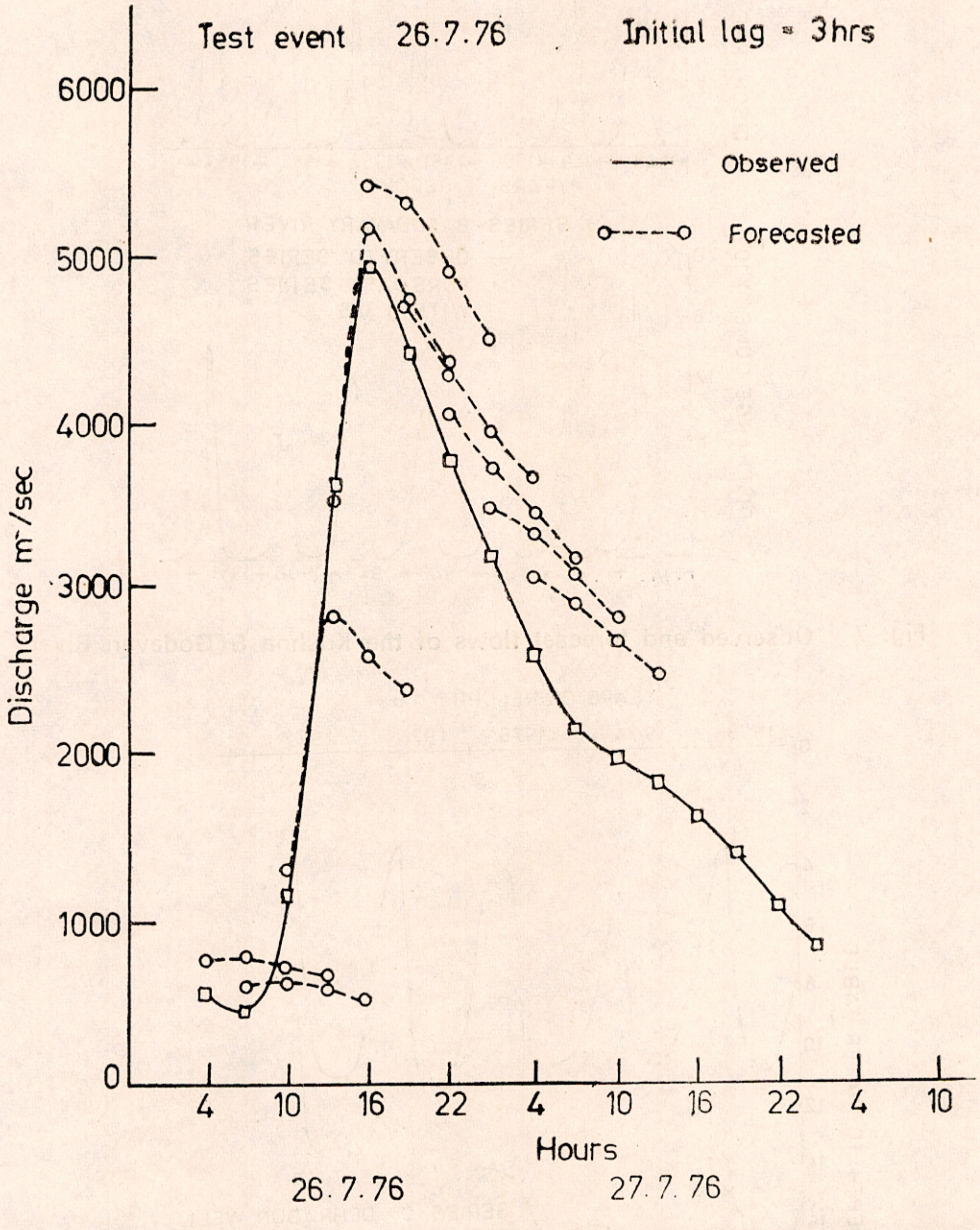


Fig. 6 : 3, 6, 9 & 12 Hours Ahead Forecasts at Kalanaur using ARMAX Model

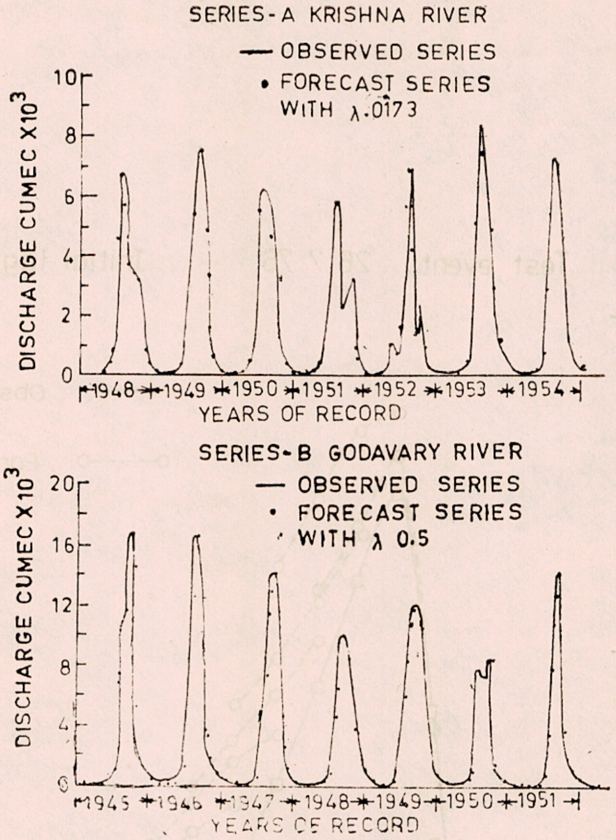


Fig. 7 : Observed and forecast flows of the Krishna & Godavari Rivers

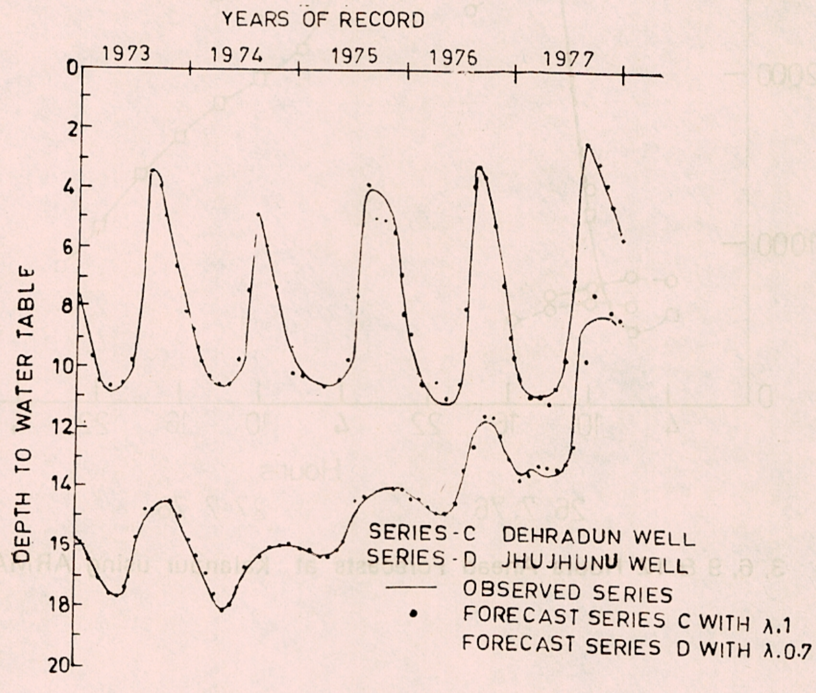


Fig. 7a : Observed and forecast levels at the Dehradun and Jhunjhunu wells et. al (1984) used a NWSRFS model (Fig. 8) which is a typical model of this category for real time forecasting on River Yamuna. Kitanidis et. al (1980) formulated this model in state space form and used it for real-time forecasting work. The computer package in some of these models has the capability to simulate an interconnected system of sub-basins and streams as well as man-made reservoirs. Fleming (1975) has reviewed a number of these models. These models have an elaborate data management sub-programmes and are cumbersome to use. Gosain (1984) compared U.H. based forecast model, ARMAX model and NWSRFS model and concluded that all the models perform equally well.

4. Decision Models

The usefulness of a forecast depends on coherence between the forecast and subsequent decisions leading to protective action. The best forecast becomes useless if the forecast information is not backed by a good management system. Similary late and inaccurate forecast wastes the effort of the management. The response system and a good management system depends on the use to which a forecast is put to. In the following paras some of the uses and requirements of the response system are discussed.

4.1 Response system for warning the population likely to be flooded

In this type of use, forecasts are communicated to the response system above a predefined danger level. The decision maker uses the forecast stage to determine the area which is likely to be flooded and takes the following protective actions.

1. Disseminates the information through a public address system or radio, or both to

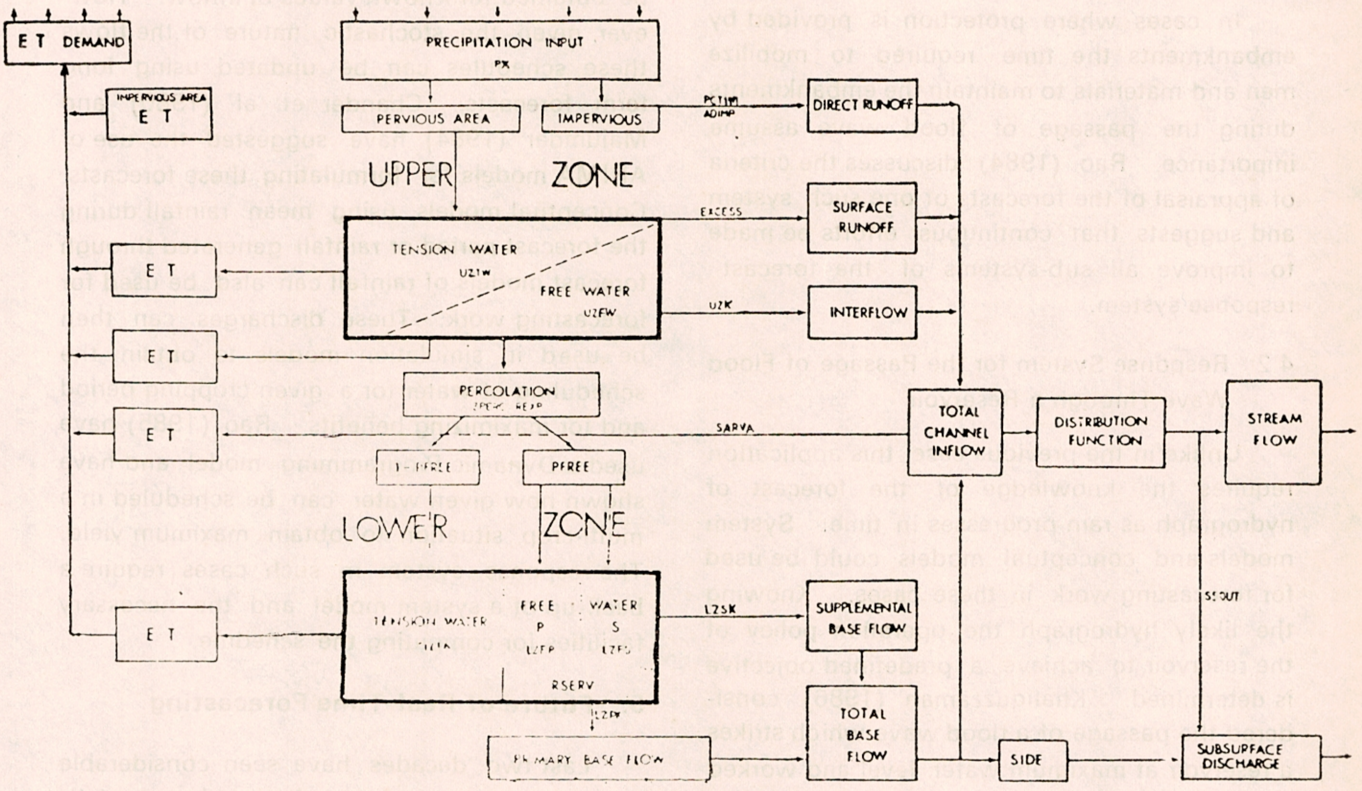


Fig. 8 : NWSRFS catchment model (Sacramento)

the households and other interests which are likely to be flooded.

2. Prepares and implements a schedule to shift the people, cattle and other moveable property to predefined places and provision of temporary rations, cooking facilities, and health care system to the people moved.

3. Provides security to the areas vacated by the people during the period.

4. Estimates the damage during and after the flood. This exercise requires time for mobilization. The forecast is useful only if the lead time of the forecast is more than the mobilization time. In the years to come it is expected that the mobilization time can be reduced considerably by using computer graphics in identifying the areas or house-holds likely to be affected and by installation of modern dissemination systems.

In cases where protection is provided by embankments the time required to mobilize men and materials to maintain the embankments during the passage of flood wave assume importance. Rao (1984) discusses the criteria of appraisal of the forecasts of one such system and suggests that continuous efforts be made to improve all sub-systems of the forecast–response system.

4.2 Response System for the Passage of Flood Wave Through a Reservoir

Unlike in the previous case this application requires the knowledge of the forecast of hydrograph as rain progresses in time. System models and conceptual models could be used for forecasting work in these cases. Knowing the likely hydrograph the operation policy of the reservoir to achieve a predefined objective is determined. Khaliquzzaman (1986) considered the passage of a flood wave which strikes a reservoir at maximum water level and worked out the maximum intensity of flood which should be discharged from the spillway to ensure that the reservoir remained full after the flood. The M.W.L. in the reservoir is not allowed to be exceeded during the passage of the flood wave. The capacity of spillway was assumed to be sufficient to pass the peak flood. A 24-hour forecast could help to pre-release water as the flood was forming, thus reducing the peak to 80% of its value (Fig. 9). Such situations require prior specification of the objectives of operation of reservoir and a decision model will need to be solved as the forecast becomes available. A computer based simulation model would be necessary for such an operation. This would enable the updating of the release policy as more information becomes available.

4.3 Response System for Scheduling of Water for Crop Use

Optimal use of water in Agriculture can be worked out through simulation studies and cropping pattern for maximizing benefits can be obtained for known values of inflow. However, given the stochastic nature of the flows these schedules can be updated using long term forecasts. Chander et. al (1980) and Majumdar (1984) have suggested the use of ARIMA models for formulating these forecasts. Conceptual models using mean rainfall during the forecast period or rainfall generated through forecast models of rainfall can also be used for forecasting work. These discharges can then be used in simulation models to obtain the scheduling of water for a given cropping period and for maximizing benefits. Rao (1985) have used a Dynamic Programming model and have shown how given water can be scheduled in a multi-crop situation to obtain maximum yield. The response system in such cases require a back-up of a system model and the necessary facilities for computing the schedule.

5. Future of Real-Time Forecasting

Last two decades have seen considerable development in real-time forecasting models. It is expected that in the following decade

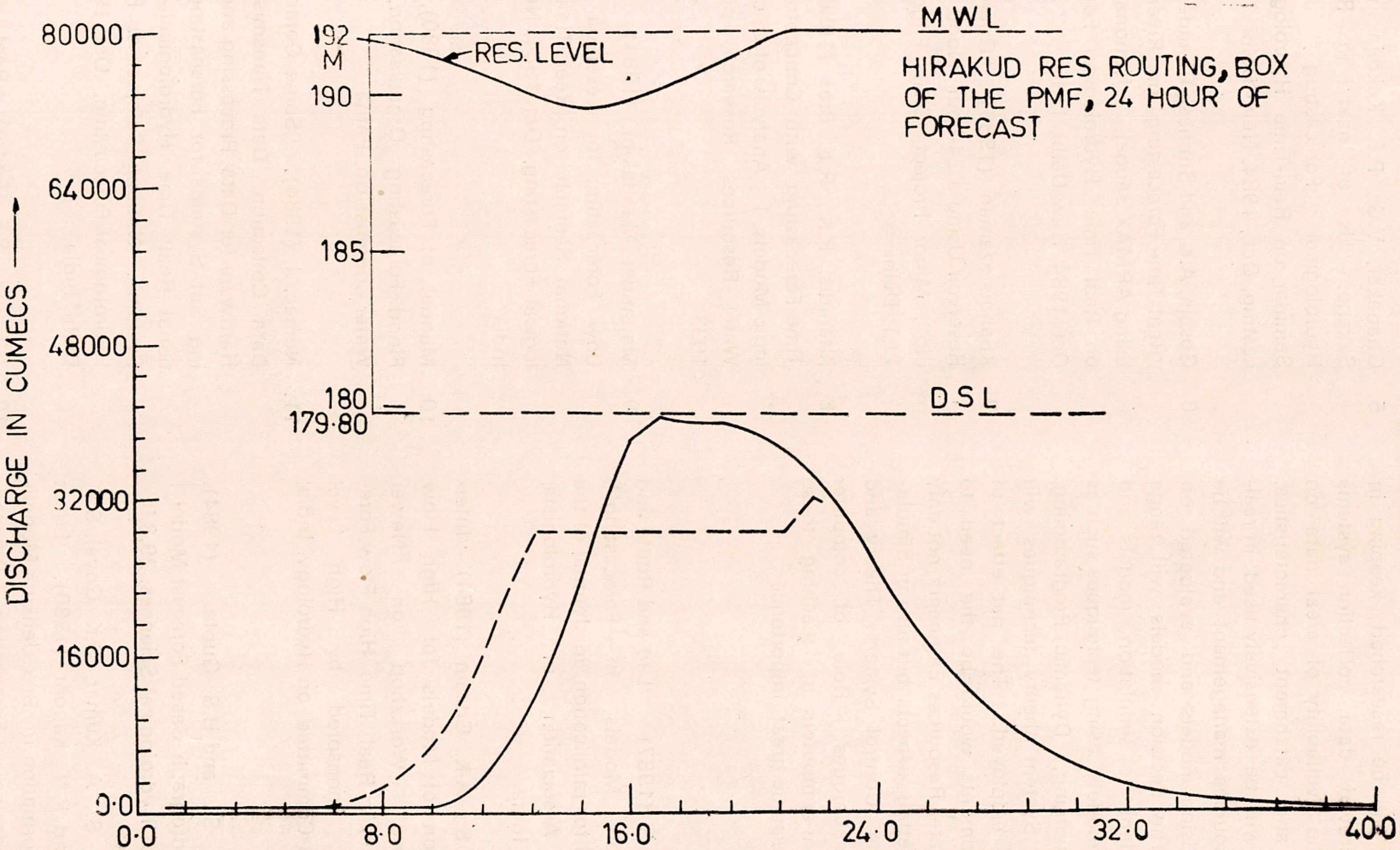


Fig. 9: 8—Hourly Time Periods→

these models will be researched keeping in view the improved data collection systems leading to the availability of areal data on precipitation and catchment characteristics. These models will be extensively used in real-time water resources management and will be linked to decision-models and evaluated on that lines. The decision models will range from action plans to simulation models and mathematical models using techniques such as Linear Programming, Dynamic Programming, etc. Control System theory techniques will be extensively employed. The net effect of these developments would be the need to train future Water Resources Engineers not only in the Engineering aspects but also in Simulation, Modelling, Control Systems Theory and Stochastic Techniques. Role of computer especially mini-computers in teaching these subjects will assume great importance.

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