CS-99

FLOOD FORECASTING SYSTEM FOR MACHHU-II RESERVOIR

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PREFACE

Efficient utilisation of water resources requires that reservoirs must be operated in most judicious and scientific manner. Efficient regulation of the reservoirs can lead to increased benefits from the reservoir as well as significant reduction in damage due to floods. For this purpose, the Irrigation department, Govt. of Gujarat entered into an agreement with the National Institute of Hydrology, Roorkee for the preparation of Reservoir operation manual for the Machhu-II dam located in the Machhu river basin. The work has been taken up as a consultancy project.

The present report deals with the development of flood forecasting scheme for flood control regulation of Machhu-II dam. Detailed basin description and data used in this study have been presented. Real-time forecasting model has been applied to the basin and the parameters have been adjusted to obtain best poosible match for the observed and simulated discharge. A software has been developed for the inflow forecasting of Machhu-II reservoir for flood regulation. One-hour, Two-hour and three-hour forecasts are also issued by the model. Detailed description of the model and the results have been presented in this report.

This report has been prepared by Dr. S.K. Jain, Scientist "E", Sh. M.K. Goel, Scientist "B" and Sh. R.K. Agarwal, R.A. and of this institute.

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DIRECTOR

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CHAPTER 1

1.0 INTRODUCTION

The Irrigation Department, Govt. of Gujarat, Gujarat has requested the National Institute of Hydrology, Roorkee to prepare Reservoir operation manual for the Machhu-II dam. This work has been entrusted to NIH through an agreement signed between the Irrigation Department, Govt. of Gujarat and the National Institute of Hydrology, Roorkee.

The scope of the project is preparation of reservoir operation manual and flood forecasting schemes for Machhu-II project with the following objectives:

a) To develop reservoir operation manual for conservation as well as flood control (i.e. flood forecasting and flood warning).

b) To develop spillway gate operation schedule for normal and emergency flood conditions including floods of different return periods 100, 200, 500, 1000 years as well as maximum observed flood SPF and PMF.

c) To recommend establishment of comprehensive flood warning system, reservoir inflow/outflow monitoring and procedures for altering the downstream areas.

This work has been subdivided into two parts, first dealing with development of operation policies for conservation purposes and second dealing with the development of policies for flood regulation. For effective flood regulation, real-time forecasting of inflow at the dam site is required.

The aim of this report is to develop real-time forecasting model for the Machhu basin. Detailed basin description and data used in this study have been presented along with the existing hydrometeorological network. The real-time forecasting model, developed in Japan, has been applied on the Machhu-II catchment. The model parameters have been adjusted for the catchment in order to obtain best match for the observed and forecasted discharge. The model used and the results obtained have been discussed in detail. Short interval data used in the study, data processing and analysis have been described. A software has been developed to forecast one-hour, two-hour and three-hour inflow forecast at the dam site.

CHAPTER 2

BASIN DESCRIPTION AND DATA AVAILABILITY

2.0 MACHHU RIVER BASIN

Machhu is one of the major rivers of Saurashtra region of Gujarat. It originates in the Mandva hill ranges near Anandpur. It traverses a Northern, North-Western course and disappears in the little Runn of Kutch downstream of Malia. On the way, a few rivers and tributaries join it. Important among them are Jumbudi, Banaiya, Patalia Vonkala, Asoi, Maha and Matelio. The total length of the Machhu river is 161 km and its total catchment area is 2331 sq. km. Two important hydraulic structures located in the Machhu basin are Machhu-I dam and Machhu-II dam. The index map showing the Machhu basin up to Morbi with Machhu I and Machhu II dams is given in Fig. 1.

2.1 MACHHU-I DAM

This dam is located on river Machhu near Jalsika village in Wankaner taluka of Rajkot district. The location of the dam is 57 km from the source of the river. The town of Wankaner, one of the seats of former princely states lies 22 km downstream of Machhu-I dam. The dam was completed in 1958. The catchment area up to the dam site is 735 sq. km. The project has been designed for gross and live storage capacities of 72.70 Mcum and 70.8 Mcum respectively with FRL at 135.33m.

The Machhu-I dam has been conceived as a reservoir impounding water for purposes of irrigation and municipal water supply. The spillway of this project was designed to pass a flood of 2595 cumec with HFL at 137.46m. The command area of project lies on the left bank of river Machhu in Wankaner and Morbi talukas of Rajkot district. The gross command area is 18218 ha. and culturable command area is 10409 ha.

2.2 MACHHU-II DAM

This dam is located on river Machhu near village Jodhpur in Morbi taluka of Rajkot district. It is 103 km from the source of the river. This dam was breached in 1979 floods. The dam has been rebuilt now. The total catchment area up to the dam site is 1928 sq. km. The gross and live storage capacities of this dam are $1.699*10^8$ m^3 and $1.01*10^8$ m^3 respectively. The Machhu-II dam has been conceived as a reservoir impounding water for irrigation and municipal water supply and for flood control. The highest observed flood for this project is 13026 cumec (4.60 lakh cusec) while the peak of design flood hydrograph is 26420 cumec (9.33 lakh cusec).

The towns of Morbi and Malia, lie 9 km and 46 km respectively downstream of Machhu II dam. Morbi is situated on the left banks of the river whereas Malia is situated about 1.5 km away from the left bank. The railway bridge near Malia is also an important location to be safeguarded.

2.3 EXISTING HYDROMETEOROLOGICAL NETWORK

The existing network of hydrological & meteorological stations is as follows:

(i) Rain gauge station are located at Malia, Morbi, Machhu-II, Lunsar, Wankaner, Machhu-I, Beti, Kuvadva, Adiya, Anandpur, Rajkot, Chotila, Than, and Sardhar.

(ii) River gauging sites are located at Beti, Machhu-I dam, Wankaner, Machhu-II dam and Morbi. In addition, the gauges are also located at Matel (Matelio river) and Dhuva (Maha river).

(iii) Wireless stations (Police) are located at Malia, Morbi, Wankaner, Rajkot and Chotila. The proposed wireless stations are Beti, Machhu-I, Machhu-II, Than and Maha (Dhuva). The existing police wireless stations are connected with Rajkot and Rajkot is connected with Ahmedabad wireless station.

2.4 SHORT INTERVAL DATA AVAILABILITY

Hourly rainfall data for this basin is available only at Beti, Chotila, Wankaner, Lunsar and Machhu-II for the period 1984-1988, and has been used in this study. In the present study, the observed discharge data at Morbi is used in modelling since no observed gauge/discharge data at short time intervals is available at Machhu-II. The difference in catchment areas at Machhu-II and Morbi is quite small.

For the period (1984-1986), discharge data is available four times a day (at 7:00 hrs, 11:00 hrs, 15:00 hrs and 19:00 hrs) at Beti, Dhuva, Matel, Morbi and Wankaner while for 1988, hourly discharge data is available at these stations. It may be mentioned that because the discharge (or gauge) is observed only four times each day, many medium and small peaks or substantial parts of the hydrograph might remain totally unobserved. This is specially true for those events which occur between 19:00 hrs on a particular day and 7:00 hrs on the next day.

CHAPTER 3

REAL-TIME HYDROLOGICAL FORECASTING

3.0 INTRODUCTION

Hydrological forecasting is one of the most important aspects of applied hydrology. The hydrological forecasting helps in rational regulation of runoff, utilization of water resources in hydropower generation, inland navigation, irrigation, drinking and industrial water supply. They are also gainfully utilized for advance flood warnings. The use of hydrologic forecasting in operation of reservoirs can make the reservoirs more efficient in achieving the purposes for which these are designed. The main components involved in the inflow forecasting are weather forecasting if possible, rainfall- runoff modeling and channel routing.

The forecasting can be classified in two categories : long term forecasting and short term forecasting. The long term forecasting is usually aimed towards generation of random events which preserve, to a certain extent, the statistical behavior of historical data. The variables used in this type of forecasting are aggregate parameters like monthly discharges, weekly rainfalls and so on. On the other hand short term forecasting is done in real-time and the processing of data is done at the same time when the events take place. The forecasts are also continuously updated using observed values of the variables at discrete times. It has been revealed by a number of studies that benefits from real-time operation of a reservoir can be substantially increased if good forecasts are available.

Real-time flood forecasting involves the estimation of flood discharges or water levels in a river some period prior to it's occurrence. The forecast lead time proves useful in mitigating some of the adverse effects of flooding. The forecast lead time is a characteristic of the catchment and may be due to (1) the time taken by the catchment to transform the rainfall into the run-off output at a point or (2) time taken by the flood wave to move from one point to another point in the river without any intermediate contributions. For these two cases, forecasts are formulated using different categories of mathematical models. Rainfall-runoff models are used for case (1), whereas flood routing models are used for case (2).

The time interval at which a reservoir is to be controlled depends on the purpose of the control. If the operation is for flood control during months of high flows, the operation decision may be taken and updated at very short interval such as a day or several hours. For other purposes, a larger interval may be adopted.

3.1 DATA PROCESSING AND ANALYSIS

The average daily rainfall and discharge data for each month in the monsoon period were plotted for each subbasin. From these graphs inconsistencies with respect of time and magnitude were observed. In many cases, the discharge started well before the beginning of rainfall. Sometimes the discharge was found to rise even days after the beginning of rainfall which was probably due to wrong entry of either rainfall time or discharge time or both. It was also observed that for some events, the volume of discharge was significantly more than the volume of rainfall. In a few instances, the variation in the rainfall of several nearby stations was quite erratic. However, required records were not available to remove most of these inconsistencies in an objective way.

Next, synthetic unit hydrographs for each subbasin were developed and the response of the subbasins was simulated using these. The hourly rainfall which was used was obtained by first computing the average daily rainfall for the subbasin. The average daily rainfall was distributed in hourly ordinates using the hourly rainfall data at the nearest station. It was found that there was significant deviation between the observed and simulated discharge hydrographs in respect of time and magnitude. It would have been quite difficult task to obtain an acceptable match, particularly in view of inconsistencies and errors of an uncertain magnitude in the input data.

Attempt was also made to develop synthetic unit hydrograph for the whole basin up to Machhu-II dam and to determine the catchment response. Still the match was not satisfactory. At this stage, it was decided not to use the daily rainfall data in the study and the hourly rainfall data and simple model was chosen to model the catchment response.

The catchment area up to Morbi has been considered free for the purpose of inflow forecasting at Machhu-II dam. It may be mentioned that the flood control storage provided in the Machhu I dam is very small. The gauging station at Morbi is quite close to the Machhu-II dam and moreover, no discharge data is available at

Machnu-II dam. Therefore average hourly rainfall data of the basin and discharge data at Morbi have been used for modelling purposes.

For the catchment of Machhu-II reservoir, hourly rainfall data of the monsoon period is available at five raingauge stations namely, Beti, Chotila, Lunsar, Wankaner and Morbi from the year 1984 to 1988 except 1987. Thiessen weights for these stations have been worked out and hourly average rainfall in the catchment up to Machhu II has been obtained by multiplying the respective thiessen weights with corresponding station rainfall and then adding the weighted rainfall of all stations.

However, at any river gauging station, discharge data is available only four times a day at 7:00 hrs, 11:00 hrs, 15:00 hrs and 19:00 hrs and hourly discharge values are not available. The hourly discharge values for the period for which hourly rainfall data is available have been obtained by linear interpolation using discharge observed 4-times a day. Since the observations are available at distant discrete points, it is possible that many short fluctuations in the hydrograph might have gone unobserved. Observed hourly discharge data is available at Morbi and has been used in this study.

While analyzing the hourly discharge data, it was observed that at some times, the discharge observations are available after the hydrograph has risen significantly. In such cases, some small initial values of discharge have been assumed and discharge has been increased steadily in accordance with the magnitude and timing of rainfall. Secondly, if at some hour, zero discharge is observed, a small value (say 0.1 cumec) of discharge has been used to avoid division by zero in the model.

3.2 MODEL USED AND ITS CALIBRATION

In the present work, a conceptual model has been used for flow forecasting. This model was developed in Japan. The model has a simple structure. Besides, it can be easily implemented and run on a personal computer. The model has a small number of parameters and its data requirements are also quite modest. The model can be easily calibrated for a basin, particularly if a graph drawing software is available. The details of this model are given in the next chapter.

With the hourly rainfall and hourly discharge data for the concurrent period as input, the runs of this model were taken. The model parameters were adjusted in such a way that the observed and forecasted discharge values match to the best extent possible.

For the Machhu basin, the parameter k_1 and f_c were found to be 40.0 and 0.3 respectively. The model was used to forecast discharge for the catchment. At any given time, the observed rainfall and discharge data up to the current time 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 two highest events in 1984 are shown in Fig. 2 and 3. The same for an event in the year 1985 are shown in Fig. 4. Similar graphs for the year 1986 and 1988 (Fig. 5, 6, and 7) also show a good match between the observed and forecasted flow. From the graphs, it can be seen that the model performance is satisfactory.

3.3 DEVELOPMENT OF RESERVOIR OPERATION SUPPORT SYSTEM (ROSS)

The ROSS is a menu-driven package which has been developed for decision making for flood control operation of a reservoir using the previously developed policy (see the report "Flood Control Regulation of Machhu-II Reservoir). The system has been developed keeping in mind that it should be easy for a layman to use it. Further, the ROSS has been planned in such a way that it should be possible to use it in real-time decision making. In the present report, only the inflow forecasting module of the software is being discussed.

After the user activates the ROSS, the menu as shown in Fig. 8 appears on the screen. The user can move to a particular choice by moving the menu bar, shown by the highlight row (in red colour if a colour monitor is being used), up/down through the menu template using the arrow keys. The current item is chosen by pressing the <ENTER> key. Once a particular.item is chosen, the control is passed to the corresponding module. The control is transferred back to the main menu after exiting from a particular module and the user can then choose any another option.

3.3.1 Inflow Forecasting Module

The first option of the menu can be used for forecasting of reservoir inflow. When this option is chosen, the user is asked to enter the current year, month, date and hour. At the current time, the natural flow in the river may be very small and the user may like to use the previously calibrated parameter. The other possibility is that the software had been used for forecasting some time ago and the current run is just an extension of the previous run (something similar to warm reboot). In that case, the values of various variables are read from a HOT file. This file contains the values of various (state) variables and parameters (as they were before termination of previous run). However, if the time span between the last model run and the current time is relatively long, the values of various variables may not be up-to-date and a warning is issued to that effect. A sample session with this module is given in Fig. 9.

The ROSS system has been developed on an IBM compatible PC/AT in MS-DOS environment. It can run on any IBM compatible PC/XT, AT or AT-386 with a graphics card. The system has been developed on a PC with color graphics adapter and hence the screen display will be in colour if ROSS is run on a PC having a CGA or EGA card. The program is written in FORTRAN and C programming languages.

CHAPTER 4

DESCRIPTION OF THE MODEL

4.0 INTRODUCTION

The model used in this study 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. 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.

4.1 RELATIONSHIP BETWEEN KINEMATIC AND STORAGE ROUTING MODELS

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

$$\partial h/\partial t + \partial q/\partial x = r_e \qquad (1)$$

$$q = \alpha\, h^m \qquad (2)$$

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

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,

$$d/dt\int_0^L h(x,t)\, dx = L r_e - q(L,t) \qquad (4)$$

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

$$\begin{aligned} S &= \int_0^L h(x,t)\,dx \\ &= \int_0^L [q(x,t)/\alpha]^{1/m}\,dx \end{aligned} \tag{5}$$

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:

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

$$ds/dt = r_e - q = fr - q \tag{7}$$

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

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

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

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

$$f_c = (n/\sqrt{i})^{0.6}$$

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

$$d(x_1)/dt = x_2 \qquad (13)$$

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

These equations is expressed in matrix form as

$$dX/dt = F(X) \qquad (15)$$

Expanding eq. (14) using Taylors series

$$F(X) = F(X^*) + A(X^*)\ (X - X^*) \qquad (16)$$

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

$$dX/dt = A(X^*)X + F(X^*) - A(X^*)X^* (17)$$

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).

4.2 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_c 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_c are chosen by trial and error or optimization technique such that the best match between observed and simulated hydrograph is obtained.

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CHAPTER 5

CONCLUSIONS

5.0 CONCLUSIONS

A conceptual model for real-time inflow forecasting for the Machhu-II dam has been applied on the Machhu catchment. The parameters have been adjusted for the basin and from the results, the model performance seems satisfactory. An interactive software for flood regualtion of Machhu-II has been developed. Inflow forecasting is one of its modules The software is PC-based which can be easily installed at the dam control station. The system can provide inflow forecasts using the hydro-meteorological data, can assist in decision making for reservoir operation as well as spillway gate regulation.

It may be emphasized here that the software presented here is aimed to assist the operator or the decision maker; it is not to replace them. It may happen sometime that the decision maker, who is supposed to be well versed with the system, feels that the computer generated results are not the true indicator of the actual situation. In such a case, he may over-rule the computer provided he has sufficient and strong reasons to do so.

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Practice of Flood Forecasting Technology in the Ishikari River Watershed, River Hydraulics and Hydrology Section, Civil Engg. Research Institute, Hokkaido Development Bureau, Japan, 1990.

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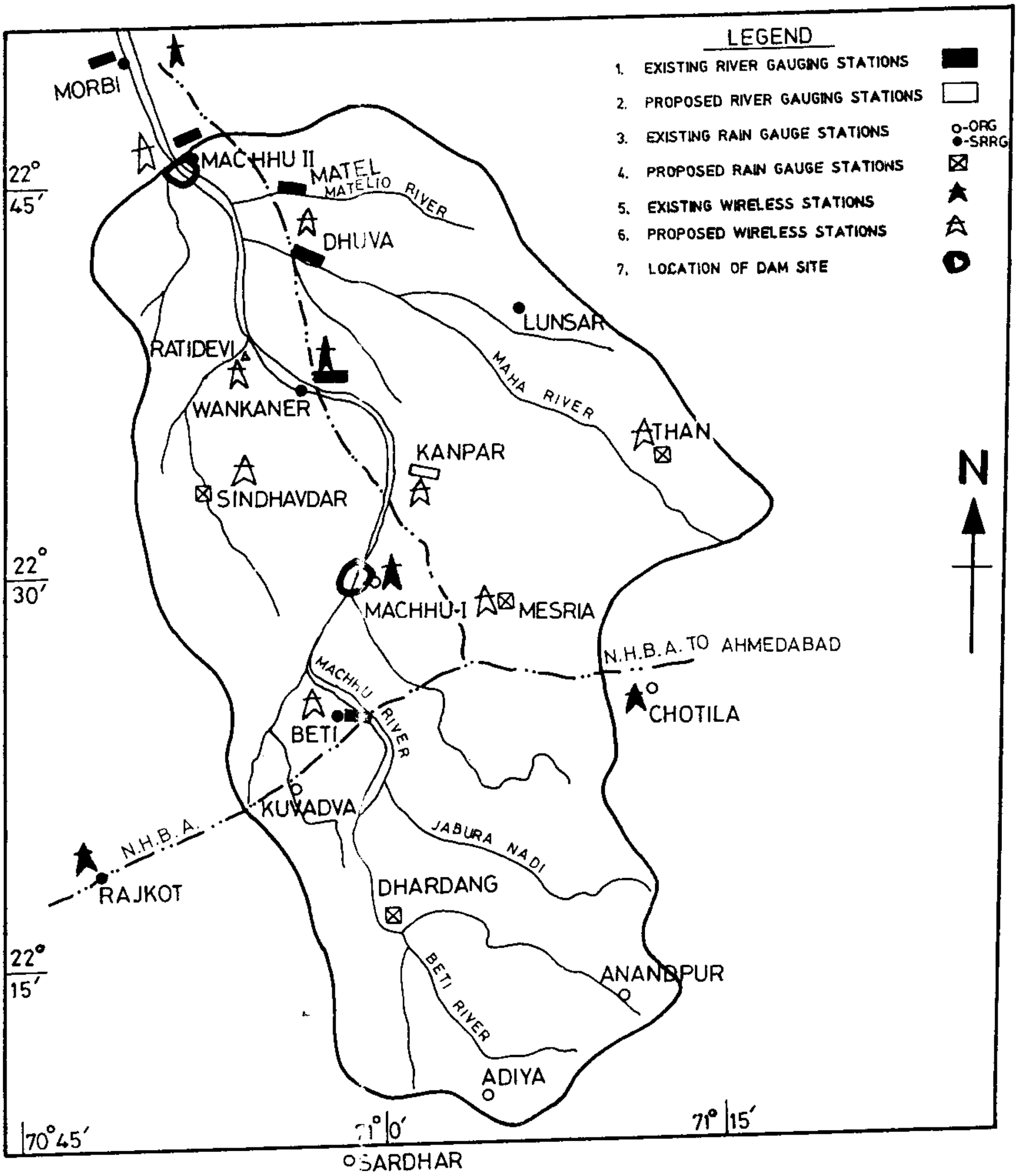


FIG. 1 INDEX MAP OF MACHHU BASIN UPTO MACHHU II DAM

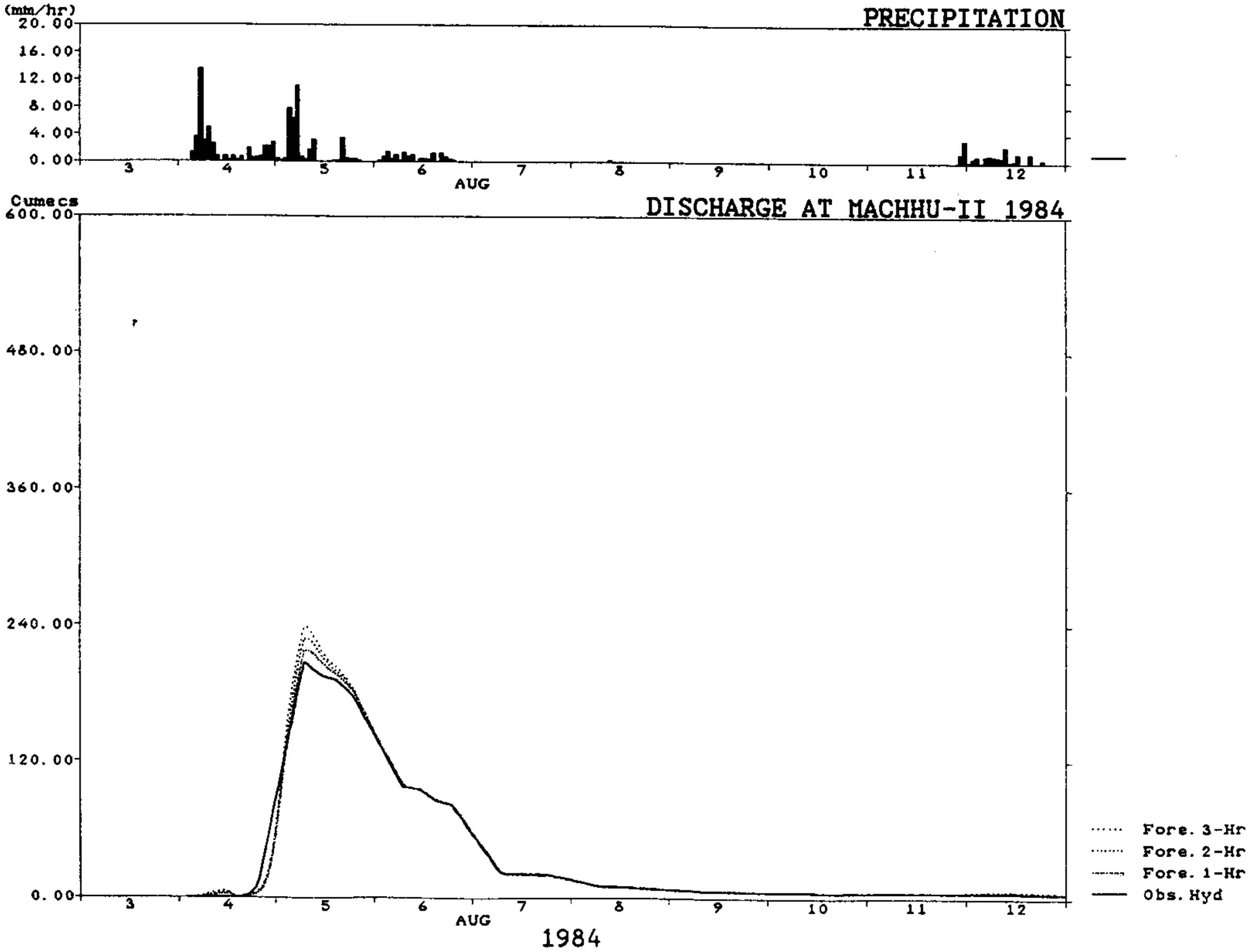


Fig 2 Plot of Observed & Forecasted Discharge and Precipitation for an event in Aug. 1984

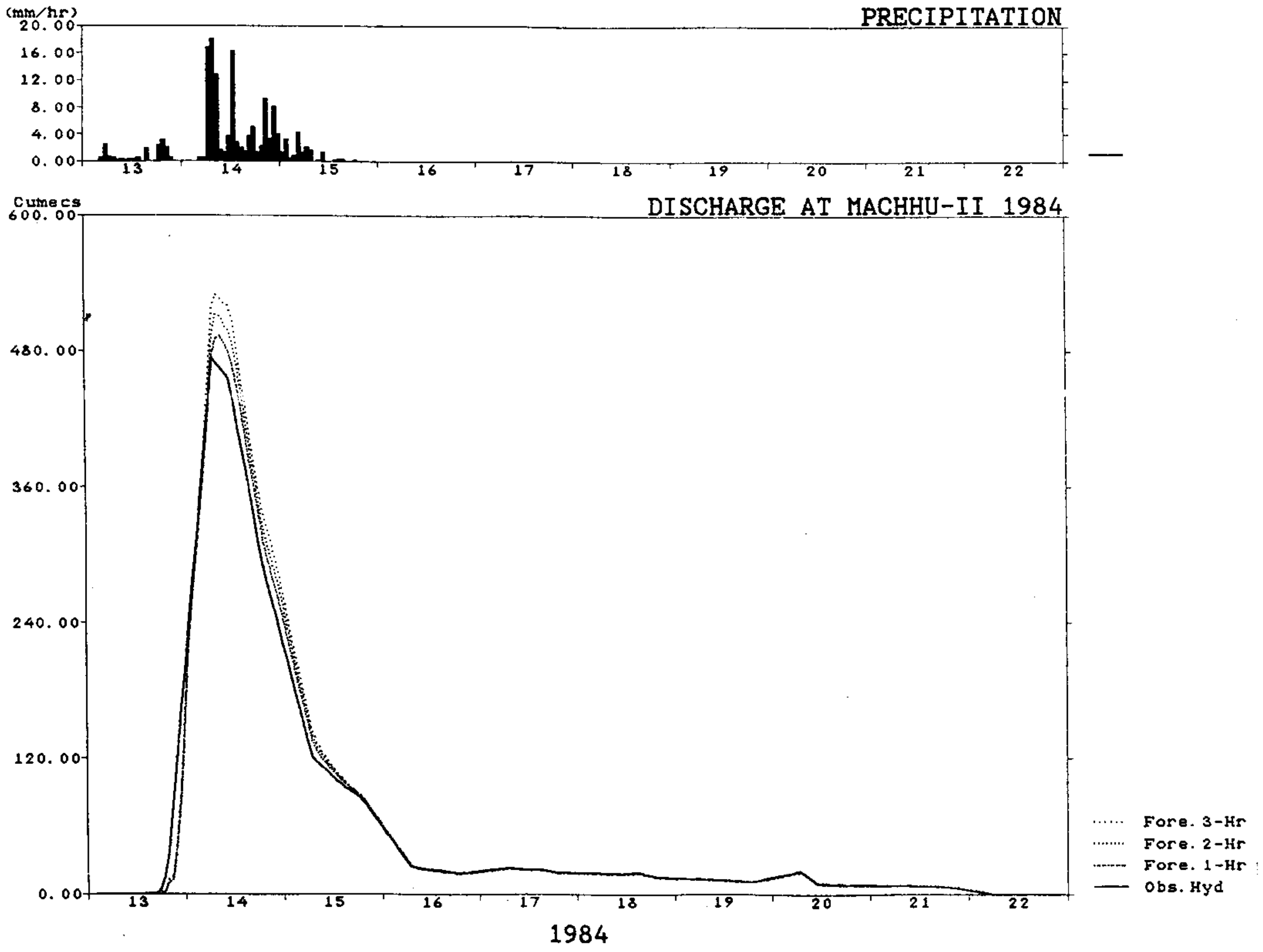


Fig 3 Plot of Observed & Forecasted Discharge and Precipitation for an event in Sept. 1984

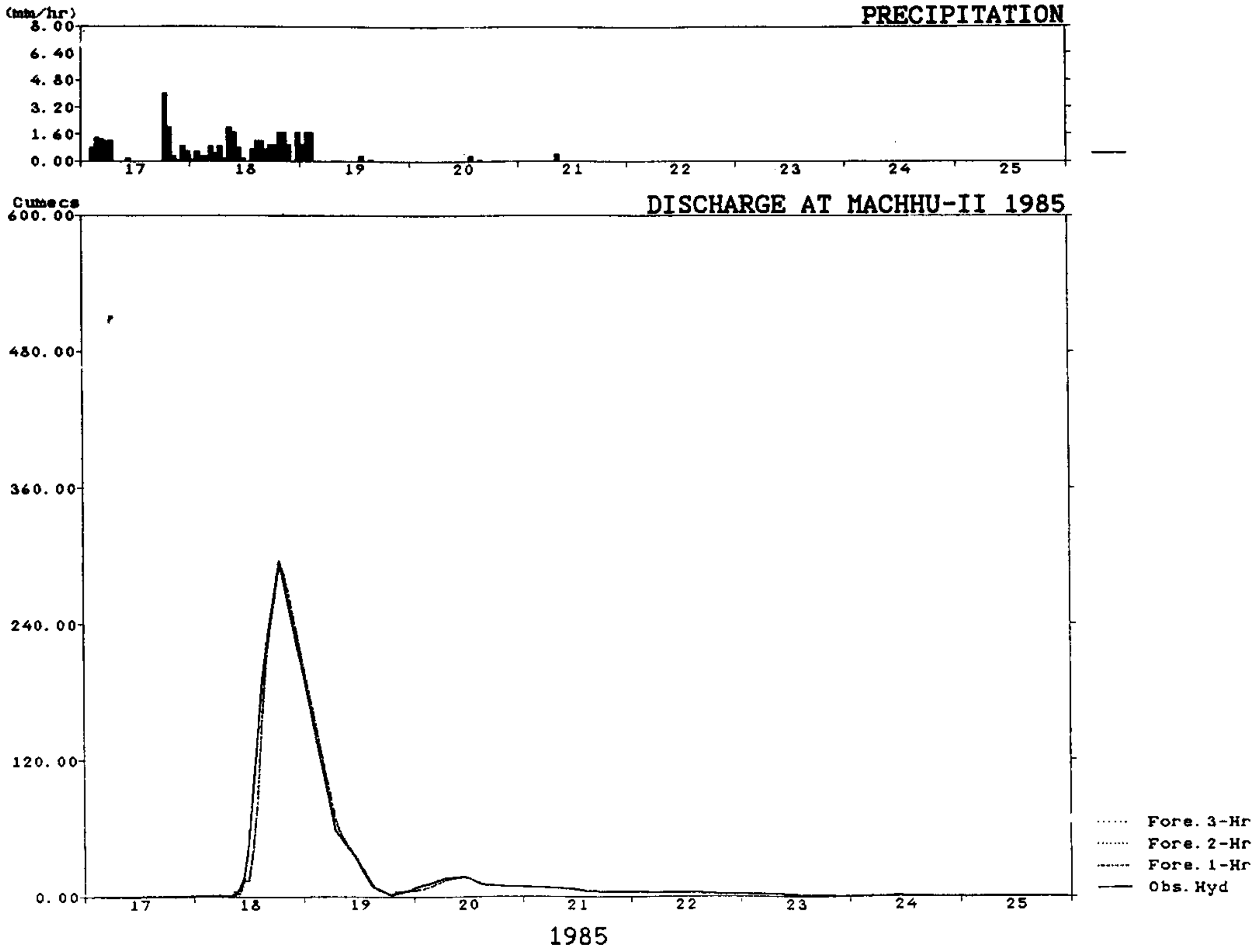


Fig 4 Plot of Observed & Forecasted Discharge and Precipitation for an event in July 1985

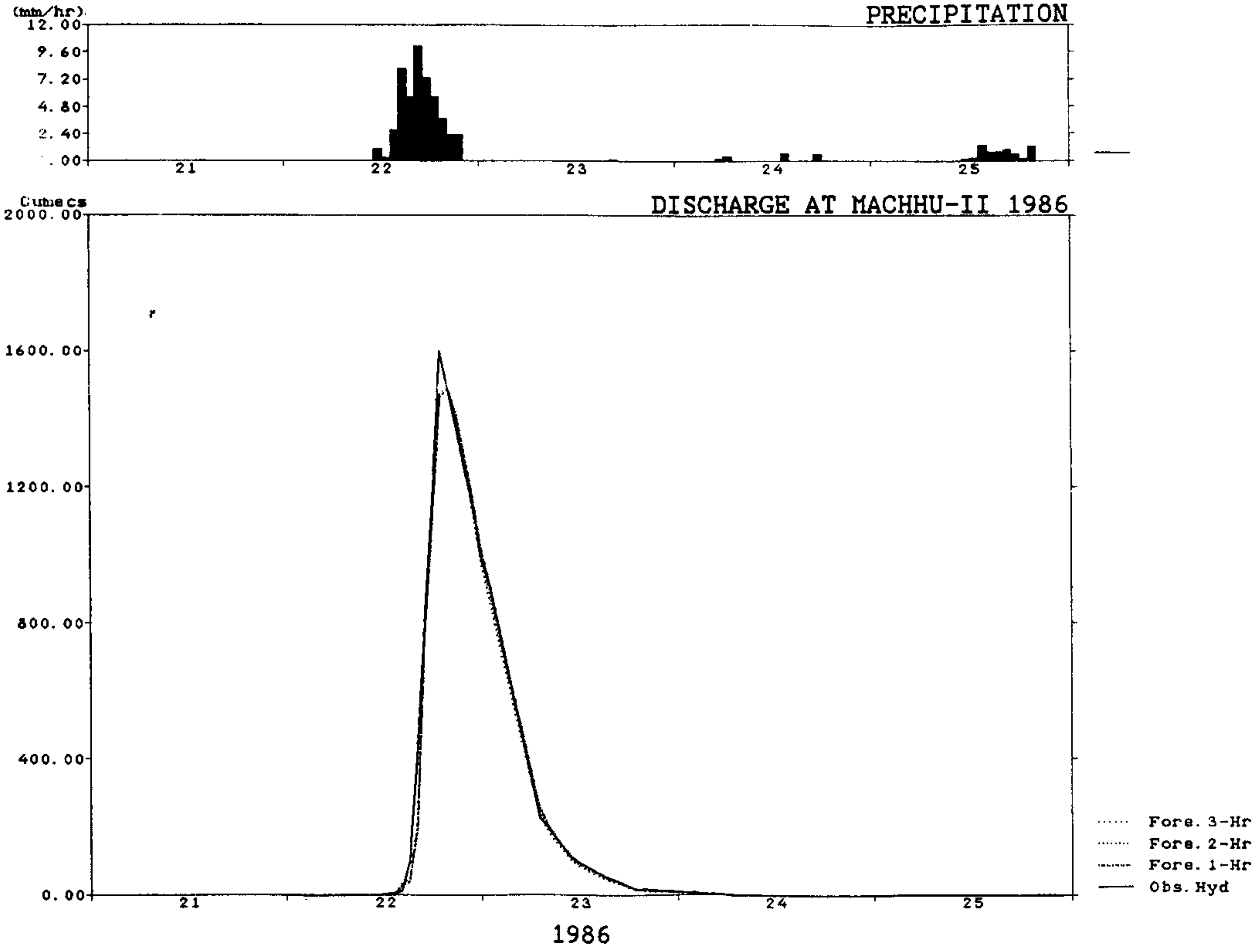


Fig 5 Plot of Observed & Forecasted Discharge and Precipitation for an event in June 1986

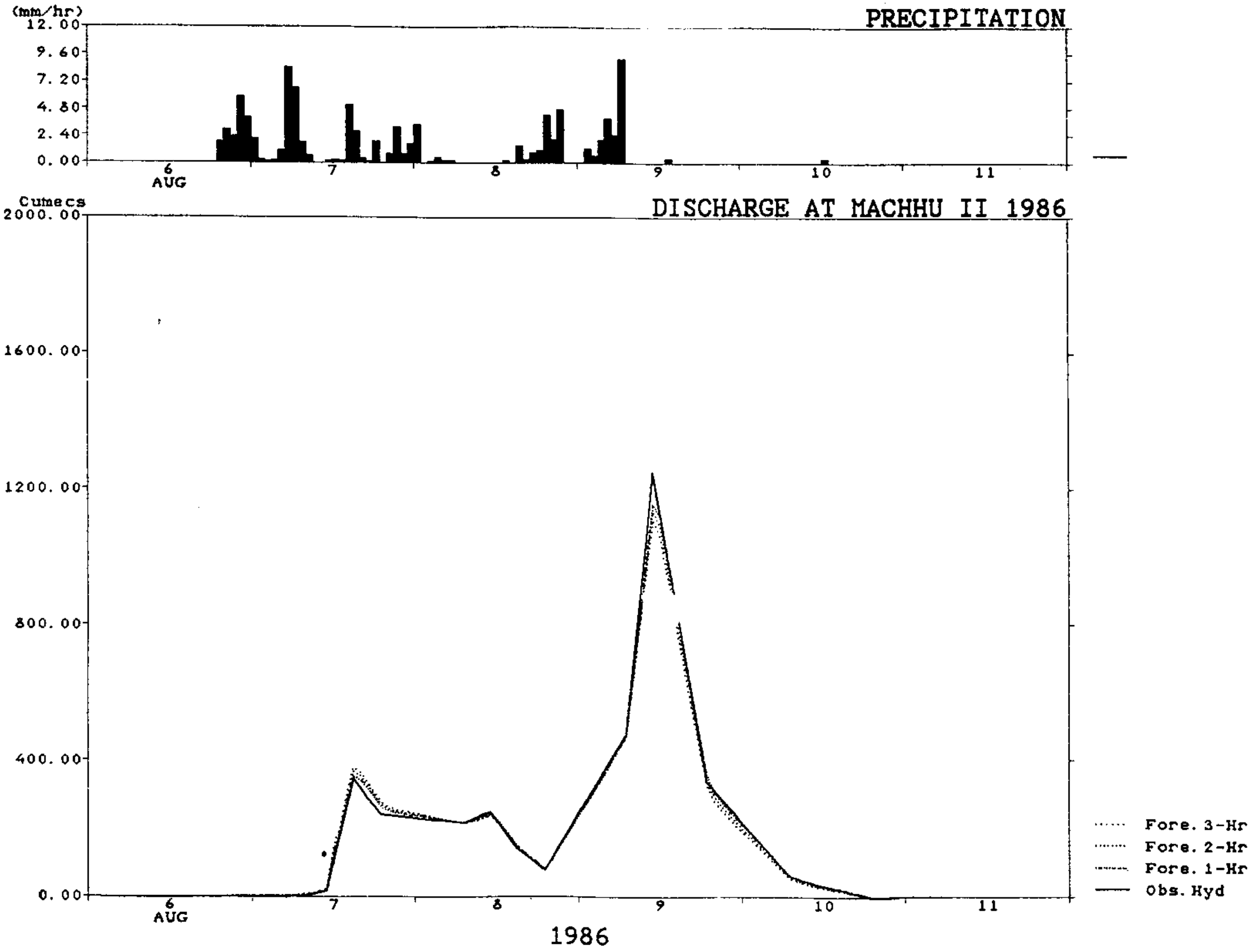


Fig 6 Plot of Observed & Forecasted Discharge and Precipitation for an event in Aug. 1986

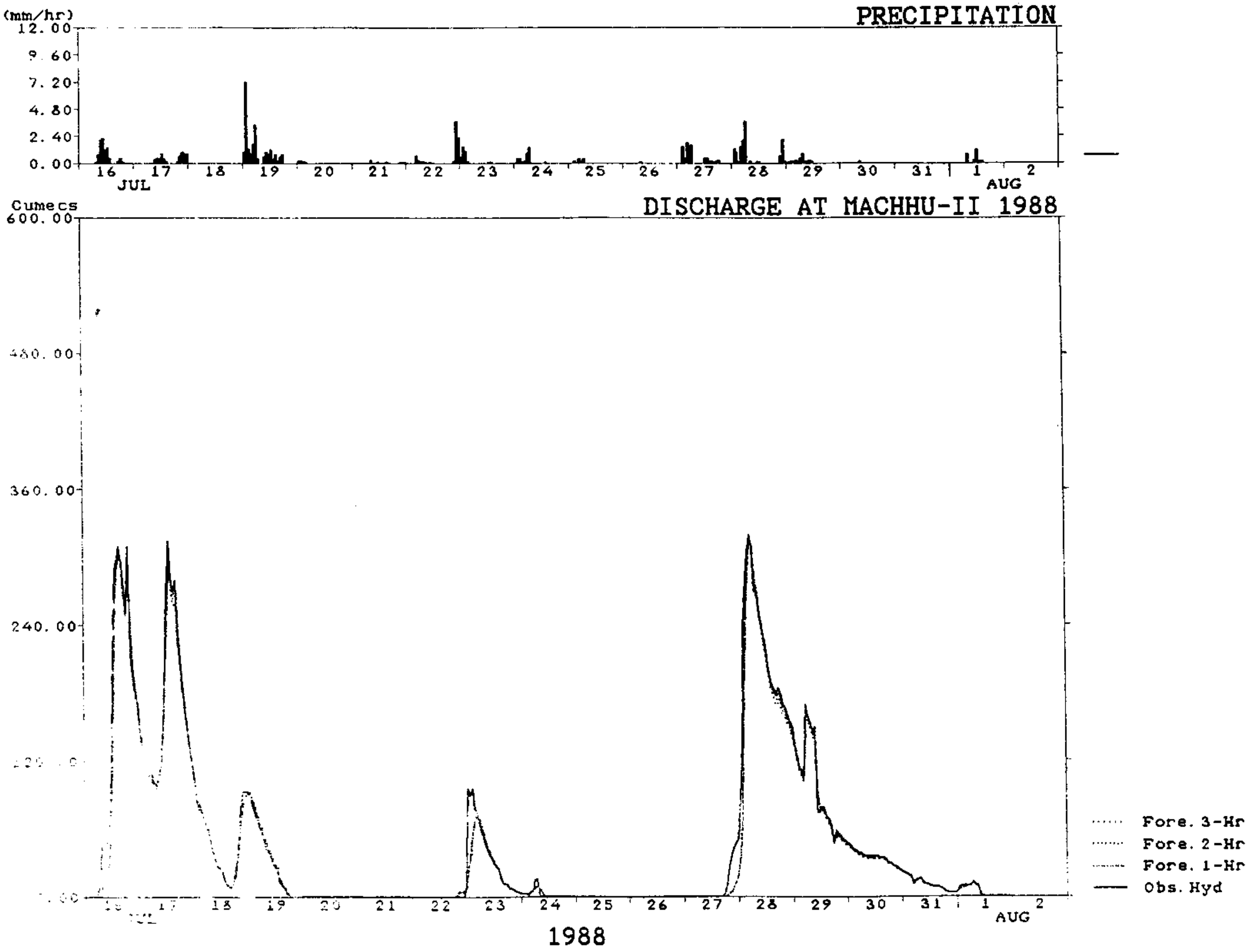
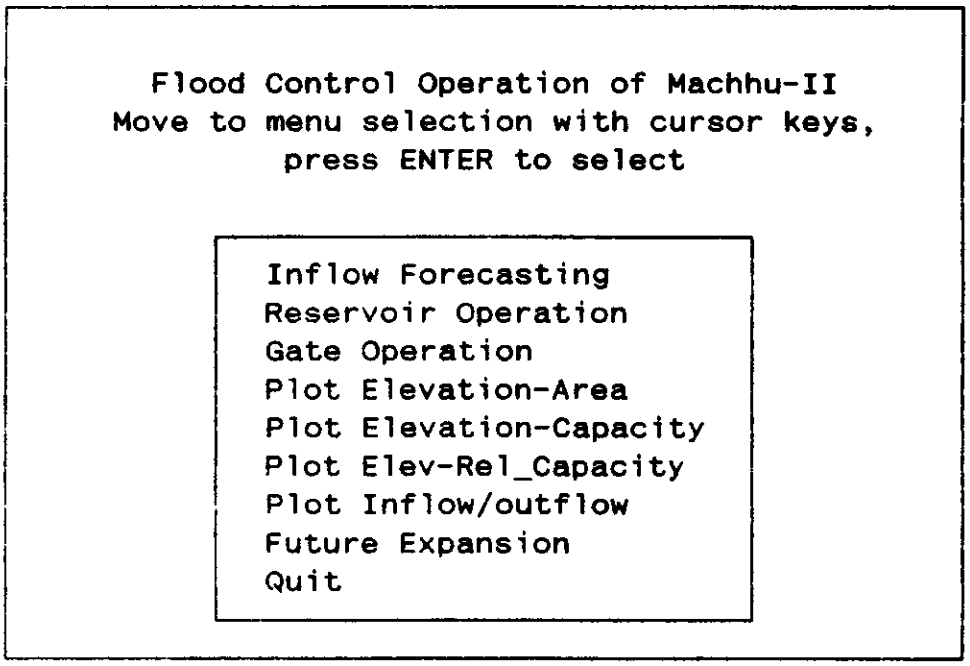
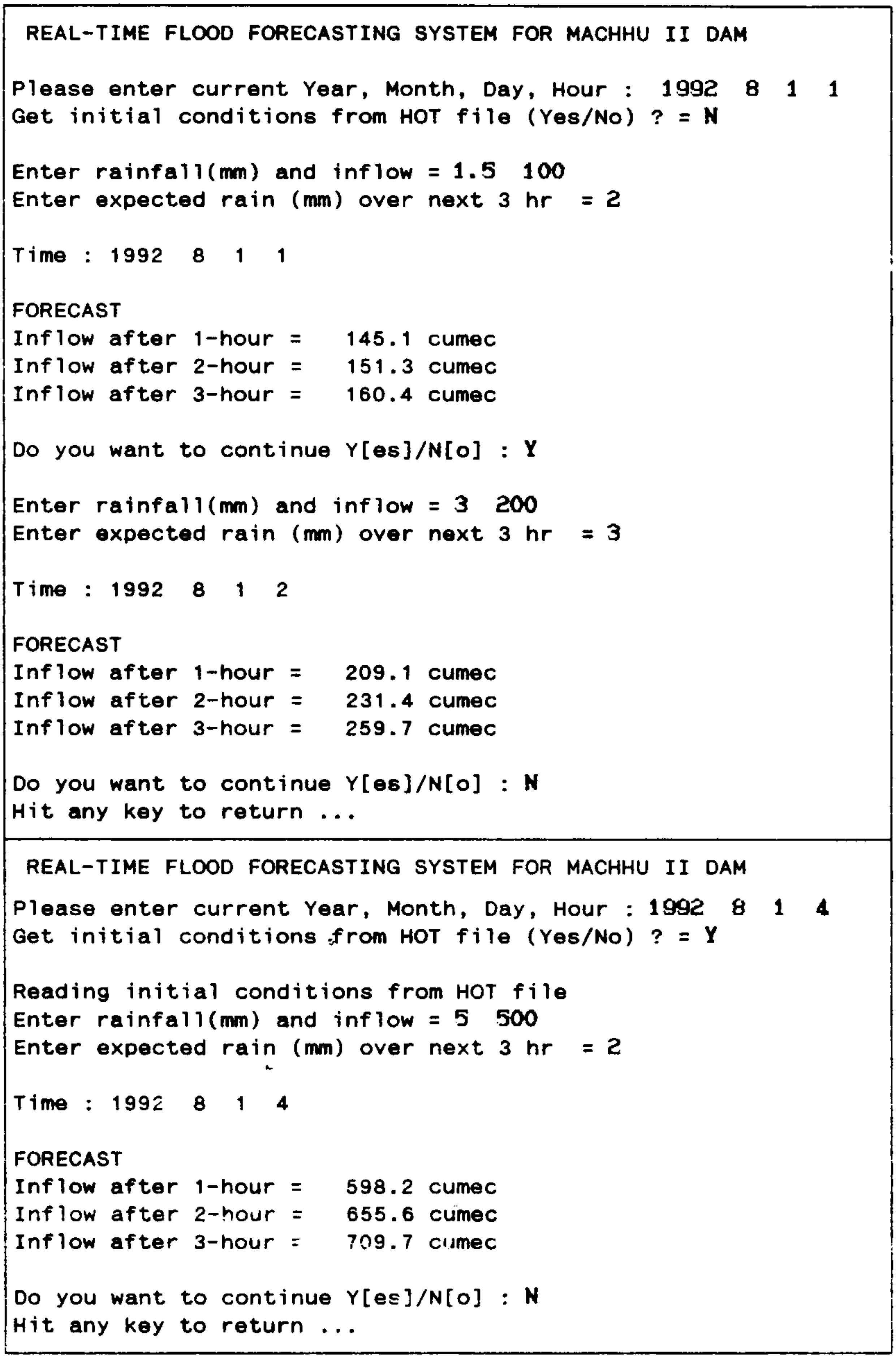


Fig ' Plot of Observed & Forecasted Discharge and Precipitation
for an event in July 1988



Flood Control Operation of Machhu-II
Move to menu selection with cursor keys,
press ENTER to select

Fig. 8 Opening Menu Screen of the ROSS system



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 REAL-TIME FLOOD FORECASTING SYSTEM FOR MACHHU II DAM

Please enter current Year, Month, Day, Hour :  1992  8  1  1
Get initial conditions from HOT file (Yes/No) ? = N

Enter rainfall(mm) and inflow = 1.5  100
Enter expected rain (mm) over next 3 hr  = 2

Time : 1992  8  1  1

FORECAST
Inflow after 1-hour =   145.1 cumec
Inflow after 2-hour =   151.3 cumec
Inflow after 3-hour =   160.4 cumec

Do you want to continue Y[es]/N[o] : Y

Enter rainfall(mm) and inflow = 3  200
Enter expected rain (mm) over next 3 hr  = 3

Time : 1992  8  1  2

FORECAST
Inflow after 1-hour =   209.1 cumec
Inflow after 2-hour =   231.4 cumec
Inflow after 3-hour =   259.7 cumec

Do you want to continue Y[es]/N[o] : N
Hit any key to return ...
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 REAL-TIME FLOOD FORECASTING SYSTEM FOR MACHHU II DAM

Please enter current Year, Month, Day, Hour : 1992  8  1  4
Get initial conditions from HOT file (Yes/No) ? = Y

Reading initial conditions from HOT file
Enter rainfall(mm) and inflow = 5  500
Enter expected rain (mm) over next 3 hr  = 2

Time : 1992  8  1  4

FORECAST
Inflow after 1-hour =   598.2 cumec
Inflow after 2-hour =   655.6 cumec
Inflow after 3-hour =   709.7 cumec

Do you want to continue Y[es]/N[o] : N
Hit any key to return ...
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Fig 9   Sample Sessions with inflow forecasting module