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Operational Hydrologic Forecasting and Real Time Reservoir Operation

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Abstract : *For whatever purpose the reservoirs are designed and operated it can be served much better if hydrological forecasts are available. Hydrological forecast can be short term, medium term, long term or seasonal. While short term forecasts are more reliable, the reliability decreases for forecasts of longer duration. There are a number of conventional and modern procedures including time series for forecast of flows. Reservoirs can be operated more efficiently for flood control by use of forecasts through prereleases without affecting the conservational benefits. A model for such an operation is discussed in the paper. Conservational benefits can be increased by using inflow forecasts in case these are available with reasonably good reliability. With the advancement in technology of forecasting and the associated techniques of operation the benefits derived from the reservoirs can increase considerably.*

1. INTRODUCTION

Forewarned is forearmed. It is true for reservoirs also. If hydrologic forecast related to a reservoir is known, the reservoir can serve much better the conservational or non conservational purpose. Forecasts are sometimes necessary even for safety of the dams. Inflow forecasting is, of course, a very important factor influencing the operation of reservoirs but forecasting of demand from reservoirs can also result in considerably higher efficiency in operation. The emphasis in this paper, however, is on forecasting of flows which form inflow to the reservoir and operation of reservoirs with such inflows.

The purpose for which reservoirs are built can be broadly grouped into two categories, conservational and non conservational. Conservational uses include water supply for irrigation and other uses, hydropower generation, recreation, fisheries development etc. where it is desirable to store as much water as possible during surplus season and use it during the lean season. Flood control is a non conservational use of reservoir where emphasis is on short term regulation of river flows rather than conservation of water. Hydrologic forecast helps in operation of reservoir in different ways for different purposes. It also helps in maximizing the benefits derived from operation of a reservoir meant for both the purpose of conservation and flood control.

It is not enough to have reliable hydrological forecasts. Systematic procedures and mathematical models are often necessary to use the forecasts and envolve efficient real time operational criteria. Such models should take into account current and forecasted inflows, demands, state of the reservoir, release and spill capacity related to reservoir state, downstream flooding, safety of the dam and other related structure and any other relevant factor. In case of short term operations the model calculations should be done quickly so as to provide enough time for taking decision and carrying out physical operations. Computers may be a very useful tool in such situations.

2. HYDROLOGIC FORECASTING

Hydrologic forecasting can be short term (upto 2 days), medium term (2-10 days), long term (beyond 10 days) or seasonal (several months) according to the classification of WMO (1983). Short term forecasts have higher reliability and these are often used for operation of reservoir. Long term forecasts which are related to meteorological conditions have low reliability inspite of extensive use of high technology of remote sensing, numerical techniques and electronic instrumentation in the area of weather prediction. Due to the low reliability long term or seasonal forecasts are not very useful in operation of reservoirs.

Short term forecasting is common for use in flood forecasting and reservoir operation for flood control. Such forecasts can be based on observed river flows at an upstream point and routing it to the downstream station where forecast is required. The routing can be by a simpler hydrologic procedure based on conservation of mass or more complex hydraulic models based on conservation of mass and momentum, involving solution of differential equations of unsteady flow in open channels. The forecast in either of the two cases is limited to the travel time between the two stations. This time can be increased considerably by using catchment response models which use precipitation as input, in addition to routing of flows. An extensive description of practical conventional and modern procedures and models of flood forecasting including application of some of these in India is given in the Manual on Flood Forecasting (CWC 1989).

One of the means of short term forecasting is by use of time series analysis and stochastic modeling. Earlier methods of forecasting were based on the last observed value or a mean value from a historical record. Later the concept of moving average was introduced. Exponential smoothing of errors can be used but a more flexible and systematic method of smoothing errors and making short term forecasts is by means of the Box-Jenkins models (Kottegoda, 1983). These models are useful for generating likely future sequences but are effective for immediate future because the variance of the forecast function increases with time.

An alternative to Box-Jenkin models, overcoming some of its limitations, are the adaptive types & where model parameters are updated prior to forecasting using the previous estimates of the model parameters and a function of the prediction error process. This way the models can cope with short term non stationary behaviour.

Time series analysis has also been used for long term forecasting consisting of seasonal or monthly forecasts (Thomas and Fiering, 1962), Rosener and Yevjevich, 1966. Chander et al. (1980) used time series models of ARIMA category for monthly forecasts of the Krishna and Godavri rivers. Seth (1986) describes various aspects of long term forecasting including low flow forecasting and concludes that operationally reliable methods for use in hydrological forecasting are yet to be evolved.

3. RESERVOIR OPERATION FOR FLOOD

Flood control can be one of the important functions of a reservoir. However, reservoirs are rarely constructed solely for flood control. Often flood control is combined with conservational purposes like hydropower generation and water supply for irrigation and other uses. In such cases a conflict arises between the two types of uses. While conservational use requires reservoirs to be filled as soon as possible during the monsoon season, flood control benefits are derived when reservoirs have empty storage space to absorb the likely floods during the monsoon. In some reservoirs a solution to the conflict is sought at the design stage when a fixed amount of storage in the top portion of reservoir is reserved for use as flood control and the storage below this zone is used for conservational purposes. Reservoirs of Damodar Valley Corporation have provision of such exclusive flood control zones. Often the storage capacity of a reservoir is shared for conservational and flood control purposes and flood control storage zone capacity varies with time in a year instead of being fixed. Estimation of flood control storage requirement during various time periods forms part of the operation of reservoir. It is here where forecast of inflow into reservoir plays a very vital role in increasing the flood control efficiency without reducing the conservational benefits.

3.1 Prerelease

In case of a reservoir with variable flood control storage zone, the reservoir could be either at full conservation storage level or below that level when flood wave strikes it. In the situation when it is at the top of conservation level the flood benefits can be derived by making additional release from the reservoir in anticipation of flood before the flood actually strikes. Such a release is called prerelease. Prerelease makes storage space available in the reservoir to absorb part or whole volume of incoming flood.

Prerelease can be effective even if reservoir is at levels lower than the full conservation level when the flood wave strikes the reservoir. In such a situation the storage space created due to prerelease is in addition to the storage space available between the maximum water level and the current reservoir level.

It is important to determine the amount of prerelease at any instant of time. The prerelease will depend on the forecast values of inflow, amount of storage space available in the reservoir, safety considerations of dam, release capacity and downstream flooding. Since most of these parameters change with time the process of estimation of prerelease is a dynamic one. Prerelease can be estimated in the beginning of a discretised time period and updated at the end of the period. The underlying principle in estimating the amount of prerelease is that the expected inflow upto a foreseeable time ahead is greater than or equal to the prerelease upto that time. It is therefore necessary to estimate the volume of water that is likely to come in the reservoir.

3,2 Expected inflow volume

The expected volume of inflow into the reservoir can be considered in two parts. The first is the forecasted part of inflow and second is the recession that follows the last forecasted value of inflow. If the maximum time of forecast T is divided into n discretised time periods of duration $t_1, t_2, \ldots t_n$, and average inflow during these periods is $I_1, I_2 \ldots I_n$, the total volume of inflow V_1 can be estimated as follows.

$$V_1 = \sum_{i=1}^{n} I_i t_i \qquad (1)$$

A better approximation of inflow volume can be obtained by using trapezodial rule or by fitting a curve. The likely arrangement of forecasted inflows and recession is shown in Figure 1

The recession graph in Figure 1 can be assumed as an exponential decay function (USACE, 1959). This function is given as

$$I_t = I_n C_r^t \qquad (2)$$

Where I_n is the Initial flow for the recession graph which is same as the last forecsted value (n=4 in Figure 1)

I_t is the flow after time t, and

C_r is a constant known as coefficient of recession

The inflow volume V_2 under this recession curve is given as

$$V_2 = \int I_n C_r^t \, dt \qquad (3)$$

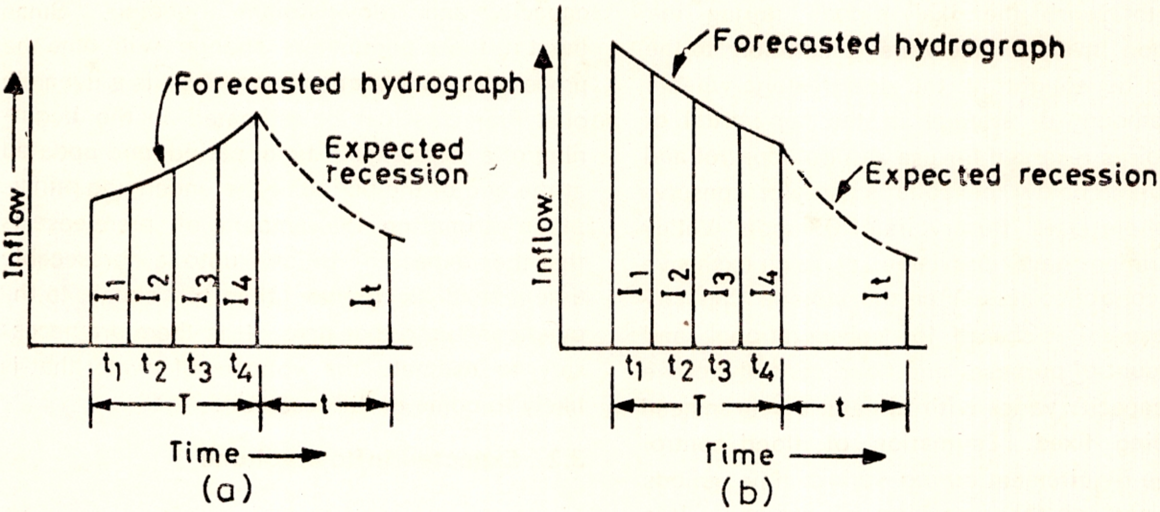


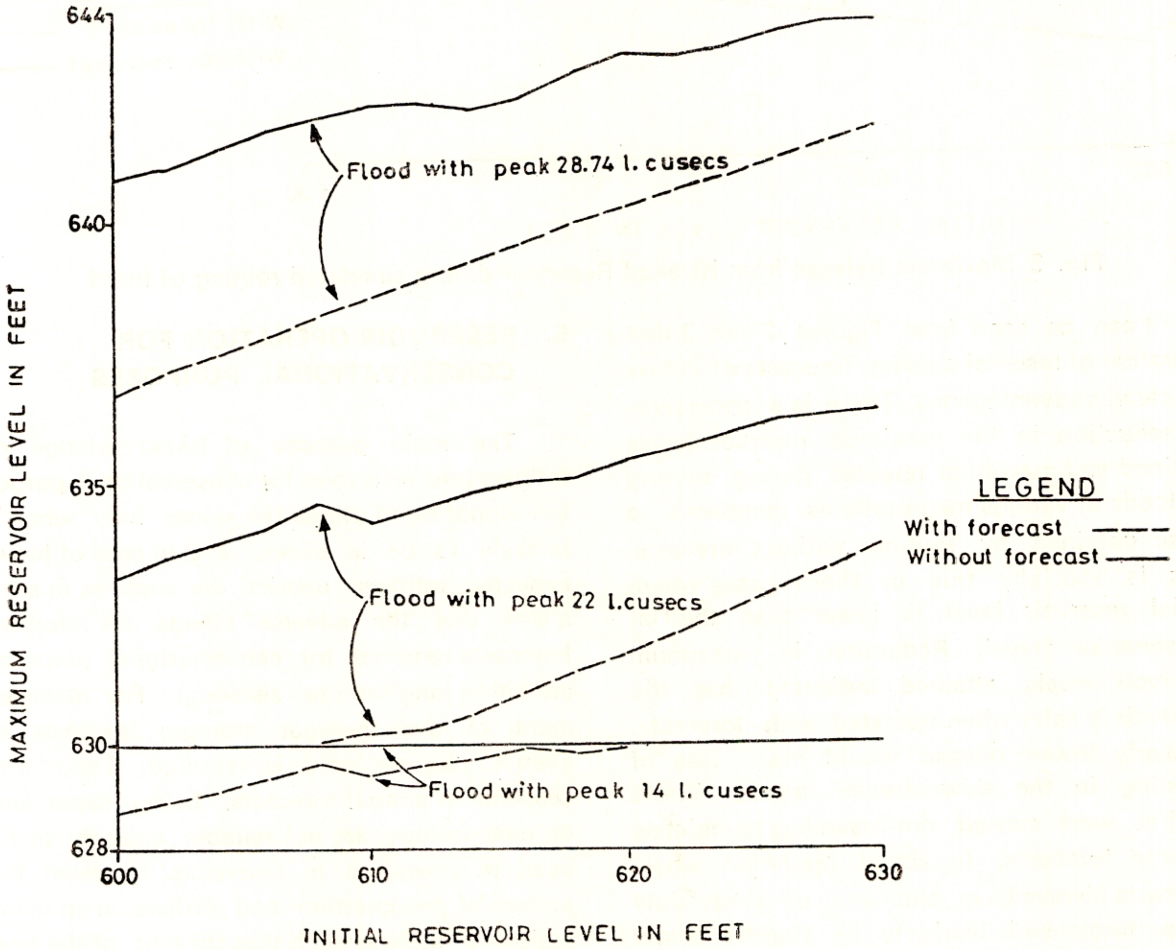
Fig. 1 Inflow into reservoir, forecasted and due to recession during, (a) rising and (b) falling of flood hydrograph.

Total volume of inflow during the time T+t is V_1+V_2 where V_1 and V_2 are as given in Equations (1) and (3). While T in Eq. (1), representing the forecasting time, is fixed, t has to be decided by the operator or the modeler. Moreover, at the end of each time period, say t_1, a new value of inflow forecast is available at time period T ahead. Alongwith this the remaining values of forecast may also be revised. This will result in another estimate of the set of volumes V_1 and V_2. Depending on V_1, V_2 and the storage space available in the reservoir at any instant of time the value of prerelease can be determined on the basis that the volume of prerelease plus the storage space in the reservoir equals V_1+V_2. A complete derivation for estimation of V_2 including determination of t and detailed procedure of dynamic estimation of prerelease is given by Khaliquzzaman and Chander (1992).

4. HIRAKUD STUDIES

Hirakud reservoir is used mainly for the conservational purpose of hydropower generation and irrigation supplies. Flood control is attempted by keeping the reservoir at levels lower than the full conservation level during earlier part of the monsoon. Thus a variable flood control zone is created in the reservoir. The reservoir has a special problem. The spillway capacity is much less than the peak of the estimated design flood hydrograph. Safety of the long earth dam is also a primary concern in operation. Therefore, operation of Hirakud reservoir using forecast of inflow and prerelease can help not only in better flood control but also in saving the dam in case of excessively large floods. Khaliquzzaman (1987) showed that with a 24 hour forecast and the associated prerelease the peak discharge can be reduced to 80% as compared to the routing without forecasts in case of a large flood striking the reservoir when it is full. The procedure used in this study was further improved to make it more generalised so that real time flood routing operations can be started from any reservoir level instead of only from the full reservoir level (Khaliquzzaman and Chander, 1992)

Khaliquzzaman and Chander (1992) also describe an interactive PC-based computer program with graphic display for real time operation of Hirakud reservoir using the model described briefly in Section 3. The program contains all the features and data of the reservoir. On feeding the current state of the reservoir and current and forecasted values of inflow it suggests releases and provides sluice and spillway gate opening sizes for the release. Reservoir with water levels, inflow and release hydrographs, gate openings and complete information on state of the reservoir after the release is displayed on the monitor of PC. There is a provision to repeat computations with different values of inflow forecasts to account for uncertainty in the forecasts. Using this program, floods of different magnitudes were routed in simulation runs to study the effect of operation with forecasts and prerelease. Design flood with a peak value of 28.74 lakh cusecs and two proportionately reduced floods of peak values of 22 lakh cusecs and 14 lakh cusecs were routed at different initial reservoir levels with four six-hourly (24-hour) forecasts of inflow to study the effect on maximum reservoir levels attained and the maximum releases from the reservoir. The results of the simulated routing with the conventional procedure and with forecasts are plotted in Figures 2 and 3.



Fig, 2 Maximum Hirakud Reservoir Levels during simulated routing of floods

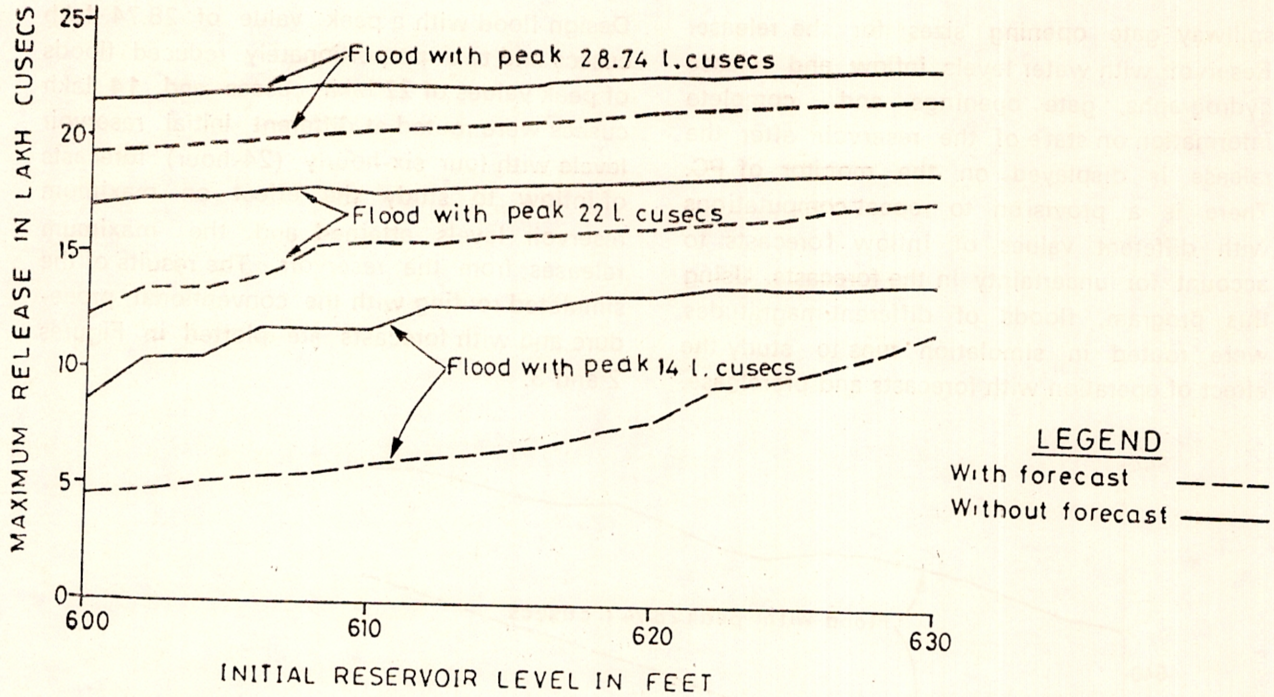


Fig. 3 Maximum Release from Hirakud Reservoir during simulated routing of flood

It can be seen from Figures 2 and 3 that operation of reservoirs using forecasts of inflow are clearly advantageous. There is a considerable reduction in the maximum reservoir levels attained and maximum releases during routing of floods of various magnitude as compared to those obtained by routing without forecasts. This is specially true in those cases where initial reservoir level is lower than the full conservation level. Reduction in maximum reservoir levels attained indicated that the reservoir is safer when operated with forecasts. Similarly lower release would mean less of flooding in the downstream areas. These studies were carried out assuming completely reliable forecasts. In actual operation where forecasts always have elements of uncertainty the performance is likely to be slightly below those indicated here. The 24-hour forecast used in the studies can be obtained by channel routing only. In case catchment rainfall and catchment response models are used the forecasting time can increase considerably and performance of reservoir by operating with forecasts would be better than those indicated in these studies.

5. RESERVOIR OPERATION FOR CONSERVATIONAL PURPOSES

The main purpose of foreknowledge of inflows into reservoirs for conservational purposes would be to utilise the water fully when it is likely to be in excess and in case of lower expected inflows, restrict the supplies in such a way that the adverse effects are minimal. Forecasts required for conservational purposes are either long term or seasonal. For management of over-the-year storage, forecasts of even a year or more is required, Long term, seasonal or annual forecasts, being dependent on meteorology, are not reliable enough to be used in operation of reservoirs However the pattern of precipitation and utilisation in many regions of India is such that for part of the year reservoirs can be operated with foreknowledge of water availability.

Most of the inflow into reservoir on non snow-fed rivers occur during the summer monsoon period. Winter rains are generally scanty and unreliable. Depending on the availability of water in the reservoir at the end of the monsoon season, the supplies for the subsequent Rabi season can be planned and any shortfalls can be distributed in such a way as to minimize the associated adverse effects. One of the ways is to distribute it as uniformly as possible, resulting in shortfalls of small magnitude spread over a large number of periods. The optimum distribution of shortfalls can be achieved by use of optimization models which can consider long periods of inflow and demand as shown in a planning exercise by Khaliquzzaman (1992). In real time operation such distribution is possible only with complete foresight which is yet to be developed. The real problem in reservoir operation in absence of forecasts is for Kharif supplies during short term failures of monsoon, when inflow into the reservoir decreases and demand rises.

In case of reservoirs on snow-fed rivers a substantial part of inflow comes from snowmelt during the nonmonsoon period. Forecast of snowmelt runoff can help in operation of such reservoirs. National Remote Sensing Agency has been engaged in forecasting of snowmelt runoff into Bhakra reservoir using satellite imageries of the snow cover in the catchment. Since these forecasts depend mostly on the snow cover and not on meteorological factors affecting the rainfall, these are expected to be reliable enough for use in operation of Bhakra reservoir.

6. CONCLUSIONS

Reservoirs can be operated much more efficiently if hydrological forecasts are available and utilised. Significant advancement has been made in the field of hydrological forecasting. Short term forecasts are available with good reliability. This is specially true in case of forecasting based on river routing. These forecasts, in conjunction with a suitable procedure or model, can be used to great advantage in short-term operation of reservoirs. Long term, seasonal or annual forecasts, specially those dependent on meteorological conditions are not very reliable. Use of forecasts in operation of reservoirs for conservational purposes, which generally require longer term forecasts, is therefore limited. With rapid advances in related sciences it is expected that in times to come hydrologic forecasts would be available for longer periods and with greater reliability and using these forecasts it would be possible to operate the reservoirs much more efficiently even for conservational purposes.

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