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Dynamic rule curves for flood control of a multipurpose dam

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Abstract

The balance of using the normal retention capacity of a multipurpose dam between flood control and conservative objectives is usually necessary for operating its reservoir. This paper proposes dynamic flood control rule curves (DFCRCs) for the dam whose reservoir size is too limited to manage the uncertainty in design flood occurrence by current practice (i.e., flood control rule curves, FCRCs). The DFCRCs effectively adjust the allocated spaces of the limited reservoir to satisfy both referred purposes for each predicted flood. Hence, an approach for computing the DFCRCs is composed of a combination of a flood prediction model and a storage routing method. The prediction model estimates the volume and peak properties of an arriving flood, and takes a design flood with its characteristics being equal to the estimates as the expected one. The DFCRCs of the predicted flood are calculated using the storage routing method. The computational approach for the DFCRCs of a small multipurpose reservoir against a wide range of floods has been developed to assess their operational performances by comparing with those of the existing FCRCs. Results have indicated that the operational performances of the DFCRCs and the FCRCs are equally acceptable for an extremely large flood of return period >10,000 yrs. However, when dealing with the flood of recurrence interval ranging from 200 yrs to 3 yrs, the DFCRCs are better because they successfully secure the dam, protect the areas downstream from being inundated, and meet the water demands during consecutive dry season.

Keywords: Multipurpose dam; Reservoir operation; Dynamic flood control rule curves (DFCRCs); Storage routing method; flood prediction model

1. Introduction

Multipurpose dam is an important engineering infrastructure for the management of floods and droughts in a watershed area. In general, the dam of sufficient height with storage space clearly allocated for conservative purpose (e.g., hydropower generation, irrigation, water supply, industry, salinity control, recreation, and environmental preservation) and flood control objective can be built if the geological and topographic features at its location and the availability of project funds permit. The total effective capacity of such a reservoir is the sum of normal retention storage and flood control space. However, the size of most multipurpose reservoirs is usually limited for accommodating project design flood separately, and the additional space taken from the retention capacity is often used to serve this limitation. The space sharing between both referred objectives leads to the conflict in using the reservoir storage because the satisfaction of the conservative purpose requires the reservoir to be filled to the maximum extent possible whereas the fulfillment of the flood control objective is best met when sufficient vacant space is available in the reservoir. The balance use of the retention capacity between the conservative and flood control purposes is necessary to be resolved, while developing its operation strategies (James and Lee, 1971). If the flood control purpose is emphasized on using more reservoir space than the conservative objective is, a higher risk on water shortage in the following dry season will result because of less conservative storage allocated.

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Flood control rule curves (FCRCs) are usually an accepted practice in allocating the reservoir space of a multipurpose dam with the conflicting characteristic to both flood control and conservative purposes. The FCRCs generally define the amount of empty space be kept available or that of desirable storage for managing a flood of known or expected magnitude over a specified time interval (e.g., weekly, biweekly, or monthly period). Most previous investigations focused on determining the FCRCs of a system of interconnected reservoirs (Mariën, 1984; Kelman et al., 1989; Mariën et al., 1994), and rebalancing them in response to anticipated climate variability and change (Lee et al., 2009, 2011). To ensure the safety of the multipurpose dams, these FCRCs are usually derived from the total hydrographs of project design floods based on the hypothesis that each incoming flood might develop as the design flood (Developments in Water Science, 2003). The vacant reservoir space defined by the obtained FCRCs will be entirely utilized if the current flood turns out to be the same as the design flood. Further, as the design flood is an unusually large event, the schedule of the FCRCs will normally afford a satisfactory moderation of most floods.

The application of the FCRCs is limited to the multipurpose dam whose reservoir capacity is sufficient for managing the uncertainty in design flood occurrence. That is, the remaining conservative storage allocated for each time interval by the FCRCs must be greater than or equal to the total water demands of successive dry season. Such storages ensure the satisfaction of the conservative purpose even when the design flood does not arrive as expected. However, if the conservative storage of any period is less than the desirable water requirements, the adequacy of water available for the next dry season will depend on the magnitude of arriving flood hydrograph. The application of the FCRCs to a large flood is possible to compensate for the storage deficits during the time interval. Nevertheless, they likely fail to meet the dry-season water demands, due to insufficient inflows to fully fill the conservative storages as expected by the FCRCs. Note further that the frequency on the shortage of water is rather high because the return period of this flood is small.

This paper therefore proposes dynamic FCRCs (DFCRCs) for a multipurpose reservoir system whose capacity is inadequate to handle the uncertainty in design flood occurrence. The proposed DFCRCs effectively use the limited reservoir space for flood control and conservative purposes by adapting their flood control levels to suit each predicted flood. Hence, the DFCRCs are calculated by first predicting a total hydrograph of incoming flood based on a set of referred design floods for various return periods, and subsequently routing the predicted flood through the reservoir to meet its flood control and conservative purposes. It is shown in the present paper that the DFCRCs are advantageous over the existing FCRCs in the regulation of a small multipurpose reservoir because the operational performances of the DFCRCs for prevention of flood and drought are satisfactory against a wider range of inflow hydrographs than those of the FCRCs.

2. Computational approach for dynamic flood-control rule curves

As described earlier, DFCRCs are necessary for storage allocation to flood control and conservative objectives of a small multipurpose reservoir. The DFCRCs provide the guidelines on judicious use of its available reservoir space during each predicted flood event to insure the safety of the dam, and to reduce flood and drought damages at control areas downstream as much as possible. Such flood control and conservative benefits are considered in a storage routing method for deriving the DFCRCs of the predicted flood hydrograph. Hence, a combination of a baseline storage-routing method and a flood prediction model is briefly presented for calculating the DFCRCs as follows.

2.1. Flood prediction model

Several flow forecasting techniques; such as rainfall-runoff model, time series analysis, and artificial neural network (see, e.g., Dawson et al., 2002; Sivakumar et al., 2002; Baareh et al., 2006; Chetan and Sudheer, 2006; Joorabchi et al., 2007); are available in water resource literature. These existing techniques generally aim to forecast the flows for a short period (e.g., a few days) ahead. The referred short-period-forecasting objective is, however, different from that required by a flood prediction model of this computational approach because the model needs to predict the total hydrograph of incoming floods.

A flood prediction model that anticipates the total hydrograph of arriving flows based on a set of design floods for various return periods is therefore developed in the present study. The developed model is generally divided into 2 parts. The first part deals with the development on a method to estimate the volume and peak discharge properties of the incoming flood hydrograph for characterizing its size. The second part is the establishment of design-flood-characteristic diagram as a reference for expecting the total hydrograph of predicted flood (Boonyasirikul, 2004; Sookchom, 2004). The procedure for building the prediction model is briefly described as follows.

2.1.1. Estimation of flood volume and peak discharge

Let $\mathbf{X} = [x_\tau]$ be an actual flood hydrograph consisting of a series of observed consecutive flows x_τ for day $\tau = 1,2,\ldots,n$ ($n =$ the time base of $\boldsymbol{X}$), and ℓ be the time-to-peak of $\boldsymbol{X}$. Also, denote V as the flood volume characteristic which is the sum of all successive flows $\boldsymbol{X}$ during the n-day time base and define P as the maximum flow property of $\boldsymbol{X}$. These flow properties V and P are usually used for sizing the flood hydrograph $\boldsymbol{X}$.

The estimation of the flood characteristics in the first part of the flood prediction model starts with describing the flood volume V. To obtain the descriptor for the volume property V, its above mentioned definition, which is the total amount of cumulative flows over the period of n-day time base, is considered. Fig. 1 depicts the series of the cumulative daily flows for 2 different flood hydrographs $\boldsymbol{X1}$ and $\boldsymbol{X2}$ whose