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Multiple duration limited water level and dynamic limited water level for flood control, with implications on water supply

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Summary With water shortages occurring in semi-arid areas of the world, the need for multipurpose reservoirs that can, under the requirement of reservoir safety, store sufficient water for supply during dry seasons is becoming egregious. In order to increase water storage of a reservoir while maintaining its security for flood control, two approaches, multiple duration limited water level and dynamic limited water level, are proposed in this study. Contrary to traditional annual limited water level, multiple duration limited water level employs a multiple duration design storm. When a large storm takes place in the first part of multiple duration, the likelihood of another large storm to be occurring in the next part of the duration diminishes. Based on this intuitive reasoning, this study proposes a dynamic limited water level for flood control based on conditional probabilities of large storms. In order to obtain these conditional probabilities, a multivariate autoregressive model with lag one [AR(1)] is chosen for extending multiple duration rainfall series. Using Menlou drainage area in China as an example, multiple duration limited water level and dynamic limited water level for flood control are applied and their benefits for water supply are discussed.

Introduction

Multipurpose reservoirs are used for flood control, water supply, hydropower generation, recreation, fisheries, and tourism. Flood control and water supply, which may be equally important in semi-arid areas, correspond to two different reservoir water levels, as shown in Fig. 1. One is

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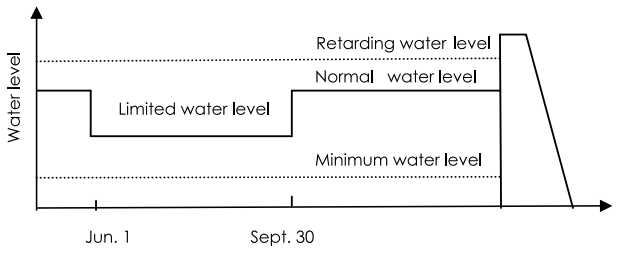

Figure 1 Annual limited water level (suppose the flood season is from June 1st to September 30th).

the limited water level which is used for flood control (hereafter, it is called limited water level unless there is a risk of confusion), which should not be surpassed by the water level during the flood season. The storage between the limited water level and the retarding water level is used for flood storage. The other water level is the normal water level, which is the highest water level under ordinary reservoir operation. The storage between normal water level and minimum water level is the active storage and is used for water supply. For the most effective use of a reservoir, the limited water level is lower than the normal water level (Maidment, 1993; Wurbs and James, 2002).

In Shandong province of the People's Republic of China (henceforth called China), the flood season in any year is deemed to last from June 1st to September 30th. The limited water level is determined using the annual design storm or annual design flood (whose design frequency or return period is chosen according to the importance of the reservoir) through reservoir regulation, and it has only one value for the whole flood season. Generally, this kind of limited water level is named as annual limited water level. At the beginning of the flood season, June 1st, if the water level in the reservoir is higher than the limited water level, the surplus water needs to be discharged out in order to secure the limited water level for flood control purposes. At the end of the flood season, September 30th, runoff is stored in the reservoir till the water level reaches the normal water level.

Application of the annual limited water level or the only-one limited water level for the whole flood season gives rise to two problems for water supply purposes of the reservoir. One problem occurs when the flood season is delayed, i.e., the flood season starts after June 1st, say, for example, July 1st (hereafter it is called delayed flood season). For this delayed flood season, water shortage may take place between June 1st and June 30th, because of the reduced or low rainfall during this period and the corresponding need for increased water supply. Another problem occurs when the flood season ends earlier than the normal flood season, i.e., the flood season ends before September 30th, say, for example, August 30th (hereafter it is called short flood season). For this short flood season, there will be less rainfall after September 30th than in the normal flood season. In this situation, the water level may not reach the normal water level and water shortage might occur for the whole of the following water supply season.

Observations of rainfall from 1964 to 2001 in Menlou drainage area in China show that for storms greater than 50 mm, the proportion of storms to those of the whole flood season is 0% in the first ten days of June; 1.33% in the second ten days of June; 44% in the third ten days of June and July; 49% in August and 5.39% in September (Shandong Water Resources Conservancy Bureau, 1999). These observations show that the short flood season and the delayed flood season frequently occur in Menlou drainage basin. These two problems, short flood season and delayed flood season, also occur for other arid and semi-arid areas in China.

To address these two problems without reducing the degree of security of reservoir for flood control, two approaches, based on multiple duration limited water level and dynamic limited water level, are proposed. The paper is organized as follows. Section ''Multiple duration limited water level'' explains the concept and method of computation of multiple duration limited water level; and section ''Dynamic limited water level'' explains the concept and method of computation of dynamic limited water level. Using Menlou drainage area in China as an example, multiple duration limited water level and dynamic limited water level for flood control are analyzed in section ''Application''. Benefits and risk analysis are briefly discussed in section ''Benefits and risk analysis'', and conclusions and recommendations are summarized in last section.

Multiple duration limited water level

Multiple duration design storm

During flood season, weather changes gradually in China with rainfall also changing gradually. It then follows that design storm and limited water level for flood control during the flood season should also change gradually. In other words, the design storm for the whole flood season (hereafter called annual duration design storm or annual design storm derived from annual duration peak series) may be comprised of several different duration design storms, such as weekly duration design storms (or weekly design storms) and monthly duration design storms (or monthly design storms). Here the ''duration'' means the period in which the largest daily rainfall (or 24-hour rainfall or 3-day rainfall) is chosen. Compared with annual duration which consists of lots of weekly durations or monthly durations, the weekly duration or monthly duration is called multiple duration. In the same way, weekly design storms or monthly design storms are called multiple duration design storms. Annual design storm is used to compute annual limited water level. In a similar manner, multiple duration design storms can be used to compute multiple duration limited water levels. This means that the sole annual limited water level for the whole flood season can be replaced by several multiple duration limited water levels, such as weekly duration limited water levels or monthly duration limited water levels.

Analogous to annual design storm, which is computed from annual maximum rainfall series by frequency analysis, multiple duration design storms are computed from multiple duration maximum rainfall series, and this is discussed in sections ''Frequency distribution of multiple duration maximum rainfall series'' and ''Computation of multiple duration design storm for flood control''. Like annual limited water level, which is computed from annual design storm through reservoir regulation, multiple duration limited water levels are computed from multiple duration