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Probabilistic Risk Assessment of Reservoir Operation

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ABSTRACT

The objective of this study was to provide a probabilistic risk assessment of the reservoir operation for the Shihmen Reservoir. The probability-based assessment was achieved by coupling a deterministic network flow reservoir operation model and a stochastic reservoir inflow simulation model. Stochastic inflow simulation was composed of a Poisson model for typhoon occurrences, a bivariate-gamma typhoon flood flow simulation model, and an ARMA(1,1) model for non-typhoon daily inflow simulations. Yearly series of simulated 10-day-period reservoir inflows were used in reservoir operation simulation using the network flow model. Results of reservoir operation simulation were then used for reservoir operation evaluation. It was found that the risk of agricultural water shortage was highest in February and lowest in September. The simulation results can also facilitate a drought frequency analysis.

KEY WORDS: Reservoir Operations; Network Flow Model; Flow Simulation

INTRODUCTION

From time to time, Taiwan experienced droughts which resulted in various degrees of water shortage in different seasons and different regions. Although a sound reservoir operation practice can alleviate the economic losses of water shortages, effects of reservoir operation are highly variable due to the random nature of reservoir inflow. Reservoir operations in Taiwan are based on rule curves which generally provide satisfactory results. However, there have been concerns about the performance of reservoir operations based on rule curves, and quantitative evaluations of reservoir operations have been conducted. For instance, Huang et al. (2000) used simulation methods to evaluate the operation rule curves of the Shihmen reservoir. Using a minimum cost network flow model, Chou and Wu (2014) established a model, WRASIM, for reservoir operation simulation. The WRASIM model has since then been extensively used in reservoir operation simulation in Taiwan. In general, performance of the rule curves was often evaluated by simulating reservoir operations with the observed (deterministic) reservoir inflows series.

It is also desired to understand the risks of water shortage in different seasons and the probability of occurrences of hydrological droughts (Wilhite & Glantz, 1985) through a quantitative evaluation of the performance of reservoir operations. A critical issue in drought frequency analysis is that the sample size of observed droughts may be too small for a reliable estimation. In this study, a large number of simulated reservoir inflow series were used to circumvent the problem of sample size, and a network flow model was used to simulate the reservoir operation.

Besides the network flow model, other simulation and optimization models have also been used in simulating reservoir planning and management. The network flow model was chosen for this study because of (1) its capability of providing an upper bound of performance that can be achieved in reality (Yerrameddy and Wurbs, 1996); (2) its intuitive and tractable decision making framework; and (3) its superior computing efficiency among the optimization models.

METHODS

Synthetic Flows

Typhoons mostly occur during the summer season (Jluy – October) and flood flows induced by typhoons are much higher in magnitudes and variations than non-typhoon flows. Therefore, in this study, daily typhoon and non-typhoon flows were independently generated and then combined to form the synthetic daily flow series. Daily flows induced by individual typhoons were extracted from historical flow records by referencing to the warning periods of individual typhoons issued by the Central Weather Bureau and a lower threshold (185 m^3/s-day) of daily flows. Following the typhoon-induced flows, a period of flow recession which characterizes withdrawal of stored water was also considered for generation of typhoon flood flows. After removal of typhoon flows, the observed daily non-typhoon flow series were interpolated by a nonparametric method to fill in missing non-typhoon flows.

Typhoon daily flows. Daily inflows of the Shihmen Reservoir of the 1975-2013 period were analyzed. There were 101 typhoon occurrences in the 39-year period. Flood flows induced by these typhoons were characterized by four characteristic variables – (1) inter-event time, (2) event-total flow, (3) duration and (4) annual counts of typhoons. As shown in figure 1, the inter-event time represents the time span between two typhoons; duration represents the elapsed time length of a typhoon; the event-total flow is the total flow volume of a typhoon. Table 1 summarizes the probability distributions of these typhoon characteristic variables through the chi-square goodness-of-fit tests.