Water Science and Engineering, 2014, 7(4): 433-445
doi:10.3882/j.issn.1674-2370.2014.04.008

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e-mail: wse2008@vip.163.com

Simulation-optimization model of reservoir operation based on target storage curves

Hong-bin FANG[1], Tie-song HU*[1], Xiang ZENG[1], Feng-yan WU[2]

1. State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, P. R. China
2. Hubei Water Resources Research Institute, Wuhan 430070, P. R. China

Abstract: This paper proposes a new storage allocation rule based on target storage curves. Joint operating rules are also proposed to solve the operation problems of a multi-reservoir system with joint demands and water transfer-supply projects. The joint operating rules include a water diversion rule to determine the amount of diverted water in a period, a hedging rule based on an aggregated reservoir to determine the total release from the system, and a storage allocation rule to specify the release from each reservoir. A simulation-optimization model was established to optimize the key points of the water diversion curves, the hedging rule curves, and the target storage curves using the improved particle swarm optimization (IPSO) algorithm. The multi-reservoir water supply system located in Liaoning Province, China, including a water transfer-supply project, was employed as a case study to verify the effectiveness of the proposed join operating rules and target storage curves. The results indicate that the proposed operating rules are suitable for the complex system. The storage allocation rule based on target storage curves shows an improved performance with regard to system storage distribution.

Key words: *reservoir operation; joint operating rules; simulation-optimization model; improved particle swarm optimization*

1 Introduction

Inter-basin water transfer-supply projects are mainly meant to rectify the imbalance between supply and demand in the water shortage region, so as to realize appropriate allocation of water resources. For a multi-reservoir water supply system with transfer-supply projects, joint operating rules should answer three basic questions: (1) the amount of water to be diverted in a period; (2) the total amount of water supplied to meet the joint demands; (3) and the amount of water to be released from each individual reservoir. The three questions are connected to one another, so they should be addressed at the same time.

Operation policy is essential for reservoir operation as the impact of the operation on the society and economy is significant (Sui et al. 2013). Some types of reservoir operating rules

This work was supported by the National Natural Science Foundation of China (Grants No. 51339004 and 71171151).
*Corresponding author (e-mail: *tshu@whu.edu.cn*)
Received Jan. 13, 2014; accepted Aug. 5, 2014

have been discussed in previous studies (Lund and Guzman 1999).

Previous research on the water diversion rule to determine the amount of water to be transferred has mainly been focused on systems of separated recipient reservoirs without joint demands (Xi et al. 2010; Sadegh et al. 2010; Li et al. 2009).

Hedging rule curves are often employed to trigger the hedging rule, and are often applied in operation of a single reservoir to determine the release to meet the demands (Tu et al. 2003). However, for the multi-reservoir system with joint demands in this study, the reservoir aggregation method is an effective approach for transforming a multi-reservoir system into an equivalent reservoir (aggregated reservoir) (Brandão 2010; Guo et al. 2011b). The reservoir aggregation method performs well in determining suitable total release from a water supply system.

For parallel multi-reservoir water supply systems having joint demands, that is, downstream demands that can be satisfied by any one or more of the multiple reservoirs, two rules are usually used to define the spatial distribution of reservoir storage volumes (Oliveira and Loucks 1997). The space rule attempts to equalize the ratio of available space in each of the parallel reservoirs at the end of a period to the expected inflow into each reservoir during the remainder of the refill season, while the New York City (NYC) rule attempts to equalize the probability of filling of each reservoir. Both the space and the NYC rules attempt to avoid a situation in which some reservoirs are spilling over while others remain unfilled (Lund and Guzman 1999), but they cannot be applied directly and do not provide clear indications on how to operate a complex system that has several purposes and heavy constraints. There is another frequently used method in actual application, referred to as the compensation regulation rule (Guo et al. 2011a), by which small-capacity reservoirs in systems supply water to meet the joint demand first and then the remaining water is supplied by large-capacity reservoirs. Although operation by this rule is simple, the results are sometimes imperfect.

Additionally, most researchers just focus on one or two questions. Study of multi-reservoir systems including water transfer-supply projects should concurrently consider the three issues listed above.

In this study, an improved storage allocation rule based on target storage curves (Perera and Codner 1996; Lund and Ferreira 1996) is proposed. Join operating rules are also proposed based on a water diversion rule, a hedging rule based on an aggregated reservoir, and a storage allocation rule. A simulation-optimization model was established for a multi-reservoir system, including a water transfer-supply project, located in northern China. The improved particle swarm optimization (IPSO) algorithm (Jiang et al. 2007) in combination with the simulation model were employed to optimize the decision variables, including the key points of water diversion curves, hedging curves, and target storage curves. Different schemes, including other operating rules, were also implemented to simulate the operation of the system for verifying the reasonability and applicability of the proposed rules.