Optimal Operation of Water Distribution Networks under Water Shortage Considering Water Quality

Mohammad Solgi[1]; Omid Bozorg-Haddad[2]; Samaneh Seifollahi-Aghmiuni[3]; Parisa Ghasemi-Abiazani[4]; and Hugo A. Loáiciga, F.ASCE[5]

Abstract: Water shortages are caused by hydrological droughts and by the disruption of the operation of water distribution networks (WDNs). The water pressure and residual chlorine concentration are examples of quantitative and qualitative indexes, respectively, of a WDN's performance. This work considers quality and quantity variables simultaneously in the operation of WDNs under water shortages. An optimization model is developed to find the optimum water allocation schedule in WDNs. The objectives of the optimization model are maximizing the number of node-times in which the chlorine concentration is in the allowable range, and maximizing the number of supply nodes under desirable pressure. These objectives satisfy the principle of justice in water distribution under water shortage. The optimization model was solved for a real WDN under different scenarios using the honey-bee mating optimization (HBMO) algorithm linked to a hydraulic simulator. The performance of the developed model was compared to an operation rule based on standard operation policy (SOP) that allocates water among consumers based on constant priority of water supply. The results show that water-shortage operation affects water quality and decreases the chlorine concentration below the allowable minimum in the network, and that applying a water allocation schedule obtained with the developed optimization model minimizes this effect so that this allocation schedule maintains residual chlorine concentration mostly within the allowable range throughout the network. The optimized operation of the WDN satisfies consumer demands fairly under desired pressure while reservoir and hydraulic constraints are satisfied. **DOI: 10.1061/(ASCE)PS.1949-1204.0000233.**

Author keywords: Water distribution network; Water-shortage management; Water quality; Chlorine; Mathematical models; Optimization.

Introduction

Many recent publications dealing with newly developed models for water-shortage management have covered several domains of water resources systems, such as reservoir operation (Ashofteh et al. 2013a, 2015a, b), design-operation of pumped-storage and hydropower systems (Bozorg Haddad et al. 2014), levee layouts and design (Bozorg Haddad et al. 2015a), hydrology (Ashofteh et al. 2013b, 2015c), qualitative management of water resources systems (Bozorg Haddad et al. 2015b). However, very few reported models have focused on the optimal operation of water distribution networks under water shortage considering water quality.

[1]M.Sc. Graduate, Dept. of Irrigation and Reclamation Engineering, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, Univ. of Tehran, Karaj, 31587-77871 Tehran, Iran. E-mail: Solgi_Mohammad@ut.ac.ir

[2]Associate Professor, Dept. of Irrigation and Reclamation Engineering, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, Univ. of Tehran, Karaj, 31587-77871 Tehran, Iran (corresponding author). E-mail: OBHaddad@ut.ac.ir

[3]Ph.D. Candidate, Dept. of Irrigation and Reclamation Engineering, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, Univ. of Tehran, Karaj, 31587-77871 Tehran, Iran. E-mail: Seifollahi@ut.ac.ir

[4]M.Sc. Graduate, Dept. of Water Engineering, Univ. of Shahrekord, Shahrekord, Iran. E-mail: Parisaa.Gh@gmail.com

[5]Professor, Dept. of Geography, Univ. of California, Santa Barbara, CA 93016-4060. E-mail: Hugo.Loaiciga@ucsb.edu

Note. This manuscript was submitted on April 13, 2015; approved on November 4, 2015; published online on January 20, 2016. Discussion period open until June 20, 2016; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Pipeline Systems Engineering and Practice***, © ASCE, ISSN 1949-1190.

The possibility always exists that a water distribution network will be unable to fulfill demands because of the reduction of water resources due to hydrological drought, physical events, or intentional and inadvertent pollution (Solgi et al. 2015). Several studies have developed operating rules and optimization models to counter droughts (Barros et al. 2008; Wilchfort and Lund 1997; Xuning et al. 2010). Soltanjalili et al. (2013) reported water-demand management in which the allocation or nonallocation of water to each node of the water network at each time was considered as a decision variable of an optimization model. The purpose of the optimization model was maximization of the number of water supply nodes with desired pressure. The hydraulic network was simulated with *EPANET* (Rossman 2000), and the developed optimization model was solved applying the honey-bee mating optimization (HBMO) algorithm. Solgi et al. (2015) considered equanimity and justice principles for allocation of water among customers under water shortage and developed an optimization model to find the optimal allocation schedule that divides available water among customers fairly, so that the number of water supply nodes with the desired pressure was maximized.

In addition to quantitative indexes (such as water pressure), qualitative ones such as residual chlorine concentration in the network must be considered in the operation of municipal WDNs. There must always be a minimum concentration of chlorine in a WDN's water after treatment and during water conveyance to delivery points to ensure water with a desirable quality for human use. The chlorine concentration at injection stations must be enough to maintain adequate residual chlorine throughout the WDN. At the same time, water chlorination causes disinfection by-products (DBPs) such as trihalomethanes. The DBPs are carcinogenic and harmful to consumer health. Therefore, WND operators attempt to maintain the chlorine concentration in an allowable range