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Authors

Soleimani, Shima
Seifollahi-Aghmiuni, Samaneh
Loáiciga, Hugo A

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Shima Soleimani[1]; Samaneh Seifollahi-Aghmiuni[2]; and Hugo A. Loáiciga[3]

[1]M.Sc. Candidate, Dept. of Irrigation and Reclamation Engineering, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, Univ. of Tehran, Karaj, 3158777871 Tehran, Iran. E-mail: Shimasoleimani@ut.ac.ir

[2]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, 3158777871 Tehran, Iran (corresponding author). E-mail: Seifollahi@ut.ac.ir

[3]Professor, Dept. of Geography, Univ. of California, Santa Barbara, CA 93106-4060. E-mail: Hugo.Loaiciga@ucsb.edu

Zhu et al. (2014) developed a set of water-diversion strategies that consist of water-diversion rule curves, diversion flows, and supply rules to improve water diversion in inter-basin projects. The water-diversion rule curves involve hydrological-stage and water-level factors. An optimization model was constructed to minimize urban, agricultural, and ecological water shortages, and the decision variables were optimized by a genetic algorithm. Furthermore, three scenarios were defined including historical operation without any water diversions, regular operation with an even water diversion, and operation according to optimized water-diversion rule curves. The paper's authors presented a case study of the Biliu reservoir in China. They concluded that use of optimized water-diversion strategies dramatically reduce supply shortages, and suggested the design diversion capacity based on optimized analysis to range between 100 and 220 hm^3.

The following notes of this discussion are presented for consideration by Zhu et al. (2014) as suggestions for their paper and future related studies.

Optimization problems with objective function and constraints are defined as linear or nonlinear. Recently, many linear and nonlinear optimization models have been developed and applied in all aspects of water resources systems such as reservoir operation (Afshar et al. 2011; Bozorg Haddad et al. 2008b, c, 2009, 2011a; Fallah-Mehdipour et al. 2011b, 2012), cultivation rules (Moradi-Jalal et al. 2007; Noory et al. 2012), pumping scheduling (Bozorg Haddad and Mariño 2007; Bozorg Haddad et al. 2011b; Rasoulzadeh-Gharibdousti et al. 2011), water distribution networks (Bozorg Haddad et al. 2008a; Soltanjalili et al. 2010; Fallah-Mehdipour et al. 2011a; Seifollahi-Aghmiuni et al. 2011; Ghajarnia et al. 2011; Sabbaghpour et al. 2012), operation of aquifer systems (Bozorg Haddad and Mariño 2011), and site selection of infrastructures (Karimi-Hosseini et al. 2011). In a linear programming problem, the objective function and the set of constraints are linear mathematic equations. In nonlinear programing problems, all or some of the constraints, or the objective function, are nonlinear mathematic equations. In the paper by Zhu et al. (2014), the constraints and objective function [Eq. (1)] are linear equations. Applying a linear objective function in optimization problems may be disadvantageous, such as, for example, by increasing the vulnerability efficiency criterion. In this discussion the vulnerability efficiency criterion is applied to demonstrate that in order to meet water demands with high reliability in water systems threatened by drought, it is preferable to use quadratic and nonlinear objective functions.

In the operation of water-resources systems, failures do not have all similar severity and frequency. For instance, a $1 \times 10^6\ \mathrm{m}^3$ shortage is less impacting than a $5 \times 10^6\ \mathrm{m}^3$ shortage when the water demand equals $10 \times 10^6\ \mathrm{m}^3$ demand. To illustrate this argument, the vulnerability efficiency criterion (VEC) is useful. The VEC is expressed as a normalized sum of differences between water demands and releases during an operating period

$$\lambda = \frac{\mathrm{Max}_{t=1}^{T}(D_t - R_t)}{\sum_{t=1}^{T} D_t} \tag{1}$$

in which λ = vulnerability efficiency criterion during the operation period; R_t = reservoir release during t-th period; and D_t = water demand during the t-th period. A water system's vulnerability to shortages decreases with decreasing λ.

This discussion presents, for the sake of argument, a planning problem, in which reservoir inflows, water demands, reservoir storage, area, and water level variations with evaporation and precipitation are specified for twelve operating periods in Table 1. The planning problem is solved for one year in which periods are one month long. The objective is to minimize the water shortage rates in the water-supply system. The problem is solved first using a linear objective function, and, thereafter, it is solved using a nonlinear objective function applying the software *Lingo 11.0*. The two set of results corresponding to the solution of the water-planning problems with linear and nonlinear objective functions are presented in Fig. 1 and Table 2. Data for this example is shown on Table 1.

Alternative objective functions

$$\text{Minimize } f_1 = \sum_{t=1}^{T}(D_t - R_t) \text{ linear case} \tag{2}$$

Table 1. Problem Data

t	Q $(10^6\ \mathrm{m}^3)$	Ev (mm)	D $(10^6\ \mathrm{m}^3)$	S_{Min} $(10^6\ \mathrm{m}^3)$	S_{Max} $(10^6\ \mathrm{m}^3)$	$S(0)$
1	3.29	0.020	7.19	20 for all t	290 for all t	22 for all t
2	4.40	0.004	5.15			
3	10.29	−0.001	11.04			
4	10.73	−0.013	4.20			
5	9.82	−0.017	9.50			
6	11.76	−0.015	5.27			
7	6.58	−0.002	12.99			
8	3.11	0.006	8.88			
9	2.77	0.031	17.38			
10	2.40	0.039	10.51			
11	2.11	0.039	10.06			
12	2.04	0.037	7.99			

Note: D = water demand; Ev = evaporation–precipitation; Q = inflow to reservoir; t = time period.

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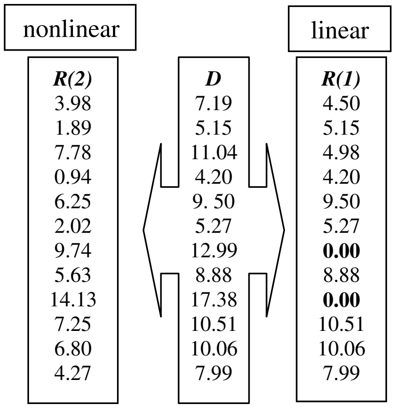

R(2)	***D***	***R(1)***
3.98	7.19	4.50
1.89	5.15	5.15
7.78	11.04	4.98
0.94	4.20	4.20
6.25	9. 50	9.50
2.02	5.27	5.27
9.74	12.99	**0.00**
5.63	8.88	8.88
14.13	17.38	**0.00**
7.25	10.51	10.51
6.80	10.06	10.06
4.27	7.99	7.99

Fig. 1. Monthly demands (D) and releases R (10^6 m^3) for linear (1) and nonlinear (2) cases

Table 2. Results for the Linear and Nonlinear Cases

t	$S(1)$ (10^6 m^3)	$S(2)$ (10^6 m^3)	Def(1) (10^6 m^3)	Def(2) (10^6 m^3)	$\lambda(1)$	$\lambda(2)$	f_1^*	f_2^*
1	22.00	22.00	2.69	3.26	0.15	0.029	515	127.3
2	20.76	21.32	0.00	3.26	overall	overall	overall	overall
3	20.00	23.82	6.06	3.26				
4	25.33	26.35	0.00	3.26				
5	31.89	36.17	0.00	3.25				
6	32.25	39.78	0.00	3.25				
7	38.78	49.57	12.99	3.25				
8	45.36	46.41	0.00	3.25				
9	39.57	43.87	17.38	3.25				
10	42.26	32.44	0.00	3.26				
11	34.05	27.50	0.00	3.26				
12	26.02	22.74	0.00	3.27				

Note: Def(1) = demand–release, linear case; Def(2) = demand–release, nonlinear case; $S(1)$ = reservoir storage, linear case; $S(2)$ = reservoir storage, nonlinear case; $\lambda(1)$ = vulnerability efficiency criterion, linear case; $\lambda(2)$ = vulnerability efficiency criterion, nonlinear case.

$$\text{Minimize } f_2 = \sum_{t=1}^{T} (D_t - R_t)^2 \text{ nonlinear case} \tag{3}$$

Constraints (apply to linear and nonlinear objective functions)

$$S_{t+1} = S_t + Q_t - Sp_t - R_t - L_t \quad t = 0, 1, 2, \ldots, T-1 \tag{4}$$

in which S_o = initial storage (known); and S_T = final storage.

$$L_t = Ev_t \times \left(\frac{A_t + A_{t+1}}{2}\right) \tag{5}$$

$$Sp_t \times \left(1 - \frac{S_t}{S_{\max}}\right) = 0 \tag{6}$$

$$A_t = k(S_t) \tag{7}$$

where k = function that converts storage (S_k) to reservoir water area (A_k)

$$0 \le R_t \le D_t \tag{8}$$

$$S_{\text{Min}} \le S_t \le S_{\max} \tag{9}$$

where f_1 = objective function in linear case; f_2 = objective function in nonlinear case; S_t = reservoir storage water volume; S_t = reservoir storage water volume with initial storage S_0; Q_t = inflow discharge to the reservoir; R_t = reservoir release; S_{Max} = maximum reservoir storage capacity; S_{Min} = minimum reservoir storage capacity; Sp_t = spillage; Ev_t = difference between evaporation and precipitation expressed as a depth of water; A_t = reservoir area; and L_t = volumetric difference between evaporation and precipitation. In addition, in Table 2, Def(1) and Def(2) are the reservoir shortages ($D_t - R_t$) rates for the linear and nonlinear cases, respectively; $\lambda(1)$ and $\lambda(2)$ are the reservoir VECs [Eq. (1)] for the linear and nonlinear cases, respectively; f_1^* = value of the optimized objective function in the linear state; f_2^* = value of the optimized objective function in the nonlinear case; $S(1)$ and $S(2)$ represent the reservoir storage in each period for the linear and nonlinear cases, respectively.

According to Table 2 and Fig. 1, the solution to the water-planning problem with linear objective function supplies 100% of the water demand in eight months, but at the same time, the system also endures severe failures and its VEC equals 15%, to be compared with a VEC about five smaller and equal to 2.9% in the nonlinear case. Furthermore, f_1^* is approximately four times more than f_2^*.

Zhu et al. (2014) added a d^i_{pub} parameter, the number of cumulative shortage periods to Eq. (2) in their paper to prevent causing consecutive water shortages, and attempted to minimize the latter parameter. The d^i_{pub} parameter only influences the resiliency efficiency criterion, but does not prevent serious failure in a water-supply system. Therefore, it does not improve the vulnerability efficiency criterion, which produces severe water shortages, as the results of this discussion example illustrate.

The results of Fig. 1 show there are no consecutive failures in the solutions corresponding to the linear case. Nonetheless, in the 7th and 9th months, the supply rates equal zero. These failure rates can cause severe stress in the water-supply system. Moreover, in many water-supply projects, the allowable supply percentage of demand is achieved using a nonlinear objective function.

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