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Stochastic operation analysis of irrigation reservoir in low-flow conditions: a case study from Eleviyan Reservoir, Iran

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Abstract: In Iran, an arid and semiarid country, the distribution of precipitation is irregular and uneven, making the replenishment of reservoirs difficult during periods of scant rainfall. In this paper, a method has been devised to make available the maximum amount of water for irrigation, drinking, and the flow regime of Sofi Creek. The optimal performance of the Eleviyan Dam was evaluated based on reservoir inflows. Before the construction of the dam, 21 years of flow data (October 1973 to September 1994) was measured, and possible low flows were calculated. In this study, 2 scenarios are considered; the first scenario is based on the assumption of an initially full reservoir, and the second is based on the assumption of full dead volume in addition to drinking and utility water. In the first scenario, system shortages were observed in September at all confidence levels and in August at 80% and 90% confidence levels. In the second scenario, considerable shortages were observed in September at all levels, and in August with a 70%–90% and July with a 90% confidence level.

Key words: Optimization model, reservoir operation, distribution functions, low flow

1. Introduction

Across the world, and especially in arid regions, the temperatures are increasing; as a result, river flows are rapidly decreasing and reservoirs cannot be refilled at the desired rates and levels (Development Alternatives, 2010). In implementing any reservoir operations, the low flows should be closely followed and the regime of flows and low-flow estimates should be determined. Models considering low flows in reservoir operation modeling will be more accurate than other models, such as those using high flows as an input. Over the years several researchers have examined reservoir operations; however, it is unlikely that any system will be accurately judged based only on these optimization models (Wurbs, 2005). Factors such as actual reservoir inflow and current conditions should be included along with real data in the inputs of a reservoir system. Low flows can be summarized as a seasonal phenomenon and an integral component of any river's flow regime (Smakhtin, 2001). According to the International Glossary of Hydrology low flows are defined as the "flow of water in a stream during prolonged dry weather" (WMO, 1974). In the last century, there have been a number of studies on reservoir operation models. Srinivasan et al. (1999) optimized reservoir performance indicators through the integer linear programming model. Similarly, Needham et al. (2000) studied the Iowa and Des Moines rivers and determined optimum operation principles to enhance flood prevention using the integer linear programming method. In another study in Northern India (Jairaj et al., 2003), optimum operational policies were determined through a model that assumed the variability in soil moisture and hydraulic parameters of an irrigation reservoir to conform to certain probability distribution functions. Considering possible annual restrictions, Turgeon (2005) determined daily optimum operation principles for the Kenogami Dam in Canada with a dynamic programming method. In another study conducted by Akbulut (2003), an operation simulation model was established using the HEC-5 program for the Aslantaş Dam in Ceyhan Basin and 14 downstream dams. Tu et al. (2003) determined the operational rules for dry periods at a reservoir in Taiwan by using integer linear programming. Suresh and Mujumdar (2004) evaluated the performance of an irrigation reservoir in India using the fuzzy risk method. Işık (2001) devised a study with an irrigation program developed by incorporating standard operation policies, resulting in the monthly evaluation of reservoir storage continuity. Sattari et al. (2006) applied a

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deterministic nonlinear program to calculate the active capacity of Keyserek Reservoir in Iran. In Iran, Sattari et al. (2008) determined the capacity of the Yalkiz Agac Dam by both classical and optimization methods and then compared the results of both methods. In central Tunisia, which is characterized by a semiarid climate similar to Iran's, Chebbi et al. (2008) also applied 2 optimization models to define operating decisions around pumping from aquifers for agriculture that concerned water conservation for future periods. Sattari et al. (2009) also determined the efficiency of the Eleviyan irrigation dam system in 3 phases and formed an optimization model that maximized the water release for irrigation purposes after municipal water needs were met, and they continued by studying the application of data mining techniques for the extraction of Eleviyan Reservoir operating rules. They found that the capacity determined during the preliminary studies was accurate and that the recently conducted operation was up to a satisfactory standard. In this model, artificial neural networks were represented as generators of future scenarios, emphasizing their ability to reproduce flow statistics related to drought and storage. You and Cai (2009) compared critical period analysis with another time scale, the forecast horizon, which underlies hedging rule policies for reservoir operation. Srivastava and Awchi (2009) applied a set of nested models as a strategy for evaluating the storage, water yield, and operational performance of the multipurpose Mula Reservoir in India. Celeste and Billib (2012) introduced a reservoir operation model based on implicit stochastic optimization in which release policy is guided by the forecast of the mean inflow for a given future horizon rather than by current-month inflow predictions, as in typical implicit stochastic optimization models. Li et al. (2012) applied a new approach for the optimization of long-term operation of large-scale reservoirs that incorporates incremental dynamic programming and the genetic algorithm. This study showed that a hybrid incorporating the incremental dynamic programming and genetic algorithm approaches would be a promising way to the address the long-term optimization problems of large-scale reservoirs. Murray et al. (2012) developed spatial optimization models to support water supply allocation between service provider districts, as some districts experience deficits and others experience surpluses in certain years. The approach seeks to reconcile and integrate projections derived from a complex simulation model that takes current and future climate conditions into account. Eum et al. (2012) presented an integrated reservoir management system that was developed to adapt existing reservoir operations to changing climatic conditions. The reservoir management system integrates the K-nearest neighbor weather generator model, the HEC-HMS hydrological model, and the differential evolution optimization model.

In this study, appropriate distributions for dam preconstruction flows were determined, and possible low-flows for these distributions were calculated at various confidence levels. The flows obtained for different probabilities were taken as the inputs of an established linear programming model, and optimum operational values at every confidence level were determined and evaluated.

2. Materials and methods

2.1. Study area

Eleviyan Dam is located in northwestern Iran, southeast of Urmu Lake and 120 km southeast of Tabriz (37°25′N, 46°14′E). It is constructed over Sofi Creek, 3.5 km from the city of Maraghan. Flows were measured at the Tezekent Flow Observation Station between October 1973 and September 1994. Dam construction was started and completed in 1997, and the dam began to operate. In the period from October 1997 to September 2007, inflowing, stored, and released amounts of water were measured. The Eleviyan Dam irrigates 9008 ha and supplies a part of the drinking and utility water demands of Maraghan, the surrounding area, and the small-scale industrial facilities of the region (Sattari et al., 2009) The location of the Eleviyan Reservoir is represented in Figure 1. The annual regulatable water capacity of the reservoir is 123.4 hm^3, and its normal capacity is 60 hm^3 (57 hm^3 active + 3 hm^3 dead storage). The height of the dam embankment is 76 m, and its length is 935 m. It has a watershed area of 313.6 km^2 and an average altitude of 2319 m. The average daily temperature in the region varies between –3 °C and 26 °C, and the annual average precipitation is 292 mm.

2.2. Precipitation and evaporation data

In the reservoir operations, the most significant water loss is the evaporation from the reservoir surface, and long-term total evaporation was 2056 mm $year^{-1}$. Monthly amounts of evaporation from open water surfaces are measured at a meteorological observation station near the Eleviyan Dam. Total precipitation is 292 mm, which is considerably lower than the evaporation levels. After comparing the total irrigation water requirements (total 1112.6 mm) and precipitation values (total 292 mm; Table 1), the need for irrigation becomes clearer. Using the relationship between evaporation volume and reservoir area, the amount of water evaporating from the reservoir and the amount of precipitation being received by the reservoir can be calculated (Sattari et al., 2009). An equation was obtained using volume–area values; evaporation heights measured at a meteorology station were used to calculate the amount of evaporation from the reservoir surface using the equation $V = 0.4584A - 0.2334$, with a determination coefficient of $r^2 = 0.9973$.

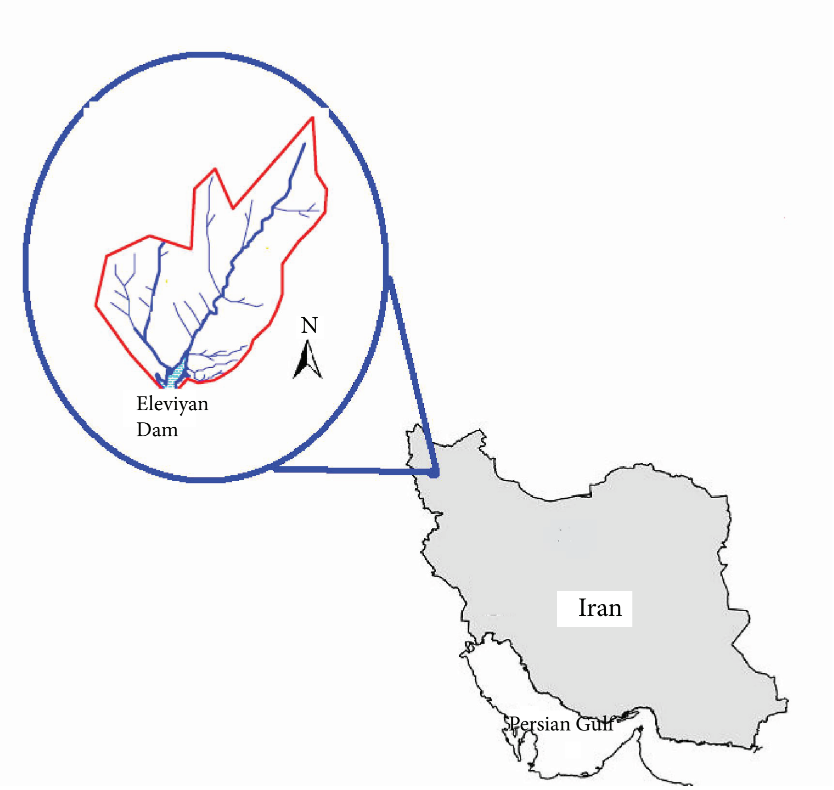

Figure 1. Location of the Eleviyan Reservoir and basin.

Table 1. Mean gross crop and municipal water requirements.

		Months												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Crop water requirements	(hm^3)	4.53	1.51	3.21	1.61	0	0.57	5.86	10.02	23.55	19.86	19.23	10.24	100.19
	(mm)	50.4	16.8	35.6	17.9	0	6.4	65.1	111.2	261.4	220.6	213.5	113.7	1112.6
Municipal water demand (hm^3)		1.90	1.71	1.58	1.60	1.55	1.64	1.71	1.77	2.01	2.23	2.28	2.12	22.10

Based on the general agricultural practices, the cropping pattern of the region was determined. As summarized in Table 1, the Penman–Monteith method was used to calculate the mean crop water requirements. As seen in Table 1, the annual irrigation water requirement for the 9008 ha of irrigable downstream land area was 100.19 hm^3. Within the study area, the surface irrigation method is the most common irrigation practice. If high-efficiency drip and sprinkler irrigation methods were utilized, the irrigable land could reach up to 12,500 ha. In addition to the demands of small-scale industrial facilities (i.e. municipal demands), other water consumption (e.g., standard annual drinking and utility water requirements) was calculated at about 22.1 hm^3. Monthly municipal demands are also given in Table 1.

The total average municipal and agricultural demand equals 122.29 hm^3 $year^{-1}$ (100.19 + 22.1). In this study, water demand in nature has been ignored.

2.3. Flows

Flows were measured between October 1973 and September 1994 at the Tezekent Flow Observation Station. The average amount of flow in Sofi Creek over the 21 years of observation was 136 hm^3 $year^{-1}$ (4.32 m^3 s^{-1}); this was taken as inflow for the reservoir in a linear programming model. Monthly flows are displayed in Figure 2. As seen in Figure 2, the lines representing dry periods of lower-than-average discharges are greater than the lines representing wet periods of higher-than-average discharges. Additionally, dry periods are more regularly distributed than wet periods. If evaporation losses and the

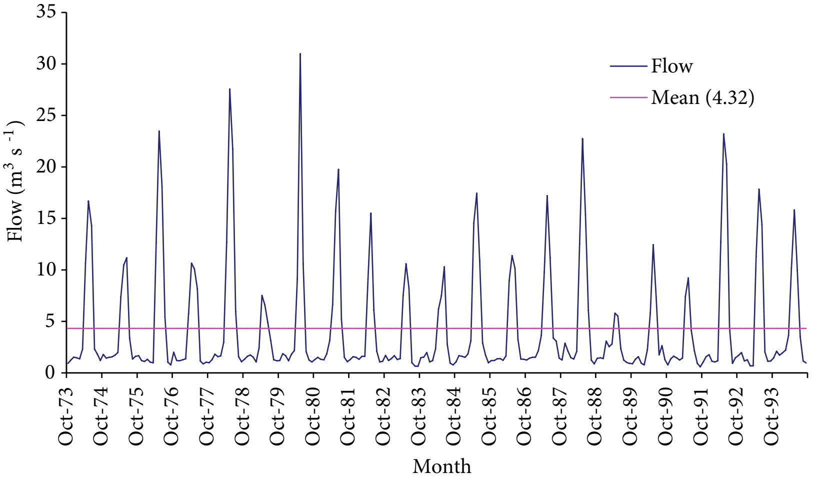

Figure 2. Monthly flow averages ($m^3 s^{-1}$).

amount of water taken from upstream are not considered, then the flow coming from Sofi Creek is roughly enough to meet a demand of 122.29 hm^3. Although the reservoir capacity is sufficient and the average inflow is higher than the demand, the amount of water to be stored in each period should be calculated and a proper management policy should be adopted according to variations during the year. When all reservoir parameters are included in the optimization model and optimum results are calculated, it may be possible to make more definite comments.

2.4. Method

Low flows can be summarized as lower-than-average flows, and based on the confidence level they tend to show some variety. In the case of reservoirs, inflows are more often than not lower than the long-term average flows. As a result, with increasing confidence levels the chances of flow occurrence decreases, and these periods are thus the dry periods. Depending on the intensity of the drought, various decreases can be observed in flows. In this study, for a water year from October to September, at a confidence level of 50%–90% flows were determined with 10% increments. Based on these flows, optimum operational values were calculated. Based on the flow data of Sofi Creek (October 1973 to September 1994), low flows were determined. According to these low flows, the possible operational conditions of Eleviyan Dam were evaluated by a linear programming model. In this study 2 scenarios were taken into consideration. The first assumed that the reservoir was initially full; the second assumed that only drinking and utility water were available over the dead storage period.

2.5. Optimization model for the Eleviyan Reservoir

In the linear programming model for the Eleviyan irrigation reservoir, the assumption of fully met municipal demands was made as an objective function, and the model endeavored to reserve the maximum amount of water for irrigation purposes. The restrictions of the linear programming model are described as follows.

(1) A water budget equation balances the inflow and amount of water released from the reservoir system. This is the most significant system restriction.

(2) The amount of water stored in the reservoir at any time cannot be higher than the total reservoir capacity. With this restriction, the model aims to release less water for irrelevant purposes.

(3) The amount of water stored in the reservoir should always be higher than the dead storage capacity.

(4) The amount of water to be released from the reservoir for irrigation purposes should be based on water requirements for a predetermined cropping pattern. Releasing more water than is demanded would be undesirable. Within the model, the rate of water reserved for municipal demands should not be less than the amount calculated in the planning phase. When necessary, savings from irrigation water may be used, and shortages may exist; however, the municipal water can never equal zero.

(5) Evaporation from the reservoir surface and precipitation into the reservoir were also included in the model as other components, with some simplifications. Following the definitions of objective function and restrictions, the linear programming model was established in this manner:

$$\text{Objective function: Maximize } Z = \sum_{t=1}^{12} \text{IR}(t)$$

subject to:
(1) $ST(t+1)=ST(t)+QF(t)-EV(t)-IR(t)-DR(t)-SPILL(t)$,
(2) $ST(t)\leq(Ka+Kd)$,
(3) $ST(t)\geq Kd$,
(4) $IR(t)\leq DE(t)$,
(5) $STmean(t)=[(ST(t)+ST(t+1))]/2$,
(6) $Area(t)=A0+\alpha^{*}STmean(t)$,
(7) $EV(t)=e(t)^{*}Area(t)$,
(8) $PP(t)=p5t)^{*}Area(t)$.

In the model, IR = amount of water released for irrigation purposes, ST = reservoir storage at the beginning of the period, QF = reservoir inflow, PP = precipitation amount on the reservoir surface, EV = evaporation amount from reservoir surface, DR = target demand for municipal requirements, SPILL = amount of spill, DE = target demand for irrigation purposes, Ka = reservoir active capacity, Kd = reservoir dead storage capacity, STmean = mean reservoir storage between 2 periods, Area = mean reservoir surface area between 2 periods, e = rate of evaporation, p = rate of precipitation, A_0 = constant rate for linear equation (–0.2334), α = slope of linearized equation (0.4584),and t = months.

IR, ST, and SPILL are the decision variables in the model, and their quantities will be determined after running the model. PP and EV are dependent variables. I, DR, and DE are the values calculated as model inputs at different occurrence probabilities. In water research studies, optimization models automatically search for an optimum set of diction variable values (e.g., release, reservoir capacity, and firm yield) for maximizing or minimizing the objective function. The historical inflow records have a stochastically identity; therefore, the application of simulation models provides an assessment of system performance (Wurbs, 2005). In this study, GAMS software was used for solving the developed optimization model.

3. Results

3.1. Determination of best-fitting distributions for monthly flows

The best-fitting statistical distributions were evaluated for monthly average flows over 21 years, as observed before the construction of the Sofi Creek Reservoir. Initially, old flow values were investigated by SYSTAT software, and the best distributions were selected. The most common statistical distributions used in hydrology (e.g., normal, lognormal, Weibull, gamma, Pareto, and Gumbel distributions) were tested to select the best-fitting distribution. Kolmogorov–Smirnov (KS) test values were calculated for each distribution. The distribution yielding the smaller KS value was selected as the best-fitting distribution (Table 2).

After establishing the best-fitting distributions of the flows, the flow occurrence probabilities were calculated based on those distributions. As seen in Table 3, higher probabilities and confidence levels indicate low flows; lower probabilities indicate high flows and, generally, flood periods.

3.2. First scenario: reservoir is full

As the name suggests, in this scenario calculations were performed assuming a full reservoir at the beginning of the year. The values obtained from the optimum reservoir operation model, established based on possible flows from 50% to 90% confidence levels, are given in Table 4. Since the municipal demands (DR) and demands for irrigation (DE) are the same at all levels, they are given once at the beginning of Table 4. Other values are given separately for all levels.

Table 2. The best-fitting distributions for Sofi Creek flows and their parameters.

Month	KS	Best-fitting distribution	Distribution parameters	
			Shape	Scale
Oct	0.104	Gamma	Shape (alpha) = 17.554	Scale (beta) = 0.197
Nov	0.161	Gumbel	Location (alpha) = 3.608	Scale (theta) = 0.832
Dec	0.081	Weibull	Shape (alpha) = 6.473	Scale (beta) = 4.363
Jan	0.194	Gumbel	Location (alpha) = 3.358	Scale (theta) = 0.905
Feb	0.111	Lognormal	Location (mu) = 1.305	Scale (sigma) = 0.326
Mar	0.089	Gumbel	Location (alpha) = 4.826	Scale (theta) = 2.392
Apr	0.142	Lognormal	Location (mu) = 3.179	Scale (sigma) = 0.273
May	0.120	Weibull	Shape (alpha) = 2.488	Scale (beta) = 46.396
Jun	0.116	Gumbel	Location (alpha) = 23.418	Scale (theta) = 11.287
Jul	0.086	Lognormal	Location (mu) =1.975	Scale (sigma) = 0.511
Aug	0.142	Lognormal	Location (mu) = 1.202	Scale (sigma) = 0.356
Sep	0.076	Normal	Location or mean (mu) = 2.826	Scale or SD (sigma) = 0.670

Table 3. Possible flows at selected probabilities (hm³).

Occurrence probability (%)	Months											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90	2.46	2.91	3.08	2.60	2.43	2.83	16.90	18.75	14.00	3.75	2.10	1.96
80	2.76	3.21	3.46	2.92	2.80	3.69	19.08	25.39	18.04	4.70	2.46	2.26
70	2.99	3.45	3.72	3.19	3.10	4.38	20.80	30.65	21.32	5.52	2.76	2.47
60	3.20	3.68	3.93	3.43	3.39	4.99	22.40	35.41	24.40	6.35	3.04	2.65
50	3.41	3.91	4.12	3.69	3.68	5.70	24.01	40.04	27.53	7.22	3.32	2.82

Table 4. Operational values at full reservoir conditions.

Confidence level		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	DR	1.90	1.71	1.58	1.60	1.55	1.64	1.71	1.77	2.01	2.23	2.28	2.12
	DE	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	10.24
50%	ST	60.00	12.55	12.83	12.18	12.76	15.01	18.74	34.60	60.00	54.19	31.57	9.56
	QF	3.41	3.91	4.12	3.69	3.68	5.70	24.01	40.04	27.53	7.22	3.32	2.82
	EV	3.02	0.58	0.14	0.05	0.00	0.01	1.38	3.88	7.99	7.81	3.83	0.61
	PP	0.08	0.21	0.19	0.17	0.13	0.27	0.80	1.03	0.21	0.06	0.02	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	9.66
	SPILL	41.50	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
60%	ST	60.00	20.68	20.51	19.69	20.09	22.12	25.25	39.37	60.00	51.26	28.33	6.63
	QF	3.20	3.68	3.93	3.43	3.39	4.99	22.40	35.41	24.40	6.35	3.04	2.65
	EV	3.36	0.95	0.23	0.08	0.00	0.01	1.68	4.08	7.78	7.24	3.24	0.40
	PP	0.09	0.34	0.31	0.28	0.20	0.38	0.98	1.08	0.20	0.05	0.02	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	6.77
	SPILL	32.82	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
70%	ST	60.00	28.85	28.21	27.21	27.44	29.25	31.89	44.28	60.00	48.38	25.17	3.77
	QF	2.99	3.45	3.72	3.19	3.10	4.38	20.80	30.65	21.32	5.52	2.76	2.47
	EV	3.70	1.32	0.32	0.11	0.00	0.01	1.98	4.28	7.58	6.68	2.67	0.20
	PP	0.10	0.48	0.42	0.38	0.27	0.50	1.15	1.14	0.20	0.05	0.01	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	3.92
	SPILL	24.11	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
80%	ST	60.00	37.85	36.70	35.47	35.52	37.11	39.17	49.71	60.00	45.31	21.87	3.00
	QF	2.76	3.21	3.46	2.92	2.80	3.69	19.08	25.39	18.04	4.70	2.46	2.26
	EV	4.08	1.74	0.42	0.14	0.00	0.02	2.32	4.51	7.36	6.10	2.28	0.14
	PP	0.11	0.62	0.55	0.50	0.34	0.62	1.35	1.20	0.19	0.05	0.01	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	16.78	3.00
	SPILL	14.50	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
90%	ST	60.00	49.24	47.45	45.88	45.71	47.02	48.38	56.56	60.00	41.53	17.85	3.00
	QF	2.46	2.91	3.08	2.60	2.43	2.83	16.90	18.75	14.00	3.75	2.10	1.96
	EV	4.56	2.26	0.55	0.19	0.00	0.02	2.74	4.79	7.10	5.38	1.90	0.14
	PP	0.12	0.81	0.72	0.64	0.44	0.78	1.60	1.27	0.18	0.04	0.01	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	12.79	2.70
	SPILL	2.35	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00

Surveys of the Eleviyan Dam were conducted based on an average 50% confidence level. All irrigation and municipal needs were met in accordance with the results obtained at this confidence level, and a total of 41.62 hm^3 of water spilled from the reservoir during the months of October–May. This discharged amount equaled 70% of the total capacity of the reservoir. The amount of water in the reservoir at the end of the season (September) was 9.56 hm^3. If the reservoir is full at the beginning of the water year, then no water shortage will occur under average conditions (except in September, at 0.58 hm^3). Additionally, the irrigated land area may increase, and valuable cash crops with higher water requirements may also be cultivated. All of the demands, except in September (3.47 hm^3), were met at a 60% confidence level, and a total of 32.93 hm^3 of water (about 55% of the reservoir) was spilled from the reservoir during the months of October–May. All of the demands were met at a 70% confidence level (except in September, which experienced a 6.32-hm^3 shortage), and a total of 24.22 hm^3 of water (about 40% of the reservoir) was discharged from the reservoir during the months of May, June, and July. At an 80% confidence level, the shortages were statistically expected to occur as inflows to the reservoir decreased. A shortage of 2.45 hm^3 occurred in August, a shortage of 7.24 hm^3 occurred in September, and 14.61 hm^3 of water was discharged from the reservoir from October through May. At a 90% confidence level, representing the driest conditions, a shortage of 6.44 hm^3 occurred in August, a shortage of 7.54 hm^3 occurred in September, and 2.46 hm^3 of water spilled from the reservoir. A reservoir inflow at this confidence level is less than the inflows at other levels. Although the initial storage is 60 hm^3, this amount decreases during the year, and the amount of water in the reservoir at the end of the season (at 80% and 90% confidence levels) decreases to dead storage (3 hm^3).

To provide more detailed and visual interpretations of the results, the reservoir parameters calculated at different confidence levels were compared (Figures 3 and 4).

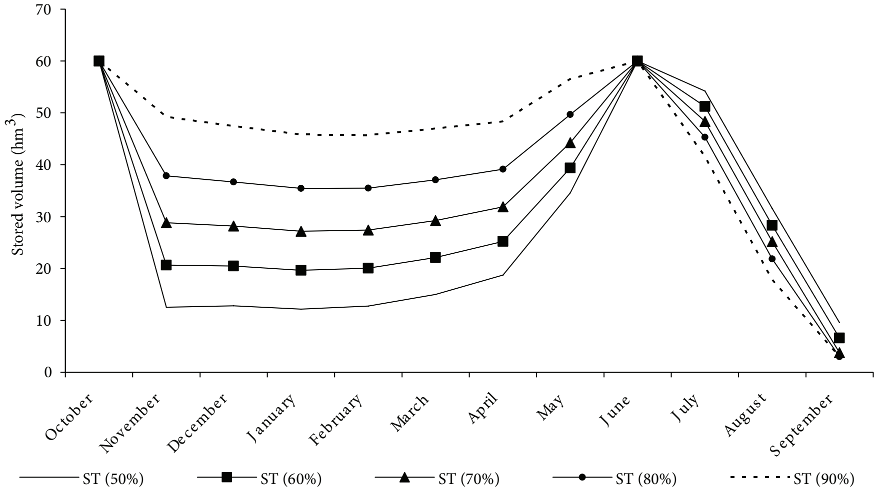

Figure 3. Amounts of reservoir storage at various confidence levels (first scenario).

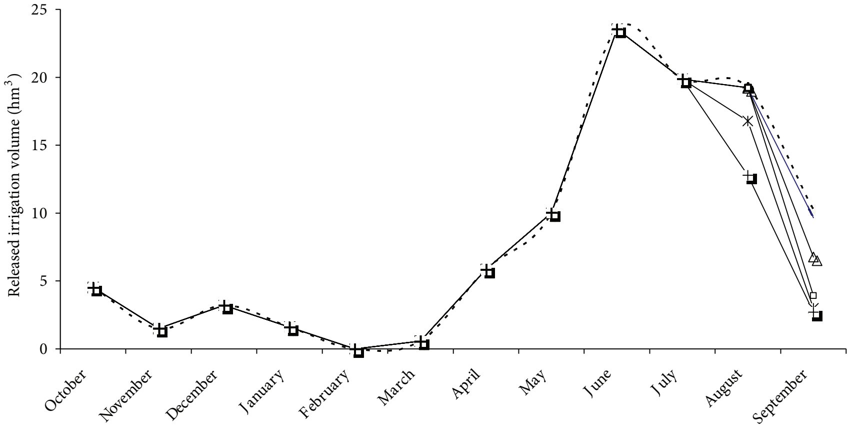

Figure 4. Amounts of water released for irrigation purposes at various confidence levels (first scenario).

As seen in Figure 3, the reservoir storage amounts at all confidence levels are under the 60-hm^3 lines. Since the month of June has a precipitation rate, inflows to the reservoir during this month are higher than the inflows in other months. Therefore, the fullness of the reservoir system in June results from a natural process. The highest spill was observed at a 50% confidence level. At a 90% confidence level, spill was almost negligible. As seen in Figure 4, water shortages related to irrigation demand were observed only in August and September. Due to temperature and evaporation increases in this period, the demand increases, as well; thus, a shortage is common at this time of year. Demand was met at all times in other periods.

3.3. Second scenario: initial reservoir capacity is 25 hm^3

In this stage, the initial storage of the reservoir was assumed to be 25 hm^3, corresponding to the total of dead storage and municipal needs, and the optimization model was rerun at various confidence levels. Values obtained from the optimum reservoir operation model, based on possible flows at 50%–90% confidence levels, are given in Table 5.

Table 5. Operational values at 25-hm^3 reservoir storage conditions.

Confidence level		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	DR	1.90	1.71	1.58	1.60	1.55	1.64	1.71	1.77	2.01	2.23	2.28	2.12
	DE	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	10.24
50%	ST	25.00	12.48	12.80	12.15	12.74	15.00	18.73	34.60	60.00	54.19	31.57	9.56
	QF	3.41	3.91	4.12	3.69	3.68	5.70	24.01	40.04	27.53	7.22	3.32	2.82
	EV	1.54	0.57	0.14	0.05	0.00	0.01	1.38	3.88	7.99	7.81	3.83	0.61
	PP	0.04	0.21	0.19	0.17	0.13	0.27	0.80	1.03	0.21	0.06	0.02	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	9.66
	SPILL	8.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60%	ST	25.00	19.97	19.85	19.05	19.46	21.49	24.62	38.77	59.43	50.77	27.92	6.30
	QF	3.20	3.68	3.93	3.43	3.39	4.99	22.40	35.41	24.40	6.35	3.04	2.65
	EV	1.85	0.92	0.23	0.08	0.00	0.01	1.64	4.03	7.71	7.16	3.17	0.37
	PP	0.05	0.33	0.30	0.27	0.19	0.37	0.96	1.07	0.20	0.05	0.02	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	19.23	6.45
	SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70%	ST	25.00	19.77	19.43	18.42	18.58	20.31	22.81	35.41	51.65	41.11	19.12	3.00
	QF	2.99	3.45	3.72	3.19	3.10	4.38	20.80	30.65	21.32	5.52	2.76	2.47
	EV	1.84	0.90	0.22	0.07	0.00	0.01	1.51	3.57	6.48	5.46	2.02	0.14
	PP	0.05	0.32	0.29	0.26	0.18	0.35	0.88	0.95	0.17	0.04	0.01	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	14.59	3.21
	SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80%	ST	25.00	19.54	18.98	17.70	17.59	19.01	20.79	31.73	43.09	30.58	9.60	3.00
	QF	2.76	3.21	3.46	2.92	2.80	3.69	19.08	25.39	18.04	4.70	2.46	2.26
	EV	1.84	0.89	0.21	0.07	0.00	0.01	1.36	3.06	5.13	3.61	1.11	0.14
	PP	0.05	0.32	0.28	0.24	0.17	0.32	0.79	0.81	0.13	0.03	0.01	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	19.86	5.68	3.00
	SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90%	ST	25.00	19.26	18.40	16.74	16.30	17.33	18.22	27.06	32.26	17.35	3.72	3.00
	QF	2.46	2.91	3.08	2.60	2.43	2.83	16.90	18.75	14.00	3.75	2.10	1.96
	EV	1.82	0.86	0.20	0.07	0.00	0.01	1.17	2.42	3.43	1.85	0.55	0.14
	PP	0.05	0.31	0.27	0.23	0.16	0.28	0.68	0.64	0.09	0.01	0.00	0.00
	IR	4.53	1.50	3.22	1.61	0.00	0.58	5.86	10.01	23.55	13.32	0.00	2.70
	SPILL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Demand was fully met at a 50% confidence level (except in September, when the shortage was 0.58 hm^3), and a total of 8.05 hm^3 of water was spilled from the reservoir during the months of October–February. When the average of reservoir inflows is calculated, it is clear that the reservoir has exhibited a satisfactory performance. Spill did not occur at the 60% confidence level due to decreased amounts of water; however, the shortage increased to 3.79 hm^3 in September. At a 70% confidence level, flows decreased relative to previous levels; therefore, shortages of 4.64 hm^3 in August and 7.03 hm^3 in September were observed. At this level, the amount of water stored in September decreased to dead storage (3 hm^3), which signified an empty reservoir. At the 80% confidence level, a shortage of 13.55 hm^3 occurred in August and a shortage of 7.24 hm^3 occurred in September. At this level, the reservoir was empty in September, and spill did not occur. Flows significantly decreased at the 90% confidence level, and a total shortage of 33.31 hm^3 was observed in the months of July, August, and September. Thus, 33% of total demand was not met in July, 100% in August, and 74% in September.

Reservoir parameters, calculated at various confidence levels, are compared in Figures 5 and 6. As shown in Figure 5, reservoir storage can only reach 60 hm^3 in June, and only at the 50% confidence level. The reservoir has the most water at other confidence levels in June. In this section, discharges were observed only at 50% confidence levels and only during the fall and winter months. The demands and the amounts of water to be released were generally the same among the months, except in the summer. As seen in Figure 6, shortages coincide with summer months, and demand was fully met in the other months of the year.

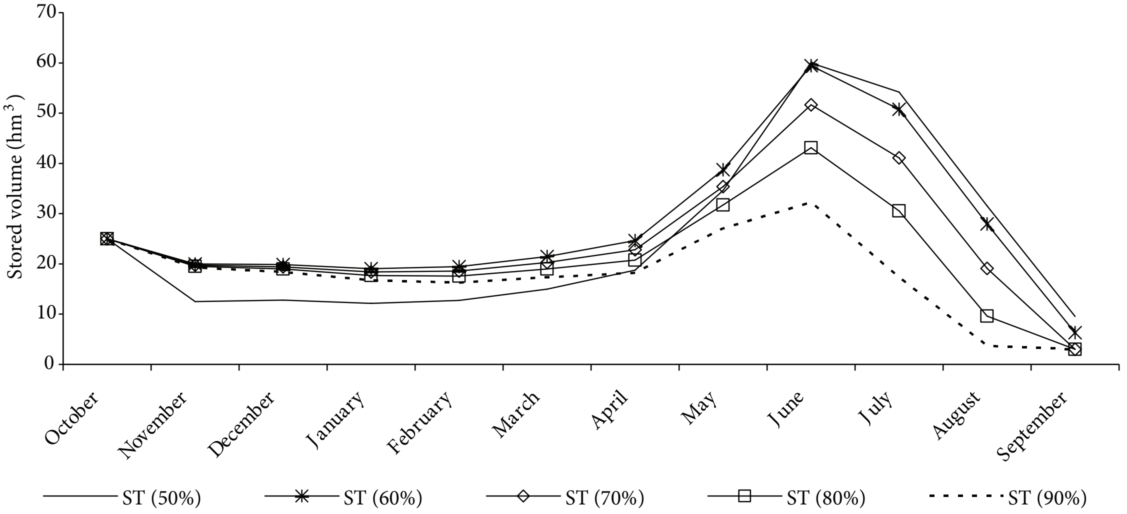

Figure 5. Amounts of reservoir storage at various confidence levels (second scenario).

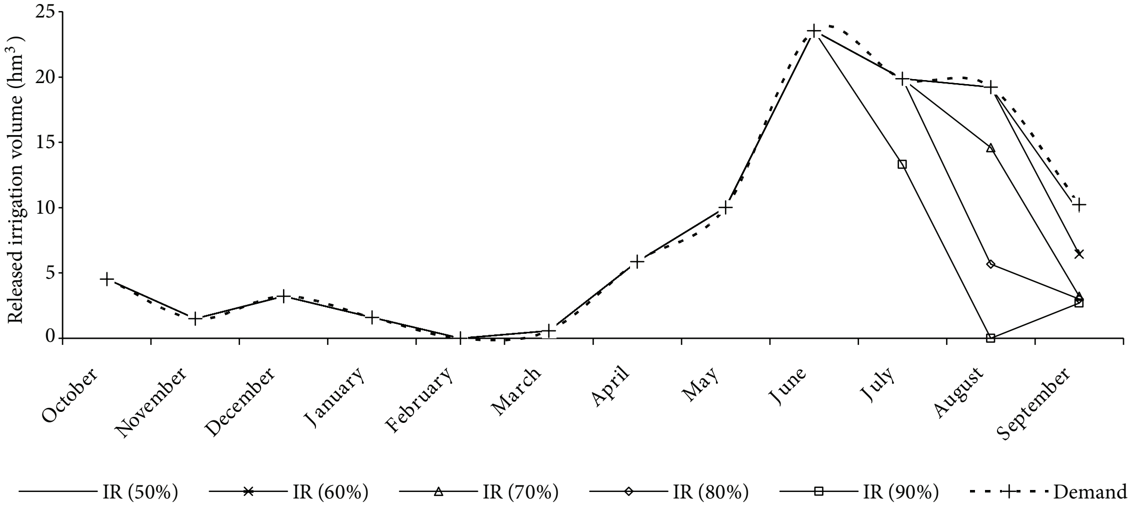

Figure 6. Amount of water released for irrigational purposes at various confidence levels (second scenario).

4. Discussion

A thorough and complete understanding of low-flow processes and reliable estimations are necessary to sustain water catchment areas. Though low flow seems to be a dynamic process, it cannot be described by a single characteristic. In other words, a long time period seems crucial in order to perform through studies. A long period will help researchers understand the stochastic characteristic of the flow and allow them to monitor catchment area responses closely and develop useful strategies. By observing the catchment flow response, flow duration cures can be developed (Smakhtin, 2001). Global warming and unpredictable and unseen precipitation have all resulted in significantly reduced reservoir inflow. These losses in turn lead to serious operational difficulties, which ordinary solutions cannot address; determining these losses and presenting proper operational strategies are of great importance in reservoir management. In the present study, first the low flow was calculated, and then an applicable model was developed accordingly. This model was applied to 2 scenarios, changing the initial fullness of the reservoir storage. The results showed that the water resource shortages generally existed in summer, as temperature and evaporation rates increased due to global warming. The findings also revealed that the low flows and the stochastic process of flows can be improved by applying mathematical optimization models; and they yield reliable results even when applied in arid and semiarid regions. Under these circumstances, the use of more efficient irrigation techniques, cultivation of less water-intensive crops, and trained operational personnel can reduce possible shortages, mitigating the resulting losses and damages.

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