International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol. 5, No. 1, 2018, pp. 200-210.
ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Optimal Reservoir Operation of Karun 4 Reservoir by Linear Programming

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Abstract

Storage systems often lack the appropriate and academic utilization patterns in Iran. Therefore, investigating the methods and providing suitable models for the optimal utilization of such systems during normal operation and periods of intense drought had high priority. On the other hand, the limitation on the total amount of water and the fixed total amount of it, increasing industrialization process and the subsequent process of increasing urban growth in demand in various fields, create a set of factors related to each other and brings the issue of water crisis to the mind in the near future. In this regard, efficient management and operation of the facilities have special importance. So, in this study, a linear model which is modeled in LINGO is used to calculate the maximum volume of the reservoir. The results showed very good compliance linear programming model with optimal values and historical observations in this regard.

Keywords: Reservoir Operation, LINGO, Time Series, Driest Month, Wettest Month

Introduction:

Water is recognized as one of the most significant basis of economic prosperity, development, and social well-being. Its shortage may cause many hindrances (Vahid, Noori et al. 2016). The surface water are the crucial water resources which have an important role in providing water needs for different activities (Salarian, Najafi et al. 2015). However, human lives have been subject to various natural dangers through the entire history all around the world (Othman, Sadeghian et al. 2012). Flood is one of those mentioned damages which can affect human beings' life (ShahiriParsa, Vuatalevu et al. 2013). That is required to perform many studies and apply subsequent and consistent activities with the nature of the river (ShahiriParsa, Noori et al. 2016). But the actual fact should be considered that flood is not completely controlled, but its deficits could be decreased by dams construction and floodplain management

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

(ShahiriParsa, Vuatalevu et al. 2013). Also, the potential power of water behind a dam provide electric energy. In case like this the power of the water is dependent upon stored water of dam and the level difference between water resource and the withdrawal of water from dam (Sadeghian, Heydari et al. 2016). There are other reasons besides flood control and hydropower generation for dam building, including raising demand of water, agricultural applications, water supply, tourism and recreational water for multi objective applications and so on (Heydari, Othman et al. 2013). Demand for water is generally aggressive in multi-objective systems for instance the necessary level of reservoir storage for flood handling and useful reservoir storage (Othman, Heydari et al. 2014).

Researchers have used various methods to optimize the operation of reservoirs. Linear Programming (LP) (Heydari, Othman et al. 2015), Nonlinear programming (NLP) (Chu and Yeh 1978), fuzzy programming (Russell and Campbell 1996), Dynamic Programming (DP) (Hall, Butcher et al. 1968), Stochastic dynamic programming (SDP) (Stedinger, Sule et al. 1984), Genetic Algorithms (GA) (Noori, Othman et al. 2013; Daghighi, 2017), Honey-bee mating optimization (HBMO) algorithm (Afshar, Haddad et al. 2007), were some of common methods for solving these types problems. In recent years, researchers have used newer methods to reach their optimum solutions. Some of these methods are Non-Dominated Sorting Genetic Algorithm (NSGA-II) (Sadeghian, Heydari et al. 2016), Stochastic Dual Dynamic Programming (Raso, Malaterre et al. 2017), Harmony Search Algorithm (Afshar, Azizipour et al. 2017), shark algorithm (Ehteram, Karami et al. 2017), weed optimization algorithm (Azizipour, Ghalenoei et al. 2016), and etc. The optimization model for multiple reservoir operation should reflect the exchange between the advantages obtained from releasing the water. Besides, there's an exchange between the advantages of keeping water in high level and loosing caused by the overflow of water (Heydari, Othman et al. 2016).

Methodology:

Karun IV reservoir: Karun River is the most important river in Iran and is located in Karun and Dez watershed (Sadeghian, Salarijazi et al. 2016). Karun 4 dam constructed on the Karun River. This dam is the largest double-arch concrete dam in Iran and it is the fifth highest dam in the world. Figure 1 displays the area volume elevation relationship for Karun 4 reservoir.

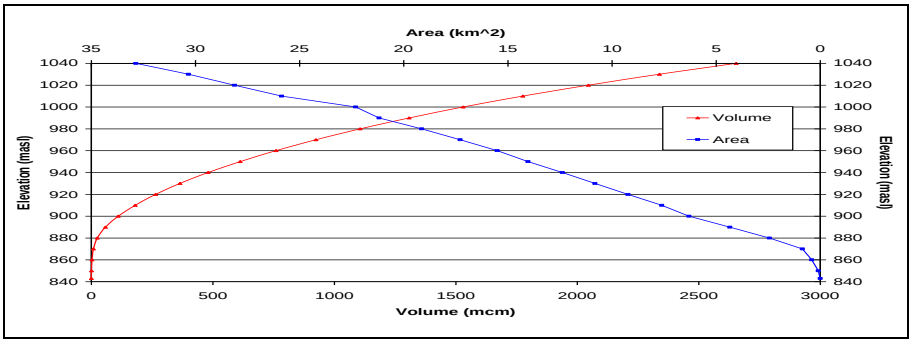

Figure 1: Area-Volume-Elevation relationship for Karun IV reservoir

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

Method

The initial step to verify the reservoir's storage, is to obtain the years that the reservoir has its extremum volume. Usually, in drought years the reservoir has the minimum inflow and also in the wet years the reservoir has the utmost input. The actual compatibility of range of modifications with the obtained results in the optimization model is suggestive of the validity of the model especially in terms of flood control. So, the time series of inputs must be prepared and therefore the monthly discharge needs to be subtracted from the averages discharge. The next thing is to get the driest and wettest years, so a linear model that is modeled in LINGO is utilized to calculate the highest volume of the reservoir. The gained values may validate the obtained results.

Results:

Following the mentioned description of model validation method for reservoirs storage (compared to the wet situation section), we perform the following steps.

Data collection: The first step in water project engineering studies, agricultural development plans and such like is to use of correct data and information (Habibi Khalifeloo, Mohammad et al. 2015). For this specific purpose, initially, we have to provide time series inflow for reservoirs to understand wet and dry years. A part of the inflow of the Karun reservoirs is displayed in Table 1 to in MCM.

Table 1: Time series of Karun IV reservoir inflow (Heydari 2017)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1970	64.80	65.30	83.50	82.30	113.20	264.70	252.70	219.30	151.20	106.50	80.90	67.80
1971	64.30	56.50	63.90	96.80	92.80	280.20	391.00	414.30	245.70	166.50	111.50	90.20
1972	69.80	75.10	125.70	92.50	118.60	189.60	205.10	150.40	102.60	68.10	58.20	52.30
	...											
2009	62.60	229.90	492.30	200.80	236.50	236.00	287.80	305.00	206.30	125.30	98.20	91.20
2010	72.30	69.10	70.20	78.40	119.60	306.70	527.50	427.50	226.50	131.70	97.60	77.30

Also a histogram of Karun I, II and IV reservoirs inflow for 40 years is shown in the Figure 2.

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

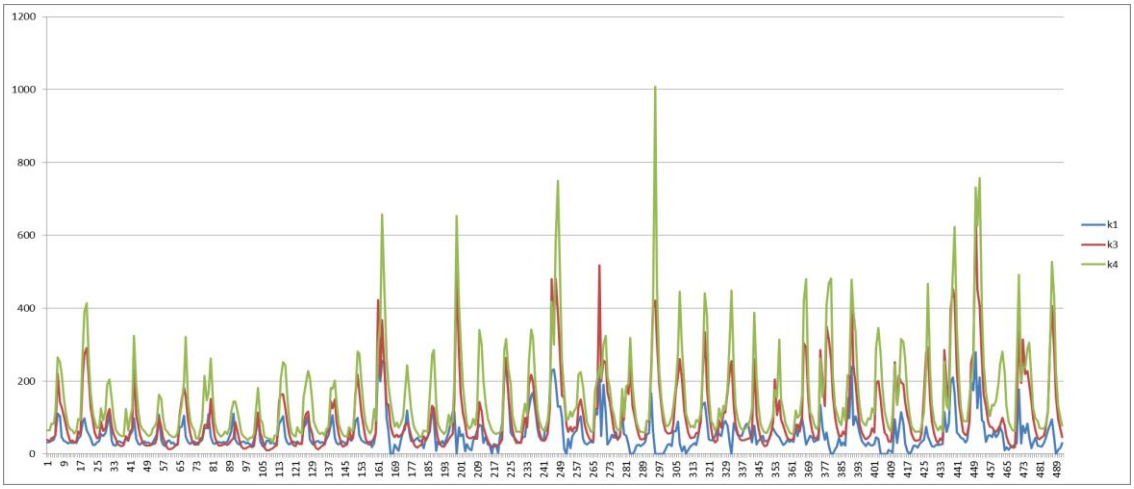

Figure 2: The inflow histogram of Karun I, III and IV reservoirs (Heydari 2017)

In order to get drought sequence, the average input regarding every month ought to be calculated using Table one, then the historical info must be subtracted from the determined averages (Figure 3).

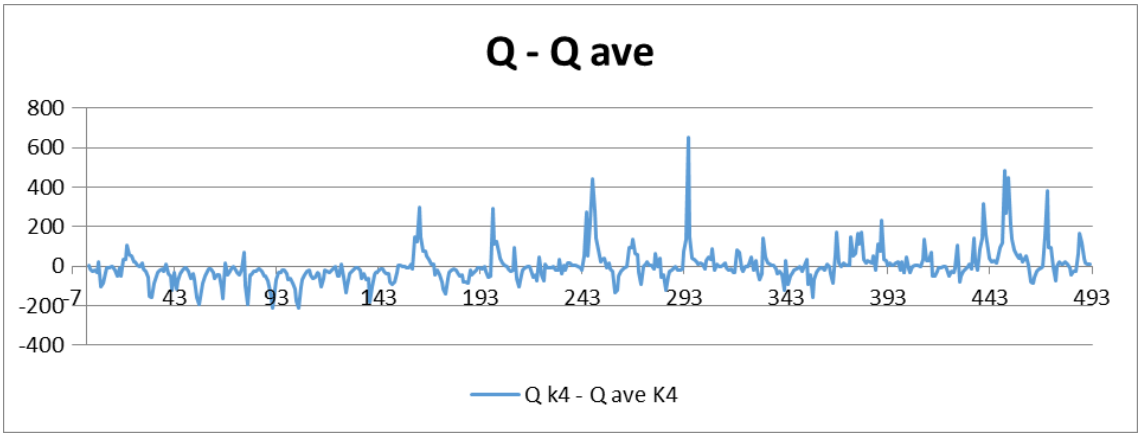

Figure 3: The difference between the inflow and the average inflow in Karun IV dam

The visible difference between the drought and also wet situation in Karun 4 reservoirs are demonstrated in Figure four.

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

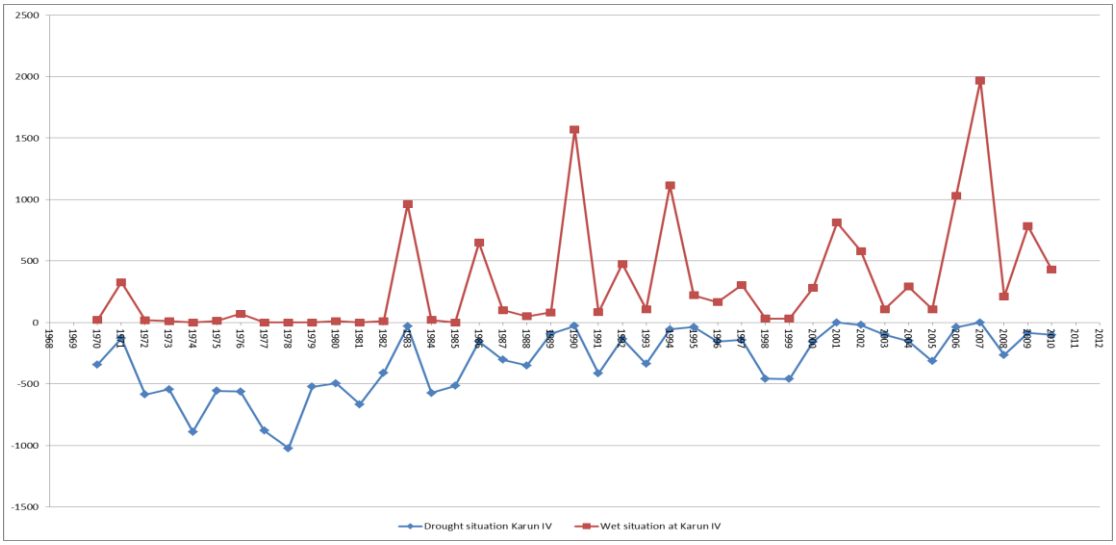

Figure 4: The difference between the drought and wet situation in Karun IV dam

Table 2 indicates the drought year with the most intensity year of historical data. Figure 5 displays the chart that belongs to the presented period.

Table 2: Inflow histogram for Karun IV in the drought year (Heydari 2017)

Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Inflow	0.7	1.8	5	2.2	1.9	1.7	5.9	1.4	2.2	1	2.1	0.9
Monthly average inflow	3.4	4.6	6.1	7.6	7.9	10.3	12.5	12.4	9.4	5.8	4.8	3.4
Inflow - average inflow	-2.7	-2.8	-1.1	-5.4	-6	-8.6	-6.6	-11	-7.2	-4.8	-2.7	-2.5

Which means that, we consider this year as the base year for obtaining maximum storage in drought time period and in the same way, we can do this particular for that wettest year to get the lowest level of reservoir volume.

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

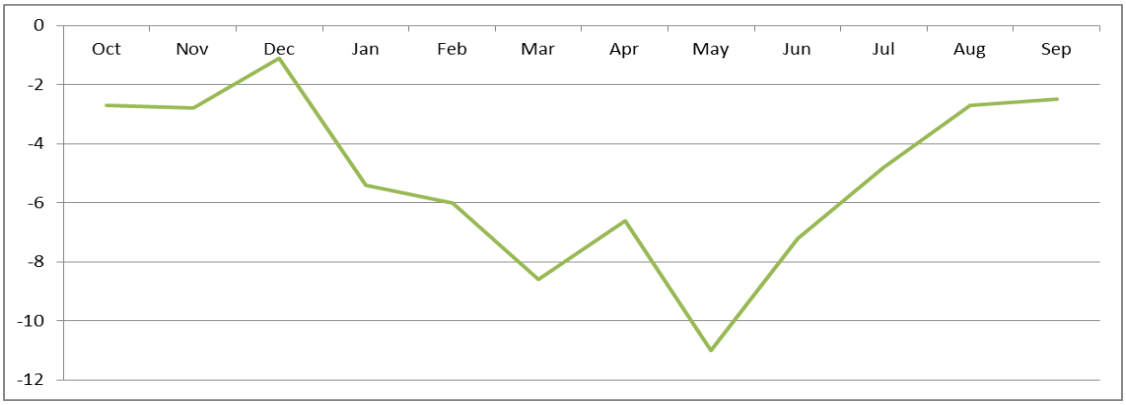

Figure 5: Inflow histogram for Karun IV in the drought year

The next step is to obtain the maximum storage of the reservoir, therefore a linear model which is modelled in LINGO is utilized for calculating the maximum volume of the reservoir. Using the hydrological balance methods can be useful to attain an evaluation of the volume of water flowing and precipitation deficits in the regarded scale. In order to carry out the essential estimations in the context of these type research, using the existing experimental formulations in this discipline, the assessment and computation of the total annual rainfall losses are inevitable (Fazlolahzade Sadati, Heydari et al. 2014).

Maximum Storage in drought period

In this model the maximum amount of outflow is obtained for constant volume of the reservoir.

Minimize Z = C	Equation 1
Subject to	Equation 2
$S_{t+1} = S_t + i_t - q_t - w_t$	Equation 3
$S_t \leq K$ (constant reservoir volume)	Equation 4
$S_t \geq S_1$	Equation 5

Where, C is the reservoir capacity, St Storage of the month t, it inflow in month t, wt the amount of overflow in month t and q is the constant monthly need of downstream. The requirement data of Karun IV reservoir for this model are shown in Table 3 to Table 6.

Table 3: The details of Karun reservoirs storages (Heydari 2017)

	Karun IV
Reservoir Storage	2192
Dead Storage	1097
Storage Area	29.23
Dead Storage Area	19.55

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

Modelling the evaporation losses in Karun reservoirs

To be able to determine the amount of evaporation, the reservoir surface should be calculated. The surface of reservoir is a function of the volume (Figure 6).The specific of this curve is actual convexity.

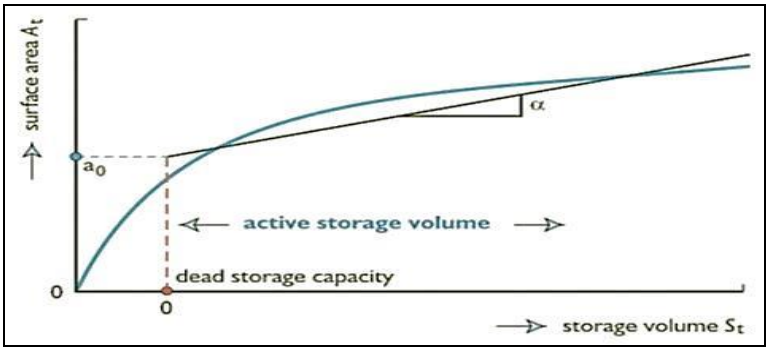

Figure - 6 Evaporation relationship with the area and volume of reservoir

Aside from, surface-volume curve, the depth of periodic evaporation through reservoirs' surface (εt) should be given. As it is demonstrated in the image α0 will be the dead storage of the reservoir. Within Karun IV reservoir, for a storage of 2190 MCM a surface equivalent 29.23 km^2 is usually available. Furthermore with regard to dead storage capacity (1097 MCM) we have a surface of 19.55 km^2. Therefore by writing a linear relation "α" slope could be calculated. The average amounts of evaporation in reservoir are found in Table 4 in terms of mm.

Table 4: The average amount of evaporation in Karun reservoirs in mm (Heydari 2017)

ε_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0	0	0	47.6	137.2	263.2	324.8	330.4	277.2	184.8	56	0

Thus the amount of monthly evaporation volume for that reservoir is achieved by using the following equation (Equation 6) where, Lt Value is based on the Table 5:

$$Lt = \varepsilon t * a_0 \qquad \text{Equation 6}$$

Table 5: The average of Lt Value in Karun reservoirs (Heydari 2017)

L_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0.0	0.0	0.0	52.2	150.5	288.7	356.3	362.4	304.1	202.7	61.4	0.0

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

"α0" as being a non-dimensional amount is defined by the Equation 7 that'll be utilized in continuity formula of the reservoir:

$$a_t = \frac{\alpha \varepsilon t}{2} \qquad \text{Equation 7}$$

Table 6: The average of "at" value in Karun reservoirs (Heydari 2017)

a_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0	0	0	0.021	0.061	0.116	0.144	0.146	0.123	0.082	0.025	0

Observing the all stated above, the optimization model could be described as following (Equation 8 to 12):

Maximize $Z = q$ Equation 8
Subject to Equation 9
$(1+a_t)S_{t+1} = (1-a_t)S_t + i_t - q - w_t - L_t$ Equation 10
$S_t \leq C$ Equation 11
$S_t \geq S_1$ Equation 12

Based on the mentioned problems as well as considering the utmost reservoir volume, that is 2279 MCM, the maximum constant water supply for the downstream will be 883 MCM usually. (Heydari 2017)

Conclusion and Recommendations:

The following items should be considered alongside the direct operation of the reservoirs:

Since a small change in hydraulic factors may lead to real change in the operational system, the impacts of climate change on rivers were briefly regarded with a conceptual look (Dehghani Vahid, Noori et al. 2015).

Calculating the useful life and economic yield (for dead storage estimation) perform an essential role in the first design of dams because sometimes reservoirs are filled quicker than was estimated, or before the end of the predicted useful life (Othman, Sadeghian et al. 2013). Thus, performing systematic and detailed reports in terms of sedimentation phenomena and calculating the quantity of transposed sediments are necessary for optimum advantageous asset of water resources of dams (Sadeghian, Heydari et al. 2014).

Understanding of river behavior and the capability to predict the future event is a requisite for the preparation of optimal models (Othman, Heydari et al. 2017). The effect of climate change on hydrologic modelling and administration of hydro systems could possibly be one of the main challenges faced by

Received:9 February 2018/Accepted:14 May/Published:1 June 2018

future practicing water resources experts and managers. Due to raising demand for water, understanding the potential climate change and their influences on water resources is essential (Noori, Sharifi et al. 2014).

Nowadays, the administration of water resources has been taken under consideration based on sustainable progress in the earth (Salarian, Shokri et al. 2014) and the character of the multi objective system needs not just technical and economic variables but it needs invisible parameters such as environmental parameters to evaluate their objectives since these parameters have major effects on the environment (Othman, Heydari et al. 2014).

Almost every mathematical programming model could just be an estimated explanation of an actual water resources system in a very good conditions. The solution might just be an optimum for prepared model and wouldn't always be perfect for the actual problem (Othman, Sadeghian et al. 2012).

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