PERFORMANCE EVALUATION OF JIROFT STORAGE DAM OPERATION USING HEC-RESSIM 2.0

Hossein Babazadeh [1], Hossein Sedghi [2], Feriydon Kaveh [3] and Habib Mousavi Jahromi [4]

[1] Ph.D. Candidate. Islamic Azad University. Science and Research Branch-Tehran-Iran. E-mail: h_babazadeh@sr.iau.ac.ir ; h_babazadeh@hotmail.com
[2,3] Academic Members of Islamic Azad University. Science and Research Branch, Tehran, Iran.
[4] Hydraulic Structure Department, Faculty of Water Science Engineering, Shahid Chamran University, Ahvaz, Iran

ABSTRACT

The application of simulation models is one of the most efficient ways of analyzing water resources systems, which is based on physical relations accompanied by a series of operational rules attempting to simulate a phenomena as close as possible to reality and the system behavior under a specified policy. HEC-ResSim is one of the simulation models that possess of multi reservoir simulators and can simulate water resources systems. In this research, performance of Jiroft storage dam and its water supply was evaluated. With this model Reliability, resiliency and vulnerability indices were used for system evaluation. Model verification results indicate that, this model is able to simulate the behavior of the system very well. Jiroft storage dam was simulated with various scenarios in the present condition, different periods considering sedimentation, project expansion and increased efficiency. Introducing the system expansion had shown a serious deficit and considerable failures in 25% of the operation periods. But, by increasing irrigation efficiency from 30 to 50%, failures in the system were decreased 12% and resilience was increased to 17%.

Keywords: HEC-ResSim, Simulation, Reliability, Resiliency and Vulnerability

INTRODUCTION

Due to arid and semi-arid climate, various parts of Iran are pacing acute water shortage. Due to limited water resources, optimum operation of these resources is unavoidable. Latest estimates show, the demand for water in Iran will be 116.2 billion cubic meter in 2020 with a population of 100 millions. Agriculture and fishery sectors with 88.5% are greatest water consumers. Supply of this water in 2020 horizon is only possible if the number of operating dams is increased to 300 or 400%. To achieve this goal 13500 billion Iranian Rials (about 17 billion US$) is spent yearly for construction of these dams. [8]

Therefore, it is required that most of research be undertaken toward saving, storage, management and water demand of water resources in this country. Ingredients include analyzing various parameters such as population, economy, water use efficiency and etc.

Analyzing of all of these parameters without computer model is time consuming and almost impossible [11].

In operation of special system, some of long term, short term, certain time and simulation model was used [12]. In this study, simulation model was used for system evaluation. Simulation model is a best way of using physical rules and a series of operational rules try to simulate genuine phenomena and approach and accurate scheme to predict the behavior of the system under a specific policy [14].

Input data of simulation model could be classified in three parts: fix data, design data and time series data. Fix data are properties of system such as physical and economic properties and relationship between them. Design data, in fact, are decision variables which in determined in modeling process are reservoir capacity and plant generating power capacity. Inflow to system is in the form of artificial data or time series data [7].

Simulation models can present efficiency and system performance in different combination of reservoir, plant powers, reservoir storage, output etc. and in this manner, they have good flexibility. But, for the selection of the best combination, they are not useful tools. Simulation models every time for special condition of possible combination of and with a specified operation policy is run and shows the performance option. In large system that different components affect system performance, simulation model alone could not help. Therefore, in this condition we must use optimization models. Linear, non-linear and dynamic programming is different optimization techniques in water resources system and various models are using these methods [1].

Eichert and Davis (1976) used HEC-5 model for study of flood control on Sasquehanna reservoir system. Karamouz et al (1992) used combined simulation and optimization model for operation of multipurpose reservoir system [9].

In 2004, for evaluation and reservoir management of Tigris and Euphrates rivers system in Iraq HEC-ResSim 2.0 was used. First, multi-reservoir system of these rivers where setup on HEC-ResSim. Model contains six main reservoirs, three off-stream reservoirs and seven small reservoirs and many diversion dams for diverting water from Tigris and Euphrates rivers. Priority in these multipurpose reservoir system are water supply for agriculture demand then flood control, while, hydroelectric power was also generated. HEC-ResSim 2.0 was used for simulation history events special flood and drought periods [4, 5].

USACE experts used HEC-ResSim for water resources simulation in Afghanistan. Engineers of US Army Corps of Engineers and Afghani engineers created a team for

simulation of Kajakai reservoir and project development downstream plains. This model simulates system operation for power generation, flood control, irrigation and changes in power generation capacity, live storage and release structures (5).
Momeni et al (2006) with using dynamic system method modeled operation of multipurpose reservoir in Zayandehroud storage dam and devoting accuracy the allocation of surface water between different irrigation networks can develop and supply agriculture water demands and decrease groundwater level decline in basin at the same time [10].

In the present study HEC-ResSim simulation model was to evaluate performance of Jiroft storage dam operation and ability of the model to simulate of reservoir system was studied. First, model structure was described and then using related equation of reservoir analysis Jiroft storage dam and study reservoir storage change by sedimentation and recent droughts was analyzed downstream system. Finally, the possibility and effect of irrigation efficiency on system performance as a result of irrigation network expansion was evaluated.

MATERIAL AND METHODS

1. HEC-ResSim 2.0 Introducing

HEC-ResSim 2.0 was developed by US Army Corps of Engineers on September 2003. This model was used in reservoir simulation for water resources allocation, flood control, river routing and etc with different operation policy. This model has three main modules: Watershed Setup, Reservoir Network and Simulation. In this model we can make different management in reservoir system by defining scenarios in a time series data. Model input data are: reservoir properties (Volume-Area and Elevation Curve, Operation levels, Operation rules and etc) control and operation points, rivers routing properties and time series input file. The highest capability of this model was defining of different operation rules in power plant generation flood control conditions, creating scenarios for conditional operation, downstream control point, reservoir system balance (series and parallel) to imitate the hydrological condition and installing of different structures in dam body, comparison of output with observed data, defining of different operational level, different computational steps (15 min to a day), adjusting output and etc.[13]

2. Performance Evaluation Criteria of Water Resources System

Performance of water resources is mostly defined by simple criteria content of average benefits variance and operation variables that is good but not enough. Using of Reliability, Resiliency and Vulnerability (RRV) for classification and performance evaluation of water resource system that was proposed by Hashimotoo et al (1982) can help to upgrade the above performance. These indices were used for test of water resources performance evaluation for various scenarios, evaluation of water resources system output regarding demands was used. First, a criterion (C) for every water resources defined that equal to unsatisfactory value. Under these conditions, system couldn't deliver to expected performance. Daily value of simulation times series of river flows or reservoir levels X_t for periods (T) were studied. Every water resources has a defined satisfactory range *(S)* and unsatisfactory *(U)* for related criteria (C).

If $X_t > C$ then $X_t \in S$ and $Z_t=1$, else $X_t \in U$ and $Z_t=0$. But, another criteria was defined is W_t that show a transform from un-satisfaction to satisfaction [6].

$$W_t = \begin{cases} 1; & X_t \in U \quad \& \quad X_{t+1} \in S \\ 0; & \text{Else} \end{cases}$$

If we define un-satisfactory period (X_t) by $J_1, J_2, \ldots, Jn$ then reliability, resiliency and vulnerability are following equations.

$$C_R = \frac{\sum_{t=1}^{T} Z_t}{T} \qquad \text{Reliability} \qquad (1)$$

$$C_{RS} = \frac{\sum_{t=1}^{T} W_t}{T - \sum_{t=1}^{T} Z_t} \qquad \text{Resiliency} \qquad (2)$$

$$C_V = \max\left\{ \sum_{t \in J_i} C - X_i \qquad i = 1, \ldots, N \right\} \qquad \text{Vulnerability} \qquad (3)$$

Equations 1, 2 and 3 were used for evaluation of reliability, resiliency and vulnerability of Yorkshire present water resources system and climate change scenarios. Reliability (C_R) is frequency criteria of failure resources. Resiliency (C_{RS}) show returns rate or recovery of resource from failure state and Vulnerability (C_V) is extend of failures. Surpassing system performance from threshold performance and/or inability of reservoir system in supplying of water is termed system failure [3].

3. Study Location and Characteristic

Halil River is one of biggest river of Jazmourian basin and Kerman province, Iran. The area of Halil river basin is 31462 km^2. The starting point of this permanent river is snow covered mountain near city of Baft and Rabor in Kerman province. Annual volume of water carried by Halil River as measured by monitoring station in 42 years time series is 515 MCM. Jiroft storage dam is the largest dam in this river basin that started operation in 1992. Average annual inflow of dam reservoir over 42 years is 422 MCM and from initial operation up to 1995 is 536 MCM. First of all, operation reservoir volume is 415 MCM at elevation 1184 meter from sea level and inactive level is 1126 meters from sea level. This is an arched dam and average evaporation from water surface is 2076 mm. Length of dam crest is 250 m and its height from river bed is 125 m and crest width is 5 m. This dam has two Francis turbines with power generation 32 MW. Main purpose of this dam construction is supply of downstream agriculture water demand, flood control of Halil River and secondary is hydropower generation. Due to drought in recent years, power station was not operated.

Based on field survey and published data from Jiroft Storage Dam Operation Company, agricultural sector use of water from dam reservoir is shown in table 1 and classified base on priority to three sections. Table 2 shows monthly agriculture water demand of Jiroft and Roudbar plain. Fig. 1 shows watershed setup, storage dam, diversion and consumption points in HEC-ResSim model.

Note the points located after junction of Shour and Halil rivers, south of unit No. I, Roudbar and Jazmourian sections can use Shour river surface water. The water loss in Halil and Shour River due infiltration losses of river bed materials was also considered. From 1992 to 2005, the thickness and extend of sediment pileup was surveyed three times and the change of storage was evaluated. Fig. 2 shows area-volume and elevation of Jiroft reservoir in years 1992, 1996 and 2005.

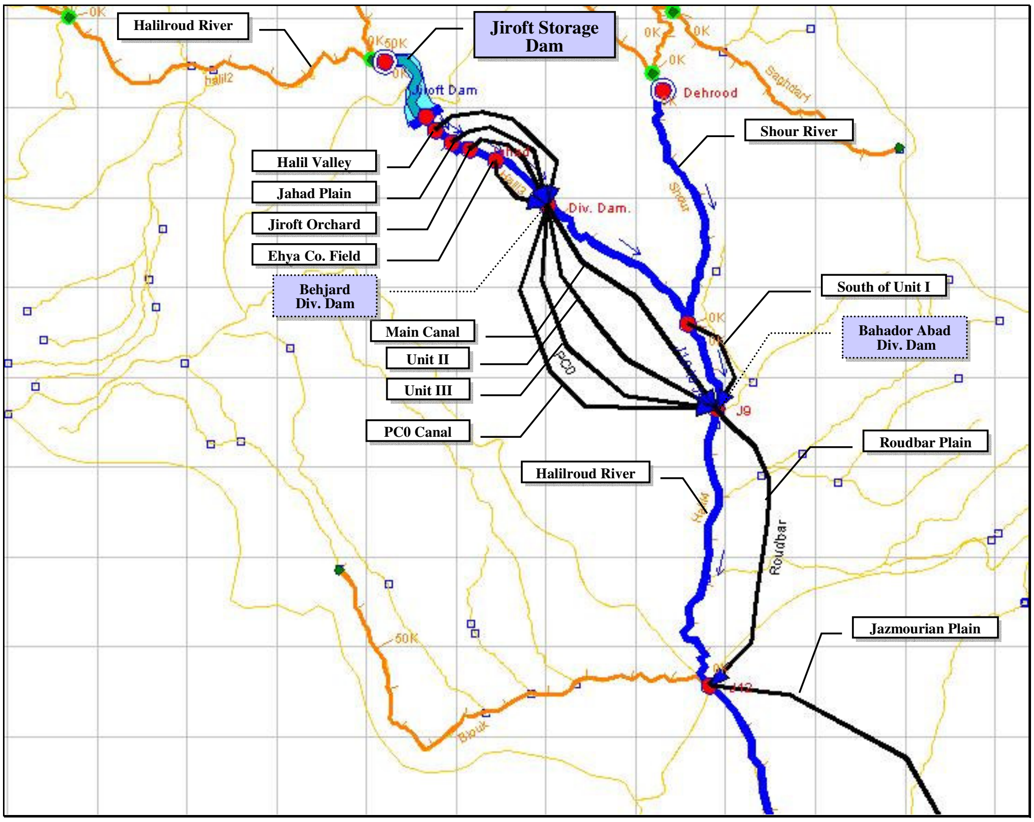


Fig. 1: Resources and Demands Layout of Halil River and Jiroft Storage Dam

Table 1: Area and agriculture water demand and operation priority of Jiroft storage dam

	Jiroft Dam to Behjard Div. Dam				Jiroft Irr. & Drinage Net.			Downstream of Halil and Shour junction			Total
Operation Priority	1	2	3	4	5	6	7	8	9	10	
Agriculture Demand	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	South of Unit I	Roudbar Plain	Jazmourian Plain	
Area(ha)	1000	1000	330	1600	577	506	2374	540	7120	5000	20074
Water Demand(MCM)	16.8	16.8	5.5	26.85	9.68	8.5	39.84	9.06	77.5	54.4	265

Table 2: Monthly Agriculture water demand of Jiroft storage dam downstream and Roudbar plain (Cubic Meter per Hectare)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Jiroft Plain	390	642	1201	2061	2233	1737	1680	1918	2061	1425	889	545	16781
Roudbar Plain	256	608	1262	2050	1652	737	555	837	1320	805	483	315	10880

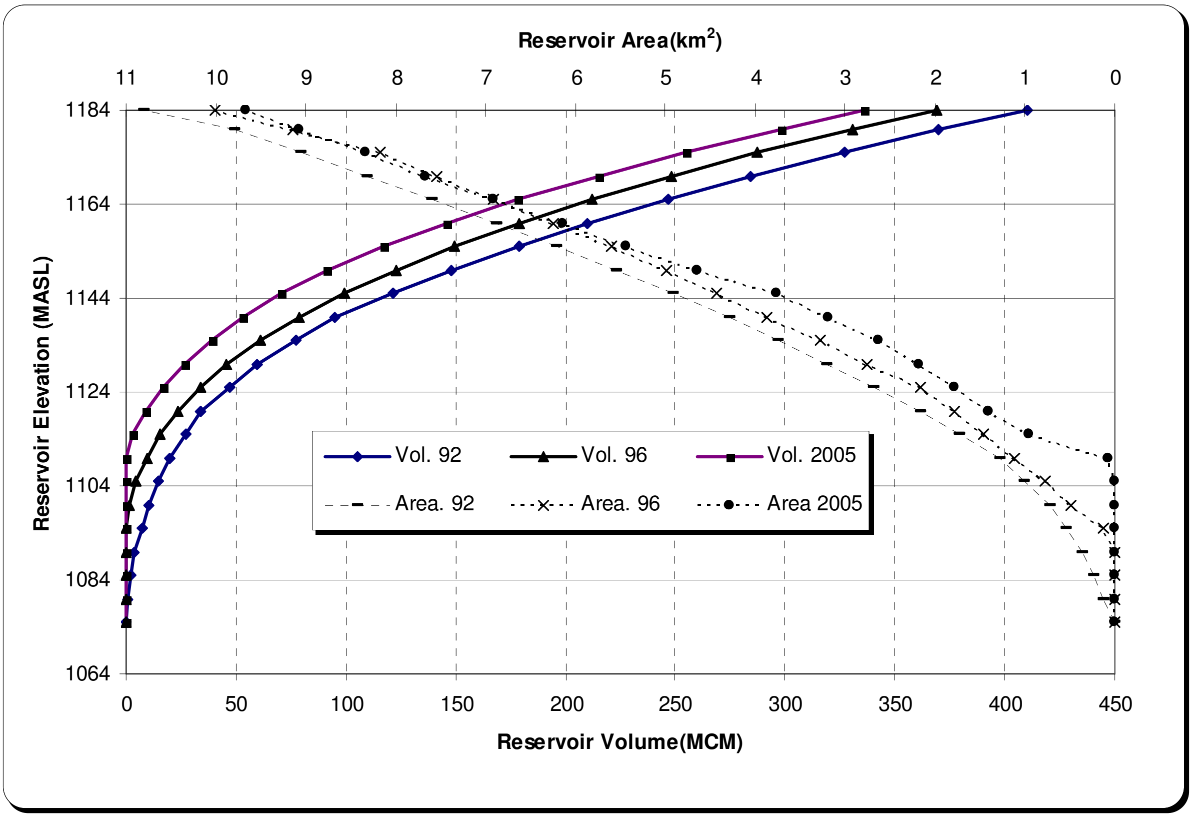


Fig. 2: Area-Volume and Elevation Curve of Jiroft Storage dam in Before and after sedimentation.

RESULTS AND DISCUSSION

72 months operation from 1999 to 2005, data of Jiroft Storage Dam (such as: inflow, outflow, reservoir level, storage and power generation as daily data) have been recorded by Jiroft Dam Operation Company. These data were used for validation and estimation of model accuracy. Fig. 3 shows chart of observed data from Jiroft storage dam.

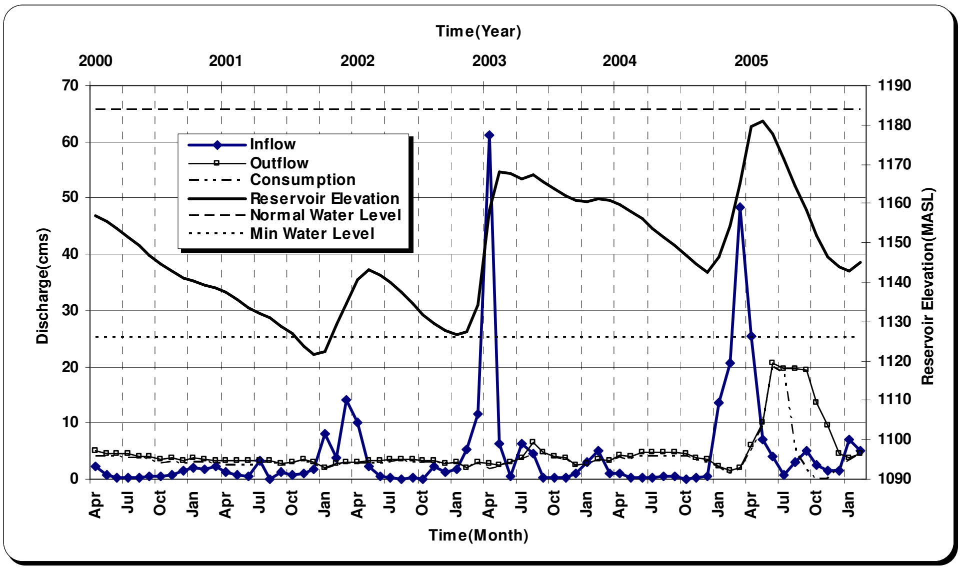
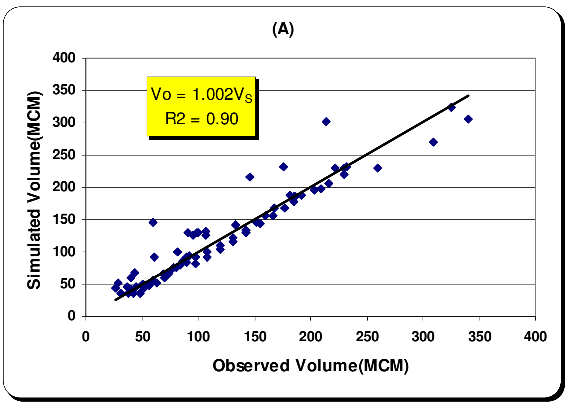


Fig. 3: Observed parameters of Jiroft storage dam operation (April2000 to March 2005)

Model Validation

For study of accuracy and validation of model, observed data from April 1999 to March 2005 was used. Therefore, input data, output data and reservoir and dam properties were supplied to the model and changes in computed volume of reservoir were compared with observed data. Observed data input to model as history data and reservoir storage were compared with observed data in observation periods. Fig. 4 (A and B) shows results of comparison. The value of absolute error was 11% and root of mean square error was estimated 23 million cubic meters. Therefore, model ability and efficiency are acceptable.



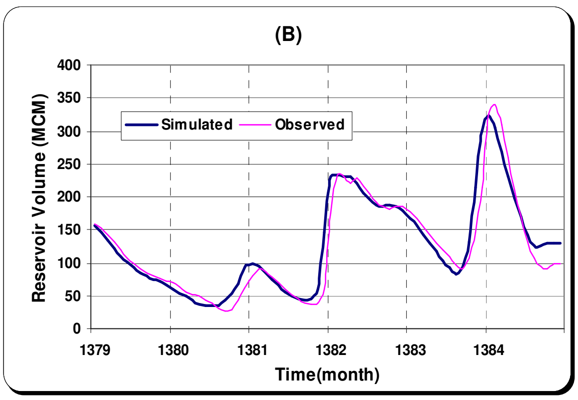


Fig. 4: Comparison between observed and simulated storage data of Jiroft Dam

Performance evaluation of Jiroft system in various sedimentation conditions.

In this section of study Jiroft storage dam performance from starting operation to end of 2005, which the time series, have a wet and a dry condition, was evaluated by model for different sedimentation. Regarding dam regulated flow in river, therefore, upstream operators had more safety to divert reservoir regulated water. This fact is considered in operation priority of model. For plains in upstream of Behjard diversion dam to Jiroft dam 20% return flow and for Jiroft irrigation and drainage network 10% that downstream agriculture unit can use this flows. For system evaluation to agriculture use, 85% of monthly satisfaction criteria were considered.

Summary of simulation results and evaluation parameters of Jiroft system and downstream agriculture demand for various sedimentation at years 1992, 1996 and 2005 are shown in tables 3, 4 and 5. As observed, satisfaction, time and volume reliability of system from upstream to downstream and from 1992 to 2005 with reservoir sedimentation was decreased. Due to recently drought, Jazmourian plain in downstream of Halil River has been faced to serious deficits. As results in all of sedimentation condition in 14 years, reliability was less than 50% of agriculture water demand. But in upstream of Halil and Shour rivers junction, its reliability was more than 85%. That can be controlled in drought events by deficit irrigation and apply of application and conveyance efficiency. Roudbar plain in 35% of time has been faced to water deficit, that for compensating of these deficits, suitable management in distribution and using of reuse water resources is necessary to decrease of pressures(Stress) on groundwater resources that was critical limitation in this regions.

Table 3: Evaluation parameters of Halil river system and Jiroft dam, 1992

Evaluation Items	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	South of Unit I	Roudbar Plain	Jazmourian Plain	Average	Standard Deviation	Coeff. Of Variation
No. Satisfied Months	156	152	150	149	150	149	140	126	94	73	133.9	26.8	0.2
No. of Failure Months	12	16	18	19	18	19	28	42	74	95	34.1	26.8	0.8
Satisfied Percent(%)	92.8	88.9	88.1	87.4	89.7	87.3	85.4	88.6	68.0	45.3	82.1	13.9	0.2
Reliability(%)	92.9	90.5	89.3	88.7	89.3	88.7	83.3	75.0	56.0	43.5	79.7	16.0	0.2
Resiliency(%)	33.3	18.8	16.7	15.8	16.7	15.8	35.7	33.3	31.1	27.4	24.4	8.0	0.3
Vulnerability(%)	72.0	75.0	75.0	75.0	73.9	75.0	75.0	69.6	75.0	75.0	74.1	1.7	0.0

Table 4: Evaluation parameters of Halil river system and Jiroft dam, 1996

Evaluation Items	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	South of Unit I	Roudbar Plain	Jazmourian Plain	Average	Standard Deviation	Coeff. Of Variation
No. Satisfied Months	152	149	147	146	147	146	137	122	91	72	130.9	26.3	0.2
No. of Failure Months	16	19	21	22	21	22	31	46	77	96	37.1	26.3	0.7
Satisfied Percent(%)	91.8	86.7	85.8	85.0	87.9	84.9	83.1	86.1	65.9	46.5	80.4	13.0	0.2
Reliability(%)	90.5	88.7	87.5	86.9	87.5	86.9	81.5	72.6	54.2	42.9	77.9	15.7	0.2
Resiliency(%)	37.5	26.3	19.0	18.2	19.0	18.2	35.5	30.4	28.6	26.0	25.9	6.8	0.3
Vulnerability(%)	69.7	75.0	75.0	75.0	73.2	75.0	75.0	69.6	75.0	75.0	73.7	2.1	0.0

Table 5: Evaluation parameters of Halil river system and Jiroft dam, 2005

Evaluation Items	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	South of Unit I	Roudbar Plain	Jazmourian Plain	Average	Standard Deviation	Coeff. Of Variation
No. Satisfied Months	153	148	147	145	147	145	136	118	89	70	129.8	27.1	0.2
No. of Failure Months	15	20	21	23	21	23	32	50	79	98	38.2	27.1	0.7
Satisfied Percent(%)	92.0	86.7	85.5	84.7	87.8	84.6	82.8	79.6	64.3	45.4	79.3	13.3	0.2
Reliability(%)	91.1	88.1	87.5	86.3	87.5	86.3	81.0	70.2	53.0	41.7	77.3	16.1	0.2
Resiliency(%)	40.0	25.0	19.0	17.4	19.0	17.4	34.4	28.0	27.8	25.5	25.4	7.2	0.3
Vulnerability(%)	67.8	75.0	75.0	75.0	72.5	75.0	75.0	75.0	75.0	75.0	74.0	2.2	0.0

Simulation of Jiroft storage dam operation in PC0 canal development

During design and construction of Jiroft storage dam, a section of irrigation and drainage network as named PC0 canal due to different reasons hasn't been constructed yet. Now, final step of this canal construction is operating. Covering area by PC0 is 3296 hectare that operating from Jiroft surface water. Base long time simulation (42 year), evaluation parameters in development conditions is shown in table 6. In this condition, Jiroft storage dam can regulate 213 MCM per year. Fig. 5 shows variation of Jiroft storage in 42 years time series data. Volume of uncontrolled flow (Spill) is estimated 197 MCM per year. As can be seem in table 6, in developing conditions, fields which is located from storage dam to diversion dam have 88% reliability, but irrigation and drainage network fields is faced to 20% deficit. Downstream fields of Halil and Shour river junction have significant and serious deficit. Under these conditions for supply of water demand of Roudbar and Jazmourian, the other water resources such as regulation of Shour River flows must be considered.

Table 6: Evaluation parameters of Halil river system and Jiroft Dam PC0 development condition

Evaluation Items	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	PCO Channel	South of Unit I	Roudbar Plain	Jazmourian Plain	Average	Standard Deviation	Coeff. Of Variation
No. Satisfied Months	468	447	435	415	434	413	408	370	322	253	192	377.9	83.2	0.2
No. of Failure Months	36	57	69	89	70	91	96	134	182	251	312	126.1	83.2	0.7
Satisfied Percent(%)	94.6	87.0	84.2	80.7	87.7	79.6	78.6	75.1	81.6	57.1	37.6	76.7	15.3	0.2
Reliability(%)	92.9	88.7	86.3	82.3	86.1	81.9	81.0	73.4	63.9	50.2	38.1	75.0	16.5	0.2
Resiliency(%)	52.8	38.6	30.4	21.3	30.0	20.9	20.8	28.4	24.2	28.3	23.1	29.0	9.1	0.3
Vulnerability(%)	68.8	75.0	75.0	75.0	72.9	75.0	75.0	75.0	69.7	75.0	75.0	73.8	2.2	0.0

Simulation of Jiroft system in increasing of efficiency condition to 50%

Increasing of irrigation efficiency in the district with different approach such as change of irrigation method, suitable of filed management, lining of conveyance facilities and etc, are possible, can decrease water deficit in the system. As simulation results in efficiency increasing condition (table 7), fields from storage dam to diversion dam would be 2.5% deficit, but filed in irrigation and drainage network district have 4.75% deficit. Therefore, their deficits decreased to 15% and satisfaction of downstream will increase to 69%. Fig. 5 shows variation of reservoir storage in 30 and 50% efficiency. Therefore, in this region for conservation of limited water resources, there isn't any way unless increase of efficiency, water use efficiency and conservation of water resources.

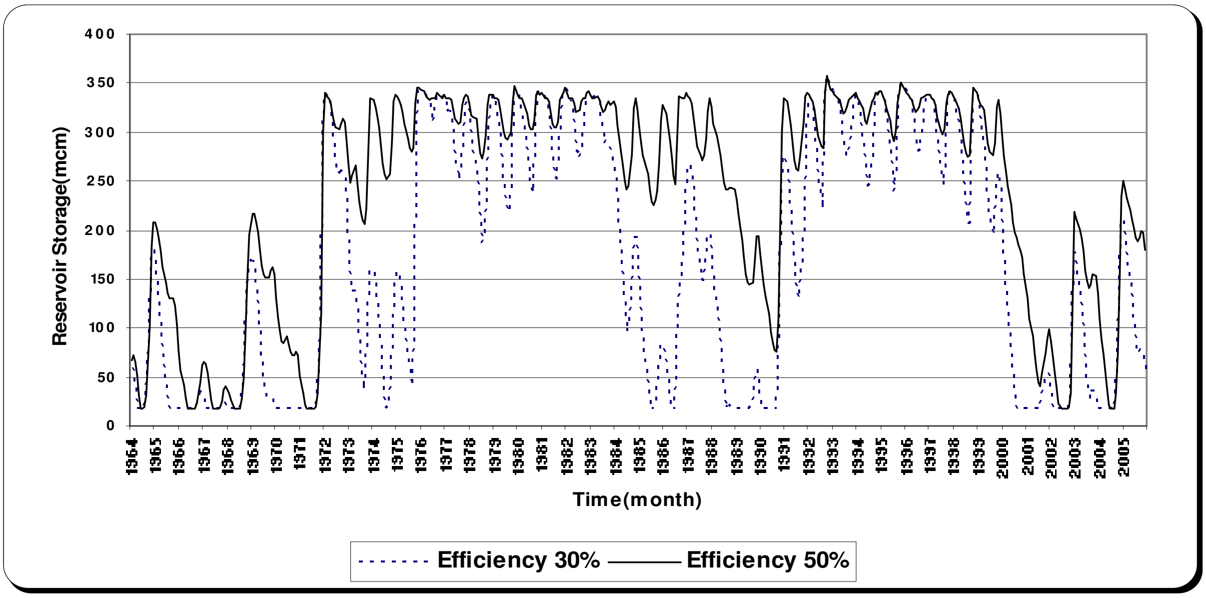


Fig. 5: Reservoir storage variation of Jirof dam in PC0 development condition with efficiency 30 and 50%

Table 7: Evaluation parameters of Halil river system and Jiroft Dam by increasing efficiency from 30 to 50%

Evaluation Items	Halil Valley	Jiroft Orchard	Jahad Plain	Ehya Co. Field	Main Canal	Unit II	Unit III	PC0 Channel	South of Unit I	Roudbar Plain	Jazmourian Plain	Average	Standard Deviation	Coeff. Of Variation
No. Satisfied Months	499	493	484	482	485	481	476	444	492	270	232	439.8	90.4	0.2
No. of Failure Months	5	11	20	22	19	23	28	60	12	234	272	64.2	90.4	1.4
Satisfied Percent(%)	99.3	97.7	96.7	95.8	97.6	95.5	94.5	91.9	96.2	66.1	44.5	88.7	16.5	0.2
Reliability(%)	99.0	97.8	96.0	95.6	96.2	95.4	94.4	88.1	97.6	53.6	46.0	87.3	17.9	0.2
Resiliency(%)	80.0	63.6	40.0	31.8	36.8	30.4	25.0	53.3	83.3	32.9	30.9	46.2	19.8	0.4
Vulnerability(%)	48.8	75.0	75.0	75.0	65.9	75.0	75.0	75.0	53.1	74.9	75.0	69.8	9.3	0.1

CONCLUSION

This article attempts to study performance of Jiroft storage dam in present conditions, sedimentation condition and developing condition using HEC-ResSim and evaluation indices. First, results of model validation showed that model was capable of simulation with suitable accurate. Secondly, in the present condition of operation (1992-2005), and regarding to many droughts, significant deficit was considered and with increasing sediment volume in reservoir and decrease live volume of reservoir, this deficit was more than what was hypothetically assumed. Finally, system performance for develop of PC0 canal was evaluated and results was shown, deficit of downstream was increased to 18%. Therefore, systemic and global study in design condition, system management and increase of irrigation efficiency and conservation of water resources in this system with promotion of effective approach in irrigation, rainfall harvesting for conservation of water resources, using of reusable water in this region must be more considered than before.

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