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Quantitative Effects Influencing Factors in the Urmia Lake Water Level Changes Using a System Dynamics Model

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ABSTRACT: System dynamics model is in fact the object oriented simulation modeling and it is based on feedback that in addition to describing complex systems based on reality, it allows the effective involvement of the user in the development of the model and provides his confidence during the modeling process. Increased speed of model development, group model development capacities, effective interrelationship with results and increasedconfidence in the model in the result of user participation is the most important features of this method of simulation. The ease of modifying the model and perform sensitivity analysis have made this model more appealing than other analysis methods. In this paper the system of surface water resources pouring into Zarinehrud, Shahrechay, Alavian, Nahand, Mahabad and Shahid Madani dams as a part of Urmia Drainage Basin is simulated with system dynamics and using Vensim computer program and their construction effect on the Urmia Lake level. The system dynamics model of the Lake Urmia provides the possibility of addressing the effects of various factors on the lake separately or simultaneously; also the model can predict the performance of new policies in the future. After creating the model structure in the program and data collection and analysis to model the dams and introducing these data to the model the simulation of the function of these dams was performed in the program and the behavior results of each dam from (1960-1961) to (2009-2010) indicated that the effect of dam construction on reducing the lake level is approximately 21%.

Key words: Drainage basin, System dynamics model, Lake Urmia, Vensim

INTRODUCTION

One of the ways to overcome the problem of shortage of water resources and contribute to the sustainable development of water resource systems is the assessment of management policies and help in decision-making at the macro level. One of the important issues in water resource management is the evaluation and decision-making based on the total system rather than restricting a single reservoir approach which requires having an integrated vision of the mentioned system. In recent decades using various methods of analysis in the field of system simulation and in optimization has become an efficient tool in resource management which has an important role in overcoming the challenges in this field (Simonovic, 2000).

Irregular population development, agricultural development and rapid growth in industry increase water demand every day. A part of requirements is provided by the surface water supplies' control through dam construction. Limited controllable waters and continuously increasing needs demands better planning in order to water management and proper utilization of the limited resources. If these available resources are properly utilized, it is possible to provide for the current and even future needs (Bozorg and Seif 2012).

In the optimization methods the effect of different policies on the performance of water supply system is measurable through the objective functions and solution set points; while in the simulation method the results of various policies must be interpreted in a way that they provide the selection of the better policy (Rezai and Changizi 2011). Different purposes in the analysis of reservoir systems lead to various models of these systems. The main purpose of these models is to regulate and evaluation of various plans in order to respond the needs associated with water. The conventional models in systems engineering that are used in the reservoirs are the optimization simulation models and a combination of optimization and simulation. The optimization models are based on making an objective function minimum or maximum which consists of decision variables considering the constraints. In other words, these models are automatically after the optimum decision variables that provide for all constraints. The purpose of the simulation models is to improve the plans and operation policies. These models predict the system behavior based on the value of the variables specified by the user. The reliability of the simulation methods is in their ability to solve models of analysis of water resources system that have non-linear relations and constraints, whereas the optimization methods are less capable of conducting them [Loucks *et al.,* 2005).

System analysis has an important role in water resources management and simulation is an essential decision-making tool in the process of reservoir management. However, there is a need for tools that can describe complicated systems based on the realities and help the user to participate in model development to increase the confidence in modeling (Larry *et al.,* (2011).

Models with dynamic characteristic are among the numerous models of water management. In these models the understanding of the problems and changes are in the form of loops and feedback. By means of this method the unpredicted uncertain outcomes of the decisions become clear. The purpose of this method is to simulate the behavior of systems in current and future conditions to accelerate and facilitate the learning process. The system dynamics is easier and more effective compared to other system analysis methods and does not need complicated mathematical descriptions in system description. This method was originally developed by Forrester to provide a better understanding of strategy problems in Complex system dynamics (Sterman, 2000).

System dynamics approach is a method for analysis, problem solving and system simulation. This technique is a method for the analysis of complex systems and problems with the help of computer simulations which was developed by Forrester in 1960s in the MIT College. System dynamics is a formulated method for analyzing the components of a system that has a cause and effect relationships, logical and mathematical foundation and feedback loops (Chen *et al.,* 2005). Keyes and Palmer used the system dynamics approach in the stimulation of the drought studies. Fletcher used the system dynamics approach as a decision making analysis method in water management. Simonovich and Fahmy used the above method for evaluating long-term water resources and the analysis of the policies in the Lake Nile basin in Egypt. Royston used the system dynamics approach in providing water demand and operation of multipurpose reservoir. Ahmad and Simonovich using the method analyzed the operation of Shellmouthreservoir in the Lake Assiniboinfor a year of high water and some occurred floods. In this research the effects of flood management in the reservoirs with gated overflow and gate-less overflow were compared and the model behavior is sensitively analyzed for the initial condition of the reservoir level.

Teegavarapu and Simonovich in order to model the operation of the multi reservoir system to produce electricity used system dynamics and in order to analyze the performance of the system used the reliability and vulnerability indices. Simonovich and Lee (2003) after developing a simulation model based on system dynamics for a complicated flood control system used reliability in evaluating the performance of system components under applying various scenarios.

Van Derzag (2005) explored the concept of water integrated management and using this concept he has provided a solution for the allocation of optimal water in a part of south Africa and has defined the water integrated management as a new method to manage the resources and attain the development goals, mutual respect, understanding and cooperation between the water users in the South Africa.

Kronaveter and Shamir (2009) have presented an appropriate model regarding the cooperation and negotiation in the allocated water reservoirs. In this model a negotiation backup system is used to help both negotiators in allocating water reservoirs. Through analyzing the benefits of this system, they have introduced it as a solution to find a solution in decision space. Mimi and Sawalhi (2003) through using an optimization method based on simple additive method through considering various criteria provided optimal water reservoir allocation of the River Jordan among the parties. In this paper the application of The International laws in solving the dispute over the Jordan River led to some inconsistencies among the countries of negotiation and they have presented the multivariate decision making method as a solution to allocate the Jordan River water among the parties. Jalali and Afshar (2004) presented a model based on System dynamics to operate the hydroelectric dams. Sadeqi (2004) presented a model based on System dynamics to operate the reservoirs in order to control flood. Hosseini and Baqeri (2012) analyzed the System dynamics of Dasht-e-Mashhad water resources to examine the strategies of sustainable development. This research is conducted to describe the implementation of Integrated Water Resources Assessment, evaluation of Dashte Mashhad water reservoirs and the actions and policies in the process of economic development programs.

Abrishamchi *et al* (2012) evaluated the water resources development projects in multi reservoir system under the Dare Rud basin using the functional indices. In this study the system dynamics approach was devised to simulate the water resources under the Dare Rud basin of the Aras River. The comparison results of the indices with various definitions indicated that although using the estimators based on maximum amount was recommended in the previous studies but the estimators based on the average have more useful information due to considering system condition in various conditions. Sheikh Khozani *et al* (2010) modeled the utilization of multipurpose reservoirs using system dynamics approach. The purpose of the above modeling was to determine the effect of various policies of utilization on the reservoir behavior and the providing moderate needs in future (2031). Based on the obtained results it was revealed that the implementation of appropriate policies not only it is possible to provide for the current needs but also consider the future needs. Safari and Zarghami (2013) studied the optimal allocation of surface water resources of the Urmia basin to the interested provinces based on distance based decision making methods.

In this study a multivariate decision making mode was performed based on distance by methods of simple additive method, compromise programming and TOPSIS method of water allocation the water of Urmia Lake is shared among the beneficiaries considering social, economic and the environmental criteria and the optimal share of each province of the surface water was determined and the capability of these methods was compared.

In this study the the system of surface water resources pouring into Zarinehrud, Shahrechai, Alavian, Nahand, Mahabad and Shahid Madani dams as a part of Urmia Drainage Basin is simulated with system dynamics and using Vensim computer program and considering that the provided structure is to simulate the water reservoir system thus it is possible to simulate the whole basin and in fact this mode has the capacity to accept and random combination of the reservoirs ant the effect of the parallel and serial systems. After the reservoir modeling of the dams the water resource allocation of these dams will be addressed using the system dynamics. The purpose of this study is to analyze the effect of constructing each dam on the inlet streams to Lake Urmia and finally the effect of dam construction on the Lake Urmia level.

MATERIALS AND METHODS

System dynamics formulated method for analyzing the components of a system. This technique was developed in the world of industry and commerce but nowadays it has been entered in many scientific fields.

System dynamics has many advantages. Due to analytical and critical approach to the modeling process, this process provides a better understanding of the system. The system dynamics model provides the possibility of entering qualitative and quantitative variables in the system simultaneously (Safari and Zarghami 2013). The tools being used in better understanding of system dynamics model are the causal diagram and flow diagram (Lane & Oliva 1998). The causal diagram is a diagram that represents the causal relationships between the system variables. By this tool the mental models of individuals is easily understood. The causal relationship is presented in through a curve with an arrow to indicate the operation. In order to build a model and collect data various research methods are applicable (Kirkwood 1998).

System Dynamics is a management tool for decision making about the dynamic systems that allow simulation and understanding complex systems using mathematical models, In other words, a method for understanding the dynamic continuous behavior of systems. System Dynamics is based on two main principals: The first principal is the attention to the time factor in which the system behavior is evaluated over time. The second principal is the attention to the feedback in each system (Sterman, 2000). The potential of using the system dynamics in water resources was first introduced by Lee in the 90s. He stressed that Hydrological modeling is performed in two stages: conceptualization and programming that these two stages are presented in System dynamics. System dynamics in water resources management is used in water resources, ecological and environmental modeling and basin modeling (Lee, 1993). In system dynamics the variables are divided into two major groups of state and rate variables. State variable is the main component of the system which is the main objective is the simulation, cognition and behavior changes in this variable over the time. What causes changes in the state variable is the rate variables associated with it. In addition to these two variables some covariates are used to apply the mathematical relationship between the components of the system. In this simulation method changes and the variable behavior of the stave variable is performed using the numerical solution of differential equations governing the relationships between the components (Jutla, 2006).

A. Introducing the Compromise Programming

The advantages of this method including its ease of understanding, data normalization, and considering the distance from the ideal in calculating the ideal alternative and considering the weight of criteria and the successful application of this method in previous studies were the reason to choose it in this study. The ideals are determined based on the needs and demands of the decision maker and based on the previously determined amount for the purposes or criteria. The criteria include the measures, rules, standards, demands ans the guidelines of the decision makers. In this method the score of each beneficiary is calculated through the following equation:

$$F_i = \left(\sum_{j=1}^{n} \bar{a}_{ij}{}^{p} . w_j^{p}\right)^{\frac{1}{p}} \ldots(1)$$

$\bar{a}_{ij}{}^{p}$ is the normalized value of the i^{th} beneficiary's share based on the j^{th} criteria, w_j is the weight of the j^{th} criteria and p is the factor that determined the sensitivity of the decision maker to the distance from the inappropriate point. The parameter I varies 1-3 and the parameter j varies 1-6. n is the number of criteria used in the allocation. If p [0,1] the calculation (1) cares smaller values which indicates the pessimistic view toward the decision making issue. In fact, the risk aversive manager chooses this point of view. If p > 1 the input is greater has a greater effect and if $p \rightarrow \infty$ only the larger factors are considered. This state represents optimistic viewpoint toward the issue and reflects the venturing manager or decision maker [30].

To normalize the data (the share of i^{th} beneficiary from the view point of the j^{th} criteria) the following relations are used. Relation (2) is used for normalizing the positive factors and the relation (3) is used for normalizing the negative factors.

$$\bar{a}_{ij} = \frac{a_{ij}-m_j}{M_j-m_j} \quad \ldots(2)$$

$$\bar{a}_{ij} = \frac{M_j-a_{ij}}{M_j-m_j} \quad \ldots(3)$$

In these relations m_J and M_J are the highest and lowest points of the beneficiaries from the jth criteria.

B. Simple additive weighting

If P = 1 the compromising the compromise programming method is converted into simple additive method in which all inputs that are the normalized share of the i^{th} beneficiary based on the viewpoint of the j^{th} criterion, in this method the point of each beneficiary F_i is calculated through the following relation:

$$F_i = (\sum_{j=1}^{n} \bar{a}_{ij} . w_j) \qquad (4)$$

C. TOPSIS (technique for order performance by similarity to ideal solution) method

This method was offered by Huang and Yun in 1981. The basic concept of this method is based on the fact that the selected alternative must have the shortest distance from the positive ideal solution and the largest distance from the negative ideal solution. The positive ideal solution is the solution that maximizes the benefit criteria and minimizes the cost criteria (Huang and the Yun 1981). In this method the value P = 2 is selected and the point of each F_i alternative is calculated through the following relation:

$$F_i = \frac{d_i}{d_i + D_i} \qquad (5)$$

d_i is the distance of the i^{th} alternative from the ideal point and D_i is the distance of the i^{th} distance from the inappropriate point when P = 2. After calculating the point of each beneficiary his share of the total annual renewable water resources is calculated as follows where m equals the number of the beneficiaries:

$$\bar{F}_i = \frac{F_i}{\sum_{i=1}^{m} F_i} \times 100 \qquad (6)$$

D. Introducing the area under study

The Lake Urmia is the largest water surface inside the country located between the east and west Azerbaijan provinces. In normal conditions it has 140 km Length and 16-64 Km width. The area of the lake in normal conditions is 5263 km^2 based on the satellite images also in normal level the average area of the lake is about 5500 km^2 with 5.4 m and maximum13 meters depth the northern water of the lake is approximately 31 billion m^3. The deepest part of the lake is 14 meters in the North West in low water season and 20 meters in high water seasons. Since the depth of the lake is low in the case of long wind periods the water is pushed toward the beach and creates swampy lands. Although the lake water is very clear but it has among the lakes that have the highest amount of minerals. The salinity of rivers varies based on the rivers that pour into it. The lake water is mostly provided by the lakes that pour into it and through the rain. Under normal circumstances15 rivers with permanent regime, 7 seasonal streams and 39 floodways pour into the Lake Urmia.

E. Monthly surface evaporation distribution

For the purpose of calculating the amount of monthly evaporation from the surface of the reservoir it is necessary to define the evaporation height from the open surface of water at the dam in different months of the year. In order to calculate the surface evaporation of the reservoir by the evaporation pan method the following method must be used:

$$E = K (Epan) \qquad \ldots(7)$$

Where E is the Evaporation from water surface in the reservoir, E_{pan} is the evaporation pan and k is the constant the value of which for the standard grade for pan A(US) is between 58/0 and 78/0. The Pan coefficient for different months of the year can be seen from Table 1.

Table 1: Mqadbr pan coefficient in different months.

Coefficient	Month	Coefficient	Month
0.76	July	0.62	January
0.75	August	0.72	February
0.73	September	0.77	March
0.69	October	0.77	April
0.63	November	0.78	May
0.58	December	0.77	June

Among the reasons of reducing the amount of water entering the lake are increased amount of removed for implementing the agricultural development projects, construction of water structures on the rivers entering the Lake and the existence of drought in recent years. In the present study the effect of dam construction on the water level reduction is addressed.

In order to analyze the behavior of the dams the long term series of discharge entering the reservoir of these dams is required. Therefore the river discharge data at the input of each dam are obtained from the Regional Water Organization of East Azarbaijan through a Hydrologic report regarding these dams. These statistics are related to the years 1960-2010 upon which some analysis must be performed to be ready to be used in the model. These analytics are presented in the Figs. 1-6:

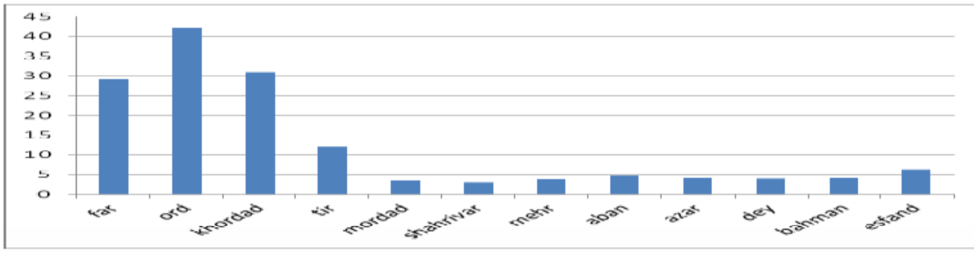

Fig. 1. Average monthly discharge of the river at the entrance to Alavian Dam (mcm).

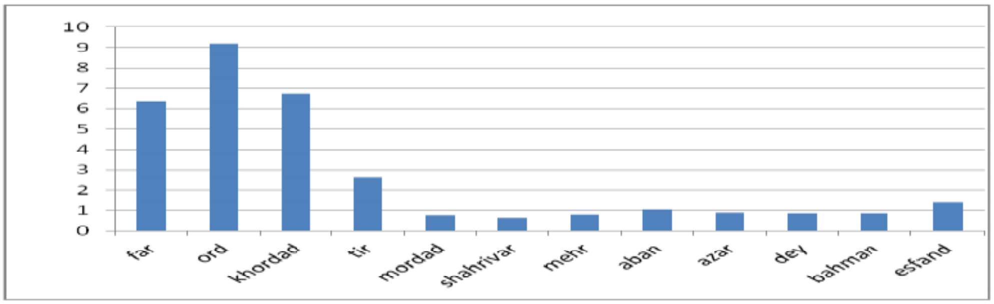

Fig. 2. Average monthly discharge of the river at the entrance to Nahand Dam (mcm).

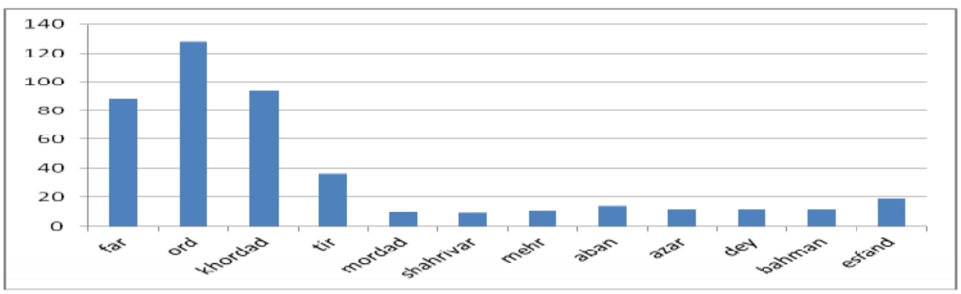

Fig. 3. Average monthly discharge of the Ajichairiver at the entrance to Shahid Madani Dam (mcm).

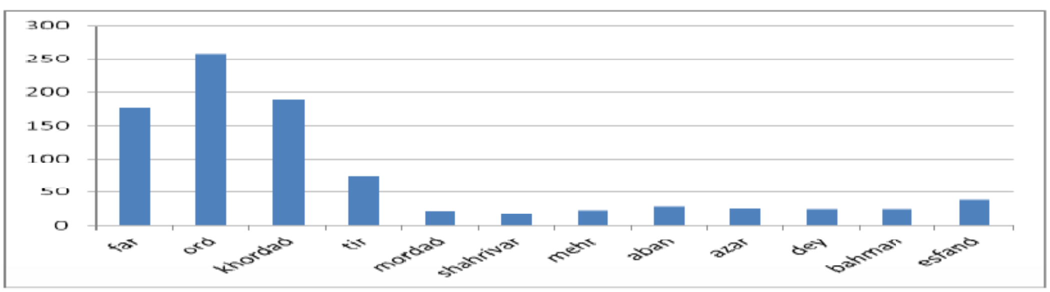

Fig. 4. Average monthly discharge of the river at the entrance to Zarrinerud Dam (mcm).

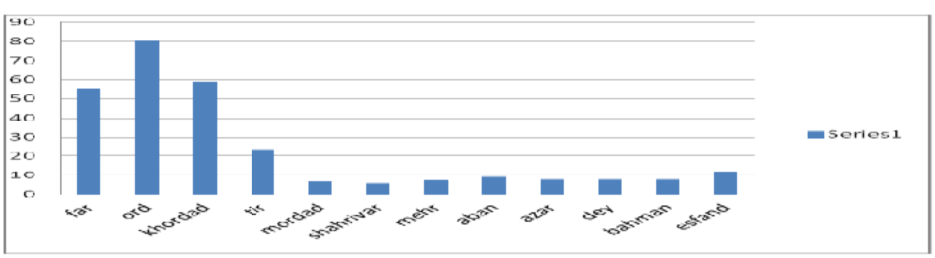

Fig. 5. Average monthly discharge of the river at the entrance to Mahabad Dam (mcm).

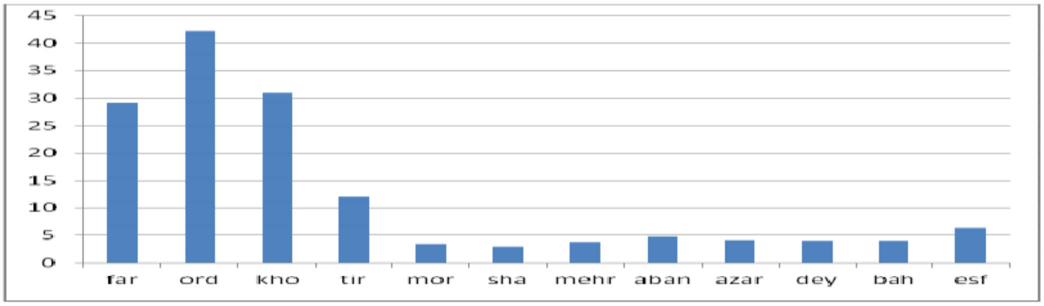

Fig. 6. Average monthly discharge of the river at the entrance to Shahrchay Dam (mcm).

DISCUSSION AND RESULTS

After creating the Structure Model of the dams inVensim program and collection and analysis of data required for the modeling of the dams and defining these data to the model, the simulation of the performance of these dams was performed by the program and the results of the behavior of each dam during the simulation period (1960-1960) to (2009-2010) and the rate of change of the input discharge into the lake before and after construction of the dam are presented in Figs. 7-14:

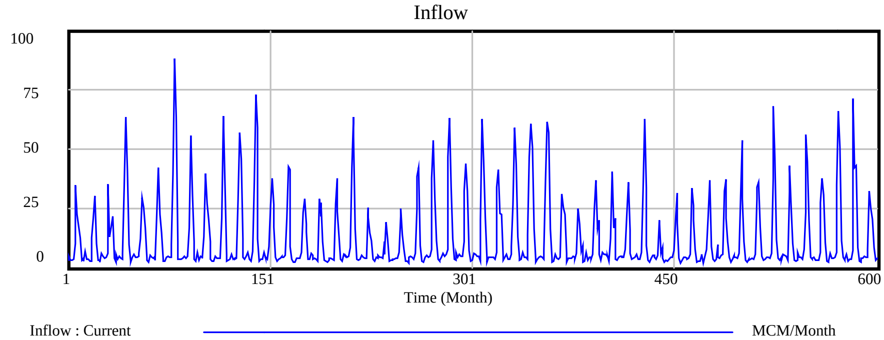

Fig. 7. Input dischargeentering the Urmia Lake before Alavian Dam construction

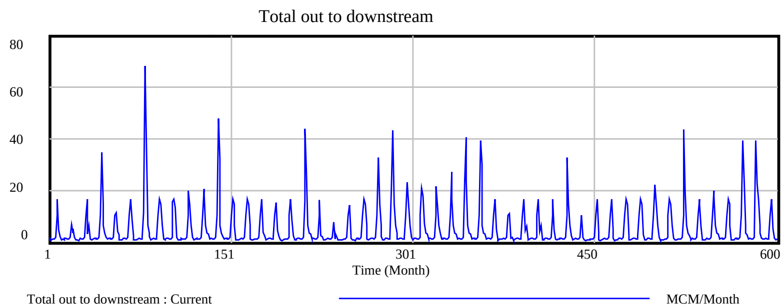

Fig. 8. Input discharge entering the Urmia Lake after lavian Dam construction.

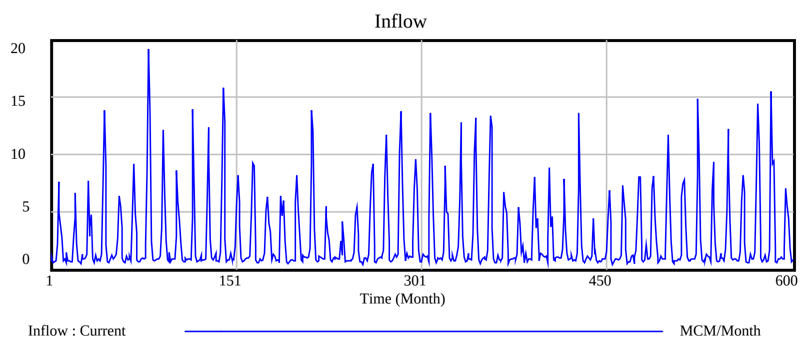

Fig. 9. Input discharge entering the Urmia Lake before Nahand Dam construction.

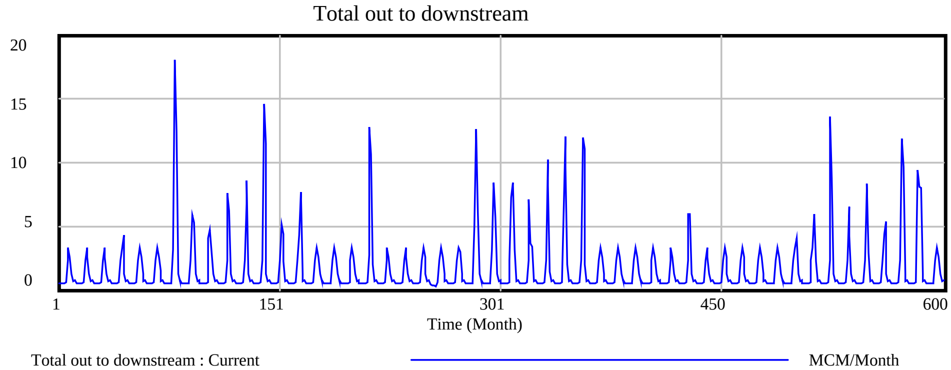

Fig. 10. Input discharge entering the Urmia Lake after Nahand Dam construction.

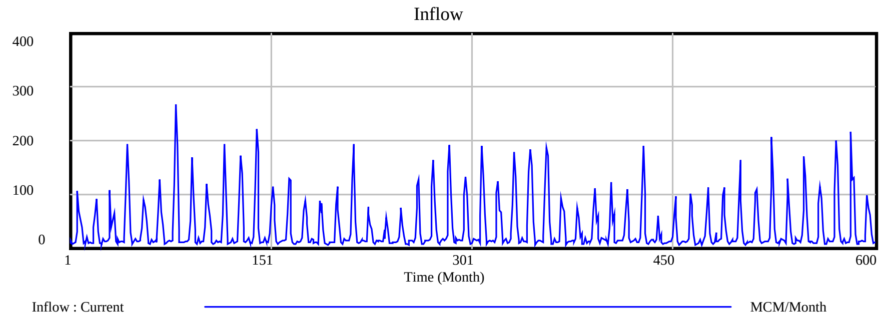

Fig. 11. Input discharge entering the Urmia Lake before Zarrinerud Dam construction.

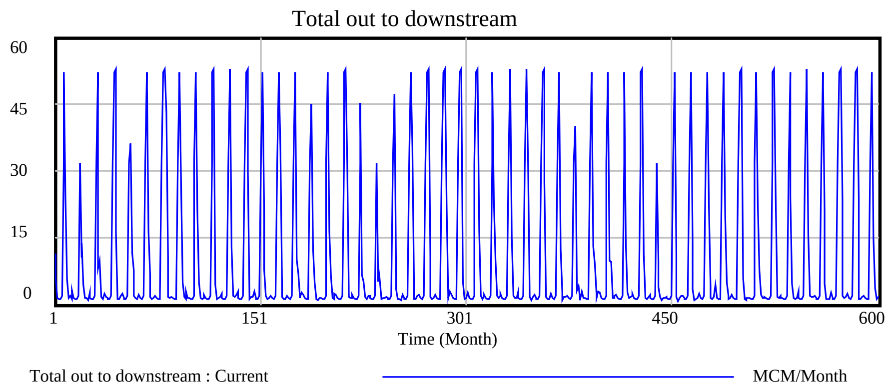

Fig. 12. Input discharge entering the Urmia Lake after Zarrinerud Dam construction.

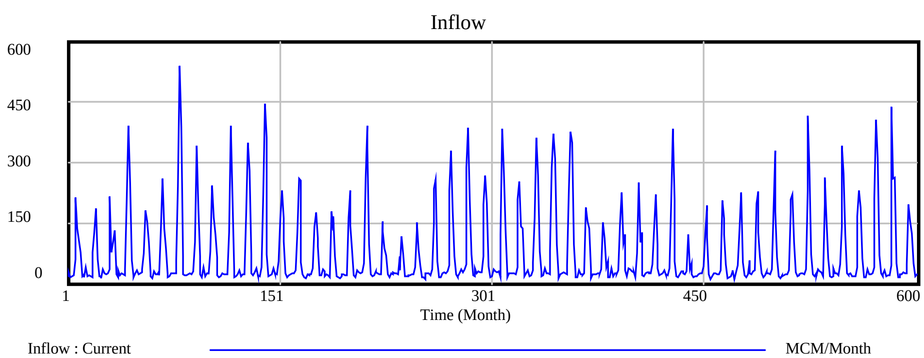

Fig. 13. Input discharge entering the Urmia Lake before Shahid Madani Dam construction.

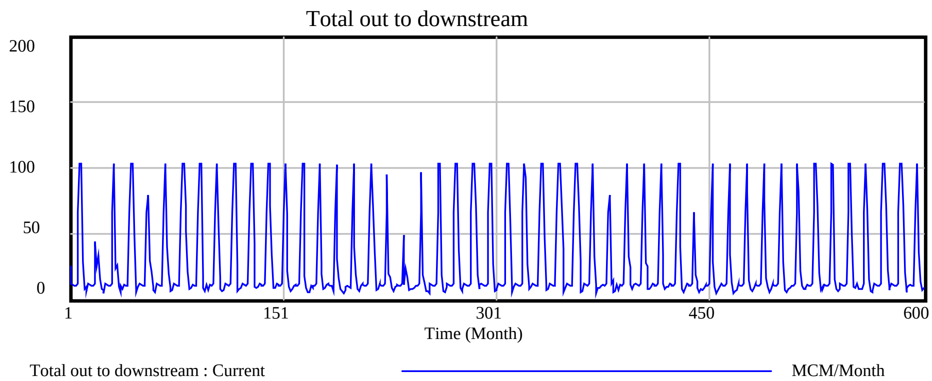

Fig. 14. Input discharge entering the Urmia Lake after Shahid Madani Dam construction.

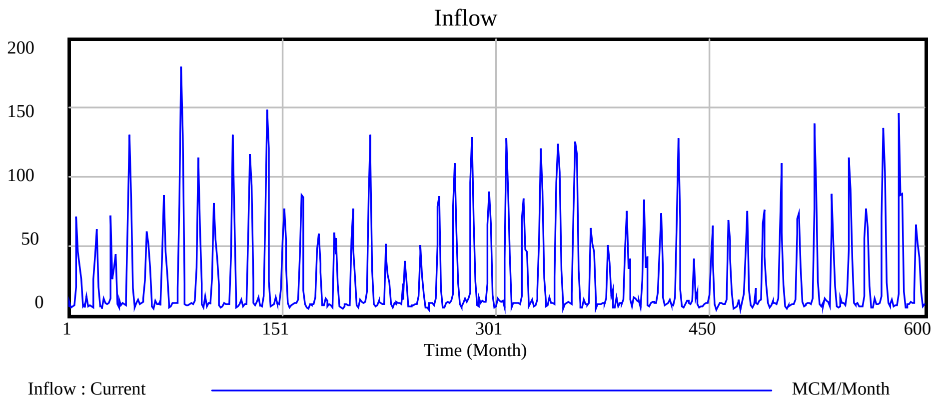

Fig. 15. Input discharge entering the Urmia Lake before Mahabad Dam construction.

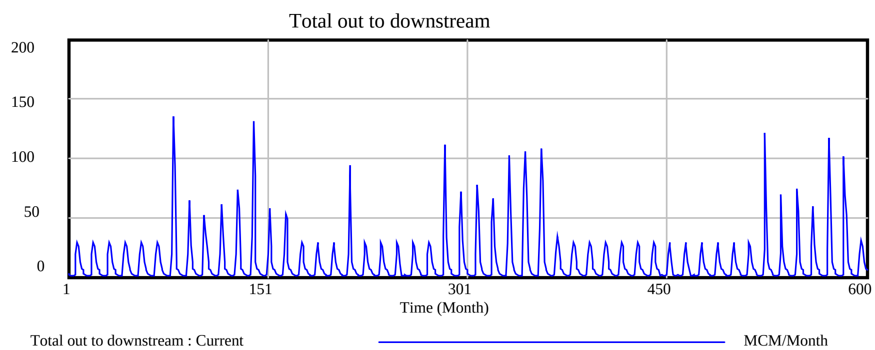

Fig. 16. Input discharge entering the Urmia Lake after Mahabad Dam construction.

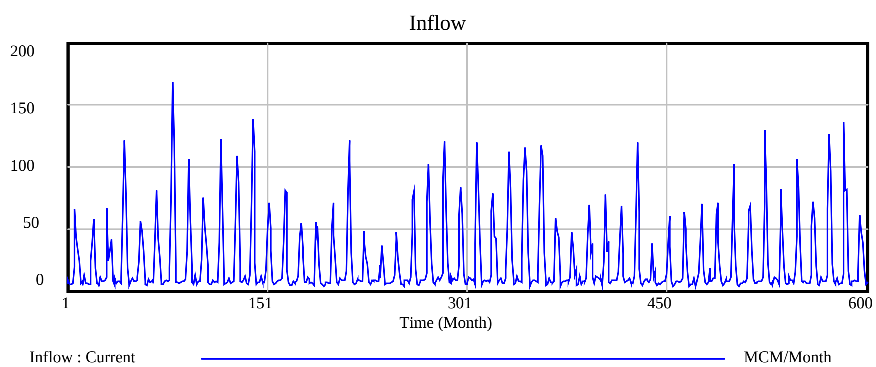

Fig. 17. Input discharge entering the Urmia Lake before Shahrchay Dam construction.

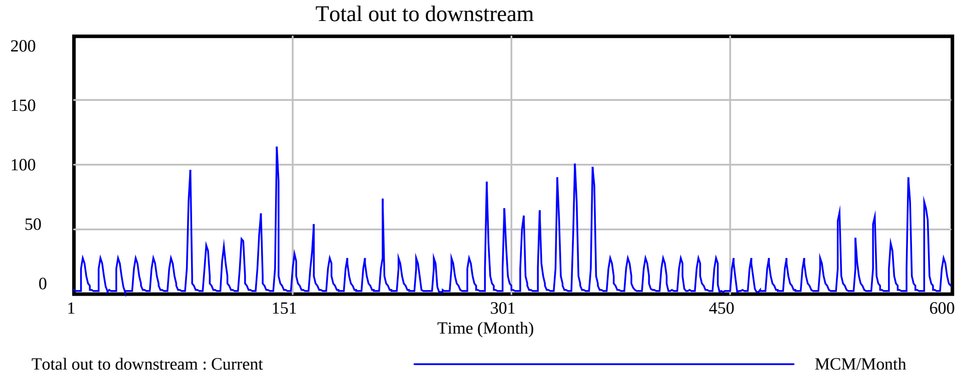

Fig. 18. Input discharge entering the Urmia Lake after Shahrchay Dam construction.

Simulation results for the six dams are shown in Fig. 19 and Table 2.

Table 2: Results of the simulation of dam.

The dams	Average annual flow of water entering the lake before the dam construction (MCM)	Average annual flow of water entering the lake after dam construction(MCM)	The annual volume of water stored behind the dam (MCM)	The relative decrease in the amount of water entering the river to the lake
Zarineh River	903.38	345.13	558.25	0.61
Shahrechai	281.04	38.91	242.13	0.50
Madani	446.65	133.58	313.07	0.70
Alavian	147.74	61.81	85.93	0.58
Mahabad	301.11	151.45	149.66	0.49
Nahand	32.11	19.80	12:31	0.38
Total	2112.03	750.68	1361.65	0.64

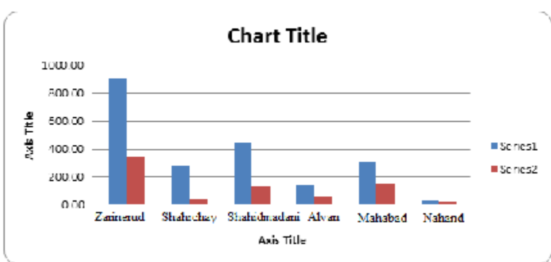

Fig. 19. The discharge rate of the river before and after dam construction (mcm).

CONCLUSIONS

According to the simulation results the simulation of each of the damto determine the quantitative effect of their construction in the reduced level of Lake Urmia the following results was obtained:

-The most reduced discharge is due to the construction of Zarinerud Dam.

-The average reduction of discharge of the rivers entering the Lke Urmia due to dam construction is 64%.

-Based on the fact that the normal area of Lake Urmia is 5500 km2 and the average annual evaporation id 1200 mm annually, through considering the 1361.65 milliom m^2 reserved water behind the dams using relations (2 and 3) it is concluded that the effect of the dams on reducing the Lake level is 21% and dams have a considerable role in reserving and providing water for their downstream. In fact it can be said that the dams are the regulators of the upstream water to prevent flood and the undesired consequences and providing the agricultural, industrial, urban and environmental water requirements and the problem is in the optimized utilization management.

$$H = \frac{1361.65MCM}{5500Km^2} \quad \ldots(8)$$

$$A = \frac{0.25}{1.20} = 0.21 \quad \ldots(9)$$

The relation (8) represents the water level reduction followed by the regulation of the water reservoir behind the dams and the relation (9) indicates the effect of dam construcyion in reducing the Lake level.

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