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Investigation and evaluation of the sedimentation and flushing in stream dams (Case study Dez stream dam)

M. Hadadian Nejad Yousefi and M. Mahmoodian Shooshtari
Chamran University, Dezfoul, Iran.

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ABSTRACT

About 1% of the total storage capacity in the world's reservoirs is lost annually due to sedimentation. Sediments can also block intakes in reservoirs and damage tunnels or turbines. One of the most effective techniques to remove these sediments is flushing, whereby water level is lowered sufficiently to re-erode deposits and flush them through the intakes. Outflow sediment discharge may well be related to the parameters such as the sediment characteristics in the reservoir, sediment discharge and hydrological conditions. In this paper, investigation and evaluation of sedimentation and flushing in Dez1 stream dam are considered. Sensitivity analysis of the mathematical model is evaluated for input parameters variation on sedimentation and flushing in reservoirs. Results shows that the rate of sediment flushing is strongly associate with grain size of sediment. This paper shows that flushing can retrieve about 50% of beneficial storage of reservoirs.

Introduction

An important factor that reduces useful life of dams is sedimentation in reservoir created by the dams. Problems caused by reservoir sedimentation are aggregation in the backwater region causing increased flood levels, elevated ground water levels, navigation impairment, deposition from or into a tributary, entry of sediments into hydropower turbines and loss of beneficial storage. Significant advances have been made in understanding the importance of the factors involved in reservoir sedimentation. However, predicting the accumulation of sediment in a reservoir is still a complex problem. In estimating reservoir sedimentation and accumulation, a number of uncertainties arise. These are related to quantity of stream flow, sediment load, sediment particle size and specific weight, trap efficiency and reservoir operation. Several methods can be applied for removal of sediment from reservoir of dams, for example, flushing is a method for removal of sediment. Many researchers studied sedimentation in reservoir and effects of flushing. But they paid attention to theoretical aspects of this subject. They applied numerical models and stochastic methods for their researches. For example, Salas & et al. (1999) made used of Monte Carlo simulation and Latin hypercube sampling for quantify the uncertainty of annual reservoir sedimentation and accumulated reservoir sedimentation through time. Their case study was the Kenny Reservoir at the White River Basin in Colorado[1]. Fan & et al. (1992a, 1992b) applied hydraulic models for studying sediment routing during floods, sediment flushing during floods, emptying and flushing, and density current venting. They considered several dams and rivers in China (Sanmenxia, Guanting, Shanyiujiang, and Liujiaxia reservoirs, as well as the Shanshenggorig barrage and Xijin hydropower station)[2,3]. Chaudhuri (2006) evaluated different methods for preventing from entrance of sediment to Maithon Reservoir in India. He considered different methods for removal of sediment in this reservoir too. His aim was increasing life of Maithon Reservoir4. Wu & et al. (2007) studied on the reservoir sedimentation processes in response to changes in incoming flow at the upstream and changes in the pool level at the downstream for Sanmenxia Reservoir, which is located on the middle reach of the Yellow River in China[5].

Flushing may be one of the most economic methods which offer recovering lost storage without incurring the expenditure of dredging or other mechanical means of removing sediment. The studies of HR Wallingford on 50 reservoirs which are being, or have been flushed, show that in some cases the flushing was successful and in others there was little or no success. Also, studies show that successful flushing depends on some characteristics such as the catchment's area, the storage capacity of the reservoir, the shape of the reservoir basin, the deployment of full or partial draw down, the low level outlet facilities provided and downstream impacts[6]. A study stated that it is doubtful whether flushing is effective in larger reservoirs[7] and another study argued that this solution is only suitable for reservoirs with a yearly excess input of water[8].

However, it has been proved that flushing can be highly effective at some sites, for example, the Baira reservoir in India, Gebidem reservoir in Switzerland, Gmund reservoir in Austria, Hengshan reservoir in China, Honglingjin reservoir in China, Mangahao reservoir in New Zealand, Naodehai reservoir in China, Palagneda reservoir in Switzerland, Santo Domingo reservoir in Venezuela[9] and Sefid Roud reservoir in Iran. Two methods are applied for flushing (free flow flashing and pressure flushing). During under pressure flushing, water is released through the bottom outlets while the water level in the reservoir is kept high. Free flow flushing means that the reservoir has been emptied and the inflowing water Journal of Food, Agriculture & Environment, Vol.8 (2), April 2010 981 from upstream is routed through the reservoir, resembling natural river conditions.

In the research described in this paper, sedimentation and free flow flushing were evaluated in hydropower plant of the Dez1 stream dam. In addition, sensitivity analysis was performed to evaluate the importance of input various factors on the sedimentation and flushing in reservoir. These factors are quantity of stream flow, sediment load and sediment particle size.

Tele:
E-mail addresses: mohsen.hadadian@gmail.com

Case Study

Making new large dams on the Dez River is not possible but construction of small dams is possible. In this regard, three successive Dez stream dams (the Dez 1 dam, the Dez 2 dam and the Dez 3 dam) were designed on the Dez River at the downstream of the Bakteary storage dam to produce electrical energy. On the other hand, the Dez dam is rather large and was constructed on the Dez River in 1962. Three successive stream dams will be constructed at the upstream of the Dez dam in future. The difference between water surface elevations in reservoir of the Dez dam and hydropower plant of the Bakteary dam is 175 m. This difference in the elevation is very useful for producing electrical energy. The major part of discharge of hydropower plant of the successive Dez stream dams is outflow from hydropower plant of the Bakteary dam. Reservoirs of successive Dez stream dams will prepare another part of discharge of hydropower plant of the Dez dam by saving and regulating daily discharge of the Dez River and the Sezar River.

The hydrographic action in 2002 showed that sedimentation reduced useful storage of reservoir of the Dez dam from 3315.6 MCM to 2700 MCM (19% reduction). Also, sedimentation increased the level of bed surface of deposited sediment from 180 to 256 m above sea level. The Level of inlet of turbine is 270 m above sea level. Difference between levels of inlet of turbine and bed surface of deposited sediment is 14 m. Sedimentation will fill this space in near future. Therefore, construction of successive Dez stream dams at the upstream of the Dez storage dam for producing electrical energy is necessary. The successive Dez stream dams are shown in Figure1.

Methodology and structures of sediment evacuation in reservoirs of Dez stream dams

The volumes of reservoirs of the successive Dez stream dams (Dez 1, Dez 2 and Dez 3) are 12, 5 and 11, respectively, while annual sediment discharge is 16.5 MCM in successive Dez stream dams[11]. If this sediment deposits in the reservoirs of the successive Dez stream dams, these reservoirs will lose their economic justification and regulating characteristics rapidly. Almost 63% of sediment is trapped by the construction of the Bakteary dam. This sediment belongs to the Bakteary River which is measured in Telezang station. After trapping the sediment in the Bakteary dam, sediment discharge decreases to 6.1 MCM, but this value is very high and can fill reservoir storage of successive Dez stream dams at very short time. The major part of sediment belongs to floods and they move to the downstream at the duration of flood, but concentration of sediment is low at other situations. Flushing structures must be designed based on flood conditions. A number of spillways with large sluice gates are to be provided on the body of successive Dez stream dams for flushing of sediment. When these gates are opened, a great discharge enters the Dez River. The width of these spillways is equal to the width of the Dez River. The height of radial gates is more than half the height of the body of the dam.

With the start of floods, radial gates are opened completely end flushing begins. Flood overflows from the crest of spillway freely and it is conducted to the downstream. Flood and total of stored water of the reservoir are vacated. Evacuation of flood decreases water surface elevation in the reservoir of the dam and it increases velocity of flow and decreases the rate of sediment settlement in the reservoir of dam considerably. Also, flushing washes the deposited sediment above the bottom level of spillway and moves it out of the reservoir. With the increase of intensity and duration of flood, its flushing power increases[10]. Figure 2 shows sedimentation procedure and flushing.

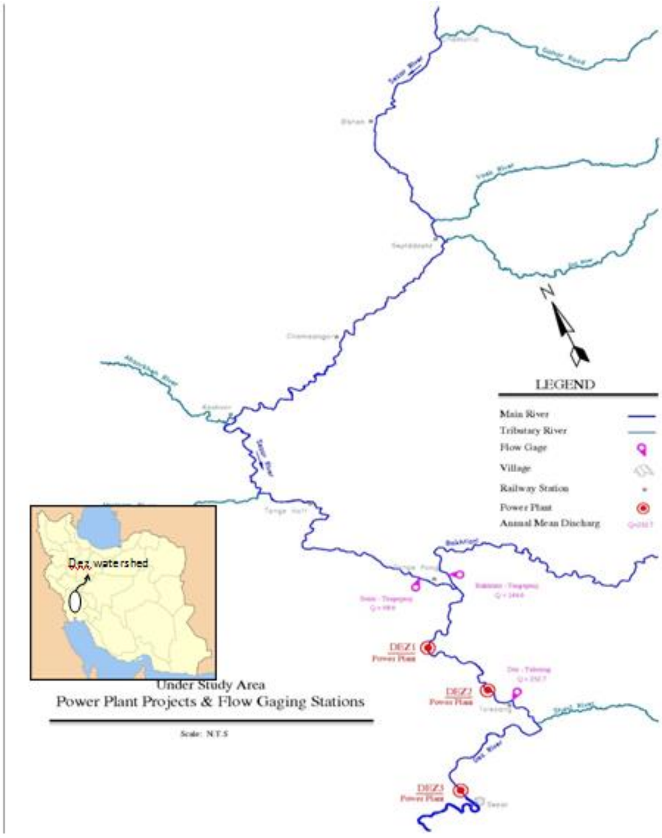


Figure 1. The site of the successive Dez stream dams

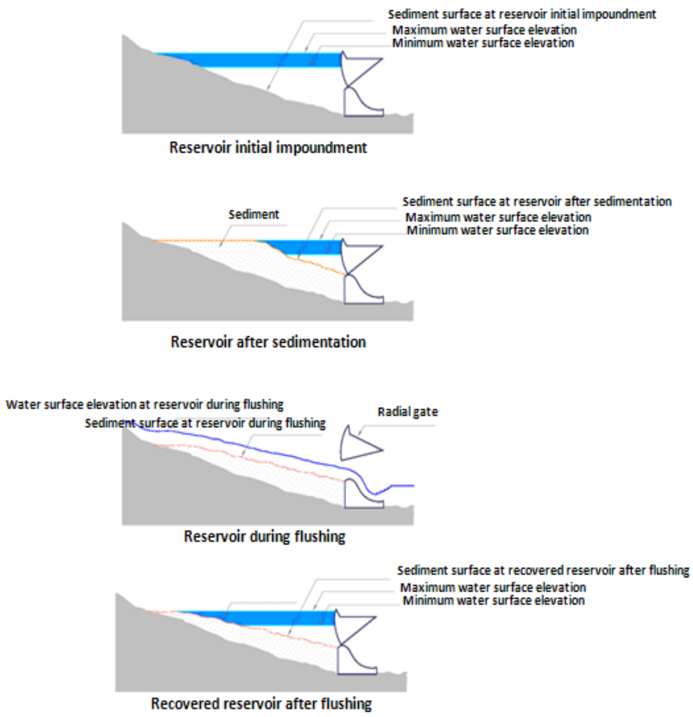


Figure 2. Sedimentation and flushing procedure in reservoir

Sediment transport soft wares

For simulation of sediment transport, a number of models were developed. Some models were developed for a special project. These models can be applied for similar projects to this project. They can not calibrate for rivers with different conditions. But a number of models were established based on correctly theoretical principles. These models need to a great amount of data for calibration. On the other hand a number of models are very simple and accuracy of their results is very low. A sediment transport model must have follow characteristics:

1- Assumptions of model must suitable for considered site.
2- Model can be applied to channels with constant and mobile wall.
3- Model can be applied to sub critical, super critical and critical flows.
4- Model can simulate flow and movement of sediment in longitude and lateral directions.
5- Model must consider particle size curve of sediment. In this case model can simulate armoring phenomena and stability time of bed form.
6- Model can predict depth and lateral variations of cross section of channel.
7- Model can simulate transport and deposit of sediment in steady and unsteady conditions.
8- Model can consider stability of wall of channel and calculate amount of its erosion.
9- Necessary data of model are not very much[12]. (Yang, 2006)
The most famous models for simulation of sediment transport are: Mike 11, Wendy (Saflow, Seflow, Susflow and Odirmo) models, NETSTARTS, FLDSTARS, HEC-6, GSTARS 2.1, GSTARS 3 and SRH-1D.
Because of unsteady flow and increase of suspended sediment concentration when flushing is occurred, SRH-1D is selected.

SRH-1D soft ware

SRH-1D (Sedimentation and River Hydraulics - One Dimension) is a one-dimensional mobile boundary hydraulic and sediment transport computer model for rivers and manmade canals. Simulation capabilities include steady or unsteady flows, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport, and lateral inflows. The model uses cross section based river information.

The model simulates changes to rivers and canals caused by sediment transport. It can estimate sediment concentrations throughout a waterway given the sediment inflows, bed material, hydrology, and hydraulics of that waterway.

Potential Applications:

Specific applications demonstrate potential uses of the model including:
1- Identification of areas undergoing geomorphic adjustment or likely to experience future adjustment under current or proposed management plans.
2- Quantification of adjustment processes and future conditions.
3- Estimation of channel change in a river system caused by dam construction, dam removal, or sediment sluicing.
4- Estimation of sediment concentrations in a waterway subject to erosion of deposition.
5- Estimates of basin sediment yields.
6- Sensitivity analysis and evaluation of the impact of management alternatives in a river system.

Applicability and Limitations:

SRH-1D uses one-dimensional solutions for flow simulation. It should not be applied to situations where two-dimensional or three-dimensional models are needed to represent local hydraulic conditions. SRH-1D is based on the sub-channel concept. Secondary currents, transverse movement, transverse variation, and lateral diffusion are ignored. Therefore, the model cannot simulate such phenomena as river meandering, point bar formation, pool-riffle formation, and many plan form changes. It may not be able to simulate local deposition and erosion caused by water diversions, bridges and other in stream structures.

SRH-1D can simulate:
1- Steady and unsteady flow and is stable for any combination of sub- or super-critical flow.
2- Dentrendic or looped channel networks.
3- Sediment concentration can be tracked with either the Exner or advection-dispersion equations.
4- Changes to bed material gradations can be simulated and multiple bed layers can be tracked.
5- Many different sediment transport capacity formula are available.
6- Cohesive or non-cohesive sediment transport.
7- Bank erosion simulated using angle of repose conditions.
8- Channel geometry data is similar to HEC-RAS.
9- Excel can be used to quickly generate input files.
10- Output is in multiple structured text files[13]. (Greimann and Huang, 2009)

Geometric and hydrologic characteristics of the Dez River:

For determination of cross sections of the Dez River, topographic map of the Dez River was used. The scale of this map is 1:12000. The natural regime of the Dez River is determined by discharge data of the Telezang station for 48 years. By construction and starting of exploitation from reservoir of the Bakteary dam, the natural regime of the Dez River will vary. The reservoir of the Bakteary dam will control and save floods of the Bakteary River. By simulation to daily operation of hydropower plant of the Dez dam, outflow from dam is calculated. Outflow from the dam shows the effects of the Bakteary dam and its hydropower on variation of the natural regime of the river. For determination of discharge of the Dez River in regulated condition, the natural discharge of the Bakteary River is eliminated and the outflow from the reservoir of the Bakteary dam is replaced. The calculated discharge is regulated discharge of the Dez River and this discharge arrives at reservoir of the Dez 1 dam. The simulation model determines the outflow from reservoir of the Dez 1 dam based on operation of its hydropower plant. This outflow arrives at reservoir of the Dez 2 dam and outflow from reservoir of the Dez 2 dam is inflow of reservoir of the Dez 3 dam.

Sediment discharge of the Dez River:

The hydrometric stations of the Dez watershed have not measured the bed load data. Because of lack of skilled employees and suitable sampling tools, suspended load data of these stations is not correct. They cannot show sediment concentration in different hydraulic conditions, especially on the flood condition. For determination of sediment discharge-discharge relation, suspended sediment load data of Telezang station is used. Then this relation was modified based on total volume of sediment that deposited in the reservoir of the Dez dam from construction time of the dam. Also, bed load was considered 15% of total sediment load based on results of hydrography test. The total sediment load of the Dez River was predicted by deposited sediment data in the reservoir of the Dez dam accurately (the total sediment load of the Dez River entrances the reservoir of the Dez dam). Volume of its reservoir was determined by hydrography in 1972 and 2002. The total of deposited sediment in the reservoir of the Dez dam was estimated at 617 MCM from 1962 to 2002. Avout 88% of sediment arriving at reservoir of the Dez dam passes from Telezang station. Based on the above data and efficiency of trapped sediment of the reservoir of the Dez dam, the annual total sediment load is estimated at 18.2 million tons in the Telezang station. In this calculation, density of sediment of the Dez River was estimated at 1100 kg/m3 14. After construction of the Bakteary dam, the sediment discharge of the Dez River will decrease considerably. Because of inaccuracy of sediment discharge-water discharge relations, application of sediment discharge-discharge relations of the Dez River and Bakteary River contemporarily is not suitable for calculation of daily sediment discharge in the regulated conditions of the Dez River because these relations shows that sediment load of the Dez River is negative for almost 50% of the days of the year. A part of the error is of concern to the inaccuracy of discharge data in Tang pang-Bakteary station. About 63% of sediment load of the Dez River (11.4 million tons/year) is supplied by the sediment of the Bakteary River. Based on the above, sediment discharge-water discharge relations after construction of the Bakteary Dam are estimated by the following forms[14]:

$$Q_s = 0.0282374 Q_w^{2.21428} \qquad Q_w \leq 505(CMS) \qquad (1)$$

$$Q_s = 0.03961137 Q_w^{2.21428} \qquad Q_w \geq 505(CMS) \qquad (2)$$

Where Q_s is the total sediment load of the Dez River in regulated condition (tons/day) and Q_w is the discharge of the Dez River in regulated condition (CMS).

Sediment grain size in the Dez River:

A few samples of suspended sediment load were prepared in the Telezang station. Sediment concentration and sediment grain size were determined by these samples, but very few samples were concern to flood conditions. There were no samples of bed sediment load; therefore, sediment grain size was determined by classification test of deposited sediment grain size in reservoir of the Dez dam. There were 337 samples of deposited sediment prepared from different parts of the reservoir in 2004. These samples were obtained by weighted sampler in 103 different points of the reservoir. The depth of the sampling was from surface of the deposited sediment to 8 m below this surface (8 m). The deposited sediment of the reservoir of the Dez dam was classified in two types: 1) coarse sediment grain that deposited in the delta of reservoir and 2) fine sediment grain that deposited in the reservoir. The results of hydrography test in 2002 distinguished that 30% of the deposited sediment is coarse sediment grain. The sediment grain size was determined by combination of coarse sediment grain size and fine sediment grain size. Among them, 30% of the sediment is coarse sediment grain and 70% of the sediment is fine sediment grain. This curve was named range curve (Figure 3).

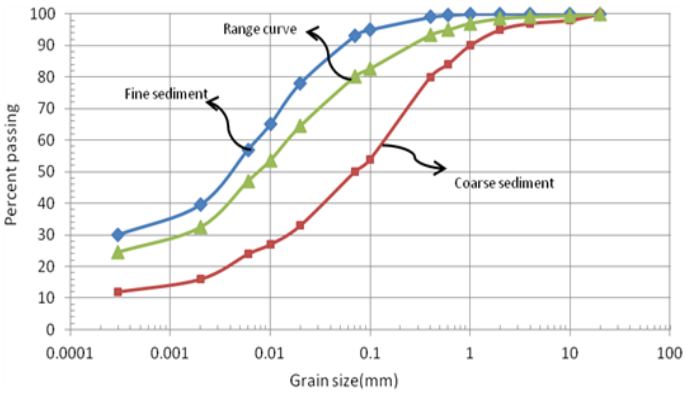


Figure 3. Sediment grain size curve

Results

For determination of optimum discharge of flushing at the lifetime of reservoir, two states were considered for running of model:

1) If daily discharge is more than 1000 CMS, flushing will start.

2) If daily discharge is more than 1200 CMS, flushing will start. 1000 CMS and 1200 CMS were selected based on limitation of hydropower plant. The results of two states shows that if state 2 is considered for flushing action, remainder useful storage will sufficient and cost of flushing will optimum.

Figure 4 shows results of mathematical model in hydropower plant of the Dez1 dam at simulation period. Mathematical model shows that volume of the reservoir of the Dez 1 dam decreases very rapidly at the first years of operation of hydropower plant. If sediment surface elevation is lower than bottom elevation of ogee spillway, this situation will continue. After this stage, a large amount of deposited sediment stands in effective radius of flushing. Flushing swaps this sediment from the reservoir. In this stage, sedimentation has stable state in reservoir. Retrieval volume of reservoir is a function of power of flushing, but variation of this volume is negligible, because state of reservoir is stable. In this stage, the volume of reservoir is 6 to 8 MCM (43 to 57% of primary volume of reservoir). By flushing, the results of hydro energy study show that reservoirs of hydropower plants of the Dez River can regulate daily discharge and produce necessary energy for the peak hours of consumption.

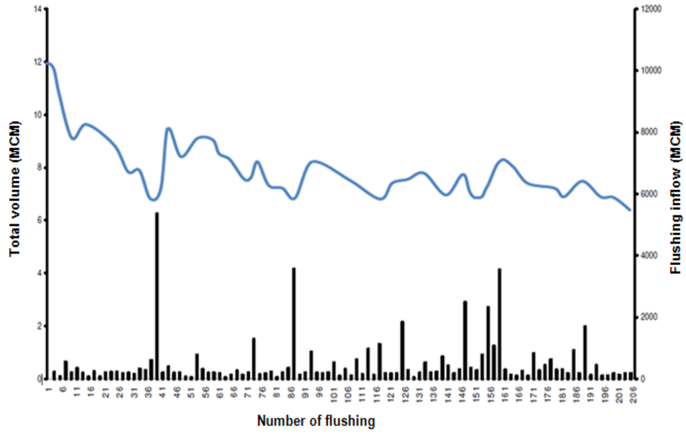
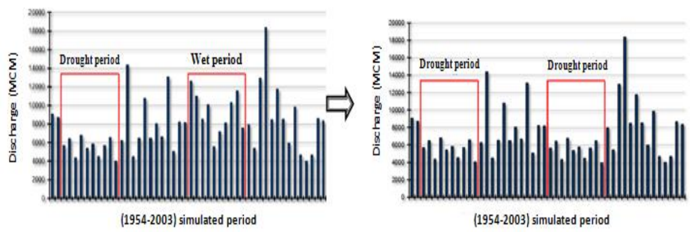


Figure 4. Variation of volume reservoir of the Dez1 stream dam

Because of shortage of sediment data in the Dez River and lack of similar flushing projects in Iran, validation of results of mathematical model is not possible, but results of similar flushing projects in the world suggest the accuracy of results of this project[15, 16, 17].

Discussion

An important effective factor on results of mathematical models is hydrologic conditions. Because of inaccuracy of mathematical models of sediment dynamics, if the range of variation of data is not large, it is not possible to determine the variation of sediment value in a reservoir, but determination of trend of this variation is possible. It is assumed that hydrologic conditions of flushing and sedimentation are similar to hydrologic conditions from the past 48 years. Wet period, draught period and discharge of river are dependent on climatic conditions. Climatic conditions may vary in the future. For example, drought period may increase. In this case, the number of flushing actions decreases and sediment cannot flush from the reservoir and beneficial storage of the reservoir decreases. For evaluation of effects of variation of hydrologic conditions and increasing drought periods, sedimentation and flushing was simulated in a critical drought period of the Dez River. For this purpose, a wet period (from 1978 to 1988) was replaced by a drought period (from 1956 to 1966) and a new time series of discharges was produced. And for evaluation of effects of variation of hydrologic conditions and increasing wet periods, a drought period from (1956 to 1966) was replaced by a wet period (from 1978 to 1988) and a new time series of discharges was produced (Figure5).



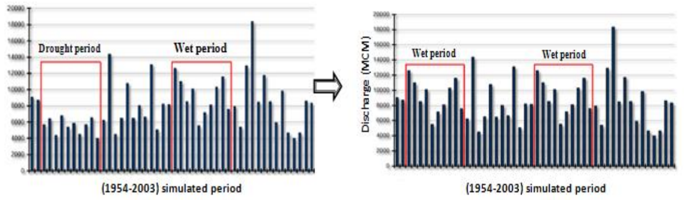


Figure 5. New time series of discharges

Results of simulation model and variation of the volume of reservoir of hydropower plant of the Dez1 dam is shown in Figure6 for new time series of discharges. The number of floods and its discharge and the number of flushing decreases in drought period and wet period vice versa.

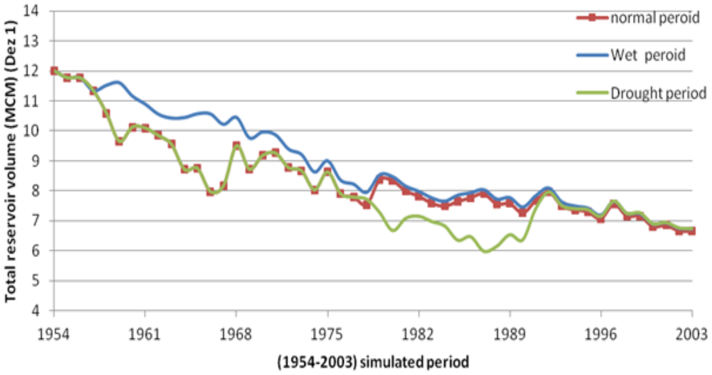


***Figure 6*. Variation of volume reservoir of the Dez1 stream dam for new time series of discharges**

Result of this simulation shown at table1.

Table 1. Percent reduction in total reservoir volume

Percent reduction in total volume		
Simulation time(year	**Wet period**	**Normal period**
5	6%	14%
6	6%	22%
7	9%	18%
8	12%	18%
9	14%	20%
10	15%	23%
11	15%	30%
12	14%	30%
13	14%	36%
14	17%	34%
15	15%	23%
Simulation time(year	**Drought period**	**Normal period**
26	42%	32%
27	47%	33%
28	44%	35%
29	43%	37%
30	45%	39%
31	46%	40%
32	50%	39%
33	48%	38%
34	53%	36%
35	51%	40%
36	48%	40%
37	50%	41%

Another effective factor on the results of the simulation model is the sediment discharge-water discharge relation. Accuracy of this relation is low because the sediment sampling and its record is very complex. Although floods bring a major part of sediment to reservoir, flushing is accomplished when floods arrive at the reservoir. Flushing prevents sedimentation in the reservoir. Nevertheless, if sediment increases in the Dez River, retrieve beneficial storage of the reservoir will decrease. For evaluation of this subject, the total of sediment concentration increases 20%. The results of simulation model are shown Figure7 for this state. This figure shows that decrease of volume of the reservoir is negligible when sediment concentration increases 20%.

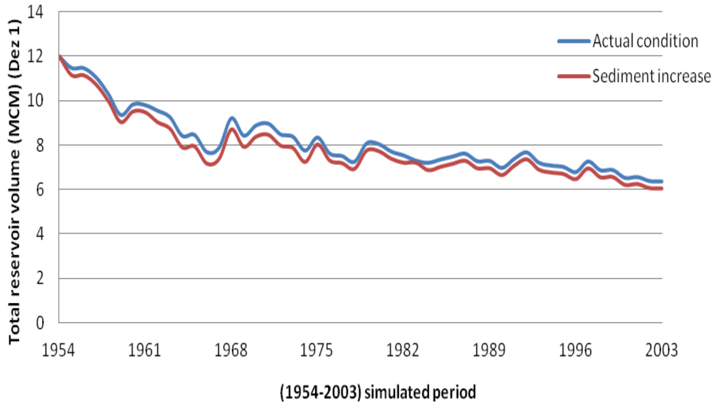


***Figure 7*. Variation of volume reservoir of the Dez1 stream dam with sediment increase**

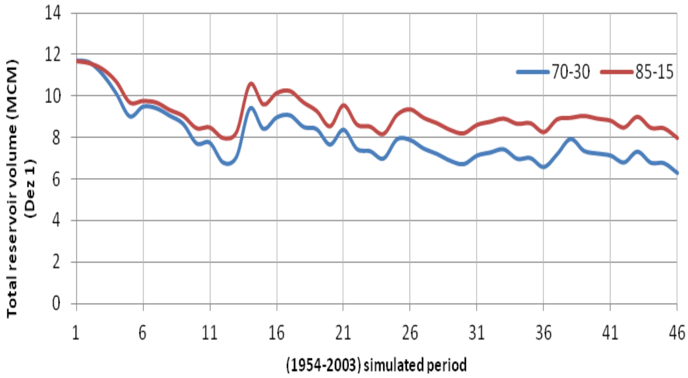


***Figure 8*. Variation of volume reservoir of the Dez1 stream dam for state 1**

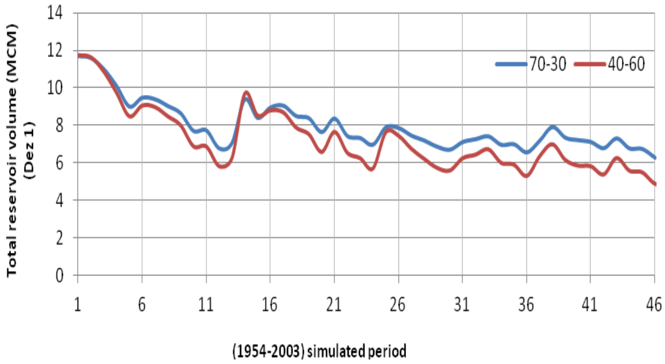


***Figure 9*. Variation of volume reservoir of the Dez1 stream dam for state 2**

By attention to lack of bed load samples and inaccuracy of suspended load samples in the Dez River, sediment grain size is determined by deposited sediment grain size in the reservoir of the Dez1 dam. In this study, variation of results of the mathematical model was evaluated. For evaluation of this subject, two situations were considered: 1) sediment grain size was coarser than the range curve and 2) sediment grain size was finer than the range curve. About 30% of sediment was coarse sediment of the delta part and 70% of sediment was fine sediment of the reservoir in the range curve. The two states were considered: 1) 40% of sediment was coarse sediment and 2) 15% of sediment was fine sediment. Results of the two states are shown in Figure8 and Figure9, respectively. If sediment grain size is finer than the range curve, efficiency of flushing will increase. If sediment grain size is coarser than the range curve, efficiency of flushing will decrease.

Conclusions

Flushing can bring about the necessary useful volume for regulation of daily discharge in the Dez River and Sezar River. Regulation of daily discharge can bring about the necessary energy for the peak hours in successive hydropower plants of the Dez River. Sensitivity analysis shows that the results of the mathematical model are reliable for simulation of long-term operation of the reservoirs. Also, the results of mathematical model are reliable for different hydrological conditions. As a result, the best method for flushing is pressure flushing in the designed and constructed dams on the Dez River; flushing can retrieve about 50% of beneficial storage of reservoirs.

Sensitive analysis showed that variation of discharge of flow and sediment discharge are effective on the variation of useful storage of reservoir in the short term but they are not effective on variation of useful storage of the reservoir in the long term. But Grain size of sediment is effective on variation of useful storage of the reservoir in the short term and long term. Results showed that the rate of sediment flushing is strongly associated with grain size of sediment.

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