INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Instruction of Operation Planning for Glevard Dam Based on Variable Demand

Hossein Jalaly & Soudabeh Deravi
Ab-Niru (Water Power) Consulting Engineers ,Tehran,Iran
Abniru.co@gmail.com

Hossein Jalaly
Prof. Tarbiat Moddares university, Tehran,Iran

ABSTRACT
Assessment of the hydrological time series fluctuations, especially existence of a trend in it, can be detected by using statistical tests. The results will derive appropriate instructions for knowing the fluctuations of the inflow to the reservoir, thus climate changes studies will effectively help water resources planning and decrease the impacts of the natural or unnatural disasters .
Forecasting of annual inflow into the dams before the beginning of the irrigation season and then derivation the optimum planning for quantity of cultivated area and also deciding about the value of shortage ratio (in the dry and very dry years), is a kind of rule curve for practical instruction of operation for the dams based on variable demands.
This paper first investigates whether annual discharge , precipitation and temperature at the project region (located in the north of Iran) during 38 years recorded data have any significant trends or not ?
With regard to the results of the tests and detection of decreasing trend of inflow into the dam and also intense fluctuations of river discharge , an operating planning as a rule curve will be necessary and very helpful for an effective water resources management and thus has been presented for Glevard dam .

Key words : Operation planning , Climate changes , Forecasting river discharge , Variable demand

1. CLIMATE CHANGES STUDIES BY TREND ANALYSIS

1.1. Introduction

Climate changes studies by trend analysis for time series such as the rivers discharge , will help us to know the fluctuations of rivers or other climatologic variables .

This assessment will help water resources planning and reduce vulnerability and the impacts of the natural (hydrological cycles) or unnatural (irregular human effects on the nature and environment) disasters .

One of the usual methods for knowing the fluctuations of the climatologic time series , is trend analysis by using statistical tests .

Different methods are known for trend analysis which are categorized in two general group , parametric and non-parametric methods . Non-parametric methods are more usual than parametric one . The main reason is that they are suitable for data series that don't follow normal distribution (like most of the climatologic data series) and also these methods have a little impressibility from the extreme values .

In the non-parametric methods , the difference between the data is the base of methodology .

As the results of non-parametric methods are independent from the distribution , they are more appropriate for data series with large skewness .

Kendall's tau and Spearman's rho tests are the more usual non-parametric methods which are used for trend detection .

One parametric method which has been employed widely for trend analysis , is the Linear Regression method (correlation between the time and the related variable).This test assumes that the data series follow the normal distribution .

In this paper for comparison the results of these tests, trend analysis have been achieved by these three methods , but with preferring the results of non-parametric methods .

1.2. Tests for Trend Detection

For all tests the null hypothesis H_0 : There is no trend And hypothesis H_1 : There is a trend in data series .

1.2.1 Kendall's tau test
This test is a non-parametric method which has a little impressibility from the extreme value (to highly skewed hydrological data) and to deviation from a linear relationship .

This test is based on the statistic S . For computation of S , n pairs of data must be arranged in order to increase $X-$ value and all of the pairs of y_i values into P case when $y_i > y_j (i > j)$ and M case where $y_i < y_j (i > j)$ and then $S = P - M$.

If n>10 the standardized test statistic Z will be :

$$Z = (S-1)/Var(S)^{1/2} \qquad S > 0 \tag{1}$$

$$Z = 0 \qquad S = 0 \tag{2}$$

$$Z = (S+1)/Var(S)^{1/2} \qquad S < 0 \tag{3}$$

Where

$$Var(S) = n(n-1)(2n+5)/18 \tag{4}$$

The standardized test statistic Z is approximately normally distributed . Thus, the null hypothesis is rejected at significance level α if $|Z| > Z_{1-\alpha/2}$ where $Z_{1-\alpha/2}$ is the value of standard normal distribution with the probability of exceedance of $\alpha/2$.

1.2.2. Spearman's rho test
This test is a non-parametric method which is a rank-based and determines whether the correlation between two variables is significant or not .

The null hypothesis means that there is no association between the ranked pairs .

The test statistic is the correlation coefficient which is obtained in the same way as the usual sample correlation coefficient , but using ranks :

$$\rho_s = s_{xy} \big/ \sqrt{S_x S_y} \tag{5}$$

Where

$$s_x = \sum_{i=1}^{n} (x_i - \bar{x}) \tag{6}$$

$$s_y = \sum_{i=1}^{n} (y_i - \bar{y}) \tag{7}$$

$$s_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) \tag{8}$$

Where x_i , y_i are the variables referred to ranks and $\bar{x}, \bar{y}$ are their means .

For samples with more than 20 values, the quantity of $Z = \rho\sqrt{n-1}$ is approximately normally distributed (with mean zero and variance of one)

1.2.3. Linear regression test
This test is a parametric method which assumes normally distributed data . It is used to test for linear trend by the linear relationship between the time and variable of interest .

The regression gradient is estimated by :

$$\hat{b} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) / \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{9}$$

Where x_i , y_i are the variables and $\bar{x}, \bar{y}$ are their means .

While

$$\hat{\alpha} = \bar{y} - \hat{b}\,\bar{x} \tag{10}$$

Then the required test statistic is :

$$S = \frac{\hat{b}}{\hat{\sigma}} \tag{11}$$

Where

$$\hat{\sigma} = \sqrt{\frac{12\sum_{i=1}^{n}(y_i - \hat{a} - \hat{b}x_i)^2}{n(n-2)(n^2-1)}} \quad (12)$$

This test statistic follows Student's "t" distribution with the degree of freedom $n-2$ under the null hypothesis where n is the sample size .

1.3. Results of the Statistical Tests

In this study annual data records of temperature, precipitation and discharge in the project region during 38 years(1970-2007) have been analyzed for trend detection .

Fig. 1. shows the boundary of the Glevard dam basin and the location of the climatologic and hydrometric stations .

Sefidchah and Nozarabad are evaporation stations , Sefidchah , Glevard , Avard and Bechim are rainfall stations and finally Sefidchah and Glevard are hydrometric stations.

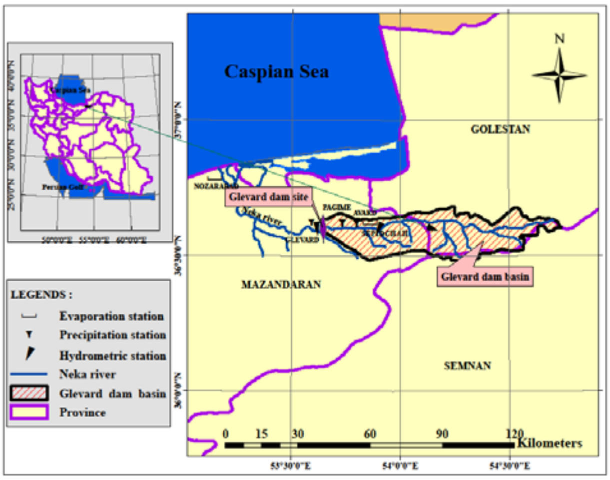

Figure 1. Glevard dam basin and location of stations

The results of statistical tests for the annual data records are shown in tables 1 to 3.

Based on the results of all of these tests , in the project region the temperature has an increasing trend at significant level of 0.01 , but the precipitation has not any significant trend and finally the discharge has decreasing trend at significant level of 0.05 to 0.01 .

This results are abnormal , because precipitation and discharge have usually a positive relationship especially in the arid and semi-arid zones .

Table 1. Results of Kendall's tau test for annual trend analysis

Parameter	Station	Kendall's tau (Standard normal dis.)			Significance level / trend
		S	Var(s)	Z	
Temperature	Sefidchah	390	6327	4.890	0.01 / +
	Nozarabad	232	6327	2.904	0.01 / +
Precipitation	Glevard	-15	6327	-0.18	no trend
	Pechim	-87	6327	-1.08	no trend
	Avard	-129	6327	-1.61	no trend
	Sefidchah	-26	6327	-0.31	no trend
Discharge	Glevard	-169	6327	-2.11	0.05 / _
	Sefidchah	-353	6327	-4.43	0.01 / _

Table 2. Results of Spearman's rho test for annual trend analysis

Parameter	Station	Spearman's rho (Standard normal dis.)		Significance level / trend
		ρ	Z	
Temperature	Sefidchah	0.742	4.514	0.01 / +
	Nozarabad	0.499	3.034	0.01 / +
Precipitation	Glevard	-0.022	-0.14	no trend
	Pechim	-0.184	-1.12	no trend
	Avard	-0.220	-1.34	no trend
	Sefidchah	-0.079	-0.48	no trend
Discharge	Glevard	-0.335	-2.04	0.05 / _
	Sefidchah	-0.683	-4.16	0.01 / _

Table 3. Results of Linear Regression test for annual trend analysis

Parameter	Station	Linear Regression (Student's t dis.)			Significance level / trend
		$\hat{b}$	$\hat{\sigma}$	S	
Temperature	Sefidchah	0.105	0.018	5.744	0.01 / +
	Nozarabad	0.034	0.009	3.679	0.01 / +
Precipitation	Glevard	-1.021	3.212	-0.32	no trend
	Pechim	-4.167	2.465	-1.69	0.10 / _
	Avard	-2.450	1.407	-1.74	0.10 / _
	Sefidchah	-1.574	1.511	1.04	no trend
Discharge	Glevard	-1.163	0.519	-2.24	0.05 / _
	Sefidchah	-0.99	0.175	-5.67	0.01 / _

Fig. 2. shows the fluctuations of the annual discharge for Neka river at two points : Sefidchah station and Glevard dam site .

In this figure the trend lines (by Linear regression) and their equations have been illustrated .

This figure shows the decreasing trend of Neka river at these two points that based on their equations, have almost an equal gradient in decreasing trend.

As the precipitation in the project region has not any significant decreasing trend , for answering the reason of decreasing trend of Neka river discharge , first assumption was the gradual changes of the basin's land use to agricultural land in the recent years and thus using of river's inflow conduce to decrease of river discharge .

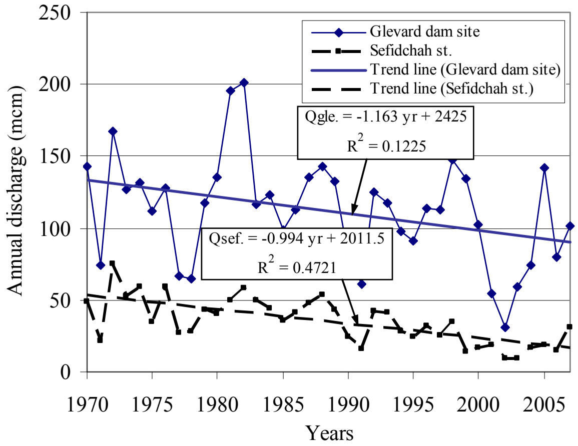

Figure 2. Annual discharge and trend lines of Neka river

This hypothesis is failed because the gradient of decreasing trend at Sefidchah station (located in the upper part of the Neka river and mountainous area , which don't use inflow of river in this parts) is similar to the gradient of decreasing trend at Glevard dam site. In addition , field investigations and studies don't confirm significant changes in land use of basin and convert them to the agricultural lands.

Comparison between recent satellite photographs and the maps of land use and vegetation covering that was prepared almost 30 years ago , confirmed intense destruction of the forests, vegetation covering and pastures of the dam basin, hence have been influenced on the decrease in runoff of the river (at low precipitation) but increase in flood occurrence (at intense storm) .

Generally based on the experiences from the different parts of the world , intense forest covering will increase runoff coefficient .

In the forest zones , several layers of the leaves over the ground are like sponge and rain drops will be trapped in them and exit gradually from it , thus it will cause increase in the runoff coefficient . In addition vegetation covering will absorb the moistures from the clouds thus produce better equilibrium for evapotranspiration .

Thus decrease of Neka river discharge is not related to significant decrease in precipitation at the project region or the increase of water using of river , but it is influenced by the decrease of the vegetation covering of the basin which is a kind of irregular human effects on the nature and environment which lead to river runoff decrease , and must be severely prevented .

With regard to the significant decreasing trend of Neka river discharge at Glevard dam site and also intense fluctuations of river discharge , an operation planning based on variable demand will be necessary for an effective water resources management .

Forecasting the hydrological condition and the annual rivers discharge before beginning of the irrigation season in each water year , can help to choose the appropriate annual demand (or the area of the lands can be cultivated) and will manage the reservoir operation based on the variable demand. This relationship for Neka river will be investigated in the following section.

2. FORECASTING HYDROLOGICAL CONDI DION OF ANNUAL RIVER DISCHARGE

For this purpose , the hydrological runoff system of the Neka river has been investigated in detail and the relation between the sum of the river discharge during the first 6 months of the water year (Oct - Mar) with the annual discharge , has been investigated.

Fig. 3. shows the points for all water years and the best correlation equation as the power form . As it can be seen, there is a very appropriate correlation relationship between these two parameters at Glevard dam site .

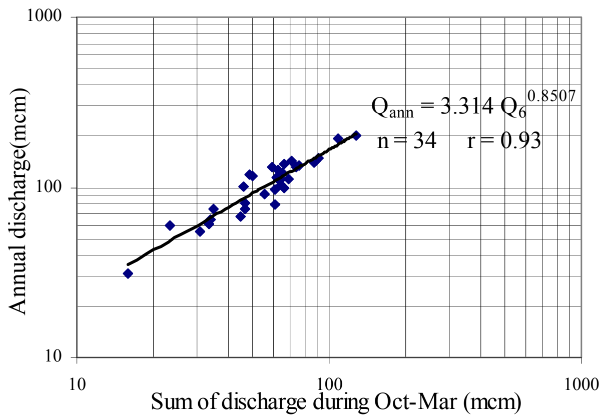

Figure 3. Sum of discharge during Oct-Mar vs. annual discharge of Neka river at Glevard dam site

The equation is as below :

$$Q_{ann} = 3.314 Q_6^{0.8507} \ , \ n = 34 \, , r = 0.93 \qquad (13)$$

Where Q_{ann} is annual discharge in mcm , Q_6 is sum of the river discharge during the first 6 months of the water year (Oct - Mar) in mcm , n is the number of the water years and r is the correlation coefficient .

With regard to the degree of freedom $(f = n - 1 = 33)$ and correlation coefficient $(r = 0.93)$, the credibility of the correlation equation is very high and is meaningful at significant level of 0.0001 .

Based on the Eq. 13. after passing 6 months from each water year , at the beginning of the irrigation season , it would be possible to estimate the river annual runoff with a high credibility and have information about the hydrological condition of the river , meanwhile , it would be possible to estimate appropriate annual demand (or the area of the lands can be cultivated) and the mean percent of supplied water(or shortage ratio of irrigation demands) in each water year by the rule curve which will be explained in the following section .

3. RULE CURVE (OPERATION PLANNING) FOR DAM BASED ON VARIABLE DEMAND

Reservoir operation of the Glevard dam was evaluated on the approved input data and information such as the water demands and other assumption of the project .

The cultivated land area related to the irrigation network downstream of the Glevard dam is 10,000 ha.

In the dry and very dry years , for the correct management and preventing the dam reservoir to get empty in the hot summer months , it seems to be necessary to implement an appropriate planning to choose annual demand .

By this method , the reservoir operation will be manage in the dry and very dry years with the decrease of the cultivated area , along with implementation an appropriate shortage ratio for demands .

Concerning the reduction of the cultivated land area , in accordance with the criteria and standards of the supplied water, the minimum percent of supplied water is considered as 80 % (acceptable reduction of water supply based on it's effects on the economical benefit of project at the time of water shortage) .

Based on the results of reservoir operation , it can be seen that with the reduction of cultivated lands to almost 7500 and 5000 ha , respectively , in the dry and very dry years , the percent of supplied water will be maintained at the acceptable limit and standard (80 %).

However , without the decrease of the cultivated land , in the dry and very dry years , the percent of supplied water will be more reduced and will get away from the desirable minimum acceptable percent of supplied water and in the mid summer , an important part of the lands will get dry and there will be a high reduction of the yields .

On the other hand , in case of more reduction in the cultivated lands , it will be possible to increase the percent of supplied water to 90 or 95 % .

Based on the economic and social studies results of the Project , for different cultivated land area and acceptable standards for percent of supplied water for agricultural demands (at least 80% for dry years) , approved area of the irrigation network (10,000 ha) is suitable for the mean and wet years period and also for the dry and very dry years , 7500 and 5000 ha reduction in cultivated lands is recommended , respectively .

Reduction of agricultural land and appropriate shortage ratio were determined through try and error on the results of the different runs , so with regard to the results of reservoir operation , optimum demands and percent of supplied water can be attained for each water years based on numeric and deterministic calculations on the long-term data series .

The results obtained from the final reservoir operation , have been used for determining the necessary codes to make decision on the rule curve or operation planning for Glevard dam .

This curve will determine the cultivated land area and the percent of water demand can be released from dam in the operation years with different hydrological conditions .

Therefore by relation between the annual runoff of the river , the area of cultivated land and the annual percent of supplied water, a reasonable relationship which can be generalized for the future years can be derived based on the last results of reservoir operation through dividing the mean ,wet ,dry and very dry periods . This relation has been shown in Fig. 4.

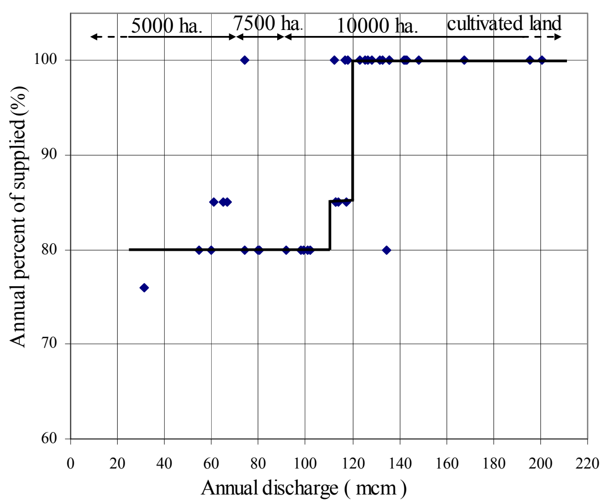

Figure 4. Rule curve(operation planning)for Glevard dam

Thus at the time of real operation , for each water year after passing 6 months from the water year (at the beginning of the irrigation season) , it would be possible to estimate the annual inflow to Glevard dam with high credibility by Eq . 13. and thus , get knowledge about the hydrological condition of the river and then it would be possible to estimate the lands to be cultivated (or annual demand) and the mean percent of supplied water(or shortage ratio)for demand .

Based on the Fig. 4. as a rule curve (operation planning) for Glevard dam , in "very dry" period where the annual inflow of less than 70 mcm into the reservoir , the cultivated area will be 5000 ha with mean percent of supplied water of 80% (or 20 percent shortage ratio)and for "dry" period , where the annual inflow into the dam is between 70 and 90 mcm , the cultivated area will be 7500 ha with mean percent of supplied water of 80% , finally for the years with runoff of more than 90 mcm per year , which are considered as "mean and wet" period , the cultivated area will be planned as equal to 10,000 ha .

In such years , the mean percent of supplied water with annual runoff of 90 to 110 mcm , will be expected as 80% and in years with annual runoff of 110 to 120 mcm , as 85% and finally in the years with annual runoff of more than 120 mcm , as 100 % .

Therefore , with regard to the mentioned lines for the operation rule curve of the Glevard dam , it seems that in the most of the operation years , the operators would be able to regulate the potential of water resources with the lands to be cultivated (based on the variable demand) and attain the acceptable and standard percent of supplied water through appropriate decision related to hydrological condition of the river .

REFERENCES

Ab-Niru Consulting Engineers. (2009) : Water Resources Management of Glevard Dam, Report No. 3.

Zbigniew W. Kundzewicz and Alice Robson (Editor) , (May 2000) : Detecting Trend and Other Changes in Hydrological Data , World Meteorological Organization , WMO-TD No. 1013 , Geneva , Switzerland .

Salas , J.D. (1993) : Analysis and Modeling Hydrologic , In Handbook of Hydrology , Maidment , D.R. , McGraw –Hill , NewYork .

Helsel , D.R., and Hirsch , R.M. (1992) : Statistical Methods in Water Resources , Elsevier , Amsterdam .