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Optimization of the Relationship Between Water and Sediment Discharge Rates (Case Study; Amameh Indicator Watershed of Iran)

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Abstract: In this study, first by using Smirnov-Kolmogorov method, the consistency of data was applied in order to optimize the relationship between water and sediment discharge rates in Amameh indicator watershed of Iran. After the consistency and authenticity of data were confirmed, by means of daily mean discharge and a software called Technical Hydrology (TH), monthly hydrograph was sketched for total period of 1969-2000 in Kamarkhani station in Amameh watershed outlet. Then, different models were tested using the equation of sediment transport and considering hydrological, climatic and biological parameters such as hydrograph situation, classification of discharge rate and the time of flow measurement. In all models, the regression relationships between the rates of water and sediment discharges were established. To choose an optimized model, the sum of the error sum of squares index was used. According to the index, the least sum of squares shows the optimized model. The results showed that the common model in which only one equation is used as a sediment rating equation has the highest error in estimation of suspended sediment. But, a model in which the data are separated based on wet and dry months and classification of the discharge rates, has the lowest error sum of squares and is considered as the optimized model.

Key words: Sediment discharge rate, suspended sediment, optimization, TH software, amameh watershed

INTRODUCTION

Water is one of the most important erosive factors of the earth's crust and transports the materials as solution, suspended and bed loads. Iran has the highest destruction with erosion of over 1 billion tons of soil per year and flood makes 300,000 and drought makes 100, 000 US Dollars of damage daily (Bikshoma and Subramania, 1988). Since there is not a desirable geographical distribution of sediment discharges stations in Iran, therefore assumed that this study from an indicator watershed can extended to the similar catchments. Measurement of suspended sediment of rivers started in 1964 in Iran and up to end of 1996-97 water year, 715 sediment rating stations with 244000 records have been reported for all over the country (Fleming, 1969). In these stations, concentrations or turbidity of flow have been measured and the results are used in the studies of water resources management, erosion, sediment and environmental issues. Fleming (Habibi, 1995) submitted the equation $Q_s = aQ_w^b$ for the watersheds without data using suspended sediments of 250 rivers of the world. In the formula, Q_s is the suspended load in tons per day and Q_w is the annual average discharge rate in m^3 sec^{-1}. Robert (Mahdavi, 2001) concluded that the common methods of sediment rating curve and flow durability curve underestimated the sediment by 51%. Mirabolghasemi and Morid (1995) in studying the sediment transport of Godovari river basin of India mentioned that geology; water discharge rate and time of flow occurrence are the controlling factors of erosion.

Habibi (1995) recognized the correlation between water and sediment discharge rates as the sediment yield of a watershed during a particular period in which the measurements are carried out. In his opinion, the least statistical period for calculation of annual average sediment yield should include both the wet and dry years. From the study of sediment yield of Karkheh watershed and some factors affecting on it, Mirabolghasemi and Morid (1995) stated that almost all watershed erosion occurred during wet months or seasons. They found a linear direct relationship between suspended load and the climatic factor of rainfall. Tarkhani (2001) evaluated more accurate annual suspended load from sediment rating equation, by separation of water and sediment discharge rates of Lighvan watershed in Tabriz based on presence or absence of green vegetation and considering river flow

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hydrographs stages. By studying the water and suspended sediment discharge rates of Gorganrood, using the sediment transport formula of $Q_s = aQ_w^b$ and errors least squares, Mohammadi Ostadkelayeh (2002) concluded that the optimized models in different stations are not the same and one can not use a particular model to optimize the relationship between water and sediment discharge rates of all hydrometric stations. The number of proposed models for optimization depends on the time and the situation of the river during sampling and the number of sediment samples.

Much of the recent research on river basin sediment processes has focused on relation between water and sediment discharges occurring in catchment marginal settings and on the major streams. Ringen (1984) and Lenfest and Ringen (1985) quantified suspended sediment-discharge relationships for a number of stream gages on tributaries of the Green River, including multiple gages on Henry's Fork and Black's Fork. Brink and Schmidt (1996) discussed sediment transport and water discharges on the south slope of the Uintas, particularly the assessment and methodology of quantifying channel migration in mountain streams. Counts and Pederson (2003) assessed the geomorphic record of a large paleflood on the Green River; Pederson (2004) evaluated the record of drainage evolution in the Green River basin and Larsen *et al.* (2004) evaluated reworking of debris fan deposits in the Green River canyon downstream of Flaming Gorge Dam. Gaeuman *et al.* (2003 and 2005) studied the effects of historic changes in discharge and sediment transportation along a reach of the lower Duchesne River near its confluence with the Green River in the Uinta Basin. Additionally, several unpublished theses have been completed (Smelser, 1998; Stamp, 2000; Paepke, 2001; Gaeuman, 2003; Larsen, 2003).

MATERIALS AND METHODS

Study area: The Amameh watershed with a long shape and area of 37.2 km^2 is located in Latian Dam basin and is an indicator of southern region of central Alborz. The watershed is in 1800-3912 MSL with average slope of 32.5%, its climate is Mountainous based on Emberger method of classification. June to September is the driest months and the rest of the months of the year are wet. The Amameh River with snow-rainy regime enters the Jajrood River at a location called Kamarkhani, after 13.5 km distance of flowing. Two hydrometric stations are located in the river, one in the Baghtabgeh in the upper portion of the basin and the other one in the outlet of the watershed at Kamarkhani. Both stations are equipped with scale, Limnigraph and Telepheric Bridge. The average annual water discharge rate at the outlet from the beginning of the installation to water year of 2001-2002 is 0.56 m^3 sec^{-1}. The average annual yield of the watershed is 17.66 million m^3 and average annual runoff is 47.47 cm. It means that 62.58% of the precipitation is wasted as runoff. If one water year is divided into wet and dry months and the months with discharge rates greater than the annual average is wet and the months with discharge rates less than annual average is dry, then in this watershed March through June are wet and the rest of the months of the year are dry. The Amameh basin is largely of rangelands and only a small portion of it, in Amameh and Glogan villages, is in agricultural production. The plant growth period is limited to April to July.

Methods: The experimental methods of sediment estimations of the watersheds are based on these data, which may cause different estimation of the sediment due to low numbers of sampling (especially during flooding) and unsuitable sampling methods. To estimate the sediment discharge of the watersheds, the sediment-rating curve is used which is made from limited number of measured water and sediment data.

The relationships that were used to determine the suspended load so far are mostly based on average daily discharge rate and/or classification of the amount of water, which considers the water and sediment relationship only and other factors affecting sediment transport are not considered. In other words, the sediment discharge as a function of water discharge is considered and other factors such as time of occurrence and/or river hydrograph for classification of the data are not paid any attention. In this research, 32 years (water years of 1969-1970 to 2001- 2002) data of daily water discharge rates and 30 years data of water and sediment discharge rates measured simultaneously in some days of the year have been used. After collection, the data have been entered into software Technical Hydrology (TH) and statistical and graphical calculations have been carried out. Before analyzing the data one should be assure of the quality and completeness of the data series. To test the homogeneity of the data two methods are available. One is graphical and the other is non-graphical. As the graphical methods do not have quantitative criteria for homogeneity or non- homogeneity, they are not considered as complete methods. TH was used in this research. The software proposes the advanced version of Smirnov-Kolmogorov method in which the homogeneity of data is tested. This test is based on comparison of experimental distribution in two parts of a divided sample. The highest difference of the two parts of the data sample for a specific flow rate, which is parallel to frequency axis (X-axis), is the maximal deviation (d_{max}) measured between two graphs. The high level of significance in homogeneity test is 70% and its low level is 30%. Therefore, if the data series have the following condition is considered homogenous. Knowing d_{max} the Z can be calculated as (Eq. 1):

$$Z = d_{max} \sqrt{[n_1 n_2/(n_1+n_2)]} \quad (1)$$

Where n_1 and n_2 are the number of elements of each portion of divided sample and Z is the random variable proposed by Smirnov and should be used for samples of similar population in Kolmogorov distribution. The probability of the variable Z from Kolmogorov distribution is determined by parameter L (Z) using (Eq. 2).

$$L(Z) = P(dmax\sqrt{n} < Z) \quad (2)$$

Where L (Z) is the probability that the maximum difference between distribution functions in two samples of a statistical population should not exceed Z and this means that for samples selected randomly from a statistical population, the maximum deviation should be 100% L (Z) and /or over 100 [1-L (Z)] in samples. Therefore, the data series with the following condition is homogenous (Eq. 3):

$$[1- L(Z)]\, 100 > 70 \quad (3)$$

In the next stage the sediment discharge rate is calculated by the Eq. 4, for the days that sediment concentration is measured:

$$Q_S = 0.0864\, Q_w\, C \quad (4)$$

Where Q_s is the suspended load in tons/day, Q_w is water flow rate in m^3sec^{-1} and C is the concentration of sediment materials in mg L^{-1}. As the water flow rate is measured in all days of the year, Q_s can be estimated from an equation of the form $Q_s = aQ_w^b$ for the whole statistical period. Therefore, in addition to use of sediment transport as a basic model in suspended sediment discharge rate estimation, the optimization of the mathematical model is also performed considering the conditions and factors affecting the suspended sediment discharge rate.

By separation and or non-separation of measured sediment discharge rate based on the situation of flow hydrograph, time of measurements and the amount of water flow rates, the following models are analyzed for suspended sediment estimation:

General model A: Estimation of sediment discharge rates based on all measured data without any classification of the data.

General model B: Estimation of sediment discharge rate based on the situation of river flow hydrograph.

General model C: Estimation of sediment discharge rate based on the time of measurement.

General model D: Estimation of sediment discharge rate based on classification of water flow rates.

General model E: Estimation of sediment discharge rate based on the situation of river flow hydrograph and time of sediment measurements.

General model F: Estimation of sediment discharge rate based on the situation of river flow hydrograph and classification of water flow rates.

General model G: Estimation of sediment discharge rate based on the time of sediment measurement and classification of water flow rates.

General model H: Estimation of sediment discharge rate based on the situation of river flow hydrographs, classification of water flow rates and the time of sediment measurement.

General model I: Estimation of sediment discharge rate based on combination of models B to H, if necessary.

In general model A or the common model the data are not separated and a regression relationship is used between all measured sediment and water flow rates. As the flood is hydrologically a sudden increase in flow rate up to a peak point and then a relatively fast decrease, in general model B the discharge data is divided into 3 parts from situation of flow hydrographs point of view: discharge data from the beginning the flood up to peak point (climbing limb data), data from peak point to the end of flood (falling limb data) and the data from the end of flood to the beginning of the next flood (base flow data). In general model C, the data separation is made based on 1.wet and dry months 2. High and low water months 3. With or without green vegetation. In general model D, the daily discharge rates are classified based on: 1. Discharge less than average annual discharge 2. Discharge of greater than or equal to average annual discharge and less than twice the average annual discharge 3. Discharge greater than or equal to twice the average annual discharge. In general model I, the data are separated based on the fact that the river flow is divided into base and flood flow.

To select the best model, mean error sum of squares and correlation coefficient were used. The closer the estimated values to the observed values, the less will be the sum of squares and mean sum of squares. The error sum of squares, mean error sum of squares and correlation coefficients are calculated as follows (Eq. 5-7):

$$SS_E = \sum_{i=1}^{n} (\log Q_{sio} - \log Q_{sic})^2 \quad (5)$$

$$R = \frac{\sum_{i=1}^{n} (\log Q_{si} - \log \overline{Q}_s)(\log Q_{wi} - \log \overline{Q}_w)}{\sqrt{\sum_{i=1}^{n} (\log Q_{si} - \log \overline{Q}_s)^2 \sum_{i=1}^{n} (\log Q_{wi} - \log \overline{Q}_w)^2}} \quad (6)$$

$$MS_E = \frac{\sum SS_{Ei}}{N} \quad (7)$$

Where SS_E is error sum of squares, SS_{EI} is error sum of squares in each sub-model, Q_{sio} is the suspended sediment discharge rate in tons/day, MS_E is mean error squares, Q_{wi} is the water flow rate in m^3 sec^{-1}, $\overline{Q}_w$ is the mean water flow rate in m^3 sec^{-1}; $\overline{Q}_s$ is the mean suspended load in tons/day and N is the total number of data in each part of the model.

The closer the mean square is to zero; the model will have higher efficiency and accuracy. In addition, the closer the coefficient of correlation between two series of data in a model is, the higher will be the efficiency and assurance. It means that when the coefficient between data (depending on their number) is closer to 1, the probability that the data follow a particular relationship is higher. Based on this, the best model is the one with lowest error sum of squares and highest correlation coefficient. After homogeneity tests of flow rates, monthly hydrographs for the whole statistical period was drawn using daily water flow rates and TH software then the relationships between water and sediment discharge rates and coefficients of correlation were obtained considering different proposed models and sediment transport equations. After making analysis of variance table, the number of data, error sum of squares, error mean squares, correlation coefficients among data, the constants a and b in each case were determined. The best model was selected based on error sum of squares and the sediment amounts were estimated for the times the sampling was not carried out using the model. Finally, the time series of daily sediment discharge rate for the whole statistical period was obtained. For the above purposes, TH and EXCEL software were used.

RESULTS AND DISCUSSION

Period, the following results were obtained using TH software, For homogeneity tests of Kamarkhani station during statistical Smirnov-Kolmogrov test and dividing the statistical population into two samples:

$$P = [1\text{-}L\ (Z)] = 0.798$$
$$d_{max} = 0.23$$

So, it can be concluded that the data series are homogenous. The homogeneity test shows that the best statistical distribution for mean annual flow rate is normal distribution based on TH software and Kolmogorov fitting test. The result of the test is as follows:

$$d_{max} = 0.1 \qquad P_f = 0.906$$

P_f is the probability of fitting test index. The selected distribution for the mean discharge data series is suitable considering the significance levels of 30 and 70%. Figure 2. shows the results of the best statistical distribution graphically. To determine the adequacy of the data the following equation is used (Eq. 8):

$$N = (4.3\ t \log R)^2 + 6 \quad (8)$$

Where N is the least number of data or statistical years required, t is the t-student amount which can be obtained from the related table using N-6 degrees of freedom and the appropriate confidence level and R is the ratio of the numerical value of the variable with 100 year return period to the amount of the variable in 2 year return period. To obtain the t-value with trial and error, different values of N is proposed and t is obtained from the related table with appropriate degrees of freedom and confidence interval. An example of using equation is as follows:

N =13, t (5% and 7), Q_{100} = 1.01 m^3/s and Q_2 = 0.56 m^3/s
$N = (4.3 \times 2.365 \times \log 1.8)^2 + 6 = 12.72$

As the assumed value of N =13 is very close to the calculated value (12.72), then at least 13 years of data is necessary for the analysis. There are 32 years of data available, so it is quite sufficient for this purpose.

After statistical tests and separation of all floods of statistical periods and drawing hydrographs of these floods with TH software, the relationships between water and sediment discharge rates have been established using proposed models and carrying out regression analysis and error sum of squares methods. It is obvious that except model A, more than one regression equation can be found between water and sediment. The models with less than 10 data have been cancelled from the analysis for being poor in data amounts. Figure 1 and 2 show the histograms of error sum of squares and error mean squares.

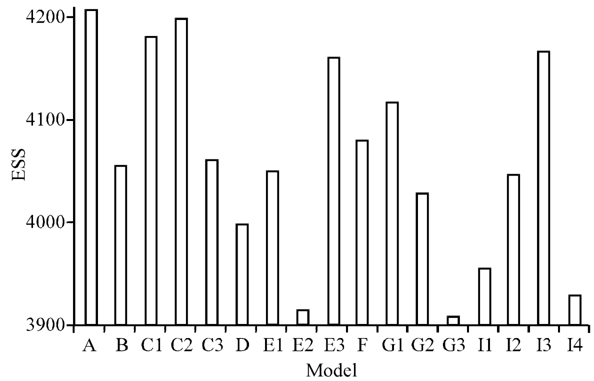

Fig. 1: Histogram of error sum of squares for the models under investigation

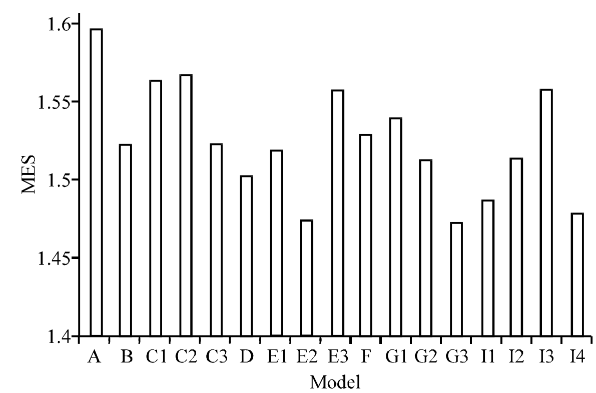

Fig. 2: Histogram of mean error squares for the models under investigation

In Amameh watershed, regression equations were established for 2635 pairs of water and sediment discharge rates. The common model A has the highest error sum of squares and as a result the highest amount of error in estimation of suspended sediment rate.

Model H was cancelled due to lack of data. Among other proposed models, G3, which was based on dry and wet months and classification of flow rate, has the lowest error sum of squares and was selected as the optimum model. The model G3 was used for estimation of daily suspended sediment of the watershed. Therefore, the optimum model of sediment transfer in Amameh watershed includes the following formulae:

- In dry months and water flow rate less than mean annual discharge rate, the sediment transport equation is (Eq. 9):

$$Q_S = 60.96Q_w^{0.9238} \quad (9)$$

- In dry months and water flow rate greater than or equal to mean annual discharge rate and less than twice mean annual flow rate, the sediment transport rate equation is (Eq. 10):

$$Q_s = 265.03Q_w^{0.9996} \quad (10)$$

- In dry months and water flow rate greater than and /or less than twice of mean annual water flow rate, the sediment transport equation is: $Q_s=13.45Q_w^{1.2561}$

- In wet months and water flow rate less than mean annual discharge rate, the sediment transport equation is (Eq. 11):

$$Q_s = 48.63Q_w^{1.093} \quad (11)$$

- In wet months and the water flow rates greater than or equal to mean annual discharge rate and less than two times of mean annual discharge rate, the sediment transport rate is (Eq. 12):

$$Q_s = 9.55Q_w^{1.1083} \quad (12)$$

- In wet months and the water flow rate greater than or equal to twice of mean annual discharge rate, the sediment transport rate is (Eq. 13):

$$Q_s = 193.68Q_w^{1.1331} \quad (13)$$

The sediment rating curves of optimum models of sediment transport (G3) are shown in Fig. 3-8.

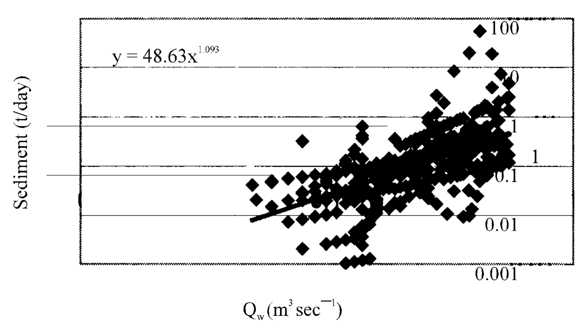

Fig. 3: Sediment rating curves of the optimum model for dry months and class 1 discharge rate situation

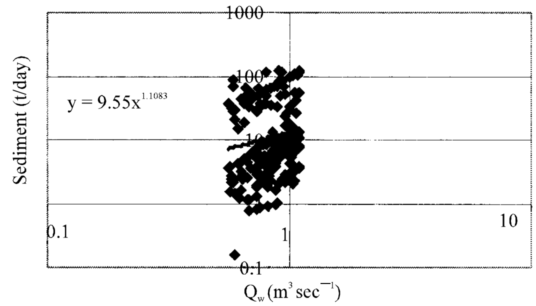

Fig. 4: Sediment rating curves of the optimum model for dry months and class 2 discharge rate situation

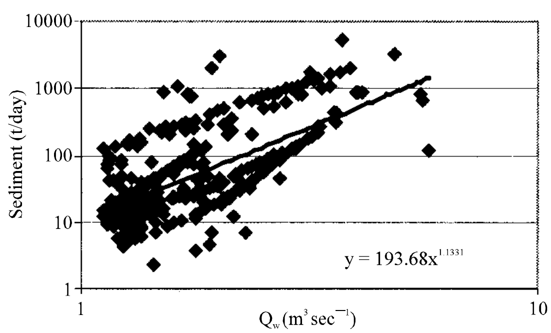

Fig. 5: Sediment rating curves of the optimum model for dry months and class 3 discharge rate situation

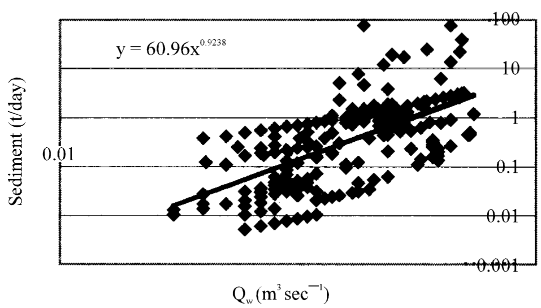

Fig. 6: Sediment rating curves of the optimum model for wet months and class 1 discharge rate situation

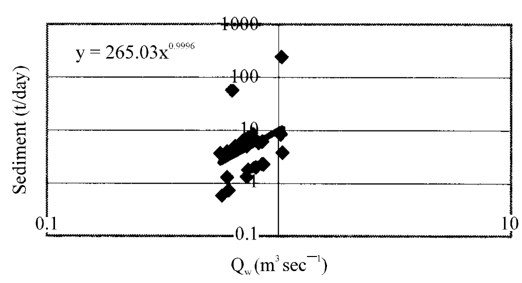

Fig. 7: Sediment rating curves of the optimum model for wet months and class 2 discharge rate situation

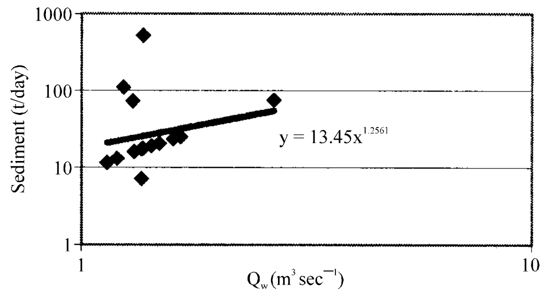

Fig. 8: Sediment rating curves of the optimum model for wet months and class 3 discharge rate situation

CONCLUSIONS

The highest error sum of squares in the Amameh watershed is for the model in which the sediment rate is estimated without considering the time of discharge rate measurements, river flow hydrographs stages and/or classification of water flow rates. The amount of sediment in climbing limb of the flow hydrograph is more than the sediment for the falling limb of the flow hydrograph. The reason for this is as follows:

In early times of rainfall, the erosion material is abundant at the watershed surface, which is transported into river along with runoff and adds the sediment concentration. But, in flood recession, rainfall intensity decreases and/or even becomes zero and therefore the frequency of the erosion materials also decreases. As a result, the amount of transported sediment and its concentration decreases. The amount of sediment transported in high water and wet months are higher than low water and dry months, because the rainfall causes more erosion of the soil and the relatively high amount of flow in the channel produces channel erosion, but in low water months the discharge rate is at base flow level and in this situation the eroding factors and also the transporting factors of sediments are in their minimum activity and effects. The highest amount of sediment transport is in March which can be attributed to high water flow rate resulting from rainfall and snow melting, absence of green vegetation growth due to presence of limiting factors and provision of erosion conditions in this month.

The lowest sediment transport is in February, which can be due to following reasons: Most precipitation on the watershed occurs in the form of snow in this month, so the water flow rate and erosive transportable materials reduces to a considerable amount. By comparisons of the transported materials from the watersheds in spring months, it can be concluded that in June a minimum amount of suspended sediment transport is observed which is due to soil fixation by green vegetation. This shows the role of vegetation in control of erosion. The results of the investigations show that separation of water flow rates and sediment transport rates by considerations of the factors like rainfall, temperature and vegetation with river flow hydrograph stages, gives a more accurate estimation of suspended sediment.

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REFERENCES

Bikshoma, G. and V. Subramania, 1988. Sediment transport of Godovari river basin and its controlling factor. J. Hydrol., 101: 275-290.

Brink, M.S. and J.C. Schmidt, 1996. Duchesne River channel: A geomorphic history, 1875 to 1995, Utah State University, Logan, Utah, pp: 47.

Counts, R.C. and J. Pederson, 2003. Evidence for a large-scale paleoflood in the northeastern Uinta Mountains, Geologic. Soc. Am. Abstr. Prog., 35, pp: 542.

Fleming, G., 1969. Deterministic model in hydrology. Irrigation and Drainage, pp: 32.

Gaeuman, D.A., 2003. A historical approach for identifying habitat maintenance flows, with application to the lower Duchesne River, Utah. Masters Thesis, Utah State University, Logan, Utah, pp: 180.

Gaeuman, D.A., J.C. Schmidt and P.R. Wilcock, 2003. Evaluation of in-channel gravel storage with morphology-based gravel budgets developed from plannimetric data. J. Geophysic. Res., 108: 2-1-2-16.

Gaeuman, D.A., J.C. Schmidt and P.R. Wilcock, 2005. Complex channel responses to changes in stream flow and sediment supply on the lower Duchesne River, Utah. Geomorphology, 64: 185-206.

Habibi, M., 1995. Application of suspended load calculation methods in selected rivers of Iran. Proceedings of National Seminar on Erosion and Sediment. The watershed management deputy of Jihad Sazandegi Ministry. In Persian.

Larsen, I.J., 2003. From the rim to the river: The geomorphology of debris flows in the Green River canyons of Dinosaur National Monument, Colorado and Utah. Masters Thesis, Utah State University, Logan, Utah.

Larsen, I.J., J.C. Schmidt and J.A. Martin, 2004. Debris-fan reworking during low-magnitude floods in the Green River canyons of the eastern Uinta Mountains, Colorado and Utah. Geology, 32: 309-312.

Lenfest, L.W. and B.H. Ringen, 1985. Streamflow and suspended-sediment discharge from two small watersheds in southwestern Wyoming and northeastern Utah. U.S. Geological Survey Open File Report 85-0161, Reston, Virginia, pp: 35.

Mahdavi, M., 2001. Land management and soil erosion in Iranian watersheds. National Seminar on Land Management, Soil Erosion and Sustainable Development. Arak, Iran, (In Persian).

Mirabolghasemi, H. and S. Morid, 1995. Investigation of sediment yield of Karkheh River and some influencing factor on it. Proceedings of National Seminar on Erosion and Sediment, the Watershed Management Deputy of Jihad Sazandegi Ministry (In Persian).

Mohammadi Ostadkalayeh, A., 2002. Optimization of water flow rate and sediment transport rate in Gorganrood river hydrometric stations. M.Sc. Thesis of Gorgan University of Agricultural Sciences and Natural Resources (In Persian).

Paepke, B.E., 2001. Controls on channel organization in a glaciated basin in the Uinta Mountains, Utah. Masters Thesis, Utah State University, Logan, Utah, pp: 115.

Pederson, J., 2004. Drainage integration as a first-order control on the erosional exhumation of the Interior West-the example of the Green River and the Uinta Mountains. Geologic. Soc. Am. Abstr. Prog., 36: 118.

Ringen, B.H., 1984. Relationship of suspended sediment to streamflow in the Green River basin, Wyoming. U.S. Geological Survey Water Resources Investigation 84-4026, Reston, Virginia, pp:14.

Smelser, M.G., 1998. Geomorphic adjustability of streams draining the Uinta Mountains. Masters Thesis, Utah State University, Logan, Utah, pp: 176.

Stamp, M.E., 2000. Hydrologic and geomorphic effects of dams and water diversions on Lake Fork River and Rock Creek, Uinta Mountains, Utah. Masters Thesis, Utah State University, Logan, Utah, pp: 140.

Tarkhani, H., 2001. Optimization of water flow and sediment transport rate relationship in Lighvan indicator watershed. M.Sc. Thesis, Gorgan University of Agricultural Sciences and Natural Resources, In Persian.