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Development of Empirical Formula for Computing Sediment Loads in Al-Meshkab Regulator Channel

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ABSTRACT

In this research, the sediments' transport and how to compute their amount have been studied in Al-Meshkab regulator channel. Twenty four cross-sections were selected along the reach of Euphrates river to study the characteristics and the rate of transport of sediments. The measured data included: cross-sections of the channel, average velocity, discharge, water surface width, water surface slope, sediment concentration, bed material samples as well as the specific gravity of bed sediments.

The length of the study region was 6 km upstream of Al-Meshkab regulator. The study was divided into two parts: the practical part (field and laboratory works) and the statistical part. The research covered the suggestion of an empirical formula which was used to fit the dimensionless form and to predict a relationship between the sediment rate and the different variables. Analysis of Variance (ANOVA) was used to examine the differences between the observed sediment rate and the predicted sediment rate. Results indicated that no statistically significant differences could be detected between observed and computed sediment rate values using the statistical model.

KEYWORDS: Sediments, Empirical formula, Al-Meshkab regulator channel.

INTRODUCTION

Rivers and channels are considered important resources for water supply, irrigation, navigation, water power generation and other public uses. The presence and movement of sediments cause many problems. The deposition and erosion of solid materials of the beds and banks of the channel increase bed deformation, which in turn will reduce the depth of water in some places and reduce the ability of the water way for navigation or hydraulic purposes. However, the raising of the river bed by the deposited materials increases the flood range to a great extent. As a result, large sums of money have to be spent to maintain the course of the river necessary for the hydraulic requirements.

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Sediments are small particles like sand, gravel, clay and silt. The water in a river has a natural capacity of transporting sediments. Man-made structures in a river may change the sediment transport capacity over a longer part of the river or locally. Sediments can be classified into deposited and suspended ones. Deposited sediments are those found on the bed of the river or lake, while suspended sediments are those found in the water column, where they are transported by water movements so that the materials transported by water are in suspension, rolling or sliding on the bed. The border line between bed load and suspension is certainly not well defined, because it is hard to imagine a particle rolling or sliding on the bed without at some time losing contact with the bed executing a short jump.

In fact, the rate of sedimentation is one of the most important quantities that need to be known before a hydraulic structure is constructed, because this quantity determines the useful life of the hydraulic structure.

Description of Al-Meshkab Regulator Channel

Al-Meshkab regulator channel is considered one of the most important projects of irrigation in the region because of the large areas that benefited from it and the technical performance. It is located in the middle Euphrates region within (20-30)km (south-east) of Najaf city. It consists of a main channel and lateral channels with some hydraulic structures. The region of this study is located at a longitude of E 45°29'31" to E 44°28'51" and a latitude of N 32°17'67" to N 31°41' 51".

In this region, Al-Meshkab regulator was constructed on Euphrates river downstream of Najaf governorate. In the reach of the study upstream of the regulator with a length of 6 km and an average width of (99 m), the accumulation of sediments in the river affected the performance of the structure.

Al-Meshkab regulator was constructed in 1959 on Kifil-Shanafiyah branch of Euphrates River downstream of Najaf governorate for irrigation purposes.

The designed flood discharge of the regulator is 1400 m^3/sec, with a downstream water level at 25.7 m above sea level. The operational discharge ranges from (50 to 230) m^3/sec with a water level of 24.5 m above sea level as mentioned in the operational report.

The regulator consists of seven rectangular openings, each with dimensions of (7x13.5)m supplied with a steel vertical gate (Iraqi Ministry of Water Resources).

Field Work

The cross-sections of the channel were observed by taking a reference point on the left side with respect to the water flow direction. From the reference point ,the whole width of the channel was divided into several parts (about six meters apart). The width of each part depended on the size of the river. Then, the depth of each part was measured. From these depths, the cross sections along the channel were drawn by using software program HEC-RAS 3.1.3 developed by the Hydrologic Engineering Center for the US Army Crops of Engineers (http://www.hec.usac.army.mil).

Type AA current meter was used in this study to measure the velocity. Each cross-section was divided into about ten parts. In each column, two measurements were taken at 0.2 and 0.8 of the depth to have the average velocity, and when the depth of water was less than 1 m, one measurement was taken at 0.6 of the depth (Rickily Hydrological Co., 2000), as shown in Figure (1).

Three samples of bed materials were taken at ¼, ½ and ¾ of the width of the stream at each-cross section in order to conduct the size analysis distribution. These samples were finally mixed well to reduce the error of measurement and get a homogenous sample. Bed material samplers may be either boring or grabbing devices. Two common grabbing devices are the scoop and dredge (Vanone, 1977).

Because of lack in the former samplers, the researchers made a sampler similar to dredge type to be used in this study. The used sampler is shown in Fig. (2).

Suspended sediments in the river were sampled to determine the sediment concentration. Different sediment samplers and procedures are available for sampling in a stream. Because of flow acceleration, there is some effect on the accuracy of the measurements. It is imperative that the sampling process would disturb the flow as little as possible.

The sampler shown in Fig. (3) is especially designed to obtain the required samples. It consists of a bottle with the capacity of one liter and an intake nozzle of (8 mm) in diameter. An air escape of (6mm) in diameter with a long plastic tube and a control valve was used to control the entering of water sediment mixture into the sampler (Ongly, 1996).

Figure 1: The current meter used in the study

(a) before sampling. **(b)after sampling.**

Figure 2: Devices used for sampling bed materials

Sediment Concentration Measurement

Infiltration is one of the methods used to analyze the suspended solids' concentration. It involves the removal of the solid matter from a sample by passing a known volume of liquid-solid mixture through a suitable filter. The collected water sediment samples were filtered by using a filtration set. Each filter paper was pre-dried for 15 minutes and weighed, and then it was clipped to the filter funnel and moistened with distilled water. A volume of 1000 ml of sample was measured into a graduated cylinder and poured through the filter, and the interior surface of the cylinder was washed out into the filter funnel with distilled water. Filtration was accelerated with a vacuum pump connected to the flask of the filtration set. After the completion of filtration, the filter paper was dried and reweighed. The difference between the two weights divided by the volume of the sample gives the concentration of the suspended sediments (UNDP, 1994):

$$C = \frac{W_2 - W_1}{V} \tag{1}$$

where:

C= concentration of suspended sediments in mg/l (ppm).

W_1= weight of dry filter paper in mg.

W_2= weight of dry filter paper+ suspended sediments in mg.

V= volume of the sample(m^3).

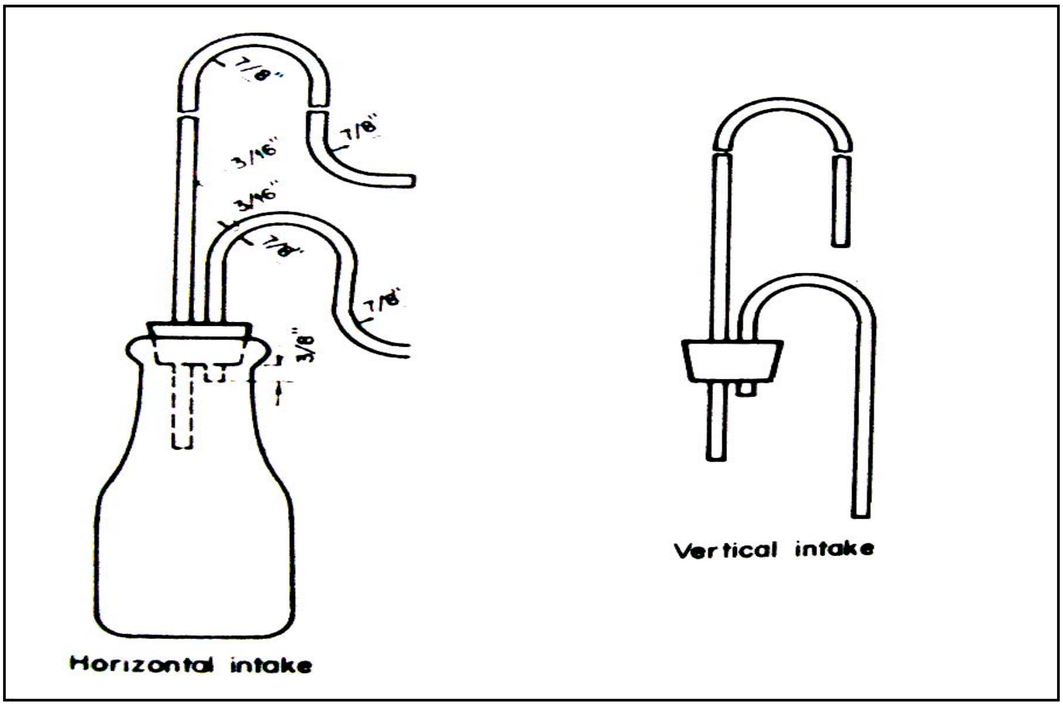

Figure 3: Taking suspended sediments by homemade tools

Sediment Discharge in the Channel

The value of field suspended sediment discharge has been calculated by multiplying the main concentration of water at each cross-section by the average discharge in the partial section. Consequently, the total discharge of suspended sediments was obtained, as shown in Table (1) .

Development of the Empirical Formula

In general, the dimensional expression of the sediment motion in rivers and alluvial channels can be expressed as:

$$f1(\rho_s, \rho_w, D_{50}, D_{90}, V, R_h, S, g, Q_s) = 0 \tag{2}$$

- No. of variables= 9.
- No. of fundamental dimensions = 3.

Table 1. Field sediment discharge for each section

No.	Concentration (mg/l)	Water discharge (m^3/sec)	Sediment discharge (kg/sec)
1	84	66.10	5.5524
2	115	72.10	8.2915
3	126	75.20	9.478
4	107	75.20	8.080
5	74	78.20	5.7868
6	97	78.20	7.5854
7	137	78.20	10.7134
8	148	78.20	11.5736
9	118	78.20	9.2276
10	95	78.20	7.385
11	107	86.20	9.2234
12	94	86.20	8.1028
13	102	86.20	8.7924
14	84	86.20	7.204
15	69	86.20	5.947
16	100	87.70	8.7700
17	109	87.70	9.5593
18	102	87.70	8.9454
19	113	87.70	9.9101
20	98	87.70	8.5946
21	148	91.7	13.5716
22	157	91.7	14.3969
23	111	91.7	10.1787
24	133	95.6	12.7148

∵ No. of variables > No. of fundamental dimensions.
∴ Buckingham's л-theorem should be used.
Choosing of repeating variables $(\rho_s, D_{50}\ and\ g)$.

Al-Gazali and Al-Suhaili (2000) proposed a method for dimensional analysis. This new method was used in presented research to find sediment discharge as shown in Table (2).

$$f\left(\frac{Q_s}{\rho_s g^{0.5} D^{2.5}}, \frac{Rh}{D_{50}}, \frac{V}{\sqrt{gD_{50}}}, S, \frac{\rho_s}{\rho_w}, \frac{D_{50}}{D_{90}}\right) = 0 \quad \text{(2-a)}$$

$$Q_s = \rho_s g^{0.5} D_{50}^{2.5} \Phi\left(\frac{Rh}{D_{50}}, \frac{V}{\sqrt{gD_{50}}}, S, \frac{\rho_s}{\rho_w}, \frac{D_{50}}{D_{90}}\right) = 0 \quad \text{(2-b)}$$

The sediment discharge given in equation (3) resulted from a regression analysis by a software program (DATA FIT version 9.0.59) which was used to analyze results and develop the empirical formula for computing sediments' discharge upstream of Al-Meshkab regulator channel:

$$Q_s = p_s\, g^{0.5}\, D_{50}^{2.5}\left[exp\begin{pmatrix} 1.11496\times10^{-2}\dfrac{Rh}{D_{50}} - 6.6551\times10^{-2}\dfrac{gD_{50}}{V^2} - \\ 1182.842S - 0.9385\dfrac{D_{50}}{D_{90}} - 2.2992\dfrac{\rho_s}{\rho_w} + 6.96176 \end{pmatrix}\right] \quad (3)$$

where:

Q_s = Total sediment load (kg /sec).

V =Mean velocity (m/sec).

g = Gravitational acceleration (m/sec^2).

R_h =Hydraulic radius (m).

S = Slope of the channel.

D_{50}= Particle size for which 50 percent by weight of the sediments is finer (mm).

D_{90}= Particle size for which 90 percent by weight of the sedimentsis finer (mm).

The coefficient of determination for equation (3) was found to be equal to (0.8949). Fig. (4) shows a well accepted correlation between predicted and observed (Q_s) values.

Table 2. Method for dimensional analysis (new approach)

		D50	ρs	g	Qs	R h	V	S	ρw	D90
1	L	1	-3	1	0	1	1	0	-3	1
2	M	0	1	0	1	0	0	0	1	0
3	T	0	0	-2	-1	0	-1	0	0	0

Row2*3+row1

		D50	ρs	g	Qs	R h	V	S	ρw	D90
1		1	0	1	3	1	1	0	0	1
2		0	1	0	1	0	0	0	1	0
3		0	0	-2	-1	0	-1	0	0	0

Row1*2+row3

		D50	ρs	g	Qs	R h	V	S	ρw	D90
1		1	0	1	3	1	1	0	0	1
2		0	1	0	1	0	0	0	1	0
3		2	0	0	5	2	1	0	0	2

Row3 / 2 and Row3*-0.5+row1

		D50	ρs	g	Qs	R h	V	S	ρw	D90
1		0	0	1	0.5	0	0.5	0	0	0
2		0	1	0	1	0	0	0	1	0
3		1	0	0	2.5	1	0.5	0	0	1

Change Row3 by row1 and change row1 by row3

					Qs	R h	V	S	ρw	D90
1	D50	1	0	0	2.5	1	0.5	0	0	1
2	ρs	0	1	0	1	0	0	0	1	0
3	G	0	0	1	0.5	0	0.5	0	0	0

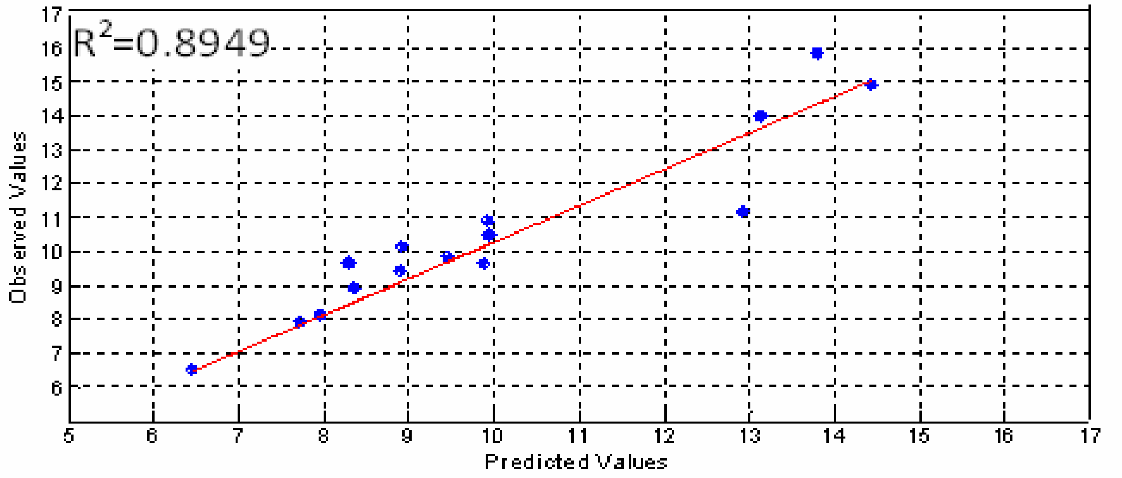

Figure 4: Observed and predicted values for fifteen sections

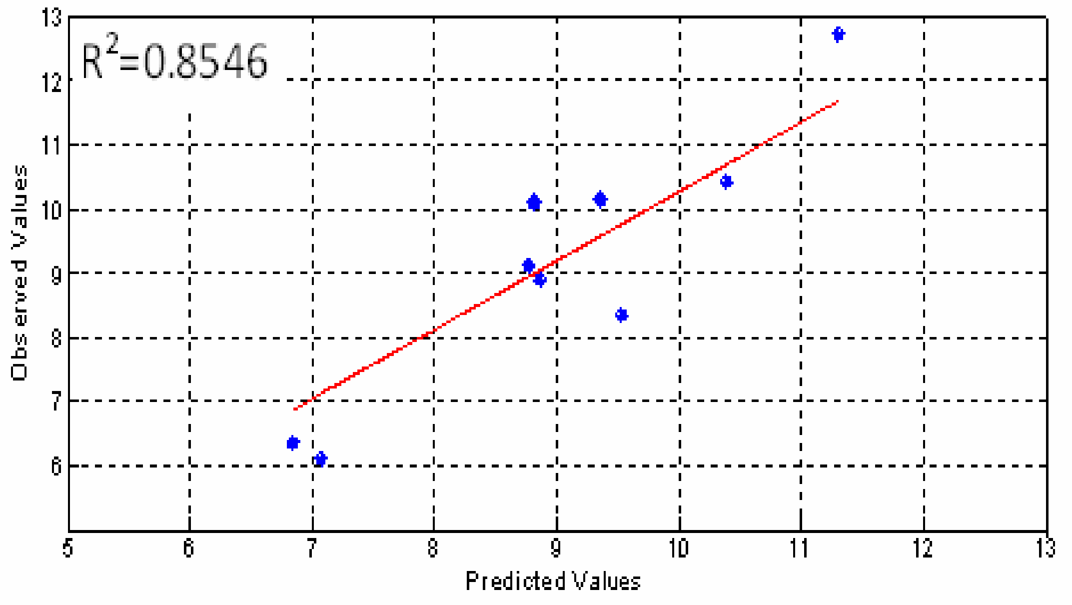

Figure 5: Observed and predicted values for nine sections

Test of the Statistical Model

The proposed model should be tested to see whether it is applicable to the given conditions or not. In order to verify Al-Meshkab regulator channel equation, variables from fifteen cross-sections along the channel were applied. In a separate step, we used data from the remaining nine cross-sections as cross checks for the fitness of the formula to the channel.

The results shown in Fig. (5) declare that Al-Meshkab regulator channel equation was quite fit to the channel as the coefficient of determination between its results and the observed values was (0.8546).

Evaluation of Sediment Discharge Formula

The predicted values of sediment discharge were calculated using the statistical model shown in Table (3).

Table 3. Predicted values of sediment discharge (kg/sec)

Sec. No.	Statistical Model
1	7.07
2	8.76
3	10.38
4	8.86
5	6.83
6	9.53
7	8.81
8	11.3
9	9.35
10	7.95
11	8.91
12	8.34
13	8.28
14	7.71
15	6.44
16	9.87
17	9.92
18	9.45
19	9.91
20	8.89
21	14.41
22	13.78
23	12.91
24	13.11

In order to show whether the used model was the best to predict the sediment discharge in Al-Meshkab regulator channel, an analysis of variance (ANOVA) (Haan, 2002) was used to examine the differences between the observed sediment rate and the predicted sediment rate using the statistical model at 0.05 significance level. This indicated that no statistically significant differences could be detected between the observed and the computed sediment rates using the statistical model.

$$F = \frac{MSK}{MSE} = \quad = \frac{1.67}{5.29} = 0.3177$$

$$F critical(n_2, n_1, \alpha) = F critical(46,1,0.05) = 4.0517;$$

where *MSK* represents the mean square of the treatments and *MSE* represents the mean square of errors. *F is* equal to 1 when *MSk* and *MSE* have the same value, since both of them are estimates of the same quantity. So, the test statistic for the null hypothesis $(H_0 : \mu_1 = \mu_2)$ will be based on *F=MSK/MSA*; therefore the null hypothesis cannot be rejected, where μ_1 is the mean for observed annual migration rate, μ_2 is the mean for predicted annual migration rate and α is the significance level.

Presentation and Discussion of the Results

The statistical model gives results close to the measured values as the two curves were very close to each other as shown in Fig. (6), despite the scattering of the points around the curves, and that was believed to be due to the range of the size which the channel can carry theoretically at each discharge value.

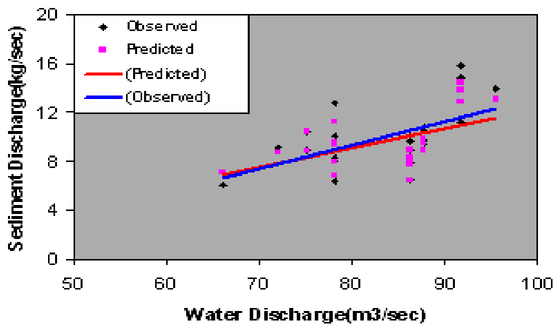

Figure 6: Graphical comparison between water discharge and sediment discharge by using the statistical model

CONCLUSIONS

This study presents the development of a statistical model for computing the sediment loads in Al-Meshkab regulator channel. The study examined the model results with respect to those observed in the field in order to determine whether the statistical model is able to predict the sediment rate in the study reach. According to the results obtained in this study, the following points are concluded:

A good agreement was observed between the measured values and the computed values of the total sediment discharge for the statistical model. Also, a new sediment transport formula has been developed in terms of the eight dimensionless groups. This formula is based on eleven points data on Euphrates river upstream of Al-Meshkab regulator. Comparisons with the measured data showed that the new formula is more accurate in predicting the total sediment load upstream of Al-Meshkab regulator channel.

NOTATIONS

Symbol	Meaning	Unit
C	The sediment concentration	ppm
D_{90}	The grain size of sediment for which 90 percent of the grains is finer	m
D_{50}	The grain size of sediment for which 50 percent of the grains is finer	m
W_1	Weight of dry filter paper	mg
W_2	Weight of dry filter paper+ suspended sediments	mg
Vol.	Volume of sample	ml
q_s	The sediment discharge	kg/sec
ρ_s	Sediment density	kg/m^3
ρ	Density of water	kg/m^3
V	Mean velocity	m/sec
S	Slope of channel or river	-
g	Acceleration of gravity	m/sec^2

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