

## ***Sediment Transport Upstream of Reservoir of Haditha Dam\****

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### **Abstract**

*This research is carried out to evaluate the amount of bed sediment load entering Haditha reservoir. The proper selection of a sediment transport formula to evaluate river's response is important. However, there are no definitive guidelines for the selection of transport formula. Therefore, an analysis was made on six sediment transport formulas, (Engelund-Hansen, Ackers-White, Yang, Maddock, Graf-Acaroglu and Karim-Kennedy) to check the applicability of each transport formula. The data used have been investigated by depth integrated sampling over a period from 26/1/2003 to 10/3/2003 and from 15/6/2003 to 16/9/2003.*

*Besides, a new formula was developed as sediment transport predictor for expected ranges of hydraulic and sediment characteristics of Euphrates river up-stream of Haditha dam.*

*It was concluded from the analyses that the used six formulas required adjustments to closely describe the measured data. Engelund-Hansen and Maddock formulas are better than other four formulas in predicting the total sediment load.*

*The predicted values using the new formula has no significance difference compared with the observed values? The analysis showed that the new formula is better than the other ones in predicting the sediment discharge, where the observed data have discrepancy ratio between (0.5-1.5).*

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## الخلاصة

اجري هذا البحث لتقدير كمية حمل مواد القاع (**Bed Sediment Load**) الداخلة إلى خزان سد حديثة. ولعدم وجود معادلة حساب انتقال مواد القاع في نهر أو مجرى مائي بشكل واف، لذلك فقد اجري تحليل على ستة معادلات وهي: **(Engelund-Hansen, Karim-Kennedy, Yang, Ackers-White, Maddock, Graf-Acaroglu Depth)** لغرض اختيار مدى صلاحية كل معادلة باستخدام بيانات رصدت بواسطة طريقة عينات العمق المتكامل **(Integrating Sample)** ضمن الفترة الممتدة من ٢٦ / ١ / ٢٠٠٣ إلى ١٠ / ٣ / ٢٠٠٣، ومن الفترة ١٥ / ٦ / ٢٠٠٣ إلى ٢٠٠٣ / ٩ / ٦. بالإضافة إلى ذلك فقد تم استخدام طريقة التحليل البعدي للتوصل إلى علاقة لحساب انتقال ترسبات القاع تتلائم مع الظروف الهيدروليكية وخصائص مواد القاع في حوض نهر الفرات ضمن الامتداد الواقع مقدم خزان سد القادسية. وقد تبين من خلال البحث إن معادلتني **(Maddock, Engelund-Hansen)** هما أكفأ من المعادلات الأخرى في حساب حمل القاع ضمن الظروف الهيدروليكية لموقع الدراسة. وتم مقارنة القيم المحسوبة باستخدام المعادلة المقترحة مع القيم المرصودة حقلياً. وقد بينت التحليلات إن المعادلة المقترحة أفضل من بقية المعادلات المستخدمة حيث إن جميع القيم المحسوبة لها نسبة اختلاف **(Discrepancy Ratio)** بين **(0.5 - 1.5)**.

## 1. Introduction

The sedimentation rate is one of the most important quantities that should be taken into account before a dam is constructed. This importance is due to that this quantity determines the useful life of the dam.

In order to minimize the effect of this problem the mechanism of sediment transport has been studied centuries ago. None of the available equations for the calculation of sediment discharge has gained universal acceptance in predicting sediment rate.

## 2. Description OF Haditha Dam

Haditha dam project is located in the construction of the Euphrates River valley 7-km up-stream from the town of Haditha as shown in **Fig.(1)**.

The project is multi-purpose development intended for irrigation, electric energy generation and partial storage of extreme inflows to the reservoir that may be caused by floods and /or releases from the up-stream dams.

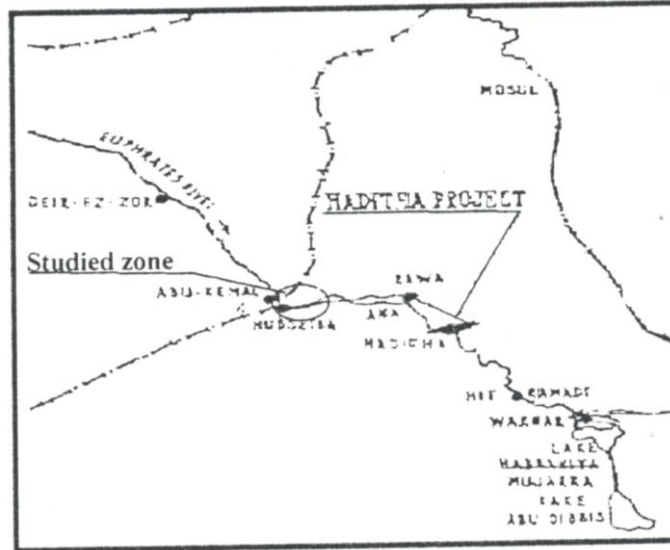


Figure (1) Haditha Reservoir and Husseiba Gauging Station [1]

### 3. Total Load Formulas

The following well known formulas will be selected

#### 3-1 Engelund-Hansen Formula

According to Raudkivi [2]. Engelund-Hansen proposed the following relationship:

$$q_s = 0.05 \rho_s V^2 \sqrt{\frac{d_{50}}{g(sg-1)}} \left[ \frac{\tau_0}{(\gamma_s - \gamma)d_{50}} \right]^{3/2}; \frac{u_* d_{50}}{v} > 12 \dots\dots\dots (1)$$

The previous formula is dimensionally homogenous it can be used with any consistent of units.

#### 3-2 Graf-Acaroglu Formula

Graf-Acaroglu [3] proposed the following relationship:

$$\frac{CVR_h}{\sqrt{(Sg-1)gd_{50}}} = 10.39 \left[ \frac{(Sg-1)d_{50}}{SR_h} \right]^{-2.52} \dots\dots\dots (2)$$

in which C=volumetric concentration of the transported particles. This form was determined using experimental data from laboratory and field measurements and applied a regression analysis.

Ranga <sup>[4]</sup> reported that this can be expressed as:

$$\frac{qs}{\gamma_s u_* d_{50}} = 10.39 \tau_*^{2.02} \dots\dots\dots (3)$$

where

$$\tau_* = \frac{\tau_0}{(\gamma_s - \gamma) d_{50}} \dots\dots\dots (4)$$

**3-3 Ackers and White Formula**

Based on Bagnold’s stream power concept, Ackers and White <sup>[5]</sup> applied dimensional analysis technique to express the mobility and transport rate of sediment in terms of some dimensionless parameters.

$$G_{gr} = \frac{CD}{S_g d_{50}} \left( \frac{u}{V} \right)^n = c_1 \left( \frac{F_{gr}}{A_1} - 1 \right)^m \dots\dots\dots (5)$$

in which  $G_{gr}$  = Sediment transport mobility  $F_{gr}$  = Sediment particle mobility number.

$$F_{gr} = \frac{u_*^n}{\sqrt{g d_{50} (sg - 1)}} \left[ \frac{V}{\sqrt{32} \log \left( \frac{10D}{d_{50}} \right)} \right]^{1-n} \dots\dots\dots (6)$$

in which value of  $n$ ,  $A_1$ ,  $c_1$  and  $m$  are associated with  $d_{gr}$  value

$$d_{gr} = d_{50} \left[ \frac{g(sg - 1)}{v^2} \right]^{1/3} \dots\dots\dots (7)$$

$$n = 1 - 0.56 \log d_{gr} \dots\dots\dots (8)$$

$$A_1 = \frac{0.23}{\sqrt{d_{gr}}} + 0.14 \dots\dots\dots (9)$$

$$\log c_1 = 2.86 \log d_{gr} - (\log d_{gr})^2 - 3.53 \dots\dots\dots (10)$$

$$m = \frac{9.66}{d_{gr}} + 1.34 \dots\dots\dots (11)$$

in which  $d_{gr}$ = dimensionless particle size.

**3-4 Maddock’s Formula**

Maddock <sup>[6]</sup> used an empirical regime type approach to express the total sediment concentration which includes wash load, as a function of unit stream power. i.e.

$$VS \times 10^3 = C^{3/4} \times \phi(d_{50}) \dots\dots\dots (12)$$

Then Maddock modified this formula to the following form:

$$C = \left[ 10^3 \frac{VS}{\phi(d_{50})} - \frac{60 \left( \frac{\gamma_s}{\gamma} - 1 \right) g^{1/2} d_{50}}{\phi(d_{50}) D^{1/2}} \left[ \frac{\left( \frac{\gamma_s}{\gamma} - 1 \right) g d_{50}}{w^2} \right]^{1/4} \right]^{4/3} \dots\dots\dots (13)$$

**3-5 Yang Formula**

Yang <sup>[7]</sup> proposed the following formula:

$$\log C = 5.165 - 0.153 \log \frac{w d_{50}}{v} - 0.297 \log \frac{u_*}{w} + \dots\dots\dots (14)$$

$$(1.78 - 0.36 \log \frac{w d_{50}}{v} - 0.48 \log \frac{u_*}{w}) \log \left( \frac{VS}{w} \right)$$

in which C= The total sediment concentration in ppm by weight, w= The average fall velocity of sediment particle. V= Average flow velocity S= The enemy slope,  $V_{cr}$  = The average flow velocity at incipient motion. VS= The unit stream power.

**3-6 Karim-Kennedy Approach (1998)**

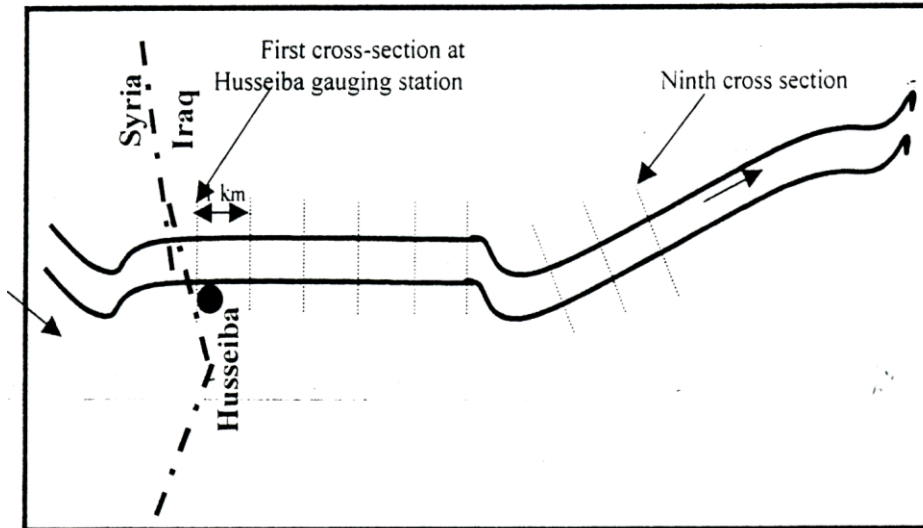
Fazle Karim and Kennedy <sup>[8]</sup> proposed the following formula:

$$\frac{q_{sv}}{\sqrt{g(sg-1)d_{50}^3}} = 0.00139 \left( \frac{V}{\sqrt{g(sg-1)d_{50}}} \right)^{2.97} \left( \frac{u_*}{w} \right)^{1.47} \dots\dots\dots (15)$$

in which ,  $q_{sv}$  = sediment discharge by volume

## 4. Field Measurements

The field measurements were carried out within Husseiba town. At Husseiba gauging station the first cross section was reproduced. The other eight cross sections were located down-stream of the first one, as shown in **Fig.(2)**.



**Figure (2) Observed Cross Sections**

The field measurements involve the following measurements:

### 4-1 Cross Section Measurement

Nine cross sections were selected at intervals about (1km) between one to other, extended from Husseiba gauging station forward the water flow direction. The cross sections of channel were observed by taking reference point on the right side with respect to the water flow direction. From the reference point, the whole width of the river was divided into several parts (20m a part). At the end of each part the depth was measured, as shown in **Fig.(3)**.

### 4-2 Discharge Measurement

The velocity of a certain cross-section and consequently the corresponding discharge were determined using Husseiba gauging station. **Table (1)** shows the observed water discharges.

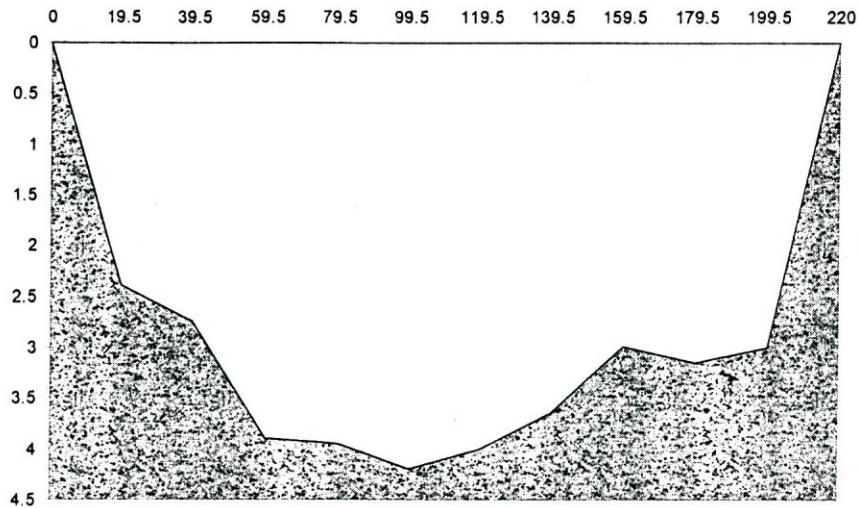


Figure (3) Typical Cross Section

Table (1) Observed Water Discharges

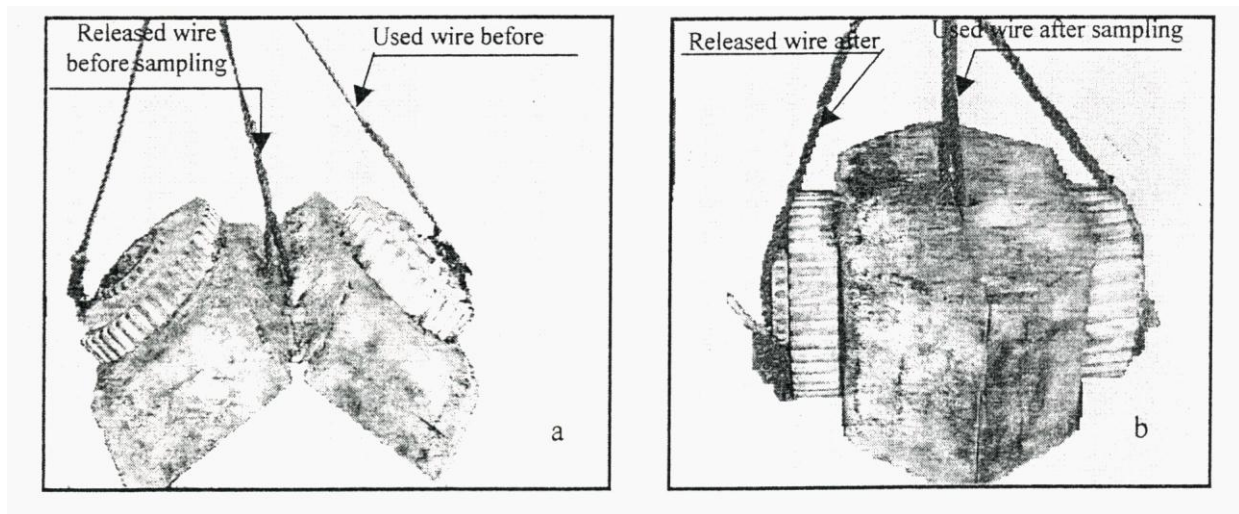
Date	Section No.	Water discharge (m3/sec)	Date	Section No.	Water discharge (m3/sec)
/01/2003 26	1	000	/06/2003 17	9	430
/01/2003 27	4	043	/06/2003 18	2	462.8
/02/2003 01	3	710	/07/2003 01	4	380
/02/2003 02	0	700	/07/2003 02	2	310
/02/2003 03	0	777	/07/2003 03	8	340
/03/2003 03	8	740.16	/08/2003 02	9	306
/04/2003 04	8	002	/09/2003 01	1	296
/03/2003 10	1	839	/09/2003 02	1	232
/03/2003 10	3	839	/09/2003 10	7	300
/06/2003 10	0	310	/09/2003 16	7	290
/06/2003	6	404			

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### 4-3 Bed Material Sampling

Three samples of bed materials were taken at 1/4, 1/2, 3/4 the width of the river in each cross section in order to conduct the size analysis distribution. These samples finally mixed well to reduce the error of measurement and get a homogenous sample.

Because of lack of the former samplers the researcher made a sampler to be used it in this study. The used sampler is shown in **Fig.(4a)** and **(4b)**.



**Figure (4) The used Bed Material Sampler  
(a) Before sampling, (b) After sampling**

### 4-4 Suspended Load Sampling

Suspended sediment samples are taken using depth integrated sampling with the aid of sampler designed by the researcher for purpose as shown in **Fig.(5a)** and **(5b)**.



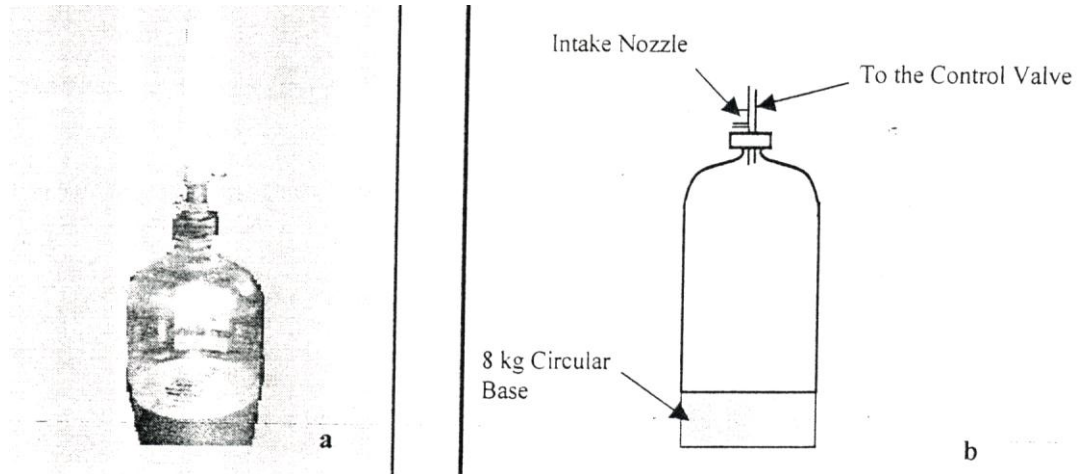


Figure (5) The used Suspended Sampler

A sample was obtained by slowly lowering the sampler to the bottom of the river and then raising it to the surface at some speed, this operation was repeated several times until the bottle is nearly full.

### 5. Laboratory Measurements

It involves collecting of laboratory data including measurements of:

#### 5-1 Specific Gravity Determination

The specific gravity of the bed sediment was measured and concluded that the Arithmetic mean of it equal to 2.7.

#### 5-2 Sieve Analysis

The sieve analysis was conducted on the collected bed materials using a stack of sieves,(0.85,0.6,0.42,0.3,0.25,0.21,0.15,0.075) mm. **Table (2)** shows the mean sediment particle diameter.

Table (2) Mean Sediment Particle Diameter

Date	Section No.	d50(mm)	Date	Section No.	d50(mm)
26/01/2003	١	0.23	17/06/2003	٩	0.23
27//01/2003	٤	0.24	18/06/2003	٢	0.215
01/02/2003	٣	0.23	01/07/2003	٤	0.23
02/02/2003	٥	0.24	02/07/2003	٢	0.21
03/02/2003	٥	0.23	03/07/2003	٨	0.23

03/03/2003	१	0.23	02/08/2003	१	0.225
04/03/2003	१	0.24	01/09/2003	१	0.218
10/03/2003	१	0.22	02/09/2003	१	0.218
10/03/2003	३	0.225	15/09/2003	१	0.225
15/06/2003	०	0.245	16/9/2003	१	0.225
16/06/2003	६	0.24			

### 5-3 Sediment Concentration Measurement

All collected water mixture samples were filtered using a filtration set with filters with lump opening. Each filter paper was pre-dried for 15 min and weighted, then it was clipped into the filter funnel and moistened with distilled water. A volume of 200ml of sample was measured in graduated cylinder and poured through the filter and all interior surface of the cylinder was washed out into funnel with distilled water. After 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 suspended sediment.

$$C = \frac{(W_2 - W_1)}{\text{Vol.}} \dots\dots\dots (16)$$

in which, C= Concentration of suspended sediment in (mg/l),  $W_1$ = Weight of dry filter in (mg),  $W_2$ = (Weight of dry filter paper + suspended sediment) in (mg), Vol.= Volume of sample (200ml).

### 5-4 Sediment Discharge Measurement

The sediment discharge is obtained by the following equation.

$$Q_s = C \times Q \times 0.001 \dots\dots\dots (17)$$

in which.  $Q_s$ = Total sediment discharge (Kg/sec) and  $Q$ = Water discharge ( $m^3$ /sec). The observed sediment discharges are shown in **Table (3)**.

**Table (3) Measured Concentration and Sediment Discharges**

Date	Section No.	Water discharge (m <sup>3</sup> /sec)	Concentration (g/m <sup>3</sup> )	Sediment discharge (kg/sec)
26/01/2003	1	550	235	129.25
27/01/2003	4	543	135	73.305
01/02/2003	3	715	400	286
02/02/2003	5	700	335	234.5

03/02/2003	5	676	310	209.56
03/03/2003	8	645.16	366	236.13
04/03/2003	8	552	271	149.592
10/03/2003	1	839	500	419.5
10/03/2003	3	839	480	402.72
15/06/2003	5	315	112.5	35.4375
16/06/2003	6	454	100	45.4
17/06/2003	9	430	193	82.99
18/06/2003	2	462.8	198	91.6344
01/07/2003	4	380	73	27.74
02/07/2003	2	310	84	26.04
03/07/2003	8	340	108.8	36.992
02/08/2003	9	356	117.7	41.9012
01/09/2003	1	396	104.5	30.932
02/09/2003	1	232	50	1106
15/09/2003	7	300	95	28.5
16/9/2003	7	290	84	24.36

### 5-5 Bed Load Movement Measurement

There are no measurement carried out in this study to compute the bed load movement, this because of the fact that the bed load amount in the Euphrates river up-stream of Haditha dam is very small with respect to the suspended load. However, an investigation was carried out by Consulting scientific bureau of Baghdad University to evaluate the bed load amount at the site of Ejbail dam. Using VUV sampler, sediment concentration was measured over 55-min time interval. The bed load result was 1020.6 ton/day. The suspended sediment measured at the same time was equal to 23257.15 ton/day, then the percent of the bed load to the suspended load becomes 4.38%.

## 6. Existing Total Load Formulas

The distinction between bed load and suspended load is difficult to make and quite often artificial. For this reason, only total load formulas will be analyzed in this research. The basic assumption or approach used in each of the following six formulas will be examined and evaluated. These are Engelund-Hansen, Graf-Acaroglu, Ackers-White, Maddock, Yang, and Karim-Kennedy. Using the measured data the predicted values of sediment discharge for the previously mentioned Formulas are computed and listed in **Table (4)**.

## 7. Development of a New Formula

It is evident from the previous table that is very different answers resulted from the use of

the available predictive formulas. In order to predict the sediment discharge rate entering the Haditha reservoir a new formula is developed using the dimensional analysis. The variables involved in the determination of total sediment concentration can be described by:

$$f(C, w, u_*, B, V, R_h, d_{50}, v) = 0 \dots\dots\dots (18)$$

Using of Buckingham's  $\pi$  theorem and selecting of  $w$  and  $d_{50}$  as the dominant variables  $\pi$  parameters are obtained. These are listed in **Table (5)** shown below.

**Table (4) Predicted Values of Sediment Discharge using the Selected Formulas**

Date	Section No. (kg/sec)	Engelund Hansen (kg/sec)	Graf-Acaroglu (kg/sec)	Maddock (kg/sec)	Ackers White (kg/sec)	Yang (kg/sec)	Karim-Kennedy (kg/sec)	Observed values (kg/sec)
26/01/2003	1	269.57	313.26	128.66	139.58	65.57	139.52	129.25
27/01/2003	4	42.86	334.34	121.28	126.33	62.8	130.05	73.3
01/02/2003	3	286.71	272.8	82.06	110	42.6	84.66	286
02/02/2003	5	266.85	364.22	109.61	101.8	37.5	68.45	234.5
03/02/2003	5	115.98	341.57	97.31	95	36.16	64.09	209.56
03/03/2003	8	18.79	271.87	102.4	90.1	36.45	61.34	236.13
04/03/2003	8	207.15	242.11	89.48	87.24	23.4	57.20	149.59
10/03/2003	1	190.43	242.52	44.29	20.22	22.5	38.14	419.5
10/03/2003	3	287.56	201.14	71.92	11.87	15.8	24.10	402.7
16/06/2003	5	62.90	159.15	32.9	10.9	18.1	33.88	35.43
16/06/2003	6	67.48	259.66	22.7	7.92	10.9	15.59	45.4
17/06/2003	10	49.05	107.9	25.76	10.83	10.37	19.73	82.99
18/06/2003	2	37.59	216.06	16.9	10.76	7.8	11.17	91.63

01/07/2003	4	47.71	216.35	21.85	9.47	10.1	15.89	27.74
02/07/2003	2	43.59	194.48	18.7	8.85	9.2	13.62	26.04
03/07/2003	8	37.12	129.9	16.3	7.96	7.1	11.07	36.99
02/08/2003	9	53.76	211.35	18	9.83	8.9	13.60	41.90
01/09/2003	1	42.70	159.1	16.5	4.00	7.4	11.70	30.93
02/09/2003	1	66.82	136.8	17.94	7.96	8.1	13.88	11.6
15/09/2003	7	25.69	157	15.5	7.92	7.2	11.53	28.50
16/09/2003	7	39.78	128.3	10.1	23.03	4.5	6.48	24.36

**Table (5) II Parameters**

ΠN-M	Π1	Π 2	Π 3	Π 4	Π 5
Parameter	$\frac{V}{w}$	$\frac{U^*}{W}$	$\frac{R_h}{d_{50}}$	$\frac{B}{d_{50}}$	$\frac{V}{Wd_{50}}$

Then equation (18) can be expressed as following:

$$C = f\left(\frac{V}{w}, \frac{u_*}{w}, \frac{R_h}{d_{50}}, \frac{v}{wd_{50}}\right) \dots\dots\dots (19)$$

The following procedure was followed to reduce the number of π – terms:

$$\frac{\pi_1}{\pi_2} = \pi_6 = \frac{V/w}{u_*/w} = \frac{V}{u_*}$$

By the same way π<sub>3</sub> and π<sub>4</sub> can be combined to π<sub>7</sub>

$$\frac{\pi_3}{\pi_4} = \pi_7 = \frac{R_h/d_{50}}{B/d_{50}} = \frac{R_h}{B}$$

Hence equation (19) can be expressed as below:

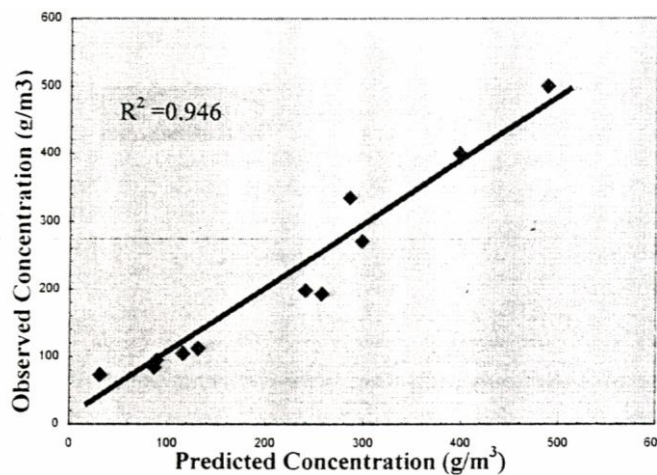
$$C = f\left(\frac{v}{wd_{50}}, \frac{V}{u_*}, \frac{R_h}{B}\right) \dots\dots\dots (20)$$

The final form of Eq.(20) has to be determined from conduct the regression analysis on the

observed data. It should be noted here that the observed data were divided into two sets: the first set used to derive the new formula depending on eleven of the observed data, and second used to verify the mentioned formula depending on ten of the remaining data. However, using the first set of the data, the regression analysis was conducted and it was found the following formula:

$$C = 55.1 \left( \frac{V}{u_*} \right) + 10164.1 \left( \frac{R_h}{B} \right) + 144.7 \left( \frac{v}{wd_{50}} \right) - 449.3 \dots\dots\dots (21)$$

**Figure (6)** shows a well accepted correlation between predicted and observed concentrations for eleven sections.



**Figure (6) Predicted and Observed Concentrations for Eleven Sections**

### 8. Advantages of the New Formula

1. The new formula is dimensionally homogenous.
2. The parameters used in the formula can be obtained from natural stream without much difficulty.
3. The computation is simple and straightforward.

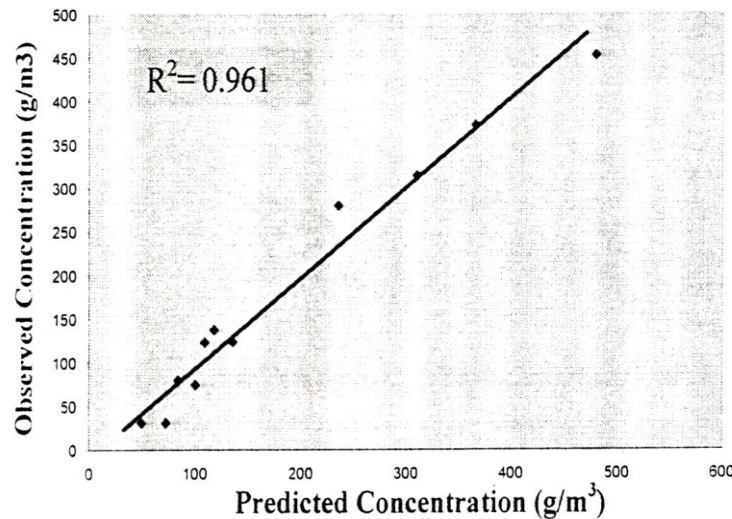
But it should be noted that this formula is applicable in the following conditions:

1. Slope of 0.00019.
2. Flow velocity (0.429-1.108) m/sec.
3. Grain size  $d_{50}$  between (0.215-0.245) mm.

### 9. Verification of the Proposed Formula

**Figure (7)** shows some examples of the comparison between the measured and predicted concentration in accordance with the proposed formula. Figure provides an independent

verification of accuracy of the mentioned formula because none of the data shown in this figure used to obtain it.



**Figure (7) Predicted and Observed Concentrations for the Ten Remaining Sections**

### 10. Comparison of Formulas Accuracy

The comparisons of predicted with observed sediment discharge can be made by two methods, comparison using statistics relation. and comparison using graphical method.

#### 10-1 Comparison using Statistics Relation

$$\text{Discrepancy Ratio } r = \frac{\text{computed} \cdot q_s}{\text{measured} \cdot q_s} \dots\dots\dots (22)$$

Table (6) shows the discrepancy ratios in range of (0.75-1.25), (0.5-1.5), and (0.25-1.75).

**Table (6) Comparison using Discrepancy Ratio**

Formula	Discrepancy Ratio		
	0.75-1.25	0.5-1.5	0.25-1.75
Engelund-Hansen	5%	62%	81%
Graf-Acaroglu	14%	19%	33%
Ackers-white	0%	0%	38%
Maddock	10%	52%	100%

Yang	0%	0%	29%
Karim-Kennedy	0%	14%	66%
New formula	81%	100%	100%

## 10-2 Graphical Comparison

Graphical comparison conducted on the mentioned formulas.

### 10-2-1 Engelund-Hansen Formula

Figure (8) shows a fairly good agreement between observed and predicted values in accordance with the Engelund-Hansen formula. It can be noted that at high flow stages the agreement increases and at low flow stages the agreement decreases slightly. This may be attributed to the fact that this formula is derived depending on laboratory data more than field data.

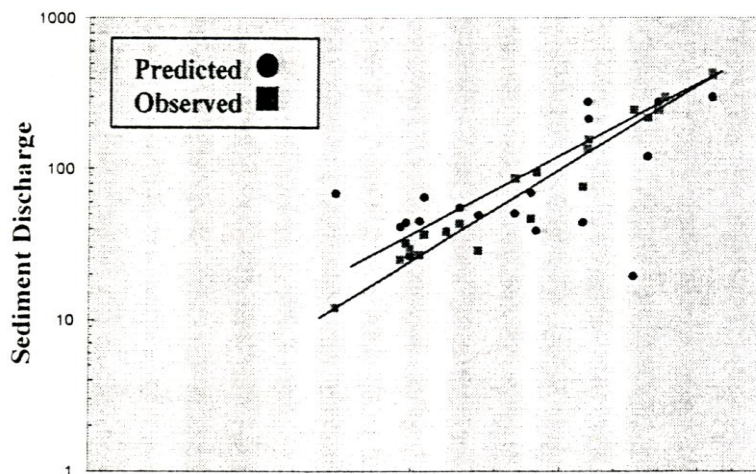


Figure (9) Graphical Comparison between Water Discharge and Sediment Discharge using Engelund-Hansen Formula

### 10-2-2 Graf-Acaroglu Formula

The line of this formula intersects the data but has too small a slope. As shown in Fig.(9). The convergence of the results is decreased gradually with the lowering of the water discharge. This resulted due to neglect velocity effect in this formula. This formula at general predicts values higher than the actual values.



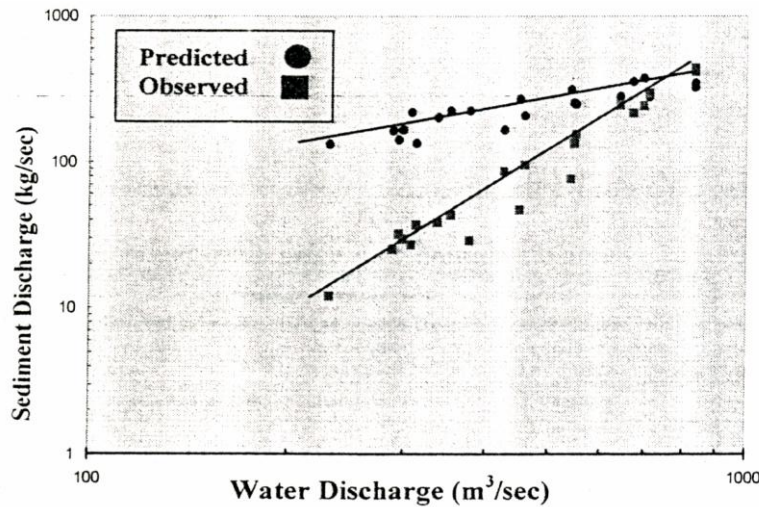


Figure (9) Graphical Comparison between Water Discharge and Sediment Discharge using Graf-Acaroglu Formula

10-2-3 Ackers-White Formula

Ackers-White formula gives results less than those measured. The computed values are distributed with large scattering as cleared in Fig.(10) shown below. This because of this formula is derived depending on flume data. However the slope of the line of this formula is closed to the line of observed data.

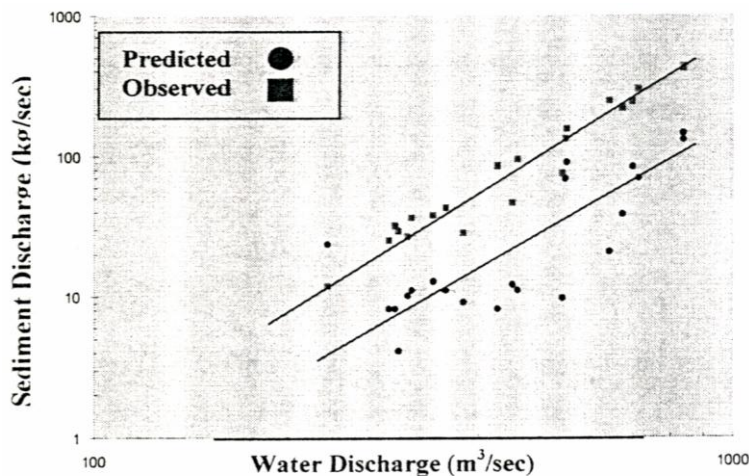
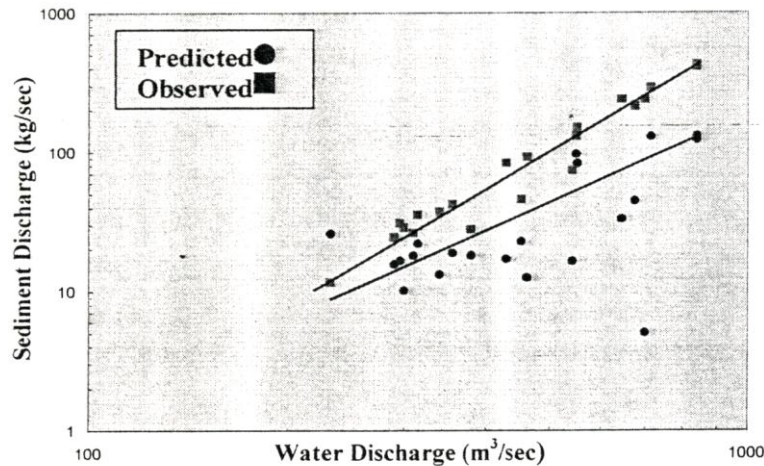


Figure (10) Graphical Comparison between Water Discharge and Sediment Discharge using Ackers-White Formula

#### 10-2-4 Maddock Formula

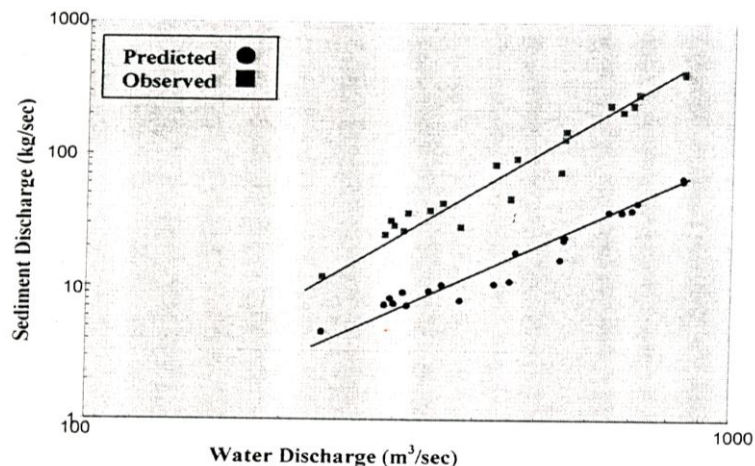
As shown in **Fig.(11)**, the computed values by Maddock are less than those measured. But it is noted that some computed values approach the measured. This formula shows large scattering about the fit line.



**Figure (11) Graphical Comparison between Water Discharge and Sediment Discharge using Maddock Formula**

#### 10-2-5 Yang Formula

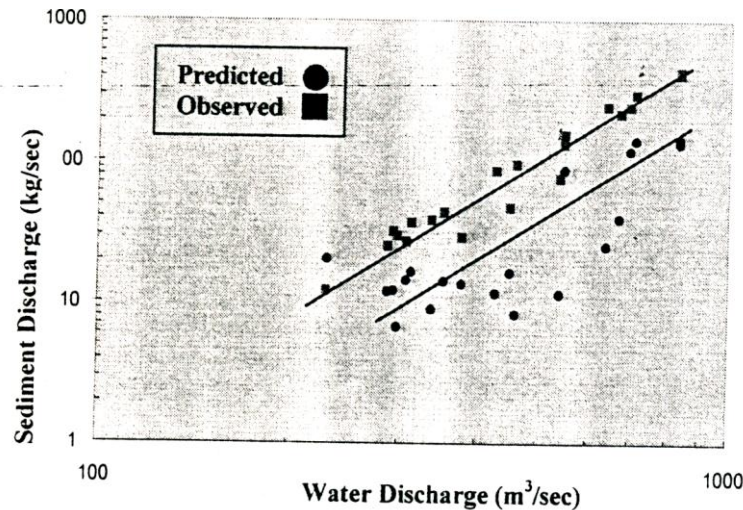
As shown in **Fig.(12)**, the calculated values using Yang formula is less than those observed. Also it is noted that the change in the calculated values are a fairly small and not reflect the actual condition well. This may be attributed to the fact that Yang formula is based on laboratory data more than field data.



**Figure (12) Graphical Comparison between Water Discharge and Sediment Discharge using Yang Formula**

### 10-2-6 Karirn-Kennedv Formula

The calculated values by Karim formula tend to be less than those observed at all flow stages, as shown in **Fig.(13)**. From the same figure one can clearly note the large scattering in the calculated values. The slope of the line for this formula is closed to the line of the observed data.

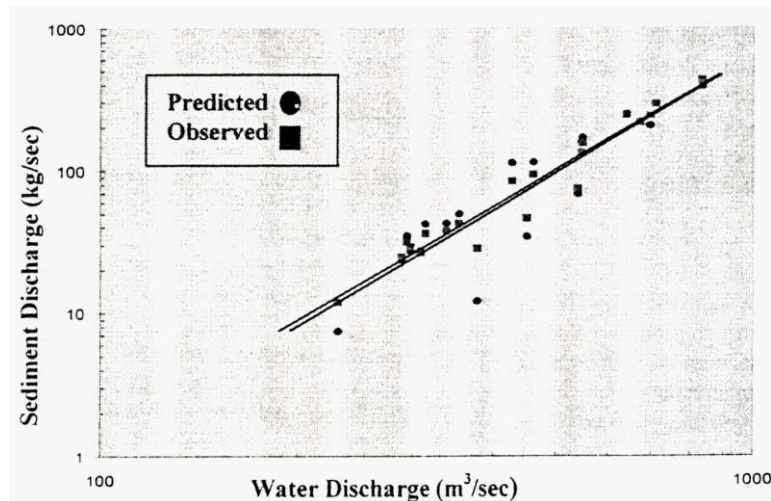


**Figure (13) Graphical Comparison between Water Discharge and Sediment Discharge using Karim-Kennedy Formula**

## 11. The Proposed New Formula

The agreement between the observed and predicted sediment discharges with respect to the new formula is very good as appear in **Fig.(14)**, using other section data. The scattering of the points around the fit line may be due to the fact that this formula does not depend on the water discharge-sediment discharge relationship.

The comparisons of accuracy indicate that the new formula is more accurate than others in predicting total bed material loads.



**Figure (14) Graphical Comparison between Water Discharge and Sediment Discharge using Proposed Formula**

## 12. Conclusions

This study has reached the following conclusions:

1. The suspended load in the studied zone can be taken as equal to the total load because of the small amount of the bed load, where it is estimated that the bed load was 4.38% of the suspended load.
2. Engelund-Hansen and Maddock formulas showed a fairly good agreement with the measured held data. These equations predict the total sediment load better than the other four formulas.
3. A proposed sediment transport formula has been developed in terms of the three dimensionless groups:  $(V/u_*)$ ,  $(R_h/B)$  and  $(v/wd_{50})$ . This formula is based on eleven points data, which were carried out on Euphrates river up-stream of Haditha dam
4. Comparisons with the measured data showed that the new formula is more accurate than some of the existing total load formulas in predicting the total sediment load upstream of the Haditha Dam.
5. The computation process involved in using the new formula is simple and straightforward.
6. The developed formula is applicable in the following conditions:
  - Slope of 0.00019.
  - Flow velocity (0.429-1.108) m/sec.
  - Median grain size between (0.21-0.245) mm.

### 13. References

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## Notations

The following symbols were used in this research:

A=	Cross-sectional area; (L <sup>2</sup> )
A1=	Constant
B =	Width of the river. (L)
C=	The sediment concentration by, (M/L <sup>3</sup> )
cl =	Constant
Ć =	Volumetric concentration of the transported particles. (L <sup>3</sup> /L <sup>3</sup> )
dgr=	Dimensionless particle size.
D=	Water depth. (L)
dm=	Effective diameter of sediment (L).
ds=	Representative diameter (L).
d <sub>50</sub> =	Median size of sediment. (L).
F <sub>gr</sub> =	Sediment particle mobility number.
Ggr=	Sediment transport mobility.
M=	Number of dimensions used in regression analysis,
N =	Number of variables used in regression analysis.
n=	Manning roughness coefficient.
n1=	Constant
Q=	Total water discharge, (L <sup>3</sup> /T).
Q <sub>s</sub> =	Total sediment load.( M/ T)
q=	Water discharge per unit width.(L <sup>3</sup> /T/L).
q <sub>cr</sub> =	Critical flow rate which produce no sediment transport. (L <sup>3</sup> / T/L).
q <sub>s</sub> =	Total sediment discharge per unit width. (M/T/L).
R <sub>h</sub> =	Hydraulic radius of stream (L).
S=	The energy slope or channel slope.
S=	Specific gravity $\frac{\gamma_s}{\gamma}$ .
u <sub>*</sub> =	Shear velocity, (L/T).
V=	Mean velocity, (L/T).
VS=	The unit stream power. (L/T).
V <sub>cr</sub> =	Critical average water velocity at incipient motion (L /T).
γ=	Specific gravity of water (F/ L <sup>3</sup> )
γ <sub>s</sub> =	Specific gravity of sediment particles,(F/L <sup>3</sup> ).
τ <sub>cr</sub> =	The critical shear stress. (F/L <sup>2</sup> )
τ <sub>0</sub> =	The average shear stress defined by τ <sub>0</sub> =γ R <sub>h</sub> S. (F/ L <sup>2</sup> ).
τ* =	Dimensionless shear stress.
φ(d <sub>50</sub> ) =	A function of median diameter of sediment.
ρ=	Water density (M/L <sup>3</sup> ).
ρ <sub>s</sub> =	Density of sediment particles. (M/L <sup>3</sup> ).
v=	kinematics viscosity (L <sup>2</sup> /T).
w=	Terminal fall velocity (L/T).