APPLICATION OF DIFFERENT SEDIMENT TRANSPORT EQUATIONS IN ASWAN HIGH DAM RESERVOIR

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ABSTRACT

A very well-known feature of the construction of a dam and creation of a reservoir is the trapping of sediments supplied by the contributing rivers. The total sedimentation is important in relation to the effective volume of the reservoir and the economic life time of the project. In some cases delta formation may occur upstream the dam. The most important problems are deposition in the storage reservoir, avoiding sediment particles reaching the sensitive turbines, and problems of bed erosion downstream of river dams. The sediment transport problem is of great importance in Aswan High Dam Reservoir (AHDR) in Egypt. Among the numerous different theoretical and semi-empirical expressions developed for sediment transport rates some attempts have been made to test the applicability of such formulas in AHDR. Data of different cross sections, velocities, suspended water samples and bed material samples for recent years; 2007, 2008, 2009 and 2012 were collected. These data were used for calculating the total sediment load in different cross sections during this period. In this research study three equations were applied to the same available data of the sedimentation zone, which starts at the inlet section km 12.5 until km 140, in the same years. The aim is to find out the most convenient equation, for which the ratio between the measured and the calculated sediment load rate is nearest to unity or to a certain constant value. Three equations which are extensively used in several sediment transport investigations were applied in this research. These equations are Bagnold's equation, Meyer-Peter and Muller equation, and Shields equation. Based on the results, some discrepancy ratios were found between the sediment load measurements and the estimated sediment load rates. Consequently; it is concluded that Bagnold's equation could be used, except in the inlet zone. Shields equation is also applicable in the whole reservoir but in some cross sections it gives high discrepancy ratios. The applicability of Meyer-Peter and Muller equation in AHDR is the best recommended one in any model for estimation of sediment transport.

Keywords: Sediment Transport, Aswan High Dam Reservoir, Sediment load Equations.

1 INTRODUCTION

Aswan high dam reservoir (AHDR) is located at the southern part of Egypt (about 325 Km) and northern part of Sudan (about 175 Km) with total length 500 Km and average width 12 Km, this forms a huge surface area about 6500 km2 at elevation182m AMSL and has a storage capacity about 162 km3 of water. The average depth is about 25m and the maximum depth is 130m. The dynamics of sediment transport is a large field, which is of interest in a wide variety of disciplines in environmental science and engineering, civil engineering and mechanical engineering. Determining the impacts of sediment on the reservoir operations is critical to maintaining current operations and planning for future needs. Sedimentation within the reservoirs is the main problem that could reduce the reservoir capacity and therefore affecting its economic life. Proper management of the reservoir requires that current reservoir volumes and sedimentation rates be determined. Aswan High Dam Reservoir (AHDR) in Egypt and Sudan, the case study in this research, is the second largest man-made lake in the world. Starting in 1973, the year of the first scientific expedition for Aswan High Dam Reservoir, by the Nile Research Institute (NRI) and High and Aswan Dam Authority are to observe hydrographic and hydraulic data to determine the amount and distribution of deposited sediment through the reservoir. Over the past hundred-plus years, numerous procedures, usually involving one or more equations or formulas, have been proposed for prediction of the sediment transport rate. Among the numerous different theoretical and semi-empirical expressions developed for sediment transport rates some attempts have been made to test the applicability of such formulas in AHDR. This study was thus initiated with the objective to evaluate several sediment transport equations; ability to predict sediment load in Aswan High Dam Reservoir. This was achieved by:

- Reviewing many sediment load equations.
- Analyzing field data of the cross sections in AHDR for different years.
- Calculating of measured sediment load using field data.
- Calculating the sediment load by selected equations.
- Analyzing the results.
- Comparison between measured and calculated sediment load.

2 OBJECTIVE

The main objective of the study is to evaluate several sediment transport equations' ability to predict sediment load in AHDR. Three equations; which are extensively used in several sediment transport investigations, were applied and results were compared to sediment field data collected in the years 2007, 2008, 2009 and 2012. The three equations are Bagnold's Equation, Meyer-Peter and Muller Equation, and Shields Equation.

3 DESCRIPTION OF THE STUDY AREA

It is important to understand the depositionprocess quite well and recognize the way the reservoir bed is developed. This helpstopredict the sediment accumulation spots that may block or hurdle the water movementand cause water stage rise within the reservoir.Many field measurements are conducted annually to collect the data necessary forstudy and analysis. Fig. 1 indicates the location of the study area in Egypt and Sudan. It shows also the regular measured cross sections.

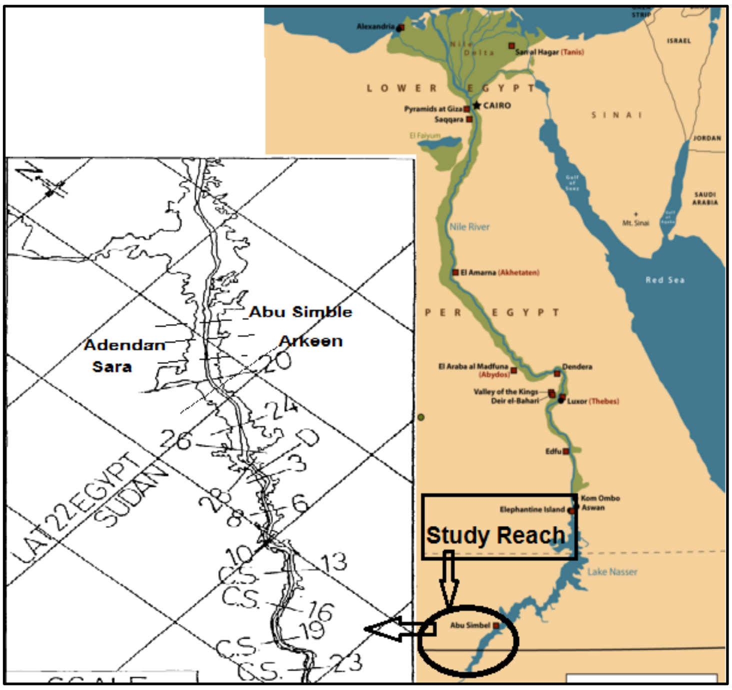

Figure 1. Study Reach at AHDRin Egypt and Sudan

4 FIELD DATA FOR ASWAN HIGH DAM RESERVOIR

4.1.Bathymetric and topographic Data

Bathymetric data describe the geometry of Aswan High Dam Reservoir (AHDR), were based on data obtained from the hydrographic survey of the reservoir provided by the Nile Research institute and Aswan and High Dam Authority in this study. The bathymetric data of years (2007, 2008, 2009 and 2012) were used. Fig. 2 and 3 showtwo observed cross sections in different years.

4.2.Hydrologic and Hydraulic Data

In addition to topographic data, the mean flow velocity was measured at a number of specific cross sections along the reservoir. Also, Bed material samples were collected at each cross section from the study reach to determine the mean diameterd_{50}.

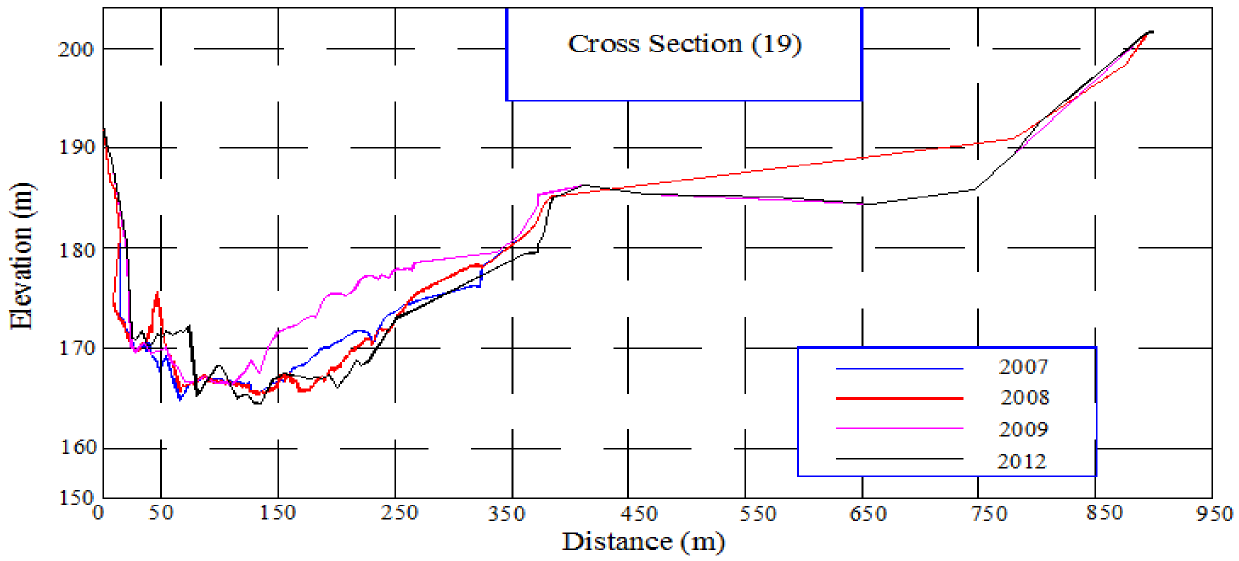

Figure 2.Cross section (19) in different years

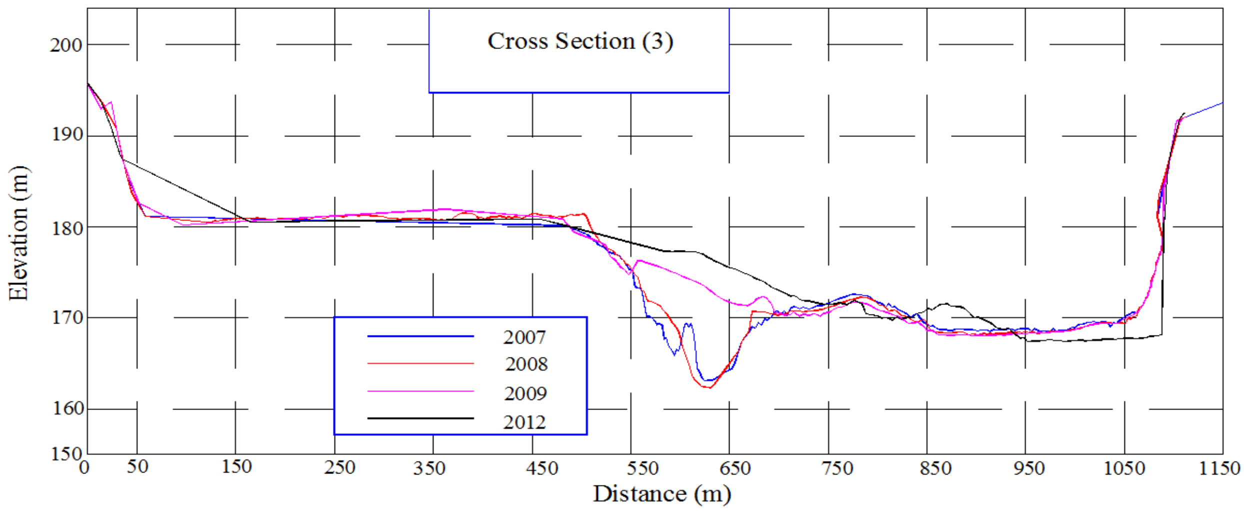

Figure 3. Cross section (3) in different years

5 METHODOLOGY

5.1.Calculation of total sediment load using field data

The general structure of data available in year 2007, 2008, 2009 and 2012 at every cross section as indicated in Table 1 in year 2007 for example, are as follow:

1-The distance measured from the inlet in (m), 2- The width of the cross section (m), 3- The average depth (m), 4- The cross-sectional area (m^2), 5- The average velocity (m/sec), 6- The water discharge (m^3/sec), 7- The average suspended sediment concentration (ppm), 8- The calculated total sediment load per unit width Q_b.

Table 1. Calculation of sediment load using field data (year 2007)

Cross section No.	Distance from inlet (m)	Width B(m)	Average depth(m)	Cross Section area A (m2)	mean Velocity (m/s)	Water discharge Q(m3/s)	Sus. Sed. ppm=kg/m3	Q_b*10^3 (kg/m.s)
23	12500	364.25	6.71	2442.80	0.37	903.84	98.00	243.17
19	34000	346.80	10.11	3504.90	0.26	911.27	105.00	275.90
16	52000	448.00	10.84	4855.80	0.23	1116.83	90.00	224.36
13	69000	909.40	5.58	5071.50	0.16	811.44	98.00	87.44
10	84500	579.10	7.52	4355.00	0.22	958.10	90.00	148.90
8	96500	501.30	11.42	5724.60	0.23	1316.66	85.00	223.25
6	106000	1129.00	5.95	6712.70	0.17	1141.16	87.00	87.94
3	121500	596.40	10.82	6451.60	0.17	1096.77	72.00	132.41
D	128000	819.30	7.96	6525.20	0.15	978.78	75.00	89.60
28	132000	535.80	10.83	5803.60	0.12	696.43	70.00	90.99

5.1.1 Example for calculated total sediment load per unit width at cross section (23) year 2007

The Calculations as shown in Table 1 are as follows:
Qb = (C_{SS}*Q_w/ B)
Where:-
Qb : Sediment load per unit width (Kg/m.s)
Q_w: Water discharge at the section (m^3/sec), where Q_w=A*V = 2442.8 * 0.37 = 903.84 (m^3/s)
C_{SS} : Suspended sediment concentration in ppm (Kg/m^3) = 98.00 (kg/m^3)
Qb = (98.00*903.84/(364.25/1000)) = 0.243 (kg/m.s)
Qb*1000 = 0.243 * 1000 = 243.17 (kg/m.s)

5.2. Applied empirical equations

The bed load may vary to several times the suspended load, though more commonly it lies in the 5 o 25% range, therefore in AHDR the bed load is assumed to 15% of the total sediment load (Mohamed EL Mottassem and A. Z. Makary 1988).

5.2.1 Bagnold's equation

Bagnold noticed that the total work rate has been related to the available stream power per unit width τ_0 u. Assuming the available stream power τ_0 u. To constitute a single common supply of energy to both transport mechanisms, namely traction and suspension, Bagnoldwrote:

$$Q_b = \frac{\tau_0 V}{(1-\frac{\rho}{\rho_S})}\left(\frac{e_b}{\tan\alpha} + 0.01\frac{U}{\omega_0}\right)$$

Where
Q_b : is the sediment load per unit width in (kg/m.s)
V: is the mean velocity of flow in (m/s)
ω_0 : is the fall velocity in (m/s)
e_b: is the bed load transport efficiency as indicated by Bagnold.
tan α : coefficient of inter granular solid friction of bed material.
τ_0 : is the shearstress in N/m2
ρ, ρs: density of fluid and bed material respectively in (kg/m_3).

$$\tau_o = \rho_s R_s = \rho_s \frac{u^2}{C^2} = \rho_s\ g \frac{u2}{C^2}$$

Where
R : is the hydraulic radius in (m)
S : is the slope of energy line (water surface).
C : is the Chezy coefficient
where

$$\text{ChezyCoef.} = \frac{1}{n}(R)\frac{1}{6} =$$

$$\text{ChezyCoef.} = \frac{1}{n}(h)\frac{1}{6}$$

for very wide cross section (Width ≥ 10 depth)
h : flow depth (perpendicular to bed) [m]
n : Manning's roughness factor [$s/m^{1/3}$]

$$\text{Fall Velocity} = \omega_0 = \left(\frac{4d50g(\rho_s-\rho)}{3\rho Cd}\right)^{0.5}$$

Where :d_{50} is the mean diameter of bed materials.

5.2.1.1 Example for applying Bagnold's equation at cross section (23)in year 2007

The Calculations as shown in Table 2 are as follows:

Depth = area/ width = 2442.8.0/364.25= 6.71 m

$$\text{ChezyCoef.} = \frac{1}{n}(h)\frac{1}{6}$$

For river bed in normal conditions n=0.027

ChezyCoefficient (C) = (1/0.027)*(6.71)^(1/6) = 50.86($m^{0.5}/s$)

$\tau o = \rho_s \frac{V2}{C2} = \rho\ g\ \frac{V2}{C2}$ = (2650*9.81)*(0.37/50.86)^2 =0.73 (N/m2)

Flow power = τ0 V = 0.73*0.37 = 0.20 (N/m.s)

$\tau^* = \tau 0/(\rho s\text{-}\rho)\ g\ \ d_{50})$ =(0.73/(2650-1000)*9.81*0.29/1000) = 0.16 dimensionless

Then tan α = 0.75 from Bagnold's graph of tanα versus bed shear stress and eb = 0.14 from Bagnold's graph of efficiency versus mean velocity for various values of grain sizes (Abdel-Aziz,T.M., 1991).

Re= (V* d50)/υ where υ is the viscosity of fluid and = 0.013*10^-4 as indicated by Bagnold

=0.37*0.29/1000/(0.013*10^-4) = 60.29 > 0.1Then

Cd = 24/Re (1+(3 /16 (Re))) = 24/60.29*((1+(3/16)*60.29))) = 4.90

Fall Velocity= $\omega 0 = (\frac{4d50g(\rho s-\rho)}{3\rho Cd})^{0.5}$

ω0 =(((4*(0.29/1000)*9.81*(2650-1000))/(3*1000*4.90))^0.5)= 0.04 (m/s)

$Q_b = \frac{\tau 0V}{(1-\frac{\rho}{\rho S})} (\frac{eb}{\tan\alpha} + 0.01\frac{V}{\omega 0})$

Q_b = (0.73*0.37)/(1-1000/2650)*(0.14/0.75)+0.01*(0.37/0.04) = 0.083 (kg/m.s)

Q_b *1000 = 0.083 * 1000 = 83.28 (kg/m.s)

R (Discrepancy ratio) = Q_b field / Q_b calculated = 243.17/83.28 = 2.92

Table 2.Calculation of sediment load using Bagnold's equation (year2007)

C. section No.	Distance (m)	Depth(m)	D_{50}	chezyeq	τ0	flow power	τ*	tan α	eb	Re	cd	w0	Qb*1000	R
23	12500	6.71	0.29	50.86	0.73	0.20	0.16	0.75	0.14	60.29	4.90	0.04	83.28	2.92
19	34000	10.11	0.10	54.46	0.59	0.15	0.38	0.75	0.14	19.18	5.75	0.02	80.10	3.44
16	52000	10.84	0.15	55.10	0.45	0.10	0.19	0.75	0.14	26.47	5.41	0.02	46.99	4.78
13	69000	5.58	0.05	49.32	0.27	0.04	0.31	0.75	0.14	6.61	8.13	0.01	22.54	3.88
10	84500	7.52	0.05	51.84	0.47	0.10	0.55	0.75	0.14	8.92	7.19	0.01	59.82	2.49
8	96500	11.42	0.01	55.58	0.45	0.10	3.87	0.75	0.14	1.26	23.61	0.00	179.16	1.25
6	106000	5.82	0.00	49.68	0.30	0.05	3.92	0.75	0.14	0.63	42.74	0.00	106.26	0.81
3	121500	10.82	0.01	55.08	0.25	0.04	2.73	0.75	0.14	0.73	37.27	0.00	76.45	1.73
D	128000	7.96	0.00	52.34	0.21	0.03	4.12	0.75	0.14	0.37	69.50	0.00	87.00	1.03
28	132000	10.83	0.01	55.09	0.12	0.01	0.81	0.75	0.14	0.87	32.16	0.00	15.79	5.76
													Average	2.81

5-2-2 Meyer-Peter and Muller Equation

The most commonly used empirical equation is the one due to Meyer-Peter and Muller, They described a reasonably simple and fairly accurate formula for bed load discharges. They developed bed load equation based on experiments with sand particles of uniform and mixed size and natural gravel. Since in AHDR, the analysis of bed material samples showed that grain size distribution are 30% fine gravel and course sand, 40% fine sand 30% silt and clay (Makary A, 1982). Therefore Mayer Peter equation can be applied to AHDR. Their equation in water streams takes the form:

$$Q_b = (250\ q^{0.67} s - 42.5\ d_{50})^{1.5}$$

where:
Q_b : rate of bed load transport per unit width in (kg/m.s)
q : water discharge per unit width in (m^3/m.s), s : energy slope (water surface slope).
d_{50}: mean diameter of the sediment in (m)

5-2-2.1 Example for using Meyer-Peter and Muller Equationat cross section (23)in year 2007

The Calculations as shown in Table 3 are as follows:

q = 903.84/ 364.25 = 2.48 (m3/m.s)

$Q_b=(250\ q^{0.67}\ s - 42.5\ d_{50})^{1.5}$ = $(250*((2.48^{\wedge 0.67})*(1.85*10^{-4})) - (42.5*(0.29/1000)))^{1.5}*1000$ =19.51 (kg/m.s)

Q_b total = 15% of the total sediment load= 19.51*(100/15) =130.07

R=$Q_b$field/ total Q_b= 243.17/130.07 =1.87

5-2-3-1 Example for using Shield's Equationat cross section (23) year 2007

The Calculations as shown in Table 4 are as follows:

$$Q_b = 10\ q\ s\ \frac{(\tau o - \tau c)}{\left(\frac{\rho s}{\rho}\ -1\right)2\ d50}$$

$\tau 0 = \rho\ s\ h$ =1000* 1.85*10^{-4}*6.71= 0.01 (N/m2)

Q_b= (10*2.48*1.85*10^{-4}(0.01-0.02)/(2650/1000)-1)^2*(0.29/1000))=1.95(kg/m.s)

Q_b total = 15% of total sediment load = 1.95*(100/15) =13.03

R=Q_b field/ total Q_b = 243.17/13.03 =18.66

Table 3. Calculation of sediment load using Meyer Peter's and Muller equation (year 2007)

Cross section name	Distance from inlet (m)	Area(m2)	Width(m)	d_{50}(mm)	W.S slop(m/m)	Normal depth	q(m3/m.s)	Bed load Qb*1000	Total Load Qb	R
23	12500	2442.80	364.25	0.29	1.85E-04	6.71	2.48	19.51	130.07	1.870
19	34000	3504.90	346.80	0.10	1.85E-04	10.11	2.63	24.37	162.46	1.698
16	52000	4855.80	448.00	0.15	1.85E-04	10.84	2.49	22.09	147.24	1.524
13	69000	5071.50	909.40	0.05	1.85E-04	5.58	0.89	8.14	54.25	1.612
10	84500	4355.00	579.10	0.05	1.85E-04	7.52	1.65	15.59	103.92	1.433
8	96500	5724.60	501.30	0.01	1.85E-04	11.42	2.63	26.02	173.45	1.287
6	106000	6712.70	1129.00	0.00	1.85E-04	5.95	1.01	9.95	66.33	1.326
3	121500	6451.60	596.40	0.01	1.85E-04	10.82	1.84	18.18	121.22	1.092
D	128000	6525.20	819.30	0.00	1.85E-04	7.96	1.19	11.80	78.68	1.139
28	132000	5803.60	535.80	0.01	1.85E-04	10.83	1.30	12.76	85.04	1.070
									average	1.405

Table 4. Calculation of sediment load using Shield's equation (year2007)

x sec. No.	Distance from inlet (m)	Normal depth	d50	W.Slope	τ0	τc	Width	q	Bed load Qb*1000	Total load Qb	R
23	12500	6.71	0.29	1.85E-04	1.24	0.02	364.25	2.48	1.95	13.03	18.66
19	34000	10.11	0.10	1.85E-04	1.86	0.01	346.80	2.63	1.63	10.85	25.43
16	52000	10.84	0.15	1.85E-04	2.00	0.02	448.00	2.49	0.24	1.60	139.96
13	69000	5.58	0.05	1.85E-04	1.03	0.01	909.40	0.89	1.60	10.70	8.18
10	84500	7.52	0.05	1.85E-04	1.39	0.01	579.10	1.65	4.89	32.59	4.57
8	96500	11.42	0.01	1.85E-04	2.11	0.01	501.30	2.63	32.77	255.58	0.87
6	106000	5.95	0.00	1.85E-04	1.10	0.01	1129.00	1.01	14.77	111.85	0.79
3	121500	10.82	0.01	1.85E-04	2.00	0.01	596.40	1.84	56.58	285.36	0.46
D	128000	7.96	0.00	1.85E-04	1.47	0.01	819.30	1.19	23.85	159.03	0.56
28	132000	10.83	0.01	1.85E-04	2.00	0.01	535.80	1.30	23.26	155.08	0.59
										Average	20.01

6 ANALYSIS OF RESULTS

The selected years were chosen since they represent the most recent measurements and to cover different case of water inflow to AHDR; where water flow to cross section 23 (entrance of AHDR) in the day of measuring in years 2007 and 2008 were high and reach 903.84 m^3/sec and 888.55 m^3/sec respectively. While it was in the day of measuring in year 2009 was low and equals 575.10 m^3/sec and in year 2009 was medium and reaches704.52 m^3/sec. For comparison between the three equations the limits of vertical axes were taken the same in all graphs except year 2009 in calculation using Shields equation since the results were high and above the average limits of other graphs. The results of different equations were indicated in Fig. 4, 5, 6 and Tables 2, 3, 4.

6.1. Results of Bagnold's Equation

The distribution of the calculated sediment load per unit width in every cross section using Bagnold's equation and the distribution of the measured values are indicated in Fig. 4 for years (2007), (2008), (2009) and (2012). To evaluate the accuracy of the calculated to the measured values, a discrepancy ratio (R) has been calculated for every cross section.The discrepancy factor is used in this comparison instead of correlation factor since it is used to compare two results, while correlation factor is used to estimate the variance of estimated equation from the given data used for the derivation of this equation.The discrepancy as indicated in Table 2 and Fig. 4, generally the results of Bagnold's equation are good except the entrance zone in year 2007. In year 2008, the calculated values are close also to the measured ones except at the distance between Km 90 and km 115. The range of the discrepancy ratio was (0.81-5.76) for year 2007, (0.22-1.96) for year 2008, (0.18-1.4) for year 2009, and (0.27-4.86) for year 2012. These values are a little bit far from one which indicates that the total sediment load calculated using Bagnold equation is not so far from the calculated one based on field measurements. Therefore Bagnold's equation seems to be useful for the comprehension of hydraulic parameters involved in sediment transport phenomena in AHDR.

6.2. Results of Meyer-Peter & Muller Equation

The distribution of the calculated sediment load per unit width in every cross section using Meyer-Peter & Muller equation and that of the measured values are indicated in Fig. 5 for years (2007), (2008), (2009) and (2012). Also, the calculated and the measured values have been compared to each other and the discrepancy ratio (R) was calculated for every cross section. The range of the discrepancy ratio was (1.07-1.87)for year 2007, (2.26-4.46) for year 2008, (0.14-3.28) for year 2009, and (0.34-1.52) for year 2012. These results indicate that the total sediment load calculated using Meyer-Peter & Muller Equation are very close to the calculated one based on field measurements. Consequently Meyer-Peter & Muller equation seems to give reliable results in AHDR.

6.3. Results of Shields Equation

Comparison between the calculated sediment load per unit width in every cross section using Shields equation and the corresponding measured values are indicated in Fig. 6 for years (2007), (2008), (2009) and (2012). The range of the discrepancy ratio was (0.46-139.96) for year 2007, (0.2-0.85) for year 2008, (0.05-0.664) for year 2009, and (0.11-5.28) for year 2012.The equation gives sediment load values close to the measured values in year 2008 and year 2012 but it’s gives a big difference in years 2007 and 2009. It seems that Sheilds equation results are very far from the measured values.

7 DISCUSSIONS

Comparing the different results in Fig. 4, 5, 6 it is noticed that Mayer Peter & Muller represents the estimation of total sediment load in AHDR with a good values; while there is a considerable discrepancy between the total sediment load in case of using Bagnold and Sheilds equations. There are some possible explanations for this discrepancy as indicated:-

- The large difference in hydrodynamic conditions between huge wide and deep streams and average wide and normal deep channels should be taken into account.
- The technical difficulty of the field measurements in a huge reservoir as AHDR may introduce some errors.
- Due to the fact that Mayer Peter & Muller considers the transverse and the vertical structure of the flow and sediment transport rates, the model is close to natural channel conditions and allows a comprehensive and physical sound interpretation of sediment transport.

8 CONCLUSIONS

The application of the three models in AHDR leads to the following conclusions:

1- Bagnold's equation could be used, except in the inlet zone since it is narrow and shallow for about 60km length from the inlet of AHDR. But for practical problems it can be used for reliable predictions of sediment transport behavior for design purposes in the rest length of AHDR.

2- Shields equation is also applicable in the whole reservoir but in some cross sections gives very high discrepancy ratios. Therefore it cannot be used for reliable predictions of sediment transport behavior for design purposes.

3- The simplicity of Meyer-Peter & Muller equation could be useful for rapid approximate estimation of sediment load transport rates in the field work. In this case, it can offer guidance to designing engineers.

4- The applicability of Meyer-Peter & Muller equation in AHDR is recommended.

5- Therefore, Meyer-Peter & Muller model is concluded to be the most suitable one to be applied in AHDR in case of sediment transport studies.

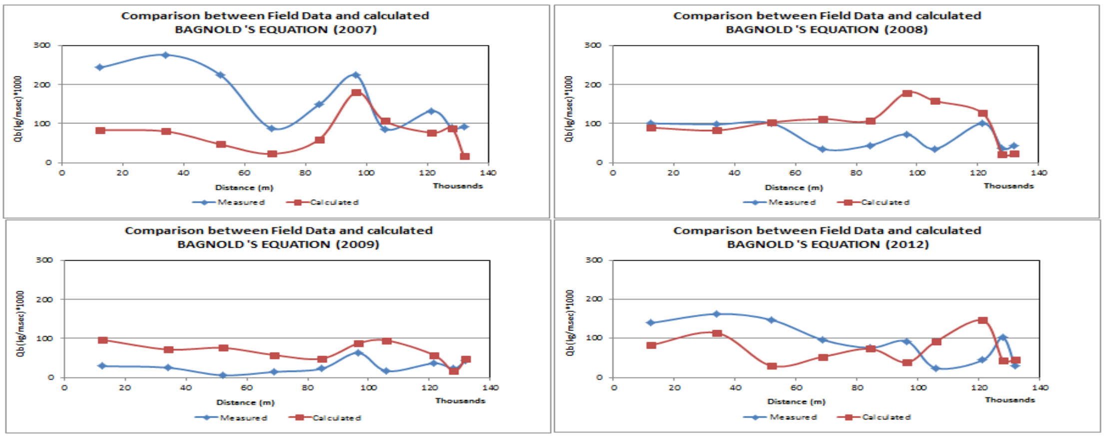

Figure 4. Comparison between total sediment load using field data and the Bagnold equation

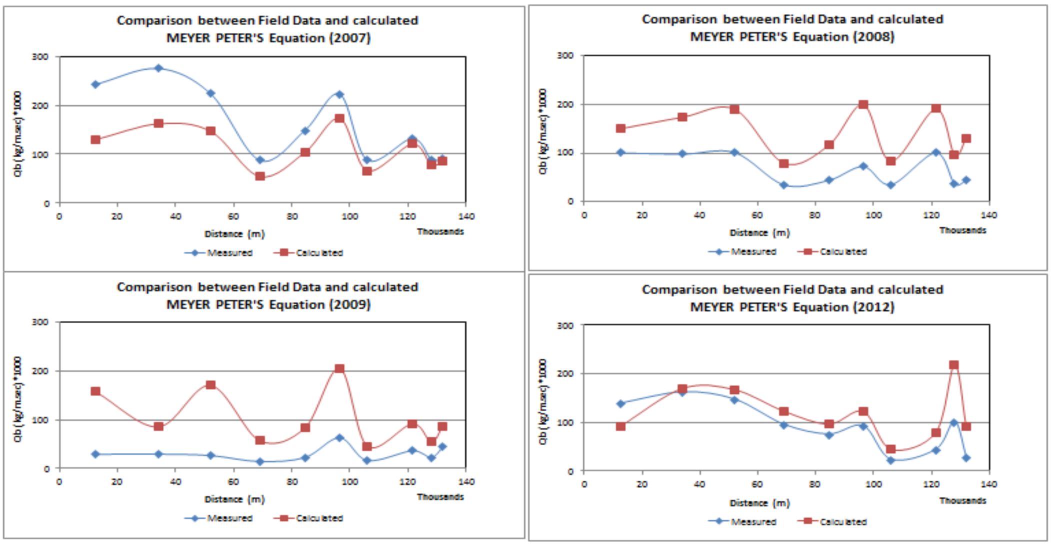

Figure 5.Comparison between total sediment load using field data and the Meyer peter and Mullerequation

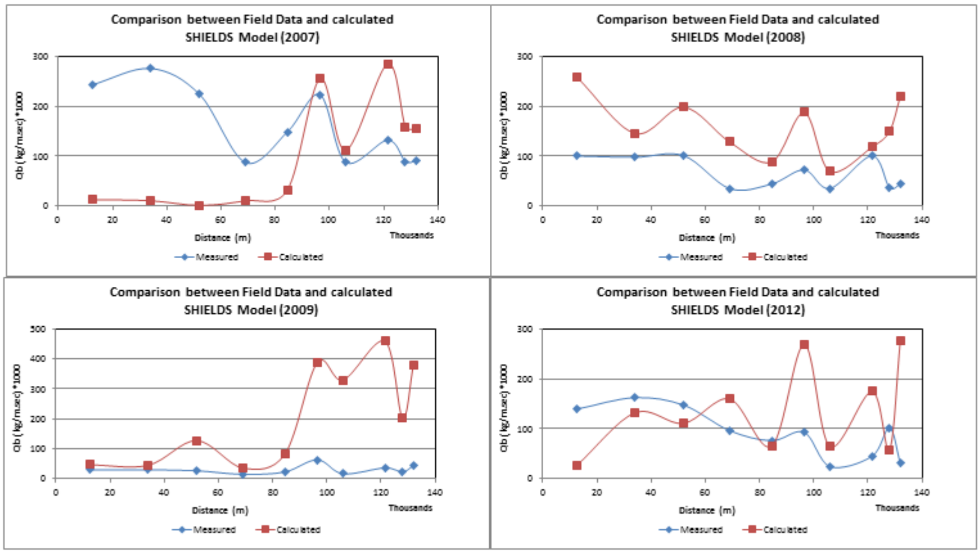

Figure 6.Comparison between total sediment load using field data and the Shield equation

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