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An Estimation of Annual Sediment Load for Egyptian Irrigation Canals.

A. Zidan
Assistant Professor, Irrigation and Hydraulics Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.

T. Owais
Dean and Head of Water Engineering Department, Zagazig University, Zagazig, Egypt.

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Zidan, A.R.* and Owais, T.M.**

* Lecturer, Irrigation and Hydraulics Dept., Mansoura Univ.
** Dean, and Head of Water Engineering Dept., Zagazig Univ.

ABSTRACT:

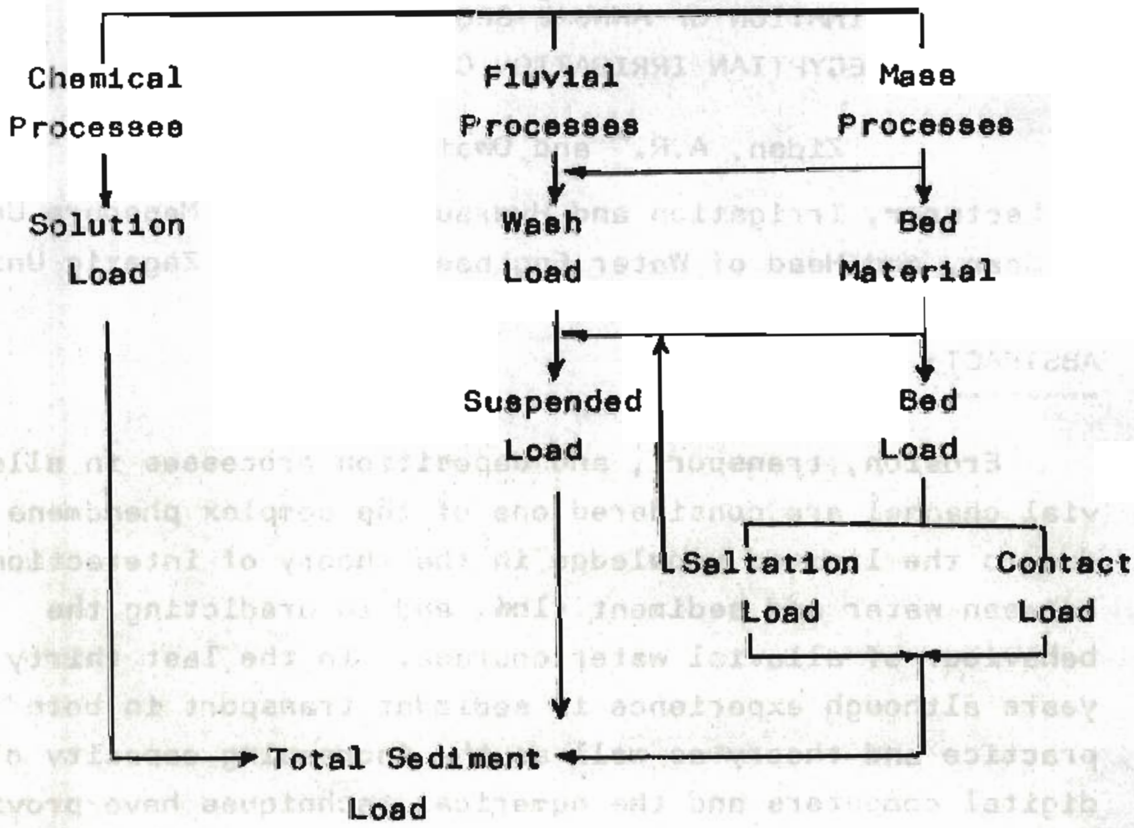
Erosion, transport, and deposition processes in alluvial channel are considered one of the complex phenomena due to the limited knowledge in the theory of interaction between water and sediment flow, and in predicting the behaviour of alluvial water courses. In the last thirty years although experience in sediment transport in both practice and theory as well as the increasing capacity of digital computers and the numerical techniques have provided a substantial aid in this field, but the mechanics of sediment transportation is still considerably far from being satisfactory.

Four conventional bed load formulae have been applied to some selected egyptian irrigation canals. Located in the Delta region. Limitations of each formula have been discussed, and the most appropriate formula has been used for an estimation of the annual bed load for these canals.

INTRODUCTION:

The sediment transport processes can be divided into wash load, suspended load, and bed load. The following figure demonstrates the sediment source (Ref. 4).

Fig. (1) Sediment Source



Much of the research into sediment transport has concentrated on the bed load, i.e. the material that moves by rolling and sliding action along the channel bed and banks. Over a hundred years of research has gone in developing relationship between sediment discharge in terms of both hydraulic and watershed parameters and sediment properties, which has been referred as bed load formulae.

Numerous bed load equations have been presented, but some of them look very similar. These bed load equations could be classified into three different approaches, (i) The du Boy's type equation, considering a shear stress relationship (ii) The Schoklitsch type equations, considering a discharge relationship, and (iii) The Einstein type equations based upon statistical consideration of lift forces.

Every single bed load equation was based on the experimental determination of its coefficient except for few cases in which the bed load was actually measured in natural water courses.

Before the construction of Aswan high dam the water discharge of the river Nile varied over the whole year from 80 mm^3/day during winter up to 900 mm^3/day during the flood period. Consequently the concentration of the suspended sediment ranged from 50 p.p.m. to 6000 p.p.m. This yielded an annual sediment load of about 125 millions tons, distributed on the river Nile, its distributers, main channels and their distributers. About 80% of the load used to pass during the flood period the river Nile was partially closed in 1964 and was under full control by the end of 1968. Due to closure of the dam and full control of the flowing discharges, water released from the dam has been relatively clear and most of the suspended sediment was being deposited in its reservoir(Ref. 3). Accordingly, this work into sediment transport has been relied on bed load formulae.

CONVENTIONAL BED LOAD FORMULAE:

Einstein's equation

$$\phi = \text{fact}\ (\psi) \qquad \text{.....(1)}$$

$$\psi = \frac{\rho_s - \rho}{\rho} \; \frac{d}{R_h} \qquad \text{.....(1.a)}$$

$$\phi = \frac{g_s}{\gamma_s} \sqrt{\frac{\rho}{\rho_s - \rho} \; \frac{1}{g d^3}} \qquad \text{.....(1.b)}$$

in which:

g_s = rate of bed load in weight per unit time and width;

ϕ = intensity of bed load transport,

ψ = intensity of shear on particles,

R_h = hydraulic radius.

ρ = density of water;

ρ_s = density of soil;

γ_s = specific weight of soil; and

d = d_{50}; diameter of particle or median diameter in a mixutre.

Schoklitsch equation:

$$g_s = \sum_i p_i \frac{25.3}{\sqrt{d_{si}}} S^{3/2} (q - q_{ci}) \qquad .....(2)$$

$$d_{ci} = \frac{0.638\, d_{si}}{S^{4/3}} \qquad .....(2.a)$$

in which;

q_{ci} = critical value of q for initiation of motion of sediment of mean size d_{si};

p_i = fraction by weight of that fraction of the bed sediment with mean size d_{si};

$\sum_i$ = indicate summation over all sets of values i, d_{si}, q_{ci}

Based on numerous experiments in laboratory flumes, and also on actual bed load measurements in the field. Skocklitsch (1950) suggested amodification to equation (2) the new equation is given by

$$g_s = 2500\, S^{3/2} (q - q_{cr}) \qquad .....(2.b)$$

$$q_{cr} = \frac{0.6\ d^{3/2}}{S^{7/6}} \qquad d \geq 0.006\,m \qquad .....(2.c)$$

$$q = \bar{U}\ .\ \bar{D} \qquad .....(2.d)$$

in which;

S = water slope;
q = discharge per unit width;
q_{cr} = critical discharge per unit width;
$\bar{D}$ = average mean depth; and
$\bar{U}$ = average velocity

Kalinske's equation:

$$\frac{q_s^{*}}{U_{*} d} = \text{fct}\ \left(\frac{\tau_{cr}}{\tau_o}\right) \qquad .....(3)$$

$$g_s = \gamma_s . q_s \qquad .....(3.a)$$

in which;

q_s = bed load in volume per unit width;
U_{*} = shear velocity;
τ_{cr} = critical shear stress; and
τ_o = average shear stress.

Meyer peter et al equation:

$$\left(\frac{K_r}{`K_r}\right)^{3/2} \gamma \cdot r_b . S = 0.047\ (\gamma_s - \gamma)\ d_m + 0.25\ \left(\frac{\gamma}{g}\right)^{1/3} \left(\frac{\gamma_s - \gamma}{\gamma_s}\right) g_s^{2/3} \qquad ..(4)$$

$$\left(\frac{K_r}{`K_r}\right) = \sqrt{\frac{`f_b}{8}} \quad \frac{V}{\sqrt{g . r_b . s}} \qquad .....(4.a)$$

in which;

γ = specific weight of water;
γ_s = specific weight of sediment grains,

d_m = median diameter of particles in a mixture;

g = acceleration due to gravity;

r_b = bed hydraulic radius;

$'f_b$ = Darcy weisbach bed friction factor for sand grain roughness defined;

V = mean flow velocity;

$$v = K_r \; r_b^{2/3} \; S^{1/2}$$

and $$V = {}'K_r \; r_b^{2/3} \; {}'S^{1/2}$$

$'S$ = is that part of the total slope S, required to overcome the grain resistance defined in terms of f_b'

$$V = \sqrt{8/f_b'} \quad . \quad \sqrt{g_{rb} \, .S} \qquad \text{.....(4.b)}$$

$K/'K = 1$ if there is no evidence of any bed form. More detail about bed load formulae are given in (Ref. 5).

Method of Synthesis:

The parameters which affect the sediment transport phenomena are:

B = channel breadth,

H = flow depth or hydraulic radius R;

d = sediment grain size;

S = channel slope;

g = acceleration due to gravity;

ρ = water density,

ρ_s = particles density;

μ = dynamic viscosity;

Q = total water discharge, and

Q_s = total volumetric sediment discharge,

According to the method of synthesis developed by Barr (Ref. 1), these variables lead to the following two similitude equations.

$$\phi\left(\underset{(1)}{B/d},\ \underset{(2)}{R/d},\ \underset{(3)}{q_s/(sg)^{1/2}\, R^{3/2}},\ \underset{(4)}{Sg/g_{\bar{w}}},\ \underset{(5)}{\rho_s/\rho},\ \underset{(6)}{g^{1/2} d^{3/2}/\nu}\right) = 0 \qquad \ldots\ldots(5)$$

or

$$\phi\left(\underset{(1)}{B/d},\ \underset{(2)}{R/d},\ \underset{(3)}{q_s/g_{\bar{w}}^{-1/2}\ d^{3/2}},\ \underset{(4)}{Sg/g_{\bar{w}}},\ \underset{(5)}{\rho_s/\rho},\ \underset{(6)}{g^{1/2}\ d^{3/2}/\nu}\right) = 0 \qquad \ldots\ldots(6)$$

where

$$g_{\bar{w}} = \frac{\rho_s - \rho_w}{\rho_w}\, g$$

<u>Meyer peter et al equation</u>

From equation (5)

$$\underset{(3)}{\frac{qs}{(Sg)^{1/2}\ R^{3/2}}} \propto \underset{(4)}{\frac{Sg}{g_{\bar{w}}}} \times \underset{(5)}{\frac{\rho}{\rho_s}}$$

<u>Kalinske's equation</u>

From equation (5)

$$\underset{(2)\ \times\ (3)}{\frac{qs}{(SgR)^{1/2}\ d}} \propto \underset{(2)\ \times\ (4)}{\frac{Sg.R}{g_{\bar{w}}\ .\ d}}$$

<u>Einstein's equation</u>

From equation (6)

$$\underset{(3)}{\frac{qs}{g_{\bar{w}}^{1/2}\ .\ d^{3/2}}} \propto \underset{(2)\ \times\ (4)}{\frac{Sg\ R}{g_{\bar{w}}\ .\ d}}$$

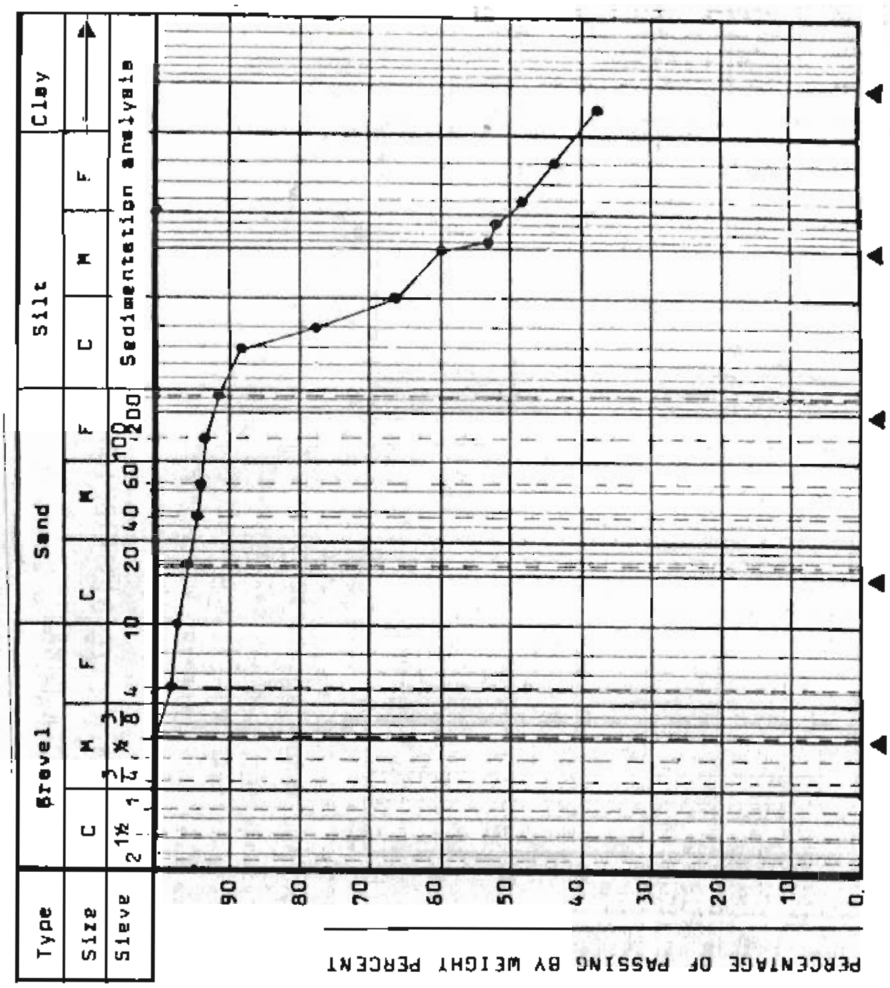
Schoklitsch's equation has been excluded from the similitude analysis as it is not dimensionally homogeneous.

Thus all the formulae examined are consistent in that the group $g^{1/2} d^{3/2}/\nu$ has been cancelled. This also implies that none of the formulae can be applied to systems of different ρ_s and d. The equations are also restricted to channels of one width and depth. Despite these defficiences in the bed load formulae they must be used by hydraulic engineers until complete correlations have been obtained.

FIELD AND EXPERIMENTAL WORK:

To calculate the sediment transport in a stream, a test reach has to be selected first. This reach should be representative to the channel. It should be sufficiently long to determine accurately the slope of the stream. It should have a uniform flow conditions and sediment composition, besides having a minimum outside effects such as vegetations, strong bends and islands. After the selection of a test reach, three soil samples, taken down to a depth of 60 cm, were collected to get information about the grain size distribution on the entire wetted perimeter. The mechanical analyses of the representative samples, for each canal, are given in Fig. (2), Fig.(3), and Fig (4) for zaghlola, El-Zahiara and Shoha canals respectively.

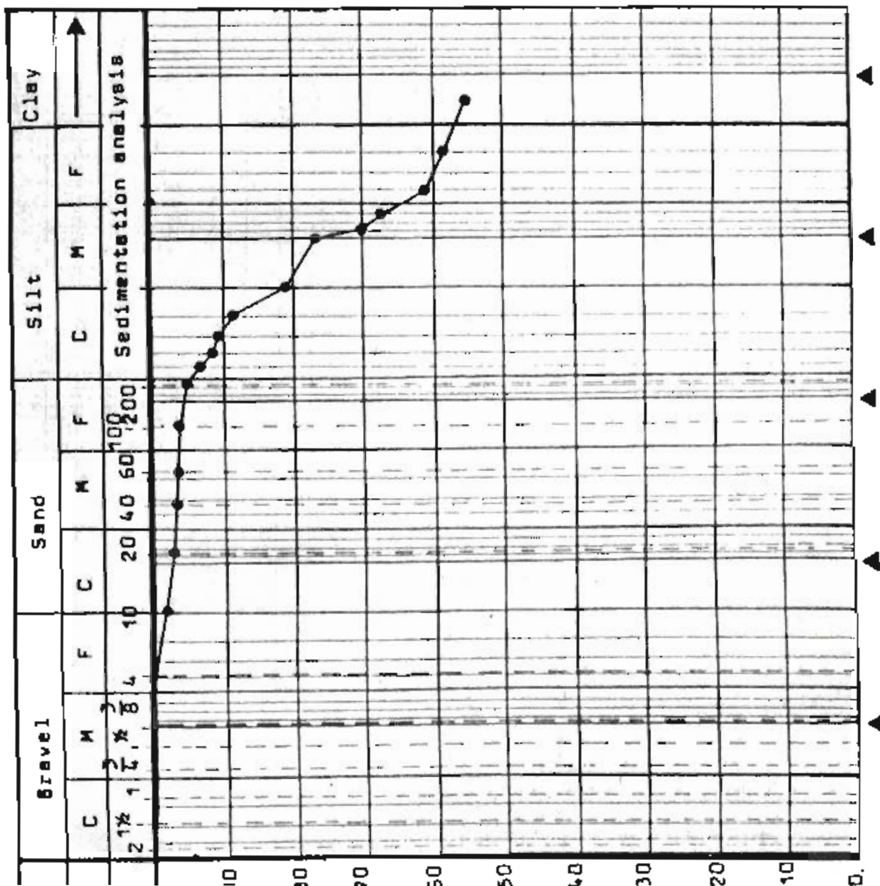
The porosity of material was determined experimentally by over drying an undisturbed sample and weighing it the sample was then saturated with some liquid such as kerosene, and weighed again. Finally, the saturated sample was immersed in some liquid (Kerosene) and the weight of liquid displaced was noted. The weight of liquid required to saturate the sample divided by the weight of the displaced liquid gave the porosity (n) as a decimal (Ref. 7).



VISUAL AND MANUAL IDENTIFICATION:

Dark grey Slightly calcareous non stratified clayey silt contains traces of sand, fine gravel and roots.

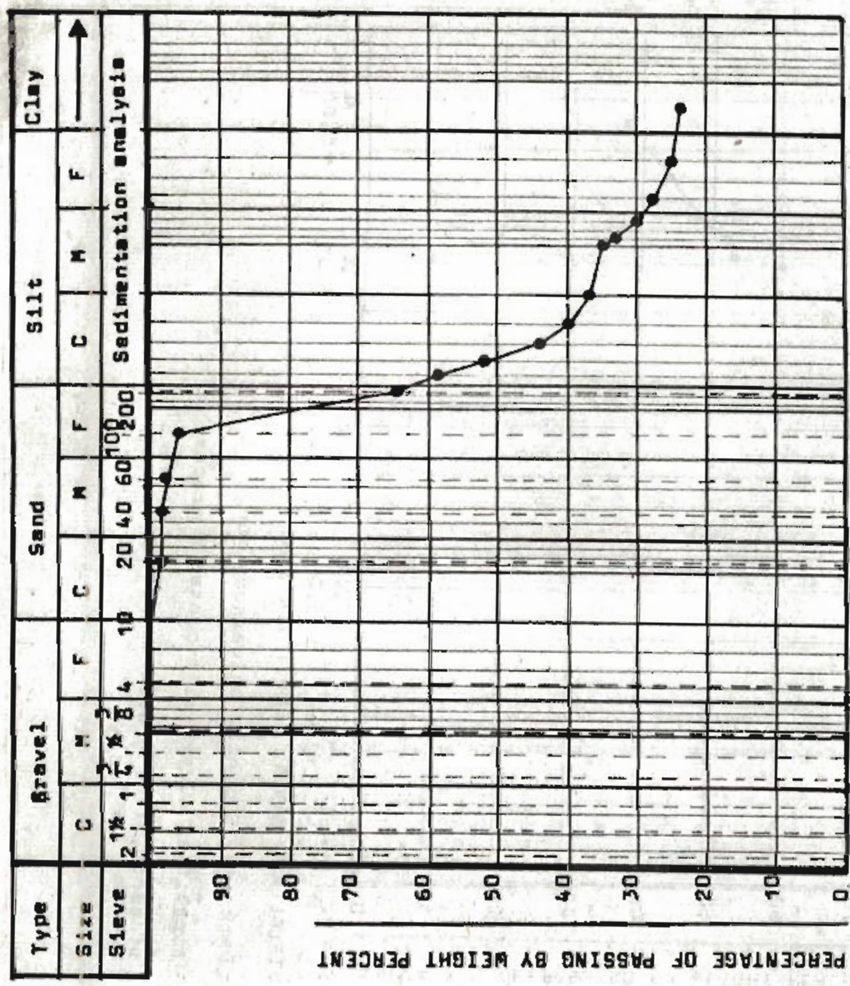
FIG.(3) GRAIN SIZE DISTRIBUTION
ZAHIARA CANAL



L AND MANUAL IDENTIFICATION:

brown slightly calcareous non ified silty clay contains traces nd and very thin roots.

FIG.(2) GRAIN SIZE DISTRIBUTION
ZAGHLOLA CANAL



VISUAL AND MANUAL IDENTIFICATION:
Grayish brown slightly calcareous nonstratified sandy silt contains some clay and traces of thin roots.

FIG. (4) GRAIN SIZE DISTRIBUION
SHOHA CANAL

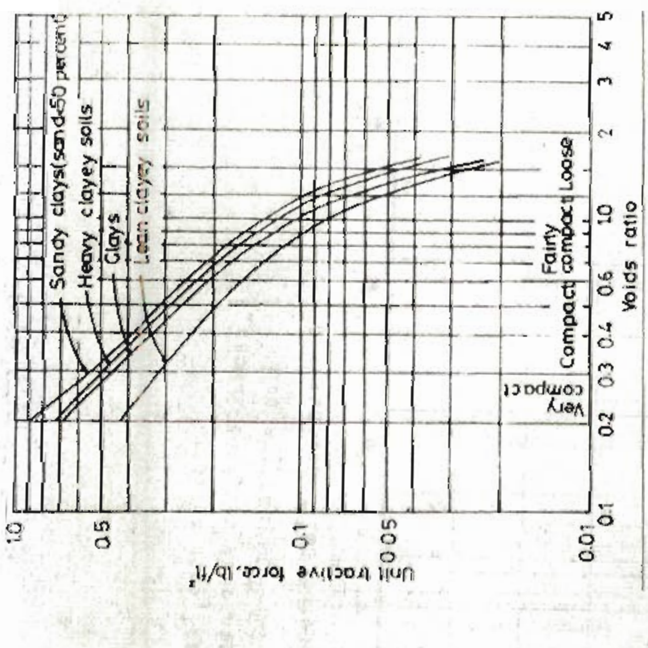


FIG. (5) RECOMMENDED DESIGN
FOR CANALSIN COHESIVE MATERIAL.

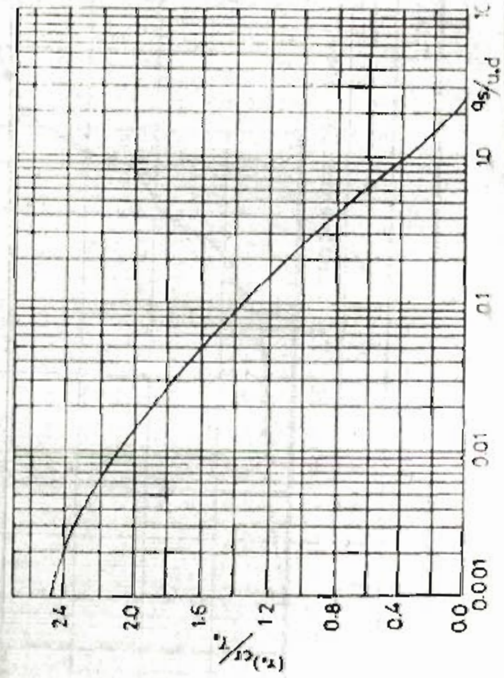


FIG. (6) KALNSKE'S RELATIONSHIP

The voids ratio (e) is equal to (n/n-1). Values of porosity and voids ratio are given in the following table

Table (1) Values of porosity, voids ratio and tractive force

		Zaghlola	El-Zahiara	Shoha
Porosity	n	0.54	0.42	0.38
Voidsratio	e	0.70	0.72	0.60
Tractive force (Kg/m^2)		0.93	0.88	0.98

Values of voids, ratio have been used in estimating the average shear stress on the wetted perimeter for each canal using Fig.(5).Reference can be made, here, to a little is known about permissible shear stresses or tractive forces on cohesive soil(Ref.6).In engineering practice cohesive material consists of mixure of clay sized (Colloidal) particles, or silt sized particles and sometimes of sand sized particles. Chow(Ref. 2) has interpreted some early Russian data on permissible velocities and expressed them in terms of permissible shear stress, which depends on clay content and the voids ratio Fig.(5).

RESULTS AND ANALYSES:

Four conventional bed load equations have been applied to some earther irrigation canals, to seek an answer to the question, what is the most convenient formula to be applied, for the case study, in predicting the annual sediment load, especially after the erection of the Aswan High Dam.

Table (2) gives the values of the rate of transport of sediment per unit width, gs, at different sections for Zaghlola, El-Zahiara, and Shoha canals respectively, by applying the formulae mentioned before. The table clearly demonstrates high discrepancies between the values of gs using the different equations; which means that not all the

Table (2) Values of gs, bed load in weight per unit width/ sec.

Sec No.	Einstein	Meyer peter	Schoklitsch	Kalinske
Zaghlola:				
1	1.22×10^{-3}	0.024	1.39×10^{-3}	1.696×10^{-7}
2	1.22×10^{-3}	0.023	1.32×10^{-3}	1.701×10^{-7}
3	1.218×10^{-3}	0.020	1.16×10^{-3}	1.58×10^{-7}
4	1.218×10^{-3}	0.016	1.17×10^{-3}	1.59×10^{-7}
5	1.218×10^{-3}	0.013	8.11×10^{-3}	1.38×10^{-7}
6	1.218×10^{-3}	0.021	1.296×10^{-3}	1.60×10^{-7}
El-Zahiara:				
1	6.328×10^{-3}	0.028	1.54×10^{-3}	5.29×10^{-7}
2	6.328×10^{-3}	0.028	1.699×10^{-3}	5.30×10^{-7}
3	5.537×10^{-3}	0.013	1.32×10^{-3}	4.13×10^{-7}
4	6.328×10^{-3}	0.018	1.10×10^{-3}	4.51×10^{-7}
5	5.537×10^{-3}	0.013	9.53×10^{-3}	4.16×10^{-7}
Shoha:				
1	3.425×10^{-2}	0.021	1.225×10^{-3}	3.98×10^{-6}
2	3.044×10^{-2}	0.018	1.077×10^{-3}	3.79×10^{-6}
3	3.425×10^{-2}	0.021	1.37×10^{-3}	3.98×10^{-6}
4	2.664×10^{-2}	0.015	0.96×10^{-3}	3.55×10^{-6}

bed load equations are suitable to calculate the annual sediment load. Application of the four bed load formulae for natural channel with median particle size d_{50} = 0.012mm Three equations have predicted the rate of sediment load within an accuracy of about 15%. Schoklitsch's equation has given value considerably below any of the other values (Ref.5). This equation was not tested under conditions similar to the present problem. Since the equation is not even dimensionally homogeneous it should be excluded from applications of the case study.

Meyer peter et al. equation gives much higher values for gs, it should be used carefully at such high rate of bed load, although experiments have been performed in this region. The formula has been tested for large grains. It was established by using a well sorted grain size ranges from 3.1 mm to 28.6 mm., in small and large flumes.

Einstein's relationship gives values of gs much less than the corresponding values of gs of Meyer peter et al. equation, the equation was developed in small flume for well sorted coarse material (0.785 mm - 7.85 mm). The Einstein formula has all the advantages of Meyer peter et al. equation (Ref. 5) which has been based on more varied experimental data for its establishment.

Einstein's formula has been applied twice, for Shoha canal, with two hypothetical median particle sizes, $d_{50} = 5 \times 10^{-5}$ mm, and $d_{50} = 6 \times 10^{-6}$ mm Table (3) gives the values of gs for each particle size. This result demonstrates the values of gs for $d_{50} = 5 \times 10^{-5}$ mm are bigger than the corresponding values of gs for $d_{50} = 6 \times 10^{-6}$ mm, the neverse could be expected; which means that the formula has been applied outwith the range of its establishment. Or in other words, Einstien's equation could not be suitable for sandy silt soil.

Table (3) Computed values of gs Kg/m/sec.

Sec. no.	1	2	3	4
$d_{50} = 5 \times 10^{-5}$ mm	3.42×10^{-2}	3.04×10^{-2}	3.42×10^{-2}	2.66×10^{-2}
$d_{50} = 6 \times 10^{-6}$ mm	6.33×10^{-3}	6.33×10^{-3}	6.33×10^{-3}	6.33×10^{-3}

The bed load equation by Kalinske pays attention to many fluid mechanical details, and such details could be considered more advanced than any other du Boys equations. The main disadvantages of this formula is having a low value of τ_{cr}/τ_o. It failsto predict accurate results. This is due to experimental difficulties in separating the bed load from the suspended load.

Case Study:

It seems from the previous analyses that Kalinske's equation is the most convenient formula to estimate the annual sediment load for Zaghlola, El-Zahiara, and Shoha canals which are all located within the eastern Delta region. The calculations are based on the assumption that every canal is liable to be eroded along its axis with its wetted perimeter. Table (4) gives the annual load for the above mentioned canals.

The du Boys type equations have been based on the du Boys formula

$$gs = \psi_D \ \tau_o (\tau_o - \tau_c).$$

where; ψ_D is the characteristic sediment coefficient; and is given by $\psi_D = 0.54/(\gamma_s - \gamma)$ for uniform grain of various kind of sand, γ_s is specific weight of particle, and γ specific weight of liquid.

Theoretically speaking, the rate of sodiment bed load, gs, equals zero if the average shear stress on the wetted

Table (4) Calculated annual bed loads.

Zaghlola Canal

Sec. no.	P m	R m	S_w	τ_o Kg/m^2	u_* m/sec.	$\frac{\tau_{cr}}{\tau_o}$
1	10.370	1.26	8	0.10	0.032	9.3
2	10.148	1.22	8	0.0976	0.0312	9.5
3	8.89	1.115	8	0.089	0.0298	10.5
4	7.67	1.0	9	0.09	0.0300	10.3
5	5.65	0.75	9	0.0675	0.0260	13.8
6	5.34	0.70	13	0.091	0.0302	10.3

Sec. no.	$\frac{q_s}{u_* d}$	q_s	g_s 10^{-7}	G_s $x10^{-7}$	L m	$G_s.Lx10^{-3}$ Kg/sec.
1	0.001	6.40	1.696	18.14	1750	3.24
2	0.001	6.42	1.701	17.27	3250	5.61
3	0.001	5.96	1.580	14.04	5750	8.073
4	0.001	6.00	1.590	12.20	6250	7.625
5	0.001	5.20	1.380	9.16	2000	1.832
6	0.001	6.04	1.600	8.55	2000	1.710
					Σ	28.09

Annual bed load = 302 m^3

Shoha Canal

Sec. no.	P m	R m	S_w	τ_o Kg/m^2	u_* m/sec.	$\frac{\tau_{cr}}{\tau_o}$
1	7.884	0.993	9	0.090	0.0300	10.90
2	7.1006	0.909	9	0.082	0.0286	11.95
3	6.2512	0.815	11	0.090	0.030	10.90
4	5.054	0.658	11	0.072	0.0268	13.60

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Table (4) Continued.

Sec. no.	$\frac{q_s}{u_* d}$	q_s 10^{-9}	g_s 10^{-6}	G_s $\times 10^{-6}$	L m	$G_s \cdot L$ 10^{-2} Kg/sec.
1	0.001	1.50	3.98	31.38	3750	11.77
2	0.001	1.43	3.79	26.91	1250	3.36
3	0.001	1.50	3.98	24.88	2000	4.98
4	0.001	1.34	3.55	17.94	2250	4.04
						Σ 23.75

Annual bed load = 1161 m^3

El Zahiara Canal

Sec. no.	P m	R m	S_w	τ_o Kg/m^2	u_* m/sec.	$\frac{\tau_{cr}}{\tau_o}$
1	1[illegible]5	1.55	7	0.109	0.033	8.1
2	11.05	1.383	8	0.110	0.0333	8.0
3	8.37	1.112	6	0.067	0.026	13.1
4	6.18	0.799	10	0.080	0.0283	11.0
5	4.24	0.565	12	0.068	0.0261	12.9

Sec. no.	$\frac{q_s}{u_* d}$	q_s 10^{-10}	g_s 10^{-7}	G_s $\times 10^{-6}$	L m	$G_s \cdot L$ 10^{-3} Kg/sec.
1	0.001	1.98	5.29	6.70	3000	20.10
2	0.001	2.00	5.30	5.86	3000	17.58
3	0.001	1.56	4.13	3.46	660	2.28
4	0.001	1.70	4.51	2.79	3300	9.21
5	0.001	1.57	4.16	1.76	1450	2.55
						Σ 51.70

Annual bed load = 253 m^3

stress τ_c, and is linearly proportional to τ_c. Table (5) gives the values of the maximum shear stress on the bed and side slopes at different sections for canals under investigation. The values of shear stress are less than the allowable shear stress developed by experimental work, according to du Boys equation no bed load will exist. On the contrary, Kalinske's equation gives a value of gs for values of $\tau . < \tau_c$. The influence of critical shear stress on the rate of sediment load are given in Table(6). The results show how sensitive the annual total load to the value of the critical shear stress.

Effect of colloids on bed load:

Colloids in either the material of canal bed or water conveged by it, or in both tend to cement particles which form the channel wetted perimeter in such a way as to resist erosive effects, and consequently will increase the permissible shear stress on the canal wetted perimeter. Before the construction of Aswan High Dam, the average annual suspended load was about 500 p.p.m. i.e. 0.05%. After the construction of the dam, relatively clear water has been released. This could decrease the permissible shear stress substantially. A 2.5% of colloids in water tends to increase the value of shear stress by 250% (Ref. 5,6). It would be expected an increase in the annual load after the construction of Aswan High Dam. The predicted annual loads in this research are based on clear water.

CONCLUSIONS:

The most important objective of research in sedimentation is to obtain a method by which one can estimate the sediment discharge in terms of both hydraulic and water shed parameters and sediment properties. By such a method it would then be possible to predict the amount of degradation or aggradation or bank erosion to be expected in a stream and therefore plan to minimise undesirable occurances.

Table (5) Calculated tractive forces on bed and sides.

Sec. no	y_m	b/y	Z	S_w Cm/Km	Coefficient side	Coefficient bed	τ_s Kg/m^2	τ_b Kg/m^2	R_m	τ_o= Kg/m^2
Zaghlola:										
1	1.90	2.63	1	8	0.47	0.93	0.071	0.141	1.26	0.101
2	1.82	2.75	1	8	0.47	0.93	0.068	0.135	1.22	0.098
3	1.73	2.30	1	8	0.47	0.92	0.065	0.127	1.11	0.090
4	1.65	1.82	1	9	0.47	0.88	0.070	0.131	0.84	0.076
5	1.29	1.55	1	9	0.47	0.85	0.055	0.099	0.75	0.068
6	1.18	1.70	1	13	0.47	0.68	0.072	0.104	0.70	0.090
El-Zahiara:										
1	2.35	2.55	1	7	0.47	0.93	0.077	0.153	1.54	0.11
2	2.14	2.34	1	8	0.47	0.92	0.080	0.158	1.38	0.11
3	1.30	1.92	1	10	0.47	0.90	0.060	0.117	0.80	0.08
4	0.97	1.55	1	12	0.47	0.85	0.055	0.099	0.56	0.067
Shoha:										
1	1.55	2.26	1	9	0.47	0.92	0.066	0.130	0.99	0.09
2	1.45	1.72	1	9	0.47	0.87	0.061	0.114	0.86	0.077
3	1.08	1.85	1	11	0.47	0.90	0.056	0.107	0.65	0.072

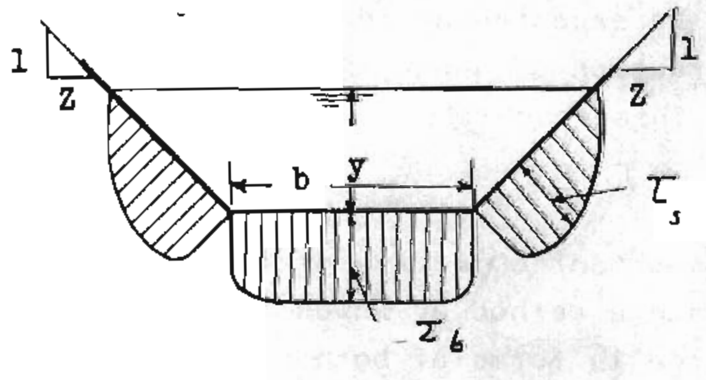

Fig.(7) Distribution of tractive force on a trapezoidal channel section.

APPENDIX (II) NOTATION

- B = channel breadth;
- $\bar{D}$ = average mean depth;
- $d=d_m$ = d_{50}; median diameter in a mixure;
- f_b = weisbach - Darcy coefficient;
- G_s = total bed load in weight per unit time;
- g = acceleration due to gravity;
- g_s = rate of bed load in weight per unit time and width;
- H = flow depth;
- L = distance between two successive cross sections;
- P = Channel wetted perimeter;
- P_i = fraction by weight of that fraction of the bed sediment with mean size dsi;
- Q = total water discharge;
- Q_s = total volumetric sediment discharge;
- q = water discharge per unit width;
- q_{ci} = critical value of q for initiation of motion of sediment mean size d_{si};
- q_{cr} = critical discharge per unit width,
- R = R_h = hydraulic radius;
- r_b = bed hydraulic radius;
- S = bed slope;
- $\bar{\bar{S}}$ = part of total slope S required to overcome grain resistance;
- S_w = water slope;
- $\bar{U}$ = average water velocity
- U_* = shear velocity;
- γ = water specific weight;
- γ_s = soil specific weight;
- μ = coefficient of viscosity;
- ρ = water density;
- ρ_s = soil density;
- τ_o = average shear stress;
- τ_{cr} = critical shear stress;
- Φ = intensity of bed load transport;
- Ψ = intensity of shear on particles;
- Ψ_0 = characteristic sediment coefficient; and

APPENDIX (I) REFERENCES:

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A comparative analysis between the results obtained from applying bed load formulas demonstrated the danger lied in the in discriminate application of formulae to earthen channel conditions outwith the range of conditions used in the development of each individual equation.

It seems that neither the Einstein formula nor the Meyer-peter et al. equation is suitable for the case study. Probably, applications of the two formulae are not convenient for either clayey or silty soil.

The Kalinske equation has been found more convenient for estimating the annual load for canals possess a cohesive material. The equation is dimensionally homogeneous and it is based on both experimental and field measurement. It is very sensitive to the value of shear stress, for that reason, care should be considered in evaluating the critical shear stress. With more undisturbed soil samples for different reaches of each canal, accurate results could be achieved.

Table (6) Effect of critical shear on the value of g_s.
Zaghlola Canal.

Sec. no.	τ_c Kg/m² 0.3	0.2	0.15
1	1.696×10^{-7}	22.05×10^{-7}	4.1×10^{-5}
2	1.701	21.5	3.84
3	1.58	1.59	2.29
4	1.59	9.54	3.07
5	1.38	1.38	0.40
6	1.60	9.60	3.28
Annual load	30 2	1901	12700

El-Zahiara Canal

Sec. no.	τ_c Kg/m² 0.3	0.2
1	5.29×10^{-7}	131.17×10^{-7}
2	5.3	132.5
3	4.13	4.13
4	4.51	4.51
5	4.16	4.16
Annual load	253	5101

Shoha Canal

Sec. no.	τ_c Kg/m² 0.3	0.2
1	3.98×10^{-6}	23.85×10^{-6}
2	3.79×10^{-6}	3.79
3	3.98	23.85
4	3.55	3.55
Annual load	1161	6714