Volume : 2 | Issue : 4 | April 2013 • ISSN No 2277 - 8160

Research Paper | Engineering

Estimating the Sediment Transport Capacity Using HEC-RAS

Jayshree Talreja	Research Scholar, M.E Civil (W.R.M), Government Engineering College, Surat, Gujrat, India
Dr. S. M. Yadav	Prof. Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Gujrat, India
Sahita Waikhom	Asso. Prof. Civil Engineering Department, Government Engineering College, Surat, Gujrat, India

ABSTRACT

Comparison of experimental results and results that obtained in HEC-RAS software is made. A steady one dimensional mathematical model for simulating the flow and estimating the sediment transport capacity of the studied flume was implemented and run by using the HEC-RAS (Version4.1.0) software. In this study experimental data set of J.P Soni has been used to compute sediment transport capacity in HEC-RAS. Englund-hansen and Ackers-White functions which were developed using mainly flume experiments are applicable in J.P Soni data set. Using HEC-RAS, the computed sediment transport rates are in much closer agreement with the actual measured values of J.P Soni data set.

KEYWORDS: HEC-RAS (4.1.0), Sediment transport capacity, Englund-hansen

Introduction

In alluvial river system, river banks will erode, sediment will be deposited, and flood plains and side channels will undergo modification with time. Effect of sedimentation in river reduces the flood carrying capacity, which may lead to flood water damage to surrounding area. Using basic principles of sediment transport one can predict the fluvial processes found in natural rivers and stream through modelling. It could be a physical model in full scale, duplicate, miniature or enlarged, or a numerical model with the help of computer software. HEC-RAS is one of the software that can help in analyzing the sediment transport capacity. Sediment transport capacity refers to the volumetric or mass rate at which the river can transport sediment (Chanson, 1999) or Sediment transport capacity is defined as the maximum sediment load that a particular discharge can transport at a certain slope Merten et al. (2001). Woo et al. (1986) studied on the sediment transport capacity under conditions remains very poorly defined. Samaga et al. (1986) introduced a multiplying correction factor. The parameters affecting this correction factor were identified and a relationship obtained for the same by analysis of an extensive amount of laboratory and river data. Aziz et al. (1989) have studied the transport of non-cohesive sediment in high gradient channels includes determination of the transport capacity of shallow flows in high gradient channels with simulated bed roughness and various grain sizes. Celik et al. (1991) formulated a fairly simple correlation for calculating the suspended sediment-transport capacity of open channel flow. Yang et al. (1991) compared different ranges of sediment concentration, Froude number, and slope for seven bed-material load formulas. The study indicates that Yang's formula by size fraction can accurately predict the size distribution of bed material in transportation, while Einstein's hiding and lifting correction factors overcorrected the effect of nonuniform size distribution of bed material on total bed-material transport. Albert Molinas et al. (2001) compared between computed and measured sediment concentrations indicate that the commonly used Engelund and Hansen, Ackers and White, and Yang equations which were developed using mainly flume experiments are not applicable for large rivers. The Toffaleti's method which was developed mainly from field data gives reasonable predictions of sediment transport rates for large rivers. Ala Hassan Nama et al. (2011) studied a one dimensional mathematical model for simulating the flow and estimating the sediment transport capacity. Jaehoon Kim et al. (2011) examined the potential restoration of abandoned channels of the Mangyeong River in South Korea using HEC-RAS. Julien et al. (1985) derived a general sediment transport capacity relationship supported by dimensional analysis. Ali et al. (2012) aimed to examine the influence of unit discharge, mean flow velocity and slope gradient on sediment transport capacity for erodible beds and also to investigate the relationship between transport capacity and composite force predictors.

Sediment transport capacity functions:

In the present study following functions are used to compute sediment transport capacity.

1. Ackers-White
2. Engelund-Hansen
3. Laursen (Copeland)
4. MPM,
5. Toffaleti
6. Yang

The details of each function along with suitability and applicability are appended as appendix I.

Flume Data

In the present study J.P Soni (1980) data set has been used to compute sediment transport capacity in HEC-RAS. The sediment used was sand of a relative density of 2.65 kg/m^3. Experiments were conducted in a 0.2m wide flume using sand of 0.320 mm. Erodible bed condition was carried out. 23 Experimental runs were carried out in this study having different slopes, and different discharges. The bed load transport rates were measured. Data set is collected from report of William R. Brownlie (1981b).

HEC-RAS

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) originally designed in 1964; The United States Army Corps of Engineers Hydrologic Engineering Center was formed to retain the expertise that post-World War II engineers had gained in hydraulics and hydrology engineering ("HEC History," 2012). It is being developed as part of the "Next Generation" (NexGen) project. A steady one dimensional flow mathematical model was used to simulate the flow in order to obtain the water surface elevation, flow velocity, and sediment transport capacity along the reach under a set of steady flow conditions. The HEC-RAS software (Version 4.1.0) was used to accomplish this target.

Methodology

In order to calculate the sediment transport capacity using HEC-RAS following steps are followed.

Step.1 Geometric data

Geometric data in HEC-RAS consists of linking the flume cross sections along the whole reach to create the schematic flume system. The modeled portion of flume having length of 30 m, 0.20 m wide and 0.50 m deep. The flume length is divided in to two parts. The down steam (end) is considered as river station 1 (RS 1) cross section while up stream of

flume is considered as river station 1 (RS 1) cross section. The data mainly include station and elevation for each cross section. Downstream reach lengths for left over bank (LOB), main channel, and right over bank (ROB) indicate the length of flume. The input data required to create geometric data file are Manning's coefficient for left over bank, main channel and right over bank. Apart from these values, expansion and contraction values are also required as input data. In the present study the Manning's value for bed is considered as 0.021 to simulate with material used in the Soni's experiment while the Manning's value for left and right over bank is taken as 0.0085 to simulate the plexi glass wall used in the Soni's experimental set up. Flow in open channel (K Subramanya) recommended value of manning's constant for plexiglass wall in the range 0.009 to 0.015. Open channel hydraulics (V.T Chow) recommended value of manning's constant for plexiglass wall in the range 0.009 to 0.015. Hence, the value considered or present study is in the range recommended by various researchers.

Step.2 Steady flow data

After entering the geometric data, flow data were entered. Flow data in HEC-RAS consists of the discharge and reach boundary conditions. The value of slope is required as one of the input to compute normal depth and carry out steady flow analysis.

Sediment transport capacity

The computation of sediment transport capacity using HEC-RAS is carried out as explained below:

1. Ackers-white In this method before computing sediment transport capacity select hiding factor from option menu.
2. Englund-hansen In this method to compute sediment transport capacity no specific function is designed in HEC-RAS.
3. Laursen In this method to compute sediment transport capacity select effective depth/effective width ratio from option menu.
4. MPM In this method to compute sediment transport capacity select hydraulic radius/top width ratio from option menu.
5. Toffaleti In this method to compute sediment transport capacity select hydraulic radius/top width ratio from option menu.
6. Yang In this method to compute sediment transport capacity select fall velocity van-rijn method from option menu.

Result and result analysis

After applying geometric data, steady flow data and hydraulic design data and by clicking on Apply window simulation has been carried out in HEC-RAS. We can get the result in sediment rating curve plot window. The morphological characteristics of the studied flume are compatible with the criteria of Engelund-Hansen and Laursen (Copeland) sediment transport function. Analysis of results has been carried out and error between computed results and actual results are shown in Table 1.

Table: 1 Analysis of J.P Soni data set

Sed Reach	Function	STC(tonnes/day)		Error %
		HEC-RAS	Actual	
SONI 1	Ackers-White	0.336	0.62477	33.80
SONI 1	Engelund-Hansen	0.684	0.62477	9.48
SONI 1	Laursen (Copeland)	0.747	0.62477	19.56
SONI 1	MPM	0.147	0.62477	-76.47
SONI 1	Toffaleti	0.082	0.62477	-86.87
SONI 1	Yang	0.4	0.62477	-35.97
SONI 2	Ackers-White	0.273	0.6057	16.39
SONI 2	Engelund-Hansen	0.594	0.6057	-1.93
SONI 2	Laursen (Copeland)	0.627	0.6057	3.51
SONI 2	MPM	0.113	0.6057	-81.34
SONI 2	Toffaleti	0.08	0.6057	-86.79
SONI 2	Yang	0.331	0.6057	-45.35
SONI 3	Ackers-White	0.348	0.5943	44.87
SONI 3	Engelund-Hansen	0.701	0.5943	17.95
SONI 3	Laursen (Copeland)	0.769	0.5943	29.39
SONI 3	MPM	0.153	0.5943	-74.25
SONI 3	Toffaleti	0.085	0.5943	-85.69
SONI 3	Yang	0.414	0.5943	-30.33
SONI 4	Ackers-White	0.268	0.8114	-14.71
SONI 4	Engelund-Hansen	0.801	0.8114	-1.28
SONI 4	Laursen (Copeland)	0.506	0.8114	-37.6
SONI 4	MPM	0.102	0.8114	-87.42
SONI 4	Toffaleti	0.139	0.8114	-82.86
SONI 4	Yang	0.379	0.8114	-53.29
SONI 5	Ackers-White	0.702	1.4876	4.79
SONI 5	Engelund-Hansen	1.596	1.4876	7.28
SONI 5	Laursen (Copeland)	1.195	1.4876	-19.69
SONI 5	MPM	0.311	1.4876	-79.09
SONI 5	Toffaleti	0.311	1.4876	-79.04
SONI 5	Yang	0.939	1.4876	-36.87
SONI 6	Ackers-White	0.395	0.8384	13.66
SONI 6	Engelund-Hansen	1.041	0.8384	24.16
SONI 6	Laursen (Copeland)	0.71	0.8384	-15.31
SONI 6	MPM	0.165	0.8384	-80.31
SONI 6	Toffaleti	0.161	0.8384	-80.79
SONI 6	Yang	0.542	0.8384	-35.34
SONI 7	Ackers-White	1.137	1.731	37.66
SONI 7	Engelund-Hansen	2.363	1.731	36.5
SONI 7	Laursen (Copeland)	1.878	1.731	8.49
SONI 7	MPM	0.506	1.731	-70.76
SONI 7	Toffaleti	0.318	1.731	-81.62
SONI 7	Yang	1.51	1.731	-12.76
SONI 8	Ackers-White	0.819	1.08	65.09
SONI 8	Engelund-Hansen	1.803	1.08	66.94
SONI 8	Laursen (Copeland)	1.378	1.08	27.59
SONI 8	MPM	0.365	1.08	-66.2
SONI 8	Toffaleti	0.311	1.08	-71.20
SONI 8	Yang	1.092	1.08	1.11
SONI 9	Ackers-White	0.229	0.9466	-35.55
SONI 9	Engelund-Hansen	0.725	0.9466	-23.41
SONI 9	Laursen (Copeland)	0.443	0.9466	-53.200
SONI 9	MPM	0.082	0.9466	-91.337
SONI 9	Toffaleti	0.13	0.9466	-86.26
SONI 9	Yang	0.33	0.9466	-65.13
SONI 10	Ackers-White	2.534	5.544	-11.41
SONI 10	Engelund-Hansen	4.844	5.544	-12.626
SONI 10	Laursen (Copeland)	4.005	5.544	-27.759
SONI 10	MPM	1.078	5.544	-80.55
SONI 10	Toffaleti	0.648	5.544	-88.311
SONI 10	Yang	3.391	5.544	-38.83
SONI 11	Ackers-White	1.441	4.057	-27.45
SONI 11	Engelund-Hansen	2.896	4.057	-28.61
SONI 11	Laursen (Copeland)	2.357	4.057	-41.9
SONI 11	MPM	0.636	4.057	-84.3
SONI 11	Toffaleti	0.322	4.057	-92.06
SONI 11	Yang	1.912	4.057	-52.87
SONI 12	Ackers-White	0.116	0.3428	5.017
SONI 12	Engelund-Hansen	0.396	0.3428	15.519
SONI 12	Laursen (Copeland)	0.295	0.3428	-13.947
SONI 12	MPM	0.028	0.3428	-91.8
SONI 12	Toffaleti	0.101	0.3428	-70.53

SONI 12	Yang	0.165	0.3428	-51.866
SONI 13	Ackers-White	0.231	0.5371	14.313
SONI 13	Engelund-Hansen	0.658	0.5371	22.502
SONI 13	Laursen (Copeland)	0.478	0.5371	-11.00
SONI 13	MPM	0.085	0.5371	-84.17
SONI 13	Toffaleti	0.126	0.5371	-76.54
SONI 13	Yang	0.315	0.5371	-41.35
SONI 14	Ackers-White	0.417	1.036	-3.76
SONI 14	Engelund-Hansen	1.165	1.036	12.45
SONI 14	Laursen (Copeland)	0.711	1.036	-31.370
SONI 14	MPM	0.174	1.036	-83.2
SONI 14	Toffaleti	0.173	1.036	-83.3
SONI 14	Yang	0.593	1.036	-42.76
SONI 15	Ackers-White	0.379	1.036	-11.29
SONI 15	Engelund-Hansen	1.177	1.036	13.610
SONI 15	Laursen (Copeland)	0.622	1.036	-39.99
SONI 15	MPM	0.153	1.036	-85.23
SONI 15	Toffaleti	0.16	1.036	-84.55
SONI 15	Yang	0.564	1.036	-45.5
SONI 16	Ackers-White	0.037	0.04133	282.28
SONI 16	Engelund-Hansen	0.129	0.04133	212.12
SONI 16	Laursen (Copeland)	0.215	0.04133	420.20
SONI 16	MPM	0	0.04133	-100
SONI 16	Toffaleti	0.041	0.04133	-0.79
SONI 16	Yang	0.047	0.04133	13.71
SONI 17	Ackers-White	0.465	1	9.7
SONI 17	Engelund-Hansen	0.964	1	-3.6
SONI 17	Laursen (Copeland)	0.911	1	-8.9
SONI 17	MPM	0.208	1	-79.2
SONI 17	Toffaleti	0.151	1	-84.9
SONI 17	Yang	0.574	1	-42.6
SONI 18	Ackers-White	0.527	1.3143	-7.25
SONI 18	Engelund-Hansen	1.165	1.3143	-11.35
SONI 18	Laursen (Copeland)	0.98	1.3143	-25.43
SONI 18	MPM	0.233	1.3143	-82.28
SONI 18	Toffaleti	0.21	1.3143	-84.021
SONI 18	Yang	0.678	1.3143	-48.41
SONI 19	Ackers-White	0.209	0.3466	61.85
SONI 19	Engelund-Hansen	0.33	0.3466	-4.78
SONI 19	Laursen (Copeland)	0.737	0.3466	112.6
SONI 19	MPM	0.094	0.3466	-72.87
SONI 19	Toffaleti	0.131	0.3466	-62.21
SONI 19	Yang	0.206	0.3466	-40.56
SONI 20	Ackers-White	0.763	1.58	6.01
SONI 20	Engelund-Hansen	1.133	1.58	-28.29
SONI 20	Laursen (Copeland)	1.699	1.58	7.57
SONI 20	MPM	0.371	1.58	-76.51
SONI 20	Toffaleti	0.361	1.58	-77.151
SONI 20	Yang	0.824	1.58	-47.84
SONI 21	Ackers-White	1.279	2.4	10.25
SONI 21	Engelund-Hansen	1.979	2.4	-17.54
SONI 21	Laursen (Copeland)	2.489	2.4	3.7083
SONI 21	MPM	0.598	2.4	-75.08
SONI 21	Toffaleti	0.491	2.4	-79.54
SONI 21	Yang	1.466	2.4	-38.91
SONI 22	Ackers-White	1.854	4.057	-8.92
SONI 22	Engelund-Hansen	3.051	4.057	-24.7
SONI 22	Laursen (Copeland)	3.303	4.057	-18.58
SONI 22	MPM	0.832	4.057	-79.49
SONI 22	Toffaleti	0.622	4.057	-84.66
SONI 22	Yang	2.246	4.057	-44.63
SONI 23	Ackers-White	2.328	5.2572	-13.54
SONI 23	Engelund-Hansen	4.109	5.2572	-21.84
SONI 23	Laursen (Copeland)	3.893	5.2572	-25.94
SONI 23	MPM	1.011	5.2572	-80.76
SONI 23	Toffaleti	0.697	5.2572	-86.74
SONI 23	Yang	2.968	5.2572	-43.54

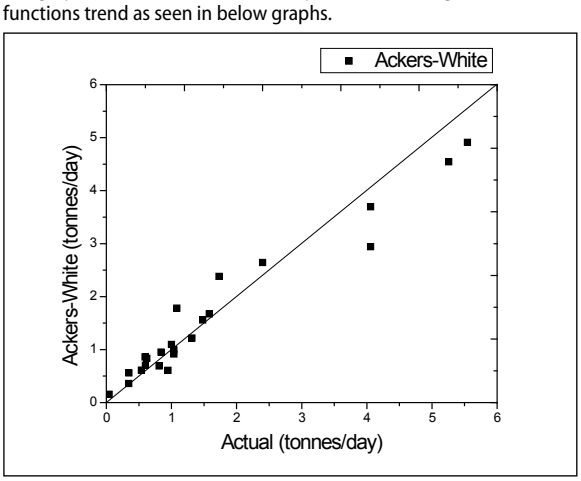
Mean normalise error is also obtained by following formula, MNE % for J.P Soni data set is shown in Table 2. The mean normalized error, MNE is defined as the average value of absolute relative error between computed and actual sediment transport capacity.

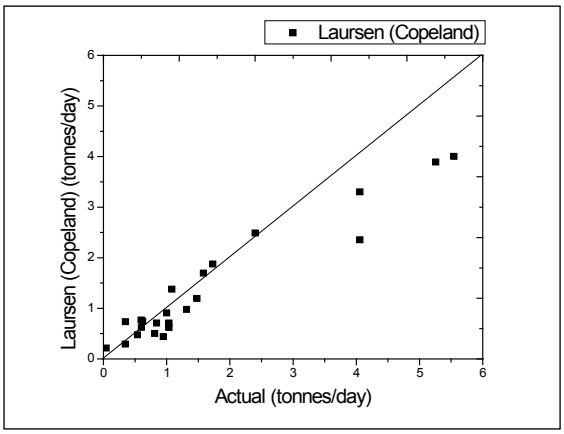
MNE % =
= Computed sediment transport capacity using HEC-RAS
= Actual sediment transport capacity given in data set

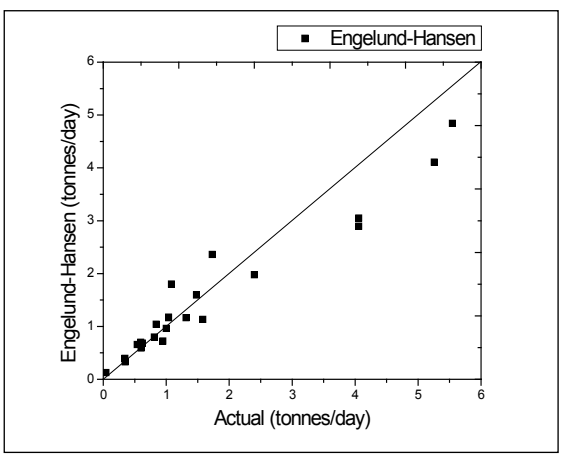
Table 2 MNE % for J.P Soni data set

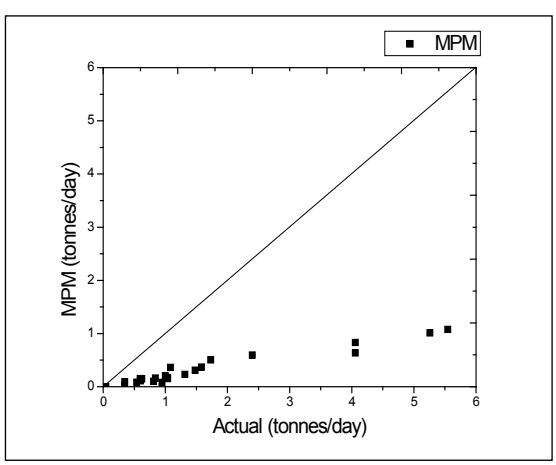
Sr No.	Function	MNE %
1	Ackers-White	20.51
2	Engelund-Hansen	11.23
3	Laursen (Copeland)	11.39
4	MPM	-80.98
5	Toffaleti	-78.11
6	Yang	-38.26

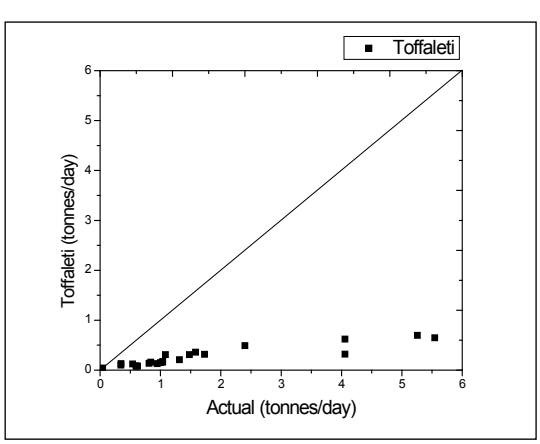
The graph of actual and HEC-RAS output is shown in fig.1 The HEC-RAS functions trend as seen in below graphs.











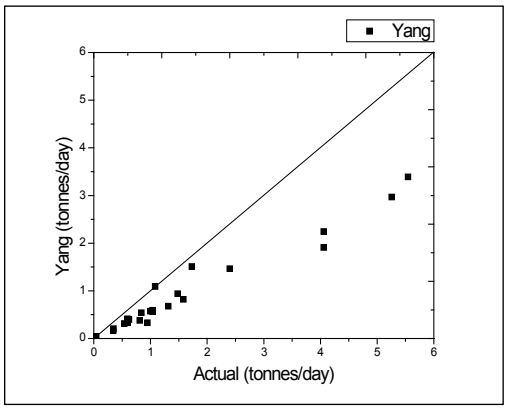


Fig. 1 The relation between actual and HEC-RAS output for J.P Soni data set

Conclusion:

- The experimental and computed values of sediment transport capacity are in good agreement after Engelund-Hansen's function.
- The experimental and computed values of sediment transport capacity are in second good agreement after Laursen's function.
- In HEC-RAS software hiding factor is considered to compute sediment transport capacity in Ackers-White's function. This may be the one of the reason that the sediment transport capacity computed by Ackers-White's function is in third good agreement with the experimental value.
- The sediment transport capacity computed using Toffaleti function under predict the computed values as the Toffaleti function is more suitable up to 0.095 mm median diameter while the median diameter of J.P Soni data set is 0.320mm.
- The sediment transport capacity computed using MPM function under predict the computed values as the MPM function is more suitable for coarser material.
- In HEC-RAS software fall velocity is computed using Van-Rijn equation. This fall velocity is used to compute sediment transport capacity in Yang's function.
- The sediment transport capacity computed using Yang function under predict the computed values.

Appendix i
Notations

Actual = sediment transport rate given by samaga et al. during their experiment
A-W = Ackers-White
E-H = Engelund-Hansen
LAU = Laursen
MPM = Meyer-Peter Müller
X= sediment concentration in parts/part,
Ggr= sediment transport parameter,
s= specific gravity of sediments,
ds= mean particle diameter,
D= effective depth,
u*= shear velocity,
V= average channel velocity,
n= transition exponent, dependent on sediment size,
C= coefficient,
Fgr= sediment mobility parameter
A= critical sediment mobility parameter.
gs=unit sediment transport,
γ = unit weight of solid particles,
γs , G = unit weight of water,
τo = bed level shear stress .
Cm= sediment discharge concentration in weight/volume,
D= effective depth of flow,
$\tau_{o'}$ = bed shear stress due to grain resistance,
τ_c = critical bed shear stress
f()= function of the ratio of shear velocity to fall velocity as defined by Larsen.
gs= unit sediment transport rate in weight/time/unit width,
kr= a roughness coefficient,
kr'= a roughness coefficient based on grains,

γ = unit weight of water (Meyer-Peter Müller function)
γ_s = unit weight of sediment (Meyer-Peter Müller function)
g= acceleration of gravity,
R= hydraulic radius
g_s = Total sediment transport (tons/day/ft), (TOFFALETI function)
g_{ssL} = Suspended sediment transport in lower zone (tons/day/ft),
g_{ssM} = Suspended sediment transport in the middle zone (tons/day/ft),
g_{ssU} = Suspended sediment transport in the upper zone (tons/day/ft),
g_{sb} = Bed load sediment transport (tons/day/ft),
M= Sediment concentration parameter,
CL= Sediment concentration in the lower zone,
R= Hydraulic radius,
d50= Median particle diameter,
z= Exponent describing the relationship between the sediment and hydraulic characteristics
nv= Temperature component.
ω = Particle fall velocity,
v= Kinematic viscosity,
SE= Energy gradient.
MNE= Mean normalize error
STC= Sediment transport capacity

Appendix ii
Equations used in HEC-RAS
Ackers-White

The Ackers-White transport function is a total load function developed under the assumption that fine sediment transport is best related to the turbulent fluctuations in the water column and coarse sediment transport is best related to the net grain shear with the mean velocity used as the representative variable. The transport function was developed in terms of particle size, mobility, and transport. A dimensionless size parameter is used to distinguish between the fine, transitionary, and coarse sediment sizes. Under typical conditions, fine sediments are silts less than 0.04 mm, and coarse sediments are sands greater than 2.5 mm. Since the relationships developed by Ackers-White are applicable only to non-cohesive sands greater than 0.04 mm, only transitionary and coarse sediments apply. Original experiments were conducted with coarse grains up to 4 mm, however the applicability range was extended to 7 mm.

The general transport equation for the Ackers-White function for a single grain size is represented by:

$$X = \frac{G_{gr} s d_s}{D\left(\frac{u_*}{V}\right)^n} \text{ and } \quad G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right) \ldots\ldots\ldots\ldots (1)$$

where *X*= sediment concentration in parts/part, *Ggr*= sediment transport parameter, *s*= specific gravity of sediments, *ds*= mean particle diameter, *D*= effective depth, *u**= shear velocity, *V*= average channel velocity, *n*= transition exponent, dependent on sediment size, *C*= coefficient, *Fgr*= sediment mobility parameter and *A*= critical sediment mobility parameter.

Engelund-Hansen:

The Engelund-Hansen function is a total load predictor which gives adequate results for sandy rivers with substantial suspended load. It is based on flume data with sediment sizes between 0.19 and 0.93 mm. It has been extensively tested, and found to be fairly consistent with field data.

The general transport equation for the Engelund-Hansen function is represented by:

$$g_s = 0.05\gamma_s V^2 \sqrt{\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma} - 1\right)}} \left[\frac{\tau_0}{(\gamma_s - \gamma) d_{50}}\right]^{3/2} \ldots\ldots\ldots\ldots (2)$$

Where *gs*=unit sediment transport, γ = unit weight of solid particles, γ_s = unit weight of water, *V*= average channel velocity, τ_o = bed level shear stress and *d50*= mean particle size.

Laursen: The Laursen method is a total sediment load predictor, derived from a combination of qualitative analysis, original experiments, and supplementary data. Transport of sediments is primarily defined based on the hydraulic characteristics of mean channel velocity, depth of flow, energy gradient, and on the sediment characteristics of gradation and fall velocity. Contributions by Copeland (Copeland, 1989) extend the range of applicability to gravel-sized sediments. The range of applicability is 0.011 to 29 mm, median particle diameter.

The general transport equation for the Laursen (Copeland) function for a single grain size is represented by:

$$C_m = 0.01\,\gamma\left(\frac{\tau'_0}{\tau_c} - 1\right) f\left(\frac{u_*}{\omega}\right) \ldots\ldots\ldots\ldots (3)$$

Where *Cm*= sediment discharge concentration in weight/volume, *G*= unit weight of water, *ds* = mean particle diameter, *D*= effective depth of flow, $\tau_{o'}$ = bed shear stress due to grain resistance, τ_c = critical bed shear stress and *f*()= function of the ratio of shear velocity to fall velocity as defined by Larsen.

Meyer-Peter Müller:

The Meyer-Peter Müller bed load transport function is based primarily on experimental data and has been extensively tested and used for rivers with relatively coarse sediment. The transport rate is proportional to the difference between the mean shear stress acting on the grain and the critical shear stress. Applicable particle sizes range from 0.4 to 29 mm with a sediment specific gravity range of 1.25 to in excess of 4.0.This method can be used for well-graded sediments and flow conditions that produce other-than-plane bed forms.

$$\left(\frac{k_r}{k_r'}\right)^{\frac{3}{2}} \gamma RS = 0.047(\gamma_s - \gamma) d_m + 0.25\left(\frac{\gamma}{g}\right)^{\frac{1}{3}} \left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}} g_s^{\frac{2}{3}} \ldots\ldots\ldots\ldots (4)$$

where *gs*= unit sediment transport rate in weight/time/unit width, *kr*= a roughness coefficient, *kr'*= a roughness coefficient based on grains, γ = unit weight of water, γ_s = unit weight of sediment, *g*= acceleration of gravity, *d50*= median particle diameter, *R*= hydraulic radius and *SE*= energy gradient.

Toffaleti:

The Toffaleti method is a modified-Einstein total load function that breaks the suspended load distribution into vertical zones, replicating two-dimensional sediment movement. Four zones are used to define the sediment distribution. They are the upper zone, the middle zone, the lower zone and the bed zone. Sediment transport is calculated independently for each zone and the summed to arrive at total sediment transport. The flume experiments used sediment particles with mean diameters ranging from 0.3 to 0.93 mm, however successful applications of the Toffaleti method suggests that mean particle diameters as low as 0.095 mm are acceptable.

The general transport equations for the Toffaleti function for a single grain size is represented by:

$$g_{ssL} = M\,\frac{\left(\frac{R}{11.24}\right)^{1+n_v-0.756z} - (2d_m)^{1+n_v-0.756z}}{1+n_v-0.756z} \quad \text{(Lower zone)} \ldots\ldots\ldots (5)$$

$$g_{ssM} = M\,\frac{\left(\frac{R}{11.24}\right)^{0.244z}\left[\left(\frac{R}{2.5}\right)^{1+n_v-z} - \left(\frac{R}{11.24}\right)^{1+n_v-z}\right]}{1+n_v-z}$$
(Middle zone).....(6)

$$g_{ssU} = M\,\frac{\left(\frac{R}{11.24}\right)^{0.244z}\left(\frac{R}{2.5}\right)^{0.5z}\left[R^{1+n_v-1.5z} - \left(\frac{R}{2.5}\right)^{1+n_v-1.5z}\right]}{1+n_v-1.5z}$$
(Upper zone).....(7)

$$g_{sb} = M\,(2d_m)^{1+n_v-0.756z} \ldots\ldots\ldots\ldots (8)$$

$$M = 43.2C_L(1+n_v)VR^{0.756z-n_v}$$

$$g_s = g_{ssL} + g_{ssM} + g_{ssU} + g_{sb} \ldots\ldots\ldots\ldots (9)$$

Where, g_s = Total sediment transport (tons/day/ft), g_{ssL} = Suspended sediment transport in lower zone (tons/day/ft), g_{ssM} = Suspended sediment transport in the middle zone (tons/day/ft), g_{ssU} = Suspended sediment transport in the upper zone (tons/day/ft), g_{sb} = Bed load sediment transport (tons/day/ft), *M*= Sediment concentration parameter,

CL= Sediment concentration in the lower zone, *R*= Hydraulic radius, *d50*= Median particle diameter, *z*= Exponent describing the relationship between the sediment and hydraulic characteristics and *nv*= Temperature component.

Yang:

Yang's method (1973) is developed under the premise that unit stream power is the dominant factor in the determination of total sediment concentration. The research is supported by data obtained in both flume experiments and field data under a wide range conditions found in alluvial channels. Principally, the sediment size range is between 0.062 and 7.0 mm with total sediment concentration ranging from 10 ppm to 585,000 ppm. Channel widths range from 0.44 to1746 ft, depths from 0.037 to 49.4 ft, water temperature from 0o to 34.3o Celsius, average channel velocity from 0.75 to 6.45 fps, and slopes from 0.000043 to 0.029.

Yang (1984) expanded the applicability of his function to include gravel-sized sediments. The general transport equations for sand and gravel using the Yang function for a single grain size is represented by:

$$\log C_t = 5.435 - 0.286\log\frac{\omega d_m}{v} - 0.457\log\frac{u_*}{\omega} + \left(1.799 - 0.409\log\frac{\omega d_m}{v} - 0.314\log\frac{u_*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \quad \text{for sand } d_m < 2\text{mm} \quad \ldots\ldots(10)$$

$$\log C_t = 6.681 - 0.633\log\frac{\omega d_m}{v} - 4.816\log\frac{u_*}{\omega} + \left(2.784 - 0.305\log\frac{\omega d_m}{v} - 0.282\log\frac{u_*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \quad \text{for gravel } d_m \geq 2\text{mm} \quad \ldots\ldots(11)$$

Where, ω = Particle fall velocity, d50= Median particle diameter, v= Kinematic viscosity, u*= Shear velocity, V= Average channel velocitand SE= Energy gradient.

REFERENCES

1 Ala Hassan Nama (2011); "Estimating the sediment transport capacity of Tigris river within al Mosul city", Journal of Engineering, Vol. 3, 17 . 2. Albert Molinas, Baosheng Wu (2001); "Transport of sediment in large sand-bed rivers Journal of hydraulic research"; Vol. 39, 2001, NO. 2. 3. Aziz, N. and Prasad, S. (1985), "Sediment Transport in Shallow Flows Journal of hydraulic engineering"; Vol. 111, Issue 10. 4. B. Camenen (2011); Discussion of "Understanding the influence of slope on the threshold of coarse grain motion: revisiting critical stream power" by C. Parker, N.J. Clifford, and C.R. 3 Thorne 4 Geomorphology, Volume 126, 5 March 2011, Pages 51-65 5. Bagnold, R. A.(1966). An approach to the sediment transport problem from general physics, United States Geological Survey Professional Paper: 422–I. 6. Belle R. Samaga, Kuttur G. Ranga Raju (1986) ; "Bed Load Transport of Sediment Mixtures, Journal of hydraulic engineering"; Vol. 112, No. 11. 7. Brownlie, W. R. 1981b, "Compilation of Alluvial Channel Data: Laboratory and Filed." Report No. KH-R-43B, W. M. Keck Laboratory of Hydraulics and Water Resources Division of Engineering and Applied Science, California Institute of Technology, Pasadena, California, 309pp. 8. Celik, I. and Rodi, W. (1991) , "Suspended Sediment-Transport Capacity for Open Channel Flow Journal of hydraulic engineering"; Vol. 117, Issue 2. 9. Chanson, H. (1999), "The hydraulics of open channel flow", New York, New York: John Wiley & Sons. 10. Dr. A.K. Jain (2007), Fluid Mechanics, Khanna Publishers, New Delhi 11. Garde, R J and Rangha Raju, K.G (2006), Mechanics of sediment transportation and alluvial stream problems, Third Edition, New age Publication, New Delhi. 12. Garnett P. Williams (1968), Flume experiments on the transport of a coarse sand Geological survey professional paper. 13. Jaehoon Kim, Pierre Y. Julien, Un Ji, Joongu Kang (2011).," Restoration Modeling Analysis for Abandoned Channels of the Mangyeong River", Journal of the Environmental Sciences, Vol. 555564. 14. K Subramanya (2004), Flow in open channel, Second Edition, Tata McGraw Hill Publication, New Delhi. 15. M. Ali, G. Sterk, M. Seeger, M. Boersema, and P. Peters 2012; "Effect of hydraulic parameters on sediment transport capacity in overland flow over erodible beds", Hydrol. Earth Syst. Sci., Vol. 16, 591–601, 2012. 16. Merten, G. H (2001)., Nearing, M. A., and Borges, A. L. O.: Effect of sediment load on soil detachment and deposition in rills, Soil Sci. Soc. Am. J., 65, 861–868. 17. Nadim M. Aziz, David E. Scott (1989); "Experiments on sediment transport in shallow flows in high gradient channels", Hydrologjcal Sciences - Journal - des Sciences Hydrolog/ques Vol. 34,4, 8/1989. 18. P.Y. Julien, D.B. Simons (1985); "Sediment transport capacity of overland flow", American society of agricultural engineers, Vol. 28(3): May-June, 2012. 19. Smart, G. (1984), "Sediment Transport Formula for Steep Channels, Journal of hydraulic engineering"; Vol. 110, Issue 3. 20. U.S. Army Corps of Engineers. (n.d.) HEC History. Retrieved February 7, 2012, from http://www.hec.usace.army.mil/whoweare/history.html 21. U.S Army Corps of Engineers "HEC-RAS Version 4.1 software" www.hec.usace.army.mil/software/hec-ras 22. V.T.Chow(1959), Open-Channel Hydraulics, Tata McGraw Hill Publication, New Delhi. 23. Vajapeyam S. Srinivasan, Raul G. Cavalcante and Celso A. G. Santos (2008)., "A Comparative Study Of Some Of The Sediment Transport Equations For An Alluvial Channel With Dunes", Journal of Urban and Environmental Engineering v.2, n.1, p.28-32. 24. Woo, H., Julien, P., and Richardson, E. (1986), "Washload and Fine Sediment Load", Journal of hydraulic engineering; Vol. 112, Issue 6. 25. Yang, C. and Wan, S.(1991), "Comparisons of Selected BedMaterial Load Formulas Journal of hydraulic engineering"; Vol. 117, Issue 8.