Academia Journal of Environmental Sciences 2(2): 029-036, February 2014
DOI: http://dx.doi.org/10.15413/ajes.2013.0032
ISSN: 2315-778X

Research Paper

Sediment transport analysis and modelling using winxspro: "A case study of the sediment transport apparatus"

I.R. Ilaboya[1]*, E.O. Oti[1], G.O. Ekoh[2] and L.O. Umukoro[3]

[1]Department of Civil Engineering, Faculty of Engineering, PMB 1154, University of Benin; Benin City, Nigeria.
[2]Works Department, Akanu Ibiam Federal Polytechnic Uwana Afikpo, Ebonyi State, Nigeria.
[3]Department of Civil Engineering, Igbinedion University, Okada, Edo State, Nigeria.

*Corresponding author. E-mail: id_rudolph@yahoo.com; Tel: +2348038027260.

Accepted 28th November, 2013

ABSTRACT

The focus of the research paper was to study the dynamics of sediment transport in river flow channel using the sediment transport apparatus. Field measurement derived from sediment transport apparatus and computer models were used to estimate bank full discharge and bed load transport along the channel. Cross-sectional profiles such as longitudinal distance along the channel and the water/bed surface elevation were measured to simulate real river scenario. Linear regression statistical model was then employed to generate the linear relationship between horizontal distance along the channel and the corresponding water/bed surface elevation. The final equation was then used to extrapolate sufficient data that was used for the modeling. These data were then incorporated into software (WinXSPRO) that aids in the characterization and computation of stage, discharge, velocity, and shear stress in addition to the hydraulic depth, fraud number and other parameters used in assessing a typical stream conditions. The relationship between the computed hydraulic parameters was thereafter studied using the parameter plot option of the software.

Key words: Winxspro, sediment transport, regression analysis, cross-sectional profiles, hydraulic parameters.

INTRODUCTION

Water flowing in a channel has the ability to remove materials from the channel bed and sides and transport it downstream. This action is called sediment transport and is of considerable economic importance (Ferguson, 1984). The removal of materials or scour around structures such as bridge piers may cause collapse of the structure. More also, deposition of sediments can block navigable channels and water control gates and weirs requiring dredging and if not, flooding can result, since the water channel capacity can be reduced drastically (Hallet et al., 1996).

Sediment transport studies are gradually becoming a very important aspect of fluid flow hydrodynamics in addition to gully head studies and erodibility. The major focus of this research work is to understand the concept and dynamics of sediment transport through simulated river channel which can find application in a real life situation. One of the most obvious problems in sediment transport analysis and modeling is the danger posed by data collection especially when it involves very deep river channel. For Shallow River, data collection can be a lot easier compare to deep river. Sediment transport studies involving the use of laboratory apparatus will help overcome such limitations.

One of the major objective of this studies, is to generate data that can be use to predict real life scenario. In this research, river flow dynamics and characteristics were studied using the sediment transport model apparatus (Figure 7). Cross-sectional profiles such as longitudinal distance along the channel and the water/bed surface elevation were measured to simulate real river scenario and linear regression statistical modeling was then employed to generate the linear relationship between horizontal distance along the channel and the corresponding water/bed surface elevation.

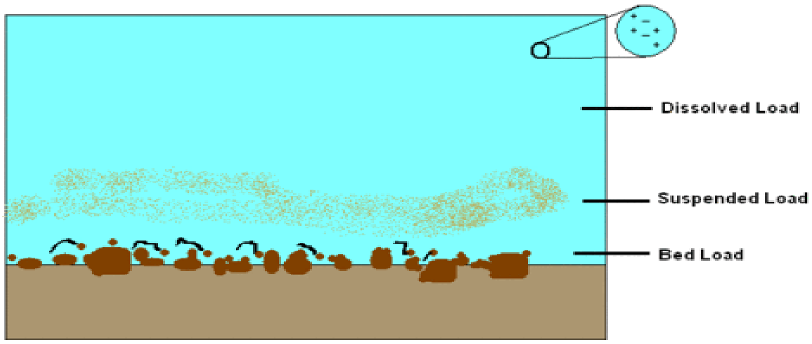

Figure 1. Different types of sediment loads.

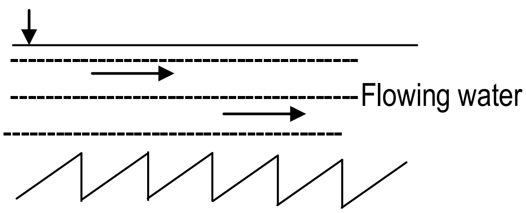

Figure 2: Saw-tooth Ripples

DYNAMICS OF SEDIMENT TRANSPORT

Sediment transport dynamics encompasses the way and manner sediment materials are moved along the channel. For bed load, materials are moved along a bed by drag force between the fluid and individual material particles. These materials (load) normally move on or near the stream bed by rolling, sliding and sometimes making brief excursions into the flow a few diameters above the bed i.e. jumping. The term "saltation" is sometime used in place of "jumping" (Hardy et al., 2005).

Bed load is generally thought to constitute 5-10% of the total sediment load in a stream, making it less important in terms of mass balance. However, the bed material load (the bed load plus the portion of the suspended load which comprises material derived from the bed) is often dominated by bed load, especially in gravel-bed Rivers. This bed material load is the only part of the sediment load that actively interacts with the bed, thus making the bed load an important component in river channel studies, more also, the bed load plays a major role in controlling the morphology of the channel (Meyer-Peter and Muller, 1948). Bed load transport rates are usually expressed as being related to excess dimensionless shear stress raised to some power (Meyer-Peter and Muller, 1948). Excess dimensionless shear stress is a non-dimensional measure of bed shear stress about the threshold for motion.

For suspended load, materials are held in the main water stream by turbulence. In times of flood, the materials can be boulders, weighing several tones, with the capacity of tremendous destruction (Parker et al., 1982).

Dissolved load is not sediment: it is composed of disassociated ions moving along with the flow. It may, however, constitute a significant proportion (often several percent, but occasionally greater than half) of the total amount of material being transported by the stream (Nielson, 1974). The different loads that occur during the flow of water along the river channel are shown in Figure 1.

Sediment motion along the channel causes the bed to form different shapes. At low velocity, there is no motion of the bed. As the velocity gradually increase, then a stage is reached when the sediment load comes just at the point of motion: this stage is called the "Threshold Stage" of motion. On further increase of velocity, the bed develops ripples of saw-tooth type as shown in Figure 2 (Miller and Drever, 1977).

As the velocity of flow of water increases further, larger features called dunes appear. Initial dunes may have ripples superimposed on their surface and a dune tends to be more rounded than ripple (Figure 3).

At higher velocity of flowing water, the ripples disappear living only the dunes (Figure 4).

As the stream velocity increases further, the dunes are erased by the flow leaving an essential flat surface with sediment particles in motion (Figure 5).

As the velocity increases further, so that the Froude number (relationship between stream velocity and wave velocity) (F= $\frac{V^2}{gL}$) is greater than unity (F>1), the flow becomes super critical and the surface waves become so steep that they break intermittently and move upstream although the sediment particles keep moving downstream (Figure 6) (Harbor and Wheeler, 1992).

MATERIALS AND METHODS

Data collection

The sediment transport apparatus (Figure 7) was used to simulate an ideal single channel flow scenario so as to allow

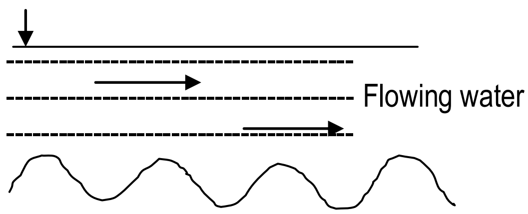

Figure 3: Dunes

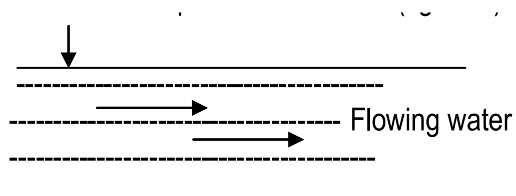

Figure 4: Flat Surface

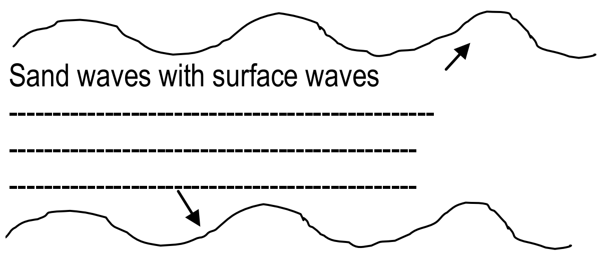

Figure 5: Sand waves in association with surface waves

for the collection of hydraulic parameters such as longitudinal distance (X) along the channel and the water/bed surface elevation that was used in the modeling. The central channel of the transport apparatus was filled with coarse particles of varying diameter to form the bed load. The apparatus was then subdivided into different horizontal section to obtain (X_1, X_2, X_3, X_4 and X_5). The corresponding (water surface/bed) elevation against the different horizontal distances was measured using the depth probe to obtain data for position-elevation. Linear regression approach using SPSS was thereafter employed to generate a linear regression equation to show the interrelationship between the horizontal distance and the water/bed elevation. Data extrapolation was done using the linear regression equation to generate enough data for the modeling.

Winxspro configuration

Before running the Ackers and White Method for bed load computation, a stage-discharge relationship was first generated for the extrapolated data using the software. The stage-discharge relationship was then set as the input file in the plan window. The input data section was set to Position-Elevation, d_{50} was computed to be 1.5 mm and the left/right horizontal boundary was set to 0.00 and 50.00 respectively. For this analysis, the user supplied manning's option from the main program window was used (0.045 and 0.025 for the low and high stage respectively). A low stage of 0.02 and a high stage of 0.35 with corresponding slopes of 0.005 were assumed in addition to a stage increment of 1.0 foot. The output file, d_{50}, and the corresponding water temperature were used as the input file for the Ackers and White method for sediment load analysis (Ackers and White, 1973; Aldridge and Garrett, 1973; Arcement, and Schneider, 1984).

Data analysis

Data generated was incorporated into the software (WINXSPRO). A constant value (0.03) of the manning's roughness factor was selected in addition to a constant channel slope of 0.005, Ackers and white model equation for bed load computation was employed for the final analysis and modeling. WINXSPRO is a software design to analyze stream channel cross section, generate geometric and hydraulic date for single channel flow and perform sediment transport analysis and modeling. The software allows the user to subdivide the channel cross-section into multiple sub-sections and has the ability to vary water-surface slopes with discharge to reflect natural conditions. Some of the application of the software includes: Evaluating changes in channel cross-sectional area, Developing stage discharge relationship and performing sediment transport analysis and modeling.

RESULTS AND DISCUSSION

The sediment transport apparatus was first subdivided into seven (7) sections and the corresponding water/bed elevation were then determined simultaneously. Results obtained are shown Table 1.

A linear regression analysis was then conducted using statistical package for social sciences (SPSS) to ascertain the correlation between the segmented channel elevation and the corresponding water/bed elevation. The results of the linear regression analysis are shown Table 2.

The Adjusted R Square value of 0.948 shown in the model summary reveals that the linear regression model developed to show the Collinearity accounts for about 94.8% of the relationship. Hence there is a strong linear relationship up to about 94.8% between the longitudinal distance along the channel and the water/bed elevation.

The coefficient of determination (R square) (0.957) which measures the fitness of the predictor values to the regression model also shown that predictor values obtained possesses a very good fitness. The linear correlation

Figure 6: Sediment Transport Apparatus

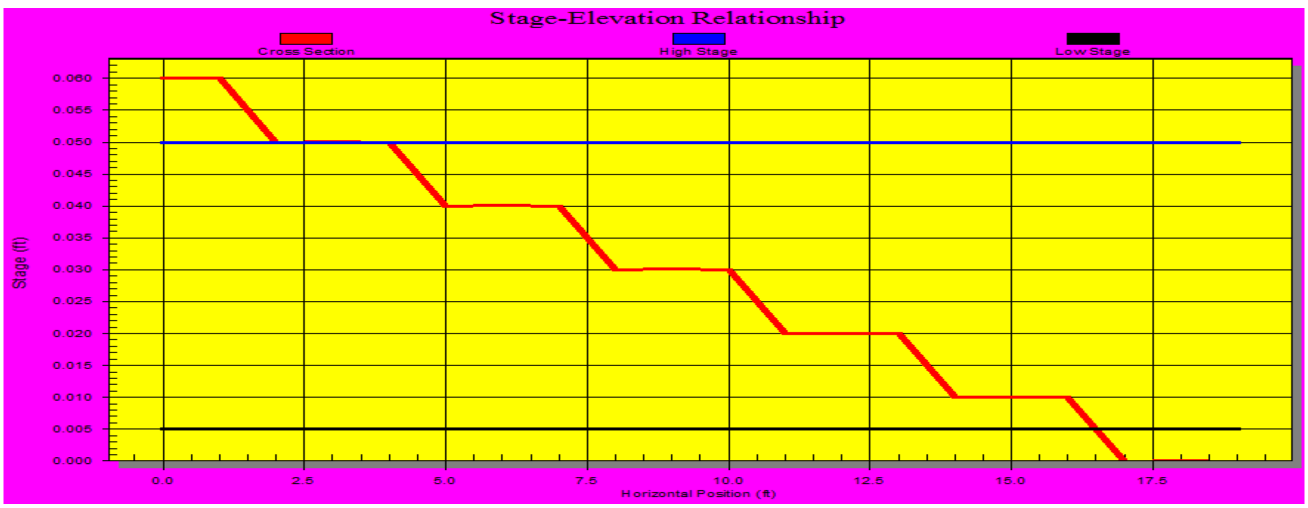

Figure 7. Stage–elevation relationship.

coefficient (R = 0.978) could also be used to established the strong linear relationship between the dependent and the predictor variable as shown in Table 2. The analysis of variance (ANOVA) result helps to assess the overall significance of our model. At $p > 0.05$, the result shows a very high significant for the model developed (Table 3).

On the bases of the statistical results, it was established that results obtained are highly significant and can be utilized for the final analysis. A linear regression equation was thereafter developed using the unstandardized coefficients as shown in Table 4.

The linear regression model equation was obtained from the results of standardized/unstandardized coefficients and given as follows:

$$X = 896.051-297.735Y \quad (1)$$

Where: X and Y represent the longitudinal distance along the channel and the water/bed elevation respectively. This linear regression model equation was then tested as follows: (at X = 0, Y =3.0), (at X = 13, Y = 2.97) and was certified very correct. The equation was then adopted to generate enough data for the modeling. The adopted equation was then taken to excel solver to extrapolate data for the analysis using WinXSPRO and results obtained are discussed.

The stage – elevation relationship as shown in Figure 8; shows a progressive decrease in the bed elevation with increasing channel stage. In Figure 9; it was established that the stage of the channel increases with increasing discharge which invariably increases with increase in the hydraulic radius occasioned by the changing configuration of the channel width. The average velocity of flow as

Table 1. Data generated from the sediment transport apparatus.

X	0	13	26	39	52	65	78
Ele.	3	2.97	2.93	2.87	2.84	2.76	2.78

Table 2. Regression analysis model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.978[a]	0.957	0.948	6.379

a. Predictors: (Constant), Elevation. b. Dependent Variable: Longitudinal Distance.

Table 3. Analysis of variance (ANOVA) result.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	4528.548	1	4528.55		
Residual	203.452	5	40.690	111.3	0.000[a]
Total	4732.000	6			

a. Predictors: (Constant), Elevation, b. Dependent Variable: Longitudinal Distance.

Table 4. Results of standardized/unstandardized coefficients.

Model		Unstandardized Coefficients		Standardized Coefficients
		B	Std. Error	Beta
1	(Constant)	896.051	81.276	
	Elevation	-297.735	28.223	-0.978

a. Dependent Variable: Longitudinal Distance.

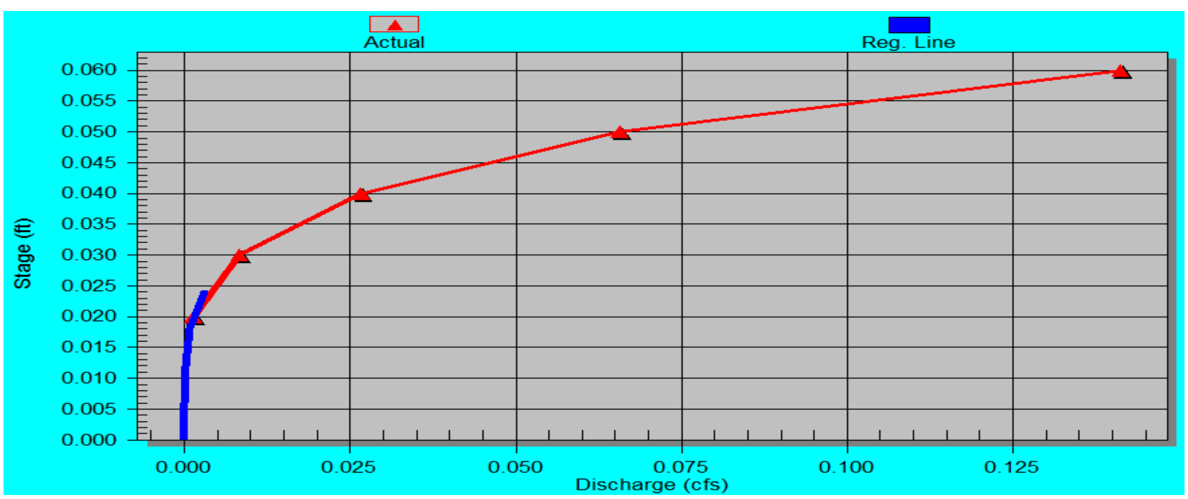

Figure 8. Stage–discharge relationship.

explained by the model shows a characteristic Fourier form which is expected for a flow that transient from uniform to non-uniform mechanism which is predefine by the hydraulic theory as postulated in the applications of general physics to solving sediment transport problems (Bagnold, 1966). Figure 12 explain flow as a function of channel area; the behaviour is typical since flow and area is directly related (both are directly proportional as define by

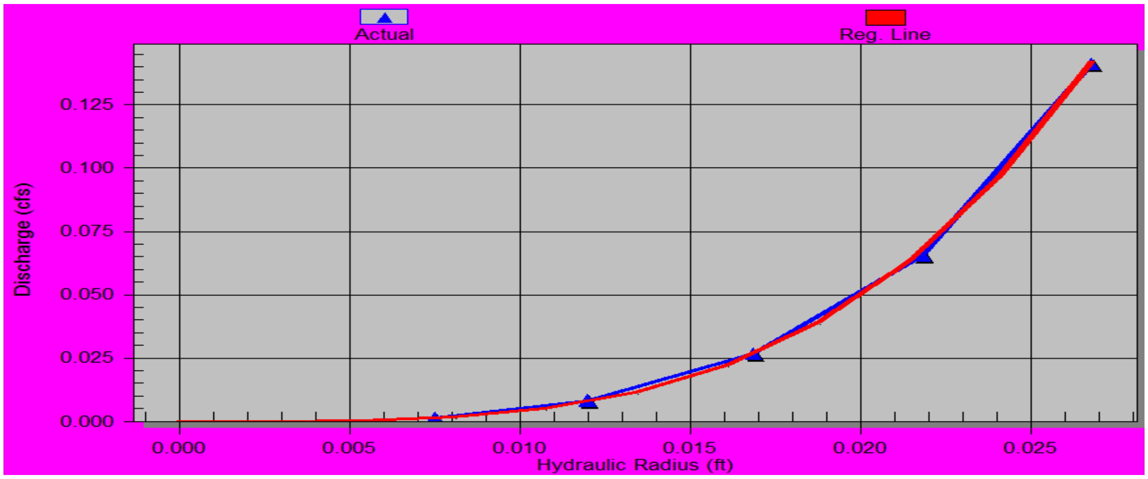

Figure 9. Discharge–hydraulic radius relationship.

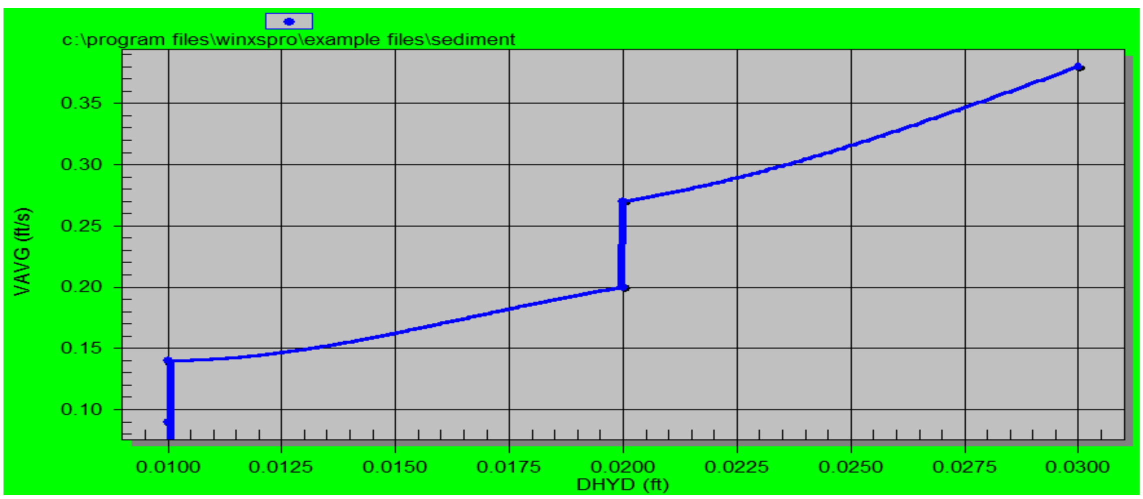

Figure 10. Average velocity–hydraulic radius relationship.

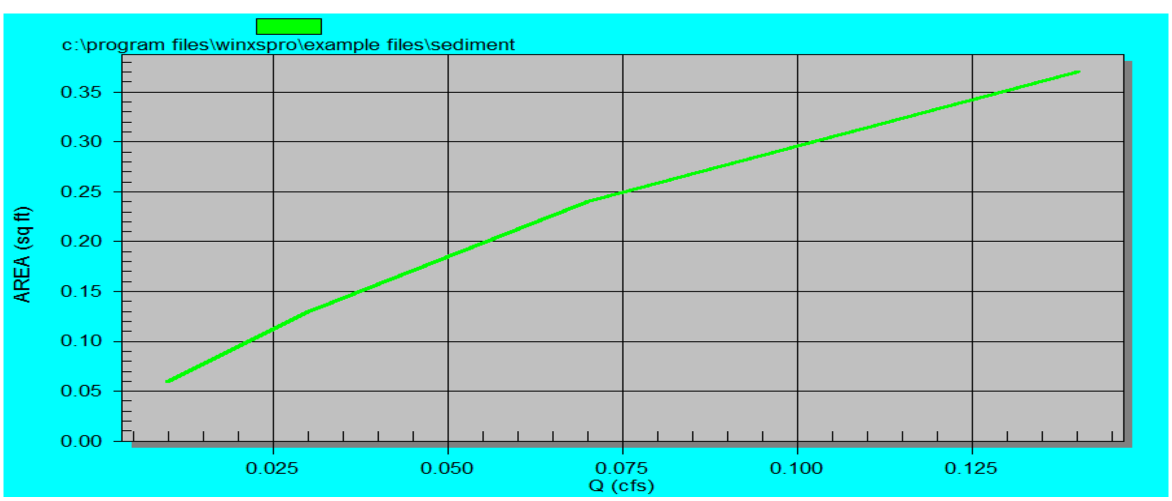

Figure 11. Area–discharge relationship.

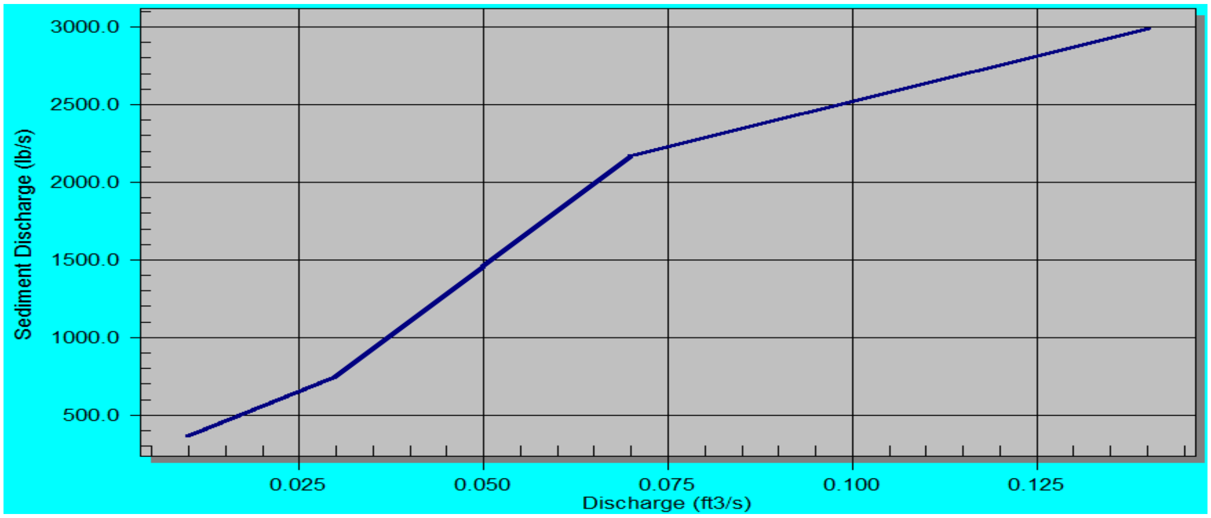

Figure 12. Sediment discharge function relationship.

Table 5. WINXSPRO hydraulic/regression analysis result.

Stage (ft)	Area (Sq. ft)	PERIM. (ft)	Width (ft)	R (ft)	DHYD (ft)	Slope (ft)	VAVG (ft/s)	Q (cfs)	Share (psf)	Alpha	Froude
0.01	0.01	2.00	2.00	0.01	0.01	0.005	0.09	0.00	0.00	1.000	0.18244
0.02	0.06	5.00	5.00	0.01	0.01	0.005	0.14	0.01	0.00	1.000	0.22200
0.03	0.13	8.00	8.00	0.02	0.02	0.005	0.20	0.03	0.01	1.000	0.26858
0.04	0.24	11.00	11.00	0.02	0.02	0.005	0.27	0.07	0.01	1.000	0.32708
0.05	0.37	14.00	14.00	0.03	0.03	0.005	0.38	0.14	0.01	1.000	0.40616

Sediment Rating Curve - Ackers and White Method
D50 (mm) = 2.0
Temp (deg. C) = 32.0

Stage (Ft)	**Q** (ft^3/s)	**Qs** (lb/s)
0.01	0.00	0.00
0.02	0.01	367.57
0.03	0.03	749.42
0.04	0.07	2171.32
0.05	0.14	2986.99

Figure 13: WinXSPRO Output Based on Stage Discharge Relationship

the general principles of physics in relation to sediment transport analysis (Bagnold, 1966). The sediment discharge dynamics was also related to the effective flow through the channel as shown in Figure 13. It was seen that the effective discharge is paramount in computing the amount of sediment that is transported along a given channel of varying cross section as proposed by Roger and Andrew (2000) in evaluating sediment transport data. Based on Ackers and White (1973) Method for establishing the sediment transport as a function of the effective discharge, the following computations in Table 5 were generated using the WinXSPRO software.

The hydraulic relationship based on hydraulic and regression analysis is shown in Table 6. Result of the hydraulic/regression model was adopted to define the mathematical equation for hydraulic radius versus discharge and stage versus discharge. From the regression results, we obtain:

$$Q = a\,(R)^{b} \quad a=71545.125000,\ b=3.62588,\ r^2=0.999446,\ n=5 \tag{2}$$

$$Q = a\,(Z)^{b} \quad a=699.863342,\ b=2.877,\ r^2=0.997359,\ n=5 \tag{3}$$

The high coefficient of determination; 0.999446 and 0.997359 was used to justify the acceptability of the model equation and its suitability in most hydraulic model computations. This is in line with model acceptability using statistical predictions.

Conclusion

The high coefficient of determination; 0.999446 and 0.997359 was used to justify the acceptability of the model equation and its suitability in most hydraulic model computations. It shows therefore that Win XSPRO can find real application in developing model equation that can be used in sediment transport analysis and hydraulic design of drainage systems.

REFERENCES

Ferguson RI (1984). Sediment load of the Hunza River. In: Miller, K.J. (Ed.), the International Karakoram Project, Cambridge Univ. Press, Cambridge, UK, 2(1):581–598.

Hallet B, Hunter L, Bogen J (1996). Rates of erosion and sediment evacuation by glaciers: a review of field data and their implications. Glob. Planet. Change. 12(1):213–235.

Hardy T, Panja P, Mathias D (2005). Win XSPRO, A channel cross section analyzer, user's manual, version. 3(1):23-56

Meyer-Peter E, Muller R (1948). Formulas for bed load transport. In: Report on Second Meeting of the International Association of Hydraulic Structures Research, Stockholm, Sweden. pp.373–410.

Parker G, Klingeman P, McLean D (1982). Bed load and size distribution in paved gravel-bed streams. J. Hydr. Div. 108(HY4) (198204):544–571.

Nielson DR (1974). Sediment transport through High Mountain streams of the Idaho Batholith. MS thesis, University of Idaho, Moscow. pp.6– 12.

Miller WR, Drever JI (1977). Chemical weathering and related controls on surface water chemistry in the Absaroka Mountains, Wyoming. Geochimica et cosmochimica acta. 41:1693–1702.

Harbor JM, Wheeler DA (1992). On the mathematical description of glaciated valley cross-sections, Earth Surface Processes and Landforms 17:477–485.

Ackers P, White WR (1973). Sediment transport: New approach and analysis, J. Hydr. Div. Am. Soc. Civ. Eng. 99(1):2041-2060.

Aldridge BN, Garrett JM (1973). Roughness Coefficients for Stream Channels in Arizona." U.S. Geological Survey Open-File Report.

Arcement GJ Jr, Schneider VR (1984). Guide for Selecting Manning's Roughness.

Roger AK, Andrew S (2000). Evaluation of Sediment Transport Data for clean sediment TMDLS, National Sedimentation Laboratory USDA. Agricultural Research Service Oxford, Mississippi.

Bagnold RA (1966). An Approach to the Sediment Transport Problems from General Physics; Physiographic and Hydraulics Studies of River, Journal of the Hydraulics Division, Am. Soc. Civ. Eng. 5(3):41-60.

Cite this article as:

Ilaboya IR, Oti EO, Ekoh GO, Umukoro LO (2014). Sediment transport analysis and modelling using winxspro: "A case study of the sediment transport apparatus". Acad. J. Environ. Sci. 2(2): 029-036.

Submit your manuscript at:
www.academiapublishing.org/journals/ajes