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Assessing River Stability and Hydraulic Geometry of Fluvial River in Malaysia

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Abstract: The fluvial geomorphological descriptions of rivers are very important to maintain the natural presence through studying the river stability and sediment transport research. Lack of knowledge on fluvial characteristics will lead to improper water resources management in long term. This research was focused to determine the fluvial river characteristics, to identify the management interpretation of the river stability and to assess the variation of flow regime and equilibrium geometry. The assessment of Rasau River was taken at different morphological appearance such as bedrock, cascade, pool, plain and step-pool. At station data collection were river width, velocity, bed materials, slope of the channel, bank slope and longitudinal profile. Classification of Rasau River were found that RCS1, RCS2, RCS3, RCS4, RCS5, RCS6, RCS7, RCS8 are classified as B4, B3, G4, F3b, F2b, E5b, B5 and B5 respectively. Based on the river classification, the conditions of cross sections RCS4 and RCS5 are not stable with sediment load low to very high and the energy of water to the stream also shows low to moderate. Low energy of water flow can lower sediment transport rates thus in long term will cause aggradation and channel narrowing. At RCS1, 2, 3, 6, 7 and 8 are classified as a stable cross section with bank vegetation as a component of the cross-section stability. The energy of water is in a range of high to moderate and the sediment load is in a range of low to moderate. On the assessment of the equilibrium geometry, Width, $B = aQ^b$, Depth, $D = cQ^f$, and Velocity, $v = kQ^m$. This study was found that hydraulic geometry equations for Rasau River are $B = 12.3Q^{0.2}$, $D = 0.9Q^{0.5}$, $V = 0.09Q^{0.3}$. It was successfully verified that the hydraulic geometry parameters satisfy continuity equation where the summation of the exponents and the multiplication of the coefficients must give a mathematical value of unity thus specify that Q = BDV. The coefficient of width (a value) shows the highest, this shows that the widening of the river can increase the significant change of the flowrate of the river.

Keywords: Fluvial geomorphology, river stability, classification of river, hydraulic geometry

1. Introduction

The existence of fluvial rivers in Malaysia has been known to be an area for leisure activities and popular retreat among the local tourist. The presence of large boulder and gravel surrounded by tropical rain forest with various types of flora and fauna surrounding the area makes it unique and naturally beauty. Therefore, the beauty of nature and the freshness of river in the area need to be preserved. The clear and fresh of river water are continuously flow many kilometers to the downstream thus reduce the risk of water pollution. Fluvial geomorphology is a study related to the

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formation and function of streams and the interaction between streams and the landscape around them. It is associated with the relationship of flowing water, earth formation and channel shape [1,] [14]. The fluvial geomorphological descriptions of rivers are important through studying the river stability and sediment transport research. Therefore, this research is focused to determine the fluvial river classification, to identify the management interpretation of the river stability and to assess the variation of flow regime and equilibrium geometry for the river. It is critical for engineers who constructing highways near rivers and bridge over the rivers because those construction activities will disturb the earth formation, streamflow and channel shape. Many greatest problems related to water arise because of the construction activities would transport the sediment and deposition happen at nearby river. Knowledge of the principles of fluvial morphology is often necessary. Failure to acknowledge the existence of those structures may deteriorate the river stability and its original landscape of the fluvial system thus affected the quality of water resources to the downstream flow. The restoration and rehabilitation work can be performed by knowing the existence of fluvial geomorphology of the river.

2. The Fluvial Geomorphology

River stability is very complex where all the components are interconnected to each other. The river stability is often described in terms of the channel form geometry surrounded by materials of riverbed and bank, under affection of water discharge and sediment load transportation [1,] [3], [4], [6], [13]. In general, a stability river may adjust their boundaries but do not exhibit trends in changes to their channel shape. One form of instability occurs when a river is unable to transport its sediment load or the energy of water too low, then the sediments deposited within the channel, leading to the condition referred as aggradation. When the ability of the stream to transport sediment exceeds the availability of sediments within the incoming flow, and stability thresholds for the material forming the boundary of the channel are exceeded, erosion occurs. Most of the fluvial streams which are not affected by human interferences can be said to be graded or in equilibrium [1], [16], [17]. Construction of dams, withdrawal or addition of clear water, addition of sediment load, contraction of stream and cutting off the bends are some the ways in which the equilibrium of the fluvial river is disturbed by human activities.

The three systems consist in the fluvial geomorphological processes which are morphological systems, cascading system and process response system [3]. A morphological system is the landform process like channel, hillslopes and floodplain. The components of the morphological system are linked by a cascading system which refers to the flow of water and sediment through the morphological system. These flows follow interconnected pathways from hillslopes to channel and through the channel network. The adjustments between the processes of the cascading system and the forms of the morphological system interact as a process response system where with its own inputs and outputs through sediment production zone, sediment transfer zone and sediment deposition zone as shown in Fig. 1. The three zones are interconnected by the factors of river equilibrium which are the sediment supply, size of particles, water discharge and the slope of channel.

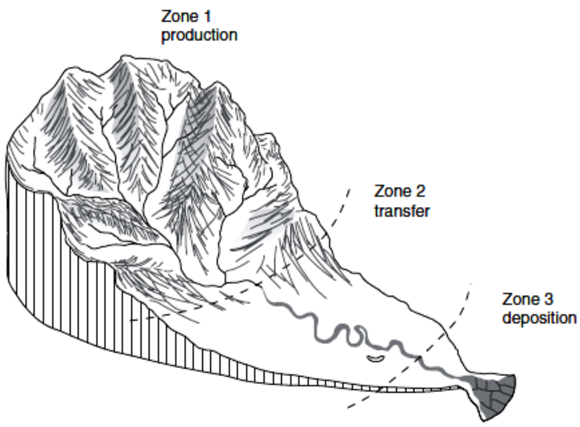

Fig. 1 - Process response systems are divided by production, transfer and deposition zone along the fluvial geomorphology process.

Lane [7] stated the relationship of equilibrium factor in fluvial morphology expressed the four variables which are by $Q_s*d \propto Q_w*S$, where Q_s is quantity of sediment, d is particle size of sediments, Q_w is water discharge and S is the slope of the channel. In a channel at equilibrium, if any of the four variables is altered, it indicates the changes which are necessary in one or more of the others to restore equilibrium [7]. This relationship provides a useful concept to describe the capability of a stream to adjust its morphology through sediment erosion, transport and deposition processes. Philip [8] stated that a change in sediment load, relative to changes in bed material size, suggests the river will compensate by adjusting its sediment transporting capacity during a period of instability until the relationship balances once more. For example, if the volume of sediment supplied to a reach over a given time period is less than the capacity of the reach to transport the volume of sediment through, then erosion of the channel boundary will be occurred. This would lead to channel instability through bed scour or channel widening. Conversely, if the sediment supply is greater than the transporting capacity, then sedimentation processes are likely to predominate with potential channel instability through aggradation or channel narrowing.

2.1 River Classification

The study of river classification will enable to group the stream having similar characteristics. According to Rosgen [2], the classification often helps in (i) prediction of river behavior from its appearance; (ii) development of specific hydraulics and sediment transport relations for a given stream type; (iii) extrapolating site specific data to stream reaches having similar characteristics and; (iv) providing a frame of reference for communicating about stream morphology among different disciplines. Rosgen classification can be determined by the diagram through a hierarchical assessment of channel morphology measured based on bankfull geometry dimensions as shown in Figure 2.

Level I classification were based on geometry measurement such as entrenchment ratio (ER), water-depth ratio (W/D), sinuosity, channel slope and pattern. Rosgen [2] name the classification in nine types designated as A (relative straight), B (low sinuosity), C (meandering), D (braided), DA (anastomosed-multiple channel), E (tortuously meandering), F (entrenched meandering) and G (entrenched gulley). Rosgen [2] mentioned the entrenchment ratio were calculated as width of flood prone area divided by bankfull surface width of the channel, flood prone area is defined as the width measured at an elevation which is determined at twice the maximum bankfull depth. Water-depth ratios were calculated as bank full channel width divided by bank full mean depth and sinuosity were calculated as stream length divided to valley length [15]. Channel slope were calculated as the difference of water surface elevation divided by stream length.

Level II classification subdivides the streams in each class into a maximum of six categories symbols with numbers depending on the channel bed materials such as 1 (bed rock), 2 (boulders), 3 (cobbles), 4 (gravel), 5 (sand), 6 (silt and clay). Level III classification is aimed to provide the description of stream condition as related to stability condition, recovery potential, and the stream function. These were based on additional inputs about hydrology, biology, ecology, and human activity. It evaluates and quantifies the channel stability, bed-stability (aggrading, degrading or stable), and bank erosion. Level IV classification is based on reach specific observations for verification of process based on Level III analysis.

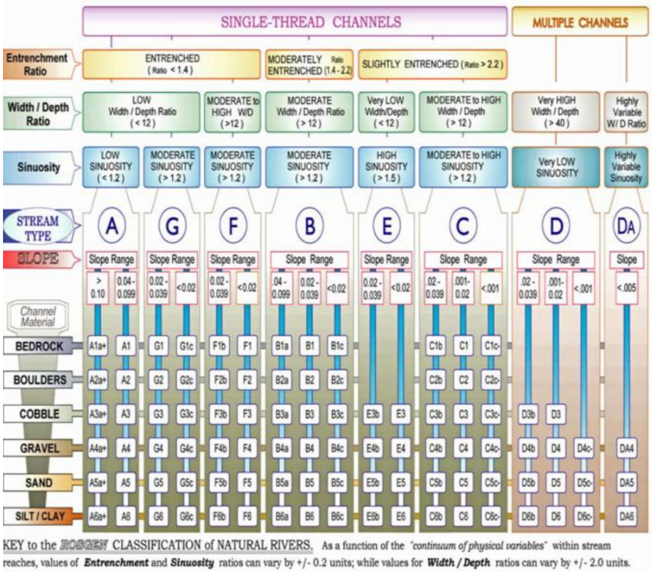

Fig. 2 - Key to the Rosgen's classification of natural river [2].

2.3 Variation of Flow Regime and Equilibrium Geometry

This chapter were described the streamflow and channel geometry relationship. It provides a set of empirical relationship between the discharge and its hydraulic variables i.e. channel width, flow depth and flow velocity. The important of determining the geometrical characteristics of Rasau River may be helpful in designing of hydraulic structures, river rehabilitation works, defining the deformation of the river channel and other regional works [5], [9]. Many researchers had done their research to determine the exponent value of the flow regime based on their selective area. Leppold and Maddock [10] expressed the hydraulic geometry relationship for a channel in the form of power function of discharge:

$$B = aQ^b,\ D = cQ^f,\ v = kQ^m \tag{1}$$

where B is the channel width; D is the flow depth; v is flow velocity; Q is flow discharge, b, f, m is the exponent value represent the rate of change of the hydraulic variables B, D and v; and a, c and k is coefficient value represent as the scale factors that define the values of B, D and v. The hydraulic variables B, D and v satisfy for continuity equation of:

$$Q = BDv \tag{2}$$

Therefore, the summation of the exponents and the multiplication of the coefficients must give a mathematical value of unity. Summation of exponent value:

$$b+f+m = 1 \tag{3}$$

Multiplication of the coefficients:

$$a*c*k = 1 \tag{4}$$

As presented in Table 1, numbers of the exponent values from other researchers are gathered from the literature by Singh [11].

Table 1 - Variation of exponent value of flow regime [11].

Source	b	f	m	Sum
Leopold and Maddock (1953)	0.500	0.400	0.100	1.000
Wolman (1955)	0.340	0.450	0.320	1.110
Leopold and Milner (1956)	0.290	0.150	0.580	1.020
Miller (1958)	0.380	0.250	0.390	1.020
Brush (1961)	0.550	0.360	0.090	1.000
Ackers (1964)	0.420	0.430	0.150	1.000
Carlston (1969)	0.461	0.383	0.155	0.999
Thornes (1970)	0.400	0.340	0.250	0.990
Ponton (1972)	0.600	0.400	-0.010	0.990
Knighton (1974)	0.610	0.310	0.080	1.000
Smith (1974)	0.600	0.300	0.100	1.000
Parker (1979)	0.500	0.415	0.085	1.000
Allen, Arnold and Byers (1994)	0.557	0.341	0.104	1.002
George (1980)	0.480	0.480	0.110	1.070

3. Site Description and Research Methodology

A fluvial river in Malaysia has been selected called Rasau River. Rasau River is located in Peninsular of Malaysia, in Ayer Hitam Forest Reserved in the state of Selangor. Originally the area covering about 4270 hectares and gazette as a forest reserve way back in 1906, it has suffered from a series of degradation and encroachment throughout the years. As now, covering an area of about 1248 hectare the forest is bordered in the north by Bandar Puchong Jaya and to its south by Putrajaya administrative township. The eastern part of the forest is bordered by the town of Seri Kembangan and to the west by the massive housing and business centre of Puchong. Rasau River was gazette under Sultan Idris Shah Forestry Education Centre (SISFEC).

The channels are flowing to the downstream heading to Puchong Lake. The channels are considered as low flow and most of the tributaries dried up during drought season. The location of study area has been shown in Figure 3; the elevation of study area which is located at high elevation in the surrounding area with rainforest has been shown in Figure 4; and the site photo of the channel at RCS1 looking upstream has been shown in Figure 5. As the surrounding of the site area is a rapid development area, the fluvial geomorphology of Rasau River is believed was disturbed.

This study was based on an extensive field sampling and data analysis. The data collection involves by two main themes which are river surveys and hydraulics data. Total of eight cross-section surveys were measured using auto level, elevation staff, measuring tape and velocity meter. The cross sections were selected at different types of morphological channel such as bedrock, pool, plain and riffle. The size of bed materials was measured using Wolman’s pebble count. About 100 samples were collected longitudinally from one cross section to another cross section. Each samples size is measured using pebble count for small size like gravel ar small cobblers; or using measuring tape for bigger size like bedrock, boulder or cobbles. For sand and clay, the samples were analyzed using dry sieving analysis.

Fig. 3 - The location of Rasau River.

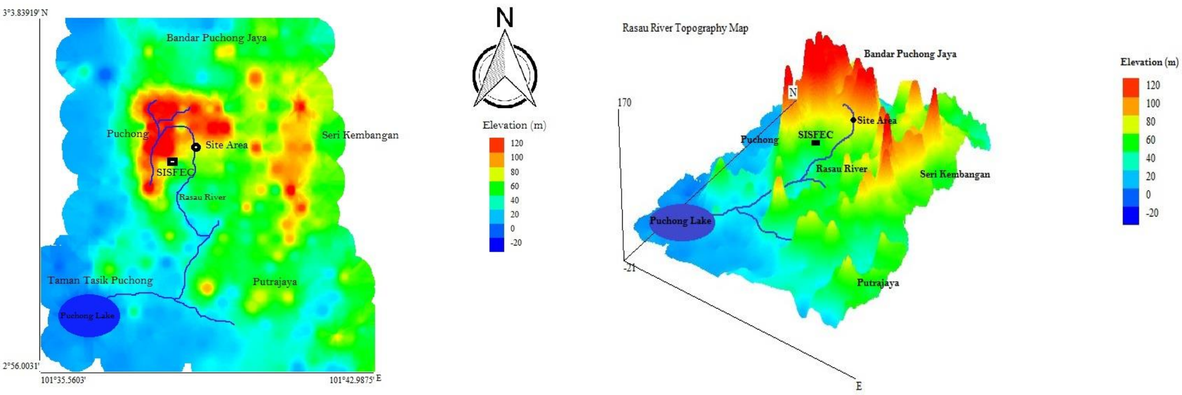

Fig. 4 - Topography of Rasau River.

Fig. 5 - Site photo of Rasau River, looking upstream.

The surveys data were analysed using microsoft excel and HEC-RAS 5.0.3 to acquire hydraulics data as required for river classification such as bankfull cross-sectional area (A), bankfull wetted perimeter (P), width depth ratio (W/d), average velocity (V), size of bed material (D_{50} and D_{84}), slope of water surface (S_w), slope of bed surface (S_b), hydraulic radius (R) and longitudinal profile

4. Results and Discussion

4.1 River Classification and Particle Size Distribution

The geometry of river such as bankfull width, bankfull depth, bank slope at left and right side, flood prone width, entrenchment ratio, width/depth ratio, channel length, valley length, sinuosity have been calculated and the result of classification Level I as shown in Table 2. Level II classifications were based on the group of average bed materials, D_{50}. The particles size was analyzed by Particles Size Distribution (PSD) Curve [12]. For RCS1 the average types of particles are very fine gravel, RCS2 is small cobbles, RCS3 is medium gravel, RCS4 is small cobbles, RCS5 is large boulder, while RCS 6, 7 and 8 have same average particles which is sand.

Therefore, RCS1, RCS2, RCS3, RCS4, RCS5, RCS6, RCS7, RCS8 have been classified as B4, B3, G4, F3b, F2b, E5b, and B5 respectively as shown in Table 3. Classification of B4 indicate that the cross section is low sinuosity with gravel as bed materials at slope range 0.02 to 0.039, B3 indicate that the cross section is low sinuosity with cobbles as bed materials at slope range 0.02 to 0.039, G4 indicate that the cross section is entrenched gully with gravel as average bed materials at slope range 0.02 to 0.039, F3b indicate that the cross section is entrenched meandering with cobble as average bed materials at slope range 0.02 to 0.039, F2b indicate that the cross section is entrenched meandering with boulder as average bed materials at slope range 0.02 to 0.039, E5b indicate that the cross section is tortuously meandering with sand as bed materials at slope range 0.02 to 0.039, B5 indicate that the cross section is low sinuosity with sand as bed materials at slope range 0.02 to 0.039. Then, at Level III, the descriptions were based on the group of classification referring to the conditions of river stability as shown in Table 4.

Table 2 River Classification at Level I.

Cross section	Entrenchment Ratio (± 0.2)		W/d (± 2.0)		Sinuosity (± 0.2)		Stream Type Level I
RCS1	1.43	> 1.4	22	> 12	1.21	<1.2	B
RCS2	1.41	> 1.4	20	> 12			B
RCS3	1.12	< 1.4	7	< 12			G
RCS4	1.08	< 1.4	34	> 12			F
RCS5	1.13	< 1.4	50	> 12			F
RCS6	1.49	> 1.4	9	< 12			E
RCS7	1.57	> 1.4	16	> 12			B
RCS8	1.47	> 1.4	13	> 12			B

Table 3 – River Classification Level II.

Cross section	D_{50} (mm)	Average Bed Materials	Slope of Channel (m/m)	Stream Type Level II
RCS1	2.83	Gravel	0.032	B4
RCS2	119	Cobble		B3
RCS3	8.62	Gravel		G4
RCS4	81.98	Cobble		F3b
RCS5	2168	Boulder		F2b
RCS6	0.857	Sand		E5b
RCS7	0.857	Sand		B5
RCS8	0.857	Sand		B5

Table 4 - River Classification Level III.

Cross section	Sediment supply	Streambank erosion	Sediment load	Energy to stream	Morphology Features
RCS1	Moderate	Low	Low to moderate	High	Riffle-pool
RCS2	Low	Low	Low to moderate	High	Riffle-pool
RCS3	Very high	Very high	Low to very high	Moderate to high	Rapids predominate with occasional pool
RCS4	Very high	Very high	Low to very high	Low to moderate	Riffle-pool
RCS5	Moderate	Moderate	Low to very high	Low to moderate	Riffle-pool
RCS6	Moderate	High	Very efficient at carrying sediment	Low	Riffle-pool
RCS7	Moderate	Moderate	Low to moderate	High	Plain pool
RCS8	Moderate	Moderate	Low to moderate	High	Plain pool

Most of the cross sections in Rasau River have been shown as riffle-pool morphology. At RCS4 and RCS5 the conditions of cross sections are not stable with sediment load low to very high, sediment supply very high to moderate, and the energy of water to the stream also shows low to moderate. Low energy of water flow can lower sediment transport rates thus in long term will cause aggradation and channel narrowing. At RCS1, 2, 3, 6, 7 and 8 are classified as a stable cross section with bank vegetation as a component of the cross-section stability. The energy of water is in a range of high to moderate and the sediment load is in a range of low to moderate.

The schematic cross section representations of fluvial geomorphology of Rasau River and the elevation have been shown in Fig. 6 and Fig. 7. At the north part of the site area, where it is near RCS8, 7 and 6 were disturbed due to the vicious development. Due to deforestation activities, the bed materials at RCS8, 7 and 6 were dominated by sand. The amount of sediment in the cross section becomes high when some of the trees have been destroyed causing the soil to be exposed to direct rainfall splash and flowing as a runoff along with the sediment into the river. The average bed materials at RCS1 to 5 were dominated by various sizes such as boulders, cobbles and gravels which are not much affected.

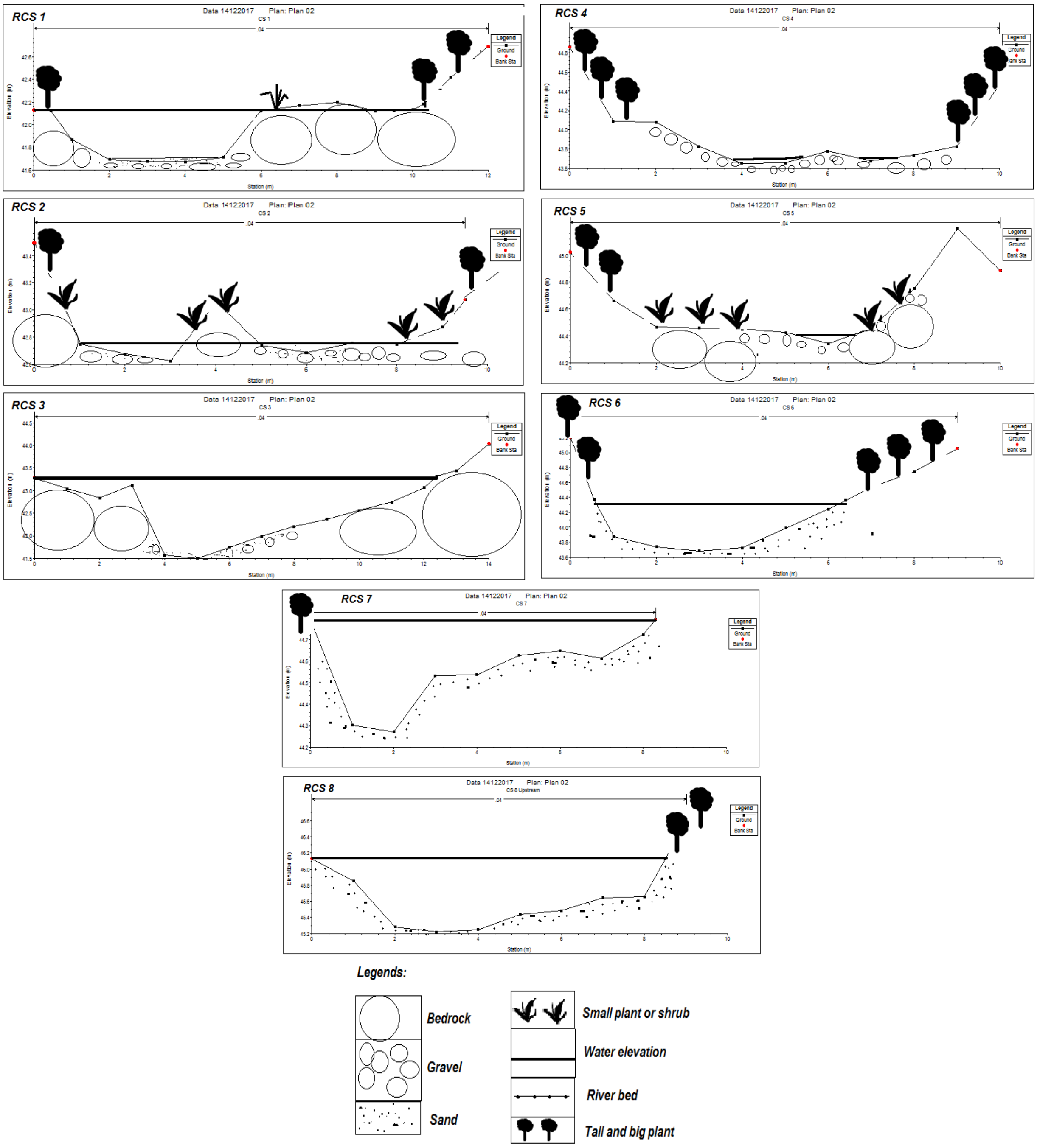

Fig. 6 - Schematic cross section.

4.2. Hydraulic Geometry

The coefficient and exponents value were determined by plotting of power law function of the hydraulic variable and flow discharge. The hydraulic variables are mean depth, mean velocity and width of the fluvial river. The hydraulics data, value of exponent and coefficient of hydraulic geometry have been shown in Table 5.

Table 5 - Variation of flow regime and hydraulics geometry.

Cross Section	Flowrate (m^3/s)	Water Surface Width (m)	Mean Depth (m)	Mean Velocity (m/s)
RCS1	0.064	9.85	0.29	0.05
RCS2	0.050	8.90	0.32	0.02
RCS3	0.314	12.40	0.89	0.03
RCS4	0.079	6.00	0.13	0.12
RCS5	0.086	6.00	0.04	0.32
RCS6	0.074	5.85	0.42	0.03
RCS7	0.037	8.30	0.26	0.02
RCS8	0.065	8.50	0.39	0.02

Relationship of discharge and hydraulic geometry were plotted as in Fig. 7. Based on hydraulic geometry relationship for a channel in the form of power function of discharge, the exponents, b, f, m and the coefficients, a, c, k of the hydraulic geometry parameters of the Rasau River were found to be 0.2, 0.5, 0.3 and 12.3, 0.9, 0.09, respectively as shown in Table 6.Thus, the hydraulic geometry for Rasau River as in Eqn. (1) can be written as below:

$$B = 12.3Q^{0.2},\ D = 0.9Q^{0.5},\ v = 0.09Q^{0.3} \tag{5}$$

The exponents and coefficients values have been found to be consistent with previous studies. Also, it has been verified that the parameters satisfy the continuity equation as in Equation (3) and Equation (4).

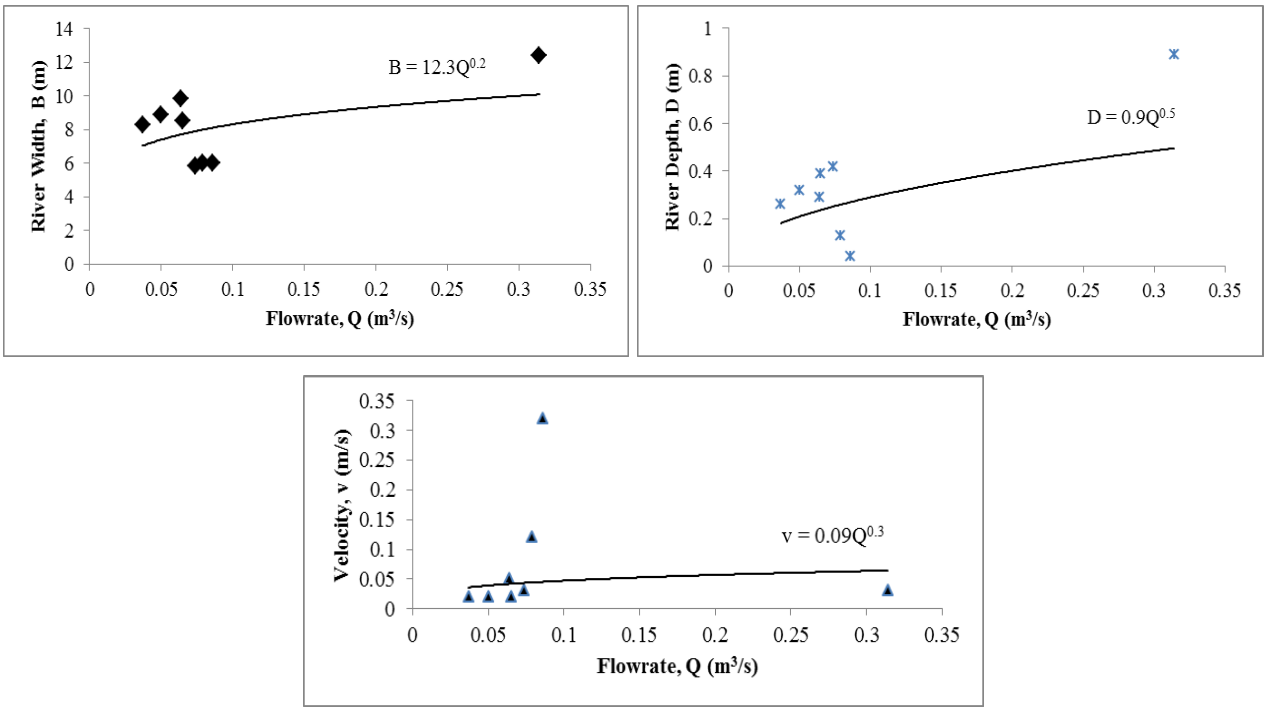

Fig. 7 - Relationship of discharge and hydraulic geometry.

Table 6 - Exponents and coefficients of hydraulic geometry parameters.

Exponents		**b+f+m**
b	0.2	
f	0.5	1.0
m	0.3	
Coefficients		**a*c*k**
a	12.3	
c	0.9	0.996
k	0.09	

5. Conclusion

The condition of stability along the study area of Rasau River has been identified. It has been shown at RCS4 and RCS5 were not stable with sediment load in a range of low to very high, sediment supply in a range of very high to moderate, and the energy of water to the stream also shown a range of low to moderate. Low energy of water flow can decrease sediment transport rates thus in cross section will cause aggradation and channel narrowing in a long term. At RCS1, 2, 3, 6, 7 and 8 were classified as a stable cross section with bank vegetation as a component of the cross-section stability. The energy of water is in a range of high to moderate, the sediment load is in a range of low to moderate and the sediment supply is in a range of low to very high.

On the assessment of the hydraulic geometry, the study has been found that the exponents, b, f, m and the coefficients, a, c, k of the hydraulic geometry parameters of the Rasau River were 0.2, 0.5, 0.3 and 12.3, 0.9, 0.09, respectively. Hydraulic geometry equations for Rasau River are $B = 12.3Q^{0.2}$, $D = 0.9Q^{0.5}$, $v = 0.09Q^{0.3}$. Besides, it has been verified that, the parameters satisfy continuity equation where the summation of the exponents and the multiplication of the coefficients give a mathematical value of unity thus satisfy the continuity equation and specify that $Q = BDv$.

Coefficient of width is the highest value compare to other exponents or coefficients. This means that the widening of the river can increase the significant change of the flowrate [18], [19]. Therefore, it can give benefit to the restoration and rehabilitation of the river. The results can be used to predict the cross-sectional parameters of any branch of the Rasau River or other rivers where the hydrological properties are similar. The relationships obtained can be used for watershed management, flood control and hydropower generation in the catchment basin.

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