Determination of Downstream Hydraulics Geometry Parameters

Zuliziana Suif[1*], Mira Azmiza Azmi[1], Nordila Ahmad[1], Maidiana Othman[1] and Jestin Jelani[1]

[1] Department of Civil Engineering, Faculty of Engineering, National Defence University of Malaysia, Malaysia
* Corresponding Author, Email: zuliziana@upnm.edu.my

Abstract. The hydraulic geometry term represents the relations between the dynamic characteristics of a river stream and its discharge. The river character istics quantitatively obtained by describing these parameters as power functions of discharge employing one coefficient and exponent. The aim of the study is determining the downstream hydraulic geometry parameters and to obtain a relation between flow discharge and sediment discharge with hydraulic geometry parameters of the channel. Depth, velocity, width, surface roughness and suspended sediment concentration data are collected at three selected stations along the channel. The downstream hydraulic geometry parameters for flow discharge relations b, f, m, p, a, c, k and N discovered as 0.0417, 0.8889, 0.0789, 0.4580, 1.9842, 1.9710, 0.3693 and 1.8056 respectively. For sediment discharge relations, the hydraulic geometry parameters b, f, m, p, a, c, k and N shown as -0.0454, 0.9054, 0.3090, 0.1739, 1.1712, 2.1230, 0.3348 and 0.9325 respectively. The values of exponent and coefficient, (b, f, m, p, a, c, k and N) varies within some limits imposed more by ways the adjustment of stream power is dispersed across variables. This is because the scales parameters are varying and depends on the hydraulics parameters of channel. In addition, according to the results, the sediment and flow discharge relations at Station 1 were determined being more relevant than those at a different station when it comes to the correlation coefficient. Generally, the findings from this study are intended to be beneficial for manager and planner of water resources initiatives in the basin.

Keywords: Hydraulic geometry, power functions, flow discharge, sediment discharge.

1 Introduction

The depth, velocity, breadth, and surface roughness of rivers, as well as their hydraulic geometry characteristics, are related to their discharge as simple power functions at a particular cross-section. Hydraulic geometry of a river does not remain exactly the same. It shows variations over a time period as a function of discharge. Hydraulic geometry parameters are important in representing the form of a stream. The characteristics of a river can be determined by using the hydraulic geometry parameters. The measurable hydraulic characteristic such as depth, velocity, width and surface roughness represents the form of a river. These measurable hydraulic characteristic will be used in the power function analysis. Depth, velocity, width and surface roughness indicate the flow discharge as a power function.

Most commonly used and very effective hydraulic geometry estimation method was introduced by Leopold and Maddock [1]. They discovered that several quantitatively measurable hydraulic properties of stream channels, such as width, depth, velocity, and suspended sediment load are fluctuating with discharge as simple power functions for a particular river cross-section. The functions derived from various cross-sections along the river which differs only in the numerical values of the coefficients and exponents. The functions derived from numerous cross-sections alongside river which differs simply in regards of coefficients and exponents numerical values [1]. Previous worked on 20 rivers and proposed a power law relation between the discharge (Q), depth (H), velocity (V), width (B) and surface roughness (n) as follows [1];

$$B = aQ^b \tag{1}$$

$$H = cQ^f \tag{2}$$

$$V = kQ^m \tag{3}$$

$$n = NQ^p \tag{4}$$

where a, b, c, f, k, m, N and p are numerical constants which b, f, m and p are its exponents meanwhile a, c, k and N are its coefficients.

Eqn. (5) and (6) indicate that the depth, velocity, width, and surface roughness of rectangular channels fulfil the continuity equation, which is to means that the summation of exponents and multiplication of coefficients are equal to 1. The relation of hydraulic geometry assumes that the flow of water is uniform and steady. The exponents and coefficients are calculated using the power function approach.

$$a \times c \times k \times n = 1 \tag{5}$$

$$b + f + m + p = 1 \tag{6}$$

Continuity requires that $a \times c \times k \times N$ and $b + f + m + p$ both equal unity at a channel cross section, but not when derived from multiple transects with different shapes. These continuity equations were only useful on rectangular channels.

Watershed management is critical due to increasing population and human activities, particularly in developing countries. Therefore, an appropriate river basin management is required to fulfil water resource demand. For this purpose, the understanding the concepts and behaviors of river channel hydraulic geometry are necessary.

Hydraulic geometry implies to the exponential correlations with hydraulic geometry parameters and flow discharge.

The aims of this study is to determine the downstream hydraulic geometry parameters and to obtain relations between flow discharge and sediment discharge with hydraulic geometry parameters of the Universiti Pertahanan Nasional Malaysia (UPNM) channel.

2 Study Area

The study area in determining the hydraulic geometry parameter located in Universiti Pertahanan Nasional Malaysia (UPNM), Military University in Sungai Besi Camp, Kuala Lumpur, Malaysia. Three (3) station was selected in UPNM area. The first and second stations are trapezoidal form channels that are man-made. While, the earth channel is the third station.

3 Methodology

For this study, the purpose of installation the equipment is to determine the value of hydraulics geometry parameters in selected station around UPNM area. The parameters such as velocity (V), depth (D), discharge (Q), surface width (B) and surface roughness (n) will all be determined using the Flow Tracker. Then, the downstream hydraulic geometry with depth, width, velocity and surface roughness were analyzed using power function analysis. Moreover, the field water sample was collected and testing for suspended sediment concentration. The Total Suspended Solid (TSS) test will be performed on the field water sample in the laboratory.

3.1 Measuring of Hydraulic Geometry Parameters

Flow Tracker2 is an equipment that measures hydraulic geometry parameters. The installation of equipment purpose to be estimate the hydraulic geometry of the specified channel. The equipment was set up on the field, as well as all data will be obtained there. The hydraulic geometry parameters obtained from the selected stations were recorded. The Flow Tracker2 is easy to operate and can measure water discharge, velocity, depth, temperature, location, and a variety of other functions. The data was measured likes depth, velocity and flow discharge of channel at various station by utilizing the equipment.

3.2 Collecting of Water Sample

Three (3) water samples will be obtained in total, with one taken each week to test the suspended sediment concentration. Moreover, the water sample data were obtained at depth of 0.3 m from the surface at the center in the main channel. Since the sample point is shallow, the technique for obtaining the sample does not pose many difficulties. The sample are transferred to laboratory and tested by TSS testing to determine the concentration of suspended sediment.

3.3 Suspended Sediment Concentration

A 1.5 L container will be used to collect water samples from all stations once a week. The sample of water will then be sent to laboratory for analysis. Firstly, weigh the filter disc and paper, and recorded the data. Afterwards, select a sample volume that will result of total suspended solids not greater than 200 mg. Next, apply vacuum while placing the filter on the base and clamping the funnel. To attach the filter against the base, wet it with a tiny amount of distilled water. Mix the sample by shaking vigorously and quantitatively transfer 100 ml of sample to the filter using a large orifice and volumetric pipette. Continue to apply vacuum after the sample has gone through filter to remove all traces of water. Next, rinse the pipette and funnel onto the filter with small volume of distilled water. Lastly, carefully remove the disc filter from the base. Dry for at least one hour at 103°C – 105°C. Later, cool in an oven and weigh. Alum that has been be weighted with glass filter paper first before the glass filter paper used to filter the water sample.

4 Results and Analysis

4.1 Relations of Flow Discharge and Hydraulic Geometry

Graph in the Fig. 1 indicates a relation between the data on depth (H), mean width (B), mean flow velocity (V), roughness (n) and flow discharge (Q) for Station 1. The plotted data are shown increase trends with increasing flow discharge (Q) for Station 1 which is a man-made channel and located at the upstream part in this study. The exponents average values of b, f, m and p are 0.1009, 0.7946, 0.1181, 0.3503 respectively. The empirical equation analysis of function is derive using statistical tool. Meanwhile, the coefficient average values of a, c, k and N are 1.4527, 1.3173, 0.5077 and 0.2977. From power function graph of H shows the highest value of data. It indicates the rates at which depth increased as a function of discharge was the highest. It also shows the highest value of flow discharge (Q) is 1.758 m^3/s.

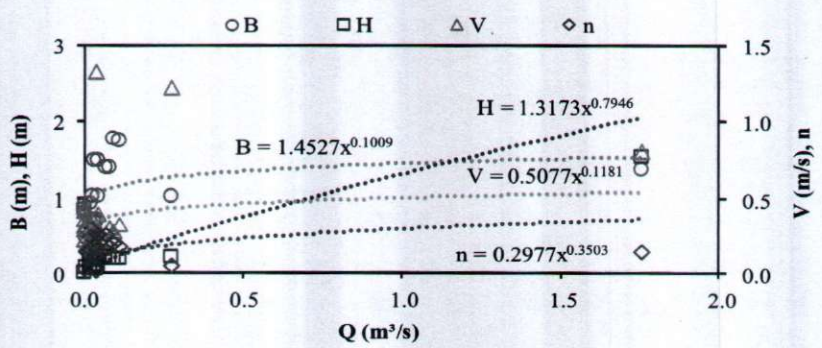

Fig. 1. Relations of flow discharge with hydraulic geometry parameters at Station 1.

Station 2 is a man-made channel. The graph in Fig. 2 shows data of width (B), mean depth (H) and roughness (n) were noticed increasing trend with increasing flow discharge (Q). The value of the exponent (b, f, m and p) are -0.0017, 1.2811, -0.2680, 1.1126 while its coefficient (a, c, k and N) are 2.4167, 3.6823, 0.1085 and 4.9764. Meanwhile velocity (V) graph is the only graph that decrease with increasing discharge which signifies slow flow. Huang and Nanson [2] examined bank vegetation and discovered that dense bank vegetation creates narrower channels, whereas bed vegetation increases the roughness and caused wider channels, lower in flow velocity and therefore no significant difference in depth [3]. Thus, the depth (H) graph only slightly increase against flow discharge (Q) indicates shallow. In addition, it also shows that low rates of velocity (V) decrease with low rates of width (B) increase when against flow discharge.

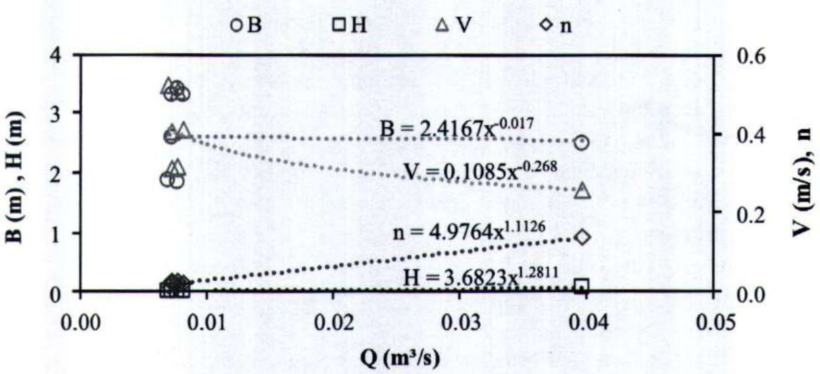

Fig. 2. Relations of flow discharge with hydraulic geometry parameters at Station 2.

Fig. 3 illustrates how the depth (H), mean width (B) and mean flow velocity (V) of Station 3 increased as the flow discharge (Q) increased. Station 3 is a natural channel and located at downstream. For Station 3, the exponent values b, f, m, and p are 0.0259, 0.5911, 0.3866 and -0.0890. Likewise, the coefficient values a, c, k and N value for Station 3 are 2.0832, 0.9133, 0.4918 and 0.1426. The roughness (n) power graph was observed and the only graph that show decreasing with the increasing flow discharge (Q). This is because erosion decreases the size of bed load material and reduces the surface roughness of channel. Kolberg and Howard [4] ascertained hydraulic geometry parameters demonstrate variations, relying on the bed materials of alluvial channel. Velocity of this channel rises downstream when more water comes towards the channel and reduces the size of bed load. Huang and Warner [5] indicated that the coefficient of hydraulic geometry parameters is correlated to hydraulic roughness (Manning's n), bank strength and slope [3]. Thus, the highest value of flow discharge (Q) on this station is 1.608 m³/s which is the value of fifth week and it shows the highest value because of rain.

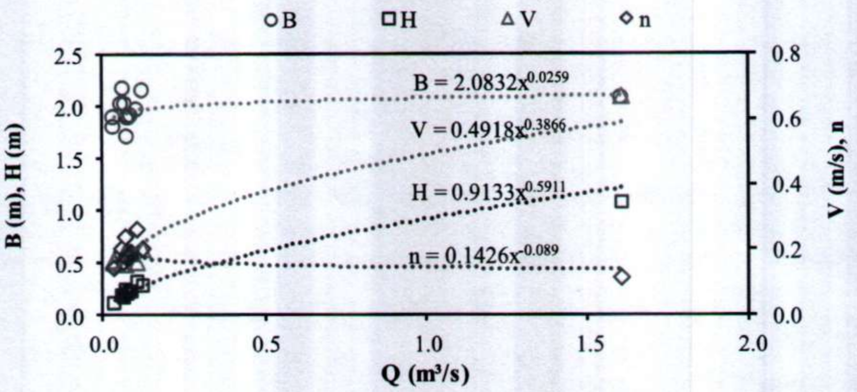

Fig. 3. Relations of flow discharge with hydraulic geometry parameters at Station 3.

Table 1 shows the summary of exponent and coefficient values at each station. Exponent b and m shows the lowest value on Station 2 among all stations. This is due to the presence of vegetation, grass, and sand along the channel. As a result, the channel is becoming narrower and the water flow is becoming unstable. This is because the natural channel is not vulnerable and always affected by water flow. Moreover, during heavy rain, it will either narrower or enlarge the channel because the wall of the channel having corrosion. In this study, it shows the channel becomes narrower during heavy rain.

Table 1 The exponents and coefficients of flow discharge and hydraulic geometry parameters.

Sta.	**Exponent**				**Coefficient**			
	b	f	m	p	a	c	k	N
1	0.1009	0.7946	0.1181	0.3503	1.4527	1.3173	0.5077	0.2977
2	-0.0017	1.2811	-0.2680	1.1126	2.4167	3.6823	0.1085	4.9764
3	0.0259	0.5911	0.3866	-0.0890	2.0832	0.9133	0.4918	0.1426
Ave	**0.0417**	**0.8889**	**0.0789**	**0.4580**	**1.9842**	**1.9710**	**0.3693**	**1.8056**

The exponent values show that f at Station 2 shows the highest value from the other exponent from all stations. This is because Station 2 has a high depth and it slower the flow of water. Conversely, Station 3 have low value of exponent f. In general, the higher the exponent value of f, the lower the value of exponent m. Rhodes [6] indicated that the exponent values for high flow rates can be considerably different from those for low flow rates [7]. This explained why their values of exponent m higher than Station 2.

Lastly, the value of exponent p shows the highest on Station 2 due to the lowest rates of erosion because of low flow. Erosion reduces the size of bed load material and decreases the roughness of the channel. It rises downstream as tributaries and groundwater flow supply more water to the channel, and the channel becomes more efficient with distance downstream. Station 2 shows rougher surface is having a higher roughness exponent and less retarding effect on the water flow, lower flow rate is produced [8]. As a conclusion, flow rate and roughness exponent were influenced by bed roughness.

The above discussion shows that the values of exponents, b, f, m and p, do not possess fixed values; rather they vary over certain ranges dictated by the way the adjustment of stream power is distributed among variables. Furthermore, the scale parameters are variable, depending on the channel hydraulics. This observation should be helpful with regionalization of scale factors.

4.2 Relations of Sediment Discharge and Hydraulic Geometry

Fig. 4 shows data on width (B), mean depth (H), mean flow velocity (V) and roughness (n) were observed to increase with increasing sediment discharge (Qs) for Station 1 which is a man-made channel. The exponent value of b, f, m and p for Station 1 are 0.0126, 0.6662, 0.2262 and 0.1180 while coefficient value of a, c, k and N are 1.0453, 0.9913, 0.8167 and 0.1285 respectively. From the power function graph of B shows the highest value of data signifies rates of width (B) increased as a function of discharge was the highest. It also shows the highest value of sediment discharge (Qs) is 0.241 kg/m³, which is the most inconsistent and far from the other data. This is because the weather for that week is always cloudy and usually raining heavily in the evening. Climate change, such as more frequent and heavy rain events, can worsen erosion and cause more silt to flow into rivers, lakes, and streams. Sediment loading from storm-water runoff can be increased by more frequent and heavy rain events.

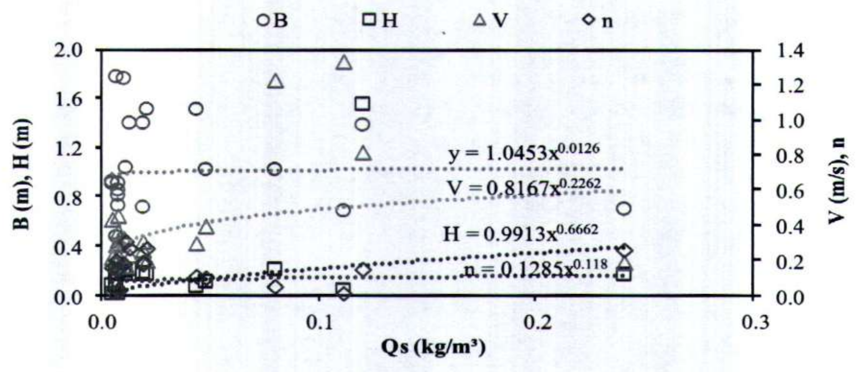

Fig. 4. Relations of sediment discharge and hydraulic geometry parameters at Station 1.

While, the Station 2 is a natural channel and the value of the exponent (b, f, m and p) are -0.1980, 0.5153, -0.3540, 0.7027 shows in Fig. 5. Whereas the coefficient value on a, c, k and N are 0.5800, 0.1092, 0.0703 and 0.7862. The plotted graph shows data of mean depth (H) and roughness (n) were observed to increase with increasing sediment discharge (Qs). Meanwhile velocity (V) graph and width (B) graph is the graph that show decreasing with the increasing sediment discharge (Qs). This is because the data of width (B) affect data of velocity of this channel. The erosion on this channel is the highest since the width (B) always become narrower when raining. When the width (B) narrower, the slower the velocity (V) of the water.

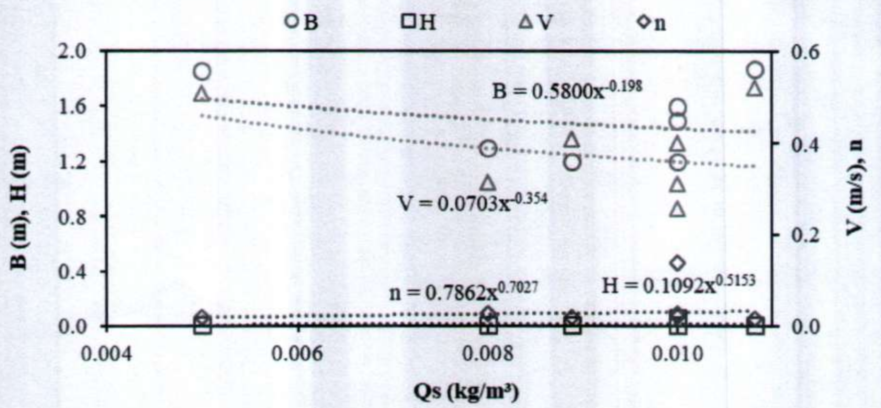

Fig. 5. Relations of sediment discharge and hydraulic geometry parameters at Station 2.

Station 3 is downstream natural channel. The Fig. 6 shows the exponent values b, f, m and p are -0.0060, 0.6459, -0.0750 and 0.4513 respectively. Likewise, the coefficient, a, c, k and N value for Station 3 are 1.8897, 5.2685, 0.1175 and 1.8827. The graph in Fig. 9 presents data of width (B), mean depth (H) and roughness (n) were observed to increase with increasing sediment discharge (Qs). However, the velocity (V) power graph was observed and the only graph that show slightly decreasing with the increasing sediment discharge (Qs). Huang and Nanson [2] examined bed vegetation increases the roughness and causes wider channels, reduction in flow velocity and no significant change in depth [3]. As shown, there is significant change in depth (H) against sediment discharge (Qs) but roughness (n) linearly increase. It indicates the higher the roughness (n), the lower the velocity (V) when against sediment discharge (Qs).

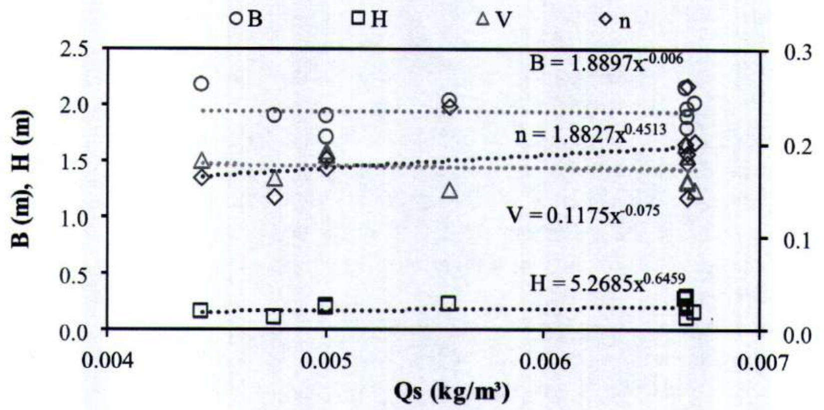

Fig. 6. Relations of sediment discharge and hydraulic geometry parameters at Station 3.

Table 2 shows the summary of the exponent and coefficient values of hydraulic geometry parameters for all selected stations. The exponent values show that f at Station 3 have the highest value from the other exponent from all stations. This is because Station 3 is located at the downstream station where the location is steep and the higher velocity. Station 3 has a higher depth and it carry higher value of sediment discharge. That explain why Station 3 have high value of exponent f. The higher the depth, the more the water contain in a channel, the higher sediment that can be carried.

Table 2 The exponents and coefficients of sediment discharge and hydraulic geometry parameters.

Sta.	Exponent				Coefficient			
	b	f	m	p	a	c	k	N
1	0.0126	0.6620	0.2262	0.1180	1.0453	0.9913	0.8167	0.1285
2	-0.1980	0.5153	-0.3540	0.7027	0.5800	0.1092	0.0703	0.7862
3	0.0491	1.5390	1.0547	-0.2990	1.8897	5.2686	0.1175	1.8827
Ave	**-0.0454**	**0.9054**	**0.3090**	**0.1739**	**1.1712**	**2.1230**	**0.3348**	**0.9325**

The exponent value of m at Station 2, it shows the lowest value because along the channel there are some plant, grass and sand along the channel. It is observed to be making the channel become narrower and make the flow of water is unstable. This is because the natural channel is not vulnerable and always affected by water flow. During heavy rain, it will either narrower or widen the channel because the wall of the channel having corrosion. In this study, it shows the channel becomes narrower when there is heavy rain. The smaller the sediment size and load, and the lower the flow velocity and stream power, the more stable the stream.

Thus, the value of exponent p shows the highest on Station 2 because Station 2 shows the lowest rates of erosion because of low flow [8]. Erosion reduces the size of bed load material and decreases the roughness of the channel. It increases downstream as more water is added to the channel and because the channel becomes more efficient with distance downstream. Station 2 shows rougher surface is having a higher roughness exponent and less retarding effect on the sediment flow, lower sediment rate is produced. As a conclusion, flow rate and roughness exponent were influenced by bed roughness.

The above discussion shows that exponents, b, f, m, and p, do not possess fixed values; rather they vary over certain ranges, depending on the way the adjustment of stream power is distributed among variables. Furthermore, the scale parameters are variant, depending on channel hydraulics, and this observation should help with regionalization of scale parameters.

4.3 Sediment rating curve (Q-Qs)

Rivers have a capacity to transport large volume of sediment while conveying water. Hence, the term sediment discharge (Qs) becomes an important factor for water resources management. The sediment volume transported by streams is critical for all hydraulic engineering projects. Power function analysis was utilised to determine the relations between the channel flow discharge and the sediment discharge. In the analysis, it was observed that the sediment discharge (Qs) is increasing with increasing flow discharge (Q) in all stations. This sediment rating curve is expected to be useful for the study on the sediment in the future.

Fig. 7 shows the relations of sediment discharge (Qs) against flow discharge (*Q*) at Station 1. The exponent value of Station 1 is 0.3665 and its coefficient is 0.0680. The data were observed and shows that the sediment discharge (Qs) was increasing against increasing flow discharge (Q). The highest value of sediment discharge (Qs) in at Station 1. This is because Station 1 have fast flow. In general, the greater the flow, the more sediment that will be conveyed. Water flow can be strong enough to suspend particles in the water column as they move downstream, or simply push them along the bottom of a waterway. Transported sediment may include mineral matter, chemicals and pollutants, and organic material.

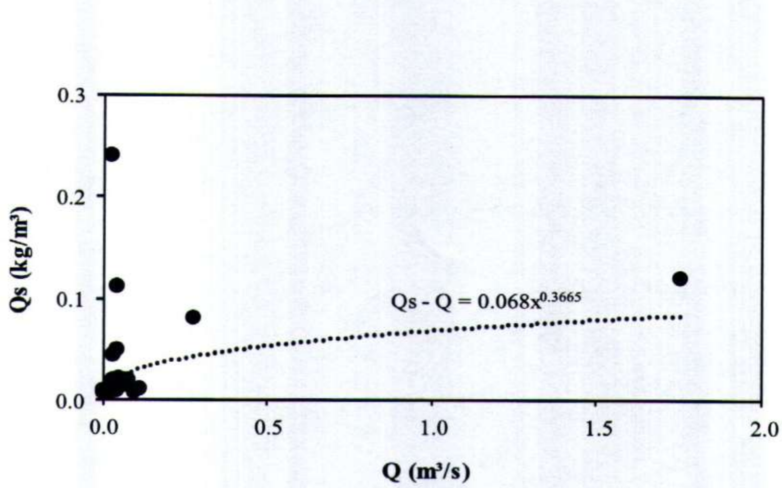

Fig. 7. Sediment rating curves (Qs–Q) for Station 1.

The Fig. 8 shows the relations of sediment discharge (Qs) against flow discharge (Q) at Station 2. The exponent value of Station 2 is 0.0789 and its coefficient is 0.0126. The data were observed and shows that the sediment discharge (Qs) was increasing against increasing flow discharge (Q). The lowest value of sediment discharge (Qs) in at Station 2. This is because station 1 have slow flow. The slower the flow, the lesser sediment that will be conveyed.

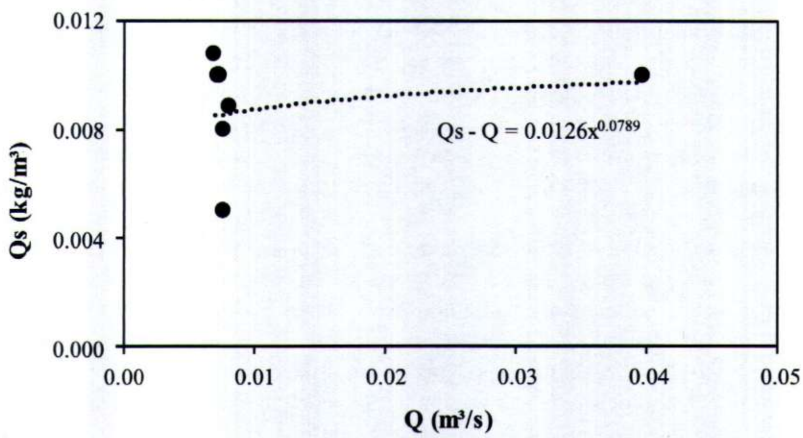

Fig. 8. Sediment rating curves (Qs–Q) for Station 2.

Furthermore, the Fig. 9 shows the relations of sediment discharge (Qs) against flow discharge (Q*)* at Station 3. The exponent value of Station 3 is 0.2718 and its coefficient is 0.0121. The data was observed and shows that the sediment discharge (Qs) was increasing against increasing flow discharge (Q).

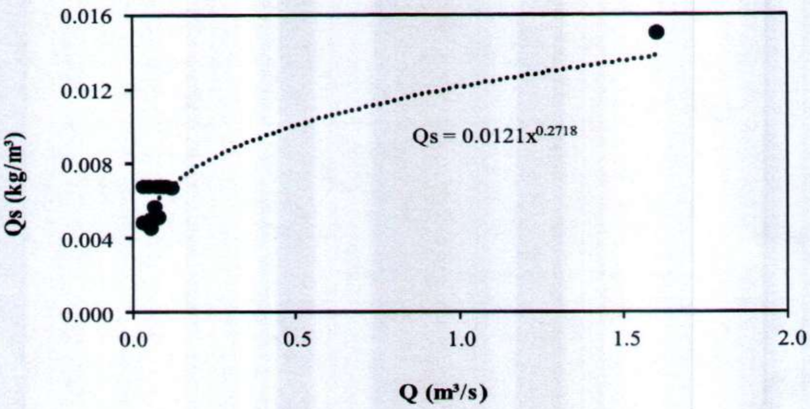

Fig. 9. Sediment rating curves (Qs–Q) for Station 3.

5 Conclusion

Sediment transport and hydraulic geometry parameters in a river are important for water resources management, as well as planning and mitigating extreme hydrological events such as floods and droughts. As in study, downstream hydraulic geometry analyses were performed at three selected stations on UPNM channel once a week for 7 weeks. In order to evaluate the relation between flow discharge and river flow characteristics, the studies were carried out in the form of a power function. The UPNM channels may adapt a consistent pattern calculated using the hydraulic geometry concept.

The presented results of exponents and coefficients given in for downstream hydraulic geometry accurately describe the general hydraulic geometry relations for UPNM channel. These relations can be inferred for other basins when they have similar characteristics. Hydraulic geometry parameters for UPNM were compared well to previously reported theoretical values. Nonetheless, diverse geologic, climatic, physiographic, and morphologic contexts apply the fundamental hydraulic geometry method, resulting in a wide variety of exponents and coefficients in downstream hydraulic geometry.

In conclusion, for downstream hydraulic geometry, mean depth, width, mean flow velocity and surface roughness were shown to rise as the flow discharge increased. Additionally, to hydraulic geometry analysis, the relations between sediment discharge and flow discharge has also been explored. According the findings, the relations in Station 1 was discovered being more significant than other stations in regards of correlation coefficient. Depends on this relations, the volume of the sediment transported in UPNM can be estimated. The output from this study is expected to shed light for hydraulic works in UPNM channel.

Acknowledgement

A part of this research was funded by Short Term Grant of Universiti Pertahanan Nasional Malaysia under grant UPNM/2019/GPJP/TK/9.

References

1. Leopold, L. B., Maddock, T.: The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper, pp. 252 (1953).
2. Huang, H. Q., Nanson G. C.: Vegetation and channel variation; A case study of four small streams in Southeastern Australia. Geomorphology 18, 237–249 (1997).
3. Yuce, M. I., Esit, M., Karatas, M. C.: Hydraulic geometry analysis of Ceyhan River, Turkey. SN Applied Sciences 1(763), 1–11 (2019).
4. Kolberg, F. J., Howard, A. D.: Active channel geometry and discharge relations of U.S. Piedmont and Midwestern streams: The variable exponent model revisited. Water Resour Res 31(9), 2353–2365 (1995).
5. Huang, H. Q., Warner, R. F.: The multivariate controls of hydraulic geometry: A casual investigation in terms of boundary shear distribution. Earth Surf Proc Landf 20, 115–130 (1995).
6. Rhoads, B. L.: A continuously varying parameter of downstream hydraulic geometry. Water Resour Res 27(8), 1865–1872 (1991).
7. Singh, V. P.: On the theories of hydraulic geometry. Int J Sedim Res 18, 196–218 (2003).
8. Suif, Z., Wahi Anuar, S. S., Ahmad, N., Othman, M., Che Osmi, S. K.: Hydraulics geometry analysis of UPNM channel. Environmental Science and Engineering, pp. 17-26 (2021).