Regional Flow Duration Curve Model for the Sg. Perak Sub-Basin

by Engr. Mohd. Rashid Mohd. Radzi

Estimation of water availably and variability in the Flow Duration Curves (FDC) are essential to provide valuable input in estimating hydropower, water supply, water pollution and other water resource applications. Due to limited stream flow stations located in rural areas, the planning of a hydropower site and assessing its potential including the economic viability and risk could be difficult. The introduction of regionalised techniques for the FDC helps to estimate the water variability at the intended site. The purpose of this study is to develop a regional FDC model at a selected sub-basin of the Sg. Perak watershed. The method uses nine stream flow stations to acquire their regional coefficients and to combine them with the regional model of logarithmic equations. A FDC can be developed at any point of the rivers in the sub-basin by using only their drainage area as the independent variable. The accuracy of the regional model is examined by comparing the measures by using the Root Mean Square Relative Error (ER). The results in model verification using logarithmic model indicate that the ER give values between 13.68% and 18.30% which is quite good for a feasibility and desktop study.

KEYWORDS: Flow Duration Curves, Hydropower, Regional Model

INTRODUCTION

The flow duration curve (FDC) is one of the informative methods that shows characteristics of the flow for a river, and has been a useful tool for various water resource problems such as in irrigation, water supply planning, pollution studies and small hydroelectric power planning. It is a historical cumulative curve that shows the percent of time specified discharges that are equaled or exceeded during a given period ordered from maximum to minimum flow. Smakhtin (2001)[1] stated that FDC can be constructed using daily, monthly or annual data and calculated on the basis of all similar calendar months from the whole record period.

The information on the availability of flow over a time from the area under the FDC is used to determine the average annual energy for the determination of economic viability of a hydropower project. Vogel and Fennessey (1995)[2] presented a power duration curves derived from the combination between an FDC and power discharge rating curves. Warnick (1984)[3] illustrated the application of FDCs to hydropower feasibility studies for run-of-river operation.

Regionalisation of FDC of an interest area is important to reduce the time and cost of a water resources study. It enables researchers to simplify and estimate the river flow availability of any water resource projects especially a hydro project. FDC regionalisation can be analyzed by several methods. Rajonaman P. *et al.* (2007)[4] states that the regional parametric method is used for estimating FDC at ungauged sites.

Yu *et al.* (2002)[5] suggests that FDC can be regionalised and methods could be divided into two groups; firstly, the one which uses mathematical equations or statistical distribution to fit FDC constructed from gauged data and secondly, the regression between the discharges of some specific percentage. Castellarin *et al.* (2004)[6] has classified regionalisation procedure based on statistical, parametric and graphical approaches.

Many of the rivers in Malaysia possess the potential to be developed as run-off river schemes supporting mini hydro-electric projects. Overall, the technical potential of Malaysia's hydropower resources has been estimated to be about 123,000 Gigawatthours (GWh) per year. The geographic distribution of hydropower resources in Malaysia is uneven. Peninsular Malaysia has only 16,200 GWh/year (13.2%) of the resources. However, Sarawak with land area slightly smaller than Peninsular Malaysia has over 65,500 GWh/year (53.2%) of hydropower resources while Sabah has 41,200 GWh/year (33.5%) of Malaysia's total technical potential hydropower resources. Sg. Perak has about 3,800 GWh which is 23.3% of 16,200 GWh of energy for Peninsular Malaysia. Figure 1 shows the potential energy distribution for a river basin in Peninsular Malaysia (Yong Huat, 1988)[7].

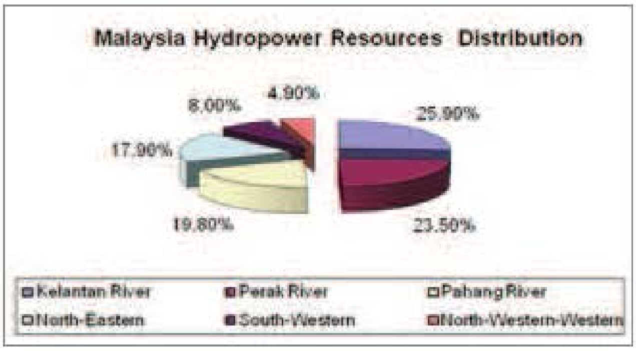

Figure 1: Technical potential of Malaysia's hydropower resources

In order to explore the feasibility of using hydropower as an additional energy source in Perak, it is necessary to be able to define the variability of flow available in the streams where the hydropower plants might be constructed.

Since most of the identified sites for small hydropower projects are normally located along small streams in remote areas where flow records are rarely available, regionalised FDC methods must be developed to estimate the stream flow water variability and the power potential at the selected site.

The objective of this study is to develop a simple regionalised model to estimate the daily mean FDC at ungauged sites in the Sg. Perak river sub-basin.

The findings of this study would help the developer of a hydro-electric project to estimate the availability of flow from the Regional FDC at Sg. Perak river sub-basin.

LITERATURE REVIEW

Subramanya (2003)[1] describes the FDC of a stream as the graphical plot of discharge against the percentage of time the flow was equaled or exceeded and consequently the power and energy on site. From this, it would then be possible to check the design scheme detailed in the pre-study for the use in power and energy calculation, prepare the operation simulation and unify the design process. This curve is also known as the discharge-frequency curve.

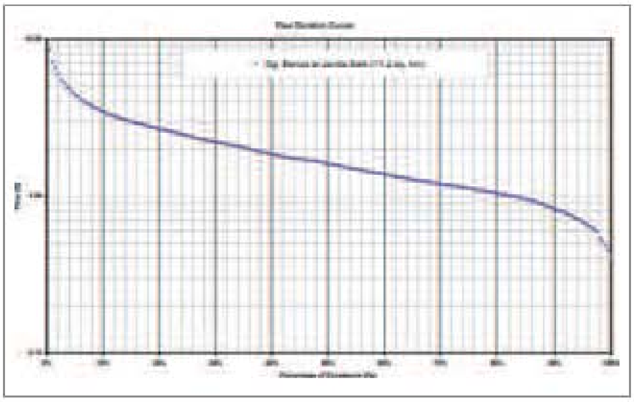

Figure 2: Typical flow duration curve in semi log graph

The stream flow data is arranged in a descending order of discharges, using class intervals if the number of individual values is very large. The data used can be the daily, weekly or monthly values. If N number of data points are used in the listing, the plotting position of any discharge (or class value) Q is:

$$Pp = [m/(N+1)]^* \ 100 \qquad (1)$$

Where m is the order number of the discharge (or class value), and Pp is the percentage probability of the flow magnitude being equaled or exceeded. The plot of the discharge, Q against Pp is the flow duration curve (Figure 2). The flow duration curve represents the cumulative frequency distribution and can be considered to represent the stream flow variation of an average water year.

STUDY AREA

Perak river basin situated in the state of Perak is the second largest watershed after Sg. Pahang river basin in Peninsular Malaysia. It flows over 420 km in a 14,834 km² catchment that covers 70% of the state land. It starts from the north-western corner of the state, flows south to Teluk Intan, where it bends westward and into the Straits of Malacca. The Sg. Perak river basins are shown in Figure 3.

The climatic features of the area are uniform temperature, high humidity and relatively high rainfall. The mean monthly temperature varies from 26°C to 27°C. The variation in monthly temperature is not more than 2°C. The minimum average relative humidity in the area is around 79% during the dry season and peaks at a mean of approximately 86% in the wet season.

Geo-morphologically, the terrain in both catchment areas can be described as steep dissected hills with a relief of 400 – 1,500m. Several of the main streams have been dissected along lineaments trending SW and NW. The main streams have incised meanders over their lower courses before entering an area of low dissected hills. The area has a high potential for hydropower developments due to its steepness and sufficient rainfall to generate electricity.

Table 1 shows the information of the stream flow gauging station in the Sg. Perak sub-basin. Nine stream flow stations in the sub-basin were selected in developing the model.

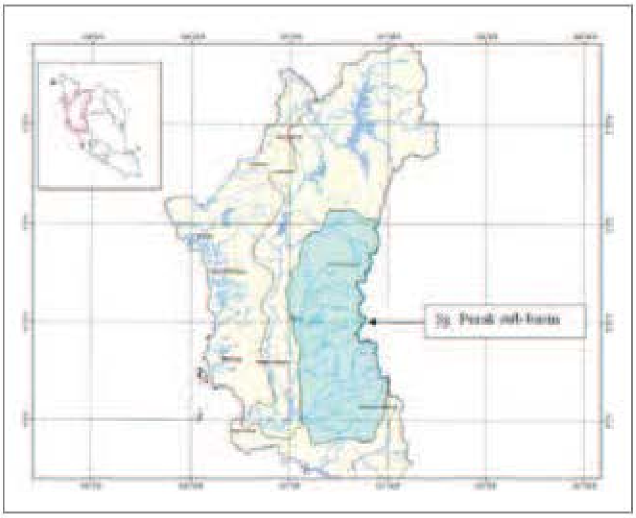

Figure 3: Sg. Perak river basin and study area of sub-basin

METHOD OF ANALYSIS

The FDC curves can be fitted with five mathematical models which are the logarithmic, quadratic, cubic, power, and exponential models. The equation (Eq.) of each model can be written as follows:

$$Q = a_1 + a_2 \ln(D) \qquad (2)$$
$$Q = b_1 + b_2D + b_3D^2 \qquad (3)$$
$$Q = c_1 + c_2D + c_3D^2 + c_4D^3 \qquad (4)$$
$$Q = d_1 (D^{d2}) \qquad (5)$$
$$Q = e_1 \exp(e_2D) \qquad (6)$$
$$Q/Q_m = f_1 + f_2 \ln(D) \qquad (7)$$
$$Q/Q_m = g_1 + g_2D + g_3D^2 \qquad (8)$$
$$Q/Q_m = h_1 + h_2D + h_3D^2 + h_4D^3 \qquad (9)$$
$$Q/Q_m = i_1 (D^{i2}) \qquad (10)$$
$$Q/Q_m = J_1 \exp(j_2D) \qquad (11)$$

where a-j are the relevant coefficients.

Table 1: Stream flow stations characteristics

No.	Station code	Station name	Period of record	Complete year record	Agency	Darainage area (km²)
1.1	4911445	Sg. Pelus at Kg. Lintang	1984-1997	11	JPS	1090
1.2	6029	Sg. Piah at Chenrob	1965-1996	12	TNB	232.6
1.3	6035	Sg. Pelus at Kuala Yum	1985-2010	8	TNB	330
1.4	4611463	Sg. Kinta at Tg. Rambutan	1960-2008	25	JPS	246
1.5	4310401	Sg. Kinta at Weir G, Kg. Tualang	1976-2010	22	JPS	1700
1.6	4212467	Sg. Chenderiang at Bt. 32	1970-2010	13	JPS	119
1.7	4012401	Sg. Bidor at Malayan Tin Bhd	1980-2010	12	JPS	210
1.8	4111455	Sg. Batang Padang at Tg. Keramat	1960-2005	11	JPS	445
1.9	3913458	Sg. Sungkai at Sungkai	1960-2010	12	JPS	289

Examples of the fitted line of Q versus D and Q/Q_m versus D from logarithmic station 6029 are shown in Figure 4 and Figure 5 respectively.

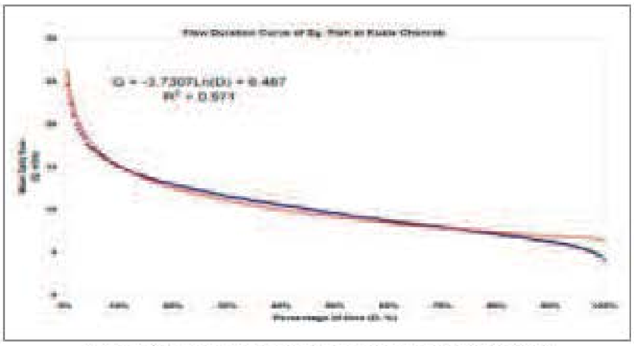

Figure 4: Fitted regression line on station no. 6029 FDC

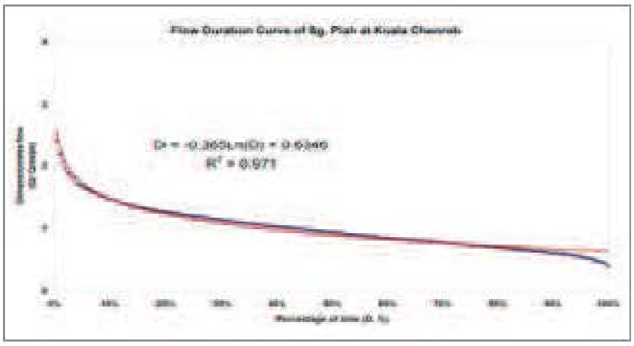

Figure 5: Fitted regression line on station no. 6029 dimensionless FDC

By using the regression analysis, the models in Eq. (2) – (6) and Eq. (7) – (11) were fitted to each set of paired values of Q versus D and Q/Q_m versus D respectively.

The model with regression coefficients (R^2) closest to 1 is the best fit selected. The values of R^2 of Eq. (2), (3), (4), (5) and (6) are equaled to that of Eq. (7), (8), (9), (10) and (11) respectively. Table 2 shows R^2 of each model for each station.

The average R^2 for all stations in Sg. Perak River basin of the logarithmic, quadratic, cubic, power and exponential models are 0.98, 0.90, 0.95, 0.77 and 0.91 respectively. The logarithmic gives the highest values closest to 1.

Therefore, the logarithmic model is then selected and takes into consideration the regionalisation of the flow duration curves models.

During the pre-feasibility study of hydropower projects, the model for prediction of FDC should be kept as simple as possible. The parameter use in the model should be obtained easily. Therefore, during the initial stage of hydropower, only the drainage area should be used in the development of the regionalised model.

Nine gauging stations in the sub-basin were selected to develop the regional model. Stream flow daily mean discharge data which were used for model development and model verification are indicated in Table 1 and Table 3 respectively.

Table 2: Regression coefficient (R^2) of five mathematical models for the FDC for Sg. Perak stream flow stations

No	Station code	Logarithmic	Quadratic	Cubic	Power	Exponential
1	4911445	0.9869	0.8982	0.9458	0.7221	0.8617
2	6029	0.9710	0.9395	0.9743	0.8546	0.9681
3	6035	0.9926	0.9228	0.9681	0.8922	0.9601
4	4611463	0.9743	0.8293	0.8915	0.8322	0.9655
5	4310401	0.9862	0.9351	0.9810	0.7534	0.9356
6	4212467	0.9904	0.8975	0.9622	0.6678	0.8769
7	4012401	0.9877	0.8676	0.9401	0.6007	0.7733
8	4111455	0.9698	0.9611	0.9848	0.8097	0.9761
9	3913458	0.9896	0.8870	0.9404	0.8197	0.9385
AVERAGE		0.9832	0.9042	0.9542	0.7725	0.9173

(Continued on page 22)

Table 3: Stream flow for model verification

Station name	Period of record	Complete year record	Agency	Darainage area (km²)
Sg. Pari at Jalan Silibin	1960-2008	16	JPS	245
Sg. Kampar at Kg. Lanjut	1960-1993	11	JPS	432

Regression coefficients of a_1, a_2 and f_1, f_2 from the logarithmic model in Eq. (2) and in Eq. (7) from each station were taken and tabulated in Table 4.

Table 4: Regression coefficients from fitted models

Station No.	Logarithmic		Dimensionless log.	
	a_1	a_2	f_1	f_2
4911445	13.66	-19.22	0.41	-0.58
6029	6.49	-3.73	0.63	-0.37
6035	6.55	-5.28	0.55	-0.45
4611463	1.14	-6.57	0.16	-0.90
4310401	27.56	-47.70	0.37	-0.63
4212467	1.79	-5.47	0.25	-0.75
4012401	3.62	-9.47	0.28	-0.72
4111455	15.32	-15.49	0.50	-0.50
3913458	6.33	-9.08	0.41	-0.59

Spatial coefficients relating the drainage area (A) and the individual regression coefficients of stream flow FDCs in Sg. Perak sub-basin are plotted by a straight line equation (Figure 6 and Figure 7). The straight line equations of these coefficients can be written as:

$$a_1 = k_1 + k_2(A) \quad (12)$$

$$a2 = k_3 + k_4(A) \quad (13)$$

$$f1 = m_1 + m_2(A) \quad (14)$$

$$f2 = m_3 + m_4(A) \quad (15)$$

The spatial coefficients (k_1 to k_4 and m_1 to m_4) are tabulated in Table 5.

The representative mean flow (Q_m) for the regionalised mean flow is performed by determining the relationship between the mean annual flow and the drainage area for all nine stream flow stations in Figure 8, which is written as Eq. (16).

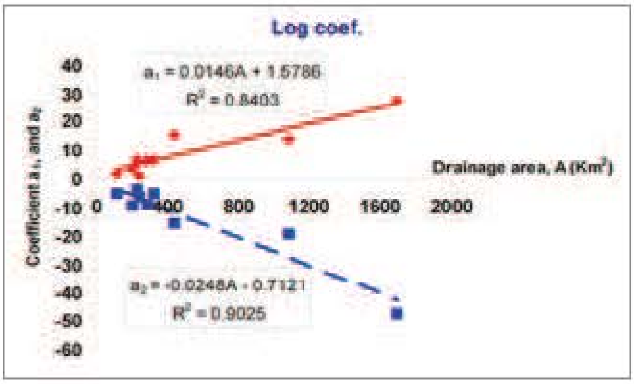

Figure 6: Spatial regional relationship of logarithmic model

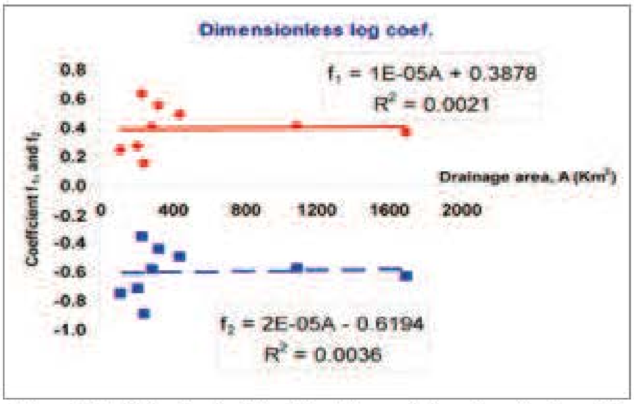

Figure 7: Spatial regional relationship of dimensionless logarithmic model

Table 5: Spatial coefficients for FDC model

Logarithmic				Dimensionless logarithmic			
a_1		a_2		f_1		f_2	
k_1	k_2	k_3	k_4	m_1	m_2	m_3	m_4
4.08	0.01	0.60	-0.02	0.66	-0.0002	-0.40	-0.0002

$$Qm = a.A^b \quad (16)$$

where A is the drainage area in km² while a and b are constants; the coefficients a, b and Q_m for each station are shown in Table 6.

Table 6: Coefficients in developing Q_{mean} (Q_m)

Station	A (km²)	a	b	$Q_{mean} = aA^b$
4911445	1090	0.0999	0.8676	43.14
6029	232.6			11.29
6035	330			15.30
4611463	246			11.86
4310401	1700			63.43
4212467	119			6.31
4012401	210			10.34
4111455	445			19.83
3913458	289			13.63

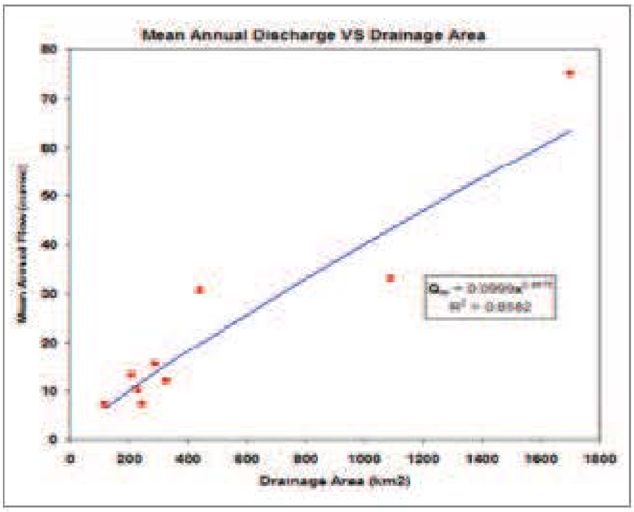

Figure 8: Stream flow for model verification

The discharge (Q) corresponding to the percentage of time (D) at the interval increasing 1% each step to 100% for each station were computed and compared between the results from the logarithmic and cubic model to find the best fitted equation.

To create a model, coefficients a_1, a_2, a_3, a_4 and coefficients f_1, f_2, f_3, f_4 from Eq. (12), Eq. (13), Eq. (14) and Eq. (15) into Eq. (2) and Eq. (7). The calculated discharges by logarithmic models can be expressed as:

$$Q = (k_1 + k_2.A) + (k_3 + k_4.(A)\ \ln(D) \tag{17}$$

$$Q/Q_m = (m_1 + m_2.A) + (m_3 + m_4.(A)\ \ln(D) \tag{18}$$

where the constant k_1 to k_4, and m_1 to m_4 are tabulated in Table 5.

RESULT ANALYSIS

Using the coefficient of k_1 to k_4, m_1 to m_4, from Table 5, constant a, b from Table 6, and the drainage area of each station, the predicted discharge from 1 to 100% with intervals of 1% for each step or percentage of time (D) are determined from Eq. (17) and (18) respectively. The error ER of model calibration and model verification for each station and sub-basin are shown in Table 6 and Table 7.

Model calibration and model verification are required to evaluate the accuracy of the regional model which is developed from data of gauging station in Table 1. The model calibration is achieved through the comparison of sets of river gauging stations used for model development, by comparing the actual measured discharge with the computed discharge using the logarithmic models, using Eq. (17) and (18).

For model verification, two sets of discharge data from station Sg. Pari at Jalan Silibin (Stn. No: 4610466) and discharge data from station Sg. Kampar at Kg. Lanjut (Stn. No: 4311464) were used.

The accuracy of regional models is examined by comparing the Model FDC with actual measured FDC. The verification of the results is presented in terms of root mean square relative error (ER) in order to evaluate the accuracy of the prediction of the developed FDC model. The ER equation is defined as in Eq. (19).

$$ER = 100\sqrt{\frac{\sum_{D=1}^{100}(QD_c - QD_m)^2}{\sum_{D=1}^{100} Q^2 D_m}} \tag{19}$$

where D is the percentage of time between 1 to 100%, QD_c is the computed discharge at any percentage of time; QD_m is the measured discharge at any percentage of time.

The average ERs for model calibration in Table 7 are 29.82% (logarithmic) and 30.62% (dimensionless logarithmic) while the ERs for model verification are shown in Table 8.

Table 7: Comparison of root mean square relative error (ER) for model calibration

Stations	Logarithmic	Dimensionless log.
6029	27.29%	31.08%
6035	38.9%	42.56%
4911445	43.28%	37.58%
4611463	53.32%	56.05%
4310401	10.54%	17.15%
4212467	20.46%	20.33%
4012401	27.21%	25.67%
4111455	34.64%	33.87%
3913458	12.78%	11.33%

Table 8: Comparison of root mean square relative error (ER) for model verification

Stations	Logarithmic	Dimensionless log.
Sg. Kampar at Kg. Lanjut	13.68%	12.66%
Sg. Pari at Jalan Silibin	18.30%	36.18%

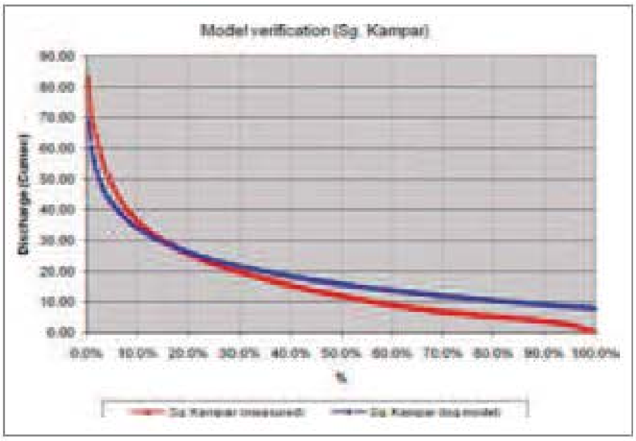

Figure 9: Model verification of Sg. Kampar FDC

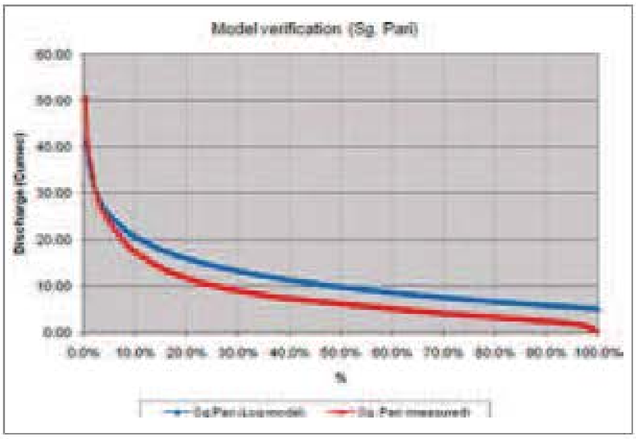

Figure 10: Model verification of Sg. Pari FDC

CONCLUSION

The FDC using logarithmic fitting distribution equations and model gives the best predictions.

The findings from this study differ from those of other researchers such as Rajonaman P. *et al.* (2007)[4] who had used the logarithmic and exponential model in the regional model of Salawin river basin. Quimpo *et al.* (1983)[9] had proposed that only the exponential equation be used in the Philippines regional FDC, while Mimikou and Kaemaki (1985)[10] suggested to use the cubic equation in modeling FDC.

The differences in the results could be attributed to several factors, namely the variations of the regions modelled, the sets of stream flow available which have been based on different lengths of recorded data, and also the different climatic characteristics of the regions.

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