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Prediction of Flood Levels Along a Stretch of the Langat River with Insufficient Hydrological Data

Thamer Ahmed Mohammed[1*], Saleh Al-Hassoun[2] and Abdul Halim Ghazali[1]
[1]*Department of Civil Engineering,*
Faculty of Engineering, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor, Malaysia,
[2]*Department of Civil Engineering,*
College of Engineering, King Saud University,
Riyadh 11421, Kingdom of Saudi Arabia
[*]*E-mail: thamer@eng.upm.edu.my*

ABSTRACT

Malaysia is a tropical country and it is subjected to flooding in both the urban and rural areas. Flood modelling can help to reduce the impacts of flood hazard by taking extra precautions. HEC-RAS model was used to predict the flood levels at selected reach of the Langat River with a total length of 34.4 km. The Langat River is located in the state of Selangor, Malaysia and it is subjected to regular flooding. The selected reach of the Langat River has insufficient data and a methodology was proposed to overcome this particular problem. Since complete floodplain data for the area are not available, the modelling therefore assumed vertical walls at the left and right banks of the Langat River and all the predicted flood levels above the banks were based on this assumption. The HEC-RAS model was calibrated and the values of Manning's coefficients of roughness for the Langat River were found to range from 0.04 to 0.10. The discharge values were calculated for 5, 10, 25, 50, and 100 year return periods and the maximum predicted flood depth ranged from 2.1m to 7.8m. Meanwhile, the model output was verified using the historical record and the error between the recorded and predicted water levels was found to range from 3% to 15%.

Keywords: Langat River, Malaysia, discharge, hydraulic modelling, HEC-RAS, flood level

INTRODUCTION

Flood can be defined as a hydrological event characterized by high discharges and/or water levels, leading to inundation of land adjacent to streams, rivers, lakes, and other water bodies. In Malaysia, there are more than 150 river systems and the courses of these rivers are relatively short with steep gradients in the upper stretches and comparatively flat and meandering stretches in the lower reaches. Flood flows are therefore transient in the upper reaches but increase in duration and intensity towards the coastal plains. The bulk of the population is concentrated in towns and villages situated in riverside valleys and coastal plains which are prone to flood damage.

Flooding is still the most significant natural hazard in Malaysia and the problem has escalated over the years as the country becomes more developed. Since the sixties of the last century, Malaysia has experienced major floods in the years 1967, 1969, 1971, 1973, 1979, 1983, 1988, 1993, 1995, 1999, 2000, and 2003. It has been estimated that some 29,000 km² or 9% of the total land areas are flood prone, affecting more than 15% of the total population. The average annual flood damage cost is estimated to be RM100 million (Ann, 1994). However, this figure is likely to be a gross

[*]Corresponding Author

under-estimate in view of the rapid socioeconomic development in the past decade, which has led to significant increases in both land and property prices. Therefore, prediction of flood levels for different frequencies will help to reduce flood damages and in checking the effectiveness of flood mitigation measures, namely the channel improvement as a solution for flood control.

Hydraulic models are essential tools in the design of flood alleviation works, assessing levels of service and estimation of residual flooding. Hydraulic models used in simulation can be classified into dynamic hydraulic models and static hydraulic models. This classification is based on the concept and approach used in the formulation of these models. Ishikawa (1984) developed a static hydraulic model for computing water surface profile in prismatic and non-prismatic channels. Meanwhile, dynamic hydraulic model were developed by Lyness & Myers (1994), Molls & Chaudhary (1995), as well as Sturm & Sadiq (1996). Nik (1996) applied both HEC-2 static hydraulic model and MIKE 11 dynamic hydraulic model to predict the water surface elevation in the Klang River, Malaysia and a difference of 5% was obtained between the two models. The effect of bed resistance on the river Rhine during flood was studied by Julien *et al*. (2002). Hall *et al*. (2005) conducted a sensitivity analysis on flood inundation model calibration. Table 1 shows the application of some hydraulic model for the flood mitigation of Malaysian rivers which have been applied by the Department of Irrigation and Drainage, DID.

In this study, the HEC-RAS model was used to predict the flood levels for a 34.4 km stretch of the Langat River, Kajang, in Selangor, Malaysia. Meanwhile, the hydrologic records acquired from the DID were used to run the model.

TABLE 1
The application of hydraulic models for selected rivers in Malaysia

No.	River	State	Year of application	Model type
1	Linggi River	Negeri Sembilan	2001	HEC-RAS
2	Klang River	Selangor	2001	Mike 11
3	Kelantan River	Kelantan	1999	Mike 11
4	Chukai River	Kuala Terengganu	1996	EXTRAN –XP
5	Georgetown River	Pulau Pinang	1995	EXTRAN
6	Kinta River	Perak	1994	Mike 11

THE STUDY AREA

The Langat River is one of the longest rivers in Selangor with frequent flooding. The river runs from north-east to south-west, i.e. from Sungai Lui Village to Dengkil. There are four gauging stations along the river but only two are located within the selected river reach (*Fig. 1*). At the downstream, the river width averages between 25-30 m.

The Langat River has been experiencing flood almost every year since 1976 and the main cause of the flood is insufficient channel capacity. The biggest flood was recorded in September 1982, with the flooded area of about 3.0 km^2 and to a depth of 4.33 m, and the damage at the flooded area was quite severe. The selected reach of Langat River is located between two gauging stations, namely Sungai Lui gauging station (upstream) and Kajang gauging station (downstream). The hydrological and topographical data for the Langat River, which included discharge, water level and

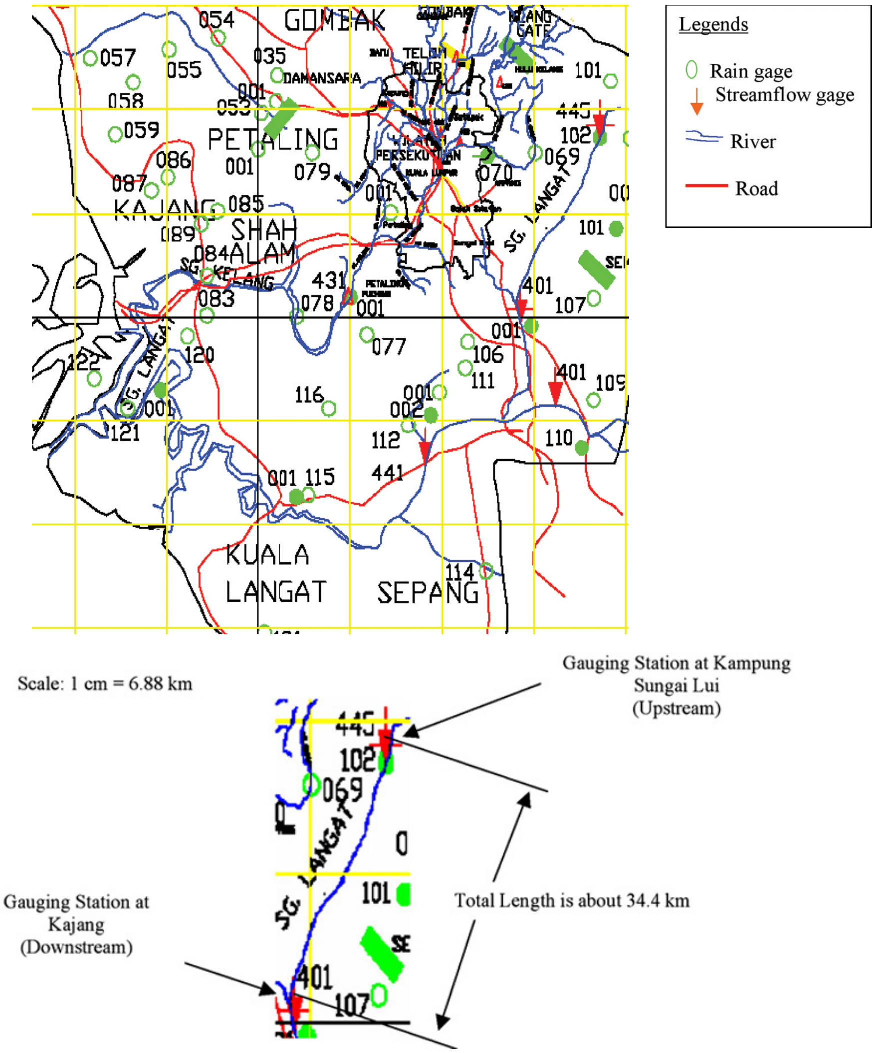

Fig. 1: Location of the selected of the Langat River
(DID, 2004)

river cross sections, were acquired from the DID. The records spanned around 27 years (i.e. from 1976 to 2003). The data were used to run the HEC-RAS model. Tables 2 and 3 show the samples of stream flow data. Along the selected reach, only 183 cross sections were available. Nonetheless, the intervals for the cross sections were not equal as they ranged from 200 m to 300 m.

METHODOLOGY

The analysis of the water surface profile for any river or open channel usually requires the discharge (Q) of a given magnitude and known Average Recurrence Internal (ARI) or return period (*T*). It is recommended to use the log-Pearson Type III method to determine the discharge frequency. The

TABLE 2
Discharge for various return periods at Lui and Kajang gauging stations

Return period (Year)	Discharge at Lui gauging station (m^3/s)	Discharge at Kajang gauging station (m^3/s)
2	6.92	37.45
5	10.16	60.09
10	12.58	81.49
25	15.87	118.06
50	18.55	153.92
100	21.72	198.93
200	24.39	255.30

TABLE 3
Discharges for 5 year return period for the Langat River

Sub-reach (km)	Flood (m^3/s)	Average discharge (Q_{avg})	Water level (m)
0	3.84		77.39
		7.66	
5	11.48		66.77
		15.30	
10	19.12		62.15
		22.94	
15	26.75		54.54
		30.58	
20	34.40		49.92
		38.22	
25	42.03		39.30
		45.85	
30	49.67		31.68
		53.03	
34.4	56.39		24.98

frequency factor equation for Pearson Type III distribution can be written in terms of discharge as follows:

$$\log Q_T = \sum_{i=1}^{n} \frac{\log Q_i}{n} + K_T(T, G_s)\left(\sqrt{\sum_{i=1}^{n} \frac{\log Q_i - \sum_{i=1}^{n} \frac{\log Q_i}{n}}{n-1}}\right) \tag{1}$$

where Q_T is the discharge for the T-year return period, Q_i is any recorded discharge for a river with the n record length, and K_T is the frequency factor.

The frequency factor is dependent on the return period, T and the coefficient of skewness, G_s. When G_s =0,

$$K_T = z \tag{2}$$

where z is the standard normal variable.

However, when $G_s \neq 0$, the approximation by Kite (1977), which is described by Equation (3), can be used to determine the value of the frequency factor:

$$K_T(T,G_s) = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5 \tag{3}$$

In Equation (3), k can be determined as follows (Mays, 2001):

$$k = \frac{G_s}{6} \tag{4}$$

In addition, a standard table given by Mays (2001) was used to determine the value of the frequency factor, K_T, for Pearson Type III distribution for any return period, T and coefficient of skewness, G_s.

For an accurate prediction of the water surface profile along a river using HEC-RAS, the discharge of a known return period at each river cross section is required. However, in the absence of suitable records of discharge along the river, particularly when the river has tributaries, a reasonable approximation is required.

The locations of the two gauging stations are at the upstream (i.e. at the beginning of the selected stretch) and at the downstream (i.e. at the end of the selected stretch). Hence, the following approximations have been proposed to overcome this particular constraint and to predict the water surface profile with reasonable accuracy:

1. Discharges of various return periods for the Langat River were determined at the upstream location and the downstream location.
2. The stretch was divided to five almost equal sub-reaches, namely, L_1, L_2, L_3, L_4 and L_5, respectively.
3. For each sub-reach, no increase or decrease in the discharge was assumed and it could be determined using the following:

$$(Q_T)_{L_i} = [\frac{(Q_D)_T - (Q_u)_T}{L}][L_i] \tag{5}$$

where $(Q_T)_{L_i}$ is the discharge of the return period, T at the sub-reach i of the river, $(Q_D)_T$ is the discharge of return period, T at downstream, $((Q_u)_T$ is the discharge of the return period, T at upstream.

4. The calibration for the HEC-RAS model can be conducted using computed discharge for a known return period by assuming the values of the Manning's coefficient of roughness for the central channel, right overbank, left over bank and for each sub-reach of the river. The correct values of the Manning's coefficient of roughness can be decided when the error in the predicted and recorded water surface profiles ranged from 0 to 15%.

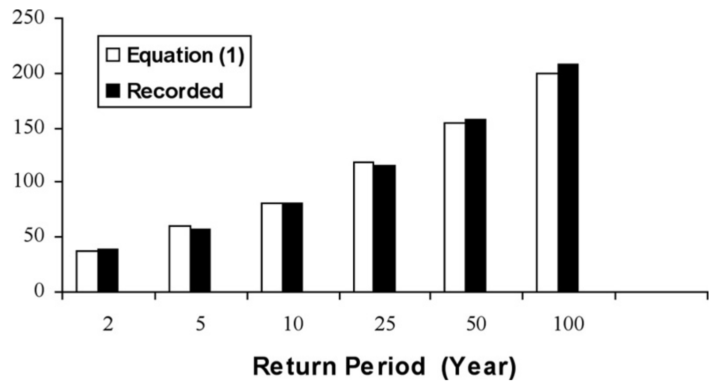

Fig. 2: Recorded and computed discharges at Kajang Gauging Station

RESULTS AND DISCUSSION

The main obstacles faced while predicting the water surface profile for the Langat River using the HEC-RAS model were the relatively short length of the historical records (for both discharge and water level) and the limited number of gauging stations along the river. To overcome this constraint, the available discharge records and Equation (1) were used to determine Q_2, Q_5, Q_{10}, Q_{25}, $Q_{50,}$ $Q_{100,}$ $_{and}$ Q_{200} for the selected reach. Table 2 shows the discharges of the Langat River with various return periods at the reach. The differences between the computed and recorded values ranged from 2% to 5% only. *Fig. 2* illustrates the comparison between the two values.

The methodology described earlier on was applied when the discharge of the known return period at the upstream gauging station and the associated discharge at downstream gauging station were used together to estimate the discharge at each reach using Equation (5). The application of Equation (5) required the determination of the difference between the discharges of the same return period (at the downstream and at the upstream) and divided by the length of the river reach, i.e. 34.4 km.

The resulting discharge per unit of one km length was then multiplied by the distance of each sub-reach to get the total average discharge in this sub-reach, which was later used to predict the water surface profile using the HEC-RAS model. The average discharge for the 5 year's return period for various sub-reaches of Langat River is shown in Table 3.

The selection of an appropriate value for the Manning's coefficient of roughness is very significant for the accuracy of the computed water surface profiles. The value of the Manning's coefficient of roughness is determined by a number of factors which include surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal changes, temperature, as well as suspended material and bed load. In general, the values of the Manning's coefficient of roughness should be calibrated whenever observed water surface profile information is available.

The calibration was performed by adjusting the value of the Manning's coefficient of roughness for the river cross-section repeatedly, until the computed water level almost matched the observed ones. The selected river reach was divided into seven sub-reaches, and each sub-reach with a length of 5 km but the last sub-reach was 4.4 km long. The values of the Manning's coefficient of roughness from the down stream to the upstream were determined for each sub-reach. In the calibration process, the values of the Manning's coefficient of roughness for left over bank, main channel and right over bank for every station at the sub-reach of the Langat River were estimated

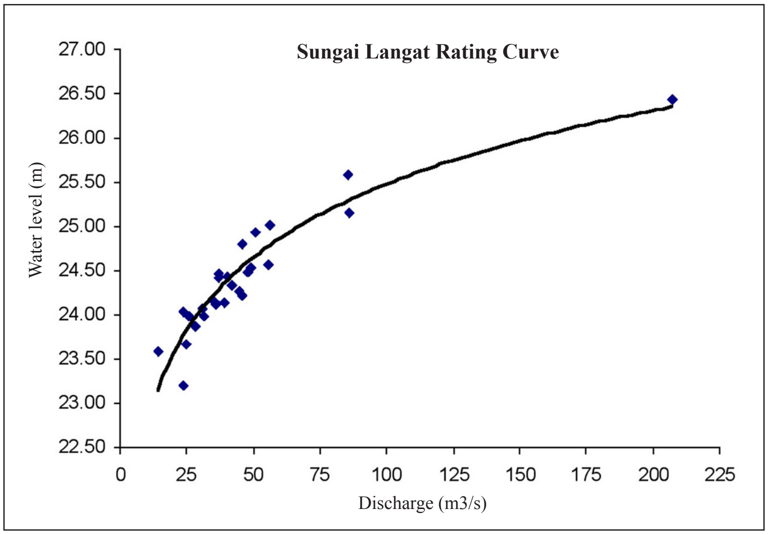

Fig. 3: Rating curve for the Langat River at downstream (DID, 2004)

using the published values. The historical records for the 2-year's return period (discharge and water levels) were used in the calibration process. In order to perform the water surface computation using the HEC-RAS model, computation was done from the downstream to upstream because the flow was found to be sub-critical for the recorded discharge of this particular reach.

It was assumed that a difference of less than 15% between the predicted and the observed water levels at each sub-reach of Langat River was acceptable. As a result, the value of the Manning's coefficient of roughness used for the computations was considered to be representing the actual conditions for the Langat River. If the difference was more than 15%, another value of the Manning's roughness would then be assumed and the process was repeated until the right values were obtained. Table 4 shows the final values of the Manning's coefficient of roughness for the Langat River. *Fig. 3* shows the rating curve at Kajang station (downstream). The calibration of the HEC-RAS model was concentrated on the determination of the Manning's coefficient of roughness for various sub-reaches of the Langat River. The trial and error method was used in the calibration process.

TABLE 4
The estimated values of Manning's coefficient of roughness for the Langat River

Sub-reach number	Sub-reach (km)	Manning's coefficient of roughness		
		Left bank	Central channel	Right bank
Sub-reach 1	CH34.4-CH29.4	0.050	0.045	0.050
Sub-reach 2	CH29.4-CH24.4	0.080	0.075	0.080
Sub-reach 3	CH24.4-CH19.35	0.060	0.100	0.060
Sub-reach 4	CH19.35-CH14.35	0.045	0.100	0.045
Sub-reach 5	CH14.35-CH9.4	0.040	0.080	0.040
Sub-reach 6	CH9.4-CH4.4	0.048	0.080	0.048
Sub-reach 7	CH4.4-CH00	0.048	0.043	0.048

The error between the recorded and predicted water surface profiles was found to range from 3% to 15% and this confirmed that the estimated coefficients of the roughness for the Langat River were reasonably accurate. The calibration process was followed by the verification process.

The main objective of the model verification was to check the accuracy of the proposed method in order to run the model. The verification was done by comparing the predicted values with the previous records. *Figs. 4* to *9* show the comparison between the predicted and the recorded water surface levels. The accuracy of the predicted flood levels is dependent on the accuracy of the

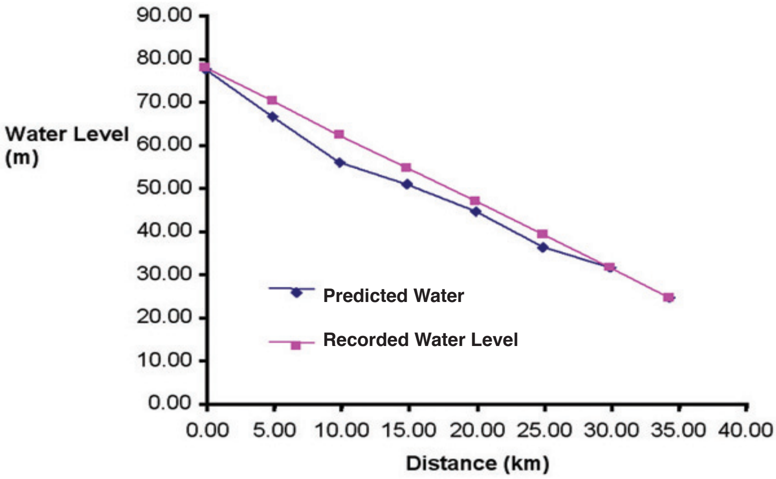

Fig. 4: The predicted and the recorded levels for flood of 2 year ARI along the Langat River reach

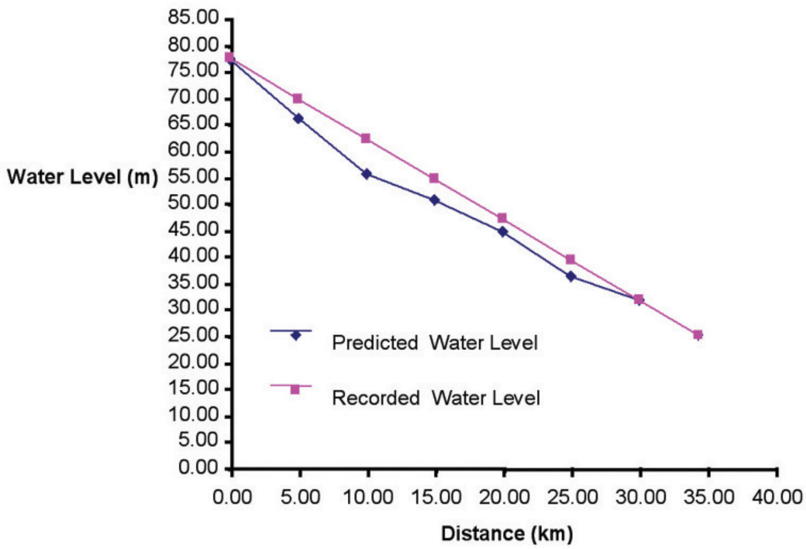

Fig. 5: The predicted and recorded levels for flood of 5 year ARI along the Langat River reach

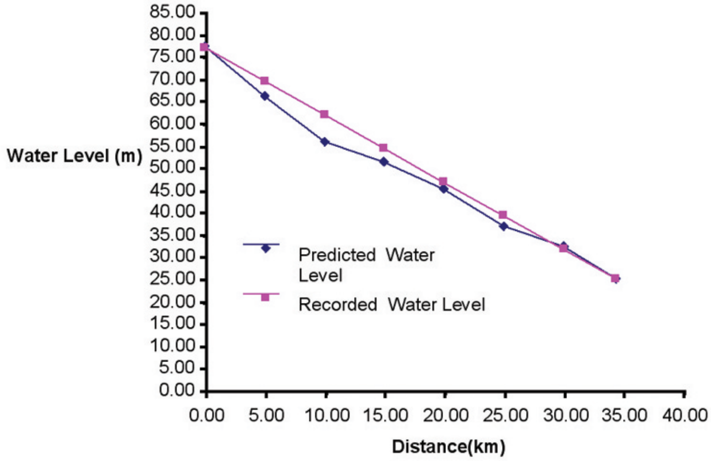

Fig. 6: The predicted and recorded levels for flood of 10 year ARI along the Langat River reach

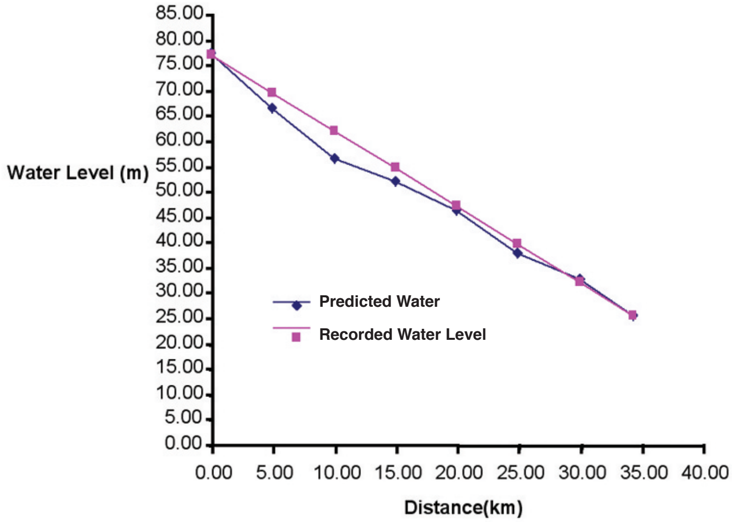

Fig. 7: The predicted and recorded levels for flood of 25 year ARI along the Langat River reach

previous records used in the calibration process. Another factor which can affect the accuracy of the predicted flood levels is the estimated value of the Manning's coefficient of roughness used in the calibration process.

The differences between the predicted and the recorded water surface levels could be attributed to ignoring the existing hydraulic structures (bridges and culverts) and river meandering. In addition, the large interval of the river cross-sections (200 to 300 m) could be another factor which contributed to the differences. Moreover, incomplete hydrological and topographical data is another source affecting the accuracy of the predicted flood levels.

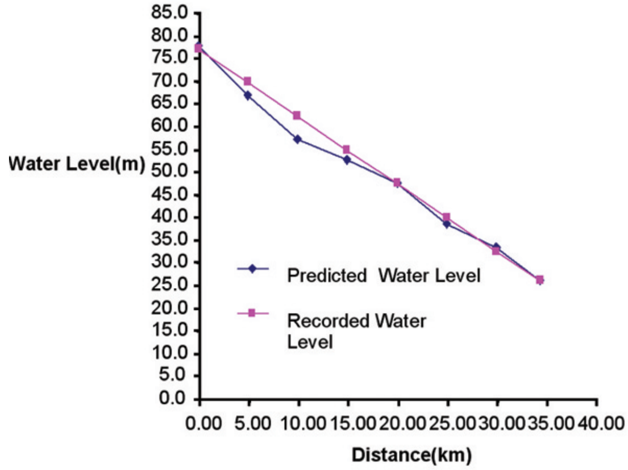

Fig. 8: The predicted and recorded levels for flood of 50 year ARI along the Langat River reach

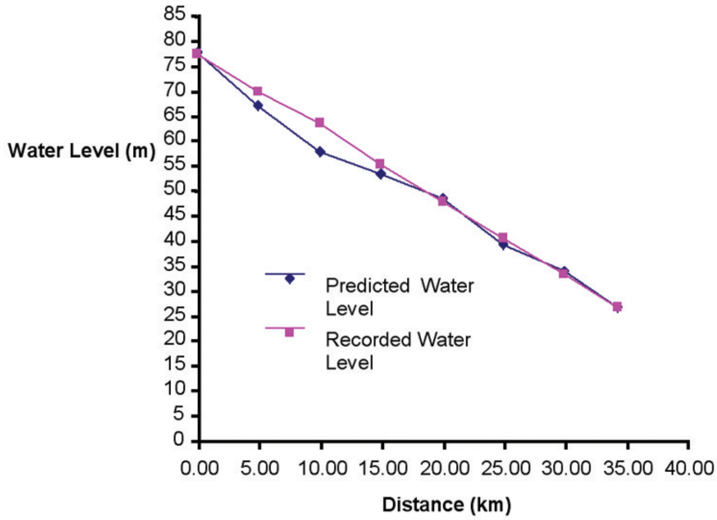

Fig. 9: The predicted and recorded levels for flood of 100 year ARI along the Langat River reach

The predicted water levels for the 200 year ARI flood for various reaches of the Langat River are shown in *Fig. 10.* Nonetheless, the historical records for the 200 year ARI flood are not available. Therefore, a comparison with the predicted values could not be done. The differences between the predicted and the recorded water levels ranged from 3 to 15%.

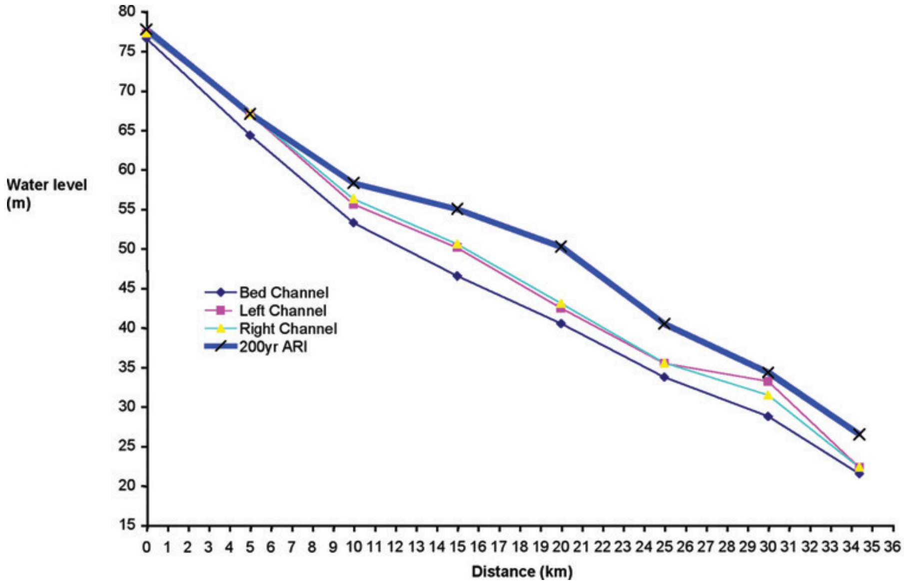

Fig. 10: The predicted flood levels for the Langat River for 200 year ARI flood

The HEC-RAS model for the Langat River was used to identify the zones which might experience inundation during the floods of various return periods. For the discharge of the return period of 200 years, the whole stretch could be subjected to flooding. Table 5 shows the flooded zones.

TABLE 5
Flood depth and flood zones for Langat River for discharges of various return periods

Return period (yr)	Flood inundation zones	Maximum flood depth (m)
5	Km 15 – Km 26, Km 32 – Km 34.4	2.65
10	Km 13.2 – Km 27, Km 31.8 – Km 34.4	2.81
25	Km 13 – Km 28.6, Km 31.2 – Km 34.4	3.78
50	Km 12 – Km 34.4	4.84
100	Km 12 – Km 34.4	5.83
200	Whole river (Km 0.0 – Km 34.4)	7.80

This information is useful for planners and developers as measures can be taken to protect these areas in any future development. The maximum and minimum depths predicted by the model were based on the vertical floodwalls which were used as defaults in the HEC-RAS model since there were insufficient input survey data describing the topography of the flood plain for the Langat River. More accurate flood levels could then be obtained if enough topographical data for Langat River flood plain were available.

Boundary conditions are required to simulate water surface level. The downstream boundary condition was set at a known water surface elevation and the value of the water surface elevation was taken from the Langat River rating curve at downstream gauging station (*Fig. 3*).

CONCLUSIONS

The HEC-RAS model is a good tool to predict the extent of flooding and help in managing flood damage. However, constraints encountered when using the model for the Langat River might affect the accuracy of the model output. An approximation was made to overcome the lack of hydrological and topographical data for the Langat River. The calibration process showed that the value of the Manning's coefficient of roughness ranged from 0.04 to 0.1. Based on the selected values of the Manning's coefficient of roughness, the predicted flood levels and the recorded flood levels were found to be in agreement. Meanwhile, the differences between the predicted and recorded flood levels were ranged from 3 to 15%.

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