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# Flood Discharge For Ungauged Catchment At Teriang River, Pahang By Using HEC-HMS

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**ABSTRACT**

Insufficiency of meteorological data during extreme rainfall events hinders simulation and forecasting analysis in flood mitigation systems. Hence, the existence of a reliable database in hydrology is crucial in flood modelling for ungauged catchments, especially for calibration and validation purposes. This paper focused on the generation of rainfall data by using Hydrological Procedure No. 1 (HP1) from the Department of Irrigation and Drainage (DID) Malaysia. Subsequently, analysis of flood hydrographs at Teriang River, Pahang, Malaysia, using HEC-HMS 4.8 for 50 and 100-year return periods was also obtained in this study. For validation purposes, the outcomes were compared to Hydrological Procedure No. 11 (HP11), designed for rural catchments. For precipitation data generation, the design rainfall was calculated based on generalised isopleth maps from HP1 for various rainfall durations ranging from 0.25 hours to 72 hours. Based on the results, the maximum peak discharge for 50 ARI was 354.7 $m^3/s$, while for 100 ARI it was 410 $m^3/s$ before calibration. Comparing the results from the HEC-HMS model and the outputs from HP11, the analysis for 50-year and 100-year return periods in the Teriang River showed that the relative percentage differences for peak discharge were 19.99% and 17.64%, respectively. The calibration process managed to obtain a relative percentage difference of 2.94% for 50 ARI and 4.36% for 100 ARI. In conclusion, HEC-HMS can be used as a reliable tool to produce simulated streamflow for ungauged catchments with the help of the generated rainfall temporal patterns from HP1, which is a procedure that contains estimation of design rainfall intensity based on the rainfall intensity-during-frequency relationship (IDF relationship).

## 1. Introduction

In the past few decades, the risk of flooding in Malaysia has increased, causing concern in both urban and rural areas. Heavy rains can cause excess runoff to rise to high water levels, resulting in flooding in low-elevation areas. River flooding has occurred in the Teriang River in December 2021 as a result of continuous heavy rains that have led the drainage and river capacity to become unable to accommodate the rising volume of water as the runoff capacity has risen. Malaysia receives flash floods and monsoon floods every year that result in property damage and loss of life. According to

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Buslima *et al*., [1], floods in Malaysia can be divided into two types: monsoon floods (river floods) and flash floods. River floods tend to be more widespread, covering large areas of land, whereas flash floods are more dangerous due to the sudden and rapid increase in water levels.

In order to study the flood problem in detail, some catchments have difficulty with missing hydrological data or data unavailability. Ungauged catchment refers to areas with no data for rainfall and streamflow data or when there are very few rainfall gauges in large catchment areas. The parameters to be utilized in the hydrograph model for this catchment cannot be produced simply by adjusting the rainfall and runoff data. In Malaysia, there are many studies reported on rainfall data insufficiency, especially in rural catchments, by several authors [2-4]. For complementary and comparison purposes, the use of mathematical formulas as in HP1 [5] and HP11 [6] was also studied to perform calibration and validation for both observed and simulated rainfall models. According to the authors [7-9], their research depicts several available methods to predict the design rainfall for ungauged catchments in Malaysia, for example, by using multivariate statistical techniques.

Many software systems have been developed in order to analyze rainfall and streamflow data. One of the popular programs for flood modeling is HEC-HMS, developed by [10]. HEC-HMS is a numerical model (computer program) that offers several elements that can assist in the generation of findings for hydrological research, such as simulating the behavior of water catchment structures, channels, and water control systems and predicting the flow of water at different stages. De Silva *et al.,* [11] stated that HEC-HMS is software that can simulate rainfall-runoff models using both lumped and distributed parameter-based models. The application of HEC-HMS can identify the stream flow pattern for various parameters and be used to assist in the flood risk assessment in Malaysia, as reported by researchers [12–17] for different states in Malaysia. According to previous studies, HEC-HMS can be used to generate flood hydrographs. River and drainage basin management can greatly benefit from this technique as well. The hydrographic system designed by HEC-HMS was conducted to perform further analysis on urban drainage, water supply, future urbanization impact, flow forecast, flood damage reduction, floodplain control, and operational requirements even in mountainous regions, as reported by Laith *et al*., [18].

HEC-HMS software was introduced to be utilized in a wide range of geographic areas to tackle a wide range of problems. For instance, problems that involve large river basins, hydrological flood analysis, water supplies, and runoff from natural and urban catchments Besides, it also consists of various components that allow for the analysis of losses, runoff transformation, open-channel routing, meteorological data analysis, rainfall-runoff simulation, and parameter estimation [12]. The interception, evaporation, and infiltration processes in the catchments are determined by using loss components, whereas runoff processes are computed by using transform components [15].

In modeling a HEC-HMS model, some parameters are required to be assigned in the HEC-HMS in order to develop the flood hydrograph. Observation data as well as the characteristics and hydraulic section of the river are examples of parameters that need to be input in the HEC-HMS. In general, an empirically derived unit hydrograph or a standard shape specified by one or two parameters such as time to peak ($t_p$) are used in this approach. The hydrograph generated by the HEC-HMS can be used directly or with a combination of other software to study water availability, the design of reservoir spillways, floodplain control, discharge forecasting, and future urbanization effects. Based on Derdour *et al*., [19], the HEC-HMS software has demonstrated its application in solving a wide range of problems in diverse geographic locations. Due to its capability to simulate and forecast streamflow, the HEC-HMS has been widely used by researchers in hydrologic studies.

## 2. Methodology
### *2.1 Study Area*

Flood in Pahang was selected as case study as the floods were said to be among the worst floods, affecting 34,924 victims from Pahang state as reported by Camoens [20]. River flooding had occurred in the Teriang River in December 2021 as a result of continuous heavy rains that led to the drainage and river capacity to become unable to accommodate the rising volume of water. The rainfall-runoff model developed for Teriang River is important to become a guideline to improve the drainage system of the river basin. Teriang River is a subbasin of Pahang River that flows from Negeri Sembilan to Pahang. This river flows in the Bera district through several Felda (Felda Bukit Mendi, Felda Bukit Puchong) and towns (Bandar Teriang, Bandar Kerayong) before flowing into the Pahang River. In Bera area, this river has a width of 40 m and a length of 64.3 km with a catchment area of 377 km$^2$. Most of the areas in the district are developed as agricultural areas while others have been officially recognized as forest reserves. Data for seven rainfall stations over 10 years (2012-2021) were obtained from the Department of Irrigation and Drainage (DID). Figure 1 shows the seven rainfall stations located near Teriang River. However, there were some issues encountered due to insufficiency of hydrological data and missing geographical information on Teriang River.

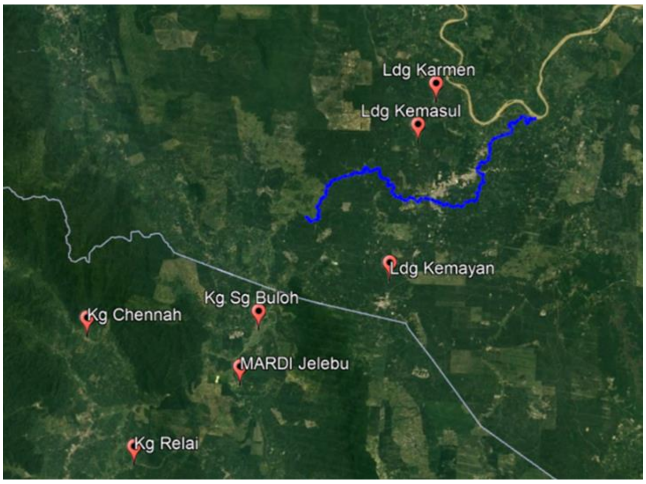


**Fig. 1.** JPS Rainfall Stations near Teriang River

### *2.2 Rainfall Intensities and Design Rainfall From HP1*

To generate rainfall data to accommodate unavailable datasets, the rainfall intensity has been calculated using Hydrological Procedure No. 1 (HP1). HP1 is a procedure to estimate the design rainfall intensity based on the rainfall intensity-during-frequency relationship (IDF relationship). It has been used as standard practice for the design of water resource systems. The IDF relationship gave an idea about the frequency or return period of a mean rainfall intensity or rainfall volume that can be expected within a certain period of storm duration [5]. Rainfall intensities and design rainfall for various storm durations are the outputs generated from HP1 that are calculated from the IDF parameters. To generate simulated discharge data for the Teriang River, Hydrological Procedure 1 (HP1) was used to calculate the rainfall intensity values by using the formula in Eq. (1):

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} \quad (1)$$

where $i$ = Rainfall intensity (mm/hr), $T$= Recurrence interval ( $T$ = 10,20,50 and 100 year), $d$ = Storm duration (hours), ($d$ =0.25 hr to 72 hr) and, $\theta$, k, λ and η = Fitting constants dependent on the rain gauge location.

The fitting constants were obtained from Generalized Isopleth maps [5] for Teriang River. Table 1 shows the list of IDF parameters obtained from the Isopleth maps for the selected catchment and Table 2 depicts the list of rainfall intensities for various storm duration from 15 minutes to 3 days for 10, 20, 50 and 100 return periods. Eventually, the rainfall intensity was calculated by using the following Eq. (2).

**Table 1**
IDF parameter from Isopleth Map for Teriang River, Pahang

| λ | κ | η | θ |
|---|---|---|---|
| 60.404 | 0.174 | 0.857 | 0.3215 |

**Table 2**
Rainfall intensities for various storm durations from 15 minutes to 3 days using HP1

| Rainfall Intensities (mm/hr) | | | | |
|---|---|---|---|---|
| Duration (hr) | 10 ARI | 20 ARI | 50 ARI | 100 ARI |
| 0.25 | 145.49 | 164.09 | 192.36 | 216.94 |
| 0.5 | 106.60 | 120.22 | 140.94 | 158.95 |
| 1 | 70.92 | 79.99 | 93.77 | 105.75 |
| 3 | 32.19 | 36.30 | 42.56 | 47.99 |
| 6 | 18.54 | 20.91 | 24.51 | 27.65 |
| 12 | 10.46 | 11.80 | 13.83 | 15.60 |
| 24 | 5.84 | 6.59 | 7.72 | 8.71 |
| 48 | 3.24 | 3.66 | 4.29 | 4.84 |
| 72 | 2.30 | 2.59 | 3.03 | 3.42 |

$$P = iD \quad (2)$$

$P$ = Rainfall (mm), $i$ = Intensity (mm/hr) and $D$ = Duration (hour)

Table 3 shows the design rainfall for 10,20, 50 and 100 ARI using HP1 for different rainfall durations. To obtain the temporal rainfall quantitative estimates, the factored design rainfall is multiplied with the derived temporal fraction of rainfall pattern from Normalized Temporal Pattern for Region 1 [5]. The rainfall temporal patterns are used as the time varying rainfall input data in the HEC-HMS model. The time series fractional rainfall for different storm durations is used with their respective temporal patterns.

**Table 3**
Design rainfall for various ARI using HP1 for Teriang River, Pahang

| | Design Rainfall (mm) | | | |
|---|---|---|---|---|
| Duration (hr) | 10 ARI | 20 ARI | 50 ARI | 100 ARI |
| 0.25 | 36.37 | 41.02 | 48.09 | 54.24 |
| 0.5 | 53.30 | 60.11 | 70.47 | 79.48 |
| 1 | 70.92 | 79.99 | 93.77 | 105.75 |
| 3 | 96.56 | 108.90 | 127.67 | 143.98 |
| 6 | 111.25 | 125.46 | 147.08 | 165.87 |
| 12 | 125.56 | 141.61 | 166.01 | 187.23 |
| 24 | 140.20 | 158.12 | 185.36 | 209.05 |
| 48 | 155.67 | 175.57 | 205.82 | 232.12 |
| 72 | 165.27 | 186.39 | 218.51 | 246.43 |

### *2.3 Hydrograph Analysis for Teriang River by Using HEC-HMS 4.8 for 50 ARI and 100 ARI*

HEC-HMS is a numerical model (computer program) that offer several elements that can assist in the generating of findings for hydrological research, such as simulating the behavior of water catchment structures, channels, water control systems and predicting the streamflow for a given rainfall intensity. In this study, the basin model was developed as a single basin method as Teriang River, Pahang does not have another river network. The model was set up with many parameters, such as the Loss Method using the SCS Curve Number (CN), the Transform Method using the SCS Unit Hydrograph (UH) as illustrated in Figure 2.

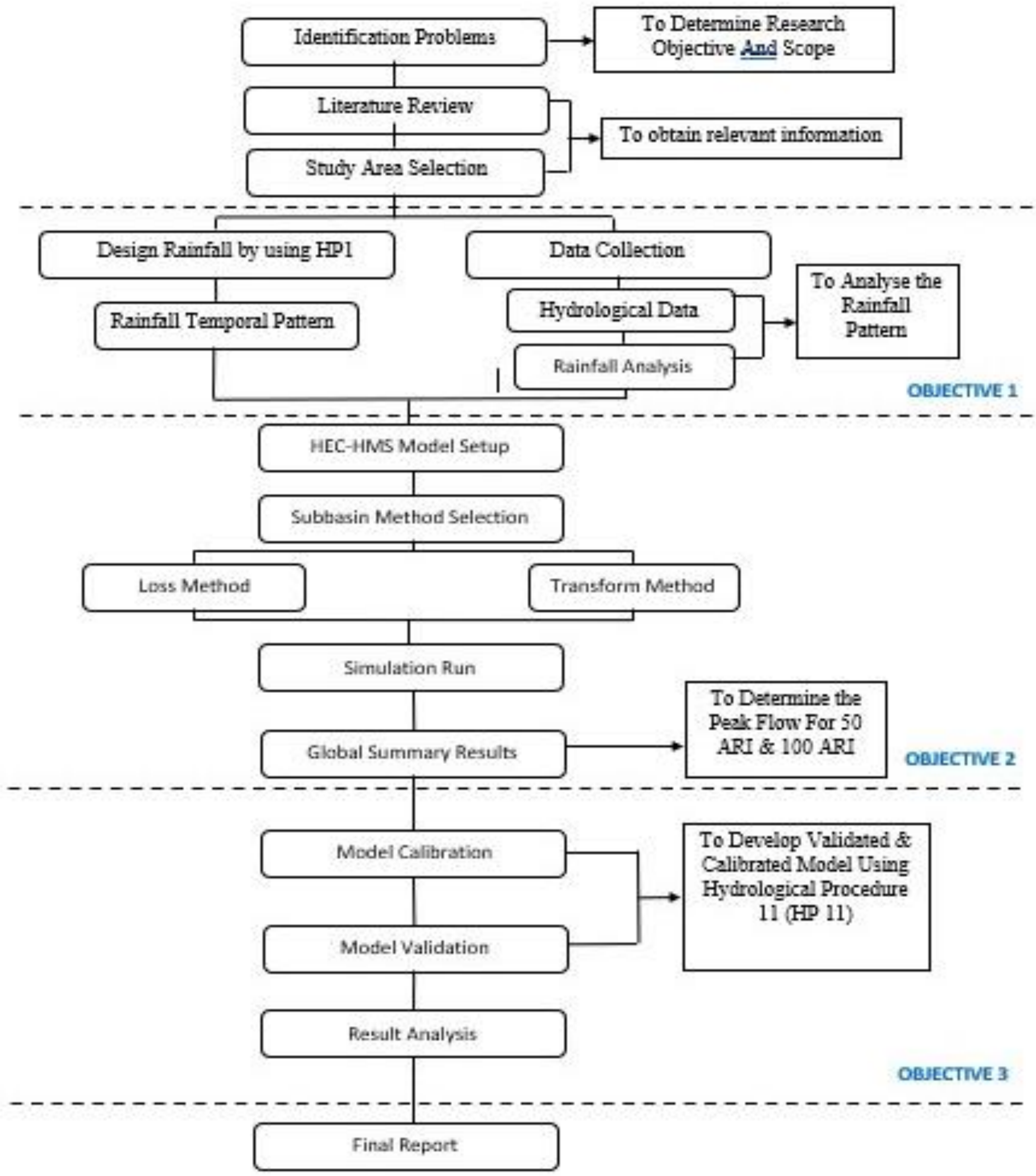


**Fig. 2.** Methods adopted in this study

Rainfall data, catchment area, lagtime, curve number (CN), and imperviousness were among the inputs for HEC-HMS. In order to run the HEC-HMS simulation, land use information was also necessary. Data on land use can be utilized to determine the SCS curve number. Digital Elevation Models (DEM) will be created using Earthdata and QGIS to collect data on land use. The present catchment land use, hydrological data, topography, river survey, and major climatological events were considered in this study. The relevant Department of Drainage and Irrigation (DID) guidelines, such as Manual Saliran Mesra Alam (MASMA) [21] and HP1 from [5], along with various sources of information, were used to meet the research requirements. Hydrological analyses have been carried out to confirm the consistency of the data among the stations. The consistency of the rainfall station record has been checked using the double mass curve technique.

This study implemented the Soil Conservation Service Curve Number Method (SCS-CN to transform the precipitation excess into direct runoff. The SCS curve number is referred to as a one-parameter empirical curve number event-runoff model. According to Rozi et al., [22], the effect of land use land cover (LULC), the type of soils, and hydrologic soil groups on surface runoff are the parameters that need to be considered when computing the one-dimensional curve number since the parameters will influence the direct surface runoff in the watershed.

The Digital Elevation Model (DEM) is a topographic representation of vacant land, which does not include trees, buildings, or any other structures on the Earth's surface. QGIS was used to create the DEM and obtain the river catchment area for this study. The study area was confirmed through the OSM Standard map, which can be found in QGIS. Next, by using the SRTM downloader plugin, the coordinates of the study area were confirmed. When the download is complete, the DEM will be utilized, and Teriang River catchment and river network data can be obtained easily for research use.

In this study, the discharge values were computed using Eq. (3) and Eq. (4). The Loss Method is a set of equations used in the HEC-HMS simulation to separate precipitation volumes from runoff excess, and it requires the identification of one or more input parameters before the simulation can begin. The Soil Conservation Service (SCS) Curve Number (CN) creates a curve number method for additional losses, which was used to estimate precipitation excess in this study. SCS CN can only be used for event simulation. The manual calculation for SCS CN is shown in Eq. (5).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{3}$$

Where
*Q* = Runoff (in.)
*P* = accumulated rainfall (in.)
*S* = potential maximum retention after runoff begins, $S = \frac{1000}{CN} - 10$ (in.)
$I_a$ = initial abstractions, $I_a = 0.2S$

Initial abstractions were optionally included in the analysis. The initial abstraction specifies the amount of precipitation that must occur before a surface excess can be formed in a particular region. If this option was left blank, it will be calculated automatically as 0.2 times the retention potential, S which was estimated based on the number of curves. With this assumption, the Eq. (3) can be simplified into:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{4}$$

To use the SCS CN method, a curve number is required. The curve number can be obtained from Digital Elevation Model (DEM) data or can be calculated by a formula.

$$CN = \frac{1000}{S+10} \tag{5}$$

For simulation purposes, hydrological data from HP1 were used. For ungauged rural catchment areas in peninsular Malaysia, this procedure presents a deterministic method approach for calculating the flood hydrograph design. The technique was based on the development of three components, which were the design storm, the rainfall-runoff relationship, and the triangular hydrograph. The baseflow values for each sub-catchment were calculated using HP11 [6]: Design Flood Hydrograph for Rural Catchment in Peninsular Malaysia, and the CN value was taken from the Table of SCS CN from USDA (1986). The simulated discharge can be adjusted by varying the input parameters, and the obtained value was compared to the observed discharge. The selected parameters can be employed if the simulation and observational data reveal similar results or only modest differences. According to the data, the variations between observed and simulated discharge values were all less than 25%, indicating that the model's accuracy has been achieved, as shown in Table 4 [23].

**Table 4**
Relative Percentage Difference (RPD) classification

| | |
|---|---|
| RPD < 10% | Very Good |
| 10% < RPD < 15% | Good |
| 15% <RPD < 25% | Satisfactory |
| RPD > 25% | Unacceptable. Need to repeat Calibration and Validation process |

## 3. Results
### *3.1 HEC-HMS Outputs*

To produce a hydrograph model through HEC-HMS for Teriang River, SCS Curve Number formula was utilized for loss method and SCS Unit Hydrograph for transform method. Input data is shown in Table 5. Once temporal rainfall quantitative estimates were calculated for 50 and 100 ARI from HP1, the selected parameters will be entered into the HEC-HMS from 30 minutes to 2 days storm duration.

**Table 5**
Parameters used in HEC-HMS

| Catchment | | Length | | CN | Potential Abstraction, S | Imperviousness | slope | Lagtime | | Initial abstraction, Ia |
|---|---|---|---|---|---|---|---|---|---|---|
| $km^2$ | $ft^2$ | km | ft | | | (%) | (%) | hr | min | |
| 377 | 406037652 | 64.3 | 210886 | 78.5 | 69.57 | 35 | 40 | 29.75 | 1784.95 | 13.91 |

Table 6 shows the peak discharge data obtained through the HEC-HMS model for a duration of 30 minutes to 2 days for a 50-year return period. The study found that the maximum peak discharge simulated at a duration of 24 hours which was 354.7 $m^3/s$. Figure 3 shows the hydrograph graph of the HEC-HMS model for a duration of 30 minutes to 2 days for a 50-year return period.

**Table 6**
Peak discharge at Teriang River, Pahang for 50 ARI

| River | 50 ARI Peak Discharge, Q ($m^3/s$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.5 hr | 1 hr | 3 hr | 6 hr | 12 hr | 24 hr | 48 hr |
| Teriang River | 106.7 | 146.3 | 234.6 | 280.6 | 323.7 | 354.7 | 336.5 |

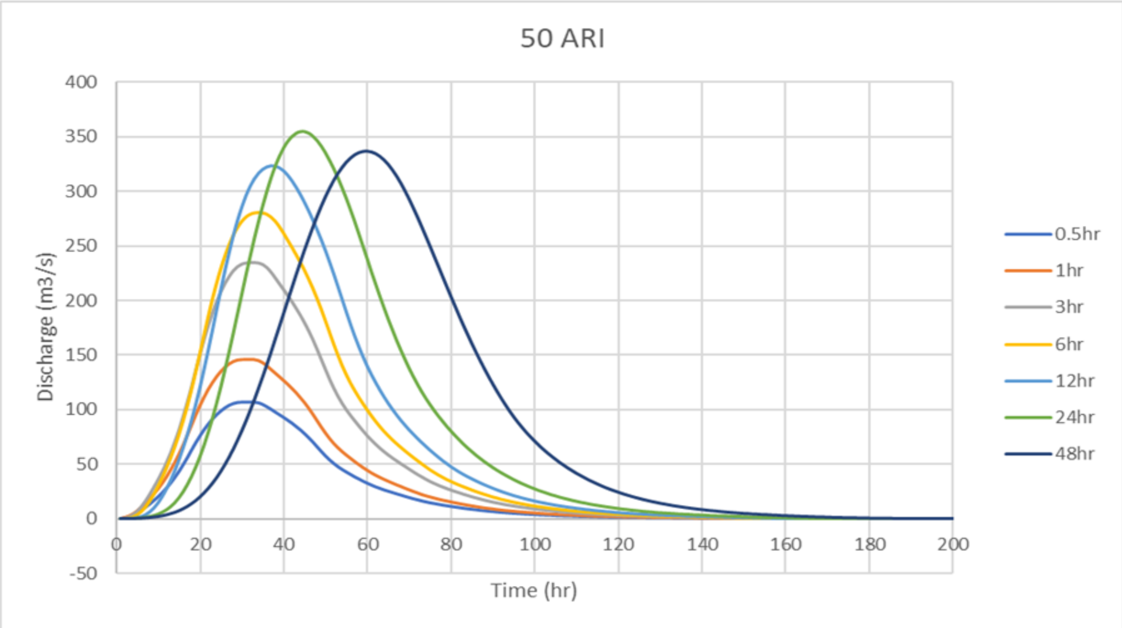


**Fig. 3.** HEC-HMS hydrograph for 30 minutes until 2 days duration (50 ARI)

Table 7 shows the peak discharge for the 100 -year return period for different durations with the maximum peak discharge of 410 $m^3/s$. While Figure 4 shows a hydrograph graph obtained from the HEC-HMS model for the 100-year return period which the maximum duration was at 24 hours.

Based on the results obtained from the HEC-HMS hydrograph for 50 ARI and 100 ARI, both graphs show that the maximum peak discharge occurred at a duration of 24 hours. This can be related to the basic characteristics of the river. Teriang River is a long river (64.3km) with a width of 40m respectively.

**Table 7**
Peak discharges for 30 minutes until 2 days duration at Teriang River, Pahang for 100 ARI

| River | 100 ARI Peak Discharge, Q ($m^3/s$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.5 hr | 1 hr | 3 hr | 6 hr | 12 hr | 24 hr | 48 hr |
| Teriang River | 125.8 | 171.6 | 273.2 | 325.9 | 375 | 410 | 387.8 |

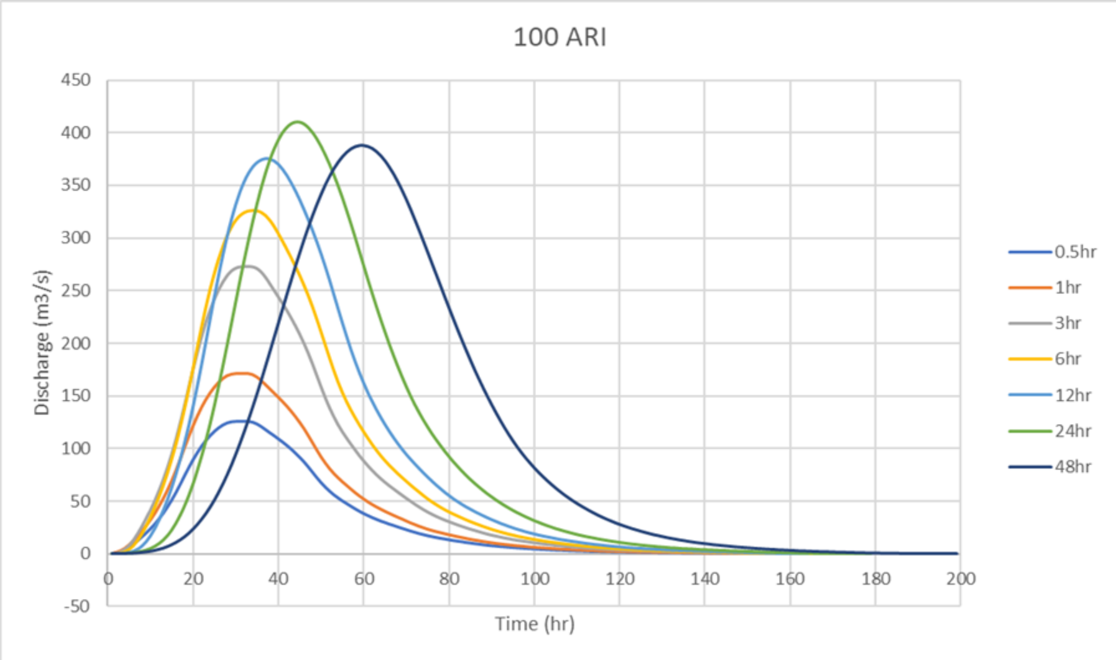


**Fig. 4.** HEC-HMS hydrograph for 30 minutes until 2 days duration (100 ARI)

### *3.2 Calibration and Validation of The Hydrograph Analysis Model for Teriang River Basin Using Hydrological Procedure 11 (HP11) for Rural Catchment*

The validation process was carried out in order to determine the robustness of the simulated model. The simulated hydrograph model will be compared to the observed hydrograph to determine which is more accurate. During the calibration process, several parameters were obtained, and these parameters were used for model validation. In this research, Hydrological Procedure 11 (HP11) was used in the streamflow calculation, and the data obtained was used to make a comparison between the observed and simulated hydrographs. A process of calibration and validation was necessary to ensure that the hydrological model ran effectively. Flow discharge data obtained from HEC-HMS and HP11 were used for calibration and validation. Table 8 shows the parameters used in the calculation of discharge using HP11. Table 9 shows the outputs from HP11 for 50 and 100 ARI. The peaking coefficient used was 0.55, according to HP11 for Peninsular Malaysia. Both peak discharges for 50 and 100 ARI were 295.60 $m^3/s$ and 348.51 $m^3/s$. Table 10 compares the observed and simulated discharge data for 50 and 100 ARI, and the values of the relative percentage difference (RPD) were 19.99% and 17.64%, respectively.

**Table 8**
Parameter for HP11 [6]

| Catchment Area ($km^2$) | Main Stream Length (km) | Weighted Stream Slope (%) | Peaking Coefficient (Table 3 HP11) |
|---|---|---|---|
| 377 | 64.3 | 40 | 0.55 |

**Table 9**
Outputs from HP11 for 50 and 100 ARI for Teriang River, Pahang

| Lagtime, Lg (hr) | Base Flow, Qb (m3/s) | Qp for 50 ARI (m3/s) | Qp for 100 ARI (m3/s) |
|---|---|---|---|
| 2.72 | 17.96 | 295.6 | 348.51 |

**Table 10**
Validation of simulated and observed data for 50 and 100 ARI (before calibration)

| ARI | Peak Discharge ($m^3/s$) | | |
|---|---|---|---|
| | HEC-HMS | HP11 | RPD (%) |
| 50 | 354.7 | 295.60 | 19.99 |
| 100 | 410 | 348 | 17.64 |

Table 11 shows the parameters used after the calibration process, where the slope value was maintained at 40% and the curve number (CN) value was changed from 78.5 to 74 for 50 ARI. While for 100 ARI, the slope value was changed from 40% to 39% and the curve number (CN) value was changed from 78.5 to 74. The calibration process using the new parameters managed to obtain a relative percentage difference of 2.94% for 50 ARI and 4.36% for 100 ARI, which indicates very good data using RPD. The results of the calculated relative percentage differences revealed that all data passed the calibration process. Table 12 shows the observed and simulated discharge data for 50 and 100 ARI after calibration, and the relative percentage differences were 2.94% and 4.36%, respectively.

**Table 11**
Parameters used in HEC-HMS (after calibration)

| CN | Potential Abstraction, S | Imperviousness (%) | slope (%) | Lagtime hr | min | Initial abstraction, Ia |
|---|---|---|---|---|---|---|
| 74 | 89.24 | 35 | 40 | 35.34 | 2120.29 | 17.85 |

**Table 12**
Validation of simulated and observed data for 50 and 100 ARI (after calibration)

| ARI | Peak Discharge ($m^3/s$) | | |
|---|---|---|---|
| | HEC-HMS | HP11 | RPD (%) |
| 50 | 286.9 | 295.60 | 2.94 |
| 100 | 333.3 | 348.51 | 4.36 |

## 4. Conclusions

For ungauged catchment, the data can be obtained from various sources including from available manual/procedures from the respective authorities. With the help of good flood modelling software, a lot of data outputs can be generated to solve for data insufficiency problem. By using rainfall design data calculated through HP1, a hydrograph model can be generated and peak discharge for the selected area can be simulated. SCS curve number and SCS unit hydrograph were used in this study due to its simplicity and practicality. The parameters required for this method were the values of imperviousness, Curve Number (CN) and Lagtime. Based on the results, the maximum peak discharge for 50 ARI was 354.7 $m^3/s$, while for 100 ARI was 410 $m^3/s$ before calibration. The calibration and validation processes were carried out so that the performance of the model could be evaluated, as well as the precision of the simulated data from HEC-HMS and the observed data. During the process, some parameters such as imperviousness, initial abstraction, Curve Number (CN), and Lagtime were adjusted. The performance and the accuracy of HEC-HMS model can be evaluated through the calculation of the relative difference percentage (RPD), which was when the difference between simulated and observed data was small or near to zero. In conclusion, HEC-HMS can be used as a reliable tool to help produce simulated streamflow for ungauged catchment. The rainfall-runoff model developed for Teriang River can also be a guideline to improve the drainage system of the river basin and human activities can be controlled to prevent the flood. In addition, it was important to know streamflow data and river capacity to estimate flood potential during heavy rainfall. The mitigation can minimize the cost required to repair the destruction that occurred in the flood-affected areas near the Teriang river. Furthermore, this flood reduction will allow people living or working in the affected areas to perform their daily activities with less difficulty. The output hydrographs from HEC-HMS are useful for further flood modelling studies in the Teriang River Basin.

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