Hydrological Modelling using HEC-HMS for Flood Risk Assessment of Segamat Town, Malaysia

N S Romali¹, Z Yusop², and A Z Ismail³

¹Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia
²Centre of Environmental Sustainability and Water Security, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia
³Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia

E-mail: zulyusop@utm.my

Abstract. This paper presents an assessment of the applicability of using Hydrologic Modelling System developed by the Hydrologic Engineering Center (HEC-HMS) for hydrological modelling of Segamat River. The objective of the model application is to assist in the assessment of flood risk by providing the peak flows of 2011 Segamat flood for the generation of flood mapping of Segamat town. The capability of the model was evaluated by comparing the historical observed data with the simulation results of the selected flood events. The model calibration and validation efficiency was verified using Nash-Sutcliffe model efficiency coefficient. The results demonstrate the interest to implement the hydrological model for assessing flood risk where the simulated peak flow result is in agreement with historical observed data. The model efficiency of the calibrated and validated exercises is 0.90 and 0.76 respectively, which is acceptable.

1. Introduction
Flood caused severe impact to human and properties, hence is known as a destructive natural disaster in the world [1, 2]. Flooding pose a serious threat to people and cause major damage to properties, infrastructures, agricultural production, give serious impact to socio-economic activities and may caused the loss of human life and decrease the quality of human health [3, 4, 5]. The consequences of natural disaster may lead to a great monetary loss to the economy of a region. Furthermore, on economic perspectives, natural disasters are also known as economic disaster [6]. In Europe, river flooding had caused about 100 billion euros of damage over 20 years’ period from 1986 to 2006 [7]. Whereas according to the Emergency Disasters Database (EM-DAT) [8], flood in Malaysia had caused an approximate loss of RM 41.9 million within the years of 1995 to 2005.

Flood risk management is a non-structural flood mitigation measures that could be significantly reduce the impact of flooding [9]. This risk-based approach is contradicting to the conventional flood control approach which focusing on structural flood mitigation measures. The assessment of flood risk is the initial step in flood risk management [10]. Flood risk assessment consist of two main elements i.e. flood hazard and flood vulnerability [7, 11, 12, 13]. Flood hazard assess the probability of a flood...
event to take place i.e. the extent or magnitude of flood while flood vulnerability assesses the potential flooding impacts to community and assets (flood damage) [14, 15].

Flood hazard normally represented by flood mapping. Generation of flood mapping needs the information of peak flood as it is the necessary input to hydraulics model [16]. Besides that, the estimation of flood damage for flood risk vulnerability assessment requires the combination of four main elements i.e. flood characteristics, exposure, value of elements at risk, and the susceptibility of the elements at risk to particular hydrologic conditions [17, 18]. The characteristics of flood such as flood depth and the information of affected area may be obtained from flood modelling.

Numerous flood modelling studies had been done by researchers worldwide (for example [16, 19, 20, 21]). Ullah et al. [19] applied the combination of remote sensing, geographical information system (GIS), HEC-RAS (1D) and HEC-Geo RAS to model a flood inundation forecasting of Kalpani River. River modelling using HEC-RAS requires two types of data, i.e., geometric data and hydrological data. Similarly, Khattak et al. [16] also utilised the application of HEC-RAS and ArcGIS to develop floodplain maps for the part of Kabul that lies in Pakistan. Peak flows from selected flood event and various return periods were the input into the HEC-RAS model to find the corresponding flood level expected along the study area. The information of the hydrologic condition needed in the hydraulic modelling can be generated from hydrologic modelling. For example, Oleyiblo and Li [22] had applied HEC-HMS to obtain simulated peak discharge for the purpose of flood forecasting in Misai and Wan’an catchments in China. The application of HEC-HMS also can be observed in the study by Bhuiyan et al. [23]. In the study, the HEC-HMS was applied to simulate the hydrological processes of Sturgeon Creek watershed system in Manitoba, Canada.

The intent of this study is to assist in the assessment of flood risk for the urban area of Segamat town, Johor. An attempt has been made to provide peak flood discharge of Segamat River, as the input to the hydraulic model for the generation of flood mapping. For the purpose, a hydrological modelling using HEC-HMS is applied. This paper presents the applicability of the hydrological results to be used for the further flood risk assessment works.

1.1. Description of study area
Segamat River is one of the tributaries of the Muar River that flows through the town of Segamat [24]. The location of Segamat River is shown in figure 1. The river is approximately 23 km in length, with average width of 40 m and is 14 m above sea level [25].

![Figure 1. Location of study area](image)

Segamat is a district in Johor which located in the north part of the state. Segamat is facing flooding problems in some areas in the last few decades, that caused displacement of people and severe properties damages. Historical records showed a series of flood occurred since 1950s, where the recent worse flood took place in 2006 and 2011. During the 2011 flood, about 31,000 people were evacuated and cause several deaths [26].
2. Methodology
The purpose of conducting hydrological modeling is to estimate flow hydrograph from tributary catchments. The estimated flow hydrograph serves as an input to hydraulic modeling. The methodology used in the hydrological modeling in this study is shown in figure 2.

![Study flow chart](image)

**Figure 2.** Study flow chart.

![Conceptual of hydrological model at Segamat River](image)

**Figure 3.** Conceptual of hydrological model at Segamat River

The first phase of hydrological modeling was a HEC-HMS model set-up. HEC-HMS used for this analysis is basically a hydrologic model which provides various options for calculating hydrologic losses, transforming excess rainfall and estimating base flow. The details of HEC-HMS model set-up are described in the next section. While in the second phase, the resulted hydrological model was calibrated and validated. The calibration model efficiency was verified using Nash-Sutcliffe model efficiency coefficient.

2.1. HEC-HMS model set-up
The hydrological analysis used the model set up of HEC-HMS. The catchment characteristics data, area of catchment, river length and slope are needed in the hydrological analysis. The main parameters used were hydrological parameters while the losses methods used were Soils Moisture Accounting (SMA). The parameters required for the model analysis are initial loss, constant rate, impervious, time of concentration, storage coefficient, and Muskingum’s $K$ and $X$ value.

The output from this hydrological analysis is the hydrograph of Segamat River. The conceptual of hydrological model and the list of the rainfall station used for the hydrological modeling is shown in figure 3 and table 1 respectively. While the element parameter and method applied in the HEC-HMS set up is shown in table 2.

2.2. Model calibration and validation
A model calibration process involved adjusting or tuning model parameters until the model simulation result closely match the observed behavior. Meanwhile, model validation is basically a similar process to model calibration but using another set of hydrological data [27]. The purpose of model calibration is to establish the model parameter values to be used for model validation and subsequently for simulating hydrograph using defined data input.

The calibration and validation model is verified using model efficiency (ME) in order to define the absolute square differences between the predicted and observed value. The ME is calculated based on Nash-Sutcliffe model efficiency coefficient shown in equation (1) according to Yusop et al. [28]:

$$ ME = 1 - \frac{\sum_{i=1}^{n} (Q_{oi} - Q_{pi})^2}{\sum_{i=1}^{n} (Q_{oi} - Q_{o})^2} $$ (1)
Where $ME$ is the model efficiency (efficiency index), $Q_{Oi}$ is observed flow at time $i$, $Q_{Si}$ is simulated flow at time $i$, $Q_a$ is an average observed flow, and $n$ is the number of data points.

### 3. Results and discussion

#### 3.1. Model calibration and validation

The results of simulated peak flow and model efficiency (ME) for model calibration and validation are presented in Table 3. The simulated peak flow is compared with the observed peak flow where the difference is 9% and 3% for calibration and validation results respectively. The model efficiency is 0.90 and 0.76 for model calibration and validation respectively, which is considered satisfactory.

### Table 1: The list of rainfall station for hydrological modelling

| Sub basin | Station | Station name | River     |
|-----------|---------|--------------|-----------|
| 1         | 2529001 | Kemelah      | Segamat River |
| 2         | 2428011 | Ldg          | Segamat River |
| 3         | 2528002 | Stesen Telemetrik | Kapeh River |

### Table 2. Element parameter and method setup in HEC-HMS model

| Model Parameter      | Method                      |
|----------------------|-----------------------------|
| Canopy method        | Simple canopy               |
| Surface method       | Simple surface              |
| Loss method          | Soil Moisture Accounting    |
| Transform method     | Clark Moisture Accounting   |
| Base flow method     | None                        |
| Routing method       | Muskingum                   |

### Table 3: Observed and simulated peak flow for model calibration and validation

| Run         | Peak flow (m$^3$/s) | ME         |
|-------------|---------------------|------------|
|             | Observed            | Simulated  |           |
| Calibration | 23.30               | 25.40      | 0.90      |
| Validation  | 79.90               | 77.50      | 0.76      |

### Table 4. Tested model parameters for 2011 Segamat flood event (Sub basin 1)

| Parameter                          | Unit | Value |
|------------------------------------|------|-------|
| Initial storage (simple canopy)    | mm   | 8     |
| Initial storage (Simple surface)   | mm   | 8     |
| Soil losses                        | %    | 18    |
| Imperviousness                     | %    | 10    |
| Time of concentration              | hour | 30    |
| Storage coefficient                | hour | 55    |

The HEC-HMS model was calibrated using rainfall and flow data of Segamat River gauging station from 26th May to 7th June 2010. Figure 4 shows the observed and calibrated hydrograph where the simulated peak flow for the calibration event is 25.40 m$^3$/s, which is close to the observed peak flow of 23.30 m$^3$/s. Table 4 shows the model parameter values adjusted for each of the components of sub basin 1. The Muskingum $K$ and $X$ applied at Reach 1 is 2.15 hr and 0.199 respectively. The parameters must be calibrated simultaneously through adjustment of their values until the model simulation replicate observed data [22].

For the model validation process, a set of storm event data was used to validate the HEC-HMS model based on the optimized model parameters obtained during calibration. Rainfall and flow data of Segamat River gauging station dated 4th August to 9th September 2010 was used for the validation analysis. The simulated peak flow for the validation event is 77.50 m$^3$/s, which is close to the observed peak flow of 79.90 m$^3$/s as illustrated in hydrograph in figure 5.
3.2. 2011 Segamat Flood Event
The HEC-HMS model was set up for a 20 January 2011 (01:00) to 14 February (01:00) flood event. The event hydrological modelling was performed using hourly time steps. The event simulation result is presented in figure 6. From the flow data obtained from Drainage and Irrigation (DID) Malaysia, the peak flow ($Q_p$) is observed as 5.1 m$^3$/s which is not presenting the major flood event occurred on 2011. However, the simulated $Q_p$ from the analysis gives a flow rate of 1238.2 m$^3$/s which is a reasonable flow value for a major flood event in Segamat. As can be seen in figure 7, other major floods occurred in Segamat recorded a high peak flow more than 1000 m$^3$/s. For example, all the four major flood events in year 1969, 1979, 1983 and 2007 (labelled as 1, 2, 3 and 4 respectively in figure 7), occurred with peak flow more than 1000 m$^3$/s.

4. Conclusion
Hydrological modeling using HEC-HMS was performed to obtain peak flow hydrograph of Segamat River. The information is useful as the input for the flood mapping of Segamat town. The peak flow of 1238.2 m$^3$/s hydrograph was obtained for 2011 Segamat flood event using a calibrated and validated HEC-HMS model. The simulated peak flow result is in agreement with historical observed data and the model efficiency of 0.90 and 0.76 is acceptable for the calibrated and validated HEC-HMS model. Hence, the hydrologic model is recommended for future works of flood modeling and flood risk assessment of the study area.
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