Advances in Engineering Research, volume 200
Proceedings of the Third International Conference on Separation Technology 2020 (ICoST 2020)

Future Flood Forecasting in Bukit Merah Using HEC-HMS Software

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ABSTRACT
Flood has occurred many times in Malaysia and it has greatly affected the residents that live in flood risk area such as Bukit Merah. Due to the climate change and land use changes issues, the flood and drought events seem to be occurred more frequently in larger scale in Bukit Merah. Therefore, the objectives of this study were to develop the hydrologic model for Bukit Merah and to forecast the flood magnitude for next twenty years by considering the factor of climate change and land use changes via HEC-HMS. After developing the hydrologic model of Bukit Merah, the model has been calibrated and validated with the coefficient of determination, R2 = 0.9066 and 0.9575 respectively. The results showed that the simulated stream flow was closely fit to the observed streamflow, therefore it was reliable. Then, the model was used to simulate the streamflow for next twenty years by using predicted future rainfall data obtained from NAHRIM. The simulated peak discharge to the Bukit Merah Reservoir for next twenty years was 113.7 m3/s. Then, the scenarios of excess rainfall and extremely lack of rainfall were simulated. In extremely lack of rainfall scenario, the peak discharge to the Bukit Merah Reservoir decreased by 76.87 % while for the excess rainfall scenario, the peak discharge has increased 379 %. After that, the Curve Number (CN) of the basin has been increased by 20% and it was assumed to have 70% of impervious area according to the future development in Perak. Then, the model was simulated but the peak discharge to Bukit Merah Reservoir remain unchanged, recorded as 113.7 m3/s. Hence, this paper outlined that climate change has the biggest impact on the magnitude of streamflow but the land use changes do not give much effects to the magnitude of streamflow in Bukit Merah.

Keywords: *HEC-HMS, flood forecasting, climate change, land use changes*

1. INTRODUCTION

The most devastating natural disaster experienced in Malaysia is flood. Throughout Malaysia, including Sabah and Sarawak, there is total of 189 river basins with the main channels flowing directly to the south china sea and 85 of them are prone to recurrent flooding (89 of the river basins are in Peninsula Malaysia, 78 in Sabah and 22 in Sarawak). When floods occurred, it has terrible impacts on people as it disrupts their day to day activities and the impacts can last for a week. In the coming years, climate change is likely to make the situation even more challenging [1]. In Malaysia, the estimated area vulnerable to flood disaster is approximately 29,800 km^2 or 9% of the total Malaysia area, and is affecting almost 4.82 million people of the country [2]. In addition, the climate change will cause more problem in water related disaster such as flood and drought. Recent years, people have experienced the effect of global warming, the weather is getting hotter and hotter. This will affect the annual precipitation or rainfall of an area. Because of climate change, some extreme climates or events might be occurred. If it is large amount of rainfall in the area, it will cause flood; if the rainfall is too little, it might cause drought in the area. These phenomena are common now in Malaysia and it is believed that these disasters will be worsen in the future due to the climate change. The land use changes will also contribute to flood. This is because the land or forest that initially served as the barrier to slow down the flood water has been cleared. Therefore, the flood water will discharge in high velocity and cause severe damage to the environment. Besides, the soil contamination due to the chemicals used in construction, acid rain or agricultural activities have reduced the ability of soil to absorb and hold water. So, it is harder for the water to seep through the soil and it will contribute to greater magnitude of flood. In order to mitigate or minimize the flood impacts, something must be done. One of the methods is through flood forecasting. Recently, flood forecasting application is being more and more important because it can provide lead time for the people to take immediate or emergency response before the occurrence of flood, thus reduce the impacts of flood. Besides, the study of flood forecasting application has been started many years ago and is proven that it is reliable and trustworthy. In many developed countries, they had implemented the flood forecasting system in order to prevent or minimizes the flood impacts. Many software had been developed to forecast the flood and one of them which used widely by other researchers is Hydrologic Engineering Centre - Hydrologic Modelling System (HEC-HMS). By using HEC-HMS, it can provide hydrographs (time of flood flows and volume) and estimated peak flow of a river basin. According to United States Army Corps of Engineers, flood forecasts can support emergency operations by providing estimates of the timing and extent of expected hazardous or damaging flood conditions [3]. It is fundamental to the effective operation of flood control reservoirs.

Therefore, in this study the flood forecasting method was used to tackle the flood issues in Bukit Merah. Bukit Merah is a place located in District Kerian and it is one of the flood risk area in Perak. The Star has reported flood event near Bukit Merah in Kerian [4]. About 180 people from Bukit Merah were evacuated after the area was hit by floods. It is believed that the release of water from Bukit Merah Reservoir causes the flood at that time. Bukit Merah is historically a flood risk area in Perak, and it is located near to Bukit Merah Reservoir, the possibility for a flood to happen again in the future is high. So, something must be done to mitigate the flood in the Bukit Merah area. The objectives of this study were to develop the hydrologic model for Bukit Merah and to forecast the flood magnitude for next twenty years by considering the factor of climate change and land use changes via HEC-HMS.

In order to develop the hydrologic model for Kurau River Sub-basin, some data should be collected. These data included rainfall data and streamflow data of the Bukit Merah, Perak. The data to be collected is only limited to the hydrological data but the water quality data is not being studied at this project. After collecting the data, calibration and validation process should be done to verify the model. The flood forecasting is limited to the area of Kurau River Sub-basin only. The flood forecasting is limited to twenty years. The software used to forecast the flood is HEC-HMS. The predicted future rainfall data will be collected from National Hydraulic Research Institute of Malaysia (NAHRIM). The simulation of flood for next twenty years in Bukit Merah, Perak will be done by using the predicted future rainfall data from NAHRIM. In order to study the effect of land use changes on the flood magnitude in Bukit Merak, Perak, the simulation of flood for next twenty years will be done by assuming increase of Curve Number (CN) by 20% for all sub-Basin. It is important because it gives the researchers the general picture of the area of Bukit Merah in the future, whether it will experience flood or not in the future. If yes, then what is the magnitude of the flood. If the researchers can get this information prior to the disaster, it can help in planning of the mitigating measures to prevent flood and minimize the damage of flood.

Concept of Flood Forecasting

Flood forecasting is an important mechanism for reducing the damaging effects of flood events. Flood protection and awareness have continued to rise on the political agenda over the last decade accompanied by a drive to 'improve' flood forecasts [5]. Operational flood forecasting systems form a key part of 'preparedness' strategies for disastrous flood events by providing early warnings several days ahead [6], giving flood forecasting services, civil protection authorities and the public adequate preparation time and thus reducing the impacts of the flooding. The incorporation of quantitative precipitation forecasting (QPF) in flood warning systems has been acknowledged to play a key role, allowing for an extension of the lead-time of the river flow forecast, which may enable a more timely implementation of flood control. Many flood forecasting systems rely on precipitation inputs, which come initially from observation networks (rain gauges) and radar [7].

1.1 Forecasting Requirements

Forecasting requirement depends on the needs of users of the model outputs. For a given situation, a model may help in addressing some or all of these requirements. Although it is difficult to generalize, in moving down Table 1, the types of model required will be generally be more complex, and take longer to develop [8].

For example, for a river flow model, to estimate the flood peak at a single location, a simple rainfall runoff model may in some cases be sufficient whilst, to estimate flow depths and velocities at property and street locations, a real time hydrodynamic model of the floodplain flow would ideally be required. Similarly, for coastal forecasting, to estimate inundation extent behind a sea defence, offshore-nearshore wave transformation, wave overtopping, surge and floodplain models might be required. In particular, models to assist with control structure operations, and decision support applications, can sometimes require considerable exploratory work to implement.

1.2 Concept of HEC-HMS Software

To meet the objectives of a flood forecast analysis, peak flow, total runoff volume, hydrograph timing, and peak reservoir stage are often required. These values are calculated for a look back period and then a forecast period. In general, the modelling process includes two parts: model development and flood forecasting. Model development typically utilizes the simulation run compute type where the time window is set to a historic flood event and the model is calibrated to observations from the historic event. A separate basin model is used for each calibration event (each basin model has a unique set of parameters). Flood forecasting uses the forecast alternative compute type which includes forecast specific parameter editors that efficiently estimate initial condition and allows for quick adjustments to the base model. The base model is used as a starting point for real-time calibration [3].

A. Model Development Steps include:

1. Select appropriate methods to represent watershed,
2. Collect watershed data and characteristics,
3. Utilize regional studies and equations to estimate parameter values,
4. Calibrate the model using historical data,
5. Validate the model using historical event data, and
6. Develop model parameter sets for different watershed conditions (such as dry, average, and wet conditions). These parameter sets can be used to initialize the flood forecasting model and will then be refined for the flood event being modelled.

B. Steps for Flood Forecasting include:

1. Configure the forecast alternative,
2. Calibrate the model to observed data in the look back period by adjusting model parameters,
3. Import future precipitation, and

4. Run the calibrated model to develop a flow forecast.
5. Analyze and view the results. Model results can be extracted for additional model applications such as HEC-ResSim and HEC- RAS.

1.3 Example of Flood Forecasting by using HEC-HMS

A. Flood Estimation Studies using Hydrologic Modelling System (HEC-HMS) for Johor River, Malaysia [9]

This study presented a flood estimation model for Johor River in Kota Tinggi watershed, Malaysia using HEC-HMS. Calibration and validation processes were carried out using different sets of data. Evaluation on the performance of the developed flood model derived using HEC-HMS yield a correlation coefficient R2 close to 1. The simulated Qpeak are 150.9 m3 sec-1, while the observed Qpeak for 10 years record (1997-2006) is 145.12 m3 sec-1. The percentage of error values are 4% and the performance of the developed flood model derived using the HEC-HMS with R2 value is 0.905. Based on these findings, it is suggested that the developed model using HEC-HMS can be used as a tool for estimating Qpeak.

B. Application of HEC-HMS for Flood Forecasting in Misai and Wan'an Catchments in China [10]

The hydrologic model HEC-HMS used in combination with the Geospatial Hydrologic Modeling Extension, HEC-GeoHMS, is not a site-specific hydrologic model. Although China has seen the applications of many hydrologic and hydraulic models, HEC-HMS is seldom applied in China, and where it is applied, it is not applied holistically. This paper presents a holistic application of HEC-HMS. Its applicability, capability and suitability for flood forecasting in catchments were examined. The DEMs (digital elevation models) of the study areas were processed using HEC-GeoHMS, an ArcView GIS extension for catchment delineation, terrain pre-processing, and basin processing. The model was calibrated and verified using historical observed data. The determination coefficients and coefficients of agreement for all the flood events were above 0.9, and the relative errors in peak discharges were all within the acceptable range.

2. EXPERIMENTAL

2.1 Materials

This methodology includes flowchart of study, data collection, the establishment of GIS data and map for Kurau River Sub-basin by using ArcMap 10.1 and HEC-GeoHMS, the model set up in HEC-HMS, calibration and validation process and the simulation methods.

2.2 Flowchart of Study

Figure 1 shows the flowchart of study. Before any research to be carried out, literature review on topic related on the research interest was done. At the same time, data collection like soil map, satellite image and topography map will be obtained from the relevant agencies or previous studies. After most data are obtained, data processing and analysis will be carried out. GIS database for Kurau River Sub-basin will be prepared using topography map to produce spatial data like landuse, soil, contour, river and etc. by using ArcMap 10.1. This spatial data will be used as input for model setup. Model that will be used in this study is hydrologic model and it will be calibrated and validated until the model achieves certain level of confident for model simulations and analysis. The model simulation results in this study can assist decision maker to make decision and planning.

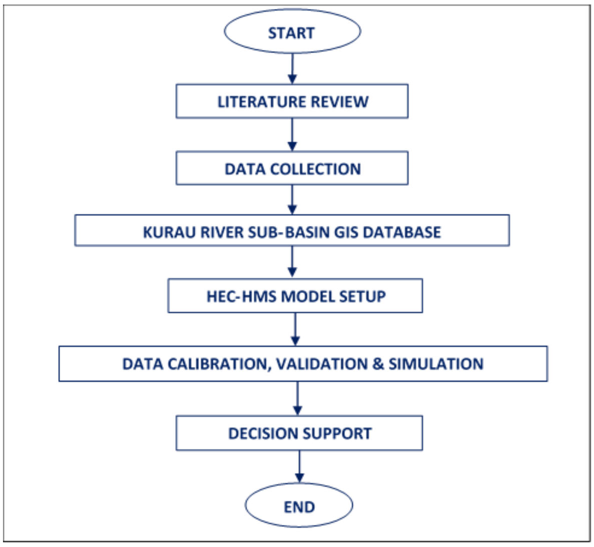

Figure 1 Flowchart of study

Table 1 Data Required for The Study

Type of Data	Source
Satellite image	Department of Drainage and Irrigation (DID)
Topography map	Department of Survey and Mapping Malaysia (JUPEM)
Soil map	Department of Agriculture (DOA)
Rainfall data	Department of Drainage and Irrigation (DID)
Streamflow data	Department of Drainage and Irrigation (DID)
Predicted future rainfall data	National Hydraulic Research Institute of Malaysia (NAHRIM)
Main morphological and cross section data	River Engineering and Urban Drainage Centre (REDAC), USM

2.3 Establishment of GIS Data and Map for Kurau River Sub-Basin

Setting GIS database for Kurau River Sub-basin is essential to produce the spatial data such as landuse, river, contour, and etc. Those spatial data are very important to develop the models for HEC-HMS. Topography maps for Kurau River Sub-basin were used to create GIS database using ArcMap 10.1. Then, HEC-GeoHMS is used to integrate the GIS database, satellite image, topography map and soil map to create a map with the location of sub-basin in HEC-HMS as shown in Figure 2.

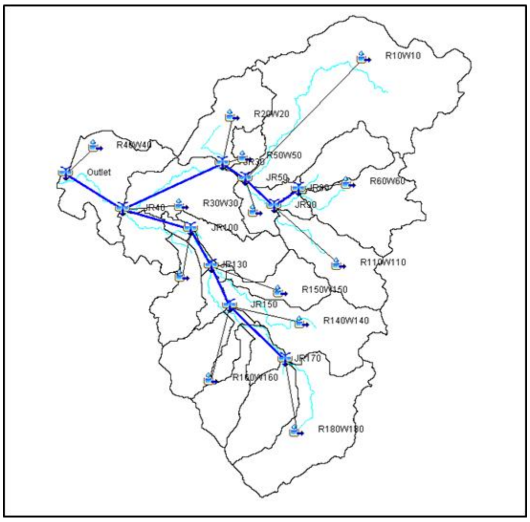

Figure 2 Map of Kurau River Sub-Basin Created in HEC-HMS

2.4 Model Setup in HEC-HMS

Table 2 shows the summary of method used in the HEC-HMS simulation.

A. Rainfall and discharge station: Pondok Tanjung Station (id no.5007421)
B. Sub-basin
  a) Selecting lose method – SCS Curve Number Loss
  b) Selecting transform method – SCS Unit hydrograph method
  c) Selecting baseflow method – Recession method
C. Reach – Selecting a routing method – Muskingum-Cunge Method
D. Meteorologic model – Thiessen polygon method

Table 2 Summary of method used in the HEC-HMS simulation

Element	Method	Parameter
Subbasin	Loss rate-SCS Curve Number Loss	Initial abstraction Curve Number
	Transform-SCS Unit Hydrograph	Time Lag
	Baseflow-Recession	Initial type-discharge Initial discharge Recession constant Threshold type Threshold ratio
Reach	Muskingum Cunge	Length Slope Manning's n Shape Bottom Width Side Slope (xH:1V)

2.5 Calibration, Validation and Simulation Process

The model calibration and validation for the discharge stations at Pondok Tanjung station (id no.5007421) are done by using two different set of data. The daily interval rainfall event starts from 05 Jan 2010 (00:00 time) to 15 Jan 2010 (00:00 time) are used for the calibration. The daily interval rainfall event starts from 16 Jan 2010 (00:00 time) to 26 Jan 2010 (00:00 time) are used for the validation. The accuracy of the hydrologic model is determined based on the coefficient of determination (R^2) value. The closer the R^2 value to 1, the better the model accuracy can be achieved, whereas the closer the R^2 value to 0, the poorer the model.

After the model has been verified, two types of simulation of flood will be performed. Table 3 shows the type of simulation that performed in this study.

Table 3 Type of Simulation Performed

Type of simulation	Method to perform
1. To simulate the flood magnitude for next twenty years in Bukit Merah by using predicted future rainfall data collected from NAHRIM.	1. Set future rainfall data as the input of precipitation. 2. Simulate the model by using data ranged from 01 Jan 2020 (00:00 time) until 31 Dec 2040 (00:00 time). 3. Increase the amount of rainfall by 5 times to simulate for the excess rainfall scenario. 4. Decrease the amount of rainfall by 5 times to simulate for the extremely lacking of rainfall scenario.
2. To simulate the flood magnitude after land use changes.	1. The future development in Perak has been identified. 2. Assume that the CN Number of all basin in Bukit Merah increase to 90 and the impervious area increase to 70%. 3. Simulate the model after altering the CN Number and percentage of impervious area.

3. RESULTS AND DISCUSSION

3.1. Related Work

The calibration and validation results are showed in Figure 3 and Figure 4 respectively. The summary of calibration and validation result is showed in Table 4.

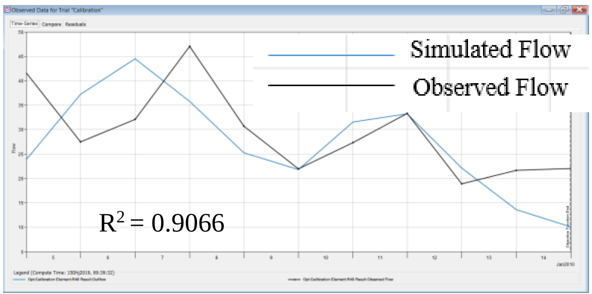

Figure 3 Calibration Results

Based on the results of calibration and validation process, it showed that the model is verified and reliable because the simulated flow in HEC-HMS is closely fit to the observed flow and the percentage different is less than 10 %. Besides, the R^2 value is close to 1, therefore it is proved that the model is trustable and can be used for flood simulation.

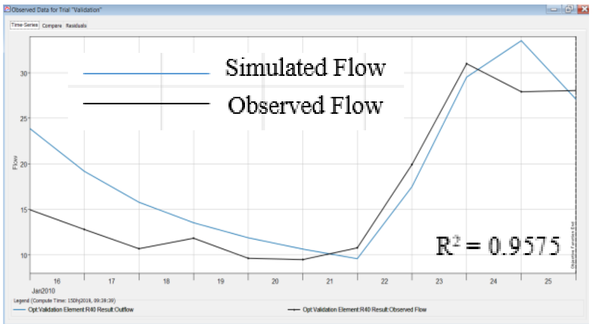

Figure 4 Validation Results

Table 4 The Summary of Calibration and Validation Results

Process	Observed	HEC-HMS	Difference	Percentage difference (%)	R^2 value
	Peak Flow (m^3/s)	Peak Flow (m^3/s)	Peak Flow (m^3/s)	Peak Flow	
Calibration	47.00	44.5	2.50	5.30	0.906
Validation	31.00	33.5	2.50	8.10	0.957

3.2 Simulation of The Flood Magnitude for Next Twenty Years in Bukit Merah by Using Predicted Future Rainfall Data

The results of the simulation of future flood to the Bukit Merah Reservoir (outlet) for next twenty years in Bukit Merah under normal condition is showed in Figure 5. The results of the simulation of excess rainfall scenario and extremely lacking of rainfall scenario are showed in Figure 6 and Figure 7 respectively. The streamflow of the three scenarios are combined and showed in Figure 8. The summary of the simulation results are showed in Table 5.

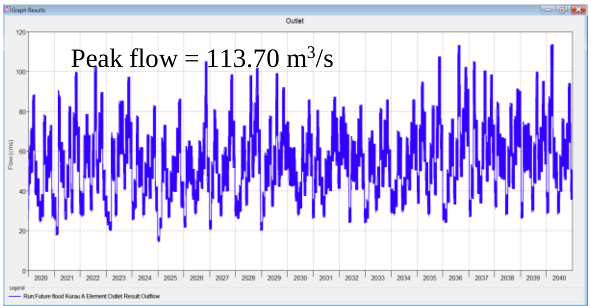

Figure 5 Simulation of Future Flood for Next Twenty Years in Bukit Merah under Normal Condition (Outlet)

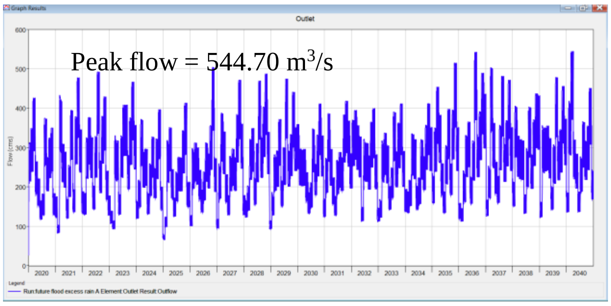

Figure 6 Simulation of Excess Rainfall Scenario in Bukit Merah (Outlet)

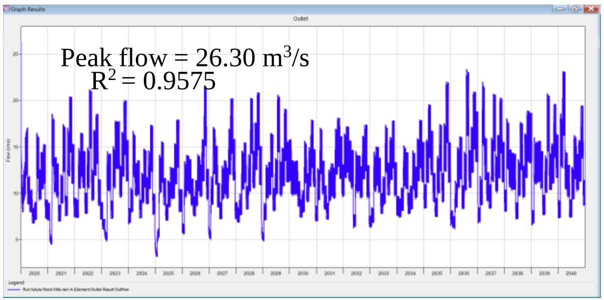

Figure 7 Simulation of Extremely Lacking of Rainfall Scenario in Bukit Merah (Outlet)

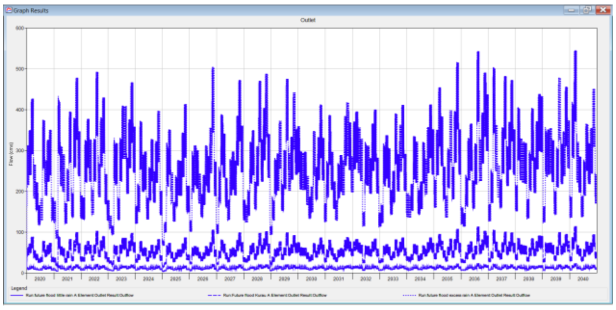

Figure 8 Combined of The Streamflow of The Three Scenarios (Outlet)

Table 5 The Summary of The Simulation Results

Station	Peak Flow (m^3/s)			Difference compared to normal condition (m^3/s)		Percentage difference compared to normal condition (%)	
	Normal condition	Excess rainfall	Insufficient rainfall	Excess rainfall	Insufficient rainfall	Excess rainfall	Insufficient rainfall
Outlet	113.70	544.7	26.30	431	87.40	+379	-76.87

Based on the results of simulation, it shows that the peak discharge for next twenty years would be 113.70 m^3/s by using predicted rainfall data. However, the issue of climate change has made the flood forecasting a bit challenging. Hence, the excess rainfall scenario and extremely lacking of rainfall scenario are simulated to get the overall picture of flood prediction even in the extreme events. Therefore, the range of the streamflow for next twenty years are from 26.30 m^3/s to 544.70 m^3/s. It is a very large range because of the issues of climate change. In excess rainfall condition, the peak discharge can rise to 544.70 m^3/s which is 379% higher than the normal condition. This is very scary and the damaging effect is unimaginable. For the extremely lacking of rainfall condition, peak discharge will drop to 26.30 m^3/s which is 76.87% lower than normal condition and this will lead to drought. Hence, from the simulation, it is clearly showed that Bukit Merah is a flood risk area that will easily being flooded if there is excess rainfall in the area. This is most probably due to the topography of the land which is hilly and their Curve Number are generally high, which is over 60%. Due to climate change, the flood would be greater than usual as the results in excess rainfall and the drought would be more extreme too as the results in the extremely lacking of rainfall. Hence, flood forecasting by using HEC-HMS can be used as a solution to tackle such events because it can predict those events earlier and provide lead time for the government and residents to take action. In HEC-HMS, it will show the date and time of the flood predicted, so it can make the prevention action to be taken in time.

3.3 Simulation of The Flood Magnitude After Land Use Changes

The results of the flood simulation after land use changes are shown in Figure 9. The summary of the simulation results are shown in Table 6.

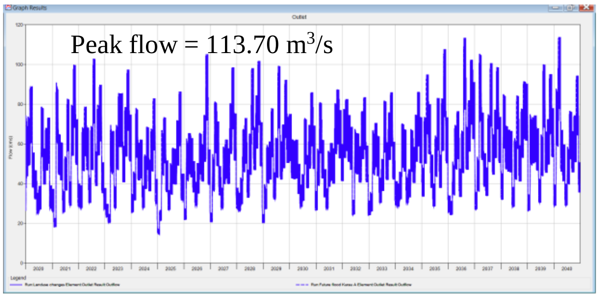

Figure 9 Flood Simulation After Land Use Changes

Table 6 Summary of The Simulation Results

Station	Initial land use	Land use changes	Difference	Percentage difference (%)
	Peak Flow (m^3/s)	Peak Flow (m^3/s)	Peak Flow (m^3/s)	Peak Flow
Outlet	113.70	113.70	0	0

Based on the simulation results, it can be said that the land use changes do not give significant impacts on the flood magnitude in Bukit Merah. However, it is believed that the land use changes will give huge impact on water quality. This is most probably because the CN Number of the Bukit Merah is initially high enough and further development will not affect it too much. CN Number is the number to show that whether the place is easy for water to seep through underground or not, the higher CN means it is harder for water to seep through. Therefore, something must be done to reduce the CN number in Bukit Merah to mitigate the flood events. For example, replanting of trees, set up forest protection area and create more landscape area.

4. CONCLUSION

As a conclusion, the flood is the damaging natural disaster in Malaysia and it has affected the residents in Bukit Merah for many years. Currently, the issue of climate change and land use changes had increased the impact of flood. Therefore, one of the solutions would be flood forecasting using HEC-HMS software. In this study, the hydrologic model of Bukit Merah has been successfully developed. The verified model has been used to simulate the future flood in normal condition, excess rainfall condition and extremely lacking of rainfall condition successfully. It showed that the climate change has very great impact on the magnitude of flood in the future. Besides, the simulation of flood after land use changes also successfully performed but the results showed that the land use changes do not give significant impact to the magnitude of flood in Bukit Merah in the future. It is believed that the land use changes will greatly affect the quality of water in Bukit Merah although it gives less impact on quantity of water. Hence, for the recommendation, the next researcher is suggested to taking into account of the quality of water in Bukit Merah. This can be done by quantifying the sedimentation or particles in the basin or doing the water quality testing of the water in Bukit Merah.

ACKNOWLEDGMENT

The authors gratefully acknowledge with thanks to Ministry of Higher Education Malaysia and partially funded by Universiti Tun Hussein Onn Malaysia (UTHM) for financial assistance of this experimental work via Fundamental Research Grant Scheme Vot No. FRGS/1/2019/TK01/UTHM/03/2

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