JOURNAL OF FLOOD ENGINEERING
Vol. 10 No. 2 (July-December, 2019)

Received: 11th June 2019 Revised: 4th August 2019 Accepted: 19th November 2019

GIS-BASED HYDROLOGICAL MODELLING IN KAYU ARA RIVER BASIN, MALAYSIA

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ABSTRACT: Hydrological modeling is one of the principle components of water resources studies such as flood modeling, water quality, irrigation, salinity assessment. Meanwhile, necessity of hydrological modeling in climate change and land-use development assessment studies increases the importance of precise and efficient hydrological modeling which is strongly depended on quality and accuracy of input data. However, broad availability of digital topography data and also improvement of Geography Information System (GIS) tools lead to opportunity of GIS application in hydrological modeling. Present paper aims to perform a hydrological modeling under various scenarios using capabilities of GIS to assess the effects of rainfall and river basin development conditions on hydrological response. In this regard, GIS was used as a pre-processor in order to prepare and extract the input data for hydrological model. In this research, HEC-HMS was applied as the hydrological model which linked to GIS environment using HEC-GeoHMS GIS extension. The case study of this research was Sungai Kayu Ara river basin in Kuala Lumpur, Malaysia. Different rainfall durations and ARIs in existing, intermediate and ultimate river basin land-use development conditions were considered to examine the effects of rainfall and land-use development conditions on river basin hydrological response (36 scenarios). The results approve the reasonable capability of GIS as a tool in this process.

Keywords: Hydrological Modeling, Geography Information System, Land-use Development, Hydrological Response, HEC-HMS, HEC-GeoHMS, Sungai Kayu Ara, Malaysia.

1. INTRODUCTION

Hydrological models are regarded as a powerful tool for predicting river basin response to rainfall events and assessment of the impacts of parameters such as land-use cover change on river basin hydrology (Whitehead and Robinson 1993). In fact, hydrological modeling is a technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of water resources. In recent years, hydrological processes in river basins have increasingly been studied in order to quantify the possible impacts of changes in land-use, land cover or soil surface conditions and urbanization on river basin hydrological processes, water quality and on extreme hydrological events such as floods and droughts (Cole and Moore 2009; Hong and White 2009; Salerno and Tartari 2009; Sheikh, Visser *et al.* 2009;

Kusre, Baruah *et al.* 2010). The regionalization analysis improves at-site estimates in this regard (Eslamian 2010).

In this research, HEC-HMS3.1.0 is used as hydrological model which was widely applied in many water resources studies (He and Croley Ii 2007; García, Sainz *et al.* 2008; Chen, Xu *et al.* 2009; Lin, Verburg *et al.* 2009; Kousari, Malekinezhad *et al.* 2010). The Hydrologic Modeling System (HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flood forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (U.S. Army Corps of Engineers (USACE) 2006).

2. CASE STUDY

Sungai Kayu Ara river basin is the case study in this research which is located in Kuala Lumpur, Malaysia. Sungai Kayu Ara river basin is geographically surrounded within N 3° 6′ to N 3° 11′ and E 101° 35′ to E 101° 39′. Sungai Kayu Ara river basin covers an area of 23.22 km^2. The main river of this river basin originates from the reserved highland area of Penchala and Segambut. The Sungai Kayu Ara river basin can be a suitable study river basin for this research because of some reasons such as follows: primarily, a large part of this river basin area is well developed urban area with different land-use and also high population density that shows the importance of this river basin. Secondly, the availability of high density rainfall station network, whereby 10 rainfall stations and one water level station are available. Figure 1 shows location and base map of Sungai Kayu Ara in Malaysia.

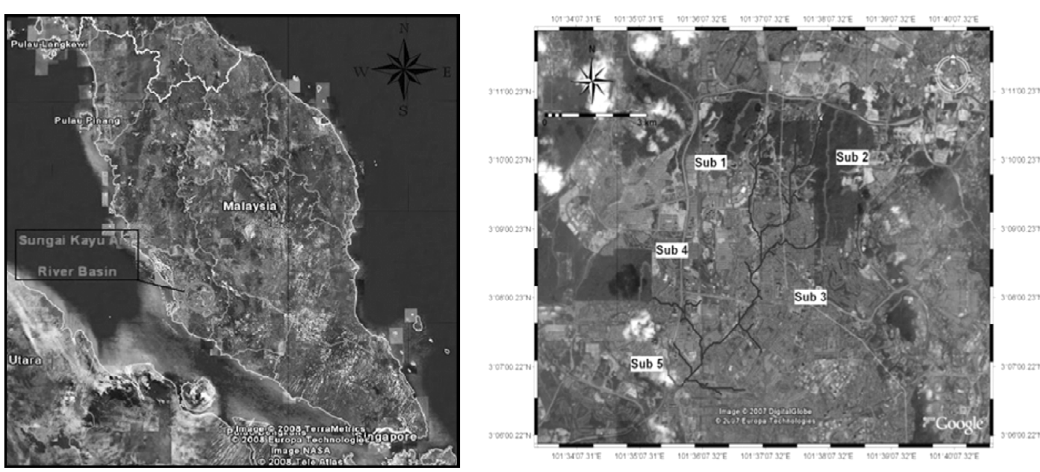


Figure 1: Location and Base Map of Sungai Kayu Ara in Malaysia

3. HEC-HMS3.1.0

HEC-HMS3.1.0 is a hydrological model developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers. In 1968, HEC released the HEC-1 computer model to aid engineers in hydrologic analysis. The window-based HEC-HMS3.1.0 software was released in 1998. The program simulates a rainfall-runoff response of a river basin system to a precipitation input by representing the entire river basin as an interconnected system of hydrologic and hydraulic components, which include river basins, streams and reservoirs. The results from HEC-HMS3.1.0 model can be used as an input for hydraulic models.

The HEC-HMS3.1.0 software provides the following computational options to derive runoff response from rainfall-runoff process simulation: several alternatives for hydrologic losses determination, lumped or linearly distributed runoff transformation methods, routing options and optimization system for calibration(USACE 2006). HEC-HMS comprises of three main components for rainfall-runoff simulation; loss method, transformation method, base-flow method and routing method. Green-Ampt, Snyder unit hydrograph, recession and kinematic wave methods are selected and applied for rainfall-runoff simulation in Sungai Kayu Ara river basin due to suitability of them for similar catchment and availability of required parameters.

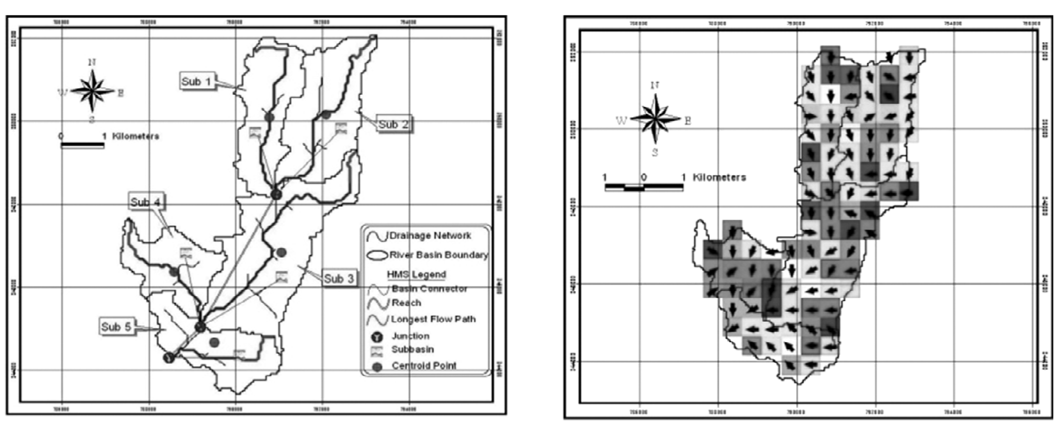
4. HEC-GEOHMS1.1

Numerous past studies have shown HEC-GeoHMS to provide accurate and useful results in river basin hydrological studies (Knebl, Yang *et al.* 2005; Bonnet, Barroux *et al.* 2008; Chen, Xu *et al.* 2009; Jang, Kim *et al.* 2010; Koutroulis and Tsanis 2010). It is called the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS). The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package which can be used as an extension of the Arcview Geographic Information System. ArcviewGIS uses HEC-GeoHMS and Spatial Analyst to develop a number of hydrological model inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities of HEC-GeoHMS include the development of grid-based data for linear quasi-distributed runoff transformation (such as Modified Clark UH method), the HEC-HMS3.1.0 basin model, physical watershed and stream characteristics, and background map file. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points (USACE 2003). The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS3.1.0, where simulation is performed.

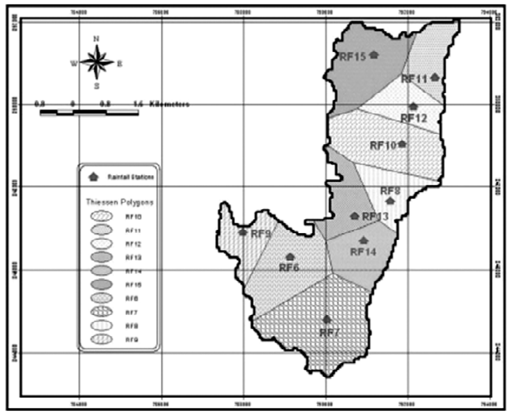
HEC-GeoHMS1.1 is used as a pre-processor for hydrologic model which means that, some significant inputs which are needed for hydrological modeling are prepared by this extension, these inputs are as follows: drainage network, river basin boundary, sub-river basin boundary, river basin and sub-river basin centroid points (as the location of the object of sub-river basin in the HEC-HMS), longest flow path and flow direction. Figure 2 shows the subdivision of the sub-river basin and the result maps of HEC-GeoHMS1.1 analysis in the Sungai Kayu Ara river basin. The HEC-GeoHMS1.1 can extract the sub-river basins based on the topographic characteristics of the river basin which is distinguishable in digital elevation model (DEM) of the study area. This research considers five main criteria for selecting optimum number and form of the sub-river basins. First of all, topographic characteristics of the river basin are considered, this step is executed by HEC-GeoHMS1.1. The sub-river basin of the Sungai Kayu Ara river basin is based on the topographic points surrounded the river system in the area .i.e. ground level around the river system. The rational is that the rainfall falls on this area (sub-river basin) will eventually converge to the outlet of the demarcated sub-river basin. Secondly, land-use of the river basin is focused. The North and West zones of the Sungai Kayu Ara are covered by sub-urban land-use while the eastern, southern and central zones include developed urban land-use. The third criterion is drainage network shape for each sub-river basin. This means, attempt has been made that each river basin to consist a reasonable representative drainage network which includes a main river and drainage branches. Fourthly, location of the study reach is essential to consider in division of sub-river basins as an upstream boundary condition at the beginning of the study reach is necessary for hydraulic modeling. Upstream boundary condition for sub-river basin 3 is the outlets of sub-river basins 1 and 2. And finally, the location of the rainfall stations was associated in the sub-river basin division process, in other word each sub-river basin must include at least one rainfall station. Table 1 shows the characteristics of Sungai Kayu Ara sub-river basin.

Table 1
Characteristics of Sungai Kayu Ara Sub-River Basins

Sub-river basin	*Area (Km^2)*	*Perimeter (m)*	*Slope (10-85% method)*	*Longest Flow Path (m)*	*Centroid Point Elevation (m)*
Sub 1	3.958	12700	0.013	4655.6	45.0
Sub 2	5.120	13700	0.010	5412.7	55.0
Sub 3	7.645	19500	0.006	6934.1	40.9
Sub 4	3.050	11900	0.006	3679.9	31.5
Sub 5	3.452	12200	0.012	3098.5	35.0



a. b.



c.

Figure 2: Characteristics for Sungai Kayu Ara River Basin
(a. HEC-HMS Data b. Runoff Surface Flow Direction c. Thiessen Polygon Map)

5. INPUT DATA

Hydrological modeling main output is the response of river basin to precipitation. The response is a flow (runoff) hydrograph for each individual sub-river basin in the system. The initial step in this process is the preparation and collection of appropriate data which is required for hydrological modeling. In this regard, this section explains the procedure of data collection and generation for hydrological modeling in Sungai Kayu Ara river basin. The selected observed data are used during sensitivity analysis, calibration and validation of the HEC-HMS. There are 10 rain gauges installed within the Sungai Kayu Ara river basin. The rain gauges are self-recording and the rainfall data is stored in the built-in data logger memory. Amount of recorded rainfall will be based on the frequency of the series of tips (tipping budget rain gauges) generated by rainwater. Such information will be useful to determine rainfall intensity, rainfall duration and daily total rainfall. The hydrological record will be retrieved on site using SRAM (Static Random Access Memory) Card by the Department of Irrigation and Drainage (DID) staff. Furthermore, all data is converted into the Time Dependent Data Processing System (TIDEDA®) in the DID hydrology unit. The software system is developed and supplied by the National Institute of Water and Atmosphere Research of New Zealand (NIWA) and currently version 1.9 is being used. The DID Hydrology Unit at Jalan Ampang, Kuala Lumpur was the main reference for extracting the required data in this research. The location for the rain gauges and water level station on the Sungai Kayu Ara river basin is illustrated in Figure 3.

In order to accomplish the hydrological model, it is required to obtain sufficient recorded rainfall-runoff events to establish the credibility of the model before running the model. A total of 10 rainfall stations and 1 water level station are available; where the rainfall and water level data at 5 minute, 10 minute and 15 minute intervals for the year 1996 to 2004 were retrieved from DID Hydrology Unit. The 10 minutes interval data are more complete record than data in other intervals.

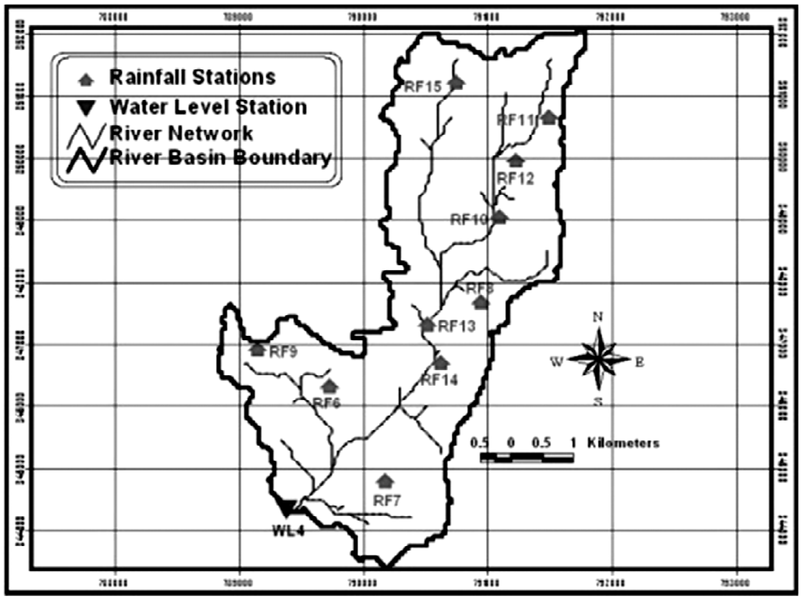


Figure 3: Location of Rainfall and Water Level Stations in Sungai Kayu Ara Basin

6. MODEL ESTABLISHMENT

Schlesinger (Schlesinger 1979) defined model calibration as the procedure of adjustment of parameter values of a model to reproduce the response of a river basin under study within the range of accuracy specified in the performance criteria. Also model validation is considered as the substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model. It is important in this connection to assess the uncertainty in the estimation of model parameters, for example from sensitivity analyses. While, the model validation involves conducting tests which documented the given site-specific model is capable of making sufficiently accurate predictions. This requires using the calibrated model, without changing the parameter values, to simulate the response for a period other than the calibration period. The model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits or to provide acceptable errors. In other words, validation is the testing of calibrated models with respect to additional set of field data preferably under different environmental conditions to further examine the validity of the model (Thomann 1982). Model validation is designed to confirm that, the calibrated model is applicable over the limited range of conditions defined by the calibration and validation data sets. Hence, it is important that collection of calibration and validation data must cover the range of conditions over which predictions are desired. The data should be such that, the calibration parameters are fully independent of the validation data (Himesh 2000). One of the methods for establishment of the credibility of the model is Nix method; which is employed for hydrological and hydraulic modeling in Sungai Kayu Ara river basin (Nix 1994).

6.1 Sensitivity Analysis for HEC-HMS3.1.0 Model

In this research, Green and Ampt, Snyder Unit Hydrograph, recession model and kinematic wave methods were utilized for loss, transform base-flow and routing components in HEC-HMS, respectively. In this case, there are 11 main parameters are applicable for sensitivity analysis. For sensitivity analysis, each individual parameter is changed for ±5%, ±10%, ±20%, ±30%, ±50% and ±75% ranges and then simulated while the other parameters are constant, because the effect of each individual parameter on the outputs (runoff volume and runoff peak discharge) are intended. Figure 4 illustrates the results of the sensitivity analysis for HEC-HMS in Sungai Kayu Ara river basin.

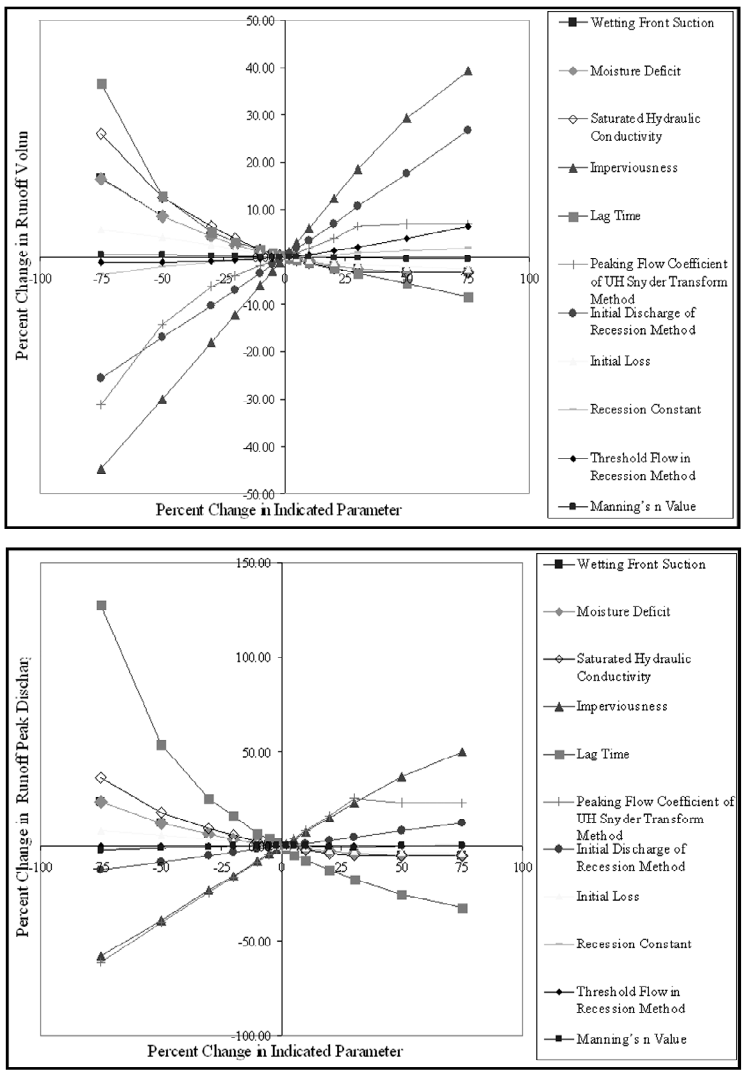


Figure 4: Sensitivity Analysis of HEC-HMS3.1.0 for Runoff Volume and Peak Discharge

According to the results of the sensitivity analysis for HEC-HMS in Sungai Kayu Ara river basin, it is shown that, imperviousness, initial discharge of recession method, peak flow coefficient, lag-time, hydraulic conductivity, moisture deficit and wetting front suction are the most effective on the runoff volume (more than 5% changes). On the other hand, lag-time, imperviousness, peaking flow coefficient, hydraulic conductivity, moisture deficit, wetting front suction and initial discharge are more important parameters on the runoff peak discharge (more than 5% change). These parameters must be considered and focused during the hydrological modeling. Table 2 denotes the ranking of the effectiveness of sensitive parameters on runoff volume and runoff peak discharge.

In order to calibrate and validate the HEC-HMS model for Sungai Kayu Ara river basin 18 rainfall events which were occurred between the year 1996 and 2001 are selected for calibration process and 18 rainfall events between the years 2002 and 2004 are used for validation. The basin mean areal rainfall depth for the 18 calibration and 18 validation rainfall events which are calculated with Thiessen method ranges between 7.14 mm and 58.93 mm, respectively. The maximum runoff peak discharge and runoff volume were observed at the outlet of the river basin on 10th February 1999 which are 220 m^3/s and 1190000 m^3, respectively.

Table 2
Ranking of the Effectiveness of Sensitive Parameters on Runoff Volume and Runoff Peak Discharge

Rank	*Sensitive Parameters on Runoff Volume*	*Rank*	*Sensitive Parameters on Runoff Peak Discharge*
1	Imperviousness	1	Lag-Time
2	Initial Discharge	2	Imperviousness
3	Peaking Flow Coefficient	3	Peaking Flow Coefficient
4	Lag-Time	4	Hydraulic Conductivity
5	Hydraulic Conductivity	5	Moisture Deficit
6	Moisture Deficit	6	Wetting Front Suction
7	Wetting Front Suction	7	Initial Discharge

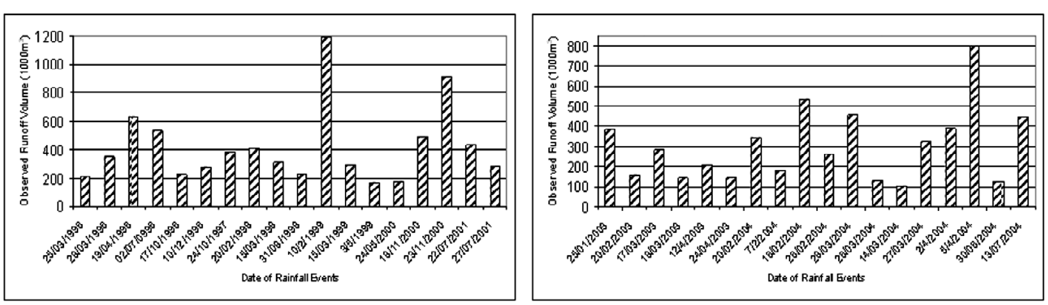


Figure 5: Observed Runoff Volume for Hydrologic Model Calibration and Validation

Eighteen selected rainfall events for validation of HEC-HMS for Sungai Kayu Ara river basin were observed between the years 2002 and 2004. The minimum and maximum validation events were observed on the 20th February 2003 and 5th April 2004. The minimum and maximum runoff peak discharges were observed at the river basin outlet; 15.27 and 181 m^3/s, respectively, while the minimum and maximum observed runoff volumes are 158000 and 800000 m^3, respectively. Figure 5 represents the values of observed runoff peak discharge and runoff volume, respectively, of selected rainfall events for validation of HEC-HMS.

6.2 Calibration of HEC-HMS Model

The results of sensitivity analysis show that imperviousness, initial discharge of recession method, peaking flow coefficient, lag-time, hydraulic conductivity, moisture deficit and wetting front suction are the most affective parameters on the runoff volume. On the other hand, lag-time, imperviousness, peak flow coefficient, hydraulic conductivity, moisture deficit, wetting front suction and initial discharge are more important parameters on the runoff peak discharge. According to the results, it seems that these parameters must be considered as sensitive parameters. Saturated hydraulic conductivity, moisture deficit and wetting front suction can be extracted from related references such as SWMM5.0 user manual.

Initial discharges and threshold flow of recession method are specific for every rainfall event which can be extracted using the observed stream flow hydrograph at the location of the water level station at the outlet of the Sungai Kayu Ara river basin. In order to select the value for initial discharges and threshold flow of recession method for design hydrograph simulation in HEC-HMS, the average value of the observed initial discharges and threshold flows of the observed runoff hydrographs are used.

In calibration process of HEC-HMS in Sungai Kayu Ara river basin, a total of 18 rainfall events which are selected as calibration rainfall events, simulated in HEC-HMS. The model is calibrated based on three factors of simulated hydrograph consists of peak value, runoff volume and time to peak. In the calibration procedure, imperviousness, lag time and peak flow coefficient are used to adjust the simulated hydrograph to the observed. The results of the calibration process for Sungai Kayu Ara river basin are evaluated using, the coefficient of

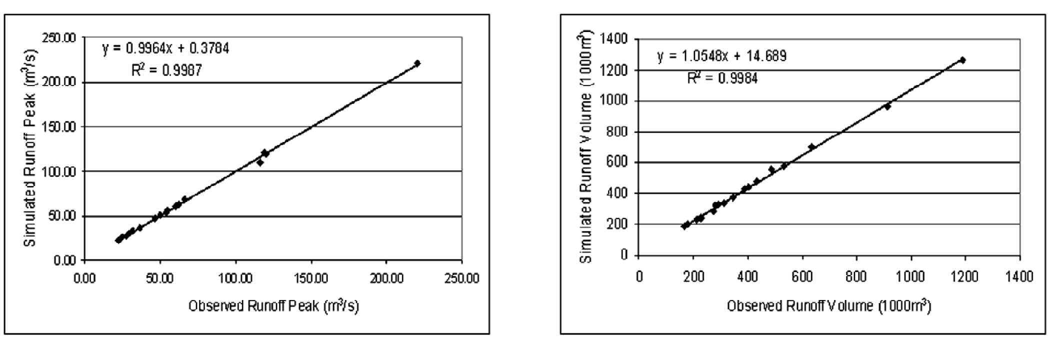


Figure 6: Correlation of Observed and Simulated Runoff Peak Discharge and Runoff Volume in Calibration Process for HEC-HMS in Sungai Kayu Ara River Basin

determination (R^2) which exhibits higher than 0.9 that shows acceptable correlation between simulated and observed data. The coefficient of determination (R^2) and the correlation between observed calibration events and simulated values for calibration events are calculated by REGRESS1.0 software.

By consideration to Figure 6, it appears that there is a good correlation between observed and simulated data in calibration process. It is intended to reduce the difference of observed and simulated values by adjusting the calibration parameters. All the coefficient of determination R^2 are higher than 0.9. These results show that the values selected for three calibrated parameters are adequately adjusted with the Sungai Kayu Ara river basin. Figure 6 illustrates the results and correlation of the simulation and observed runoff peaks and volumes in calibration process. Note that, the *Y* and *X* represent the observed and simulated data, respectively.

6.3 Validation of HEC-HMS3.1.0 Model

Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model adequately assesses the range of variables and conditions that are expected within the simulation. Although there are several approaches to validating a model, perhaps the most effective procedure is to use different data set of the available record of observed values for calibration and validation. Once final calibration parameters are developed, simulation is performed for the remaining period of observed values and the goodness-of- fit between recorded and simulated values is reassessed. Calibration process led to range of values for each parameter, in other words, it is possible to have different values for each parameter during calibration, even very near to each other, and it makes a range of value. Table 3 shows the results of this process.

Table 3
Results of Calibration Process for Hydrologic Model

Parameter	*Statistical Factor*	*Sub-river basin1*	*Sub-river basin2*	*Sub-river basin3*	*Sub-river basin4*	*Sub-river basin5*
Lag Time (hr)	Minimum	0.536	0.668	0.775	0.520	0.380
	Maximum	0.625	0.780	0.904	0.607	0.444
	Ave	0.563	0.702	0.814	0.547	0.400
	Median	0.557	0.694	0.805	0.540	0.395
	Mode	0.596	0.742	0.861	0.578	0.423
Imperviousness (%)	Minimum	23	23	63	33	63
	Maximum	28	28	68	38	68
	Ave	25.9	25.9	65.9	35.9	65.9
	Median	25	25	65	35	65
	Mode	25	25	65	35	65

Table Contd…

Table 3 Contd…

Peaking Flow Coefficient	Minimum	0.58	0.58	0.58	0.58	0.58
	Maximum	0.63	0.63	0.63	0.63	0.63
	Ave	0.61	0.61	0.61	0.61	0.61
	Median	0.61	0.61	0.61	0.61	0.61
	Mode	0.60	0.60	0.60	0.60	0.60

In the calibration process for imperviousness, lag time and peaking flow coefficient, a range of values are estimated. But for validation procedure only one set must be fixed. For selecting the best set among these, average, median and mode of values were compared with each other. The simulations are performed with 18 validation rainfall events and execute according to these parameter values. This means that three sets of parameter values (average, median and mode of values range) applied for each 18 validation rainfall events. Goodness-of-fit of results is compared according to the coefficient of determination R^2 of the simulation and observed stream flow hydrographs. Figure 7 shows the R^2 values of 0.8922, 0.8959 and 0.8678 for average, median and mode parameter values, respectively.

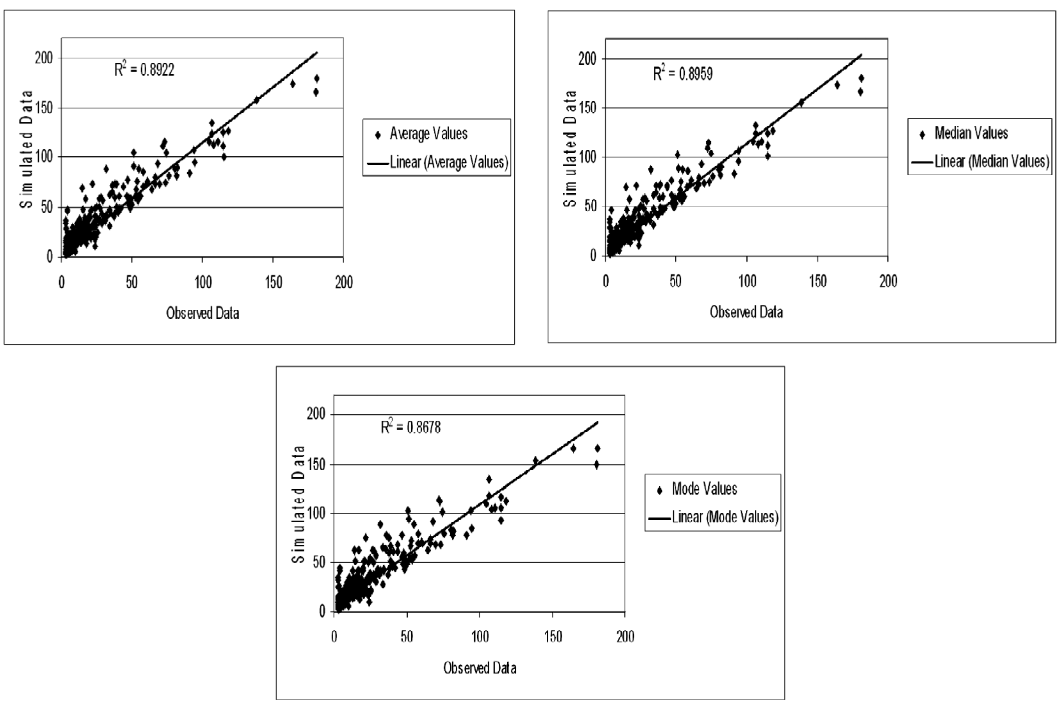


Figure 7: Evaluation of Calibrated Values Based on Average, Median and Mode Parameter Values of Calibration Range

According to the Figure 7, it can be concluded that median of the calibrated values performs the best performance of the hydrological model. Hence, median of the calibrated values are implemented for hydrological model validation for Sungai Kayu Ara river basin. After selection

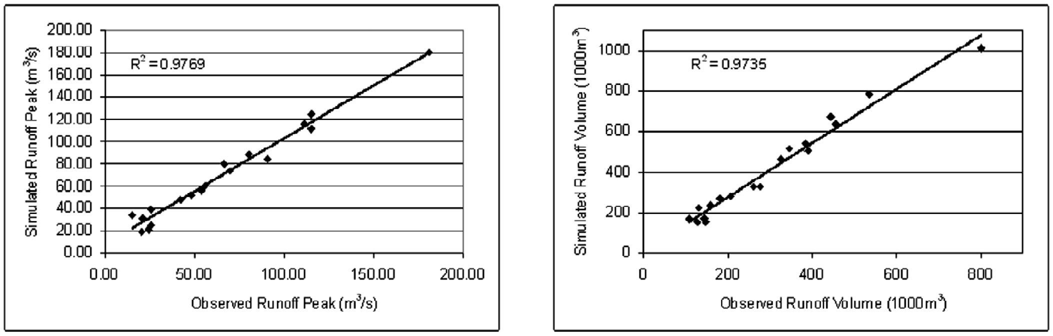


Figure 8: Correlation of Observed and Simulated Runoff Peak Discharge and Runoff Volume in Validation Process

of median values of calibrated parameters value, a total of 18 validation rainfall events are simulated in HEC-HMS for Sungai Kayu Ara river basin. In validation process, all of the values are kept constant and output values for runoff volume and runoff peak discharge are evaluated and compared with observed runoff volume and runoff peak discharges. In fact, during validation process the reliability and credibility of the calibrated values are clarified. The results of the validation process for 18 rainfall events are illustrated in Figure 8 which shows reasonable correlation between observed and simulated values. This shows that the parameter values for HEC-HMS model have been adequately identified to represent Sungai Kayu Ara river basin. Table 4 indicates the final validated parameters value for of HEC-HMS model for Sungai Kayu Ara.

Table 4
Final Validated Parameters Value for of HEC-HMS Model for Sungai Kayu Ara River Basin

Component (Method)	*Parameter*	*Sub Basin 1*	*Sub Basin 2*	*Sub Basin 3*	*Sub Basin 4*	*Sub Basin 5*
Loss Method (Green & Ampt)	Initial Loss (mm)	3.75	3.75	3.75	3.75	3.75
	Moisture Deficit	0.19	0.19	0.19	0.19	0.19
	Wetting Front Suction (mm)	109.9	109.9	109.9	109.9	109.9
	Hydraulic Conductivity (mm/hr)	10.9	10.9	10.9	10.9	10.9
	Imperviousness (%)	25	25	65	35	65
Transform (Snyder UH)	Lag Time (hr)	0.557	0.694	0.805	0.54	0.395
	Peaking Flow Coefficient	0.61	0.61	0.61	0.61	0.61
Baseflow (Recession)	Initial Discharge	Average of Initial Discharge in Observed Runoff Hydrograph				
	Recession Constant	0.3	0.3	0.3	0.3	0.3
	Threshold Flow	Average of Threshold Flow in Observed Runoff Hydrograph				

7. DESIGN HYDROGRAPH

Design rainfall duration is an important parameter that defines the rainfall depth or intensity for a given frequency, and therefore affects the resulting runoff peak discharge and volume. Intense rainfalls of short durations usually occur within longer-duration rainfalls rather than as isolated events. Recommended practice for river basins containing storage is to compute the design flood hydrograph for several rainfalls with different durations equal to or longer than the time of concentration for the river basin, and to use the one which produces the most severe effect on the pond size and discharge for design (DID 2000). The polynomial expression in the form of Equation 1 has been fitted to the published Intensity-Duration-Frequency (IDF) curves for the 35 main cities/towns in Malaysia.

$$\ln\left({}^{R}I_{t}\right) = a + b\ln\left(t\right) + c\left(\ln\left(t\right)\right)^{2} + d\left(\ln\left(t\right)\right)^{3} \quad (1)$$

where,

${}^{R}I_{t}$ = the average rainfall intensity (mm/hr) for ARI R and duration t

R = average recurrent interval (years)

t = duration (minutes)

a to d are fitting constants dependent on ARI

Equation 1 considers to the 3rd degree polynomial to keep the calculation simple for a reasonable degree of accuracy. Higher degree of polynomial can be used to obtain more accurate values of rainfall intensity. Equation 1 can be used for deriving rainfall intensity values for a given duration and ARI, once the values of coefficients a to d are known.

The generation of design hydrograph is accomplished using HEC-HMS model. The IDF polynomial equation for, three different ARI (20, 50 and 100 years) are used to derive the design rainfall as an input to HEC-HMS hydrological model. Duration of rainfall events are selected according to two criteria, first the time of concentration of the river basin which is equal to 2 hours, secondly with consideration to the availability of spatial temporal pattern in Storm Water Management Manual for Malaysia which is used as a reference in this research (rainfall temporal patterns are available only for 10, 15, 30, 60, 120, 180 and 360 min). Therefore, the durations selected are 60 minutes, 120 minutes, 180 minutes and 360 minutes. Table 5 shows the calculated rainfall densities and depth values for Sungai Kayu Ara river basin for three different ARI and four different durations.

This research focuses on three scenarios of land-use development conditions; existing, intermediate and ultimate. To this end, three types of percentage of land-use coverage are applied in HEC-HMS hydrologic model. Table 6 shows the percentage of imperviousness area in each sub-river basin for each development condition in Sungai Kayu Ara river basin.

Table 5
Design Rainfall Intensity and Depth for Sungai Kayu Ara River Basin

Event	*20 yr*		*50 yr*		*100 yr*	
Duration (min)	*Intensity (mm/hr)*	*Depth (mm)*	*Intensity (mm/hr)*	*Depth (mm)*	*Intensity (mm/hr)*	*Depth (mm)*
60	91.34	91.34	100.54	100.54	110.21	110.21
120	54.47	108.93	59.77	119.53	65.39	130.78
180	39.44	118.31	43.22	129.67	47.22	141.66
360	22.43	134.56	24.66	147.98	26.83	160.95

Table 6
Percentage of Impervious Area in Each Sub Basin

	Imperviousness (%)		
Sub Basin No.	*Existing Development Condition*	*Intermediate Development Condition*	*Ultimate Development Condition*
1	25	50	90
2	25	50	90
3	65	80	90
4	35	70	90
5	65	80	90

8. HYDROLOGICAL SIMULATION

Hydrological model such as HEC-HMS simulates the hydrograph of generated runoff caused by rainfall event. To simulate HEC-HMS for Sungai Kayu Ara river basin, for each scenario, input design rainfall hyetograph is required. The input hyetograph for each scenario, totally 36 rainfall hyetographs are extracted according to the storm water management manual (DID 2000). In order to obtain the best results, all 36 scenarios rainfall hyetographs are applied in HEC-HMS3.1.0 to distinguish the most critical conditions. In other words, for each development

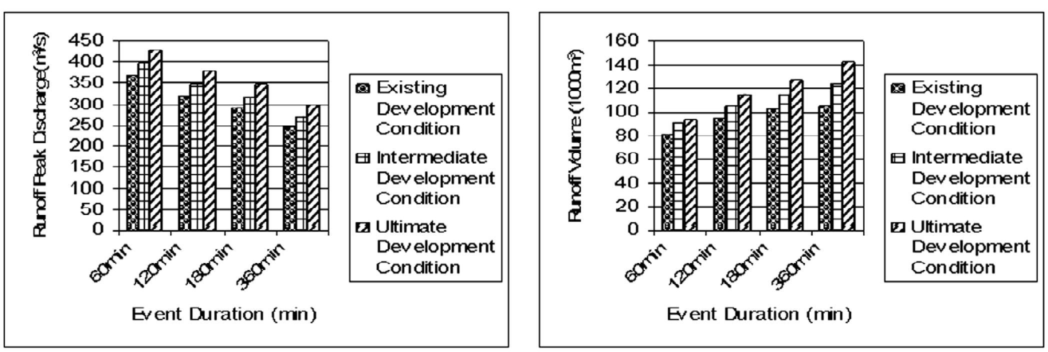


Figure 9: Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 20 Years ARI in Sungai Kayu Ara River Basin

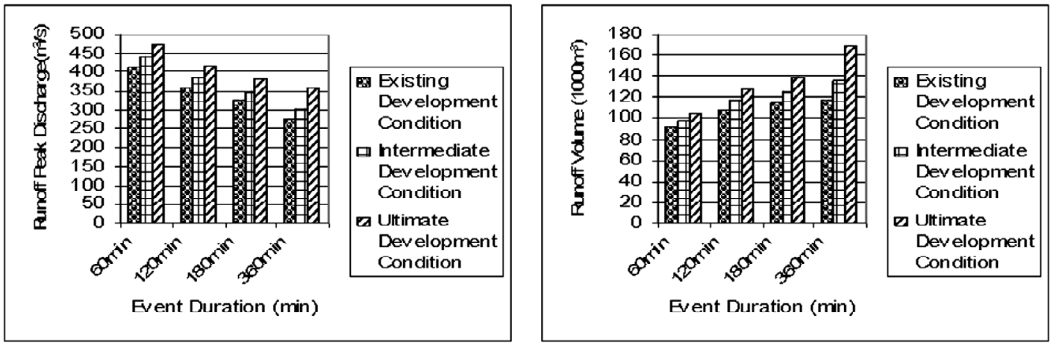


Figure 10: Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 50 Years ARI in Sungai Kayu Ara River Basin

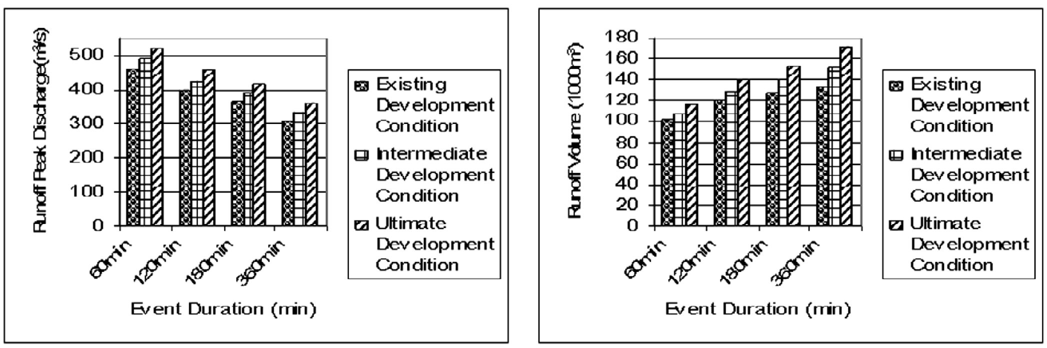


Figure 11: Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 100 Years ARI in Sungai Kayu Ara River Basin

situation there are 4 scenarios to account for 4 different ARIs in each storm recurrent interval, then, for each specific ARI in each condition one scenario must be selected for hydraulic modeling which is the most critical rainfall event in terms of runoff volume and runoff peak discharge values. Figures 9 to 11 demonstrate the results of the HEC-HMS simulation for all 36 scenarios, as it is clear, for each scenario the runoff peak discharge and runoff volume are calculated.

According to Figures 9 to 11, it can be concluded that, in each specific ARI with increasing development (from existing to ultimate development condition), the runoff peak discharge and runoff volume are increased which can be attributed to the increasing of the impervious area in the river basin. This pattern is similar for each specific development condition; it means that in a similar development condition, the runoff peak discharge and runoff volume of the 100 year ARI is higher than, the runoff peak discharge and runoff volume of the 50 year ARI and 20 year ARI, respectively. Furthermore, the results of the HEC-HMS3.1.0 simulation for three development conditions (existing, intermediate and ultimate) for three 20-year, 50-year and 100-year ARI for four duration (-hour, 2-hour, 3-hour and 6-hour), for a total of 36 scenarios, demonstrates that, effect of development condition in river basin response is more pronounce than the ARI, it means that, with increase of development condition, the changes in runoff peak discharge and runoff volume are higher in comparison with increase of the ARI. For example, the comparison between runoff peak discharges and runoff volumes of 20 year ARI and 100 year ARI in existing development condition shows 19% and 33% increase, respectively, while increase of the development from existing condition to ultimate condition, gives an increase of 91 and 45%, respectively. This implies that, runoff peak discharge is more sensitive to development condition changes, but runoff volume is more sensitive to ARI changes. The simulated runoff hydrograph of HEC-HMS3.1.0 for the 36 scenarios are illustrated in Figures 12 to 17. In these Figures, simulated runoff hydrograph for various development conditions, ARI and durations are established. With consideration to these figures comparison between effects of development condition, ARI and event duration can be studied.

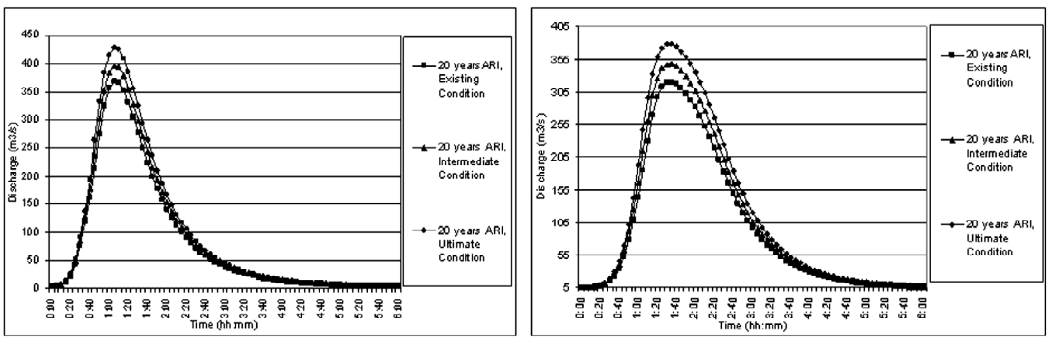


Figure 12: Simulated Runoff Hydrograph for Rainfall Events with 60 and 120 min Duration in Existing, Intermediate and Ultimate Development Condition with 20 Years ARI

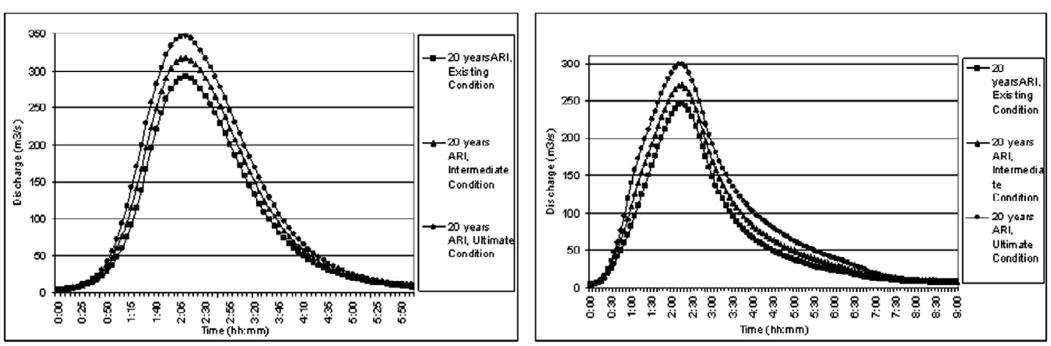


Figure 13: Simulated Runoff Hydrograph for Rainfall Events with 180 and 360 min Duration in Existing, Intermediate and Ultimate Development Condition with 20 Years ARI

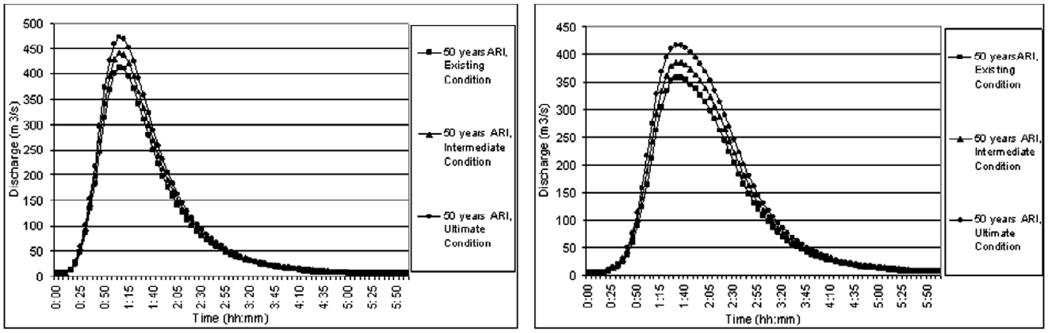


Figure 14: Simulated Runoff Hydrograph for Rainfall Events with 60 and 120 min Duration in Existing, Intermediate and Ultimate Development Condition with 50 Years ARI

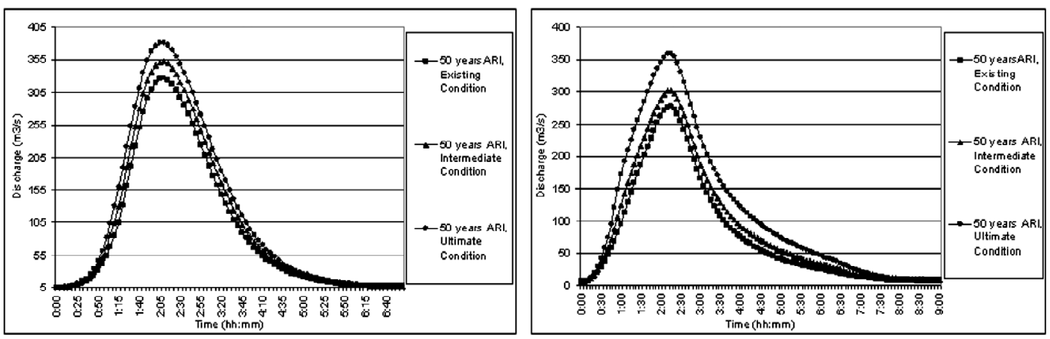


Figure 15: Simulated Runoff Hydrograph for Rainfall Events with 180 and 360 min Duration in Existing, Intermediate and Ultimate Development Condition with 50 Years ARI

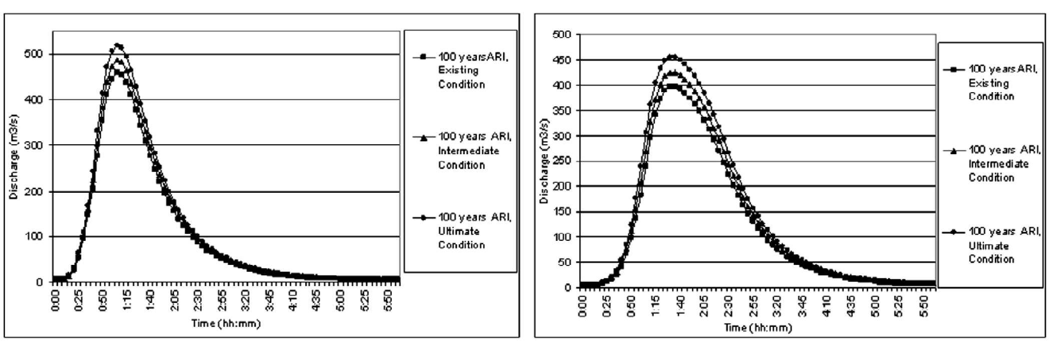


Figure 16: Simulated Runoff Hydrograph for Rainfall Events with 60 and 120 min Duration in Existing, Intermediate and Ultimate Development Condition with 100 Years ARI

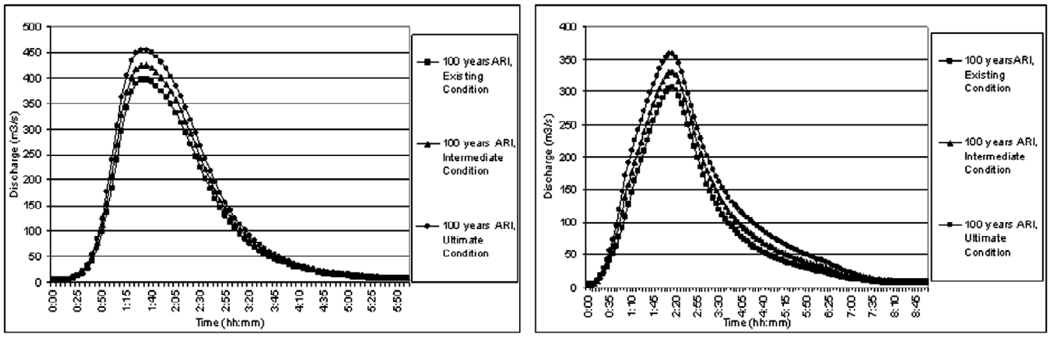


Figure 17: Simulated Runoff Hydrograph for Rainfall Events with 180 and 360 min Duration in Existing, Intermediate and Ultimate Development Condition with 100 Years ARI

9. CONCLUSIONS

Two main objectives of this research which were application of GIS in hydrological modelling and assessment of the effects of rainfall and river basin development conditions on hydrological response are achieved. According to the findings of this research, it can be concluded that HEC-GeoHMS can be readily employed as a reliable and accurate tool for extraction of input geometric data for HEC-HMS hydrological model. Alternatively, in terms of river basin hydrological response, it has been shown that the generated runoff volume and runoff peak discharge by HEC-HMS hydrological model is significantly sensitive to, imperviousness, initial discharge of recession method, peak flow coefficient, lag-time, hydraulic conductivity, moisture deficit and wetting front suction. The median of calibrated parameter values during calibration of hydrological modelling is more accurate for validation process. Moreover, river basin land-use development condition, magnitude and duration of rainfall reflect significant effects on the generated runoff hydrograph. For instance, an increase of river basin land-use development condition leads to increase of imperviousness of the river basin and an increase of the volume and peak discharge of the generated runoff hydrograph. An increase of magnitude of rainfall event (ARI), the volume and peak discharge of the generated runoff hydrograph increase significantly. Finally, increase of rainfall event duration leads to an increase of runoff hydrograph volume and a decrease of peak discharge.

ACKNOWLEDGMENT

This work was funded by University of Science Malaysia (USM) under Short-term Research Grant. The constructive comments of four anonymous reviewers are greatly appreciated and have helped improved the manuscripts.

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