STUDY OF RAINFALL-RUNOFF RELATIONSHIP USING HYDROLOGICAL MODELLING SYSTEM (HEC-HMS) FOR JOHOR RIVER, MALAYSIA

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Civil Engineering (Hons.)

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JULY 2014

ABSTRACT

This study focused more in flood estimation model for Johor River in Kota Tinggi watershed, Malaysia using HEC-HMS (Hydrological Modeling System). HEC-HMS is necessary tool for analyzing and simulating rainfall and runoff process. In this study, HEC-HMS version 3.5 is used to simulate stream flow for Johor River basin. Calibration and validation process were carried out using different sets of data. Data of precipitation and stream flow used in this study is from the period of January 2012 until December 2012. The precision of data used during calibration and validation process depend on parameter used in HEC-HMS. Results of simulation can be generated in summary table, hydrograph and time series table. Correlation coefficient R^2 and root mean square (RMSE) are used to measure the performance of the modeling. A model with the R^2 value is nearly to 1.0 and RMSE value is close to 0 is considered as good and satisfactory. During calibration process, value of RMSE for 1836402 station is 1.9 m^3/s while value of RMSE for 1737451 station 1.89 m^3/s. During validation process, value of RMSE for 1836402 station is 1.2 m^3/s while value of RMSE for 1737451 station is 1.69 m^3/s. The simulated model were fit with the observed data and show that the HEC-HMS are suitable model to predict the hydrologic changes in Johor River.

ABSTRAK

Kajian ini memberi tumpuan lebih kepada pemodelan anggaran banjir di Sungai Johor dalam kawasan tadahan air di Kota Tinggi, Malaysia dengan menggunakan HEC-HMS (Hydrological Modeling System). HEC-HMS adalah alatan penting yang digunakan untuk menganalisa dan membuat simulasi hujan dan proses larian air. Di dalam kajian ini, HEC-HMS versi 3.5 telah digunakan untuk membuat simulasi pergerakan air untuk kawasan tadahan Sungai Johor. Proses kalibrasi dan pengesahan telah dijalankan dengan mengguna set data yang berbeza. Data hujan dan pergerakkan air yang digunakan di dalam kajian ini diambil dari tempoh Januari 2012 sehingga Disember 2012. Ketepatan data yang digunakan semasa kalibrasi dan pengesahan proses bergantung kepada parameter yang digunakan dalam HEC-HMS. Keputusan simulasi ini boleh dilihat di dalam jadual ringkasan, hidrograf dan jadual siri masa. Pekali korelasi, R^2 dan punca kuasa dua (RMSE) adalah digunakan untuk mengukur prestasi pemodelan ini. Pemodelan dengan pekali korelasi yang menghampiri 1.0 dan punca kuasa dua yang menghampiri 0 adalah dianggap tepat dan memuaskan.Semasa proses kalibrasi dalam kajian ini, nilai punca kuasa dua adalah 1.9 m^3/s untuk stesen 1836402 manakala untuk stesen 1737451 adalah 1.89 m^3/s. Semasa proses pengesahan, nilai punca kuasa dua untuk stesen 1836402 adalah 1.2 m^3/s manakala untuk stesen 1737451 adalah 1.69 m^3/s. Simulasi pemodelan adalah tepat dengan data yang diperhatikan dan ianya menunjukkan bahawa HEC-HMS adalah pemodelan yang sesuai digunakan untuk meramal perubahan hidrologi di Sungai Johor.

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October 2012, (b) Sg. Johor Rantau Panjang 1737451 in
October 2012 (Validation stage)

LIST OF SYMBOLS

Q	Design discharge
C_u	Unit conversion coefficient
A	Watershed drainage area
i	Design rainfall intensity
C	Runoff coefficient (dimensionless)
t_l	Basin lag time
t_r	Effective rainfall duration
CP	UH peaking coefficient
C	Conversion constant (2.75 for SI)
A	Basin area
CN	Curve Number
A	Total watershed area
A_t	Cumulative watershed area
T_c	Time of concentration of watershed
RMSE	Root Mean Square Error
$X_{obs,i}$	Observed value
$X_{model,i}$	Simulated values at time/place
R^2	Correlation coefficient

LIST OF ABBREVIATIONS

CFS	Cubic feet per second
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
IDF	Intensity Duration Frequency
JPS	Jabatan Pengairan dan Saliran
SCS	Soil Conservation Service
SG	Sungai
UH	Unit Hydrograph
UNESCO	United Nations Educational, Scientific and Cultural Organization

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Basically, water can be defined as a chemical substance that is essential for the survival of all forms of living creatures. Without it, there would be no life on earth. There is about 70 to 75 percent of the earth is covered with water or about 1400 x 1015 m^3 quantity of water in the world. So, not impossible for human use large amount of water everyday and every time. According to analysis of Australian water usage, water commonly used for various purposes. For instance, human used them as direct consumption by households, food production such as cook for lunch and dinner, as a dish and drinks and other domestic purpose. (National Water Policy of Australia, 2006). Besides of domestic purpose, water also important to use in agriculture and industries. For example, human used them as an ingredient of product during production processes in industries.

Hydrology deals with the waters of the earth, their circulation, occurrence and distribution on the planet, their chemical and physical properties and their interactions with the physical and biological environment including their responses to human activity. Hydrology also discusses about a process that controls the fertility of the water and their disappearances from the surface of earth.

Hydrological cycle begins with passage of water from the atmosphere and stored in one of the following major reservoirs such as rivers, lakes, oceans, soils and glaciers. Hydrological cycle also describes the constant movement and endless recycling of water between the atmosphere, land surface and under the ground. Water moves from one storage to another by the ten physical processes like condensation, evaporation, runoff, precipitation, deposition, infiltration, transpiration, sublimation, melting and groundwater flow.

Basically, river flooding occurs because of the incidence of the heavy rainfall and the resultant large concentration of runoff, which can exceed the capacity of the river. Commonly, the major problem in Malaysia due to hydrological problem is flooding. Due to the flooding problem, there are many software have been created to analyze and stimulate rainfall and runoff process. In this research, I have gone through a new program which is Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to predict rainfall data and determined runoff process. By using this software, we can obtain the relationship between rainfall and runoff by producing a hydrograph.

Structure of the model, analysis of sensitivity, results obtained from the data and calibration and verification procedures are some of the parameter estimation in HEC-HMS hydrologic model. All of this parameter is selected to analyze the surface runoff from the watershed. Finally, the result of a simulation can be generated in summary table, time series table and hydrograph.

1.2 PROBLEM STATEMENT

Generally, in urban area, rainfall-runoff directly changes due to environment, season and also human behaviors. Flooding is one of the regular natural disasters due to this factor and flooding is becoming a common phenomenon nowadays in Malaysia especially Johor. Basically, river flooding occurs because of the incidence of the heavy rainfall and the resultant large concentration of runoff, which can exceed the capacity of the river. One of the rivers that contributes flood problem in the big city like Johor is Johor River.

Johor River has a watershed system that's not enough to cattle runoff capacity especially in Kota Tinggi due to urbanization. An increase in rainfall intensity will increase the peak discharge and volume of runoff for a given infiltration rate. So, modeling system (HEC-HMS) is designed to stimulate hydrological data and precipitation-runoff processes of watershed systems because it's commonly used in a wide range of areas. For example, small urban area, large river basin water supply or natural watershed runoff.

1.3 OBJECTIVES

This research is carried out to accomplish several objectives:

i) To analyze the rainfall-runoff relationship in Johor River using HEC-HMS.

ii) To determine the best method in HEC-HMS for analyzing the rainfall - runoff relationship in Johor River after calibration, validation and verification process.

iii) To predict discharge based on appropriate model using rainfall data.

1.4 SCOPE OF STUDY

Johor River is the case study in this research which is located in Kota Tinggi, Johor. Johor River is the main river of Johor and 122.7 km long with a catchment of 1126 km^2. It comes from Mount Gemuruh and flows in a north to south direction part of Johor and lastly into the Johor Strait. The shape of the catchment is irregular. The hydrology data are analyzed by using hydrological modeling like HEC-HMS that obtained from rainfall data and flow rate from the runoff. By analyzed this data using HEC-HMS, we can predict the discharge and determine the rainfall-runoff relationship for Johor River in certain period of time. The method used to analyze rainfall and runoff relationship in this case of study is Soil Conservation Service (SCS) Method.

1.5 SIGNIFICANCE OF STUDY

From this research, the rainfall-runoff relationship can be obtained using Hydrologic Modelling System (HEC-HMS). Besides that, SCS Method used during simulation in HEC-HMS can analyze the relationship between rainfall and runoff quickly. It is important to do this research because the data from this research is effective to use in order to solve and prevent flash flood and insufficient capacity of drainage problem.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROLOGY

According to UNESCO, 1964 hydrology deals with the waters of the earth, their circulation, occurrence and distribution on the planet, their chemical and physical properties and their interactions with the physical and biological environment including their responses to human activity. There are two parts of hydrology which are regional hydrology and global hydrology. The regional hydrology studies flow of water from precipitation such as rain and snowing to run off to sea in regional scale while global hydrology cover hydrologic cycle in global scale such as global evapotranspiration between sea and land.

2.1.1 Hydrologic Cycle

The hydrologic cycle is a conceptual model that describes the movement and storage of water between the atmosphere, lithosphere, biosphere and the hydrosphere (Hubbart, J., 2011). Hydrological cycle begins with passage of water from the atmosphere and stored in one of the following major reservoirs such as rivers, lakes, oceans, soils and glaciers. It slowly passes through the soil and rock layers underground. Hydrological cycle describes the constant movement and endless recycling of water between the atmosphere, land surface and under the ground (Danne, T. and L. B. Leopard, 1977).

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Water moves from one storage to another by the ten physical processes like condensation, evaporation, runoff, precipitation, deposition, infiltration, transpiration, sublimation, melting and groundwater flow (Hubbart, J., 2011). The hydrological cycle is shown in **Figure 2.1**.

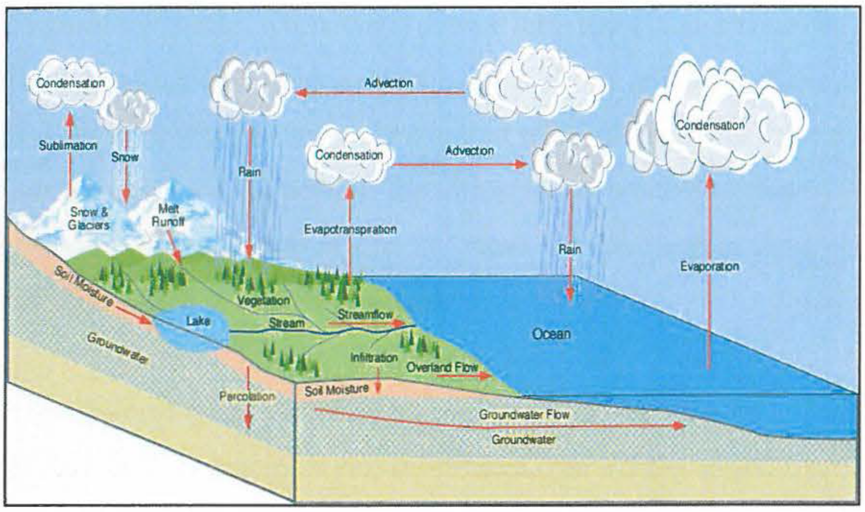

Figure 2.1 : Hydrological cycle

Source : Hubbart, J., 2011

The hydrological cycle begins with evaporation of water from the surface of reservoirs such as oceans, lake and rivers. It occurs when the physical state of water is changed from liquid state to a gaseous state. Evaporated moisture is lifted from land surfaces, ocean and water bodies as water vapor into the atmosphere. After moist air is lifted, it cools and water vapor condenses to form ice-crystal clouds. This process changes physical states of water vapor from vapor to liquid. Condensation in the hydrological cycle occurs when warm air looses its capacity to hold water vapor in the atmosphere.

After that, the moisture will undergo a precipitation process where the water drop or returns to the ground surface. Precipitation can be described as any solid aqueous deposit or liquid falls from cloud to ground surface from the atmosphere. (Chahine, M. T., 1992). In some case, if a rainfall drop in small quantity, high percentage of precipitation will return back to the atmosphere by evaporation process. Then when rates of precipitation increases, the runoff rates also increased. Runoff process includes groundwater flow and streamflow over the land surface and through reservoirs. Runoff made up from precipitation that falls directly on the stream.

Streamflow occur when water flows into lakes and stream in the low points of the landscape while groundwater flow above ground surface (Hubbart. J., 2011). The process where groundwater that released back into the atmosphere is called as transpiration. Generally, the transpiration process occurs by stems of plants or leaves. Transpiration affects by plants that are deep in the soil and the amount of light which plants are exposed.

Then, hydrological cycle has no beginning and also has no end start from the water that falls as precipitation, sublimates, run off the ground surface and soaks into the ground as infiltration where it refers to the movement of water into the soil layer (Pidwirny, M., 2011).

2.1.2 Hydrological Characteristics

Hydrological characteristic refer to rainfall distribution, runoff distribution and peak discharge at a particular location along the course of river or stream (Sudmeyer, R.A., 2004). One of the important graph to determine hydrological characteristic of the river or stream is hydrograph. Annual hydrograph can predict the changes in the flow of water over the year at a certain location (RAMP, 2007). It shows all variations of the flow and periods of high and low flows while hydrometric data refer to data collection of that flow.

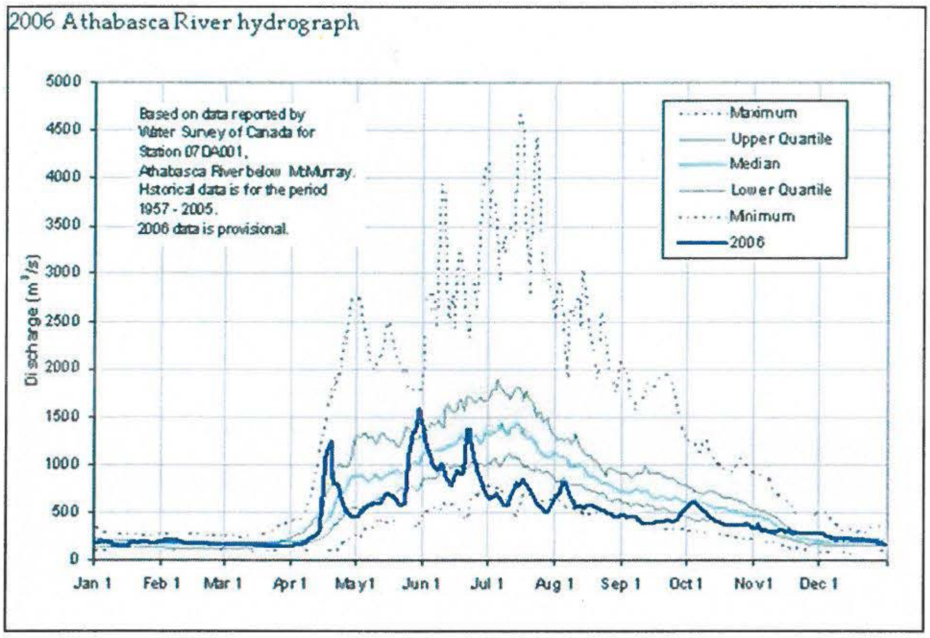

Figure 2.2 : Example of a hydrograph for Athabasca River

Source : RAMP, 2007

There are three important parts of hydrograph which are crest segment (peak flow), rising limb and falling limb (recession curve). These parts are measured at a specific point in certain river and typically time variation (Strandhagen et al., 2006). Rising limb represents the increasing of stream flow rate while peak flow shows the maximum flow rate that occur and falling limb is where the stream flow rate is decreasing.

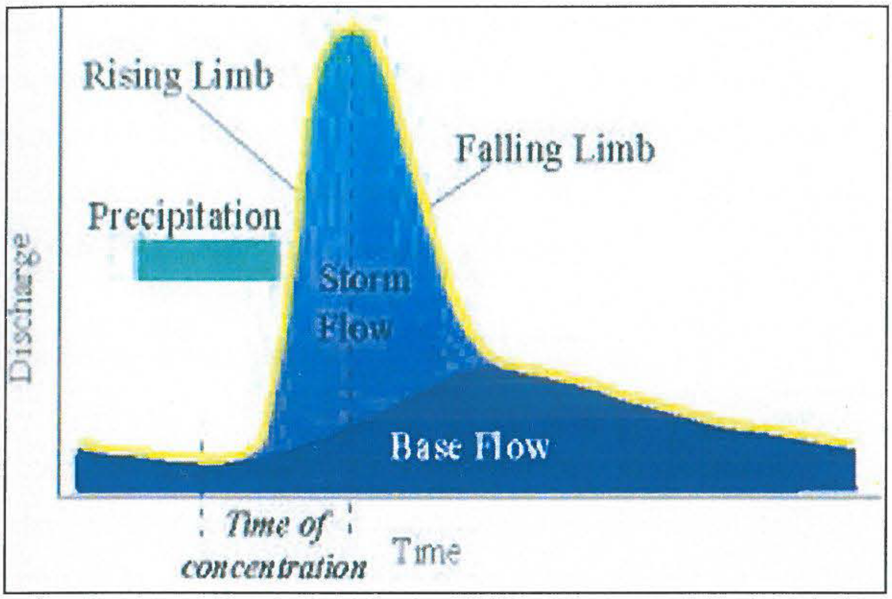

Figure 2.3 : Characteristic of hydrograph

Some of the hydrological indicators used in hydrological characteristic include discharge, maximum flow, minimum flow and median flow. Overall, hydrological characteristic deals with quantitative aspect of the hydrological cycle as well as particular space-time variation of hydrological elements (T.A Mahon, 1982).

2.2 RAINFALL

2.2.1 Rainfall Characteristic

2.2.1.1 Type of Rainfall

There are three types of rainfall which is conventional rainfall, frontal rainfall and relief rainfall. All of the type has the common process of precipitating. Convention rainfall occurs in areas where the ground warms up, it heats the air above it. (J. Sohn, 2013). The air will rise, start to condense and finally rain will fall. This type of rainfall very commons in summer month of tropical areas. Besides, frontal rainfall happens when warm and cold air masses meet together and form a front. Warm air is forced to rise and cools in contact with cold air along the fronts. So, the formation of clouds happens after condensation and rain fall. Lastly, relief rainfall or known as orographic rainfall very commons in mountain or hill area. It occurs when prevailing winds pick up warm and moist air to rise in high area. (J. Sohn, 2013). So, the formation of clouds occurs after condensation and rain is formed.

2.2.1.2 Intensity of Rainfall

Rainfall intensity is defined as the amount of rain that falls over time in millimeters per hour (mm/h). (Gabaldo Sancho et al., 2008). Intensity of rain can be determined by measuring height of water layer covering the land with them. High and low of intensity depends on local circumstance. For example, flash flood comes from the high intensity of rainfall on steep slopes as shown in the diagram below.

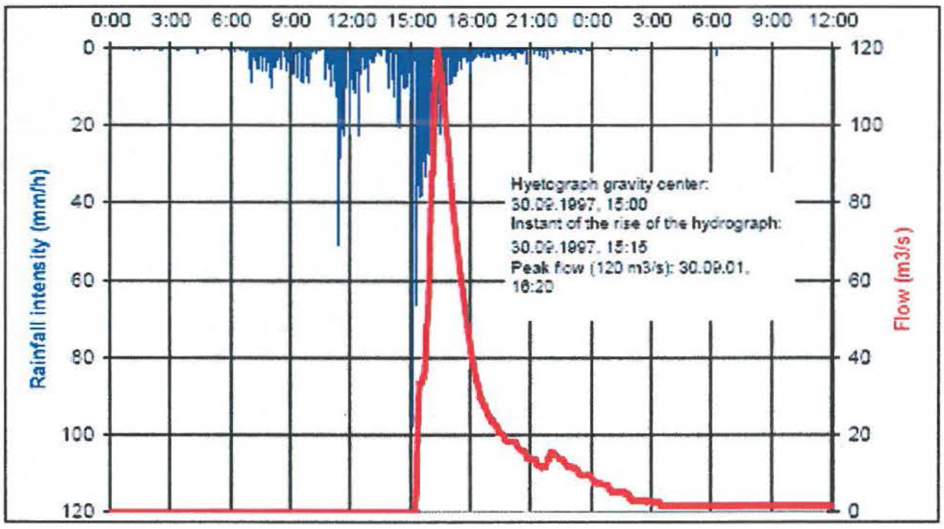

Figure 2.4 : A diagram showing flash flood and rainfall intensity in Spain

2.2.1.3 Duration of Rainfall

Duration of rainfall commonly related to rainfall intensity. According to Glossary of Meteorology, 2009, the intensity of rainfall usually predicted for any return period and rainfall intensity. The relationship of intensity-duration-frequency (IDF) also is one of the common tools used for planning, operating and design in water resources projects. (H. Ibrahim, 2011).

2.2.1.4 Distribution of Rainfall

Rainfall distribution is a various pattern of falling rain in a country. (G.K Voigt, 1960). There is great temporal and regional variation in the distribution of rainfall. For example, monsoons can affect the amount of rainfall in a country. Besides, there are some factors in controlling the distribution of rainfall such as ocean currents, air temperature and mountain ranges. (The Columbia Electronic Encyclopedia, 2012). Distribution of rainfall also expressed as distribution coefficient.

2.3 RUNOFF

2.3.1 Source of Runoff

Generally, runoff comes from two sources which is human activity and natural processes while surface runoff can be refer as water flow when soil is absorbed to full capacity and excess water from snowmelt, rain or other sources flows above the ground. After analyzing the data collected, it shows that storm runoff originated from a small portion of the total drainage area. The extent and location of the source area are dependent on antecedent moisture, rainfall intensity and depth of soil. (P. Betson et al., 2010).

Source of runoff can be divided into two which is coming from human activity or natural processes. Runoff that comes from natural processes occurs naturally as soil. It acts as a soil and carried to various bodies of water. The picture of natural process as shown in the diagram below.