STUDY OF RAINFALL-RUNOFF RELATIONSHIP USING HYDROLOGIC MODELING SYSTEM (HEC-HMS) FOR LIPIS RIVER

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ABSTRACT

In this study, Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) is used to determine the rainfall-runoff relationship of Lipis River, Pahang. HEC-HMS is software for use in analyzing, planning, and simulating the process of rainfall and runoff. HEC-HMS 4.0 is used in this study to simulate discharge for Lipis River. This study uses rainfall data and stream flow data from January 2008 to December 2014. The data needed is from eleven rainfall stations and one stream flow station in Lipis River catchment area. The analysis result of the data is depends on the parameter used in HEC-HMS. The parameters include time of concentration, storage coefficient, and lag time. The results of simulation can be generated in form of hydrograph, summary table, and time series table. Correlation coefficient, R^2 is used to show the relationship of the simulated flow and the observed flow. If the correlation coefficient is close to 1.0, it would indicate that the variables are positively linear related. During evaluation of model, the best value of correlation coefficient is 0.7943 which nearly to 1.0. It shows that the simulated models were fit with the observed data and proves that the HEC-HMS is suitable to predict and analyze rainfall-runoff relationship in Lipis River.

ABSTRAK

Dalam kajian ini, Hydrological Modeling System (HEC-HMS) digunakan untuk menentukan hubungan hujan dan proses larian air di Sungai Lipis, Pahang. HEC-HMS merupakan satu perisian yang digunakan untuk menganalisis, merancang, dan mensimulasi proses hujan dan larian air. HEC-HMS 4.0 digunakan dalam kajian ini untuk menjalankan simulasi pergerakan air untuk Sungai Lipis. Kajian ini menggunakan data air hujan dan aliran sungai dari Januari 2008 hingga Disember 2014. Data yang diperlukan adalah dari sebelas stesen air hujan dan satu stesen aliran sungai di kawasan tadahan Sungai Lipis. Keputusan analisis data bergantung kepada parameter yang digunakan dalam HEC-HMS. Parameter tersebut termasuklah masa penumpuan, pekali simpanan, dan masa susulan. Keputusan simulasi boleh dihasilkan dalam bentuk hidrograf, jadual ringkasan, dan jadual siri masa. Pekali korelasi, R^2 digunakan untuk menunjukkan hubungan aliran tersimulasi dan aliran diperhatikan. Jika pekali korelasi menghampiri 1.0, ianya menunjukkan bahawa keputusan analisis yang diperolehi ialah sangat baik. Semasa penilaian model Sungai Lipis ini, nilai terbaik pekali korelasi ialah 0.7943, yang mana nilai itu hampir kepada 1.0. Ianya menunjukkan bahawa model tersimulasi hampir selari dengan data diperhatikan. Ianya juga membuktikan bahawa HEC-HMS ialah perisian yang sesuai untuk meramal analisis hubungan proses hujan dan larian air di Sungai Lipis.

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LIST OF SYMBOLS

Q_p	Peak discharge
C	Runoff coefficient
I	Rainfall intensity
A	Catchment area
Q	Runoff
P	Peak discharge
C	Cumulative rainfall
I_a	Initial abstraction
S	Maximum soil water storage potential
L	Lag
a_x	Incremental of watershed area
Q_x	Runoff from area a_x
T_{tx}	Travel time from the centroid of a_x to the references point
T_c	Time of concentration
R^2	Correlation coefficient

LIST OF ABBREVIATIONS

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

Earth’s atmosphere, oceans, ice masses, lakes, rivers, streams, and soil contain more than 50 billion cubic feet of water. In spite of this abundance, problems are created by too much or too little water at a given location. For example, people living in southern California and other areas of the arid southwest show concern over the lack of an inexpensive source of water supply. Problems also result from variations in the time distribution of water. An overabundance of water at one time or an undersupply at other time can have serious consequences to both agriculture and manufacturing and can inconvenience the public.

Occasional flooding is a problem to homeowners and to entire cities. Crops do not grow at the optimum rate when soil is either too wet or too dry. Manufacturing operations require a constant water supply over time for a variety of purposes, such as to provide cooling water and to assimilate wastes. Thus, although earth’s total volume of water may be adequate meet all needs, problems are created by variations in both the spatial and temporal distributions of water availability. Extreme problems, including life-threatening situations, can result from extreme variations in either the spatial or temporal distribution of water, or both.

In an attempt to overcome the problems created by these variations in the temporal and spatial variations in water availability, engineers and hydrologists attempt to predict water availability. These predictions are used in the evaluation of alternative means of preventing or solving problems. A number of factors contribute to the ineffectiveness of these engineering designs.

First, the occurrence of rainfall cannot be predicted with certainty. It is not possible to predict exactly how much rain will occur in one time period, for example a day, month, or year. The uncertainty of extreme variation in rainfall amounts is even greater than the uncertainty in the rainfall volumes occurring in the more frequent storm events. Second, even if we had perfect information, the cost of all of the worthwhile projects needed to provide the optimum availability of water is still prohibitive. Therefore, only the most efficient and necessary projects can be constructed. Third, hydrologic processes such as rainfall and runoff are very complex, and a complete, unified theory of hydrology does not exist. Therefore, measurements of observed occurrences are used to supplement the scant theoretical understanding of hydrologic process that exists.

In Malaysia, the major problem due to hydrological problem is flooding. A flood is an unusually high stage in a river, normally the level at which the river overflows its bank and inundates the adjoining area. Flooding happens due to heavy rainfall and rivers do not have the capacity to convey excess water. Besides that, it can occur due to dam failure and results in flooding of the downstream area, even in dry weather conditions.

Due to this problem, there are numbers of software which are designed to analyze rainfall and runoff process. One of them is Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) which is used to predict rainfall data and to determine runoff process. The parameter estimations in HEC-HMS hydrologic model are structure of the model, analysis of sensitivity, results obtained from the data and calibration and verification procedures. By using HEC-HMS hydrologic model, the rainfall-runoff relationship can be obtained by producing a hydrograph.

The hydrograph of extreme floods and stages corresponding to flood peaks provide valuable data for purposes of hydrologic design. Further of the various characteristics of the flood hydrograph, probably the most important and widely used parameter is the flood peak. At a given location in stream, flood peaks vary from year to year and their magnitude constitutes a hydrologic series which enable to assign a frequency to a given flood-peak value.

1.2 PROBLEM STATEMENT

A common phenomenon happens in Malaysia is flooding. This phenomenon is due to the heavy rainfall and the limited capacity of the river to convey runoff. Flooding can occurs in river when the flow rate exceeds the capacity of river channel. The damages caused by floods in terms of loss of life, property, and economic loss due to disruption of economic activity are all too well known. Thousands of money are spent every year in flood control and flood forecasting. Lipis River which is located in Kuala Lipis, Pahang is one of the rivers which can contribute to this problem.

The peak discharge and volume of runoff for a given infiltration rate will increase with the increases of rainfall intensity. To overcome this problem, HEC-HMS is used to analyze the hydrologic process and to determine the rainfall-runoff process of Lipis River. The software includes hydrologic analysis procedures such as infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapotranspiration, snowmelt, and soil moisture accounting.

1.3 OBJECTIVES

The objectives of this research are:

1. To determine and analyze the rainfall-runoff relationship in Lipis River using HEC-HMS.
2. To apply Clark's Unit Hydrograph method for determining the rainfall-runoff relationship in Lipis River.
3. To analyze discharge based on rainfall data.

1.4 SCOPE OF STUDY

Lipis River is the case study in this research. It is located in Kuala Lipis, Pahang. Lipis River has a catchment area of 2065.1 km^2. Basically, Lipis River is connected to Pahang River which is the longest river in Peninsular Malaysia. Pahang River comprises almost all districts in Pahang, including Lipis, Jerantut, and Pekan. Lipis River begins at Pahang and Perak state border, and ends at the confluence of Jelai River and Lipis River at Kuala Lipis. The shape of the catchment is irregular. The hydrology data which is rainfall data and stream flow data are analyzed by using hydrological modeling HEC-HMS. By using this software, the discharge and the rainfall-runoff relationship of Lipis River in certain period of time can be determined.

1.5 SIGNIFICANCE OF STUDY

This study is conducted to analyze the rainfall-runoff relationship for Lipis River by using HEC-HMS. The data collected can be used to prevent flash flood and insufficient capacity of drainage problem in Lipis River area. Therefore, the damages caused by floods in terms of loss of life, property, and economic loss due to disruption of economic activity can be reduced.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROLOGY

Hydrology deals with the origin, distribution, and circulation of water in different forms in land phases and atmosphere. According to Northwest River Forecast Center, hydrology is also a broad science that utilizes information from a wide range of other sciences and integrates them to quantify the movement of water. Therefore, it is one of the interdisciplinary sciences that are the basis for water resources management and water resources development.

Broadly, hydrology is classified into two groups which are scientific hydrology and engineering or applied hydrology. The scientific hydrology is concern mainly with academic aspect whereas the engineering or applied hydrology is a study concern with engineering applications. It includes estimation of water resources, study of transmission process such as precipitation, evaporation, runoff, and their interdependence, understanding the properties of water in nature, and dealing with natural problems such as droughts and floods.

2.1.1 Hydrologic Cycle

Hydrological cycle is a continuous process without any beginning or end. It can be defined as the sequence of cyclic events which correlates the movement of water from the atmosphere to the earth’s surface and then to the large water bodies through surface and subsurface routes and finally going back to the atmosphere. Besides that, a hydrologic cycle undergoes the complicated process of precipitation, interception, evaporation, transpiration, infiltration, percolation, runoff, and various storages. For precipitation, it consists of rainfall and snowfall. The quality of precipitation estimates from the re-analyses strongly depends on the geographic location, as there are significant differences especially in tropical regions. The closure of the water cycle in the three re-analyses is analyzed by estimating long-term mean values for precipitation, evapotranspiration, surface runoff, and moisture flux divergence (Lorenz and Kunstmann, 2012).

Figure 2.1 is a schematic representation of the hydrological cycle for a natural environment.

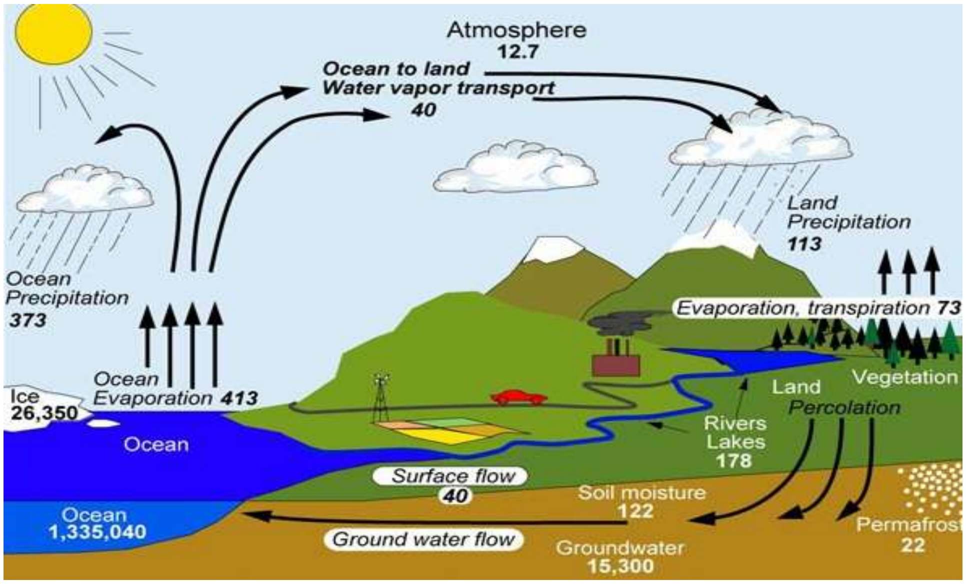

Figure 2.1: Hydrological cycle

Source: Trenberth et al. 2007

The hydrological cycle is a water changing phase, from liquid to solid to gas and back to liquid as it moves through the earth system (Trenberth et al., 2007). The starting point of the cycle is in the oceans. Due to the heat energy, water in the oceans evaporate and moves upwards to form clouds. As the clouds condense, it falls back to oceans as rain. Rain falling on earth may enter a water body directly, travel over the land surface from the point of impact to a watercourse, or infiltrate into the ground. Some rain is intercepted by vegetation which means the intercepted water is temporarily stored on the vegetation until it evaporates back to the atmosphere. Some rain is stored in surface depressions with almost all of the depression storage infiltrating into the ground.

Precipitation over land may be stored temporarily as snow or soil moisture while excess rainfall runoff which discharges the water into the ocean, or infiltrates into the soil aquifers thereby completing the hydrological cycle (Trenberth et al., 2007). The water that infiltrates into the ground may percolate to the water table or travel in the unsaturated zone until it reappears as surface flow. The amount of water stored in the soil determines the amount of rain that will infiltrate during the next storm event. Water stored in lakes, seas, and oceans evaporates back to atmosphere. Therefore, it completes the cycle and is available for rainfall.

2.2 RAINFALL

Precipitation is a part of atmospheric moisture which reaches the earth’s surface in different forms. Some of the precipitation that might get intercepted while reaching the ground by trees and buildings and evaporates back is called the initial loss. The other part meets requirements like depression storage and infiltrates into the ground. The excess rainfall flows in streams to large water bodies. Factors like type of soil, vegetation, geology, and topography of area largely determine the quantity of rainfall excess available as stream flow from the precipitable water. One-fourth of the total precipitation that falls on land reaches large water bodies as direct runoff. The balance three-fourths of water returns back to the atmosphere as evaporation (Patra, 2001).

2.2.1 Forms of Precipitation

Common forms of precipitation are rain, snow, drizzle, and sleet. Rain is the precipitations in the form of droplets of water that reaches the surface of earth. The sizes of drops vary from 0.5 mm to 6.0 mm as drops larger than this size are found to breakup during their fall in the air. Rain is considered as light if intensity of rainfall is up to 2.5 mm/h, moderate from 2.5 mm/h to 7.5 mm/h and heavy over 7.5 mm/h (Patra. 2001).

As for snow, it is the precipitation in the form of ice-crystals and normally hexagonal in shape. Snow reaches the earth's surface either separately or combines together to form flakes. The density of snow usually 0.10 g/cm^3 which means that 10 cm of snowfall is equivalent to 1.0 cm of rainfall. The other form of precipitation is drizzle. It can be defined as water droplets of size less than 0.5 mm and reaches the ground with intensity less than 1.00 mm/h. These water droplets are so light that they appear to be floating in air. As for sleet, it is the grains of ice that formed when rain falls through air of subfreezing temperature. The rain drops under this circumstance are half frozen. **Figure 2.2** shows the form of precipitation.

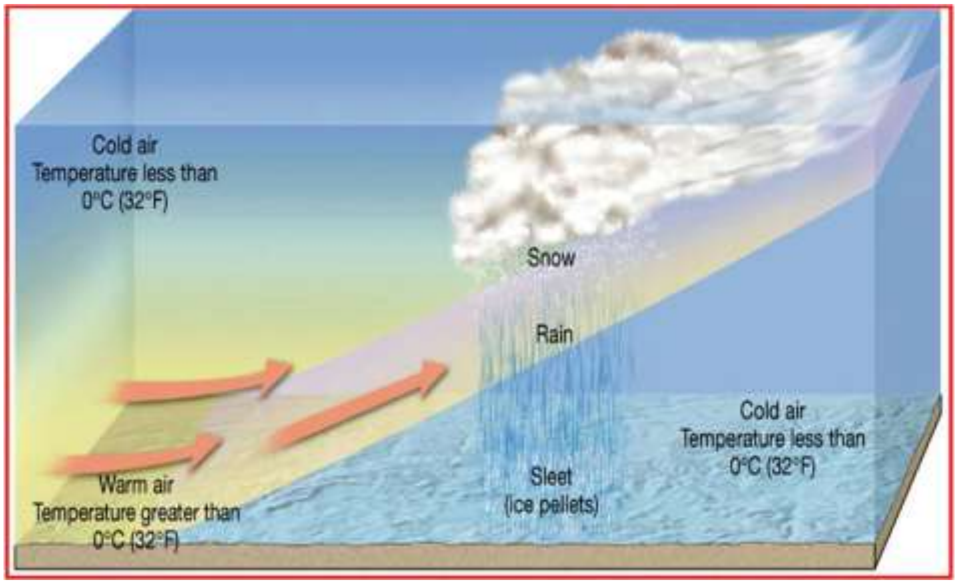

Figure 2.2: The forms of precipitation

Source: Trail Blazer

2.2.2 Types of Rainfall

Analysis of rainfall trends is important in studying the impacts of climate change for water resources planning and management (Haigh, 2004).There are three common types of rainfall which are convectional rainfall, orographic rainfall, and cyclonic rainfall. Convectional rainfall, as shown in **Figure 2.3,** occurs due to the unequal heating at the surface of earth. In summer days, air in contact with surface of the earth gets heated up, expands, and rise due to lesser density. Due to the condition, surrounding air rushes to replace it and in turn gets heated up and rises (Patra, 2001). After that, the air achieves condensation level where the water vapor condenses and turns back to liquid form. This process leads to the clouds formation. When the clouds are heavy enough, the water droplets can eventually lead to rainfall.

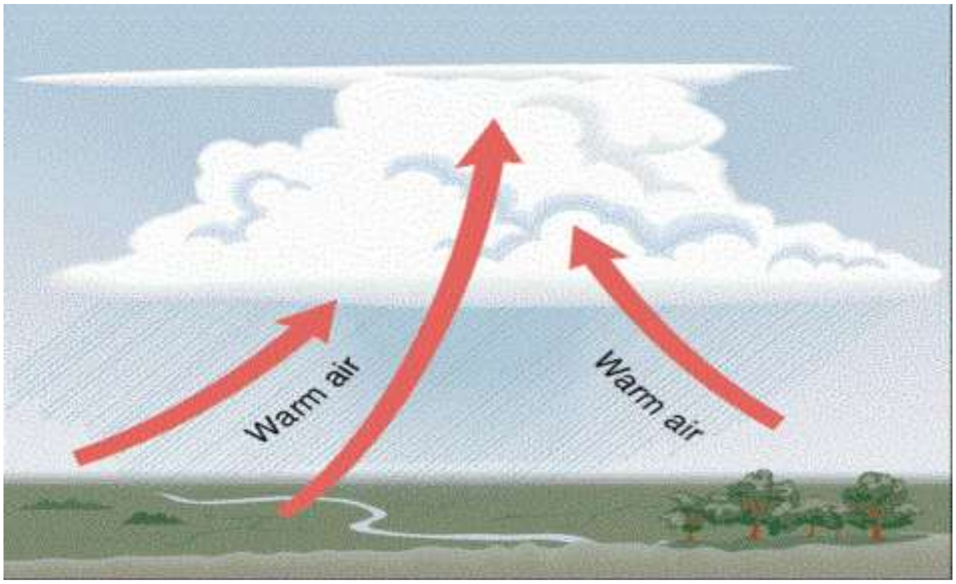

Figure 2.3: Convectional rainfall

Source: University of Washington Web Server

The other type of rainfall is orographic rainfall. Also known as mountain-range barrier, it causes lifting of the air masses. Dynamic cooling takes place causing precipitation on the side of blowing wind as shown in **Figure 2.4**. Precipitation is normally heavier on the windward side and lighter on leeward side. In India, heavy precipitation in Himalayan region and at the western coast are mainly due to orographic features associated with the south west wind carrying sufficient quantity moisture, while passing over Arabian sea. Orographic precipitation gives medium to high intensity rainfall and continues for longer duration (Patra, 2001).

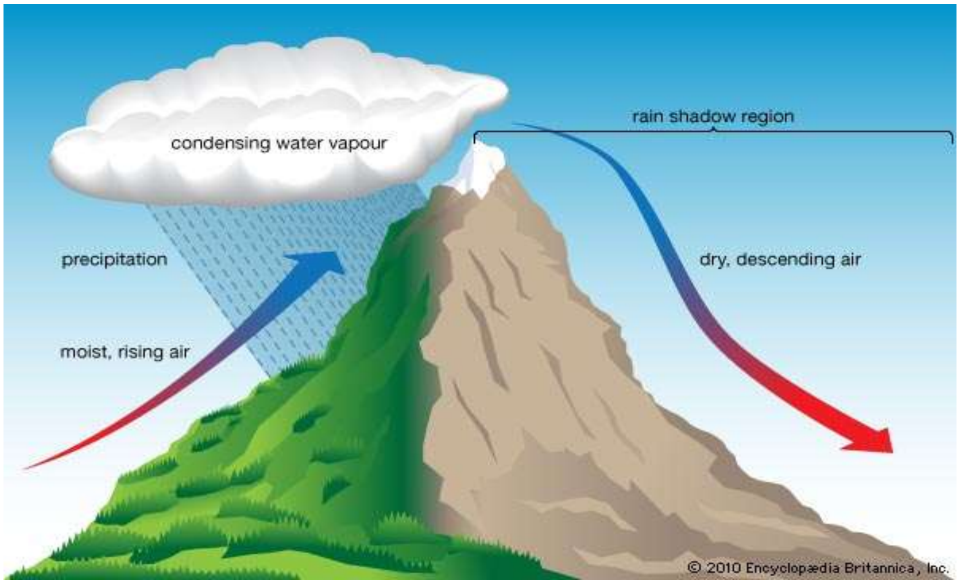

Figure 2.4: Process of orographic rainfall

Source: Encyclopedia Britannica

Another type of rainfall is cyclonic rainfall or also known as frontal rainfall. It is a condition when warm air mass meets with cool air mass. During the process, cool air mass can condense the moisture into clouds if the warm air mass and cool air mass meet as shown in **Figure 2.5**. The cool air tends to be heavy and sink towards the earth’s surface while the warm air tends to be more buoyant and rise to atmosphere. When a cool air mass charges into warm air mass, it pushes the already buoyant rising warm air even faster and higher into the air to heights where it is even cooler. Due to that condition, dark clouds are produced, and often thunder and lightning, intense rain, and hail. When a warm air mass charges into a cool air mass, it rides over the cool air because the cool air naturally sinks and warm air rises. This produces the long, gentle rain and showers that can go on for days. Because the warm, moist air is not being pushed to higher elevations and the clouds remain low.

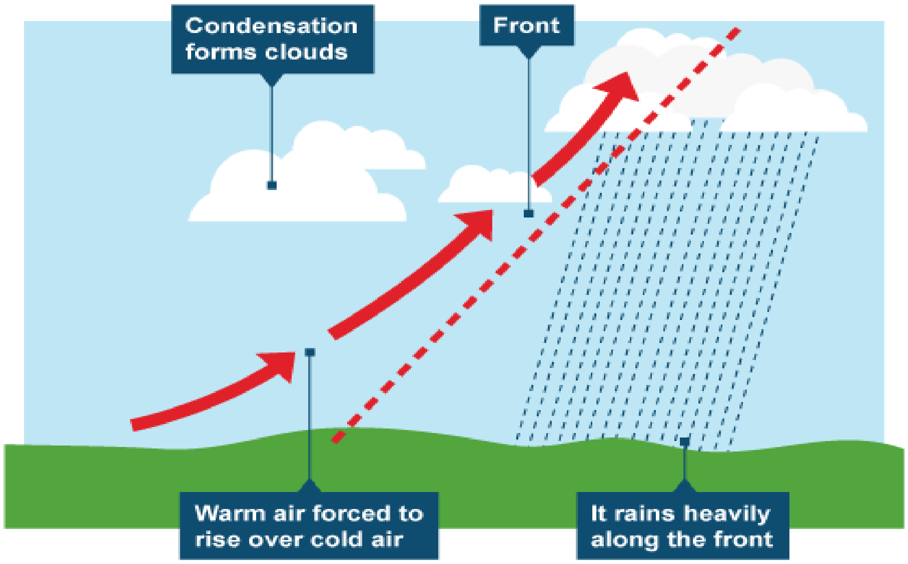

Figure 2.5: Process of cyclonic rainfall

Source: BBC

2.2.3 Intensity-Duration-Frequency of Rainfall

Intensity-duration-frequency (IDF) relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for planning, design, and operation of water resources projects (Elsebaie, 2012). Because of the importance of the IDF relationship in hydrologic analyses, IDF curves have been compiled for most localities. Besides that, the curve is most often used by entering with the duration and frequency to find the intensity. The IDF curve could also be used to find the frequency for a measured storm event. The predicted frequency is determined by finding the interception of the lines defined by the measured intensity and the storm duration. If the depth rather than the intensity measured, the intensity must be determined prior to determining the frequency. **Figure 2.6** shows the relationship between rainfall intensity, duration, and frequency.

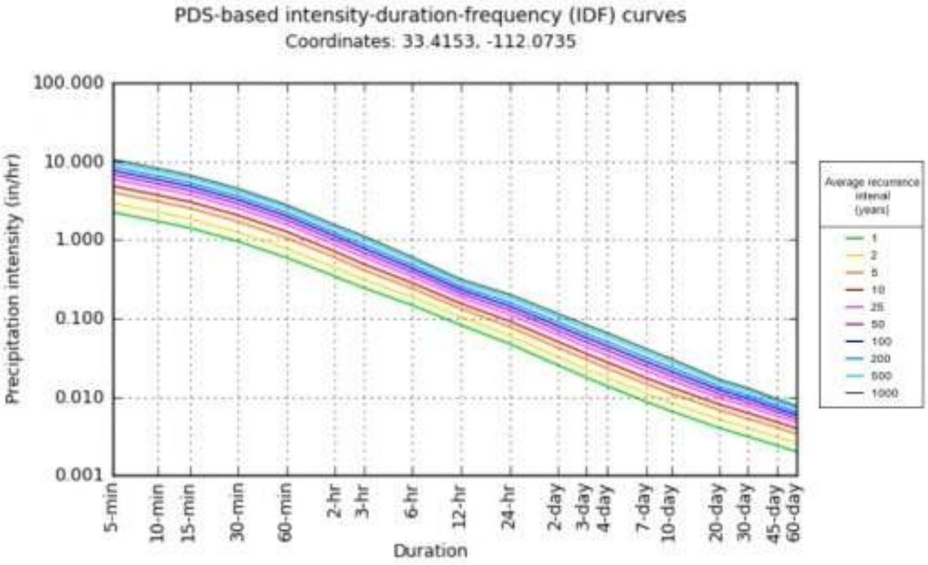

Figure 2.6: Relationship between rainfall intensity, duration, and frequency

Source: Precipitation Frequency Data Server

2.3 RUNOFF

In hydrology, runoff can be defined as the quantity of water discharged in surface streams. It includes not only the waters that travel over the land surface and through channels to reach a stream or river, but also interflow. Interflow is the water that infiltrates the soil surface and travel by means of gravity toward a stream channel. Other than that, runoff also includes groundwater that discharged into a stream (Encyclopedia Britannica). Based on the time delay between the precipitation and the runoff, the runoff is classified into two categories. The two categories are direct runoff and base flow.

According to Water Resources Authority, direct runoff is defined as the sum of overland flow and interflow. Direct runoff reaches the stream shortly after it falls as rain and is discharged from the basin within one or two days. The other category which is base flow is the sustained flow in a stream that comes from groundwater discharge or seepage. Groundwater flows underground until the water table intersects the land surface and the flowing water becomes surface water in the form of springs, streams, lakes, and wetlands. Base flow is the continual contribution of groundwater to rivers and is important source of flow between rainstorms. Groundwater continues to discharge as base flow because of the new recharge of rainwater in the landscape.

2.3.1 Runoff Characteristics of Streams

There are three classes of stream which are perennial, intermittent, and ephemeral as shown in **Figure 2.7**.

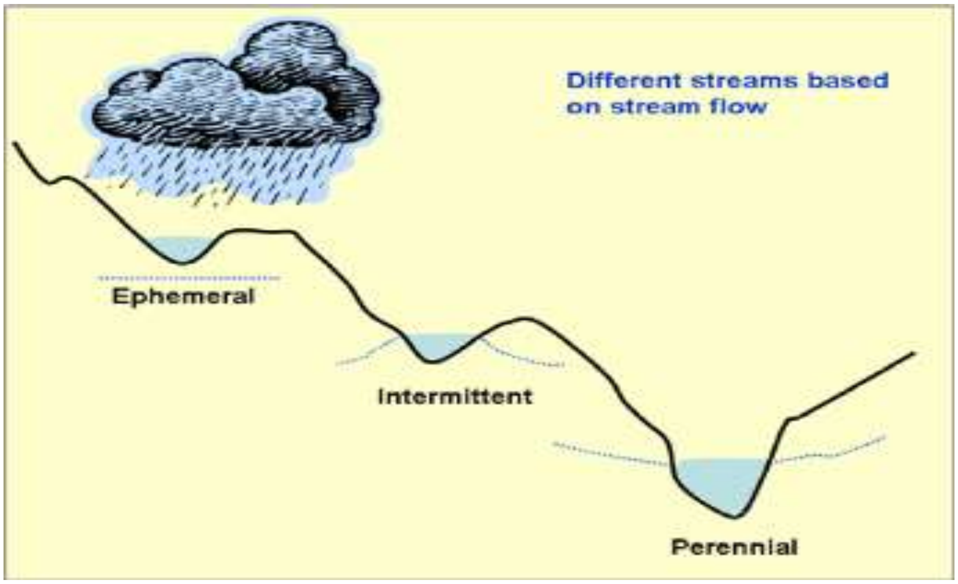

Figure 2.7: Ephemeral, intermittent, and perennial streams

Source: Zaimes and Emanuel 2006