RAINFALL RUNOFF SIMULATION USING SLOPE ADJUSTED CURVE NUMBER IN KUANTAN RIVER BASIN

AMIR AIZAT BIN JAMIL

Bachelor of Engineering (Hons) in Civil Engineering

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AMIR AIZAT BIN JAMIL

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ABSTRACT

The Natural Resources Conservation Service Curve Number (NRCS-CN) method is widely used for predicting direct runoff from rainfall. It believed that NRCS-CN has developed in an agricultural land with slope less than 5%, therefore it do not consider the effect of slope in the hilly and mountainous watersheds. Some researchers have investigated the effect of terrain slope on CN estimation. But on research can be found for assessment of slope on modified CN value and it is always a problem to find suitable source of elevation data to create slope map. It is significant that this is the first report on adjustment of Cell-based CN to determine the slope adjustment for CN using Sharply-Williams integrated with ASTER-GDEM. The adjusted CN was then tested for 25 observation rainfall runoff data. New slope adjusted CN demonstrate significant improvement from 0.12 to 0.39 in runoff estimation. This methodology can be carried out in different climate condition to get more inside CN for runoff estimation.

ABSTRAK

Sumber Asli Pemuliharaan Perkhidmatan Curve Number (NRCS-CN) kaedah yang digunakan secara meluas untuk meramalkan air larian terus dari hujan. Ia percaya bahawa NRCS-CN telah dibangunkan di tanah pertanian dengan cerun kurang daripada 5%, oleh itu ia tidak menganggap kesan cerun di kawasan tadahan air bukit dan pergunungan. Sesetengah penyelidik telah menjalankan kajian kesan kawasan cerun di CN anggaran. Tetapi penyelidikan boleh didapati untuk penilaian cerun pada nilai CN diubahsuai dan ia sentiasa masalah untuk mencari sumber sesuai data ketinggian untuk mewujudkan peta cerun. Adalah penting bahawa ini adalah laporan pertama mengenai pelarasan berdasarkan Cell-CN untuk menentukan pelarasan cerun untuk CN menggunakan Sharpley-Williams disepadukan dengan ASTER-GDEM. CN diselaraskan kemudiannya diuji untuk 25 pemerhatian data air larian hujan. Cerun baru diselaraskan CN menunjukkan peningkatan yang ketara 0,12-0,39 dalam anggaran air larian. Metodologi ini boleh dilakukan dalam keadaan iklim yang berbeza untuk mendapatkan lebih banyak di dalam CN untuk anggaran air larian.

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LIST OF ABBREVIATIONS

AMC	Antecedent Moisture Condition
ASTER	Advanced Space-borne Thermal Emission and Reflection
CN	Curve Number
DID	Department of Irrigation and Drainage
GDEM	Global Digital Elevation Models
GIS	Geographical Information System
HEC-HMS	Hydrological Modeling System
HSG	Hydrologic Soil Group
ILWIS	Integrated Land and Water Information System
KRB	Kuantan River Basin
LU	Land Use
NAHRIM	National Hydraulic Research Institute of Malaysia
NASA	National Aeronautics and Space Administration
NRCS-CN	Natural Resources Conservation Service Curve Number
SACN	Slope Adjusted Curve Number
SCS	Soil Conservation Service
SCS-CN	Soil Conservation Service Curve Number
TR55	Technical Release 55

CHAPTER 1

INTRODUCTION

1.1. Background

The rainfall runoff is a complex and non-linear hydrological process with high variability in time and space. Accurate estimation of runoff is critical in urban hydrology, because that is the design base for water resources infrastructures and flood peak discharge. Several methods is used to estimate flood runoff including statistical analysis, empirical equations, frequency analysis, unit hydrograph and so on. Soil Conservation Service Curve Number (SCS-CN) methods is empirical equation which have been widely used in different studies.

The SCS-CN method which is now called Natural Resources Conservation Service Curve Number (NRCS-CN) since 2001, has presented in 1954 by the USDA (Rallison 1980); and revisions has made in 1956, 1964, 1965, 1971, 1972, 1985, 1993 (Ponce and Hawkins 1996).The CN is an empirical parameter used for predicting direct runoff or infiltration from rainfall excess (USDA, 1986, Mahdavi, 2005, Alizadeh, 2006). Regardless of some weaknesses, the CN method presents some advantages such as quantification of the effect of landuse changes on runoff formation (Rietz and Hawkins 2000). The widespread popularity of the NRCS-CN method attributes to the wide availability of the required data and its simplicity.

As result, the NRCS-CN method which originally intended for the study of agricultural land, became a fundamental part of hydrological practice and was adopted for application in different climate and conditions (Miliani et al., 2010). Moreover the CN method has been integrated into several hydrologic models, including CREAMS (Knisel, 1980), FEST (Montaldo et al., 2007, Rabuffetti et al., 2008), EPIC (Sharpley and Williams, 1990), AGNPS (Young et al., 1989), HEC-HMS (Feldman, 2000) and SWAT (Neitsch et al., 2005).

There are many research articles and classical books in supporting and criticizing the CN method. Among them the works of Hawkins (1978, 1993), Hawkins et al. (2009), Huang et al. (2006, 2007), Garen and Moore (2005), Mishra et al. (2003, 2006) and Michel et al. (2005) are more remarkable. Review of literature shows that considerable attempted has been made for adjustment and adaptation of CN method for unaccented factors including drainage area (Simanton and Sutter, 1973, Simanton et al., 1996), soil moisture proxies (Ponce and Hawkins, 1996, Garen and Moore, 2005, Beck et al., 2009), slope (Sharpley and Williams, 1990, Huang et al., 2006) and more recently Kakuturu et al. (2013) investigated the effect of slope on estimation of CN values.

In general CN can be considered as indicator which classifies the land parcels in terms of runoff generation capacity based on their usage and storage capacity. In highly flood affected watershed, it is very useful to identify the spatial variation of runoff potential in order to implement flood mitigation projects effectively. The main objective of this research is to develop a methodology for derivation of flood runoff susceptibility map based on the modified SCS-CN.

1.2. Problem Statement

Nowadays there are many area had been fully developed with huge buildings, factory and shopping mall. Rainfall will infiltrate the more in an undeveloped area (pervious) compared to developed area (impervious). As a result, if a very large amount of rainfall in a developed area, only a little of the amount will infiltrate into the soil and the rest of them will flow to the lower level of the ground as runoff. When the quantity of the runoff is increasing and filled all the drainage and river, flood will then occur. To prevent the occurring of the flash flood, we need to determine the rainfall-runoff relationship. Flash flood had occurred in Kuantan Pahang due to drainage capacity cannot cattle the quantity of water when the capacity of runoff increases. This natural phenomenon may bring disaster that may take away human lives and loss of their properties.

In order to prevent this disaster happen, research should be carrying out to analyze the relationship between rainfall and runoff. There are many data that have to be obtaining to determine the rainfall-runoff relationship. In this science and technology era, much software had been created to simplify and also to obtain more accurate result. One of the computer programs that can be used to simplify the data is Geographical Information System (GIS). 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. Relationship between rainfall and runoff will then be determined by the producing hydrograph from this software.

1.3. Objectives

In order to make this study successful, three objectives have been determined. It works as a guide line so that the outcomes of this study can be easily achieved.

The following are the objectives of this research:

1. To improve curve number by slope adjustment.
2. To examine the performance of slope adjusted $CN_{0.05}$ in direct runoff estimation
3. To establish a relationship between traditional CN provided in TR-55 (hereafter $CN_{0.2}$) and modified $CN_{0.05}$ to facilitate conversion of $CN_{0.2}$ values to $CN_{0.05}$.

1.4. Scopes of Study

In this study, the Kuantan River Basin hereafter KRB (3.78°N, 103.22°E) is treated. It is the state capital of Pahang the most urbanized area situated near the mouth of the Kuantan River and faces the South China Sea. The climate is more influences by seasonal variation of the northeast monsoon. The main city in this watershed is Kuantan with population of 607,778 in 2012 (Noor and Rosni, 2013) . It is the 9th largest city in Malaysia. Mean annual rain fall of the study area is about 3200 mm.

The study area is located in eastern part of Peninsular Malaysia where the city of Kuantan is Located. Kuantan watershed was selected due to the high growth rate of its population and the rapid establishment of new town area (Noor and Rosni, 2013). It is identified as one of the future growth centers and a hub for trade, commerce; transportation and tourism. The watershed area is about 167437 ha, Elevation range from 0 at the mouth of watershed to 1511m in the most remote part of north-west of watershed.

Serval major flood events have been reported in KRB specifically flood events occurred in December 2013, December 2014 and January 2015. There may be serval reason behind the frequent flood in KRB. Flood susceptibility map may help to provide a closer view to watershed managers, planners, and engineers either from the government bodies or privet sector in flood mitigation activities.

1.5. Significance of Study

From this research, the relationship between rainfall and runoff can be obtained. Besides that, the different of the ArcGIS method that used to analyze the relationship can be determined. It is important to do this research because we can evaluate the performance of the model and its accuracy in predicting runoff in tropical area. It’s also to verify the relationship between the characteristics of rainfall events and runoff with the factors affecting it in the catchment which can cause flood event in Kuantan watershed. The output of this research can bring benefit to the conservation of water resources and flood planning and mitigation, as well as the soil engineering planning and hydrological structure design.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrology

Hydrology is a branch of physical geography which deals with the origin, distribution, and properties of water through the air, over the ground surface and through the earth strata. The knowledge of hydrology is of basic importance in all walks of life that involve the use and supply of water and any propose what so ever. Therefore, the knowledge of hydrology is not only useful in the field of engineering, but also in agriculture, forestry and other branches of natural science (Gupta, 1979).

2.1.1 Importance of Hydrology

In engineering hydrology is used mainly in connection with the design and operation of hydraulic structures. Therefore, with the advancement in flood control, irrigation, and power generation and etc. the importance of hydraulic structure is gaining importance (Wikipedia, 2005).

2.2 Hydrologic Cycle

The hydrologic cycle is defined as the pathway of water as it moves in its various phases through the atmosphere, to the earth, over and through the land, to the ocean, and back to the atmosphere (National Research Council, 1999). The movement of water in the hydrologic cycle is illustrated in Figure 2.0.

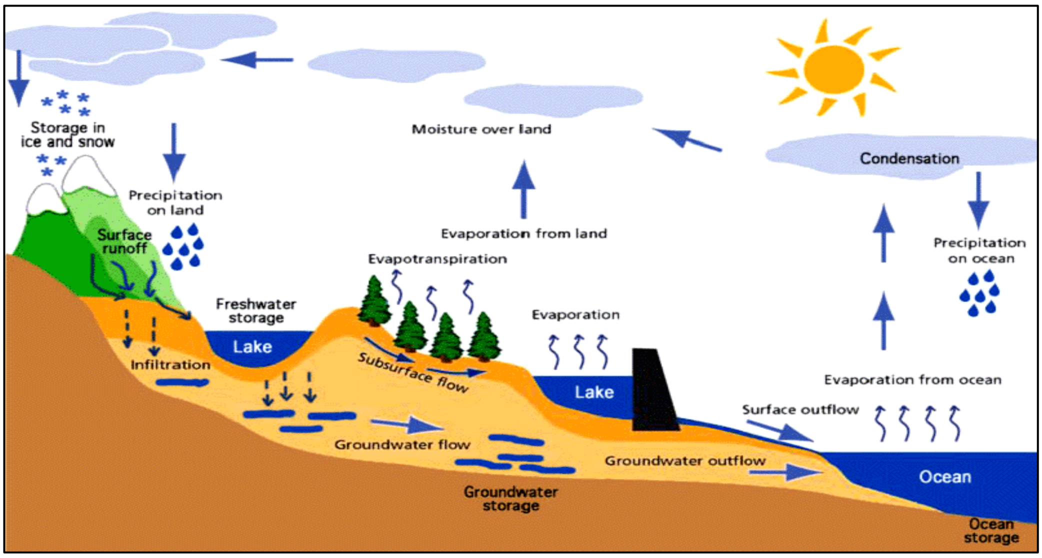


Figure 2.0: Main Component of Hydrologic Cycle

A description of the hydrologic cycle can start with the evaporation of water from the ocean driven by energy from the sun. The evaporated water, in the form of water vapor, rise by convection; condenses in the atmosphere to form clouds; and precipitates onto land and ocean surfaces as rain or snow. Precipitation on land surfaces is partially intercepted by surface vegetation, partially stored in surface depressions, partially infiltrated into the ground, and partially flows over land into drainage channels and rivers that ultimately lead back to the ocean. Precipitation that is intercepted by surface vegetation is eventually evaporated into the atmosphere; water held in depression storage either evaporates or infiltrates in to the ground; and water that infiltrated into the ground contributes to the recharge of ground water, which is either utilized by plants or becomes subsurface flow that ultimately emerges as recharge to streams or directly to the ocean (Chin, 2000).

2.2 Runoff

Precipitation is the primary source of all waters. When rain starts falling on a more or less previous area it is consumed in many ways such as: the rainfall is intercepted by buildings, trees, grasses, and other objects, preventing it from reaching the ground, some part of it infiltrates into the ground, some part of it finds its way to innumerable small and large depression, if rain continues, the soil surface becomes covered with a film of water and is known as surface detention and flow begins to start to words an established surface channel. Thus, runoff may be defined as that part of precipitation as well as of any other flow contribution which appear in surface streams (Gupta, 1979).

2.2.1 Sources of Runoff

The water flowing in a stream may have reached there from many sources such as: precipitation falling directly on the surface of the stream and its distributes, surface runoff is the portion of the precipitation which after falling on the ground surface finds its way into the stream channels without infiltrating into the soil and percolating down to the water table. Sub-surface flow is the part of precipitation which first infiltrates into the soil, moves laterally and joints the river channel before joining the water table below. Usually it is treated as surface runoff as it takes very little time to reach the river channel in comparison ground water and ground water is the portion of precipitation which after falling on the ground surface infiltrates into the soil and joined the ground water, and then after sometime found its way through the soil into the stream (Gupta, 1979).

2.2.2 Factors Affecting Runoff

The factors affecting runoff from any catchment area may be group into the following two groups; precipitation characteristics and physical characteristic of the basin.

2.2.3 Precipitation Characteristics

Precipitation characteristics include; types of precipitation, intensity of rainfall, duration of rainfall, distribution of rainfall, direction of storm movement, soil moisture and other climate conditions.

2.2.3.1. Types of Precipitation

The type of precipitation has a great influence on runoff. For instance of precipitation take place in the form of rainfall, its water will start flowing on the surface with in no time after the start of rain fall depending upon its intensity and magnitude.

2.2.3.2. Intensity of Precipitation

The intensity of rainfall affects runoff to get a great extent. The rain fall exceeding the infiltration capacity of the soil generates surface runoff very rapidly with the increase in rain fall intensity. Rain fall with higher intensity will generate more runoff than low intensity rain fall, through total amount of rain fall may be equal.

2.2.3.3. Duration of Rainfall

The duration of rain fall affects the runoff due to the fact that during a rain fall the infiltration capacity of the soil goes on reducing till it attains a constant value. As a result of this fact, even a mild intensity of rain fall may produce considerable surface runoff. Further if rains continue over an extended period, the water table may rise and sometimes even may touch the ground surface in low lying areas, reducing the infiltration capacity to zero of that area and there may be chances of serious flood hazard.

2.2.3.4. Distribution of Rainfall

For small drainage basins high peak flows are generally the result of intense rains falling only on small areas. On the other hand for large drainage basins the high peak flows are usually produced by storm of less intensity, but covering very large area. Thus, the runoff from a drainage basin depends very much on the distribution of rainfall. The rainfall distribution can be expressed by the distribution coefficient. For a given storm the distribution coefficient can be obtained by dividing the maximum rain fall at any point by the mean rainfall of the basin. For a given total rainfall all other conditions being the same, greater the coefficient of distribution, greater will be the peak runoff. However, for the same distribution coefficient, the higher peak runoff would result for the storm falling on the lower part of the basin.

2.2.3.5. Direction of Storm Movement

The direction in which the storm travels across the basin with respect to the direction of flow of the drainage system has a great influence upon the resulting peak flow and also the duration of surface runoff. It has been observed that the storm moving in the direction of the movement of water in the drainage basin, will produce more runoff and the water will remain u-in the basin for shorter duration as compared to the case when storm moves in the opposite direction of the water of the basin.

2.2.3.6. Soil Moisture

The amount of moisture in the surface layers of the soil at the time of rainfall has a marked effect on the surface runoff, as the soil moisture affects infiltration capacity very much. If the rainfall takes place after a long dry spell of time when the soil is dry and can absorb a large amount of water, in such conditions even intense rainfall may fail to produce any appreciable runoff. On the other hand, if the rainfall takes place when the soil moisture content is high i.e. after a long rainy season, in such situation the infiltration will be very leak and even very small rainfall may produce peak flows and cause considerable rise in stream water level, sometimes disastrous flood also.

2.2.3.7. Other Climate Conditions

Climate factors such as temperature, wind velocity, relative humidity, annual rainfall, etc will affect the losses from the drainage basin to a great extent and thus affect the runoff. If the losses are more, the runoff will be less and vice versa.

2.2.4 Physical Characteristic of the Basin

Physical characteristic of the basin include: land use, elevation of the basin and slope of the drainage.

2.2.4.1. Land Use

The land use or land management has a great effect on the resulting surface runoff. Consider a virgin forest area, in which a thick mulch of leaves and grass etc has accumulated. In such areas even the heaviest down pours or rains would be unable to generate surface runoff that would reach the streams. On the other hand if the forest is removed and the land is cultivated after removing the mulch, the ground will become compacted. As a result of which even a mild rainfall will result in appreciable surface runoff.

2.2.4.2. Elevation of the Basin

The elevation of the basin also effects the runoff as it governs the rainfall, its type and amount. Higher the elevation, lesser the losses. At higher elevations much of the precipitation is impounded in the form of snow etc.

2.2.4.3. Slope

The slope of the drainage has an important, but complex effect of the runoff. It control the time of over land flow and concentration of rain fall in stream channels. In case of steeper basins the velocity of flow will be more and runoff will take lesser time to reach the stream, resulting in higher runoff.

2.3 Rainfall Runoff Relationship

During a given rainfall, water is continually being abstracted to moisten the upper levels of the soil surface; however, this infiltration is only one of many continuous abstractions. Rainfall is also intercepted by trees, plants, and roof surfaces, and at the same time is evaporated. Once rain fall and fulfills initial requirements of infiltration, natural depressions collect falling rain to form small puddles, creating depression storage. In addition, numerous pools of water forming detention storage build up on permeable and impermeable surface within the watershed. This stored water gathers in small rivulets, which carry the water originating ass overland flow into small channels, then into larger channels, and finally as channel flow to the watershed outlet (Lewis and Viessman, 2003).

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity of a dry soil is high but, as the storm continues, the soil capacity will decrease until it reaches a steady value as final infiltration rate (Lewis and Viessman, 2003). The rainfall-runoff relationship is shown in Figure 2.1.

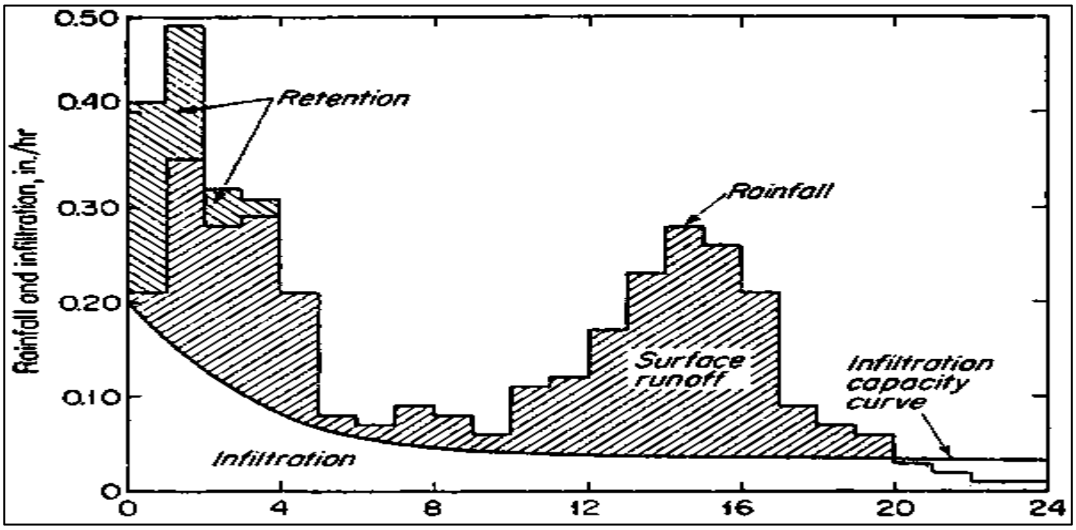


Figure 2.1: Schematic diagram of rainfall runoff relationship

The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

2.3.1 Hydrograph

The flow in a stream in a certain period of time can be representing by a unit hydrograph. A hydrograph has four component elements; direct runoff, interflow, base flow and channel precipitation. The rising portion of the hydrograph is known as the concentration curve; the region on the vicinity of the peak is called the crest segment; and the falling portion is the recession as shown in Figure 2.2.

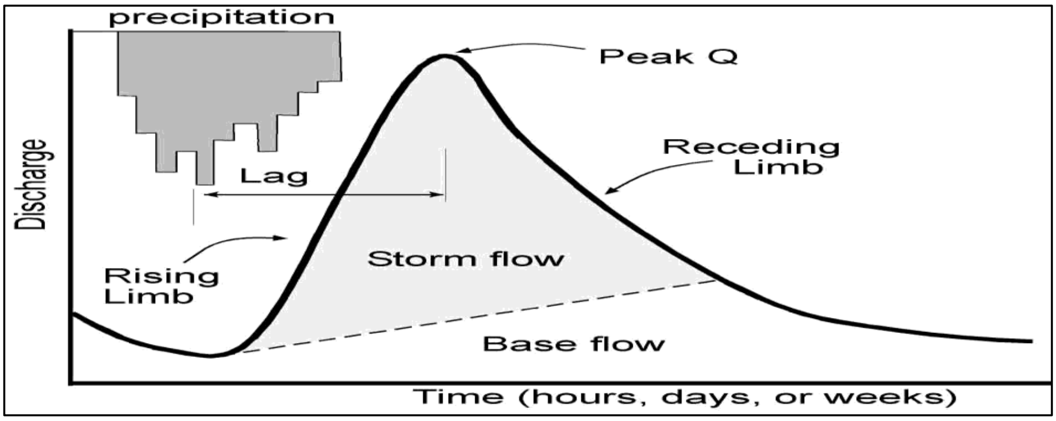


Figure 2.2: Typical Component of Hydrograph

The factors that influence hydrograph shape include vegetation or soil (infiltration capacity), level of urbanization, land use, drainage density, climate, precipitation intensity or duration contributory areas.

2.4 Urbanization

Nowadays, in urbanized country, trees were cleared, land surface graded and buildings and roads are constructed. These changes reduce infiltration rate, subsurface flow, evapotranspiration, storm water storage on hills slope and the time required for storm water to travel over and through a hill slope to a stream.

The increasing trends of mass migrating of people from villages and town the bigger cities for better basic and civic facilities and better jobs opportunities have result urbanization reaching its peak, especially in the developing country. The changes in land use pattern are immediately reflected in the shape of runoff producing capability of watershed. Usually the impact of these changes is realized on the downstream living environment in unexpected flash floods and heavy sediment transport. Therefore, in this era of development and rapid urbanization, the planners, designers and hydrologist are facing a complicated problem of mitigating the increasing runoff and flash flood (Lewis and Viessaman, 2003).

2.4.1 Effect of Urbanization on Runoff

If an undeveloped area is converted to cropland or pasture, the soil is disturbed and the overlaying absorptive cover is changed. The result is increased runoff volume and a change in the timing of flows. When lands are urbanized and storm drains installed, the flooding characteristics of these areas are modified. The drains serve to remove the water at an accelerated rate, thus increasing the peak flow and runoff volumes. In as much as there is usually a significant linkage between low, swampy areas and the underlying underground system, this relation is changed as well. The rapid removal of water from drained area decreases the time and consequently the opportunity for infiltration and the net effect is usually a lowering of the underlying water table. Changes in the vegetal cover affect the infiltration capacities of soils and land use changes that modify the nature of vegetation can have significant impact on the timing and volume of flows.

Urbanization of the land usually results in the highly accelerated removal of storm water with corresponding increases in the volume and peak rate off runoff. Both effects are described below. In many cases, infiltration might be all but eliminated and a very high percentage of the storm rainfall becomes runoff. On the other hand, by increasing an area's storage capacity and delaying the outflow, it is possible to increases the timing and delay the peak rate of runoff. For example, a shopping centre parking lot can be graded and its drains sized to permit several inches of ponding during intense storms. This delays the downstream arrival of flows from the area and significantly reduces the hydrograph peaks (Lewis and Viessman, 2003).

2.5 Method for Runoff Calculation

Four techniques are commonly used to estimate runoff, i.e Rational Method, Graphical Peak Discharge Method, Tabular Method (TR-55), and Unit

Hydrograph Method. The primary factors used to decide on a runoff calculation method are the size of the drainage area and the output information required. The table below lists acceptable calculation methods for different drainage areas and output requirements. The plan approving authority may require or accept other calculation methods deemed more appropriate for local conditions. Table 2.0 shows the appropriate calculation method for different drainage area.

Table 2.0: Appropriate calculation method for different area

Output Requirements	Drainage Area	Appropriate Calculation Methods
Peak Discharge only	up to 200 acres	1,2,3,4
	up to 2000 acres	2,3,4
	up to 20 sq.mi.	3,4
Peak Discharge and Total Runoff Volume	up to 2000 acres	2,3,4
	up to 20 sq.mi.	3,4
Runoff Hydrograph	up to 20 sq.mi.	3,4

1. Rational Method
2. Peak Discharge Method
3. Tabular Method (TR-55)
4. Unit Hydrograph Method

2.5.1 Rational Method

According to Gribbin (2002), many methods to compute runoff have been developed over the years, and the first and most enduring of this is Rational Method. Most methods are based on empirical relationships among drainage area, time of concentration, rainfall, and other factors. However, the Rational Method, introduced in England in 1889, has its genesis in pure reasoning, from which it received its name.

The Rational Method is used to compute the peak runoff, Q_p, following a fall event. It makes no attempt to estimate runoff before and after the peak, but simply the one quantity of flow that is greatest.

Originally, the Rational Method formula for peak runoff was given as:

$$Q_p = Ai \tag{2.1}$$

Where

Q_p = peak runoff (cfs)
A = drainage area (acres)
i = rainfall intensity (in/h)

This was based on the completely impervious drainage basin in which all rainfall is converted to runoff. Later, a proportionally factor, c, called the runoff coefficient, was added in an attempt to account for infiltration into the ground and for evaporation. So the formula become

$$Q_p = Aci \tag{2.2}$$

where c is the dimensionless runoff coefficient. Values of c vary between 0.0 and 1.0.

Table 2.1 shows the simplified table of Rational Method Runoff Coefficients of different types of ground cover.

Table 2.1: Simplified table of Rational Method Runoff Coefficients (LMNO Engineering, 2003)

Ground Cover	**Runoff Coefficient, c**
Lawns	0.05 - 0.35
Forest	0.05 – 0.25
Cultivated land	0.08 – 0.41
Meadow	0.1 – 0.5

Parks, cemeteries	0.1 – 0.25
Unimproved areas	0.1 – 0.3
Pasture	0.12 – 0.62
Residential areas	0.3 – 0.75
Business areas	0.5 – 0.95
Industrial areas	0.5 – 0.9
Asphalt streets	0.7 – 0.95
Brick streets	0.7 – 0.85
Roofs	0.75 – 0.95
Concrete streets	0.7 – 0.95

2.5.2 Peak Discharge Method

In the Graphical Peak Discharge Method, runoff is calculated using the following formula:

$$q_p = q_u A_m Q F_p \quad (2.3)$$

Where:

q_p = Peak discharge (ft^3/s, also written as cfs)
q_u = Unit peak discharge (cfs/$mi.^2$/in, also written as csm/in)
A_m = Drainage area ($mi.^2$)
Q = Runoff (in.)
F_p = Pond and swamp adjustment factor (no units)

2.5.3 Tabular Method

The Tabular Hydrograph method is used to develop the composite hydrograph. First the method extracts a specific unit hydrograph from a table based on a number of sub area and rainfall variables. The variables found to have significant influence in the shape of the unit hydrograph are Rainfall Type, Ia/P, Tc and Tt. Where Tc is the time of concentration within the subarea and Tt is the travel time from the subarea outlet to the watershed outlet.

2.5.4 Unit Hydrograph Method

Unit Hydrograph analysis is used for watersheds greater than 1 square mile (640 acres) in Orange Country, California. Losses are accounted for by calculating an effective precipitation. Runoff hydrographs are computed using a unit hydrograph which is developed using an S-graph. A small area hydrograph can be used instead of a full blown unit hydrograph analysis for watersheds with a Tc < 25 min.

2.5.4.1. Soil Conservation Service (SCS)

Techniques developed by the U.S Soil Conservation Service for calculating rates of runoff require the same basic data as the rational method: drainage area, a runoff factor, time of concentration and rainfall. The SCS approach however is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression, storage and an infiltration rate that decreases during the course of a storm. With the SCS method the direct runoff can be calculated for any storm, either real or fabricated by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

The SCS runoff equation is therefore a method of estimating direct runoff from 24 hr or 1 day storm rainfall. The equation is:

$$Q = (P-I_a)^2/(P-I_a) + S \qquad (2.4)$$

Where:

Q = accumulated direct runoff (in)

P = accumulated rainfall (potential maximum runoff) (in)

I_a = initial abstraction including surface storage, interception and infiltration prior to runoff (in)

S = potential maximum retention (in)

The relationship between I_a and S was developed from experimental watershed data. It eliminates the need for estimating I_a for common usage. The empirical relationship used in SCS runoff equation is

By substituting $I_a = 0.2S$ (2.5)

The SCS runoff equation becomes:

$$Q = (P-0.2S)^2 / (P+0.8S) \quad (2.6)$$

S is related to the soil and covers the conditions of watershed through the curve number (CN) or runoff factor. CN has a range of 0-100, and S is related to CN by:

$$S = (1000/CN)-10 \quad (2.7)$$

2.5.4.2. Snyder's Unit Hydrograph

Techniques According to the U.S Army Corps of Engineer, the synthetic unit hydrograph of Snyder (1938) is based on relationships found between three characteristics of a standard unit hydrograph and descriptors of basin morphology. The hydrograph characteristics are the effective rainfall duration t_r, the peak direct runoff rate, q_p and the basin lag time, t_l. from these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated.

Standard unit hydrograph is associated with specific effective rainfall duration, t_r, define by the following relationship with basin lag, t_l,

$$t_t = 5.5\ t_r \quad (2.8)$$

For a standard unit hydrograph the basin lag, t_1 and the peak discharge, q_p, are given by,

$$t_1 = C_1 C_2 (LL_c)^{0.3} \qquad (2.9)$$

and

$$q_p = C_1 C_p A / tt \qquad (2.10)$$

The basin lag time of the standard unit hydrograph (Equation 2.9) is in unit of hours, L is the length of the main stream in kilometers (miles) from the outlet to the upstream divide, L_c is the distance in kilometers (miles) from the outlet to a point on the stream nearest the centre of the watershed area, and C_1 = 0.75 (1.0 for English units). The product LL_c is a measure of watershed shape. C_t is a coefficient derived from gauged watersheds in the same region, and represents variations in watershed slopes and storage characteristics. The peak discharge of the standard unit hydrograph (Equation 2.10) is in m^3/s (cfs), A is the basin area km^2 (mi^2) and $C_2 = 2.75$ (640 for English units). As C_1 and C_p is a coefficient derived from gauge watersheds in the area, and represents the effects of retention and storage.

Estimation of model parameters C_p and C_t as in any modal parameter estimation problem, observations of the input (i.e., effective precipitation) and the output (i.e., direct runoff hydrograph) must be available. In addition, the values of L and L_c must also be available (e.g. from survey, maps, etc).

From the concurrent input-output observation, a unit hydrograph for the basin in question, also called derived unit hydrograph, can be developed. From the derived unit hydrograph of the watershed, values of its associated effective duration t_R in hours, its basin lag t_{1R} in hours, and its peak discharge q_{pR} in m^3/s are obtained. If $t_{1R} = 5.5\ t_R$, then the derived unit hydrograph is a standard unit hydrograph and $t_r = t_R$, $t_l = t_{lR}$, and $q_p = q_{pR}$ and C_t and C_p are computed by the equations for t_l and q_p given above (Equation 2.9, Equation 2.10).

If t_{lR} is quite different from 5.5 t_R, the basin lag of standard unit hydrograph for the basin is computed using:

$$t_l = t_{lR} + (t_r - t_R)/4 \qquad (2.11)$$

This equation must be solved simultaneously with the equation for the standard unit hydrograph lag time, $t_l = 5.5\ t_r$, in order to obtain t_r and t_l. With these values of t_r and t_l. The values of C_t is obtained using (Equation 2.9) for t_l corresponding to the standard unit hydrograph; the value of C_p is obtained using the expression for q_p corresponding to the standard unit hydrograph, but using $q_p = q_{pR}$ and $t_l = t_{lR}$.

When an ungauged watershed appears to be similar to a gauge watershed, the coefficients C_t and C_p for the gauge watershed can be used in the above equations to derive the required synthetic unit hydrograph for the ungauged watershed.

Development of a Required Unit Hydrograph (assume that C_l, C_p, L and L_c are known). If a t_R unit hydrograph is required, that is, if a unit hydrograph whose associated effective rainfall pulse duration is t_R, is required, proceed as follows:

i. Use (Equation 2.9) to determine the lag-time, t_l if t_R meets the criterion for a standard unit hydrograph, that is, if $t_l = 5.5t_R$ then the required unit hydrograph is a standard unit hydrograph and (Equation 2.9) and (Equation 2.10) can be used directly to estimate the peak discharge and the time to peak of the required unit hydrograph. That is

$$t_{lR} = t_l = C_1C_2\ (LL_c)^{0.3} \qquad (2.12)$$

$$q_{pR} = q_p = C_1C_p / tt \qquad (2.13)$$

If t_R does not meet the criterion of (Equation 2.1) then the required unit hydrograph is not a standard unit hydrograph and (Equation 2.9) and (Equation 2.10) cannot be used directly to estimate the peak discharge and the time to peak of the required unit hydrograph. In this case, the lag-time of the required unit hydrograph, t_{lR} is,

$$t_{lR} = t_l - (t_r - t_R) / 4 \qquad (2.14)$$

where is obtained from (Equation 2.13), t_r is obtained from (Equation 2.8) and is t_r given. The peak discharge of the required Unit Hydrograph (UH), q_{pR}, is

$$q_{pR} = (q_p t_l) / t_{lR} \qquad (2.15)$$

where q_p is obtained from Equation (2.10).

Assuming a triangular shape for the UH, and given that the UH represents a direct runoff volume of 1cm (1 in), the base time of the required UH may be estimated by,

$$t_b = (C_3 A) / q_{pR} \qquad (2.16)$$

where C_3 is 5.56 (1290 for the English System).

As an aid in drawing adequate UH, the U.S. Army Crops of Engineers developed relationships for the widths of the UH at values of 50% (W_{50}) and 75% (W_{75}) of q_{pR}. The width in hours of the UH at a discharge equal to a certain percent of the peak discharge q_{pR} is given by Chow et al. (1988) as,

$$W\% = C_w (q_{lR} / A)^{-1.08} \qquad (2.17)$$

Where the constant C_w is 1.22 (440 for English units) for the 76% width and equal to 2.14 (770 for English units) for the 50% width. Usually, one-thirds of this width is distributed before the peak time and two-thirds after the peak time, as recommended by the U.S. Army Crops Engineers. However, several other authors have recommended different distribution ratios. For example, Hudlow and Clark (1969) recommended a partition of 4/10 and 6/10 respectively.

2.5.4.3. Clark Unit Hydrograph (TC & R)

The process of translation and attenuation dominated the movement of flow through a watershed. Translation is the movement of flow down gradient through the watershed in response to gravity. Attenuation results from the frictional forces and channel storage effects that resist the flow. Clark (1945) noted that the translation of flow throughout the watershed could be described by a time-area curve, which expresses the curve of fraction of watershed area contributing runoff to the watershed outlet as a function of time since the start of effective precipitation. Effective precipitation is that precipitation that is neither retained on the land surface nor infiltrated into the soil (Chow e.t. al, 1988).

The time-area curve is bounded in time by the watershed T_c. Thus, T_c is a hydrograph parameter of the Clark unit-hydrograph method. Attenuation of flow can be represented with a simple, linear reservoir for which storage is related to outflow as,

$$S = RO \qquad (2.18)$$

Where

S = is the watershed storage,
R = is the watershed-storage coefficient, and
O = is the outflow from the watershed

Therefore, Clark (1945) proposed that a synthetic unit hydrograph could be obtained by routing 1 inch of direct runoff to the chemical in proportion to the time-area curve and routing the runoff entering the channel through a linear reservoir (smig.usgs.gov/SMIG/features_0301/clark.pdf, 2005).

2.6 Software for Analyzing Rainfall and Runoff Relationship

Numerous mathematical models have been developed for the purpose of simulating various hydrological phenomena and system. Over the years, a large number of analytical tools are developed at HEC such as: HEC-1, HEC-HMS, Unit Graph and Hydrograph.

2.6.1 HEC-HMS

The Hydrological Modeling System is designed to simulate the precipitation runoff process of dendritic watershed systems. It is design 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. Hydrograph produce by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage, reduction, floodplain regulation, and system operation.

The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the program. Program functionally and appearances are the same across all supported platforms.

2.6.1.1. Modelling Basin Component

The physical representation of watersheds or basins and rivers is configured in the basin model. Hydrological elements are connected in a dendritic network to simulate runoff processes. Available elements are subbasin, reach, junction, reservoir, diversion, source and sink. Computation proceeds from upstream elements in a downstream direction.

2.6.1.2. Losses

An assortment of different methods is available to simulate infiltration losses. Option for event modeling include initial and constant, SCS curve number, gridded SCS curve number, and green and Ampt. The-one layer deficit and constant model can be used for simple continuous modeling. The five-layer soil moisture accounting model can be used for continuous modeling of complex infiltration and evapotranspiration environment.

2.6.1.3. Runoff Transform

Several methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark technique, the Snyder technique and SCS technique. User-specified unit hydrograph ordinates can also be used. The modified Clark method, Mod Clark, is a liner quasi-distributed unit hydrograph method that can be used with gridded precipitation data. An implementation of the Kinematic Wave method with multiple planes and channels is also included.

2.6.1.4. Open Channel Routing

A variety of hydrologic routing methods are included for simulating flow in open channels. Routing with no attenuation can be modeled with the lag method. The traditional Muskingum method is included. The Modified Plus method can be used to modal a reach as a series of cascading level pools with a user-specified storage-outflow relationship. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the Kinematic Wave or Muskingum-Cungu method. Channels with overbank areas can be modeled with the Muskingum-Cungu method and 8-point cross section.

2.6.1.5. Rainfall Runoff Simulation

The time span of a simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and computation time step. A computation run is created by combining a basin model, meteorologic model, and control specifications. Run option include a precipitation or flow ratio, capability to save all basin states at a point in time, and ability to begin a simulation from previously saved states. Computation results are viewed from the basin model schematic. Global and element summary tables include information on peak flow and total volume. Time-series tables and graphs are available for elements. All graphs and tables can be printed on a Postscript 1 capable printer.

2.6.1.6. Parameter Estimation

Most parameter for methods included in sub basin and reach elements can be estimated automatically using the optimizer manager. Observed discharge must be available for at least one element before optimizer can begin. Parameters at any element upstream of the observed floor can be estimated.

2.6.1.7. Computational Results

Computation results are viewed from the basin model schematic. Global and element summary tables include information on peak flow and total volume. Time-series tables and graphs are available for element. Customizable graph and report generators are planned for future versions.

2.6.2 Other HEC Program

With the large set of included method, HEC-HMS can provide information about runoff from historical or hypothetical events, with and without water control or other flood-damage reduction, for single events or long periods of record. But even with his flexibility, HEC-HMS will not provide all information required for all planning, design, operating, permitting, and regulating decision making. (USACE, 1994)

To meet these needs, the HEC has developed a suite of other programs that provide additional capabilities, such as listed in the Table 2.2.

Table 2.2: Other HEC programs that are integrated with HEC-HMS (Loague and Freeze, 1985)

Program Name	Description of Capabilities	Reference
HEC-RAS	Solves open-channel flow problems and is generally used to compute stage, velocity, and water surface profiles, given steady flow rate, channel geometry, and energy-loss model parameters. Computes unsteady flow, given upstream hydrograph, channel geometry, and energy-loss model parameters.	USACE (2002)
HEC-FDA	Computes expected annual damage (EAD), given flow or stage frequency function, flow or stage damage function, levee performance model parameters. Uses risk analysis (RA) methods described in EM-1110-2-1619.	USACE (1998)
HEC-FIA	Computes post flood urban and agricultural flood damage, based upon continuous evaluation with flow or stage time series.	
HEC-ResSim	Simulates reservoir system operation, given description of reservoirs and interconnecting channels, reservoir inflow and local flow hydrographs, and reservoir operation rules.	

CHAPTER 3

METHODOLOGY

3.1. Introduction

This study is conducted for the purpose of study the rainfall-runoff relationship. With the aim to improve curve number by slope adjustment, a few methodologies as shown in flow chart (Figure 3.0) have been practiced;

- Selection of watershed/location extreme
- Geospatial data collection of a watershed
- Rainfall and runoff distribution for flood events
- Development spatial data using GIS and ILWIS
- Preparation of land use, soil map, DEM map
- Data analyzing and generation using HEC-HMS; SCS method

Data on rainfall and runoff are collected by Department of Irrigation and Drainage (DID) every 24 hours for 3 months in the study area in Kuantan Pahang. After data was collected, the SCS method in HEC-HMS software will be used to compute all the data. Hydrograph will be produced from the software to be compared and the best method to analyze the rainfall-runoff relationship in KRB area will be determined.

3.2. Work Flow Chart

As provided below is the basic presentation of the work flow for the completion of this research.

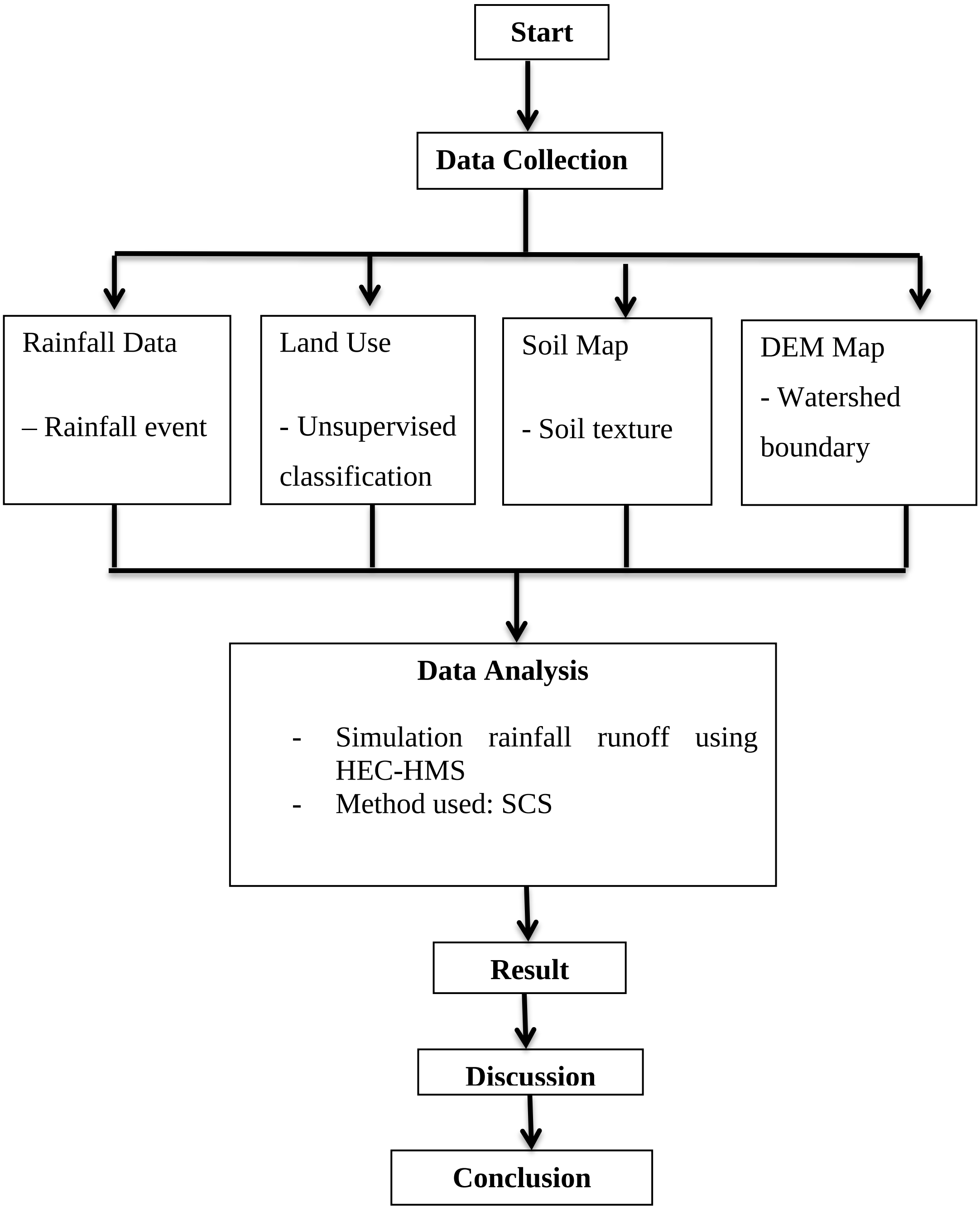


Figure 3.0: Flow Chart of Work Progress for Research

3.3. Study Area

In this study, the Kuantan River Basin hereafter KRB (3.78°N, 103.22°E) is treated. It is the state capital of Pahang the most urbanized area situated near the mouth of the Kuantan River and faces the South China Sea (see Figure 3.1).

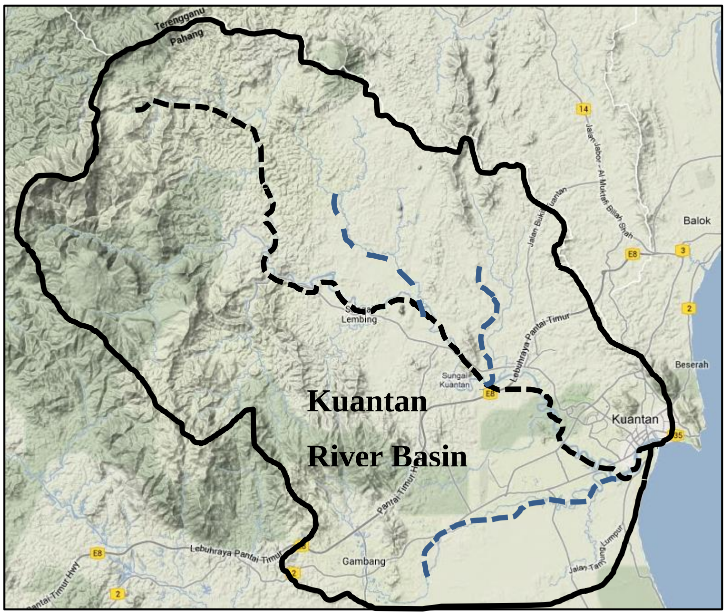


Figure 3.1: Urbanized River Basin of Kuantan/Pahang, Malaysia

The climate is more influences by seasonal variation of the northeast monsoon. The main city in this watershed is Kuantan with population of 607,778 in 2012 (Noor and Rosni, 2013) . It is the 9th largest city in Malaysia. Mean annual rain fall of the study area is about 3200 mm. The study area is located in eastern part of Peninsular Malaysia where the city of Kuantan is Located. Kuantan watershed was selected due to the high growth rate of its population and the rapid establishment of new town area (Noor and Rosni, 2013). It is identified as one of the future growth centers and a hub for trade, commerce; transportation and tourism. The watershed area is about 167437 ha, Elevation range from 0 at the mouth of watershed to 1511m in the most remote part of north-west of watershed. Serval major flood events have been reported in KRB specifically flood events occurred in December 2013, December 2014 and January 2015. There may be serval reason behind the frequent flood in KRB. Flood susceptibility map may help to provide a closer view to watershed managers, planners, and engineers either from the government bodies or privet sector in flood mitigation activities.

3.4. Data Collection

Provided in this writing are the methods used in collecting data throughout the research process. Each signifies its' own importance towards the project.

3.4.1 Rainfall Data

In a research done by (Ebrahimian et al, 2012), rainfall and runoff data for the study area was used from the published data by Department of Irrigation and Drainage. The data collected every 24 hours for 2 months from October to December with corresponding observed direct runoff and sum of 5-day prior rainfall for reach event.

3.4.2 Land Use Data

Geospatial Data for this research including Hydrologic Soil Group (HSG) and Land Use (LU) maps were obtained from National Hydraulic Research Institute of Malaysia (NAHRIM) in vector format (ESRI shape file) projected in Kertau-RSO-Malaysia metric coordinate system. Based on metadata provided by NAHRIM the LU map represents the year 2010 and generated from Landsat images processing supporting with field checking. Main LU classes are forest (49%) and Palm (27%).

3.4.3 Soil Group Data

The HSG map contains five HSG class including A&C, A&D, C&B, B and C. Unfortunately it is not possible to differentiate class A&C and A&D and C&D in HSG map because they already combined together as one unit. This is one of the main constraints of available data which may affect the reliability of the outcomes of this study. Predominate HSG in the study area are B, A&C, C&B with 56%, 15% and 15% respectively.

3.4.4 ASTER-GEDM Data

ASTER-GEDM data are available at https://asterweb.jpl.nasa.gov/data.asp. The ASTER is capable of collecting in-track stereo using nadir- and aft-looking near infrared cameras. Since 2001, these stereo pairs have been used to produce single-scene (60 × 60 km) digital elevation models (DEM) having vertical accuracies generally between 10 to 25 m (NASA, 2015). The ASTER-GDEM covers land surfaces between 83°N and 83°S with spatial resolution about 30 m. To generate slope map for the study area, thirteen ASTER-GDEM tiles were downloaded and then merged through the mosaic function in GIS software. Slope map were classified in five classes as suggested by Sprenger (1978).

3.5 Method of Simulation Rainfall Runoff Data in HEC-HMS

The Hydrological Modeling System is designed to simulate the precipitation runoff process of dendritic watershed systems. It is design 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. Hydrograph produce by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage, reduction, floodplain regulation, and system operation. There are some methods to determine the rainfall data relationship in HEC-HMS such as SCS and Kinematic Wave.

3.5.1 SCS-CN Method

The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. The traditional form of SCS equation is given by equation 3.1:

$$q = \begin{cases} 0 & for\ P \le I_a \\ \frac{(P-I_a)^2}{P-I_a+S} & for\ P > I_a \end{cases} \qquad (3.1)$$

Where; q is direct runoff depth in (mm), P is rainfall depth in (mm), S is the potential maximum soil moisture retention after runoff begins in (mm), I_a is the initial abstraction in (mm), or the amount of water before runoff, such I_a as infiltration, or rainfall interception by vegetation.

Historically, it has generally been assumed that $I_a = 0.20 \times S$ (USDA, 1986), but more recent research (Woodward et al., 2003) has proven that $I_a = 0.05 \times S$. The new initial abstraction ratio was tested in other region (Lim et al., 2006, Shi et al., 2009, Fu et al., 2011) and confirm that 5 percent initial abstraction ratio provide better prediction for runoff. However still rare research (Xiao et al., 2011) have shown that 20 or even 22 percent initial abstraction ratio provide more reasonable prediction for annual runoff prediction. The potential maximum soil moisture retention is obtained by CN through the equation 3.2:

$$S = \frac{25400}{CN} - 254 \quad (3.2)$$

Or

$$CN = \frac{25400}{254+S} \quad (3.3)$$

As the potential maximum retention S can theoretically vary between zero and infinity, equation 3.3 shows that the CN can range from 0 to 100. The CN values can be obtained from the NRCS standard tables. The lower value indicate low runoff potential while larger value represent higher runoff potential. The NRCS-CN is related to soil type, soil infiltration capability, land use, and top soil Antecedent Moisture Condition (AMC). To account infiltration capability, NRCS has defined soils into four HSGs by USDA (1986). Group A, refers to soil with high infiltration rates even when thoroughly wetted (>7.62 mm/h). Group B, refers to soils with moderate infiltration rates when thoroughly wetted (3.81 to 7.62 mm/h). Group C, refers to soils with slow infiltration rates when thoroughly wetted (1.27 to 3.81 mm/h). Group D, refers to soils with very slow infiltration rates when thoroughly wetted (<1.27 mm/h).research.

According to USDA (USDA, 1985) the CN value provided in standard tables represent moderate condition (AMC II, CN_{II}) and the CN values for dry condition (AMCI, CN_I) and wet condition (AMC III, (CN_{III}) is defined by CN_{II} using equation 4 and 5 respectively:

$$CN_I = 4.2CN_{II} / (10 - 0.058CN_{II}) \quad (3.4)$$

$$CN_{III} = 23CN_{II} / (10 + 0.13CN_{II}) \quad (3.5)$$

3.5.2 Modified SCS-CN Method

The relationship $I_a = 0.2\,S$ was derived from the study of many small, experimental watersheds. Recent analysis used model fitting methods to determine the ratio of I_a to S with hundreds of rainfall-runoff data from 307 U.S. watersheds. In the model fitting done by Woodward et al. (2003) found that the ratio of I_a to S varies from storm to storm and watershed to watershed and that the assumption of I_a/S =0.20 is usually high. More than 90 percent of I_a/s ratios were less than 0.2.

Based on this study, use of I_a/S ratios of 0.05 rather than the commonly used value of 0.20 would seem more appropriate. The new initial abstraction ratio was tested in other region (Lim et al., 2006, Shi et al., 2009, Fu et al., 2011) and confirm that 5 percent initial abstraction ratio provide better prediction for runoff. However still rare research (Xiao et al., 2011) have shown that 20 or even 22 percent initial abstraction ratio provide more reasonable prediction for annual runoff prediction. Equation 1 can be written in new form based on modified initial abstraction ratio. Thus, the SCS equation becomes as equation 3.6:

$$DR = \begin{cases} 0 & for\ P \leq 0.05 \times S \\ \frac{(P-0.05\times S_{0.05})^2}{P+0.95\times S_{0.05}} & for\ P > 0.05 \times S \end{cases} \qquad (3.6)$$

In this equation, the values of $S_{0.05}$ are not the same as the one used in estimating direct runoff with I_a/S ratio of 0.20, because 5 percent of the storage is assumed to be the initial abstraction, not 20 percent. The relationship between $S_{0.05}$ and $S_{0.20}$ is given by equation 3.7, obtained from model fitting results Woodward et al. (2003):

$$S_{0.05} = 1.33 * (S_{0.20})^{1.15} \qquad (3.7)$$

According Woodward et al. (2003), modified CN can be calculated from the relationship between the traditional CN which has been developed under the assumption that I_a/S is equal 0.2, with the modified initial abstraction ratio (0.05) through the equation 3.8:

$$CN_{0.05II} = \frac{100}{1.879*\left[\frac{100}{CN_{0.2II}}-1\right]^{1.15}+1} \qquad (3.8)$$

3.6 Antecedent Moisture Condition

The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the CN method, the soil moisture condition is classified in three AMC classes including dry (AMCI), moderate (AMCII) and wet (AMCIII) condition. CN values are converted to wet condition by equation 3.9:

$$CN_{0.05III} = \frac{100 * CN_{0.05II}}{43 + 0.57 CN_{0.05II}} \quad (3.9)$$

Where; $CN_{0.05III}$ is Curve Number for wet soil moisture condition and $CN_{0.2II}$ is Curve Number for moderate soil moisture condition.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Introduction

In this chapter, the data collected was analyzed in order to study the rainfall runoff relationship in KRB and to compare the rainfall runoff relationship using SCS method. Among the data collection during 31st October 2012 until 1st January 2013, there are three events of rainfall are selected. The data was then been analyzed with HEC-HMS software by using SCS method.

The graphs that were analyzed by using the SCS are compared with the actual hydrograph that are plotted using Microsoft Excel. The method that has the highest efficiency index is the most ideal method to be used in analyzing the rainfall runoff data.

4.2. Description on Analysis

The following are the descriptions and explanations that will detail the relevance of the step in computational result; (1) generating HSG and LU map, (2) generating CN map, (3) slope adjustment of CN calculating runoff depth, and (4) Sharply Williams Method, (5) average slope adjustment of CN, (6) average slope adjustment of modified CN.

4.2.1. Generating HSG and LU Map

A two dimensional table was crated with two classes domain including HSG domain for row and LU domain classes for column (see Table 4.0). The valued for each row and column intersection is CN, hereafter $CN_{0.2II}$) which is obtained from NRCS reference book. Both LU and HSG maps were converted to raster format with grid size of 100 m (see Figure 4.0 and 4.1).

Table 4.0: $CN_{0.2II}$ values taken from TR-55 adapted for HSG and LU of KRB

Land Use	**Hydrologic Soil Group**				
	A&C	**A&D**	**B**	**C&B**	**D**
Village	52	56	58	65	79
Gum	52	56	58	65	32
Forests	50	54	55	63	77
Forest Swamp And Buyau	50	54	55	63	77
Roads And Highways	88	88	89	91	93
Cleared Area	57	60	61	68	80
Livestock Areas	59	70	74	78	86
Vetable Garden	73	75	75	79	85
Coconut And Cocoa	52	56	58	65	79
Palm Oil	52	56	58	65	79
Quarry	83	84	85	87	91
Mining And Mining Waste	83	84	85	87	91
Padi	73	75	75	79	85
Municipal, Utilities And Related	73	75	75	79	85
Mixed Plantation	88	88	89	91	93
Various Crops	73	75	75	91	85
Grass	39	52	48	57	73

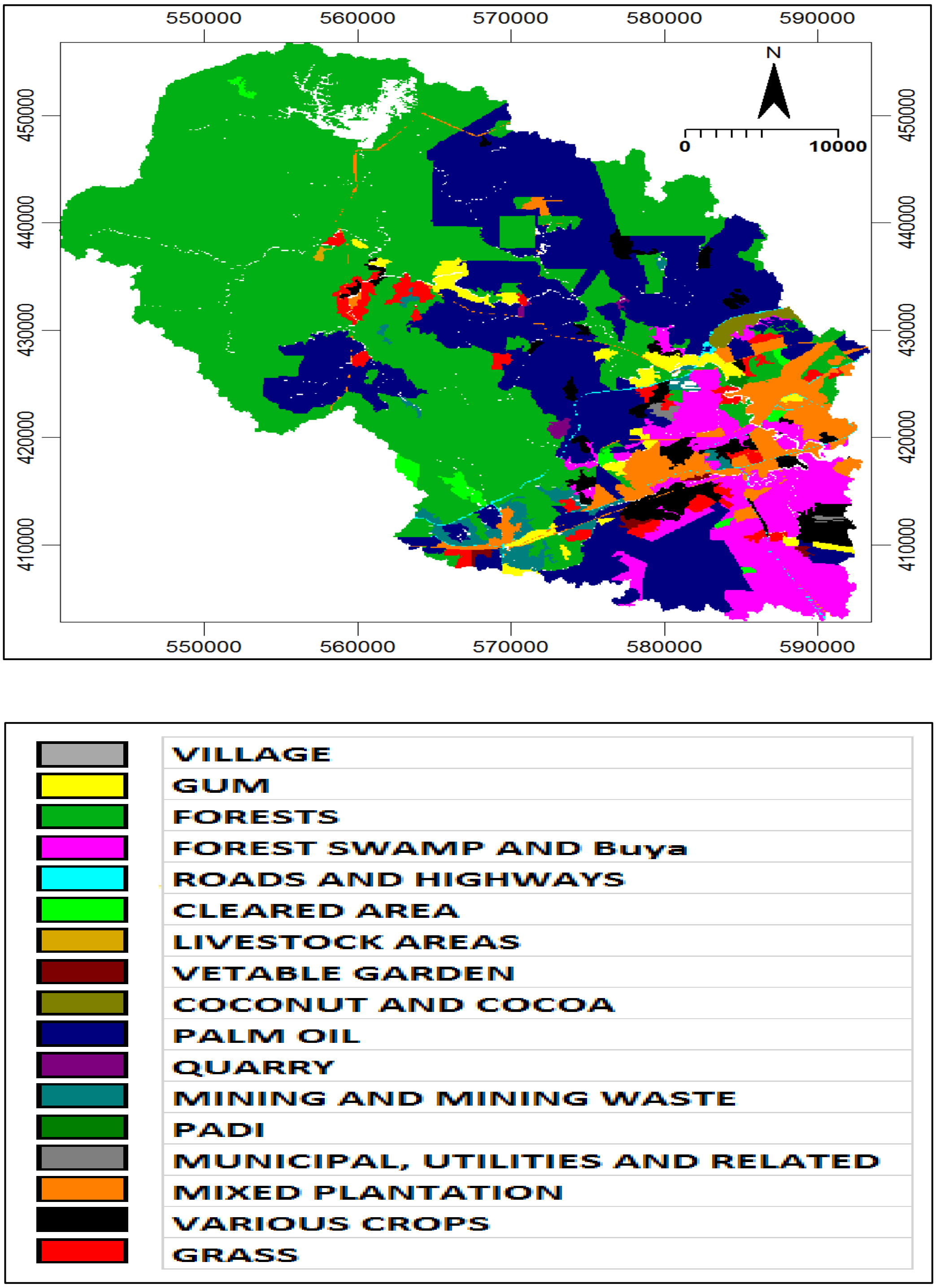


Figure 4.0: Land Use of KRB

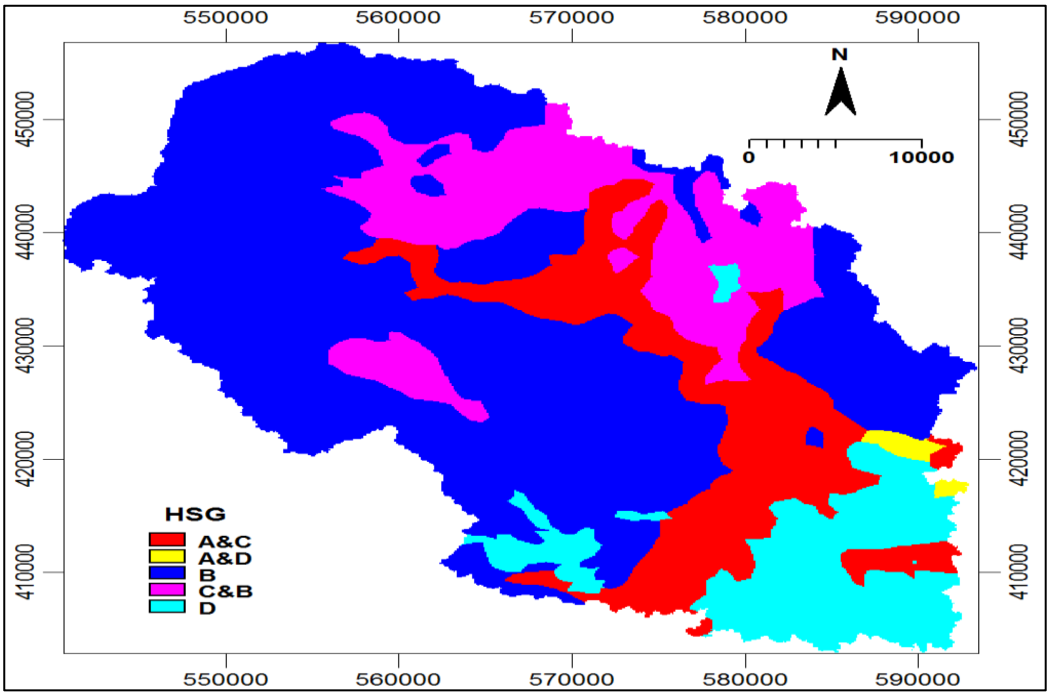


Figure 4.1: Hydrologic Soil Group of KRB

4.2.2. Generating CN Map

The $CN_{0.2II}$ map was generated by employing the equation 4.1 in ILWIS commends line (see Figure 4.2). $CN_{0.2II}$ values ranges from 32 to 100 with dominate values of 55 (38%). Then, the raster map was classified in 8 class domain using slicing operation in ILWIS (see Figure 4.3).

$CN_{0.2II}$\{raster map\} = $CN_{0.02II}$\{table\}.[HSG \{raster map\}, LU \{raster map\}](4.1)

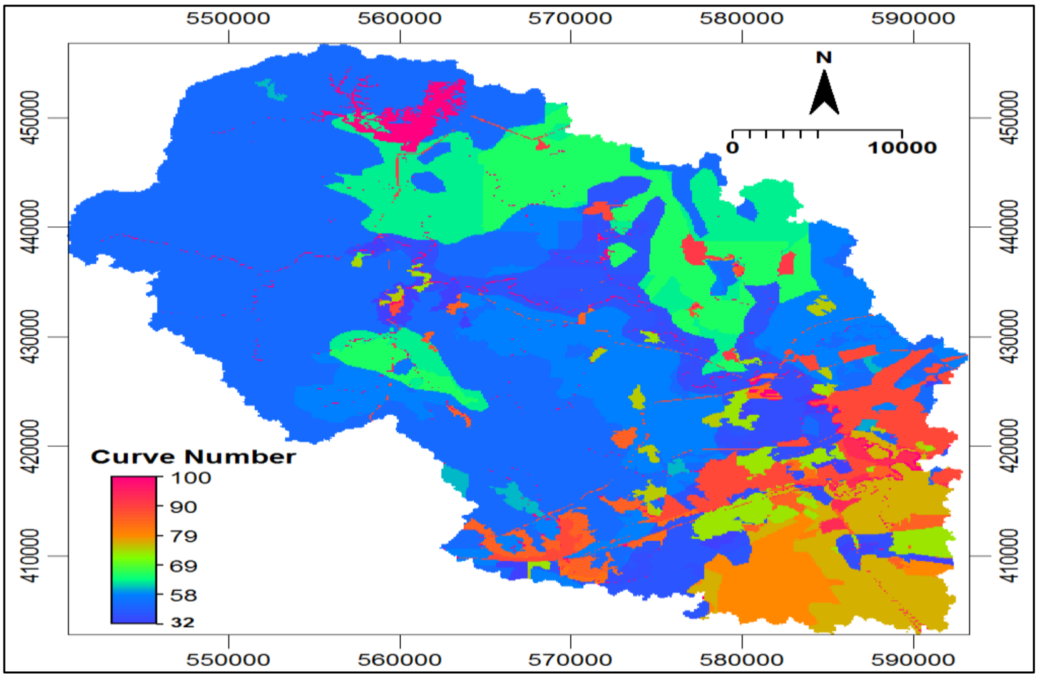


Figure 4.2: Unclassified $CN_{0.2II}$ Map in KRB

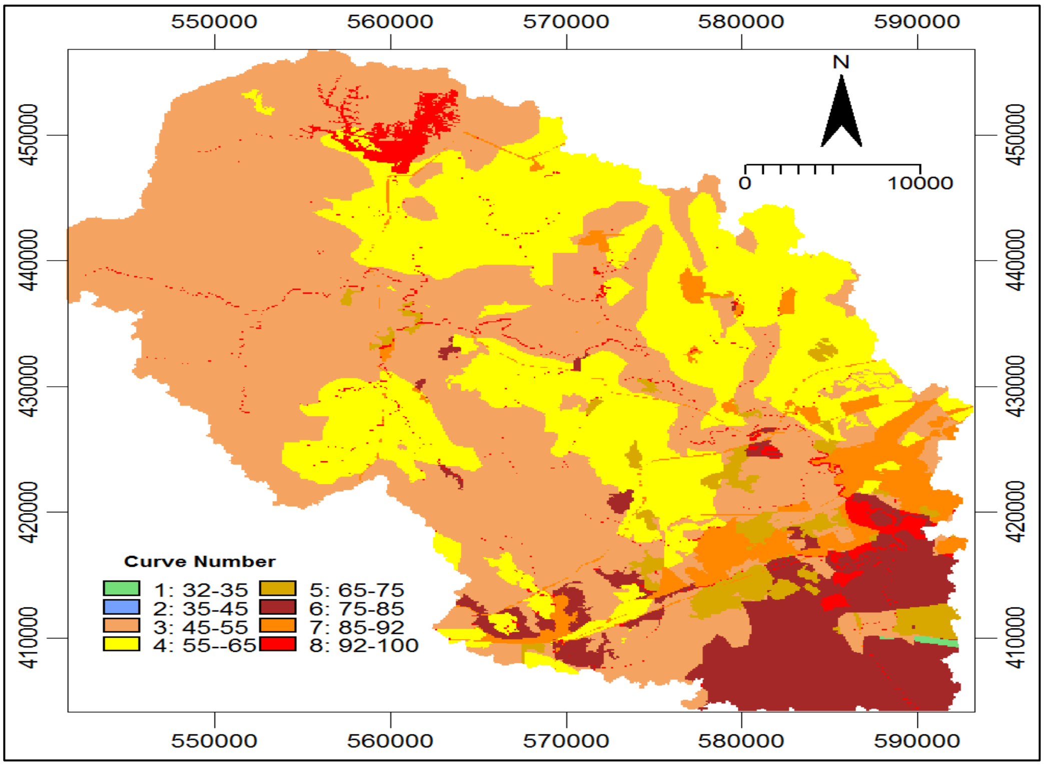


Figure 4.3: Classified $CN_{0.2II}$ Map in KRB

4.2.3. Slope Adjustment of CN

The NRCS-CN method for estimation of runoff was originally developed for agricultural watersheds with land slope near about 5%. However, over the years its application has been extended to watersheds having multiple landuse without considering effect of topography. Huang et al. (2006) has reviewed various studies on the effect of soil slope on the runoff. It has proven that terrain slope can affect surface runoff estimation based on NRCS-CN in three aspects including reduction of initial abstraction (Chaplot and Le Bissonnais, 2003), decrease in infiltration (Philip, 1991) and reduction of the recession time of overland flow (Evett, 1985). According to Ritzema (1994) cultivated land in USA, general has slopes of less than 5% and this range does not influence the CN to any greater extent. However, the slopes vary much more in north and north-east of Iran and many other regions around the world. This research has developed to investigate the effect of slope derived from the ASTER-GDEM on modified NRCS-CN. The first slope-adjusted CN table was introduced by Sprenger (1978) only for range land and wood land. The Huang et al.(2006) and Sharply-Williams (1990) methods are well known in the literatures. According to Ebrahimyan et al.(2009), Sharply-Williams method is more convenient based on research done in arid zone of Iran.

4.2.4 Sharply Williams Method

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (ASTER-GDEM V2) was used to investigate the effect of slope on CN. ASTER-GDEM V2 released on October 17, 2011 (NASA, 2013). It is freely available for download from NASA Re verb, LP DAAC Global Data Explorer, and J-space-systems ASTER-GDEM Page. The cell size of elevation data is 28×28 meter. The slope map of the study area was derived from agree-DEM. Finally, slope adjustment was made based on the Sharply-Williams presented in equation 4.2. ILWIS GIS software was used for geospatial analysis and mapping.

$$CN_{SW} = \frac{1}{3}(CN_{III} - CN_{II})(1 - 2e^{-13.86\alpha}) + CN_{II} \qquad (4.2)$$

Where

CN_{SW} is the modified Curve Number, CN_{III} is Curve Number for wet soil moisture condition CN_{II} is Curve Number for moderate soil moisture condition, α is terrain slope m/m.

It is noted that the CN values provided in TR55 represent the moderate soil moisture condition. Equation 4.2 has been provided for transferring CN from moderate condition (CN_{II}) to wet condition(CN_{III}). Slope-adjusted based on Sharply-Williams is shown in figure 4.4. Then modified CN map (hereafter $CN_{0.05II}$), classified in 8 classes with equal interval. After adjustment of $CN_{0.2II}$, the new calculated $CN_{0.05II}$ values rage from 18 to 100 and predominate value change from 55 to 40 (39% area). Adjustment for modified $CN_{0.05II}$ lead in reduction of $CN_{0.2II}$ values specifically in lower CN values. Renault are in agree with reduction of initial abstraction ratio in modified SCS approach.

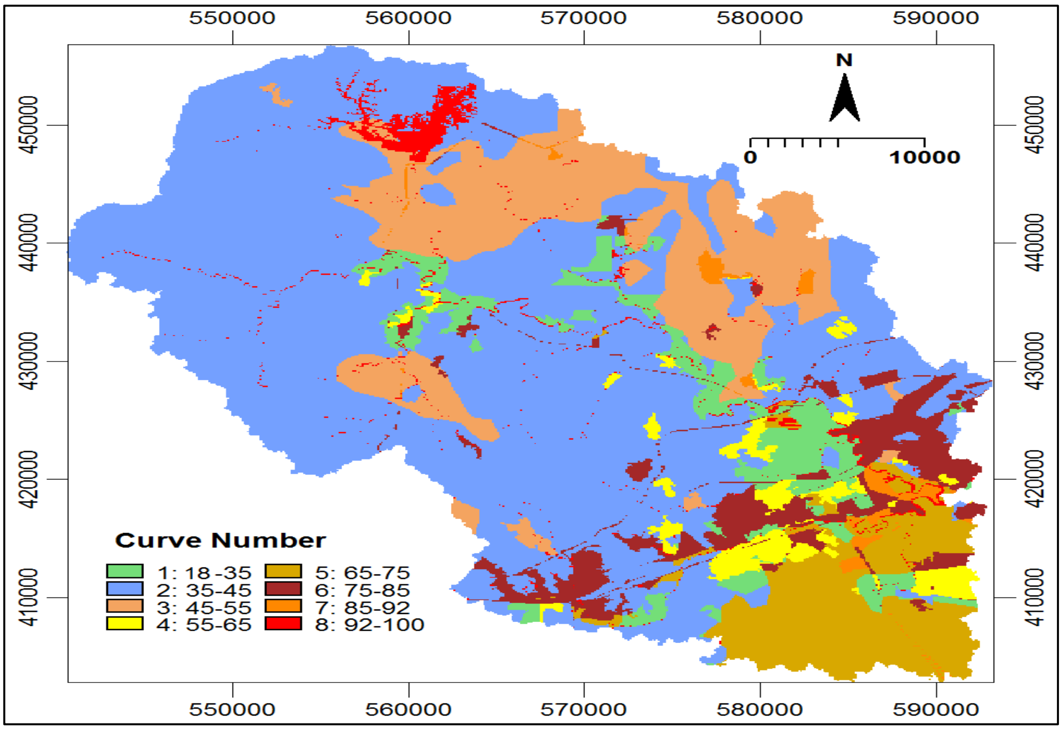


Figure 4.4: Adjusted $CN_{0.05II}$ for Modified SCS Method

4.2.5 Average Slope Adjustment of CN

To obtain the average slope adjustment of CN map, SCS transformation function (equation 4.2) was used in ILWIS commend line. The new generated map shows most susceptible areas for flood runoff generation which modified based on the NRCS indicator. Adjusted CN value for wet condition (hereafter $CN_{0.05III}$) demonstrates slightly increasing in $CN_{0.05II}$ and become almost close to $CN_{0.2II}$ (see figure 4.5). Details of analysis are provided in table 4.1 and table 4.2. In table 4.1, CN values, number of pixel, percentage of area and area assigned for each CN values are reported. In table 4.2 the same parameters for each CN class are presented.

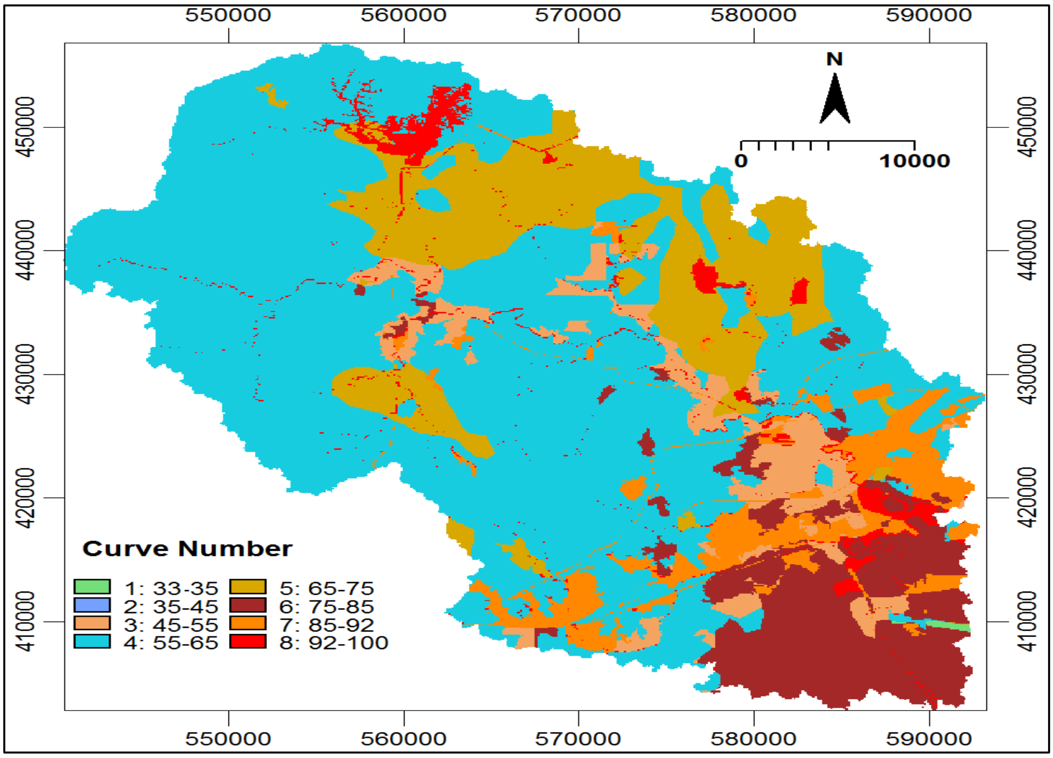


Figure 4.5: Adapted $CN_{0.05III}$ for Wet Condition

Table 4.1: CN Values with Allocated Percentage and Area in KRB

No.	**CN Value**			**Percentage (%)**			**Area (ha)**		
	$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$	$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$	$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$
1	32	18	33	0.08	0.08	0.08	136	136	136
2	48	33	53	1.17	1.17	1.17	1951	1951	1951
3	50	35	55	4.87	4.87	4.87	8153	8153	8153
4	52	37	57	6.03	6.03	6.03	10089	10089	10089
5	54	39	60	0.08	0.08	0.08	140	140	140
6	55	40	61	38.95	38.95	38.95	65227	65227	65227
7	57	42	63	0.10	0.10	0.10	166	166	166
8	58	44	64	12.78	12.78	12.78	21393	21393	21393
9	60	46	66	0.05	0.05	0.05	87	87	87
10	61	47	67	0.58	0.58	0.58	971	971	971
11	63	49	69	7.01	7.01	7.01	11731	11731	11731
12	65	52	71	7.67	7.67	7.67	12849	12849	12849
13	68	55	74	0.01	0.01	0.01	23	23	23
14	73	62	79	2.23	2.23	2.23	3739	3739	3739
15	74	63	80	0.03	0.03	0.71	46	46	1186
16	75	64	82	0.68	0.68	5.00	1140	1140	8374
17	77	67	84	5.00	5.00	2.77	8374	8374	4633
18	79	70	85	2.77	2.77	0.06	4633	4633	107
19	80	71	87	0.06	0.06	0.41	107	107	679
20	83	75	89	0.41	0.41	1.78	679	679	2985
21	85	78	90	1.78	1.78	0.07	2985	2985	124
22	87	80	91	0.07	0.07	2.41	124	124	4039
23	88	82	92	2.41	2.41	2.12	4039	4039	3555
24	89	83	93	2.12	2.12	0.47	3555	3555	782
25	91	86	95	0.47	0.47	0.57	782	782	959
26	93	89	100	0.57	0.57	2.01	959	959	3366
27	100	100	-	2.01	2.01	-	3366	3366	-

Table 4.2: CN Classes with Allocated Percentage and Number of Pixel in KRB

CN Value			Percentage (%)			Number of Pixel		
$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$	$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$	$CN_{0.2}$	$CN_{0.05}$	$CN_{0.05III}$
32-35	18-35	33-35	0.05	6.12	0.08	136	10240	136
46-45	36-45	36-45	0	57.94	0	85560	97015	0
46-55	46-55	46-55	29.95	15.31	6.03	47197	25638	10104
56-65	56-65	56-65	16.52	2.96	57.94	4948	4948	97015
66-75	66-75	66-75	1.73	8.24	15.33	16778	13793	25661
76-85	76-85	76-85	5.87	6.39	10.77	8500	10703	18039
86-92	86-92	86-92	2.98	1.04	6.8	4325	1741	11382
93-100	93-100	93-100	1.51	2.01	1.79	-	3366	3.05

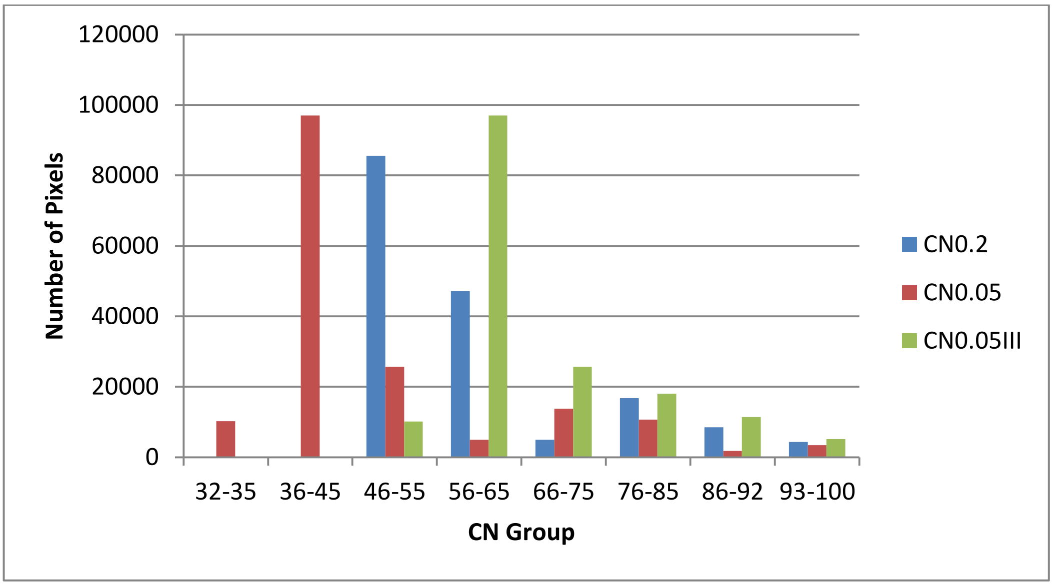


Figure 4.6: Illustration of CN Adjustment by Different Method

4.2.6 Average Slope Adjustment of Modified CN

To obtain the average slope adjustment of modified CN, by calculating average CN for each subbasin using aggregation function of ILWIS (see figure 4.7). Lower average CN is about 60 and mostly in forest LU and higher CN value is about 86 which is obtained for urbanized areas of KRB. Then CN values obtained for reach subbasin was break down into five classes with equal CN interval (see figure 4.8). About 46 % of the study area gives low response to the rainfall and only about 5% percent which is mostly urban area of KRB demonstrate a very high potential for runoff generation and flood.

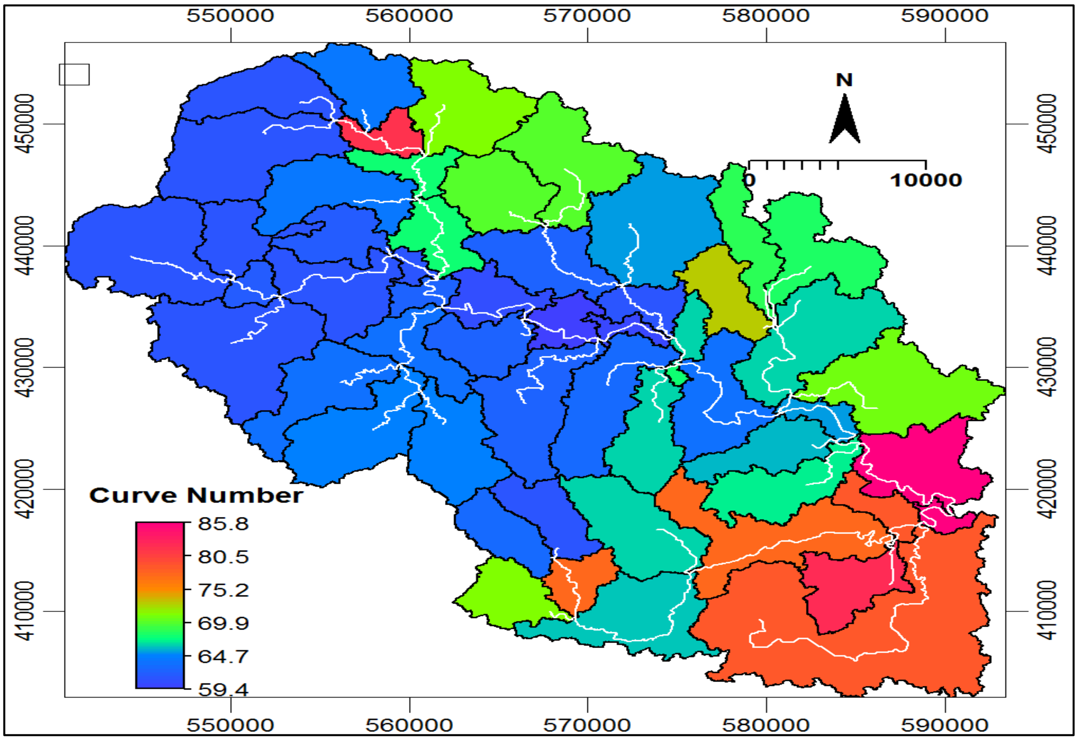


Figure 4.7: Averaged $CN_{0.05III}$ in Subbasin of KRB

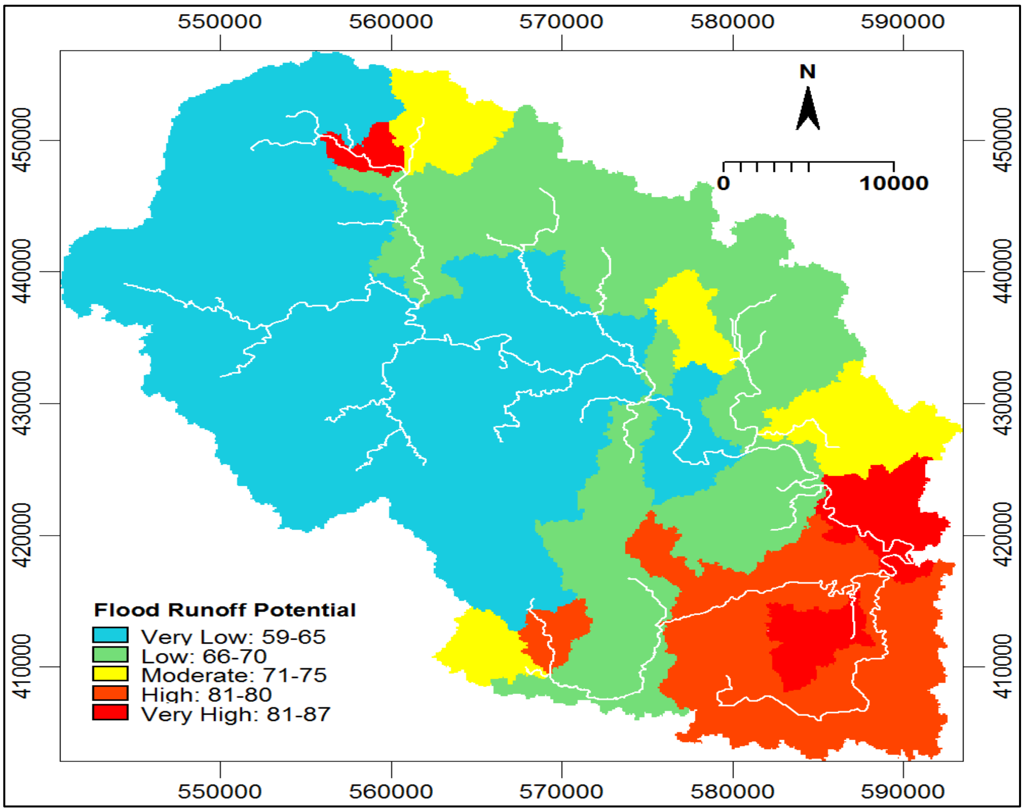


Figure 4.8: Qualitative Classification of $CN_{0.05III}$

Table 4.3: Susceptibility Classes with Allocated $CN_{0.05III}$ Domain, Number of Pixel, Differential Percentage

Susceptibility Class	$CN_{0.05III}$ Domain	Number of Pixel	Differential Percentage	Area (ha)
Low	59-65	77516	46.30	77516
Very Low	66-70	45800	27.35	45800
Moderate	71-75	13696	8.18	13696
High	81-80	22310	13.32	22310
Very High	81-87	8115	4.85	8115

4.3 Rainfall and Runoff Relationship Analysis

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event. In this analysis, three storm events are selected to analyze the rainfall-runoff relationship. Table 4.4 shows the date for every event that was selected.

Table 4.4: Summary Data of Storm Event

Event	Month	Time Duration (day)
1	December 2011	3^{rd} – 31^{st} (28)
2	March 2011	5^{th} – 31^{st} (26)
3	January 2011	4^{th} – 31^{st} (27)

4.4 Analysis and Simulation

This process will be carried out according to the parameter and data that was computed in the HEC-HMS software. Different parameters were used according to the method selected. For example, for SCS method initial abstraction, SCS curve number and etc. were used.

After analyzed and simulated the data, the result in graphic and summary can be obtained. The results can be viewed by right click at the subbasin and click at view result followed by graph, summary table or time series table.

Next procedure is the calibration process. Model calibration is the process of adjusting model parameter values until model result match historical data. The process can be completely manually using engineering judgement by repeatedly adjusting parameters, computing, and inspecting the goodness-of-fit between the computed and observed hydrograph. After the calibration process has done, all the parameters will be used for the other rainfall and flowrate event. In this case, the HEC-HMS will produce the new hydrograph. Validation will be carried out then to test accuracy of other events.

4.4.1 Model Parameters

Different method and different parameters are required to compute in the HEC-HMS program. In this project, the parameters used in SCS method are different.

4.4.1.1 Loss Rate

Initial loss is the value to account for interception and depression storage. No runoff occurs from previous areas until this quantity of precipitation has fallen. Constant loss rate is after the cumulative precipitation exceeds the initial loss, precipitation is lost at this constant loss rate to account for infiltration. Percentage of imperviousness represents the fraction of the area that is impervious, such as buildings, roads, pavements. Table 4.5 and Table 4.6 shows the loss rate parameters for SCS method. SCS curve number is to estimate total excess precipitation for a storm based on cumulative precipitation, soil cover, land used, and antecent moisture.

Table 4.5: Loss Rate Parameter for Modified SCS Method

SCS Curve Number	45.0
Initial Abstraction (mm)	0.2
Imperviousness (%)	38.00

Table 4.6: Loss Rate Parameter for Slope Adjusted SCS Method

SCS Curve Number	62.05
Initial Abstraction (mm)	0.05
Imperviousness (%)	38.95

4.4.1.2 Transform

Standard lag time for SCS method as shown in Table 4.7 from centroid of rainfall exceed the peak flow at the point of analysis.

Table 4.7: Transform Parameter for SCS Method

SCS lag (min)	12

4.4.2 Calibration

4.4.2.1 Modified SCS

Storm water event on December 2011 was selected for the calibration process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results from HEC-HMS shown in Figure 4.9, the peak discharge is 202.1m^3/s and 281.2m^3/s from the observed hydrograph at gauge shown in Figure 4.10. The peak discharges occur at December 2011. The storm water event starts from 00:00 until 00:00 with the 0.600 for the Nash-Sutcliffe.

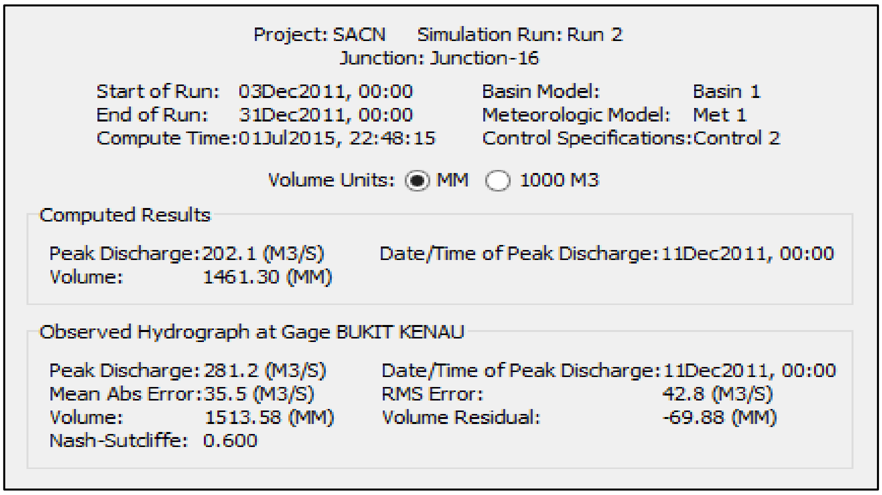


Figure 4.9: Calibration Results Summary Table of December 2011 by using Modified SCS Method.

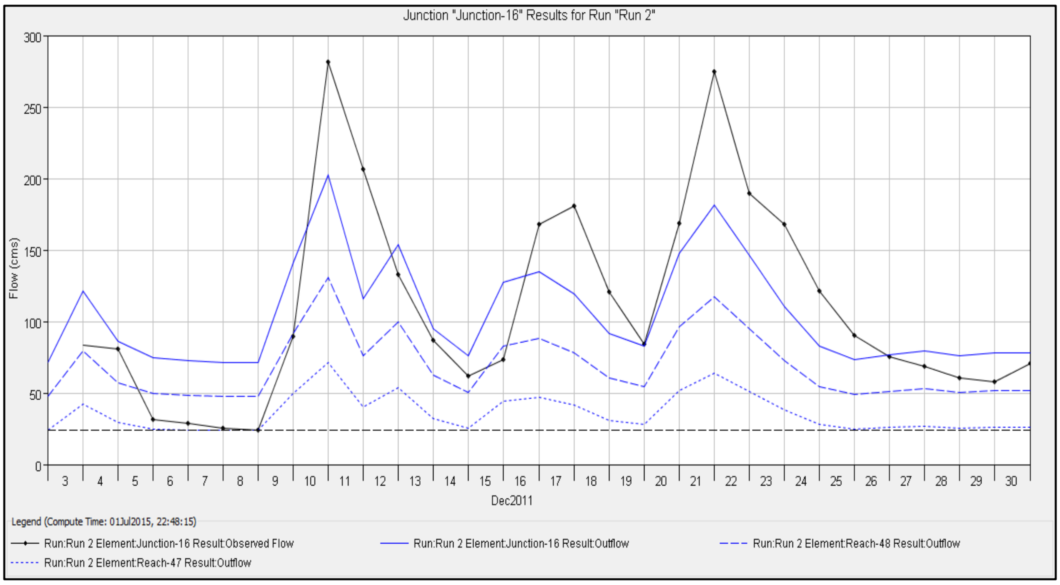
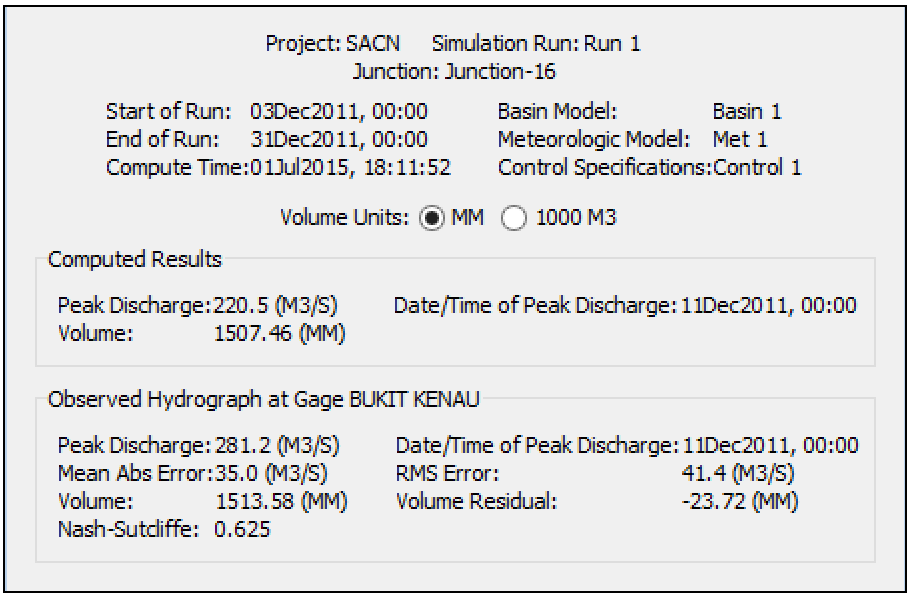


Figure 4.10: Calibration Hydrograph on December 2011 for Modified SCS Method

4.4.2.2 Slope Adjusted SCS

Storm water event on December 2011 was selected for the calibration process. Following is the results of hydrograph and its summary that obtained from HEC-HMS program.

From the computed results from HEC-HMS shown in Figure 4.11, the peak discharge is 220.5m^3/s and 281.2m^3/s from the observed hydrograph at gauge shown in Figure 4.12. The peak discharges occur at 11th December 2011. The storm water event starts from 00:00 until 00:00 with the 0.625 for the Nash-Sutcliffe.



Project: SACN Simulation Run: Run 1
Junction: Junction-16

Start of Run:	03Dec2011, 00:00	Basin Model:	Basin 1
End of Run:	31Dec2011, 00:00	Meteorologic Model:	Met 1
Compute Time:	01Jul2015, 18:11:52	Control Specifications:	Control 1

Volume Units: (●) MM ( ) 1000 M3

Computed Results

Peak Discharge:	220.5 (M3/S)	Date/Time of Peak Discharge:	11Dec2011, 00:00
Volume:	1507.46 (MM)		

Observed Hydrograph at Gage BUKIT KENAU

Peak Discharge:	281.2 (M3/S)	Date/Time of Peak Discharge:	11Dec2011, 00:00
Mean Abs Error:	35.0 (M3/S)	RMS Error:	41.4 (M3/S)
Volume:	1513.58 (MM)	Volume Residual:	-23.72 (MM)
Nash-Sutcliffe:	0.625		

Figure 4.11: Calibration Results Summary Table of December 2011 by using Slope Adjusted SCS Method.

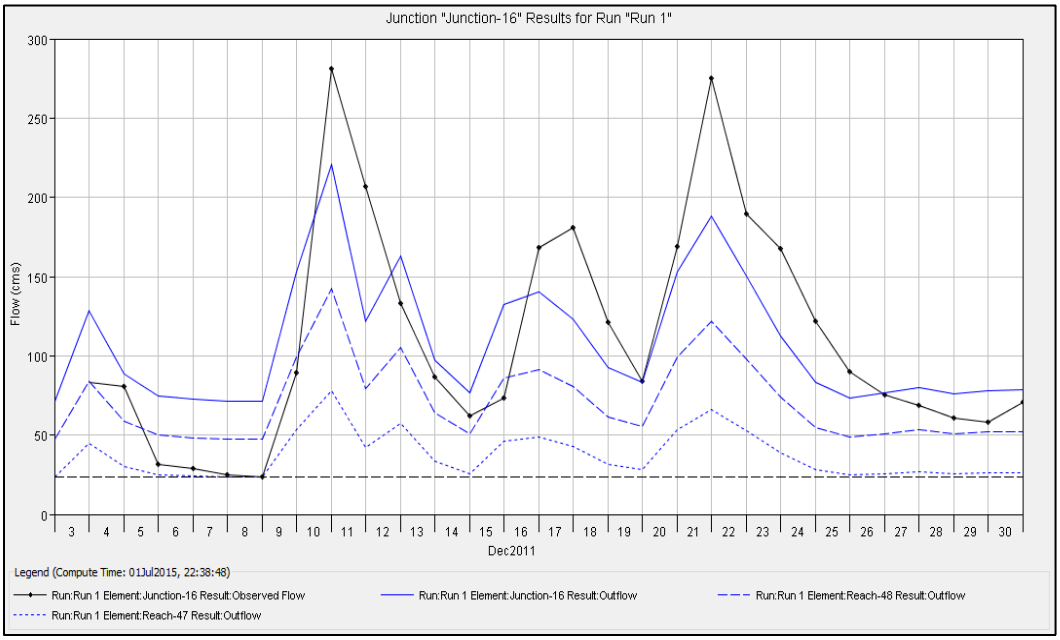


Figure 4.12: Calibration Hydrograph on December 2011 for SCS Method

4.4.3 Validation

4.4.3.1 Modified SCS

The other 2 events are used for the validation process. From the summary table as shown in Figure 4.13, the peak discharge is 251.8m^3/s and 531.9m^3/s from the observed hydrograph at gauge as shown in Figure 4.14. The peak discharge occurs at 11 Mar 2011.

Project: SACN Simulation Run: Run 3
Junction: Junction-16

Start of Run:	05Mar2011, 00:00	Basin Model:	Basin 1
End of Run:	31Mar2011, 00:00	Meteorologic Model:	Met 1
Compute Time:	01Jul2015, 23:51:16	Control Specifications:	Control 3

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge:	251.8 (M3/S)	Date/Time of Peak Discharge:	11Mar2011, 00:00
Volume:	1510.10 (MM)		

Observed Hydrograph at Gage BUKIT KENAU

Peak Discharge:	531.9 (M3/S)	Date/Time of Peak Discharge:	11Mar2011, 00:00
Mean Abs Error:	48.3 (M3/S)	RMS Error:	68.9 (M3/S)
Volume:	1252.71 (MM)	Volume Residual:	235.58 (MM)
Nash-Sutcliffe:	0.442		

Figure 4.13: Validation Results Summary Table of March 2011 by using Modified SCS Method.

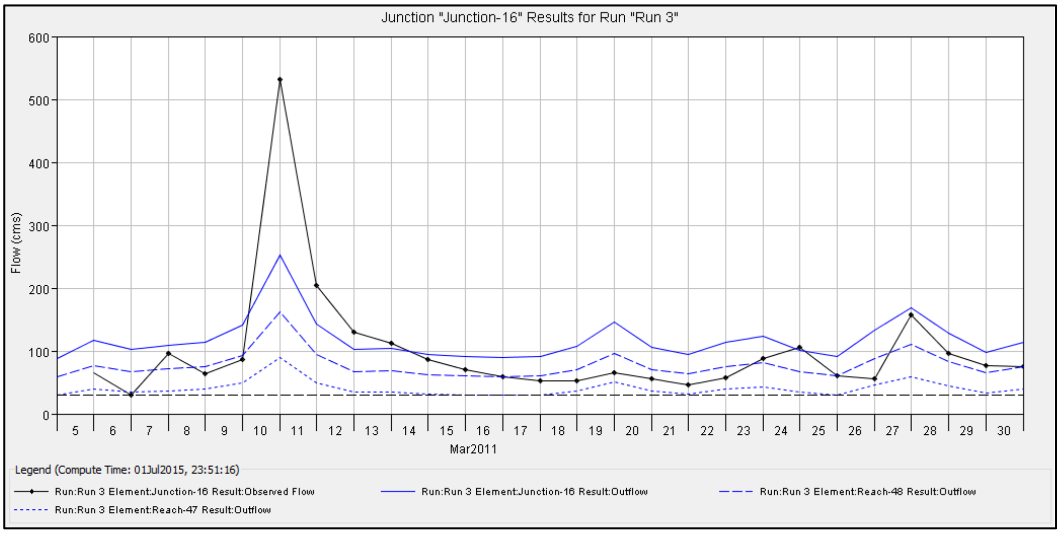
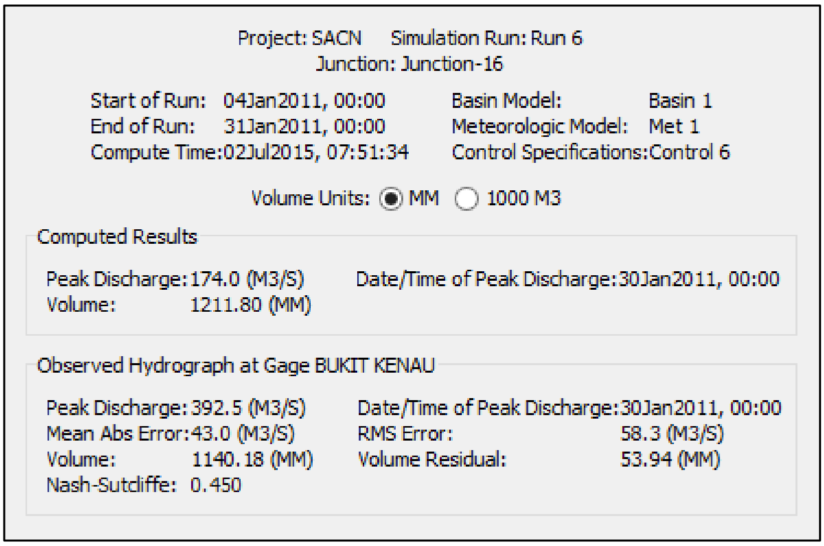


Figure 4.14: Validation Hydrograph on March 2011 for Modified SCS Method

The summary table that was obtained from HEC-HMS as shown in Figure 4.15, the peak discharge is 174.0m^3/s and 392.5m^3/s from the observed hydrograph at gauge as shown in Figure 4.16. The peak discharge occurs at 30th January 2011. The storm water event starts from 00:00 until 00:00 with the 0.450 for the Nash-Sutcliffe.


Project: SACN Simulation Run: Run 6
Junction: Junction-16

Start of Run: 04Jan2011, 00:00 Basin Model: Basin 1
End of Run: 31Jan2011, 00:00 Meteorologic Model: Met 1
Compute Time: 02Jul2015, 07:51:34 Control Specifications: Control 6

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 174.0 (M3/S) Date/Time of Peak Discharge: 30Jan2011, 00:00
Volume: 1211.80 (MM)

Observed Hydrograph at Gage BUKIT KENAU

Peak Discharge: 392.5 (M3/S) Date/Time of Peak Discharge: 30Jan2011, 00:00
Mean Abs Error: 43.0 (M3/S) RMS Error: 58.3 (M3/S)
Volume: 1140.18 (MM) Volume Residual: 53.94 (MM)
Nash-Sutcliffe: 0.450

Figure 4.15: Validation Results Summary Table of January 2011 by using Modified SCS Method.

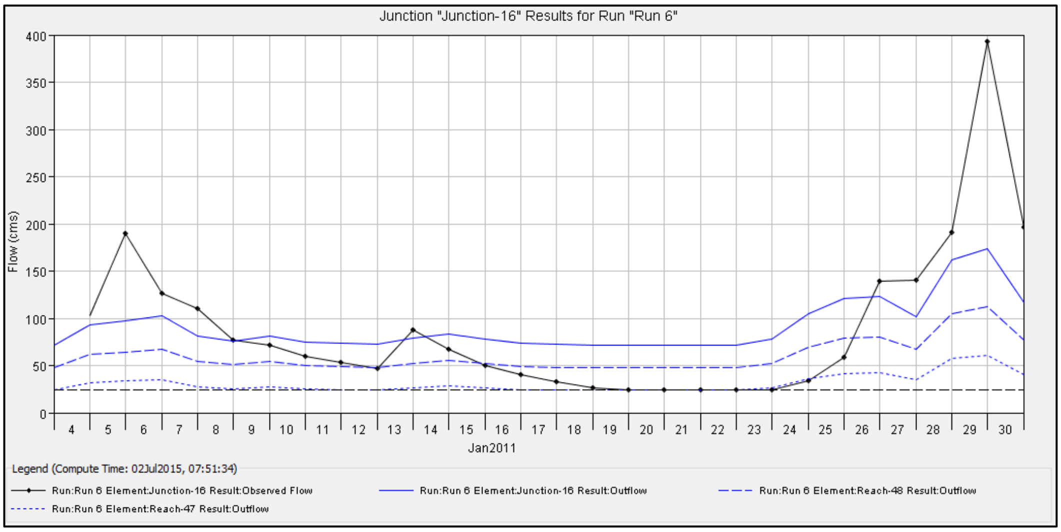


Figure 4.16: Validation Hydrograph on January 2012 for Modified SCS Method

4.4.3.2 Slope Adjusted SCS

The other 2 events are used for the validation process. From the summary table as shown in Figure 4.17, the peak discharge is 275.4m^3/s and 531.9m^3/s from the observed hydrograph at gauge as shown in Figure 4.18. The peak discharge occurs at 11th March 2011.

Project: SACN Simulation Run: Run 4
Junction: Junction-16

Start of Run:	05Mar2011, 00:00	Basin Model:	Basin 1
End of Run:	31Mar2011, 00:00	Meteorologic Model:	Met 1
Compute Time:	02Jul2015, 00:07:34	Control Specifications:	Control 4

Volume Units: (●) MM ( ) 1000 M3

Computed Results

Peak Discharge:	275.4 (M3/S)	Date/Time of Peak Discharge:	11Mar2011, 00:00
Volume:	1554.28 (MM)		

Observed Hydrograph at Gage BUKIT KENAU

Peak Discharge:	531.9 (M3/S)	Date/Time of Peak Discharge:	11Mar2011, 00:00
Mean Abs Error:	49.0 (M3/S)	RMS Error:	66.7 (M3/S)
Volume:	1252.71 (MM)	Volume Residual:	279.76 (MM)
Nash-Sutcliffe:	0.478		

Figure 4.17: Validation Results Summary Table of March 2011 by using Slope Adjusted SCS Method.

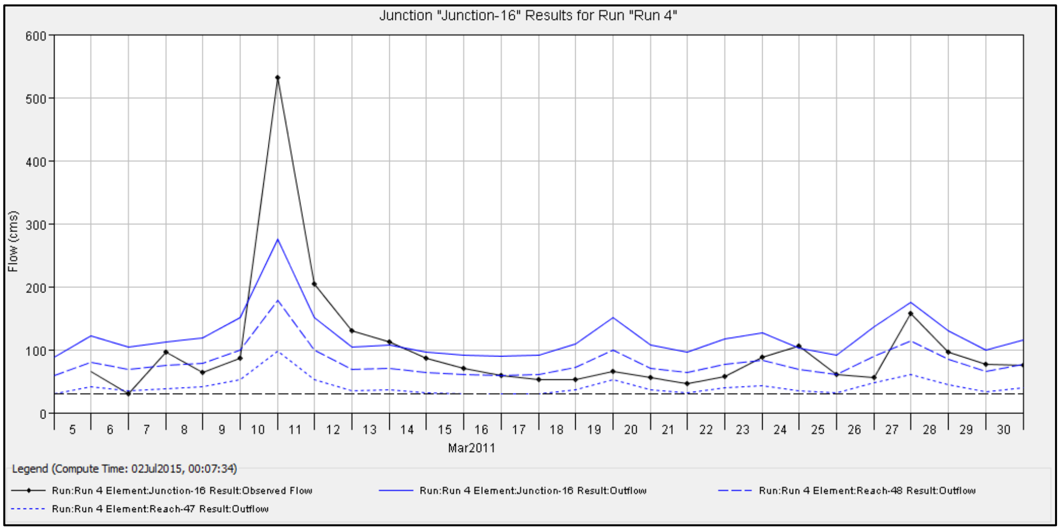
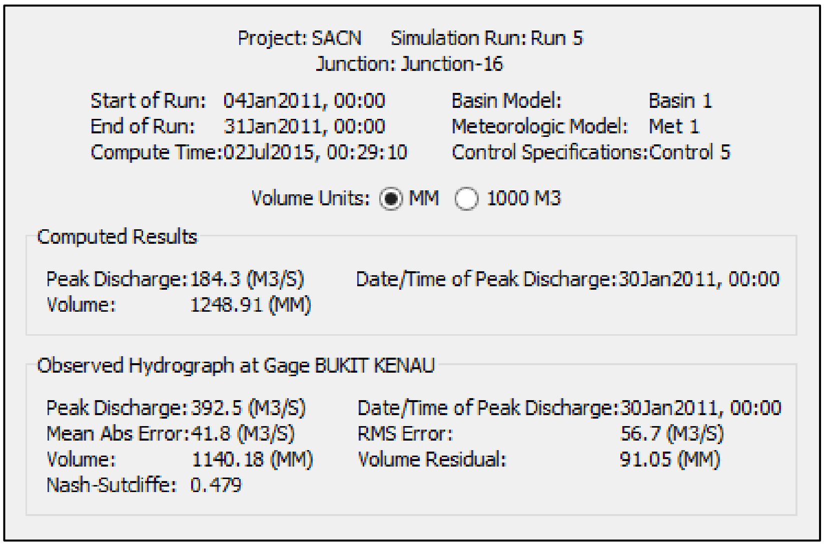


Figure 4.18: Validation Hydrograph on March 2011 for Slope Adjusted SCS Method

The summary table that was obtained from HEC-HMS as shown in Figure 4.19, the peak discharge is 184.3m^3/s and 392.5m^3/s from the observed hydrograph at gauge as shown in Figure 4.20. The peak discharge occurs at 30th January 2011. The storm water event starts from 00:00 until 00:00 with the 0.479 for the Nash-Sutcliffe.



Project: SACN Simulation Run: Run 5
Junction: Junction-16

Start of Run:	04Jan2011, 00:00	Basin Model:	Basin 1
End of Run:	31Jan2011, 00:00	Meteorologic Model:	Met 1
Compute Time:	02Jul2015, 00:29:10	Control Specifications:	Control 5

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge:	184.3 (M3/S)	Date/Time of Peak Discharge:	30Jan2011, 00:00
Volume:	1248.91 (MM)		

Observed Hydrograph at Gage BUKIT KENAU

Peak Discharge:	392.5 (M3/S)	Date/Time of Peak Discharge:	30Jan2011, 00:00
Mean Abs Error:	41.8 (M3/S)	RMS Error:	56.7 (M3/S)
Volume:	1140.18 (MM)	Volume Residual:	91.05 (MM)
Nash-Sutcliffe:	0.479		

Figure 4.19: Validation Results Summary Table of January 2011 by using Slope Adjusted SCS Method.

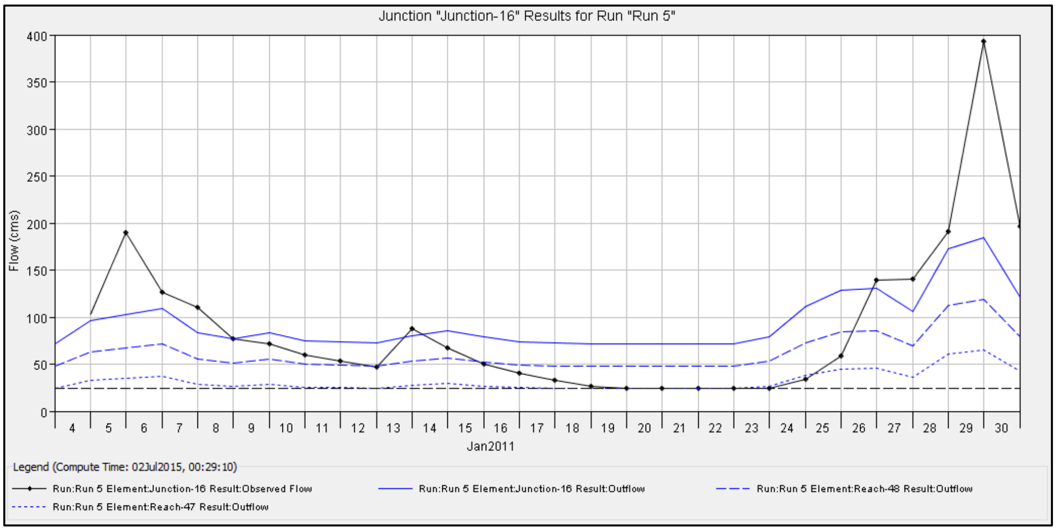


Figure 4.20: Validation Hydrograph on January 2011 for Slope Adjusted SCS Method

4.5 Efficiency Index

The accuracy of results computed by HEC-HMS is determined by using one of the statics methods which is the Efficiency Index. Efficiency Index can be defined as below:

$$\text{Efficiency Index} = SS\ Total - SS\ Error / SS\ Total \qquad (4.3)$$

SS Total, the total sum of squared error is the sum of squared error when predicting using the mean; the sum of the squared products of all the actual values minus the mean. The formula of SS Total is as follows:

$$\text{SS Total} = \sum (Qi - Qag)^2 \qquad (4.4)$$

SS Error, the sum of squared error is the sum of squared error when using the prediction model; the sum of squared products of all the actual values minus their predicted values. The formula of SS Error is as below:

$$\text{SS Error} = \sum (Qi\text{-}Fi)^2 \qquad (4.5)$$

Where,

Qi = Observed Discharge at time i

Qag = Mean of Observed Discharge, $Qag = \sum Qi / N$

N = Number of Discharge Data

Fi = Simulated Discharge at Time i

With a good prediction, the SS Error should be less than the SS Total. This comparison is an indicator of the accuracy of this prediction model and is called the proportionate reduction in error, $(R)^2$. This proportion is the percentage of variance. With a higher accuracy of the model can be achieved (Wong, 2005).

4.5.1 Efficiency Index for Calibration Process

4.5.1.1 Modified SCS

Table 4.8 shows the data of Efficiency Index of Calibration Process for Modified SCS method for December 2011.

Table 4.8: Data of Efficiency Index of Calibration process for Modified SCS Method on December 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
3-Dec-11	53.7	71.7	-18	324	-55.217	3048.94
4-Dec-11	83.3	117.1	-33.8	1142.44	-25.617	656.241
5-Dec-11	80.5	89.1	-8.6	73.96	-28.417	807.537
6-Dec-11	31.5	75.7	-44.2	1953.64	-77.417	5993.42
7-Dec-11	28.7	72.9	-44.2	1953.64	-80.217	6434.8
8-Dec-11	25.2	71.9	-46.7	2180.89	-83.717	7008.57
9-Dec-11	23.8	71.7	-47.9	2294.41	-85.117	7244.94
10-Dec-11	89.6	135.3	-45.7	2088.49	-19.317	373.154
11-Dec-11	281.2	196.6	84.6	7157.16	172.283	29681.4
12-Dec-11	206.5	122.4	84.1	7072.81	97.5828	9522.4
13-Dec-11	132.8	151	-18.2	331.24	23.8828	570.388
14-Dec-11	86.5	99.8	-13.3	176.89	-22.417	502.531
15-Dec-11	61.9	77.9	-16	256	-47.017	2210.62
16-Dec-11	73.5	123.3	-49.8	2480.04	-35.417	1254.38
17-Dec-11	168	134.2	33.8	1142.44	59.0828	3490.78
18-Dec-11	180.8	120.8	60	3600	71.8828	5167.14
19-Dec-11	120.9	93.8	27.1	734.41	11.9828	143.587
20-Dec-11	84.1	83.6	0.5	0.25	-24.817	615.893
21-Dec-11	168.8	142.7	26.1	681.21	59.8828	3585.95
22-Dec-11	275	178.7	96.3	9273.69	166.083	27583.5
23-Dec-11	189.5	149.3	40.2	1616.04	80.5828	6493.59
24-Dec-11	167.7	113.9	53.8	2894.44	58.7828	3455.42
25-Dec-11	121.5	85.1	36.4	1324.96	12.5828	158.327
26-Dec-11	90	74.7	15.3	234.09	-18.917	357.86
27-Dec-11	75.3	76.6	-1.3	1.69	-33.617	1130.12
28-Dec-11	68.8	79.7	-10.9	118.81	-40.117	1609.39
29-Dec-11	60.7	76.4	-15.7	246.49	-48.217	2324.9
30-Dec-11	58.1	78.1	-20	400	-50.817	2582.39
31-Dec-11	70.7	78.3	-7.6	57.76	-38.217	1460.55

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 3158.6 / 29

= 108.917m^3/s

Efficiency Index = SS Total – SS Error / SS Total

= 135469 – 51811.9 / 135469

= 66.46%

4.5.1.2 Slope Adjusted SCS

Table 4.9 shows the data of Efficiency Index of Calibration Process for Slope Adjusted SCS method for December 2011.

Table 4.9: Data of Efficiency Index of Calibration process for Slope Adjusted SCS Method on December 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
3-Dec-11	53.7	71.7	-18	324	-55.2172	3048.944
4-Dec-11	83.3	117.1	-33.8	1142.44	-25.6172	656.2409
5-Dec-11	80.5	89.1	-8.6	73.96	-28.4172	807.5373
6-Dec-11	31.5	75.7	-44.2	1953.64	-77.4172	5993.423
7-Dec-11	28.7	72.9	-44.2	1953.64	-80.2172	6434.799
8-Dec-11	25.2	71.9	-46.7	2180.89	-83.7172	7008.57
9-Dec-11	23.8	71.7	-47.9	2294.41	-85.1172	7244.938
10-Dec-11	89.6	135.3	-45.7	2088.49	-19.3172	373.1542
11-Dec-11	281.2	196.6	84.6	7157.16	172.2828	29681.36
12-Dec-11	206.5	122.4	84.1	7072.81	97.5828	9522.403
13-Dec-11	132.8	151	-18.2	331.24	23.8828	570.3881
14-Dec-11	86.5	99.8	-13.3	176.89	-22.4172	502.5309
15-Dec-11	61.9	77.9	-16	256	-47.0172	2210.617
16-Dec-11	73.5	123.3	-49.8	2480.04	-35.4172	1254.378
17-Dec-11	168	134.2	33.8	1142.44	59.0828	3490.777
18-Dec-11	180.8	120.8	60	3600	71.8828	5167.137
19-Dec-11	120.9	93.8	27.1	734.41	11.9828	143.5875
20-Dec-11	84.1	83.6	0.5	0.25	-24.8172	615.8934
21-Dec-11	168.8	142.7	26.1	681.21	59.8828	3585.95
22-Dec-11	275	178.7	96.3	9273.69	166.0828	27583.5
23-Dec-11	189.5	149.3	40.2	1616.04	80.5828	6493.588
24-Dec-11	167.7	113.9	53.8	2894.44	58.7828	3455.418
25-Dec-11	121.5	85.1	36.4	1324.96	12.5828	158.3269
26-Dec-11	90	74.7	15.3	234.09	-18.9172	357.8605
27-Dec-11	75.3	76.6	-1.3	1.69	-33.6172	1130.116
28-Dec-11	68.8	79.7	-10.9	118.81	-40.1172	1609.39
29-Dec-11	60.7	76.4	-15.7	246.49	-48.2172	2324.898
30-Dec-11	58.1	78.1	-20	400	-50.8172	2582.388
31-Dec-11	70.7	78.3	-7.6	57.76	-38.2172	1460.554

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 3158.6 / 29

= 108.917m^3/s

Efficiency Index = *SS Total – SS Error / SS Total*

= 135468.7 – 51811.89 / 135468.7

= 61.75%

4.5.2 Efficiency Index for Validation Process

4.5.2.1 Modified SCS

Table 4.10 shows the table of calculation for validation process. The same procedure and formula are used for the other 2 events.

Table 4.10: Data of Efficiency Index of Validation process for Modified SCS Method on March 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
5-Mar-11	65.3	97.9	-32.6	1062.76	-33.842	1145.3
6-Mar-11	29.5	86.1	-56.6	3203.56	-69.642	4850.05
7-Mar-11	96.2	91.3	4.9	24.01	-2.9423	8.65719
8-Mar-11	64.4	96.3	-31.9	1017.61	-34.742	1207.03
9-Mar-11	86	121.7	-35.7	1274.49	-13.142	172.72
10-Mar-11	531.9	225.2	306.7	94064.9	432.758	187279
11-Mar-11	204	134.5	69.5	4830.25	104.858	10995.1
12-Mar-11	129.4	88.8	40.6	1648.36	30.2577	915.528
13-Mar-11	111.6	87.9	23.7	561.69	12.4577	155.194
14-Mar-11	86.3	78.6	7.7	59.29	-12.842	164.925
15-Mar-11	70.5	74.1	-3.6	12.96	-28.642	820.382
16-Mar-11	59.4	72.3	-12.9	166.41	-39.742	1579.45
17-Mar-11	51.9	73.5	-21.6	466.56	-47.242	2231.84
18-Mar-11	52.3	88.9	-36.6	1339.56	-46.842	2194.2
19-Mar-11	64.8	125.6	-60.8	3696.64	-34.342	1179.39
20-Mar-11	55.5	91.4	-35.9	1288.81	-43.642	1904.65
21-Mar-11	45.5	79.1	-33.6	1128.96	-53.642	2877.5
22-Mar-11	57.7	96.1	-38.4	1474.56	-41.442	1717.47
23-Mar-11	88.6	106.1	-17.5	306.25	-10.542	111.14
24-Mar-11	105.9	86.5	19.4	376.36	6.75769	45.6664
25-Mar-11	60.2	75.5	-15.3	234.09	-38.942	1516.5
26-Mar-11	56.2	112.7	-56.5	3192.25	-42.942	1844.04
27-Mar-11	157.5	149.3	8.2	67.24	58.3577	3405.62
28-Mar-11	95.9	113.9	-18	324	-3.2423	10.5126
29-Mar-11	76.8	83.6	-6.8	46.24	-22.342	499.179
30-Mar-11	74.4	95.8	-21.4	457.96	-24.742	612.182

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 2577.7 / 26

= 99.142m^3/s

Efficiency Index = *SS Total – SS Error / SS Total*

= 229443.5 – 122325.8 / 229443.5

= 38.87%

Table 4.11 shows the table of calculation for validation process. The same procedure and formula are used for the other 2 events.

Table 4.11: Data of Efficiency Index of Validation process for Modified SCS Method on January 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
4-Jan-11	100.1	71.7	28.4	806.56	10.4393	108.979
5-Jan-11	103	93.1	9.9	98.01	13.3393	177.937
6-Jan-11	190	97.6	92.4	8537.76	100.339	10068
7-Jan-11	126.1	102.8	23.3	542.89	36.4393	1327.82
8-Jan-11	110.7	81.7	29	841	21.0393	442.652
9-Jan-11	76.8	76.1	0.7	0.49	-12.861	165.398
10-Jan-11	71.5	81.7	-10.2	104.04	-18.161	329.811
11-Jan-11	59.3	74.5	-15.2	231.04	-30.361	921.773
12-Jan-11	53.5	73.7	-20.2	408.04	-36.161	1307.6
13-Jan-11	46.5	72.2	-25.7	660.49	-43.161	1862.85
14-Jan-11	87.9	78.5	9.4	88.36	-1.7607	3.1001
15-Jan-11	66.7	83.6	-16.9	285.61	-22.961	527.194
16-Jan-11	49.5	78.1	-28.6	817.96	-40.161	1612.88
17-Jan-11	40	73.8	-33.8	1142.44	-49.661	2466.19
18-Jan-11	32.6	72.2	-39.6	1568.16	-57.061	3255.92
19-Jan-11	26.1	71.8	-45.7	2088.49	-63.561	4039.96
20-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
21-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
22-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
23-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
24-Jan-11	23.9	78.3	-54.4	2959.36	-65.761	4324.47
25-Jan-11	33.7	105.1	-71.4	5097.96	-55.961	3131.6
26-Jan-11	58.2	120.6	-62.4	3893.76	-31.461	989.776
27-Jan-11	139.2	122.8	16.4	268.96	49.5393	2454.14
28-Jan-11	140.1	102.1	38	1444	50.4393	2544.12
29-Jan-11	190.8	162.2	28.6	817.96	101.139	10229.2
30-Jan-11	392.5	174	218.5	47742.3	302.839	91711.6
31-Jan-11	196.2	117.1	79.1	6256.81	106.539	11350.6

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 2510.5 / 28

= 89.661m^3/s

Efficiency Index = *SS Total – SS Error / SS Total*

= 172651.4 – 95841.76 / 172651.4

= 40.49%

4.5.2.2 Slope Adjusted SCS

Table 4.12 shows the table of calculation for validation process. The same procedure and formula are used for the other 2 events.

Table 4.12: Data of Efficiency Index of Validation process for SCS Method on March 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
5-Mar-11	65.3	97.9	-32.6	1062.76	-33.842	1145.3
6-Mar-11	29.5	86.1	-56.6	3203.56	-69.642	4850.05
7-Mar-11	96.2	91.3	4.9	24.01	-2.9423	8.65719
8-Mar-11	64.4	96.3	-31.9	1017.61	-34.742	1207.03
9-Mar-11	86	121.7	-35.7	1274.49	-13.142	172.72
10-Mar-11	531.9	225.2	306.7	94064.9	432.758	187279
11-Mar-11	204	134.5	69.5	4830.25	104.858	10995.1
12-Mar-11	129.4	88.8	40.6	1648.36	30.2577	915.528
13-Mar-11	111.6	87.9	23.7	561.69	12.4577	155.194
14-Mar-11	86.3	78.6	7.7	59.29	-12.842	164.925
15-Mar-11	70.5	74.1	-3.6	12.96	-28.642	820.382
16-Mar-11	59.4	72.3	-12.9	166.41	-39.742	1579.45
17-Mar-11	51.9	73.5	-21.6	466.56	-47.242	2231.84
18-Mar-11	52.3	88.9	-36.6	1339.56	-46.842	2194.2
19-Mar-11	64.8	125.6	-60.8	3696.64	-34.342	1179.39
20-Mar-11	55.5	91.4	-35.9	1288.81	-43.642	1904.65
21-Mar-11	45.5	79.1	-33.6	1128.96	-53.642	2877.5
22-Mar-11	57.7	96.1	-38.4	1474.56	-41.442	1717.47
23-Mar-11	88.6	106.1	-17.5	306.25	-10.542	111.14
24-Mar-11	105.9	86.5	19.4	376.36	6.75769	45.6664
25-Mar-11	60.2	75.5	-15.3	234.09	-38.942	1516.5
26-Mar-11	56.2	112.7	-56.5	3192.25	-42.942	1844.04
27-Mar-11	157.5	149.3	8.2	67.24	58.3577	3405.62
28-Mar-11	95.9	113.9	-18	324	-3.2423	10.5126
29-Mar-11	76.8	83.6	-6.8	46.24	-22.342	499.179
30-Mar-11	74.4	95.8	-21.4	457.96	-24.742	612.182

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 2577.7 / 26

= 99.142m^3/s

Efficiency Index = *SS Total – SS Error / SS Total*

= 229443.5 – 122325.8 / 229443.5

= 46.69%

Table 4.13 shows the table of calculation for validation process. The same procedure and formula are used for the other 2 events.

Table 4.13: Data of Efficiency Index of Validation process for Slope Adjusted SCS Method on January 2011

Date	*Qi*	*Fi*	*(Qi-Fi)*	*(Qi-Fi)^2*	*Qi-Qag*	*(Qi-Qag)^2*
4-Jan-11	100.1	71.7	28.4	806.56	10.4393	108.979
5-Jan-11	103	91.4	11.6	134.56	13.3393	177.937
6-Jan-11	190	97.2	92.8	8611.84	100.339	10068
7-Jan-11	126.1	102.4	23.7	561.69	36.4393	1327.82
8-Jan-11	110.7	83.4	27.3	745.29	21.0393	442.652
9-Jan-11	76.8	76.6	0.2	0.04	-12.861	165.398
10-Jan-11	71.5	81.2	-9.7	94.09	-18.161	329.811
11-Jan-11	59.3	75.1	-15.8	249.64	-30.361	921.773
12-Jan-11	53.5	73.8	-20.3	412.09	-36.161	1307.6
13-Jan-11	46.5	72.4	-25.9	670.81	-43.161	1862.85
14-Jan-11	87.9	78	9.9	98.01	-1.7607	3.1001
15-Jan-11	66.7	83.1	-16.4	268.96	-22.961	527.194
16-Jan-11	49.5	78.5	-29	841	-40.161	1612.88
17-Jan-11	40	74.1	-34.1	1162.81	-49.661	2466.19
18-Jan-11	32.6	72.3	-39.7	1576.09	-57.061	3255.92
19-Jan-11	26.1	71.8	-45.7	2088.49	-63.561	4039.96
20-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
21-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
22-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
23-Jan-11	23.9	71.7	-47.8	2284.84	-65.761	4324.47
24-Jan-11	23.9	77.7	-53.8	2894.44	-65.761	4324.47
25-Jan-11	33.7	102.9	-69.2	4788.64	-55.961	3131.6
26-Jan-11	58.2	119.3	-61.1	3733.21	-31.461	989.776
27-Jan-11	139.2	122.6	16.6	275.56	49.5393	2454.14
28-Jan-11	140.1	103.8	36.3	1317.69	50.4393	2544.12
29-Jan-11	190.8	157.4	33.4	1115.56	101.139	10229.2
30-Jan-11	392.5	172.8	219.7	48268.1	302.839	91711.6
31-Jan-11	196.2	121.6	74.6	5565.16	106.539	11350.6

Calculation of Efficiency Index for

Mean of Observed discharge, Qag = $\sum Qi / N$

= 2510.5 / 28

= 89.661m^3/s

Efficiency Index = *SS Total – SS Error / SS Total*

= 172651 – 95419.7 / 172651

= 44.73%

4.5.3 Summary of Efficiency Index

Summary of Efficiency Index for all three storm events are shown in Table 4.14 for both SCS method. From table 4.14, the average Efficiency Index for both Modified and Slope Adjusted SCS methods are 48.61% and 50.97%. By using HEC-HMS analysis and simulation, it can conclude that Slope Adjusted SCS method is the best method for KRB in designing drainage density and slope system.

Table 4.14: Summary of Efficiency Index

Month	Method	
	Modifies SCS (%)	Slope Adjusted SCS (%)
December	66.46	61.75
March	38.87	46.69
January	40.49	44.73
Average	48.61	50.97

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Introduction

After the simulation and comparison of the flow rate by using HEC-HMS program, the best method can be selected for designing the drainage system in KRB. The comparison of flow rate is important to determine either Modified SCS or Slope Adjusted SCS method is the most ideal method to be used in designing drainage density and slope in KRB.

5.2. Summary of Study

As a conclusion, the objectives of this study are achieved. There are to determine the rainfall runoff relationship and to compare the rainfall runoff analysis using SCS method.

All the storm events shows a similar pattern of hydrograph that is when the flow rate increase until it reaches the peak flow when the precipitation increase. But when the rainfall started to decreased the flow rate also decreased. It shows that when the rainfall increases, the flowrate also increase and when the rainfall decreases, the flow rate also decreases.

By using HEC-HMS analysis and simulation, it can conclude that the Slope Adjusted SCS method is the best method for KRB drainage system. This is because Slope Adjusted SCS method has the highest average Efficiency Index compare to Modified SCS method. From the calculation of Efficiency Index, the average Efficiency Index for both Modified SCS and Slope Adjusted SCS are 48.61% and 50.97%.

Moreover, the Nash-Sutcliffe model efficiency coefficient shows that the Calibration process by using Slope Adjusted SCS model indicate that the model predictions are as accurate as the mean of the observed data. Which it is corresponds to a perfect match of modeled discharge to the observed data as compared to the Modified SCS method. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

It should be noted that Nash-Sutcliffe efficiencies can also be used to quantitatively describe the accuracy of model outputs other than discharge. This method can be used to describe the predictive accuracy of other model as long as there is observed data to compare the model results to. For example, Nash-Sutcliffe efficiencies have been reported in scientific literature for model simulations of discharge and water quality constituents such as sediment, nitrogen and phosphorus loading.

5.3. Recommendations for Future Studies

The methodology used here is not limited to KRB and can be use in other are with different climate condition. Optimistically, the map of KRB drainage system must be clearly enough to shows the invert level so that the direction of the flow can be clearly shown and determined. The rainfall data and the flowrate data should be taken throughout the whole year so that sufficient data can be taken to analyze the rainfall runoff relationship. More events can be selected to obtain more accurate results for the study. The flow rate must be taken more than one point. This is because different points of outlets have different flow rate and may give variety of data.

The concept of runoff CN was successfully employed to develop a flood runoff susceptibility map for KRB, Malaysia. This study also demonstrates the practical use of GIS tool in spatial analysis for hydrological process. The CN was adjusted for Modified SCS and Slope Adjusted method. It was found the adjustment for new initial abstraction ratio lead to decrease the $CN_{0.05II}$ values specifically for smaller $CN_{0.2II}$. The $CN_{0.2II}$ value was found to be ranged from 32 to 100 in KRB. After adjustment for new initial abstraction ratio (0.05), $CN_{0.05III}$ value was starched within the 18 to 100.

The study shown that runoff CN is capable to provide a reasonable indication for flood susceptibility of KBR. However, the level of accuracy, highly depend on the scale of HSG and LU maps and the methodology used for generation of those data. In addition, enough experience with deep understanding of CN theory is significantly important in successful indication and adaptation of CN values in standard tables with the real case studies. Result of this part of research can be used directly in distributed, semi-distributed of lumped model for further hydrological process.

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