

## Impact of Infiltration Methods on the Accuracy of Rainfall-Runoff Simulation

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**Abstract:** In this research, attempts are made to evaluate the performance of HEC-HMS (Hydrological modeling) in simulating the rainfall-runoff using two different rainfall infiltration methods. The rainfall-runoff process for the study area which consist of two catchments namely kenyir catchment and Berang catchment, Terengganu, Malaysia is simulated using HEC-HMS program. Two methods for estimating infiltration (rainfall abstraction losses) are built in the program. These methods are SCS Curve Number method and Green and Ampt method. The impact of selected method on the accuracy of rainfall-runoff simulation is studied. Statistical analysis include the computation of the coefficient of determination ( $R^2$ ), the mean square error (MSE) and the Mean Absolute Percentage Error (MAPE) were used to check the accuracy of HEC-HMS simulations using the two infiltration methods. The result showed that the errors in the simulation output using the SCS Curve Number method were 6.5% for Berang catchment and 8.2% for Kenyir catchment, while the errors in the simulation output using Green and Ampt method were 9.13% for Berang catchment and 11.11% for Kenyir catchment. As a conclusion, it is found that the output of HEC-HMS program is in agreement with the historical recorded data and it is recommended to use the SCS Curve Number infiltration method for the tropical catchment due to its low error in simulation output.

**Key word:** Green and Ampt method, HEC HMS program, SCS curve number method, simulation, statistical test

## INTRODUCTION

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the rainfall-runoff processes of dendritic drainage basins. It can be applicable to a wide range of geographic areas for solving the widest possible range of problems. Hydrographs produced 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 systems operation (HEC, 2000).

Infiltration is the process by which water on the ground surface enter the soil. Infiltration rate is a measure of the rate at which soil is able to absorb rainfall. The rate decreases as the soil becomes saturated. If precipitation rate exceeds the infiltration rate, runoff will usually occur. The rate of infiltration is affected by the soil characteristic including ease of entry, storage capacity and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil

temperature and rainfall intensity all play a roll in controlling infiltration rate and capacity (Mays, 2005).

The SCS Curve Number method and the Green and Ampt method are the most commonly used method for estimating the infiltration in the watershed. The SCS curve number methods was used by Knebl *et al.* (2004) to develop a flood modeling integrated with GIS and hydrological model HEC-HMS to simulate the flood in the San Antonio River basin. Simulation the impact of land use on the runoff using the SCS curve number has been studied by Ali *et al.* (2011) in Pakistan and Zhi-Hua, *et al.*, (2008), Yin *et al.* (2009) and Bo *et al.* (2011) in China. From another hand many researchers applied Green and Ampt infiltration method in their hydrological studies to simulate the peak discharge such as Russell and Curtis (1972), Xuefeng and Miguel (2005), Shu (1978), Childs and Bybordi (1969), Liu *et al.* (2011), Kale and Sahoo (2011) and Wang *et al.* (1999).

The main objective of this study is to evaluate the performance of the HEC-HMS program in simulating the rainfall-runoff for the Kenyir and Berang catchments with two different rainfall abstraction losses methods (infiltration methods).

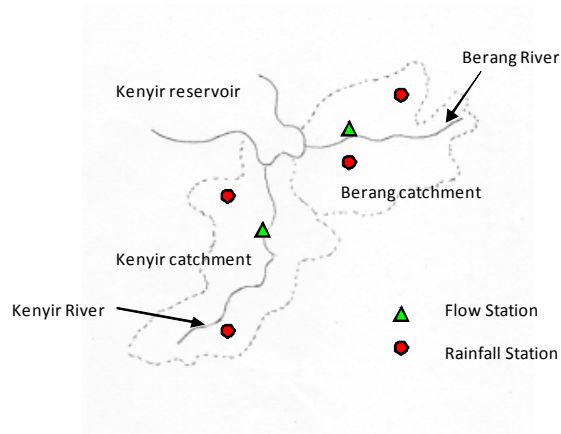


Fig. 1: Kenyir catchment and Berang catchment within the study area

Table 1: Summary of simulation methods used in the study

| Category      | Method           | Description  |
|---------------|------------------|--|
| Runoff volume | Loss method      | In this study two methods have been used to compute losses from precipitation. First SCS curve number method, second green and Ampt method, in order to evaluate the suitability of each method for simulation of runoff for the study area. |
| Direct runoff | Transform method | This method describes what happens as water that has not infiltrated or been stored on the watershed moves over or just beneath the watershed surface. Snyder's UH is used to model the direct runoff  |
| Base flow     | Base flow method | In this study, the recession method is used to model the base flow   |

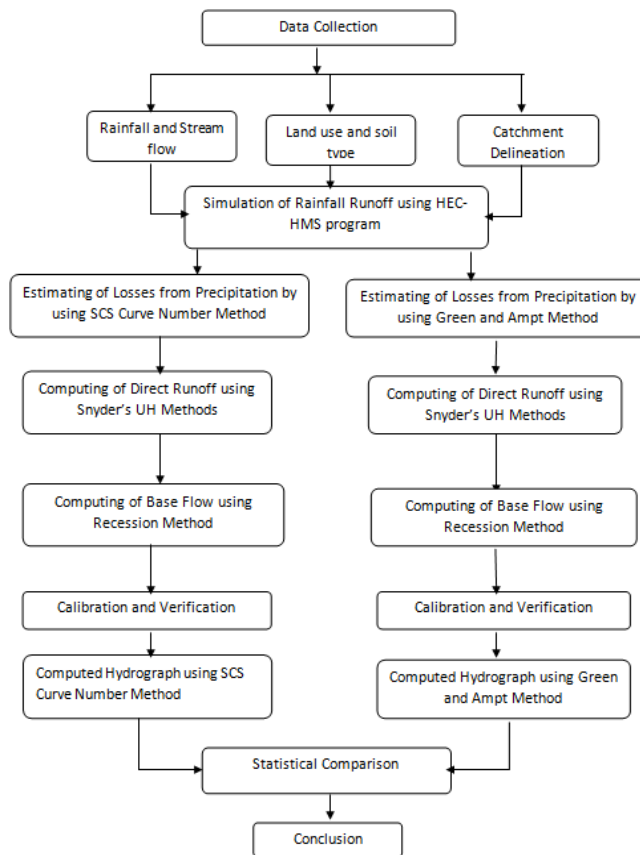


Fig. 2: General steps for applying HEC-HMS program to simulate the rainfall-runoff

## METHODOLOGY

The HEC-HMS program is used to simulate the runoff from the rainfall data for the study area which consist of two catchments namely Kenyir catchment and Berang catchment, Terengganu, Malaysia, as shown in Fig. 1, for the period starting from 1<sup>st</sup> September 1990 until 31<sup>st</sup> December 1990. The catchment of Berang is vegetated with shrubs covering loose sandy soil while the main vegetation cover in kenyir catchment is tropical rain forest. It is normally dense but with relatively open ground layer, the main storey is 25 to 30 m high and form a continuous layer while the under storey consist of small trees and cover of shrubs, herbs, palms and ferns.

A four months daily data for four rainfall station and two stream flow station within the study area have been obtained from the Department of Irrigation and Drainage, Malaysia. The soil type, vegetation cover and land use have been collected from Ministry of Agriculture, Malaysia.

The HEC-HMS program consist of three sub models namely, the basin submodel, the metrological submodel and the control specification. Each submodel that is included in HEC-HMS has parameters. The value of each parameter must be estimated so that the program can be run for estimating runoff or routing hydrographs. Some methods can estimate the parameters from various watershed and channel properties. However, some of the submodels that are included in HEC-HMS have parameters that cannot be estimated by observation or measurement of channel or watershed characteristics. The unknown parameter can be found via the calibration if rainfall and streamflow observation are available (Haan *et al.*, 1982). Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit between the computed and the observed runoff.

The type of method chosen for calibration is based on the data collection and assumptions that the author decides to use in order to run the HEC-HMS. Table 1 summarizes the methods that have been used to run the HEC-HMS for the study area.

General steps for applying HEC-HMS program to simulate the rainfall-runoff are shown in Fig. 2.

**(SCS curve number) infiltration method:** The Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use and antecedent moisture. The infiltration loss method is derived from a set of empirical equations that define the partitioning of rainfall into infiltration and runoff (HEC, 2000):

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (1)$$

$$I_a = 0.2S \quad (2)$$

$$S = \frac{25400 - 254CN}{CN} \quad (3)$$

For simplification, Eq. (2) can be substituted into Eq. (1) and the final Equation is shown below:

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (4)$$

where,

- $P_e$  = Accumulative precipitation excess at time t
- $P$  = Accumulated rainfall depth at time t
- $I_a$  = Initial abstraction (initial loss)
- $S$  = Potential maximum retention
- $CN$  = Runoff curve number

CN values ranges from 100 (for water bodies) to approximately 30 for permeable soil with high infiltration rates. The CN values for a watershed can be estimated as a function of land use, soil type and antecedent watershed moisture using table published by The Soil Conservation Service (Warren and Gary, 2003).

**Green and Ampt infiltration method:** The Green and Ampt infiltration method is essentially a simplification of the comprehensive Richard's equation for unsteady water flow in soil. The Green and Ampt method assumes the soil is initially at uniform moisture content and infiltration takes place with so-called piston displacement (Warren and Gary, 2003; Li *et al.*, 1976).

The Green-Ampt model assumes piston flow with a sharp wetting front between the infiltration zone and soil at the initial water content. The wet zone increases in length as infiltration progresses (Bras, 1990). Neglecting the level of ponding on the surface, the general equation showing the Green-Ampt relationship can be expressed as (Bras, 1990):

$$f = K \left[ \frac{1 + (\phi - \theta_i)S_f}{F_t} \right] \quad (5)$$

where,

- $f_t$  = Loss during period t, (mm)
- $K$  = Saturated hydraulic conductivity, (mm/h)
- $(\phi - \theta_i)$  = Volume moisture deficit.
- $S_f$  = Wetting front suction, (mm)
- $F_t$  = Cumulative loss at time t
- $\theta_i$  = Initial water content
- $\phi$  = Porosity (cm<sup>3</sup>/cm)

To apply Eq. (5) for entire watershed area, four separate physical characteristics must be known and

Table 2: Texture class estimates (Rawls *et al.*, 1983)

| Texture class   | Porosity, (cm <sup>3</sup> /cm) | Hydraulic conductivity, saturated (cm/h) | Wetting front suction (cm) |
|-----------------|---------------------------------|--|----------------------------|
| Sand            | 0.437                           | 21                                       | 10.6                       |
| Loamy sand      | 0.437                           | 6.11                                     | 14.2                       |
| Sandy loam      | 0.453                           | 2.59                                     | 22.2                       |
| Loam            | 0.463                           | 1.32                                     | 31.5                       |
| Silt loam       | 0.501                           | 0.68                                     | 40.4                       |
| Sandy clay loam | 0.398                           | 0.43                                     | 44.9                       |
| Clay loam       | 0.464                           | 0.23                                     | 44.6                       |
| Silty clay loam | 0.471                           | 0.15                                     | 58.1                       |
| Sandy clay      | 0.43                            | 0.12                                     | 63.6                       |
| Silty clay      | 0.479                           | 0.09                                     | 64.7                       |
| Clay            | 0.475                           | 0.06                                     | 71.4                       |

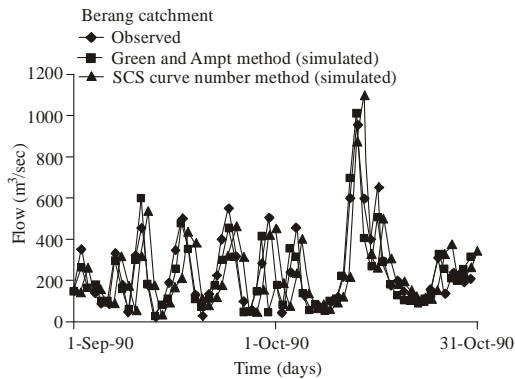


Fig. 3: Calibrated discharges of berang catchment using two methods

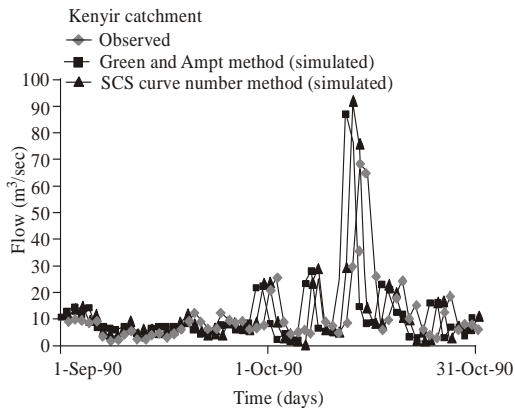


Fig. 4: Calibrated discharges of kenyir catchment using two methods

provided as input to the model. These characteristics are initial loss, hydraulic conductivity, wetting front suction and volume moisture deficit. Initial loss is a function of the watershed moisture at the beginning of the precipitation. It may be estimated via calibration. Table 2 provides estimates of hydraulic conductivity as a function of texture class, which is found from a soil survey (Rawls *et al.*, 1983). Wetting front suction can be estimated as a function of pore size distribution, which can, in turn, be correlated with texture class as shown in

Table 2. Volume moisture deficit is  $(\phi - \theta_i)$  as given in Eq. (5), which is the soil porosity less the initial water content. Rawls *et al.* (1983) have correlated the porosity with soil texture class; Table 2 shows this relationship. The initial water content must be between zero and  $\phi$ . For example, if the soil is saturated,  $\theta_i = \phi$  and for a completely dry soil,  $\theta_i = 0$  (HEC, 2000).

**Calibration and verification of HEC-HMS:** HEC-HMS was calibrated for the storm event of September and October, 1990 (event 1). This event starts at 8:00 a.m. and had total rainfall duration of 24 h. Precipitation data was taken from four rain gages that are located within the study area. The total depth for this event varied from 0 to 275 mm for Berang catchment and varied from 0 to 41 for Kenyir catchment. The result is shown in Fig. 3 and 4 for both catchments (Berang and Kenyir catchment) respectively using two infiltration methods. The model calibrated for event 1 depending on soil type, land use and vegetated cover and according to the range of possible values found given by Warren and Gary (2003).

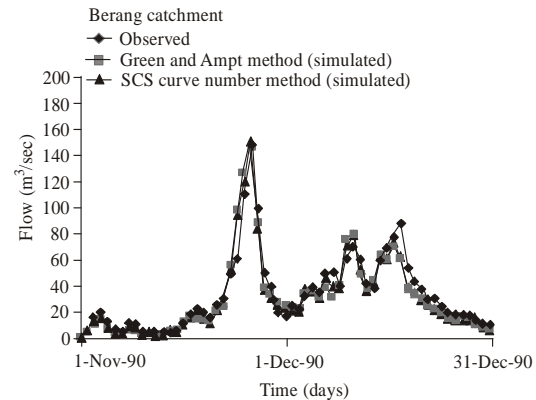


Fig. 5: Validation result of measured and simulated discharges for berang catchment using two methods

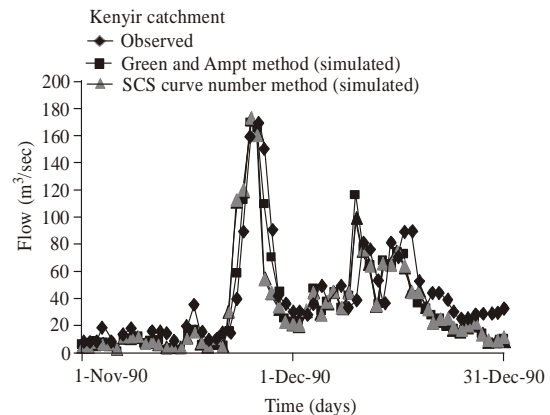


Fig. 6: Validation result of measured and simulated discharges for kenyir catchment using two methods

Table 3: Rainfall events used for calibration (event 1) and validation (event 2) for berang and kenyir catchments

| Catchment | Rainfall event            | Event 1                     | Event 2                    |
|-----------|---------------------------|-----------------------------|----------------------------|
|           |                           | 1 Sept 1990<br>-31 Oct 1990 | 1 Nov 1990<br>-31 Dec 1990 |
| Berang    | Rainfall duration (h)     | 24                          | 24                         |
|           | Rainfall depth range (mm) | 0-275                       | 0-102                      |
| Kenyir    | Rainfall duration (h)     | 24                          | 24                         |
|           | Rainfall depth range (mm) | 0-41                        | 0-295                      |

The HEC-HMS model is validated in order to evaluate the performance of the model. Different rainfall event (November and December, 1990) was used in validation process. This event began at 8:00 a.m. and had total rainfall duration of 24 h. The total depth of this event varied from 0 to 102 mm for Berang catchment and varied from 0 to 295 mm for Kenyir catchment. This was achieved using the parameters that were adjusted during the calibration process. The comparison of the measured and simulated daily discharge for Berang catchment and Kenyir catchment using the two infiltration methods, are shown on Fig. 5 and 6, respectively. Table 3 shows the data of precipitation events.

**Statistical analysis:** The accuracy of HEC-HMS program in simulating rainfall runoff by using two different methods was studied by evaluating its statistical performance. The statistical performances include the computation of coefficient of determination  $R^2$  that measure the degree to which two variables are linearly related, the Mean Square Error (MSE) that measured goodness-of-fit for the peak runoff and the Mean Absolute Percentage Error (MAPE) that measured goodness-of-fit for the moderate runoff for the output of the model compared with observed data (HEC, 2000). MSE and MAPE are defined as:

$$MSE = \frac{1}{N} \sum_{i=1}^N (P_{i_{measured}} - P_{i_{simulated}})^2 \quad (1)$$

$$MAPE = \frac{1}{N} \sum_{i=1}^N |P_{i_{measured}} - P_{i_{simulated}}| 100 \quad (2)$$

where  $P_{i_{measured}}$  is the measured flow ( $m^3/sec$ ) obtained from the survey,  $P_{i_{simulated}}$  is the simulated flow ( $m^3/sec$ ) obtained from the model output and N is number of data used.

## RESULTS AND DISCUSSION

The accuracy of the HEC-HMS program in simulating the rainfall runoff by applying two infiltration methods (SCS curve number method and Green and Ampt method) was tested using coefficient of determination  $R^2$ , MSE and MAPE for each catchment within the study area

Table 4: Statistical analyses for the study area

| Catchments | Infiltration method | MSE ( $m^3/sec$ ) | MAPE (%) | $R^2$ |
|------------|---------------------|-------------------|----------|-------|
|            |                     |                   |          |       |
| Berang     | SCS curve number    | 0.41              | 6.50     | 0.94  |
|            | Green and ampt      | 0.52              | 9.13     | 0.87  |
| Kenyir     | SCS curve number    | 0.47              | 8.20     | 0.88  |
|            | Green and ampt      | 0.66              | 11.11    | 0.72  |

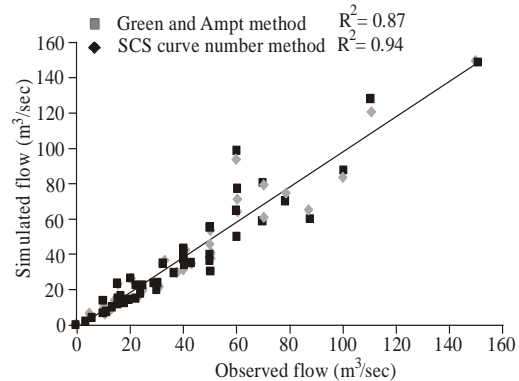


Fig. 7: Scattering for HEC-HMS simulation in berang catchment

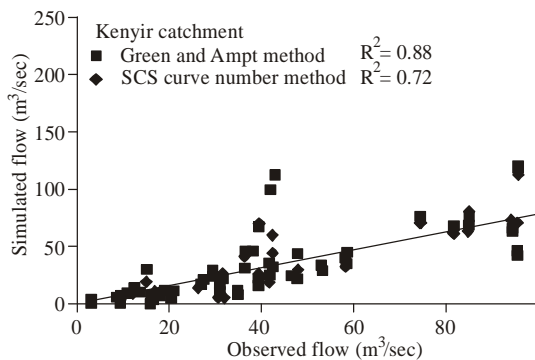


Fig. 8: Scattering for HEC-HMS simulation in kenyir catchment

and the results are shown in Table 4. The results show that the model gave the best simulation in Berang catchment using the SCS curve number method with the Mean Square Error (MSE) equal to 0.41  $m^3/sec$  and Mean Absolute Percentage Error (MAPE) equal to 6.5% and  $R^2$  equal to 0.94. The second best simulation is Kenyir catchment using SCS curve number method with MSE equal to 0.47  $m^3/sec$ , MAPE equal to 8.2% and  $R^2$  equal to 0.88. However, the HEC-HMS simulation using Green and Ampt method for both catchment, the model output is found to be in good agreement with the historical recorded data.

The flow rate simulation using the two infiltration method (SCS curve number method and Green and Ampt method) in two catchment (Berang and Kenyir) within the study area are shown in Fig. 7 and 8, respectively and they are plotted against the observed flow rate in form of scattered plots.

## CONCLUSION

In this study, two infiltration methods, SCS curve number method and Green and Ampt method are tested to study their impact on the accuracy of HEC-HMS rainfall runoff simulation. The study area is consist of two catchment namely Berang catchment and Kenyir catchment, Terengganu, Malaysia. Statistical analyses (MSE, MAPE and  $R^2$ ) were used to compare the HEC-HMS simulation flow with observed data.

Simulation of rainfall runoff using SCS curve number method is found with coefficient of determination  $R^2$  equal to 0.94, Mean Square Error (MSE) equal to 0.41  $m^3/sec$  and mean absolute percentage error equal to 0.65% for Berang catchment, but for Kenyir catchment,  $R^2$  equal to 0.88, MSE equal to 0.47  $m^3/sec$  and MAPE equal to 8.2% .In the HEC-HMS simulation using Green and Ampt method,  $R^2$  decreased by 0.07 for Berang catchment and 0.16 for Kenyir catchment, MSE increased by 0.11  $m^3/sec$  for Berang catchment and 0.19  $m^3/sec$  for Kenyir catchment and MAPE increased by 2.63% for Berang catchment and 2.91% for Kenyir catchment. Although it is found that the two infiltration methods in HEC-HMS rainfall runoff simulation gave a good agreement with the observed data, it is recommended to use the SCS curve number method for the tropical watershed.

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