INFILLING STREAMFLOW DATA USING HEC-HMS

(Date received: 17.03.2019/Date accepted: 18.12.2020)

Kee An Hong[1], Jer Lang Hong[1], Izihan bin Ibrahim[2], Nur Wajihah bt. Abd. Hakim[2]

[1]*Hong & Associates*

[2]*International Islamic University Malaysia*

ABSTRACT

A set of quality control streamflow data is always required in the planning, design and management of water resources projects. Although every effort has been made by the authority in the collection of complete and continuous hydrological data such as rainfall and streamflow, gaps and incomplete data sets with inadequate length are always encountered, as is always the case. These can be due to faulty field instruments, the occurrence of natural disasters and other reasons. Over the years, various techniques have been developed to infill the missing data, especially the streamflow data. These techniques include regression analysis ,rainfall runoff modelling and the use of artificial neural networks(ANN) data driven models. In this study, the HEC-HMS model is used to simulate long term daily streamflow of Sg Melaka. The process involved using recorded flow and rainfall data of 1989-1992 to calibrate the model and the model validation using records of 1985-1986. Results show that the model can be used to estimate the flows of Sg Melaka once properly calibrated. This is also shown in the results of flow duration curves. From this study, it can be concluded that missing flows of Sg Melaka can be infilled using the HEC-HMS moel and daily rainfall records in the basin. Streamflow records can be extended if complete rainfall records are available for periods where no streamflow records are available.

Keywords: Infill, streamflow, HEC-HMS, calibration, validation, sensitivity, performance criteria.

1.0 INTRODUCTION

Quality control streamflow data is always required in the planning, design and management of water resources projects. Although every effort has been made by the authority in the collection of complete and continuous hydrological data such as rainfall and streamflow, gaps and incomplete data sets with inadequate length are always encountered, as is always the case. These can be due to faulty field instruments, the occurrence of natural disasters and other reasons. Over the years, various techniques have been developed to infill the missing hydrological data, especially the streamflow data. These techniques include regression analysis, rainfall runoff modelling and the use of artificial neural networks (ANN) data driven models.

As available streamflow data with adequate length is of great importance in hydrological analysis and missing values cannot be ignored if the data available is limited, gaps should be infilled where possible using the available techniques and existing streamflow and hydrometric data. Streamflow data can also be extended if long term hydrometric data such as rainfall are available. In this study, we use HEC-HMS, a rainfall runoff model developed by the US army Corps of Engineers [1], to infill the missing streamflow data of Sg. Melaka as a case study. HEC-HMS has been widely applied throughout the continents for long term rainfall runoff simulation studies. Examples are Sweden and Nepal [2], Brazil [3], India [4], Kenya [5], India [6], Kenya [7], Sweden [8], Sri Lanka [9], Eastern Europe [10].

2.0 MATERIALS AND METHODS

2.1 The Study Area

The Sg Melaka basin is shown in Figure 1. The basin area is 350 km². The maximum breadth and width of the basin are 26 km and 14km. The basin is of low lying and undulating hills in the south and mountainous country in the north border. A small area in the south is below 15 m contour line.

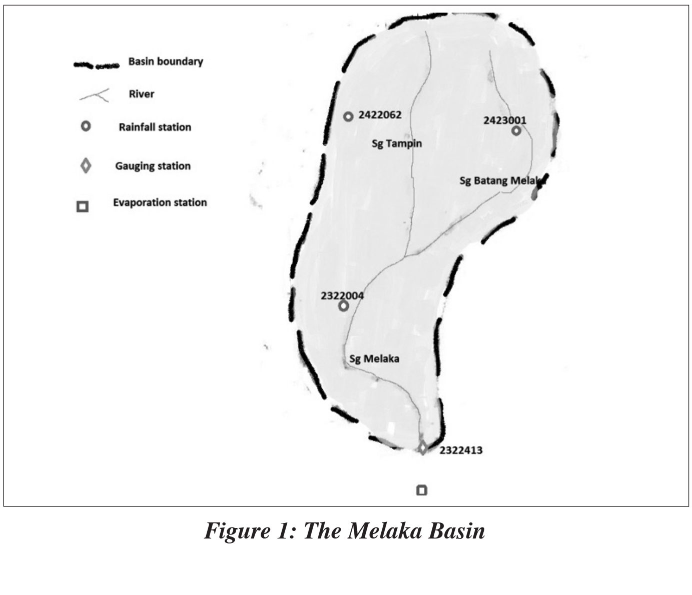

Figure 1: The Melaka Basin

The main river Sg Melaka and its major tributary, the Sg Batang Melaka rise to the hill in the north. The two rivers meander through low lying and undulating land on their way to the sea. The low-lying area is cultivated with palm oil whilst the upper basin is covered with lallang and forest. The soil cover of the basin is basically coarse and sandy clay.

2.2 Hydrological Data

The Melaka basin was chosen as a case study as there are three rainfall stations quite evenly distributed in the basin with long and rather continuous records. In this context, the mean basin rainfall can be estimated with accuracy. For simplicity mean catchment rainfall is taken as the mean of the three stations. There is a streamflow record with over 50 years although intermittent missing records exist. Years with complete records are available and can be used for HEC-HMS modelling. The evaporation station is located at Melaka Airport and the potential monthly evaporation values have been estimated [11]. Details of the data available are listed in Table 1. The data were examined carefully for consistency and the streamflow and rainfall data for the period 1/1/1989 to 31/1/1992 were used for model calibration and the period 1/1/1985 to 31/12/1986 were used for model validation. As daily evaporation data for these periods consist some gaps, the mean monthly potential evaporation (forest evaporation) presented in Water Resources Publication No 5 [11] were used in this study. The monthly forest evaporation values of Melaka Airport are shown in Table 2.

Table 1: Hydrological data of Melaka basin

Rainfall	Station name	Station ID	Period of recods
	St. Thomas School	2422062	1948- to date
	Ladang Tebolang	2423001	1953- to date
	JKR Alor Gajah	2322004	1948- to date
Streamflow	Sg Melaka at Pantai Belimbing	2322413	1960- to date
Evaporation	Melaka Airport	0210	1960-to date

Table 2: Forest evaporation, Melaka Airport, mm

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation	128	126	141	137	128	119	119	122	124	123	115	111

2.3 Methodology

HEC-HMS is useful in analyzing urban flooding, flood frequency, flood warning system planning, and in long term streamflow simulations. HEC-HMS calculates runoff using the key components of the model. Components can be chosen by users for specific needs for particular basins. In the long term streamflow simulations of Melaka basin, we choose six main components of HEC-HMS. These are: meteorology, interception, surface detention, infiltration, direct runoff, and baseflow.

Methods used in the key components to estimate model parameters of HEC-HMS in long term streamflow simulations are:

Meteorology- This involves the input of daily streamflow, rainfall and monthly potential evaporation data.

Simple canopy – This method is chosen for its simplicity due to a lack of available data defining the canopy. The model parameters are initial storage and maximum storage in canopy.

Deficit-constant soil loss method – The deficit-constant method provides the ability to simulate soil moisture characteristics using easily derived and calibrated parameters. The parameters are initial deficit-which represents initial condition of the soil layer, and it is the amount of water to saturate the soil layer, maximum deficit-which is the maximum amount of water the soil layer can hold, constant loss-which is the percolation rate of the soil layer.

Snyder unit hydrograph transformation method – The parameters for this method are fairly easy to calibrate, this method has shown to be very effective in representing the timing and shape of flow hydrographs through varying magnitudes and volumes of floods. The parameters are standard lag which is the time between the centre of mass of rainfall and the peak of the hydrograph, and peaking coefficient which determines the peak rate of runoff.

Exponent recession baseflow method-Parameters for this method such as initial discharge, recession constant and threshold can be estimated from hydrograph records and generally satisfactory parameters can be obtained through calibration. Initial discharge is the baseflow at the beginning of the simulation. Recession constant is the rate at which baseflow recedes between storm events. Threshold ratio is the ratio to the peak flow at which the baseflow is reset.

The computation process can be readily summarised as a flow diagram as shown in Figure 2.

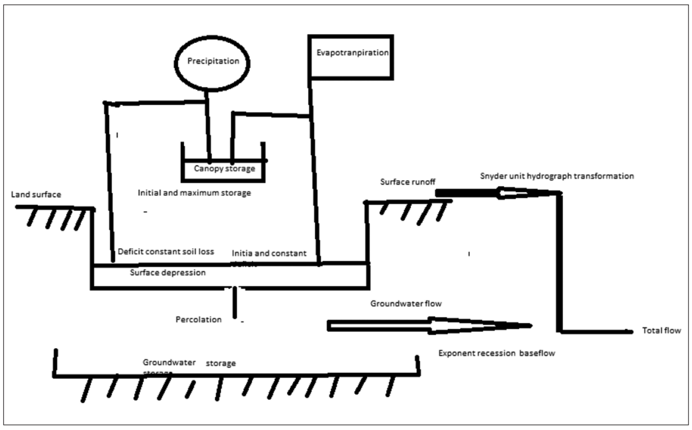

Figure 2: Representation of the HEC-HMS components in long term rainfall runoff simulation

In the HEC-HMS model, the precipitation represents the average catchment precipitation, which can be estimated using arithmetic mean, Thiessen polygon, isohyetal and inverse distance squared method. Evaporation as modelled in the program includes vaporization of water directly from the soil and vegetative surface, and transpiration combined and estimating as an average volume. The varying monthly evapotranspiration values can be input into the model. The deficit constant loss model tracked the moisture deficit continuously, and was computed as the initial abstraction volume less precipitation volume plus recovery volume during the precipitation free period. The recovery rate can be estimated as the sum of the evaporation rate and percolation rate, or some fraction thereof.

The soil moisture model is represented by a series of storage layers. Rate of inflow to or outflow from and the capacities of the layers control; the volume of water lost or added to the storage components. Current storage contents are calculated during the simulation and vary continuously both during and between storms.

The storage layers are:

Canopy storage - Precipitation is the only inflow into this layer. Precipitation fills the canopy storage and when this storage is filled, precipitation will be available for other storages. Water in canopy is removed by evaporation.

Surface storage - Surface depression storage is the water held by surface depression. Inflow into this storage comes from precipitation not captured by canopy and in excess of infiltration rate. Outflow from this storage can be due to infiltration or evaporation. Once the volume of surface interception is exceeded, this excess water contributes to surface runoff.

Soil storage - The soil storage represents water stored in the layer of soil. Inflow is infiltration from the surface.

Ground water storage - Ground water layer is the horizontal interflow processes. Water percolates into the groundwater storage from the soil profile.

Direct runoff is modelled using the unit hydrograph (UH) method. In this study, we use the Snyder UH. Snyder [12] selected the lag, peak flow and the time base as parameters for the UH.

The relationships are:

$$t_p = 5.5t_r \quad (1)$$

Where t_p is the standard catchment lag in hours
And t_r is the rainfall duration in hours

$$t_{pR} = t_p - \frac{t_r - t_R}{4} \quad (2)$$

Where t_R =duration of desired UH
t_{pR} = lag of desired UH
The peak of standard UH in terms of catchment area and lag is:

$$\frac{U_p}{A} = C\frac{C_p}{t_p} \quad (3)$$

Where Up peak of standard UH
A= catchment area
Cp= UH peaking coefficient
C= conversion factor
For other durations, the UH peak is:

$$\frac{U_{pR}}{A} = \frac{CC_p}{t_{pR}} \quad (4)$$

The tp and Cp can be calibrated using HEC HMS

The exponential recession baseflow model derived the k value using the following formula:

$$Q_t = Q_0 k^t \quad (5)$$

Where Qo= initial baseflow
Qt= baseflow after t time unit
K is a decaying coefficient

2.4 Model Performance Criteria

In this study, the model performance was evaluated following the guidelines developed by Moriasi *et. al* [13] for a monthly time step based on model evaluation statistics. The statistical measures are:

$$\text{PBIAS}=\frac{\sum_1^n (Y_{io}-Y_{is})}{\sum_1^n (Y_{io})} * 100 \quad (6)$$

$$\text{RSR}=\frac{\sqrt{\sum_1^n (Y_{io}-Y_{is})^2}}{\sqrt{\sum_1^n (Y_{io}-Y_{om})^2}} \quad (7)$$

$$\text{NSE}=1-\frac{\sum_1^n (Y_{io}-Y_{is})^2}{\sum_1^n (Y_{io}-Y_{om})^2} \quad (8)$$

Where Y_{io} is the ith observed monthly flows, Y_{is} is the ith simulated monthly flows and

Y_{om} is the mean of observed monthly flows

PBIAS is the percent bias

RSR is root mean square error-observation standard deviation ratio

NSE is Nash-Suteliffe efficiency

The recommended criteria of Moriasi *et. al* are shown in Table 3.

Table 3: General performance ratings for NSE and PBIAS, RSR for a monthly time step (from Moriasi et al., 2007)

Performance rating	NSE	PBIAS	RSR
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10%	0.00<=0.50
Good	0.65 < NSE ≤ 0.75	±10% ≤ PBIAS < ±15%	0.50<RSR<=0.60
Satisfactory	0.50 < NSE ≤ 0.65	±15% ≤ PBIAS < ±25%	0.60<RSR <=0.70
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25%	RSR>0.70

3.0 RESULTS AND DISCUSSION

A model is considered reliable only when it can estimate streamflow comparable to observed flow with accuracy. The rainfall runoff model for the Melaka basin was calibrated and validated using recorded flows for different periods. Initial model parameters were obtained by using optimization procedures of HEC-HMS. For the present study, statistical parameters such as NSE, PIAS and RVR are used to evaluate the performance of the HEC-HMS model. The 1989-1992 hydrological data were used to calibrate the model and after the model is calibrated, a different set of data(1985-86) were used to evaluate the accuracy of the model.

3.1 Calibration Results

The 1989 -1992 daily streamflow and rainfall records and the monthly forest evaporation data (Table 2) were used for HEC-HMS to obtain the model parameters of the Melaka basin. The sensitivity analysis was carried out to determine the important parameters which needed to be precisely estimated to make accurate prediction of basin flows. Thus, the model was run with initial parameter values for a simulation run. From the results, model parameter values were adjusted and trial runs were repeated with new parameters. When a good performance statistical measure like NSE is reached, a sensitivity test was carried out to test the performance of the model by changing the parameters one at a time while keeping the others unchanged. This was done until the best fit parameters are obtained. Checks are also made at the same time through graphical inspections. For the calibration runs, the best fit parameters obtained through optimization for the Melaka basin are shown in Table 4.

Results are shown graphically in Figure 3.

It can be seen from the graph that the recorded flows have been modelled quite correctly for most of the time except for some high flows and the low flows in early 1991. The statistical performance measures are shown in Table 5. Referring to the rating table of Moriasi for statistical measures, the performance of the model is satisfactory.

Table 4: Model parameter values for Melaka basin

Parameter	Optimised value
Deficit and constant-constant rate	0.38
Deficit and constant deficit	0.1
Deficit and constant-Maximum deficit	1.35
Recession –initial discharge	1.62
Recession-ratio to peak	0.1
Recession-recession constant	0.97
Simple canopy – initial storage	0
Simple canopy-maximum storage	4.7
Simple surface-initial storage	0
Simple surface=maximum storage	4.8
Snyder unit hydrograph-peaking coefficient	0.46
Snyder unit hydrograph –standard lag	56

Table 5: Performance of the calibration model based on PBIAS, NSE, and RSR, for a monthly time step

Calibration period	PBIAS	NSE	RVR
1/1/1989 - 31/12/1992	-2.54	0.62	0.62

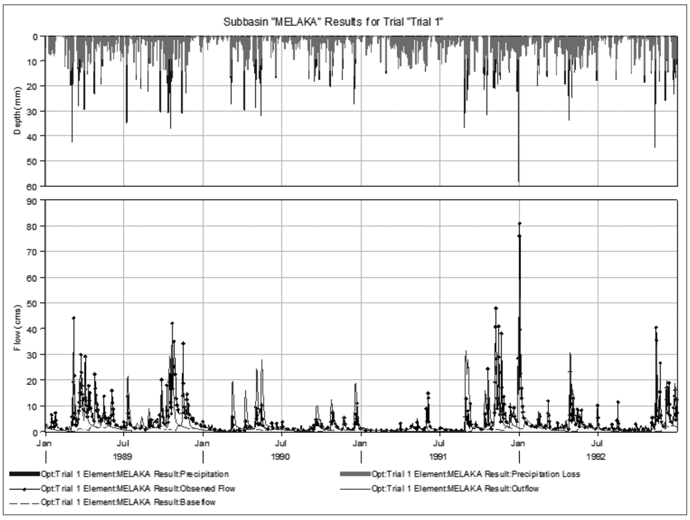

Figure 3: Observed and simulated flows, 1989-1992, Melaka at Pantai Belimbing

3.2 Validation Results

Using the derived parameters of the calibration runs, a validation run was performed adopting daily rainfall of 1985-1986 and the mean monthly forest evaporation. The model performance statistical measures are shown in Table 6. Results are also shown in Figure 4. From Figure 4, it can be seen that except for some high flows and the flows in April – May 1986, the model is generally able to reproduce the observed flows. The model also gives satisfactorily statistical parameters such as PBIAS, NES and RSR when applied to simulate the 1985-1986 data.

Table 6: Performance of the validation model based on PBIAS, NSE, and RSR, for a monthly time step

Validation	PBIAS	NSE	RVR
1/1/1985 - 31/12/1986	19.5	0.56	0.67

3.3 Comparison of Flow Duration Curves

The observed and predicted daily flows for 1985-86 were used to derive the flow duration curves as presented in Figure 5. From the curves shown in Figure 5, it is clear that the model is able to predict the observed flows well except for some medium flows.

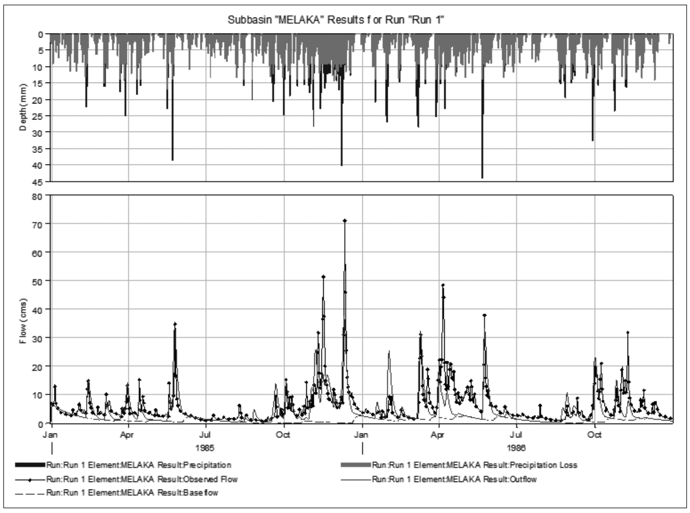

Figure 4: Observed and simulated flows, 1985-1986, Melaka at Pantai Belimbing

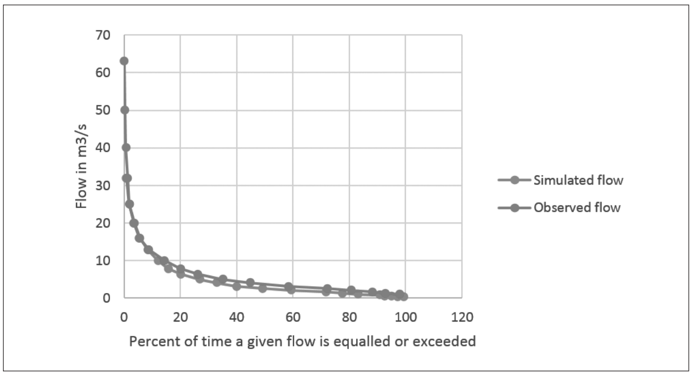

Figure 5: Flow duration curves for observed and predicted flows, 1985-86

In the study for Sava catchment [10] in Eastern Europe, data from 30 gauging stations were used to calibrate and validate the HEC-HMS model and the model evaluation statistics derived using monthly data obtained were as follows:

Type of run	PIAS	NSE
Calibration	-0.5-0.5	0.66-0.89
Validation	-20-18	0.28-0.86

Our study shows that compared to the results obtained elsewhere, satisfactory results were obtained using HEC –HMS in modelling the data of Melaka basin. In the absence of detailed field data such as soil and evaporation, the conceptual model has been used successful in estimating streamflow from rainfall data.

4.0 CONCLUSION

In this study, the HEC-HMS model is used to simulate long term daily streamflow of Sg Melaka. The process involved using recorded flow and rainfall data of 1989-1992 to calibrate the model and the model validation using records of 1985-1986. Results show that the model can be used to estimate the flows of Sg Melaka once properly calibrated. This is also shown in the results of flow duration curves. From this study, it can be concluded that missing flows of Sg Melaka can be infilled using the HEC-HMS model and daily rainfall records in the basin. Streamflow records can be extended if complete rainfall records are available for periods where no streamflow records are available.

5.0 ACKNOWLEDGEMENT

The permission of the Drainage and Irrigation Department to use the data for this study is gratefully acknowledged. ■

REFERENCES

[1] Hydrologic Engineering Centre, US Army Corps of Engineers (2016) Hydrologic modelling system, user manual

[2] Khadka J. and Jagrilee B.(2018) Rainfall runoff simulation and modelling using HEC-HMS and HEC-RAS models case study for Nepal and Sweden Department of Water resources Engineering, University of Lund

[3] Neto J.G. and Neto A.R.[2014] Assessment of rainfall runoff models for flood river extreme events, ICFMD on flood management

[4] Vishweshawaran R.[2017] Application of the HEC-HMS model for runoff simulation in the Krisha basin ,India ,National Institute of Technology Karnatar

[5] Ouedraogo W.A.A.[2018] Continuous modelling of the Mkurumudzi river catchment in Kenya using HEC-HMS conceptual model Hydrology MDPI

[6] Singh N.R. and Jai N. K.(2015) Continuous hydrologic modelling using SMA algorithm in Vamasadhara river basin, India, Jour Watr. Resr. Hydrau. Engr.

[7] Ouedraogo I and Song J. [2017] HEC-HMS modelling for runoff simulation in Ruiru reservoir American Engineering research Journal

[8] Alavimoghaddam M.(2007) Assessing the ability of the HEC-HMS rainfall runoff model to simulate streamflow across Sweden Stockhom University

[9] Halwatura D. and Najim M.M.M.(2013) Application of the HEC-HMS model for runoff simulation for a tropical catchment Environmental modelling and software Vol 46

[10] World Bank Group (2015) Development of the hydrologic model for the Sava river basin, Water partnership program

[11] Drainage and Irrigation Department (1976) Evaporation in Peninsular Malaysia, water Resources Publication No 5

[12] Snyder F.F. (1938) Synthetic unit hydrograph Trans. AGU vol 19

[13] Moriasi D. N. ,Arnold J.G., Van Liew M.W., Binger R.L., Harmel R.D., Veith T.L.(2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, American society of agricultural and biological engineers

PROFILES

HONG KEE AN is a professional Engineer major in hydrological analysis, design and modeling. He received his B. Sc. degree in Agricultural Engineering from National Taiwan University in 1971 and the M. Eng. degree in Water Science from Asian Institute of Technology in 1973. He is the author of the book "River routing using HEC-HMS Excel solver and neural designer". He is a Fellow of the Institution of Engineers, Malaysia and is listed in Who's Who in Engineering published by the American Association of Engineering Societies.
Email address: keeanhong@yahoo.co.uk

DAVID HONG JER LANG is currently the principal architect of SNS Sdn Bhd. He received his B. Sc degree in computer science from Nottingham University in 2005 and the Ph. D. degree from Monash University in 2010.He is the co-author of the book "River routing using HEC-HMS Excel Solver and neural designer". David Hong is listed in Who's Who in the World.
Email address: jerlanghong@gmail.com

IZIHAN BIN IBRAHIM is a civil Engineering graduate and he obtained a Master's degree from Imperial College UK in Engineering Hydrology. He was a lecturer of university Kebangsaan for 3 years before he joined HYDEC, a consulting Engineering firm. He is presently a lecturer in International Islamic University and he is also a Director of Rho 1, a consulting firm in Hydrology and hydraulics.
Email address: izihan@gmail.com

NUR WAJIHAH obtained her B.SC. in Civil Engineering from UNIMAS in 2017. She is a hydrologist of RHO 1 Consultant for the past 3 years and is now pursuing a Master's degree at International Islamic University, Malaysia.
Email address: nurwajihah94@gmail.com