Estimation of Probable Maximum Flood for Dam Safety in Cameron Highlands Watershed

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ABSTRACT

Dams that are not designed to withstand major storms may be destroyed and increase the flood damage opportunities downstream. For protecting the lives and land downstream of Cameron Highlands, Malaysia, the current research targeted to estimate the Probable Maximum Precipitation based on the updated rainfall and other meteorological data and predict the Probable Maximum Flood using the Hydrological Model (HEC-HMS) version 4.8. The Geographic Information System was utilized as well in order to identify the geometric and hydrologist parameters. The PMP data is obtained up to 2020 via the application of Hershfield's Statistics and by applying the model mentioned earlier, the Probable Maximum Precipitation values can be predicted. For the calibrating the model, different sets of data were applied in which the Nash-Sutcliffe Efficiency and Percentage of Bias of 0.776 and -0.03% respectively are obtained while Nash-Sutcliffe Efficiency and Percent Bias of 0.861 and 1.47% respectively are obtained for Cameron Highland dams for model validation. The hydrological model in this study was adequately calibrated for Probable Maximum Flood simulation as it is credible to describe the hydrological process in Cameron Highlands.

Keywords: ArcGIS, HEC-HMS, Modelling, Rainfall, Runoff

INTRODUCTION

Malaysia is a humid tropical country where the rainfall is abundant and subsidizes to 2000-4000 mm annually as an average (Al-Hadu, et al., 2011). The annual average precipitation may exceed the above range with the exclusion of excessive events which results in more frequent floods (Suhaila and Jemain, 2007).

The main purpose of constructing dams is for various economic, environmental, and social benefits, including flood control, water supply, hydroelectric power, irrigation, recreation, and wildlife habitat which requires constant maintenance and monitoring, regular safety inspections as well as scheduled rehabilitation to function well. Failure of these structures impacts the lives, economy and environment which may threaten public safety, economies, and the environment. In the 20th century solely, there are around 200 failure cases around the world. The key cause for that is misestimation of the real and allowed design discharge that occasioned from the lack of truthful hydrological actions. (Jing, et al., 2019; Adamo, et al., 2020). Thus, hydrologic actions need to be considered for predicting flood discharge (Bosamiya and Gandhi, 2018). Since there are many parameters that shape the runoff, it is important to identify the appropriate model which requires as minimum input data, simple structure, and accurate as possible (Sharifi, et al., 2004). HEC-HMS Model is a hydrological model that matches the mentioned criteria and has been developed by the Hydrologic Engineering Center of the US Army Corps of Engineers (US Army Corps of Engineers, 2016). The main result of modelling is to develop the hydrograph at the catchment outlet (Oleyiblo and Li, 2010). (Mokhtari, et al., 2016) applied the HEC-HMS Model in the watershed of Cheliff-Ghrib valley so as to investigate the effect of changing the climate on the basin runoff. (Skhakhfa and Ouerdachi, 2016) also applied the HEC-HMS Model so as to estimate the peak runoff for Ressoul Watershed valley in which they depend on multiple events. Another study performed by (Jabbar et al., 2021) which have applied the HEC-HMS to predict the peak flood in Cameron Highlands, Malaysia for a simulation period (2000 to 2014) in which the results of calibration and validation presented a very good fit between the real (observed) and predicted hydrographs. This study aimed to predict the Probable Maximum Flood (PMF) based on updated rainfall data using the Hydrological Model HEC-HMS version 4.8.

METHODOLOGY

The researchers implemented methodology that includes conducting the hydrological analysis in order to establish the PMP and PMF values for Cameron Highlands Hydroelectric Scheme which includes four (4) dams (i.e. Sultan Abu Bakar Dam, Jor Dam, Mahang Dam and Ulu Jelai Dam) by applying the HEC-HMS Model using the latest hydrological data until 2020. In developing the HEC-HMS model, the Soil Conservation Service (SCS) Curve Number method is to be used for the Loss Model and the SCS Unit Hydrograph Method is be adopted for the Transform Method. The flowchart of the methodology is shown in Figure 1.

Study Area

Cameron Highlands Hydroelectric Scheme is located within a couple of states of both of Perak and Pahang in Malaysia. The scheme represents the first hydropower development in Malaysia, consisting of two hydroelectric projects with a capacity of 262MW. The whole scheme is separated into two parts; upper and lower catchments. It utilizes the headwaters of two rivers, namely, Sungai Telom and Sungai Bertam, both of Sungai Pahang's tributaries. This scheme is targeted as a peak demand Power Station with a total capacity of 262MW. The study with the mentioned dams earlier is presented in Figure 2.

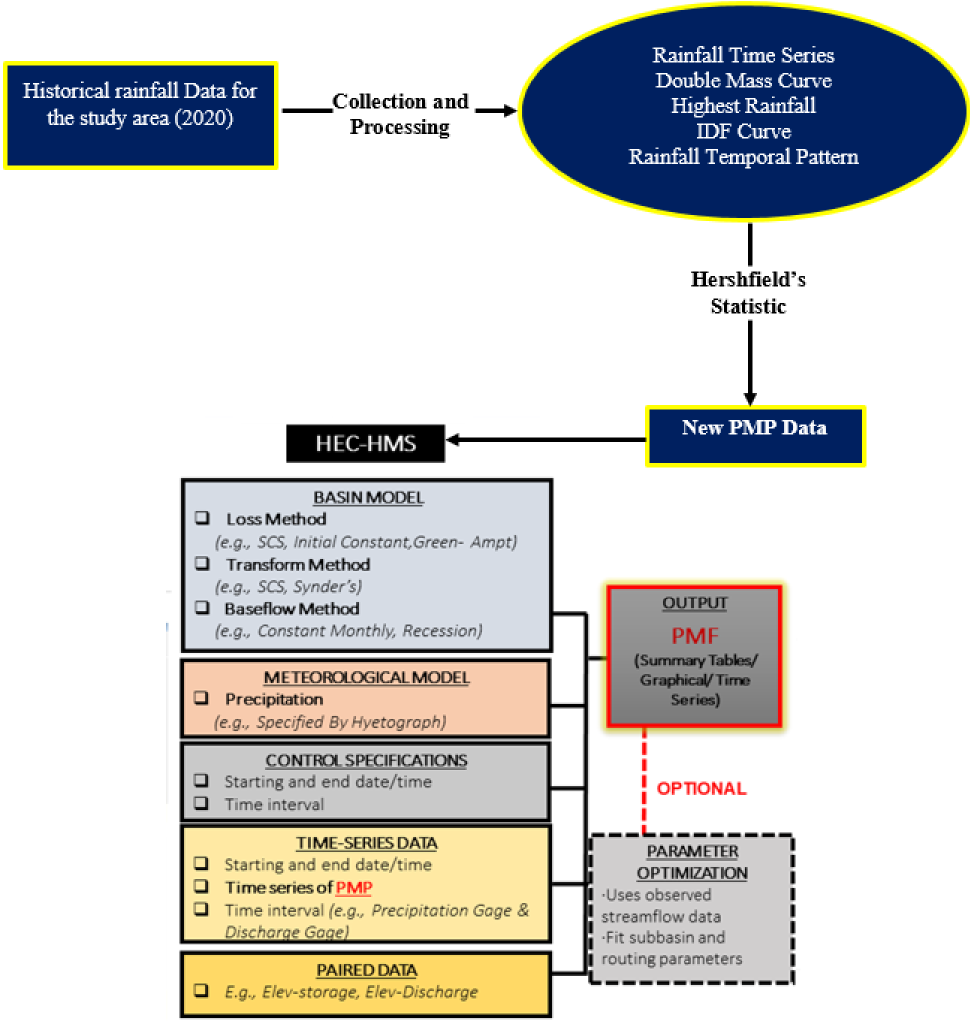

Figure 1. Methodology adopted in the current study

Hydrological Analysis

Hydrological analysis was based on seventeen (17) rainfall stations in which they are owned by the Department of Irrigation and Drainage (DID) and Tenaga National Berhad (TNB). The duration of the rainfall data is between 30 years to 60 years. The essential data is a series of annual maximum rainfall values for both daily and hourly rainfall. The annual maximum rainfall series for a station is the sequence of rainfalls formed by extracting the highest rainfall value for each year of record. Figure 3 depicts the location of rainfall stations for Cameron Highlands Watershed.

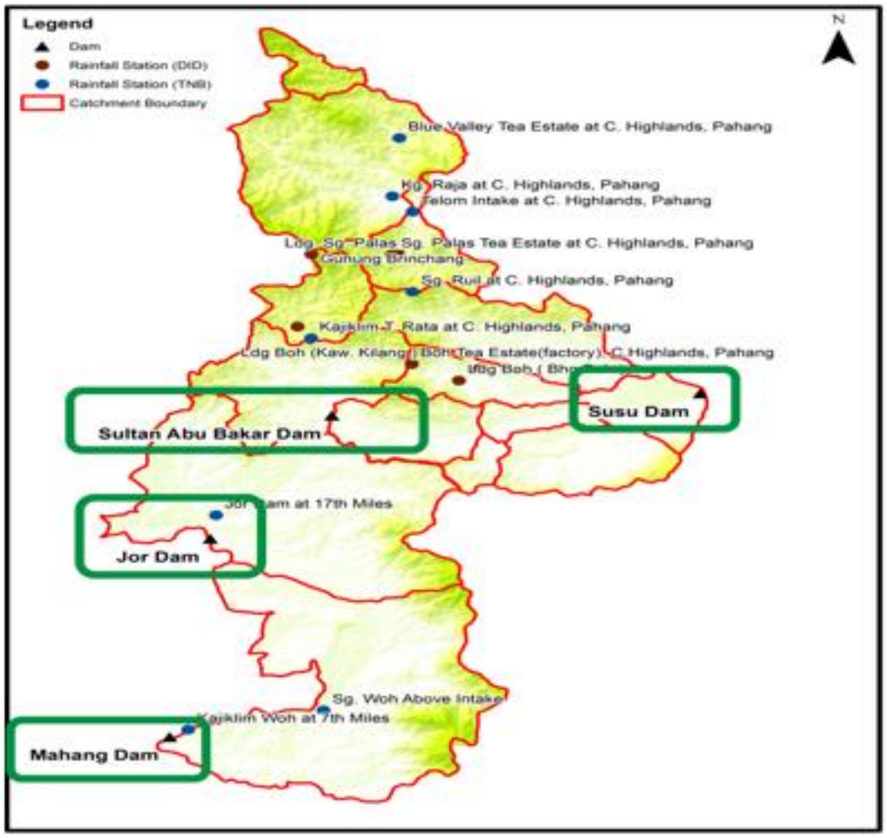

Figure 2. Location map of Cameron Highlands

For each rainfall station, the cumulative values were compared with the average rainfall cumulated for the other nearby stations which were affected by similar meteorological circumstances. For each station, the cumulative rainfall of the station and the average cumulative rainfall of the other 10 stations are plotted. It has been observed that the double mass curve method indicated consistency in their rainfall records. Thus, the maximum annual rainfall sequence adopted in the study and in analysis for all the stations were considered as homogenous. The series of highest recorded point rainfall values of rainfall for the 1-day, 3-day, and 5-day durations for each of the stations were calculated to assess the design rainfalls in which the stations in Cameron Highlands have recorded the highest rainfalls between 101.5 to 363 mm in 1-day, 147 to 404.7 mm in 3-day and 191.5 – 714 mm in a 5-day duration.

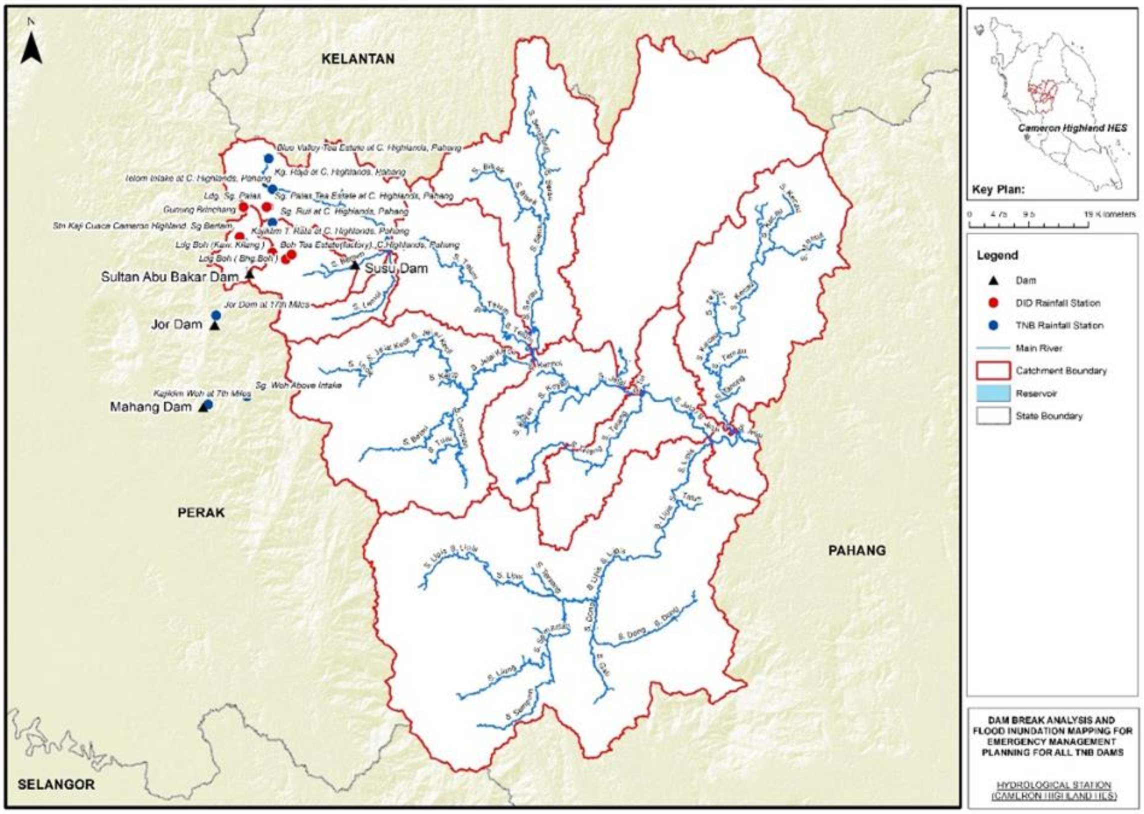

Figure 3. Location of Rainfall Stations for Cameron Highlands

Gunung Brinchang station at an elevation of 1990 m recorded the highest rainfall of 363 mm, 690 mm and 714 mm in 1-, 3- and 5-day period (extreme rainfall events). The spatial distribution of the stations (17 stations) in 2010 was mapped, and isohyet lines were drawn to indicate their spatial allocation. Regarding the Intensity-Duration-Frequency (IDF) curves, they are used to explain the rapport among the intensity of rainfall, duration of rainfall, and the return period (or its inverse, probability of exceedance). IDF curves are frequently exercised to model the hydrologic, hydraulic, and water resources systems. Apart from that, they are also used to identify the magnitude of rainfall amount that induced floods. The IDF curves is to be generated through occurrence / frequency analysis of rainfall data collected in the rainfall stations of different rainfall intervals.

Probable Maximum Precipitation (PMP)

The statistical approach (Hershfield 's statistical techniques) is applied to appraise the PMP for 1-hour, 3-hour, 6-hour, 12-hour, 1-day, 2-day, 3-day, and 5-day duration for the station in Cameron-Highland Catchment where daily rainfall data are obtainable for a long period. The Hershfield method (Hershfield, 1965) of predicting the PMP is an adaptation of the Chow (1951) method which relies on frequency evaluation of rainfall. Table 1 shows the comparison of revised PMP values between the current study and the previous PMP produced by UNITEN, 2017 in which the results illustrate about a 5% difference with UNITEN (2017). The difference may be due to the more extended range of data used until 2020 than the previous study data, whose data was until 2016. There was no significant heavy rainfall event between 2017- 2020, which affects the calculated revised PMP values.

Table 1. Comparison of Revised PMP and Previous PMP (for SAB Dam, Jor Dam, Mahang Dam and Ulu Jelai Dam)

Sab Dam, Jor Dam, Mahang Damand Ulu Jelai Dam		
Duration (hour)	**PMP (mm)**	
	Current Study (2021)	**UNITEN (2017)**
1	335	347
3	374	388
6	496	514
12	675	700
24	830	836
72	1550	1607

Probable Maximum Flood (PMF)

The PMF offers an ultimate boundary of the runoff in which the decision maker needs to take an action for the design and operation. Thus, it is essential to predict the flood runoff of a high return period in specific catchments, which is the PMF. It is essential to check the adequacy of the spillway by the PMF value because of the high risk to the community downstream of the dam. (Department of Irrigation and Drainage Malaysia, 2017). The Probable Maximum Precipitation (PMP) is used as meteorological input in which these PMP values is transformed with a rainfall-runoff into a runoff hydrograph.

HYDROLOGICAL MODELLING USING HEC-HMS

Analysis for the rainfall-runoff analysis was fulfilled to establish the design of flood flows for the main river. Hydrologic Engineering Center-Hydrological Modelling System (HEC-HMS) was applied in order to model the rainfall-runoff for Cameron Highlands watershed due to intense precipitation and the accompanied flood. In this study, the PMF will be simulated using HEC-HMS version 4.8 by using the estimated PMP as the rainfall input. The PMF hydrograph is generated in the deterministic methodology by modelling the study area's physical atmospheric and drainage basin hydrologic and hydraulic processes.

There are six-sub catchments which are Telom, including Kial, Kodol and Plau`ur (transferring the inflow through Telom Tunnel), Upper Bertam, Middle Bertam, Lower Bertam, Habu and Ringlet that will contribute to the inflow of Sultan Abu Bakar Dam. While one tunnel discharges (Bertam Tunnel), inflow from Jor Power Station and four sub-catchments, Batang Padang catchment, Jor catchment, Keteh catchment, and Sekam catchment, will contribute the inflow into Jor Dam. From the Jor Reservoir, water flows to the Tidong Intake by the Menglang Tunnel (14.5 km), after passing through Lengkok and Bot Intakes. The Tailrace Tunnel is connected to the Tidong Intake to the Mahang Dam. Water from the Jor Reservoir flows directly to Ulu Jelai Dam and has been delineated into seven-sub catchments: Bertam 1, Bertam 2, Bertam 3, Boh, Kor, Mensun, and Relung. All of these inflows from the catchments will contribute directly to Ulu Jelai Dam. Inflow to the Ulu Jelai reservoir needs to be complemented by the outflow from Sultan Abu Bakar Dam. The additional inflows from Telom and Lemoi Tunnels also contribute to Ulu Jelai Dam. Figure 4 shows the basin model of Sultan Abu Bakar Dam, Jor Dam, Mahang Dam, and Ulu Jelai Dam.

Fig. 1(a)

Fig. 1(b)

Fig. 1(c)

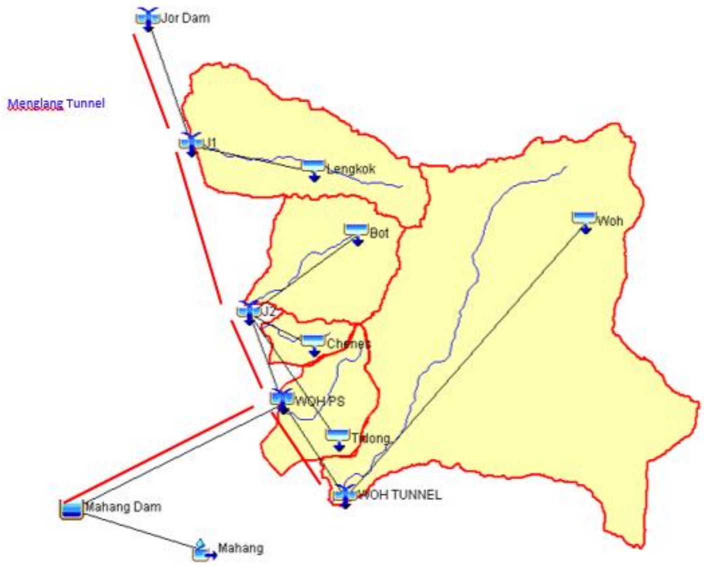

Fig. 1(d)

Figure 4. Delineation for the Dams in study area

Fig. 1(a) Abu Bakar Dam **Fig. 1(b)** Ulu Jelai Dam **Fig. 1(c)** Jor Dam **Fig. 1(d)** Mahang Dam

CALIBRATION AND VALIDATION OF THE MODEL

In this research, calibration is fulfilled since the rainfall and observations for the stream flow are obtainable in which observed hydrologic and meteorological data were used in an organized exploration for the affective parameters that produce the best fit between both of the predicted and observed data. The values for initial loss and constant rate used are 5 mm and 4 mm/hr respectively. These couple of values were attained from the processes of calibration and validation. For this study, calibration was carried out at the Telom catchment using the rainfall and streamflow data from TNB Station 9003 Alur Masuk Sg. Telom and Station 6002 Telom at Batu 49, respectively. The simulation period was from November 30, 2013, to December 4, 2013. The hydrograph produced from the calibration process for simulated and observed flow is shown in Figure 5 in which both of the hydrographs almost matching especially for the peak flows and volume. It is indicated that the processes hydrograph is very close to the observed hydrograph for the selected events, particularly the peak flows. These results were later used in the validation process. In validation, the same location was used with a different simulation period which was from 17 – 19 December 2015. Figure 6 depicts the results for the simulated and observed flow during the validation process in which both of the hydrographs are almost matching especially for the peak flows and volume. The results of calibration and validation are evaluated by the performance parameters of Nash-Sutcliffe Efficiency (NSE) and Percent Bias (PBIAS) in which for the calibration, NSE and PBIAS of 0.776 and -0.03% respectively are obtained while NSE and PBIAS of 0.861 and 1.47% respectively are obtained for Cameron Highlands dams for model validation. Table 2 summarizes the results of the developed model for the Cameron Highland in terms of the peak flow and volume.

Table 2. Summary of PMF for the Cameron Highland Watershed

Duration (hr)	**Parameters**	**SAB**	**Jor**	**Mahang**	**Ulu Jelai**
1	Peak Inflow (m^3/s)	828.2	2,042.2	***113.7***	3,971.6
	Volume (Mm^3)	40.9	66.3	207.6	105.2
3	Peak Inflow (m^3/s)	941.7	***2,141.1***	78.9	3,987.8
	Volume (Mm^3)	43.2	78.3	207.9	112.2
6	Peak Inflow (m^3/s)	***1241.7***	2,107.4	64.8	3,889.8
	Volume (Mm^3)	51.7	84.8	208.0	115.0
12	Peak Inflow (m^3/s)	1112.6	1,940.0	64.0	***4,222.7***
	Volume (Mm^3)	63.0	104.6	209.7	154.4
24	Peak Inflow (m^3/s)	881.5	1,566.0	58.6	2,576.6
	Volume (Mm^3)	71.9	119.5	210.6	172.5
72	Peak Inflow (m^3/s)	663.1	1,205.1	55.7	1,904.2
	Volume (Mm^3)	114.4	190.9	215.3	277.5

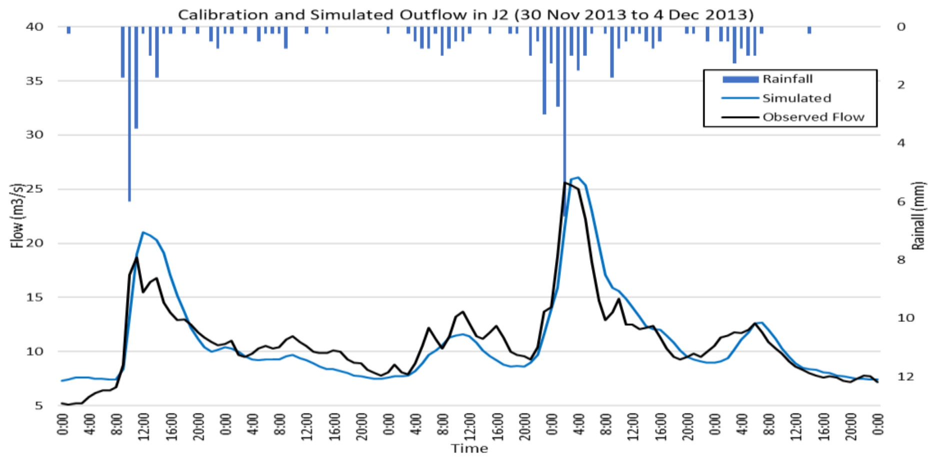

Figure 5. The Calibration Hydrograph

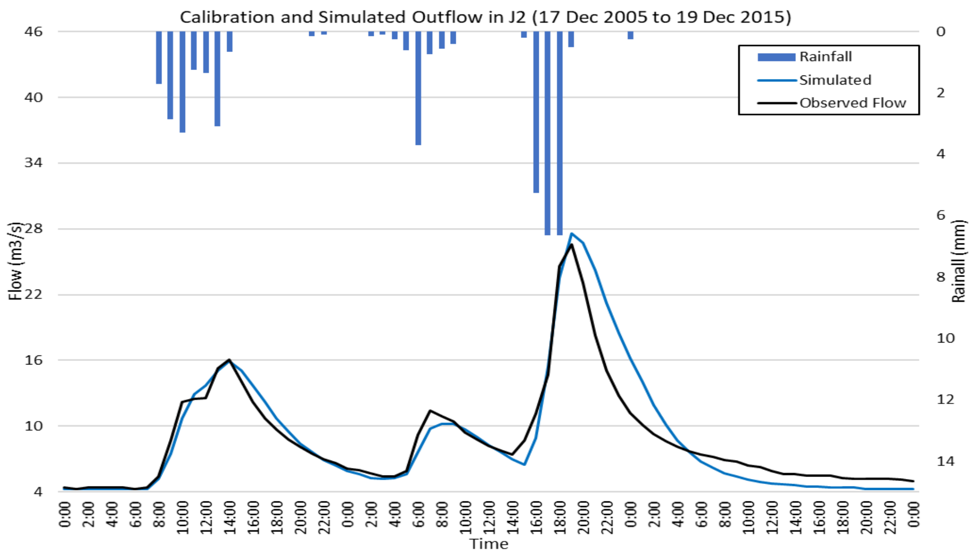

Figure 6. The Validation Hydrograph

CONCLUSIONS AND RECOMMENDATIONS

Results from the calibration and validation for the storm events showed that the performance parameters for both events are considered very good and reasonable. In conclusion, the hydrological model in this study has been adequately calibrated for PMF simulation as it is credible and applicable to describe the hydrological process in Cameron Highland Batang Padang HES. It is recommended that next studies estimate the Areal Reduction factor (ARF) and perform the PMF simulation for the mentioned dams in the current study by considering reservoir operations (reservoir routing). Furthermore, comparing the simulated maximum spillway discharge and the design spillway discharge capacity.

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