Modeling Earth Systems and Environment (2019) 5:1705–1722
https://doi.org/10.1007/s40808-019-00625-8

ORIGINAL ARTICLE

Influence analysis of peak rate factor in the flood events' calibration process using HEC–HMS

Christian Cahyono[1] · Wanny K. Adidarma[2]

Received: 28 June 2019 / Accepted: 3 August 2019 / Published online: 13 August 2019

Abstract

In flood management, analysis and modelling are needed, especially for the analysis of the occurrence of floods and decision making. One method for analyzing flood events can use the HEC–HMS software. In HEC–HMS, there are three sub-models, namely, losses, transform, and baseflow. In the development of the use of the HEC–HMS model, it still utilizes sub-model transform, where the peak rate factor (PRF) value is constant at 484 in modelling. The value of PRF is very dependent on the slope of the land (basin slope), where the value of this parameter is very varied depending on the physical condition of the area under study. Because of the fact, where the value of PRF should be varied depends on the slope in modelling stage; while the reality is still constant, this research is done. The research result shows that the role of PRF makes the modelling carried out using HEC–HMS produce comparable results as indicated by the objective function values in two study areas. The following is the comparison of the objective function of the Selorejo watershed in the March 2007 flood event between constant PRF 484 with variations in the values of PRF, RMSE (0.63 m; 0.59 m), CORREL (0.977; 0.976), and DELTAPEAK (43.04%; 41.46%). Whereas in the PDA Cipasang watershed, Nash–Sutcliffe (0.818; 0.820), RMSE (66.20 m^3/s; 65.91 m^3/s), CORREL (0.916; 0.917), and DELTAPEAK (15.55%; 15.35%). To utilize the variation of PRF into the model, based on the results of this study, the sub-model used is SCS Curve Number for Losses, SCS Units Hydrograph for Transform, and Recession Constant for Baseflow. It can be concluded that by including the influence of variations in PRF values resulting not a better model but only a slight improvement which is insignificant and a more complete model.

Keywords Analysis of flood occurrence · Peak rate factor · Basin slope · Objective function

Introduction

Flooding is one of the problems faced in Indonesia. Flood disasters carry many losses in the form of both casualties and property losses. Therefore, a study is needed to resolve this flood problem. The study carried out needs to be completed with an analysis of calculations, so that decision making can be based on this analysis. To carry out this analysis, supporting data are needed to carry out analysis in the form of hydrological data and field physical data. However, the problem that is occurring now is that the completeness of the data is lacking; therefore, the analysis is only able to utilize the physical data of the existing field. With these physical data, analysis can still be done. One method for analyzing flood events that utilize physical data is the SCS method. In the SCS method, it consists of several components to carry out a flood event analysis, namely, loss analysis using the SCS curve number and transformation analysis using the SCS unit hydrograph. Each of these components relies on physical components in the field, for example, curve number values are highly dependent on land use in the field. Likewise, the SCS unit hydrograph is strongly influenced by the slope of the land/watershed. During this flood, analysis carried out for SCS hydrograph units still uses the same peak rate factor (PRF) in a watershed. However, the reality in one watershed itself consists of several different slope

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40808-019-00625-8) contains supplementary material, which is available to authorized users.

✉ Christian Cahyono
christiancahyono12@gmail.com

Wanny K. Adidarma
wannyadi@gmail.com

[1] Parahyangan Catholic University, Bandung, Indonesia

[2] Parahyangan Catholic University Post-Graduate Program, Bandung, Indonesia

areas, where variations are only accommodated in the calculation of lag time which is one of the parameters of the SCS unit hydrograph. The function of the PRF itself is to change the shape of the hydrograph, both the peak value and the duration of the hydrograph unit. With this factor, one of the processes for analyzing flood events, namely, the flood calibration process, is expected to be more in line with the results of observation data.

Literature review

Flooding has become a problem that often occurs in the management of quantity of water, especially in developing countries. In dealing with flood events, various methods have been developed to overcome the problem in the form of structural and non-structural. However, methods in overcoming flooding events require an analysis of calculations to support existing decision making. This calculation analysis develops from conventional methods to complex analysis.

At the beginning of its development, the analysis of flood events was carried out qualitatively by assessing the level of vulnerability of various factors affecting the incidence of flooding. Based on research conducted by Paimin et al. that there are several factors that influence a flood event, namely, annual maximum daily rainfall, watershed shape, land use, and several other factors (Paimin and Pramono 2009). This qualitative method is used, because historical data that are still not long enough to carry out flood analysis; besides that, the modelling method of flood events is still difficult to do because of its complexity, so that a model aid which at that time was not developed, as it is now needed. As time went on and the development of science and technology developed, the analysis of flood calculations developed.

This analysis is divided into two methods. The first method is by statistical analysis. This method can only be done if historical flood data in the area reviewed is complete and quite long. There are studies that carry out analysis with this method on several rivers in Indonesia, where in this study can be obtained the results of certain return period flow rates on several rivers in Indonesia; for example, the 100-year return period in the Citarum watershed is 377 m^3/s. (Pawitan 2014). Because of the problem of incomplete historical data, this method was developed to conduct flood analysis. This method is known as the rainfall–runoff transformation method.

The rainfall–runoff transformation method is more often applied, because the availability of data is easier to obtain. The data are rain data in the form of short duration rain and long duration and physical condition of existing watershed. The rainfall–runoff transformation method goal is to produce a flood hydrograph to support this analysis and three sub-models are needed, namely, loss method, transformation method, and base flow method. Loss model is a method for determining the effective rain value that will become runoff. This model takes into account the value of rain lost due to several processes of the hydrological cycle, namely, evaporation in the atmosphere, interception of plants, and infiltration into the soil. Transformation model is a model for changing effective rain that exists into a hydrograph runoff discharge. Baseflow model is to determine the underground flow that flows into the river as a base flow or flow that is always present in a river. With the existence of these three sub-models, the rainfall–runoff transformation method can be done. In the application, there are several computer models that utilize this method to do some flood analysis, one of which is HEC–HMS.

In the HEC–HMS model, three sub-models consist of several methods to perform calculations as examples of loss sub-models consisting of the SCS curve number method, deficit constant, etc. Similarly, the other sub-models have several calculation methods to choose from. Several analyses in Indonesia have used this method such as analysis of the Citarum Hulu watershed (Pratiwi 2011), Duri Canal (Sitanggang et al. 2014), and Wuryantoro Watershed in Wonogiri (Munajad and Suprayogi 2015). Besides Indonesia, this method is also applied outside Indonesia, such as in Morocco, more precisely in the Boukhalef watershed (Khaddor et al. 2017). These four analyses used the HEC–HMS model to analyze flood events in their respective research locations. Although the location and type of watershed are different, the four studies have similarities in modelling, namely, using the SCS method for flood analysis, both using the SCS curve number method for the loss model, and the SCS unit hydrograph method for the transformation model. The SCS method itself is very dependent on the physical conditions of the field, where the SCS curve number method itself is strongly influenced by land use in the research area and the SCS unit hydrograph method is strongly influenced by the slope of the studied watershed or basin.

In the SCS unit hydrograph method, there are two main parameters, namely, lag time and PRF. In the implementation of the SCS unit hydrograph in the four studies above, the slope of the watershed or basin area only affects the lag-time parameter, while the PRF value does not change at all using only the value 484 which is the standard SCS value. Therefore, there is a need for a new modelling method, where the analysis does not neglect the value of the existing PRF, but needs to be adjusted to the slope of the watershed or basin area studied. Based on several studies conducted, the value of PRF influences the flood model made, so it is necessary to change the PRF value based on the slope of the study area (Sheridan et al. 2002; Fang et al. 2005). There are several ways to determine PRF value. Based on the literature study that has been done, there are two ways to determine these values, using formulas (Fang et al. 2005) and tables.

Part of the table is slope type and the value of the PRF. Because of these two methods, research needs to be done to determine which method is suitable for determining the PRF value. With the implementation of the PRF value, it is expected that the modelling results will be more accurate for the calibration process of flood events, where the parameters are used to determine the value of the return flow for decision making to overcome the occurrence of floods.

Based on literature review that has been done, there are some theories and formulas that are used in these studies. This part will explain these theories and formulas.

Losses

This hydrological component tries to model water loss that occurs during the event of rain/flood. Water losses that occur can be either interception by plants or infiltration by soil. In HEC–HMS software, there are several methods for modelling water loss that occur, but in this study, only two methods were used, namely, the SCS/NRCS method and the deficit constant method.

SCS curve number

The SCS/NRCS method is a method for calculating the amount of water loss caused by land infiltration. The amount of water loss in the SCS/NRCS method is very dependent on the curve number (CN) parameter. The CN parameters depend on the physical conditions of the watershed, such as the type of soil, type of vegetation cover, land use, hydrological conditions, antecedent moisture condition (AMC), and climate in the watershed. The greater the CN value, the infiltration value that occurs will be smaller and vice versa. This method estimates the excess rain as a function of cumulative rain, land cover, land use, and soil moisture. The following is the equation for the loss/infiltration of the SCS/NRCS method:

$$P_{\mathrm{e}} = \left\{ \frac{(P - I_{\mathrm{a}})^2}{P - I_{\mathrm{a}} + S} \right\}, \tag{1}$$

$$I_{\mathrm{a}} = \lambda \cdot S, \tag{2}$$

$$S = \left\{ \frac{25,400 - 254\mathrm{CN}}{\mathrm{CN}} \right\}, \tag{3}$$

where P_{e} is the cumulative rainfall excess (mm), P is the cumulative rainfall (mm), I_{a} is the initial water loss (mm), S is the potential storage inside watershed (mm), λ is the coefficient, and CN is the curve number

The relationship between I_{a} and S is derived empirically, where the value of λ is taken as 0.2, so also for the HEC–HMS model, the value of Ia is standard if it is not also filled at 0.2S, so that in different watersheds, the value of λ can vary. For watersheds with sub-watersheds that have different types of land and land cover, the CN composite value is determined using the CN composite formula as follows:

$$\mathrm{CN}_{\mathrm{c}} = \frac{\mathrm{CN}_1 A_1 + \mathrm{CN}_2 A_2 + \cdots + CN_i A_i \cdots + CN_n A_n}{\sum_{i=1}^{n} A_i}, \tag{4}$$

where CN_i is the CN value in the sub-watershed i, A_i is the sub-catchment area i, and n is the number of sub-watersheds

Deficit constant

Deficit constant method is a loss method that is able to calculate the amount of continuous rainfall loss, especially when it does not rain, the ability of the soil to absorb water becomes greater (recovery). This method contains three parameters: initial deficit in mm, maximum deficit/maximum storage in mm, and constant rate in mm/h.

The initial deficit is the initial condition of the calculation, indicating that the amount of water needed to fill the soil layer to reach maximum storage. The maximum deficit is defined as the amount of water from the soil layer that can be held back and expressed in thickness. The upper limit is the thickness of the active soil layer multiplied by the porosity approximated by the soil storage value of the CN SCS. The infiltration rate in the method deficit constant will reach a constant value when the soil experiences a saturated condition which can be estimated from the value of saturated hydraulic conductivity (saturated hydraulic conductivity). Calculation of these values can use the following formula:

$$\mathrm{pe}_t = \begin{cases} p_t - f_{\mathrm{c}}, & \text{if}, p_t > f_{\mathrm{c}} \\ 0 & \text{other} \end{cases}. \tag{5}$$

Until the accumulation of rain in the area that passes the water exceeds the initial deficit volume, there is no runoff that occurs:

$$\mathrm{pe}_t = \begin{cases} 0, & \text{if } \sum p_t < I_{\mathrm{a}} \\ p_t - f_{\mathrm{c}}, & \text{if } \sum p_t > I_{\mathrm{a}} \text{ and } p_t > f_{\mathrm{c}} \\ 0, & \text{if } \sum p_t > I_{\mathrm{a}} \text{ and } p_t < f_{\mathrm{c}} \end{cases}, \tag{6}$$

where pe_t is the effective rainfall at time t (mm), p_t is the rainfall at the time t (mm), I_{a} is the initial deficit (mm), and f_{c} is the potential maximum rate of rainfall loss (mm).

The parameters' initial deficit, maximum deficit or maximum storage, and constant rate in the loss modelling using the deficit constant method must be determined. The parameters' maximum deficit or maximum storage is obtained from Eq. (3), while the constant rate parameter can be determined based on Table 1.

Table 1 Basic determination of constant infiltration rate parameters (constant rate) (Source: SCS 2007)

Saturated hydraulic conductivity	Hydrologic soil group			
	Group A	Group B	Group C	Group D
in./h	> 1.42	0.57–1.42	0.06–0.57	< 0.06
mm/h	> 36.1	14.5–36.1	1.5–14.5	< 1.5

SCS unit hydrograph

SCS unit hydrograph is one method of effective rain transformation into a hydrograph. In this SCS method, the resulting hydrograph is dimensionless. In modelling in HEC–HMS, synthetic hydrograph SCS has two important components, namely, the time delay/lag time and PRF.

Lag time or time delay can be defined as the time between the occurrences of effective rain peaks until the peak flood discharge. Lag-time calculations can be estimated based on the concentration time value using the equation:

$$T_{lag} = 0,6T_c, \tag{7}$$

where T_{lag} is the lag time, $T_{c\ \text{is the}}$ time of concentration, whereas to determine, the value of concentration time (T_c) can use the formula as follows:

$$T_c = T_{Shallow} + T_{Sheet} + T_{Channel}, \tag{8}$$

where $T_{Shallow}$ is the time on land (min), T_{Sheet} is the time in shallow flow (min), and $T_{Channel}$ is the time on channel (min).

Calculation of concentration time value (T_c), TR-55, is used to estimate the value.

In addition to the lag-time value or delay time, the PRF value also influences the SCS synthesis hydrograph transformation process. PRF can be defined as a dimensionless parameter that determines the shape of the SCS synthetic hydrograph unit. The standard PRF value of the SCS hydrograph is 484. However, the PRF value varies from around 600 for mountainous regions to around 200–300 for flat-sloping areas. The PRF value itself depends on two physical parameters of the watershed, namely, the length of the water flow and the slope of the watershed. The PRF value will be even greater if the basin slope or slope of the land is increasingly steep and vice versa. The greater PRF value results in higher peak discharge. With these two physical parameters, we can determine the PRF value that is suitable for modelling flood events not only based on standard values. The following is the PRF value equation:

$$\emptyset(\alpha) = \frac{Q_p T_p}{645,33A} = \frac{\text{PRF}}{645,33}, \tag{9}$$

where Q_p is the observation peak flow (CFS), T_p is the T_c time of concentration, A is the area of basin/sub-basin area (Mile2), PRF is the peak rate factor, and $\emptyset(\alpha)$ is the dimensionless parameter (source: Fang et al. 2005).

In addition to using equations, PRF values can also be determined qualitatively using tables that have been produced by Wanielista et al. in their research in 1997. The following table as such.

By seeing Table 2, it can be seen that in the table that PRF value depends on the type of slope reviewed and also we can see that the land use effect is not to significant, because there are only two types of land use which is urban and rural, and beside that, land use effect has been accommodated on Loss method. Therefore, based on these facts, only slope can only be used as determining value. Therefore, a table for determining the grouping of slope types is needed. According to the USDA Natural Resources Conservation Service, the group of slope types consists of six types as shown in the following table.

From the collaboration in Tables 2 and 3, it can be determined that the PRF value that is suitable for each sub-watershed will be modeled.

Recession constant

The recession constant method is often used to explain the flow of water from natural reservoirs in a watershed. The relationship between base flow for each time t is

$$Q_t = Q_0 K^t, \tag{10}$$

Table 2 Table to determine PRF values (Source: Wanielista et al. 1997)

General description	Peaking factor	Limb ratio (recession to rising)
Urban areas; steep slopes	575	1.25
Typical SCS	484	1.67
Mixed urban/rural	400	2.25
Rural, rolling hills	300	3.33
Rural, slight slopes	200	5.5
Rural, very flat	100	12

Table 3 Grouping of land slope types (Source: USDA Natural Resources Conservation Service)

Simple slopes	Complex slopes	Slope gradient	
		Lower %	Upper %
Nearly level	Nearly level	0	3
Gently sloping	Undulating	1	8
Strongly sloping	Rolling	4	16
Moderately steep	Hilly	10	30
Steep	Steep	20	60
Very steep	Very steep	> 45	

where Q_0 is the base flow when $t = 0$, and Q_t is the base flow when time t and k are exponential degradation constants. The k value is defined as the ratio of the base flow at time t to the base flow 1 day before.

Objective function

The objective function is used as an indicator of whether the model has been made according to the results of the observation. In this study, there are four objective parameters used: Nash–Sutcliffe, RMSE, peak difference, and correlation value.

Nash–Sutcliffe (NS)

Nash–Sutcliffe efficiency (NS) is an objective function that is used to evaluate the results of modelling simulations conducted from the point of view of the average value of observation. NS value has a range between 0 and 1, where the NS value is getting closer to the value 1, indicating that the results of the simulation model produced are getting better, because it is close to the observed value. The smaller results indicate that the estimation of the model carried out is too large compared to the actual data (Legates and McCabe 1999). Based on the technical instructions that have been made considering the condition of the data in Indonesia, the minimum required NS value is 0.375. Following is the formula for calculating NS values:

$$\mathrm{NS} = 1 - \frac{\sum_{i-1}^{n}\left(Q_{\mathrm{obs}} - Q_{\mathrm{sim}}\right)^2}{\sum_{i-1}^{n}\left(Q_{\mathrm{obs}} - \mathrm{RQ}_{\mathrm{obs}}\right)^2}, \tag{11}$$

where NS is the Nash–Sutcliffe efficiency, Q_{sim} is the simulation flow (m^3/s), Q_{obs} is the recorded flow (m^3/s), $\mathrm{RQ}_{\mathrm{obs}}$ is the average recorded flow (m^3/s), and N is the amount of data.

Root mean square error (RMSE)

Root mean square error (RMSE) is an objective function that is used to measure the error value in the form of differences in the value of observations and simulations, where the results that are closer to the value of zero show that the simulation results are getting better. Following is the formula to determine the RMSE value:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(F - O)^2} \times 100\%, \tag{12}$$

where F is the simulation results, O is the observation data, and N is the amount of data.

Delta peak

The peak of a hydrograph is the maximum value during a flood event, indicating the critical time that needs to be simulated. There are two peak variables that are taken into account, namely, the peak of the hydrograph discharge at the water post or the inflow reservoir and the hydrograph peak of the reservoir water level. The purpose of determining this peak difference value is that modelling can model peak events in a flood event not only on average. For hydrograph discharge, peak difference is calculated as follows:

$$B_{\mathrm{P}} = \frac{\mathrm{ABS}\left(\mathrm{MAX}Q_{\mathrm{F}} - \mathrm{MAX}Q_{\emptyset}\right)}{\mathrm{MAX}Q_{\emptyset}} \times 100\%, \tag{13}$$

where B_{p} is the flow delta peak, MAX Q_{F} is the maximum simulated discharge hydrograph, and MAX $Q_{\emptyset}$ is the maximum observation discharge hydrograph.

For water surface hydrographs, the delta peak is calculated as follows:

$$B_{\mathrm{Ep}} = \frac{\mathrm{ABS}\left(\mathrm{MAX}E_{\mathrm{F}} - \mathrm{MAX}\ E_{\emptyset}\right)}{\Delta E} \times 100\%, \tag{14}$$

where B_{Ep} is the delta peak of reservoir water level, MAX E_{F} is the maximum simulated water surface hydrograph, MAX $E_{\emptyset}$ is the maximum observation water surface hydrograph, and ΔE is the difference between the lowest and highest water level observations.

Correlation value

Correlation value, also called correlation coefficient, is the value used to indicate the strength and direction of a linear relationship between two variables. Correlation values are used to find relationships between two quantitative variables. In Mathematics, correlation is a measure of how closely two variables change in relation to each other. Correlation values can be obtained using excel with the formula (= correl). The greater the correlation value between the two variables, the stronger the relationship between these variables.

Study location

In this research, there are two areas that become the location of the study. Both locations are Selorejo Watershed (DAS) and PDA Cipasang Watershed. In this section, we will discuss briefly about the two locations of the study.

Selorejo watershed

Based on calculations performed with Geographic Information System (GIS) software, topographical maps were obtained, as shown in Fig. 1, that the topographic characteristics are as follows:

- Watershed area: with DEM maps and digital river maps and with the help of GIS software, Selorejo watershed area was obtained 234.49 km2.
- With longest flow path of Selorejo watershed is 27,313 km.

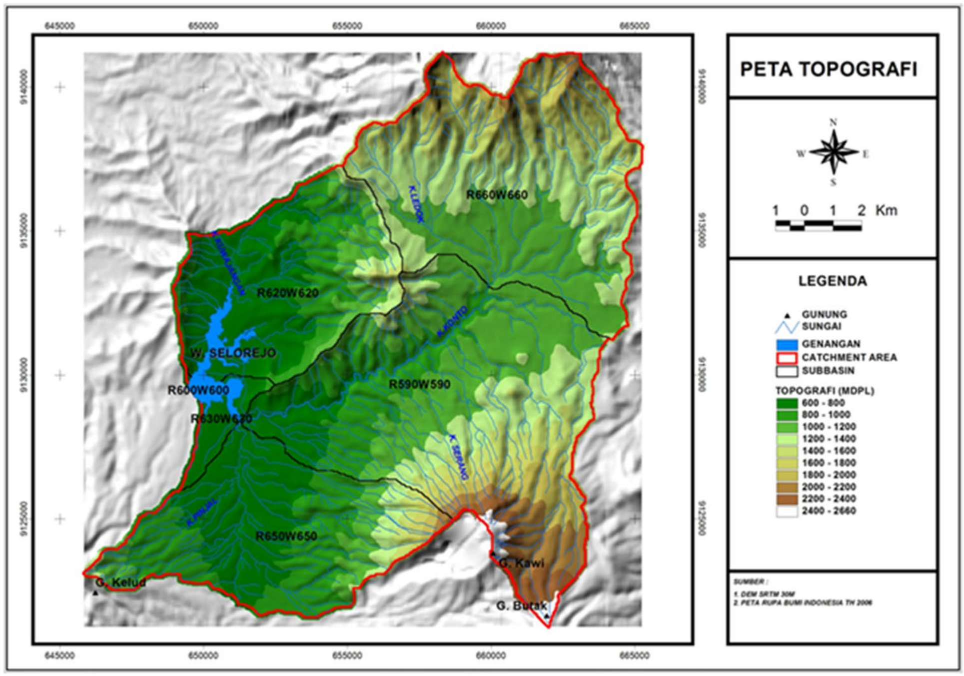


Fig. 1 Topographic map of the Selorejo watershed

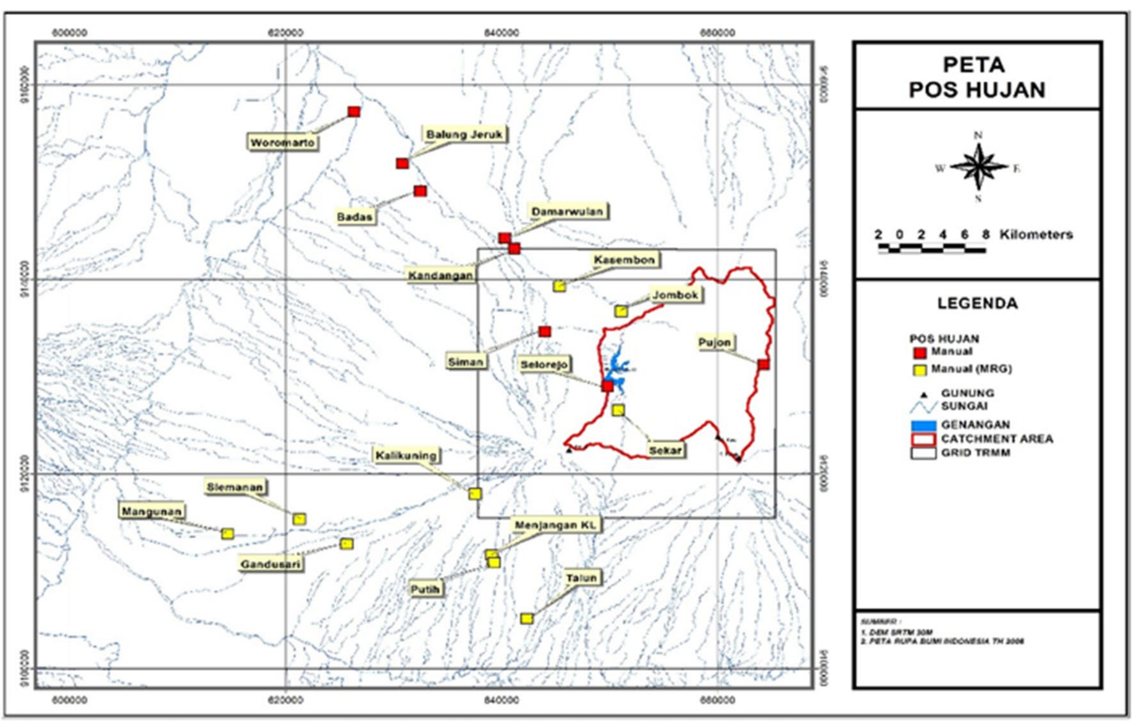


Fig. 2 Location of the Selorejo watershed rainfall post

In Fig. 2, it is shown the rainfall post around the study area. In this study, it was determined to use four rain posts, namely, Jombok, Sekar, Selorejo, and Pujon. From the four rainfall posts used, there were two automatic rain posts, namely, Selorejo and Pujon posts and two rain posts with daily rainfall data, namely, Jombok and Sekar.

In the Selorejo and Pujon automatic rainfall posts, it can be seen that extreme rain occurred twice, first on December 25–26, 2007 and second on March 10–31, 2007, as shown in Figs. 3 and 4. Based on these two extreme events, a flood event modelling was carried out.

PDA Cipasang watershed

From the digital maps that have been obtained in the PDA Cipasang watershed and with the help of Geographic Information System (GIS) or Geophysical Information System software, the topographic characteristics of the PDA Cipasang Watershed can be explained that the watershed area is 1216.3 km^2 with a form, as presented in Fig. 5.

There are several rainpost near PDA Cipasang Watershed; for this analysis, only four rainfall posts are used in which the location is shown in Fig. 6. The four rain posts consist of the Bayongbong, Leuwigoong, Tarogong, and Darmaraja rainfall posts

Based on rainfall data from four rainfall posts, information was obtained that extreme rain resulted in flooding happened on three occasions, namely, April 20–21, 2010, May 19–22, 2010, and September 20–22, 2016. From these three events, only two events were used for the modelling of flood events in the PDA Cipasang watershed, namely, May 19–22, 2010 and September 20–22, 2016 (Figs. 7, 8, 9).

Problem statement

The main problem faced is the lack of quality and quantity of flood event data collection in Indonesia. For example,

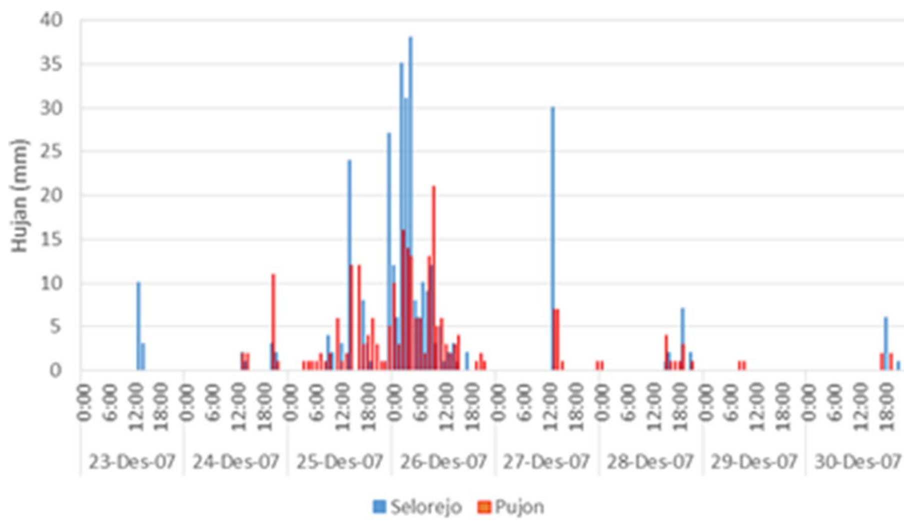


Fig. 3 First extreme rain which occurred on December 25–26, 2007

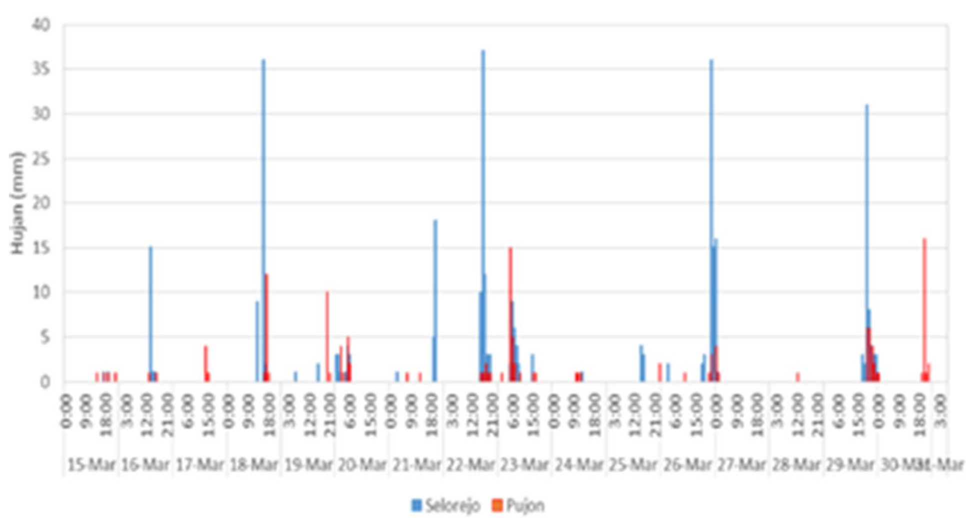


Fig. 4 Second extreme rain which occurred on March 10–31, 2007

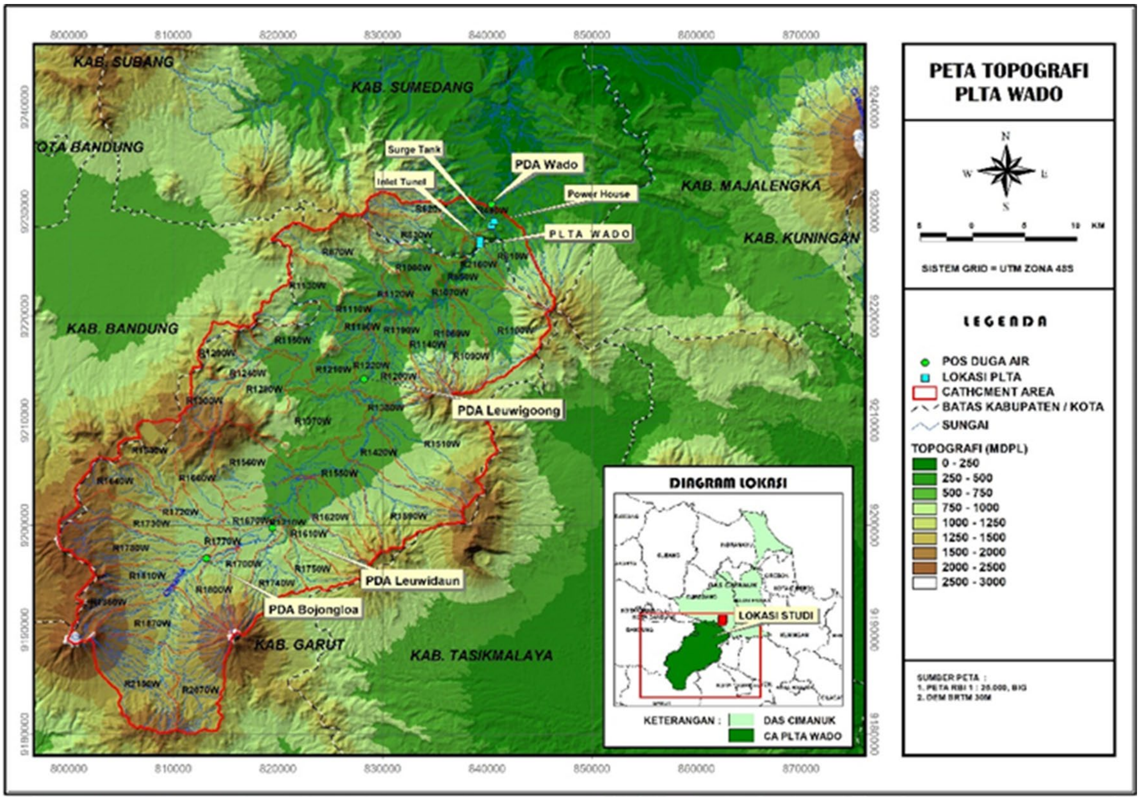
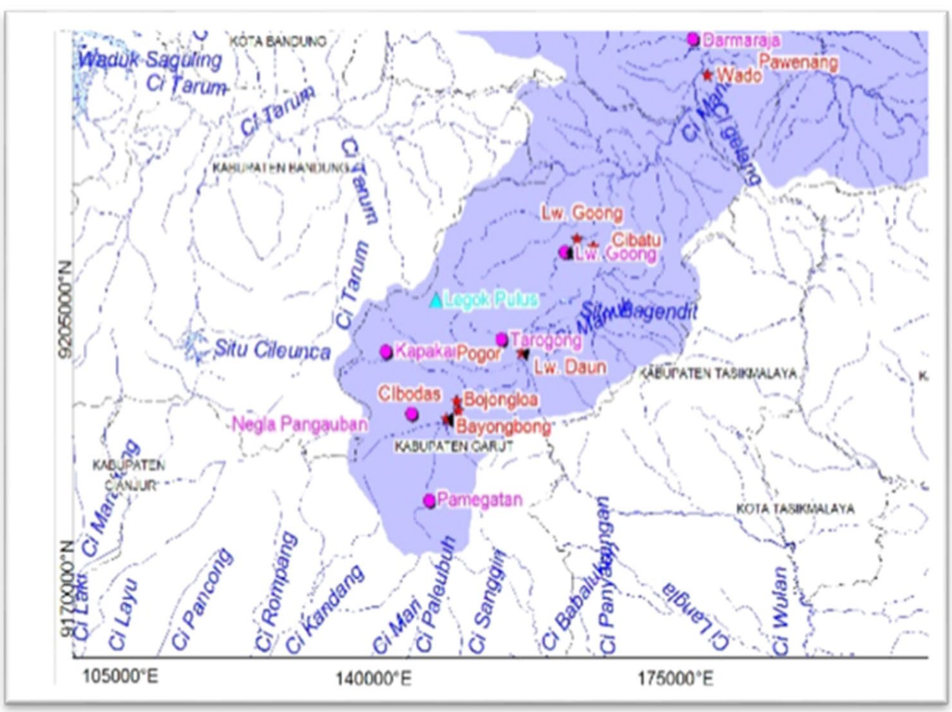


Fig. 5 Topographic map of PDA Cipasang watershed

Fig. 6 Location of PDA Cipasang watershed rainfall post



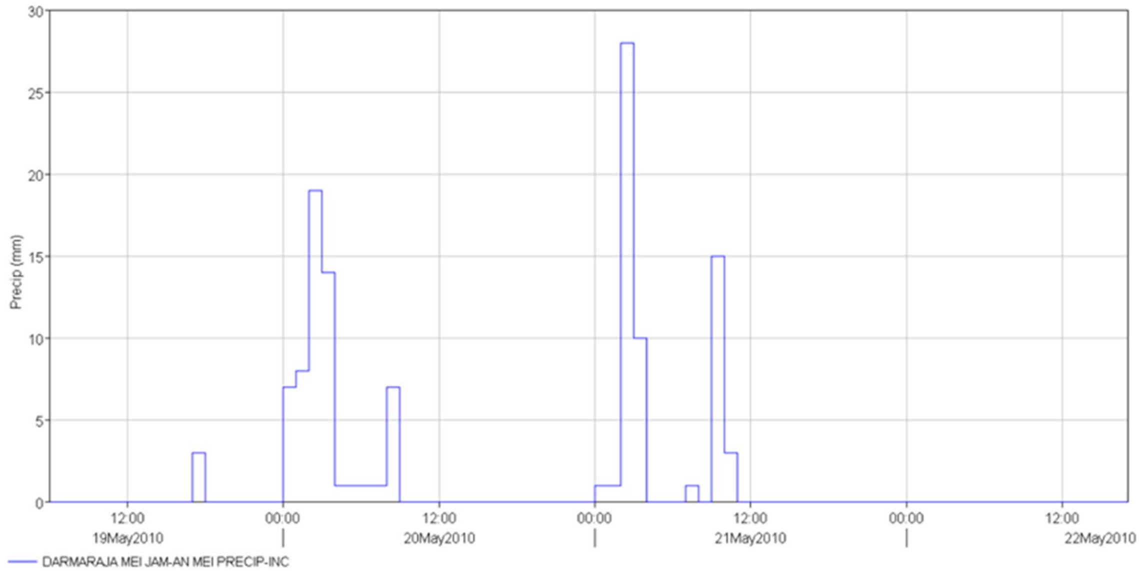


Fig. 7 Extreme rain which occurred on May 19–22, 2010

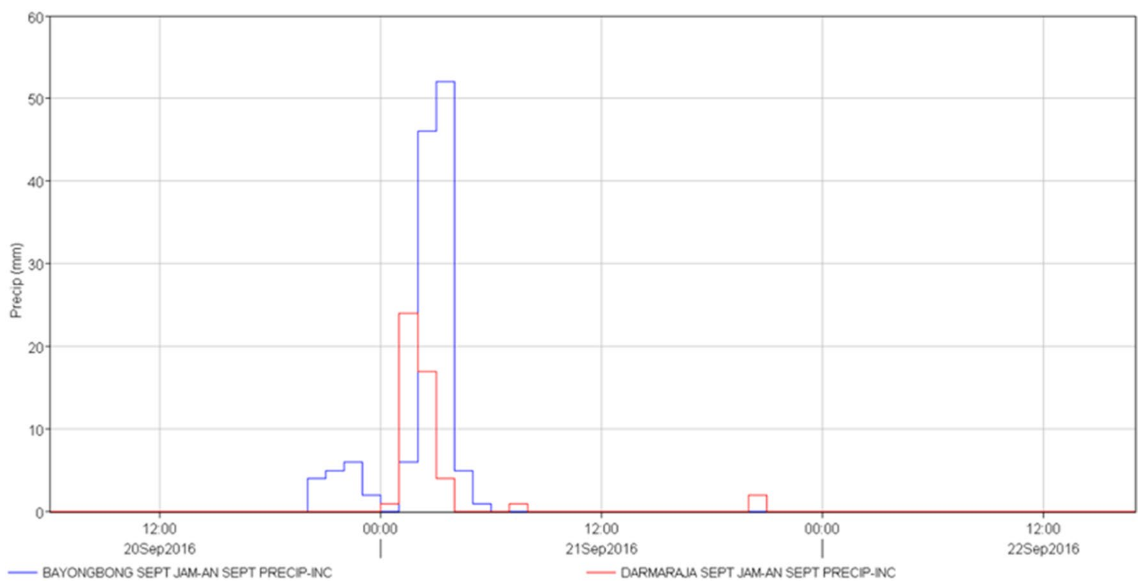


Fig. 8 Extreme rain which occurred on September 20–22, 2016

the available rainfall data are not continuous or continuous (there are blank data), besides that the measurement of the existing observation discharge is neither present nor complete. Therefore, the analysis process is difficult and can only rely on physical condition data in the field for the calibration process of flooding.

With the incompleteness of existing flood data, relying on data on the physical condition of the field is important. This is where the role of the SCS method becomes important, where the unit hydrograph produced by the SCS method is based on the physical condition of the field.

The application of the SCS method on the HEC–HMS in the old version (before version 4.2.1) uses the standard PRF, which is 484. However, the reality is that each part of the watershed reviewed has a different slope, so that the PRF of each part is different. The PRF value is very dependent on the physical condition of the watershed, namely, the slope or slope of the watershed. Based on research conducted by Wanielista et al. (1997) showed that the steeper the slope the greater the value of the PRF and can increase the peak of flooding. With the variation of PRF, it is expected that the calibration process will be more precise and can provide a

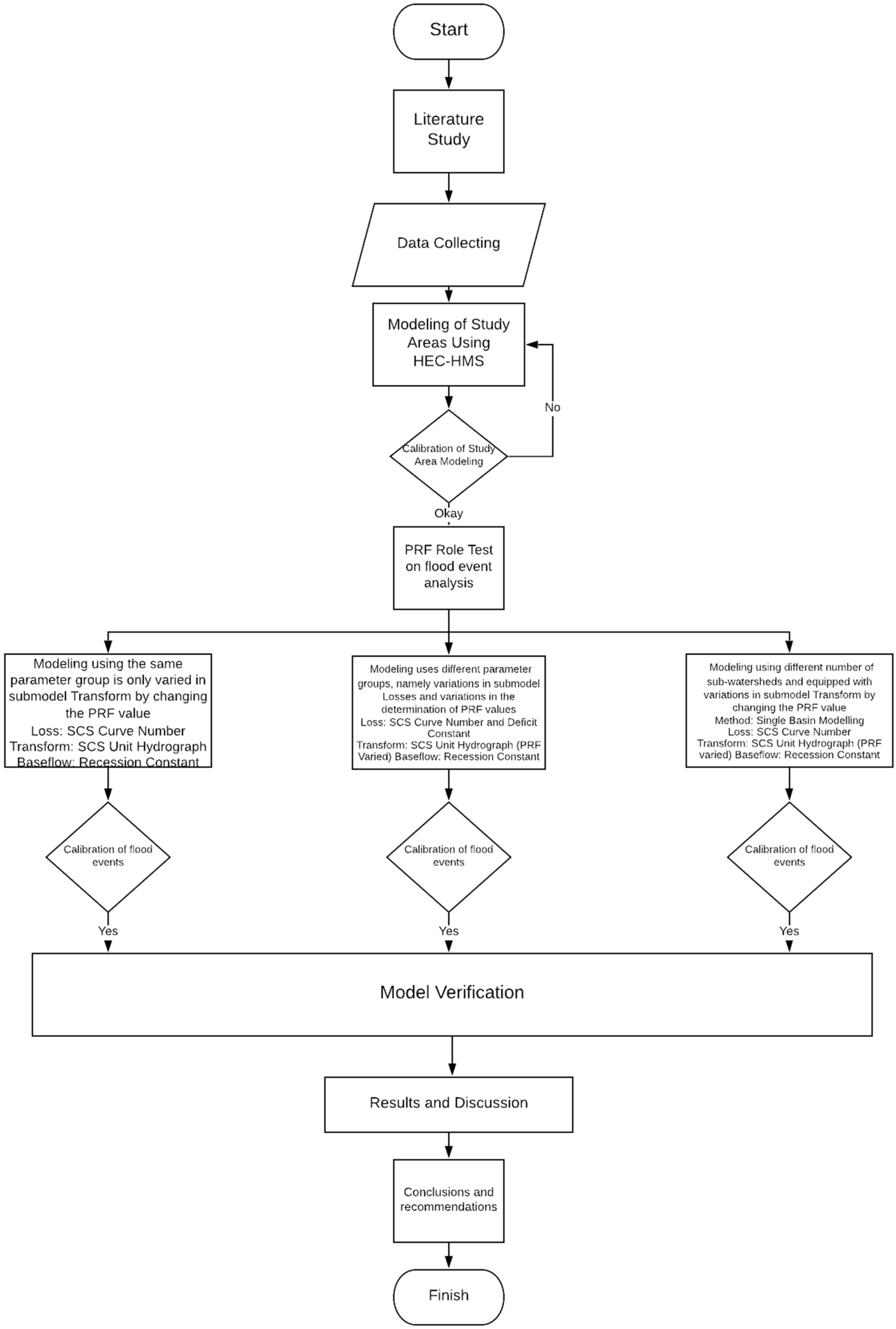


Fig. 9 Research process flow diagram

better basis for hydrological modelling. Most hydrological modelling in Indonesia does not consider the value of this PRF. In modelling using HEC–HMS, most types of Hydrographs used will be considered to be all that is Standard or Delmarva with the assumption that the slope of the land has been accommodated from the existing lag-time parameter value. This assumption is not correct, because the slope of the land itself not only affects the lag-time value, but also affects the PRF value. If the PRF value is not replaced, it is assumed that the slope of the land is considered the same, even though the slope in one watershed is varied. Therefore, for the reasons above, modelling by considering the value of the PRF can help model existing flood events for decision making. In HEC–HMS version 4.2.1, it is equipped with various PRF values to accommodate the physical conditions of the existing field. Therefore, this study tries to compare the effect of different PRF according to field conditions with a standard value whether the calibration process was more accurate or not.

Objectives

In general, this study aims to look at the role of PRF in the flood calibration process and determine the best way to determine PRF values. To achieve these objectives, several stages of analysis are carried out to determine these influences, namely:

- Analysis with variations in sub-model transform by changing the method of determining the PRF value
- Analysis with variations in sub-model transform by changing the method of determining the value of PRF equipped with variations on sub-model losses in the form of SCS curve number and deficit constant
- Analysis with variations in modelling methods between a number of sub-basins and as a single basin. The analysis also included variations in sub-model transform variations by changing the method of determining the PRF value

Methods

This study began with a literature study on the analysis of floods itself, especially in the calibration section of flood events. Then proceed to what part of the SCS method and the application of the SCS method in calculating the flood discharge. In addition, a study of modelling methods using HEC–HMS was carried out further, especially in terms of determining the existing modelling methods. The study of determining the modelling method is centered on the understanding and application of loss, transform, and baseflow method from HEC–HMS. Apart from modelling, a study on PRF was conducted.

The process continues with collecting field data from the watershed which was analyzed. Data collected in the form of physical data from the watershed in the form of soil types using the harmonized world soil database (HWSD), the length of the water flow, the slope of the watershed. In addition to physical data, hydrological data were also collected in the form of rainfall data at the rain station around the watershed which was the area of analysis and observational data that occurred in the field in the event of a flood. Field observation data in the form of water level and observation discharge in the event of a flood. The process was continued by modelling the two study areas using HEC–HMS. The watershed figure of the study area was obtained from HEC–GeoHMS in addition to such extensive physical data, input data for the loss, transform, and baseflow models based on data collected in the previous process. While the rainfall modelling for flood events using Thiessen Polygon, where each rain station has a weight proportion for each sub-basin reviewed.

After that, the PRF role test was performed on the analysis of flood calculations. To see the role, three stages of analysis were carried out. The purpose of the three different analyses is to first determine which parameter group is the most suitable for the PRF application. In this purpose, a different Loss method is used, this is expected to be able to identify which method is most suitable in the calibration event of the incident using PRF. By conducting this research, we can be assured that which loss method the most suitable for PRF modelling. The next goal is to see how the PRF influences in calibration if the sub-number of the variety varies. In the analysis, where the number of sub-Basin was made varied, the main objective was to look at modeling for the calibration of flood events that utilizes the PRF whether it can be assumed as a single basin (1 DAS is not divided) or divided into sub-basin. In this purpose, two regions have two different characteristics in which the Cipasang PDA watershed has a larger watershed, while the Selorejo watershed is relatively smaller. The final objective of this analysis was to see whether the presence of PRF calibration flood events became more accurate. To fulfill this last objective, the modeling method used is the same and only differentiated the variation from the PRF value, so that it can be seen how much influence the PRF has on the calibration process.

After all the modeling is completed, the modeling verification stage is carried out. Model verification is carried out in one of the flood events using the findings of the calibration process. If the verification process has produced the appropriate results, the stage is followed by an analysis of the phenomena that occur. In the analysis of what phenomena occur in the three models performed, it can be seen that the PRF behavior in the flood calibration process and how to

Table 4 Table to determine PRF value

Slope (%)	PRF
0–1.5%	100
1.5–4.5%	200
4.5–10%	300
10–20%	400
> 20%	575

Table 5 Modified table to determine PRF value

Slope (%)	PRF
0–1.5%	100
1.5–4.5%	200
4.5–10%	300
10–20%	400
20–25%	500
> 25%	600

apply PRF in the flood calibration process. From the analysis of the phenomenon that has been carried out, a conclusion is drawn in the form of the role of the PRF in the analysis of flood calculations and suggestions for further research are made for the same theme. After all the above processes can be done, it can be said that the research has been completed.

Results and discussion

As discussed previously, to determine the value of PRF used two ways, namely, using Eq. (9) and a combination of Tables 2 and 3. To determine the slope grouping, it is an experimental based on Tables 2 and 3. Using these two tables, a new table has been obtained to determine the value of PRF.

From Table 4, it can be seen that there are gaps in slopes within steep slopes, where the slope above 20% directly uses PRF 575, so that the PRF 500 value is not utilized properly. Therefore, a modification table was made to accommodate the PRF 500, as shown in Table 5.

Based on the PRF calculation method described in this section, the PRF value of each sub-basin in the watershed reviewed can be determined.

After PRF calculation method has been defined, process continued to modelling the two study location watershed including the three analysis to see the role and determine the best way to determine PRF values. The result of analysis on Selorejo Watershed is shown in Figs. 10, 11, and 12.

After analyzing and modelling Selorejo Watershed, the process continued by modelling PDA Cipasang Watershed. The result of analysis on PDA Cipasang Watershed is shown in Figs. 13, 14, and 15.

Based on the result of analysis and modelling shown in Fig. 10, 11, 12, 13, 14, and 15, the objective function values can be determined from each study location. The following are the objective function values of the two study locations, as shown in Tables 6 and 7.

Based on the objective parameter values shown in Tables 6 and 7, we can see several phenomena that occur, where the PRF 1, 2, and 3 in question are PRF using formulas, PRF results in Table 4, and PRF results in Table 5. First, it can be seen that with several methods for determining PRF, the method of determining the formula is less than the other methods. This is caused by the results of the calculation of Q_p and T_p not the original measurement results that occur in the field but rather the simulation results, so

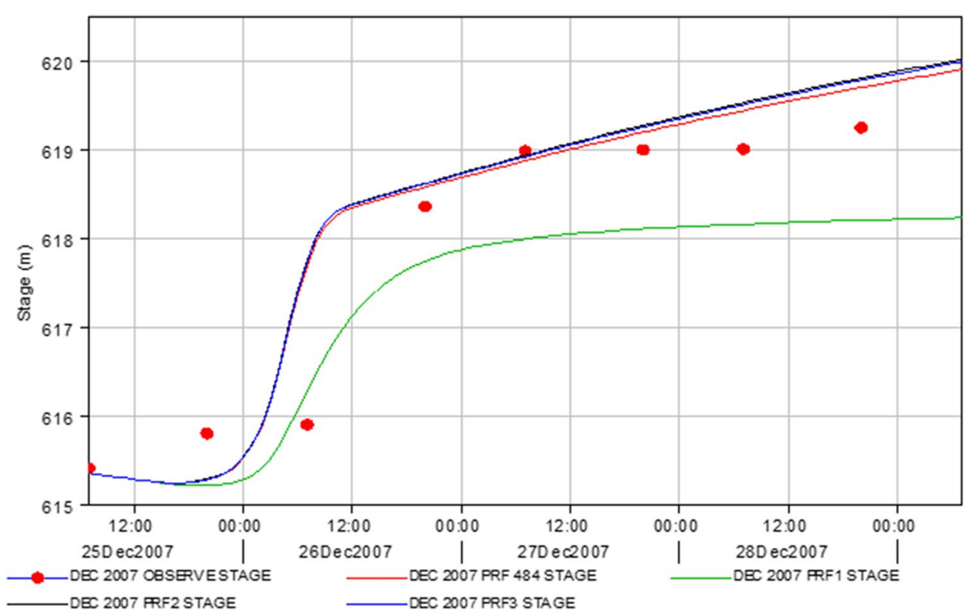


Fig. 10 Analysis result on effect of variation PRF value at Selorejo watershed

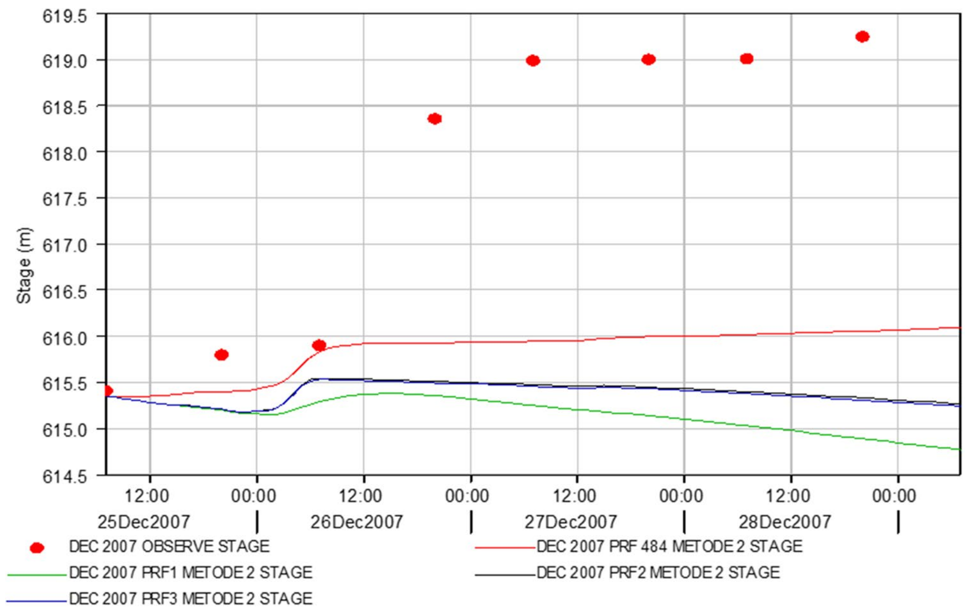


Fig. 11 Results of influence analysis variations in PRF values using the lost method of deficit constant at Selorejo watershed

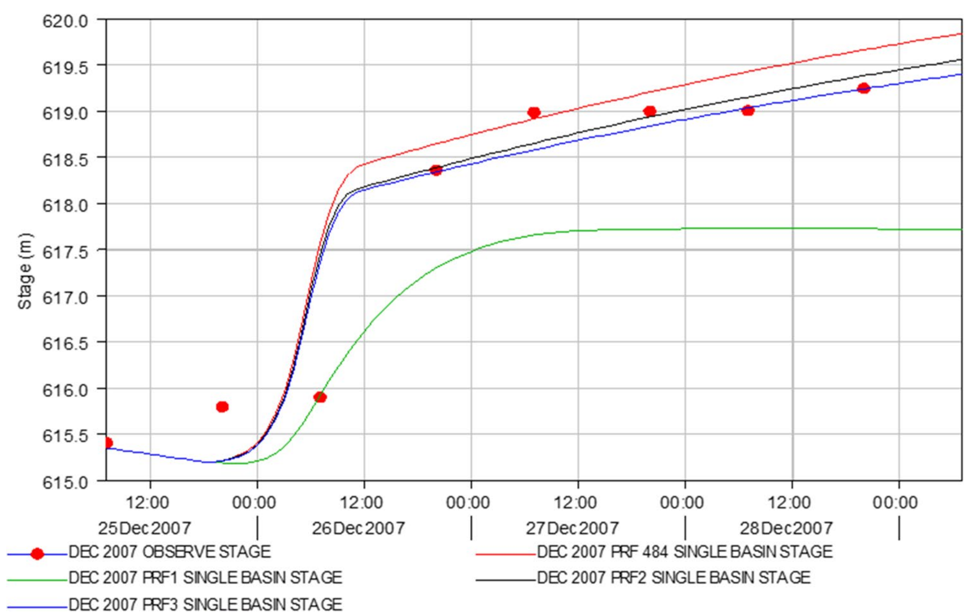


Fig. 12 Results of analysis of the effect of PRF on the single-basin model of the Selorejo watershed

that it is less able to describe the events that occur. Then, it can be seen that the results of using Tables 4 and 5 show a fairly high objective parameter value in both the Selorejo and the PDA Cipasang Watershed. However, the estimation of the PRF values found in Tables 4 and 5 gives less significant effect, as shown in Tables 6 and 7. This is due to the frequency of the PRF values that exist in each watershed. Figures 16 and 17 show the average value of the PRF used in each watershed. This frequency distribution obtained from the value of PRF of each sub-basin within each basin, respectively. It can be seen also that the average PRF value used in the PDA Cipasang watershed is close to the PRF value, so that the objective parameter values from using standard PRF and PRF variations using tables are close to the value. Likewise, in the Selorejo watershed, even though the PRF value of each sub-basin is fairly evenly divided, the average value approaches the standard PRF, so that the objective parameter values are only slightly different.

It can also be seen the phenomenon of the use of the method of losing deficit constant. In the Selorejo watershed, the use of the deficit constant method is not suitable as indicated by the value of the objective parameter that is not good enough. However, in the PDA DAS Cipasang, the use of the Deficit Constant method shows a fairly good objective parameter value. The difference that might occur is due to the condition of each watershed which has a different

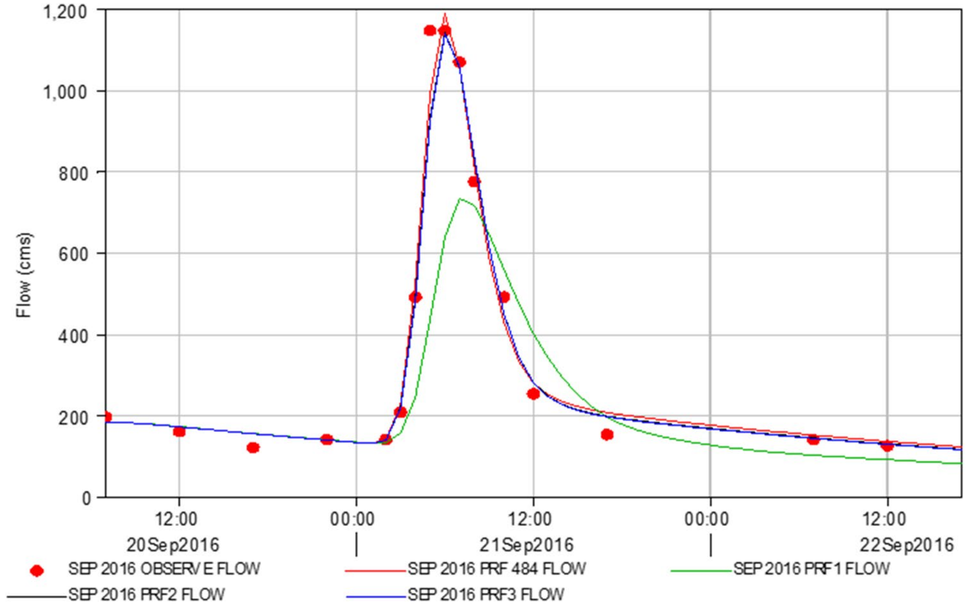


Fig. 13 Analysis result on effect of variation PRF value at PDA Cipasang watershed

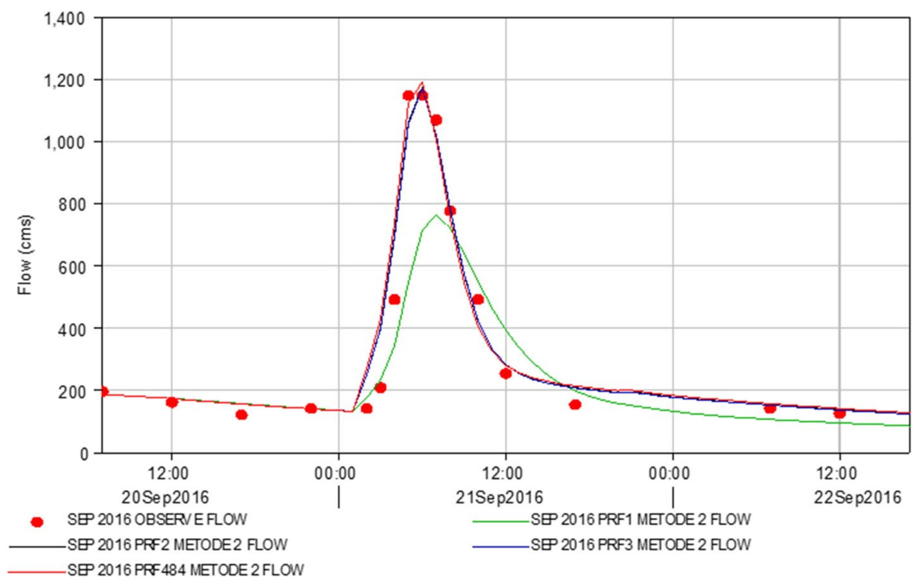


Fig. 14 Results of influence analysis variations in PRF values using the lost method of deficit constant at PDA Cipasang watershed

match with each modeling method. In addition, it can be seen also the same phenomenon, where the objective parameter value of the PRF determination method using a formula has a lower value than using a table, so that it can be said that the use of the deficit constant loss method needs to be assessed based on the studied watershed whether it is suitable to be applied to the watershed. In addition to the two previous findings, it can be seen the test results if the watershed is modeled as a single basin. Determining the PRF value in the single-basin test is based on the guidelines of HEC–GeoHMS, where the basin slope value for determining the PRF value based on Tables 4 and 5 uses the mean basin slope value of the river basin studied. In the Selorejo watershed, the single-basin modeling showed the same results with the initial modeling both with the standard PRF values and with the variation values of the PRF. However, in the Cipasang PDA watershed, the opposite results were found, where the value of the objective parameters showed a poor value and can be seen also in Fig. 15, the modeling results were much smaller than the results of the observations. This is due to the condition and extent of each watershed. In the Selorejo watershed, the condition of the watershed is more homogeneous which can be seen from the sub-watershed slope and hydrogeology of the watershed which is relatively homogeneous. Besides that, the area of the Selorejo watershed is only 234.49 km^2 compared to the Cipasang PDA watershed area of 1216.3 km^2; this indicates the possibility that the rain in the Selorejo watershed will be more evenly

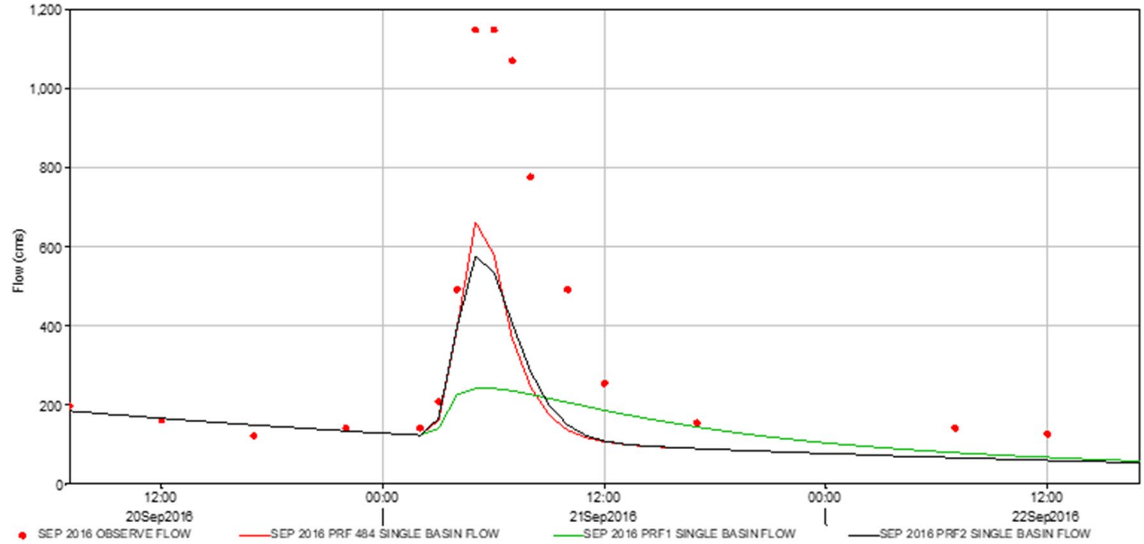


Fig. 15 Results of analysis of the effect of PRF on the single-basin model of the PDA Cipasang watershed

Table 6 Value of objective parameters in the Selorejo watershed

	Dec-07											
	SCS CN				Def. constant				Single basin			
	PRF 484	PRF 1	PRF 2	PRF 3	PRF 484	PRF 1	PRF 2	PRF 3	PRF 484	PRF 1	PRF 2	PRF 3
RMSE (m)	0.70	0.78	0.75	0.74	2.44	3.23	2.94	2.96	0.66	1.12	0.57	0.55
Correl	0.931	0.979	0.930	0.930	0.900	−0.614	0.104	0.027	0.939	0.987	0.936	0.938
Delta peak (%)	16.88	26.49	19.74	18.96	82.34	100.78	103.64	96.88	15.06	39.74	7.79	3.64

Table 7 Value of objective parameters in the Cipasang PDA watershed

	Sept-16											
	SCS CN				Def. constant				Single basin			
	PRF 484	PRF 1	PRF 2	PRF 3	PRF 484	PRF 1	PRF 2	PRF 3	PRF 484	PRF 1	PRF 2	PRF 3
RMSE (m^3/s)	49.05	247.33	59.19	60.97	95.21	208.96	83.72	82.74	306.97	419.17	311.30	
Correl	0.992	0.848	0.990	0.989	0.973	0.910	0.979	0.979	0.891	0.813	0.920	
Delta peak (%)	3.55	36.07	0.47	0.76	3.79	33.49	2.23	2.07	42.33	78.96	49.90	
NS	0.983	0.572	0.975	0.974	0.937	0.694	0.951	0.952	0.340	−0.230	0.321	

distributed compared to the Cipasang PDA watershed, so it is still suitable to be modeled with single basin. In the PDA Cipasang watershed, the varied topographic conditions of mountains, valleys and plains resulted in the modeling of the watershed as single-basin becoming less suitable. In the single-basin modeling, it can also be seen the phenomenon in the two previous tests, where the results of the modeling using the PRF table variation showed better results than the formula PRF, so that it can be concluded several things from the three PRF role tests, namely, for all modeling methods, the variation of PRF values that give the best results is to use both tables, Tables 4 and 5. For the loss method modeling, the SCS curve number method shows consistent results compared to deficit constant method. Even though in the PDA Cipasang watershed modeling using the deficit constant method, it shows good results, and it should be considered that each watershed has a different model matching method. Therefore, it is more suitable if the modeling uses the SCS curve number method that shows good and consistent results. The final conclusion obtained is divided

Fig. 16 Graph of PRF frequency distribution in each watershed based on Table 4

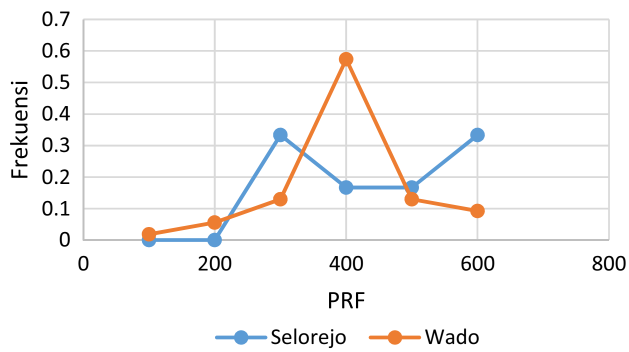


Fig. 17 Graph of PRF frequency distribution in each watershed based on Table 5

modeling (divided into several sub-basin) showing consistent results compared to modeling as single basin. Although the results in the Selorejo watershed showed good results, in the PDA Cipasang watershed, it cannot be said that because single-basin modeling shows inconsistent results and is very dependent on homogeneity and characteristics of each watershed. Based on conclusions obtained from the variation test of the PRF values above, a verification process was carried out on the two watersheds at different times to support the temporary conclusions or hypothesis above. Based on the conclusions in the data analysis, verification of the analysis of the role of the PRF in the two watersheds was reviewed, but in different flood events. The following are the results of verification of the analysis of the role of the PRF test in the Selorejo watershed and PDA Cipasang watershed, respectively.

It can be seen from the form of flood hydrographs in Figs. 18 and 19 showing quite good results and approaching the results of observations of floods that occur. Based on the results of this modeling, the objective function values of each modeling result can be calculated as follows.

The results of verification are shown in Table 8. The role test of the PRF in both watersheds shows quite good values. However, if the varied PRF modelling compared to the PRF 484, it can be concluded that the results are not much different. Therefore, based on the phenomenon, when the role testing process and verification process show the results according to that using a variation of the PRF value, the modeling results produce modeling that is as good as modeling using PRF standard and for some events produce slight better results. However, this finding cannot justify that by varying PRF values makes a better result. This shows that utilizing the variation of the PRF value, it produces not a better analysis result, but it can make the model more complete by including one modeling factor that has not been considered so far, namely, Basin Slope. In addition, to utilize

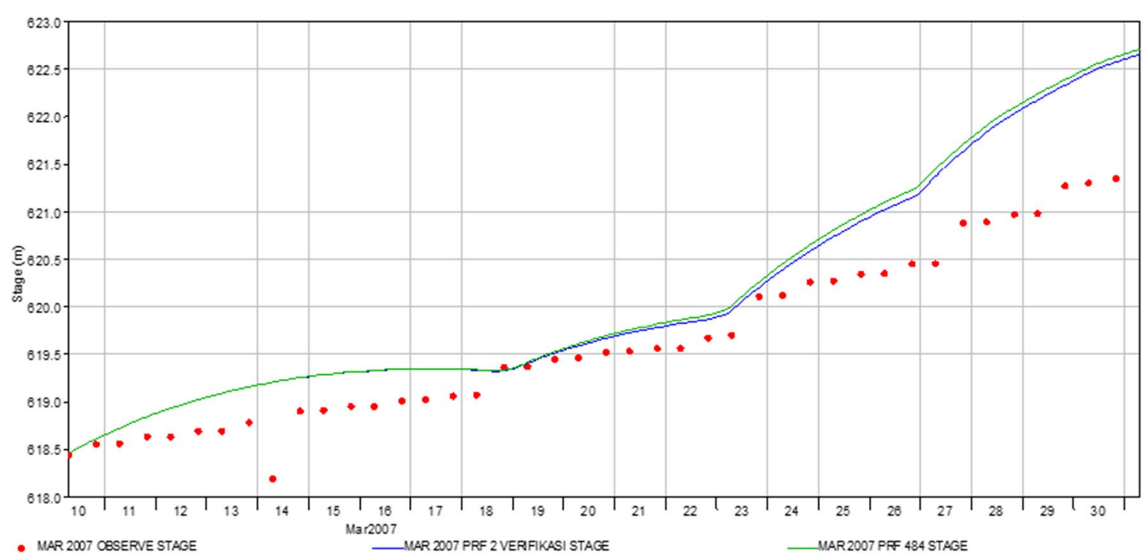


Fig. 18 Results of verification of the Selorejo watershed modeling in March 2007

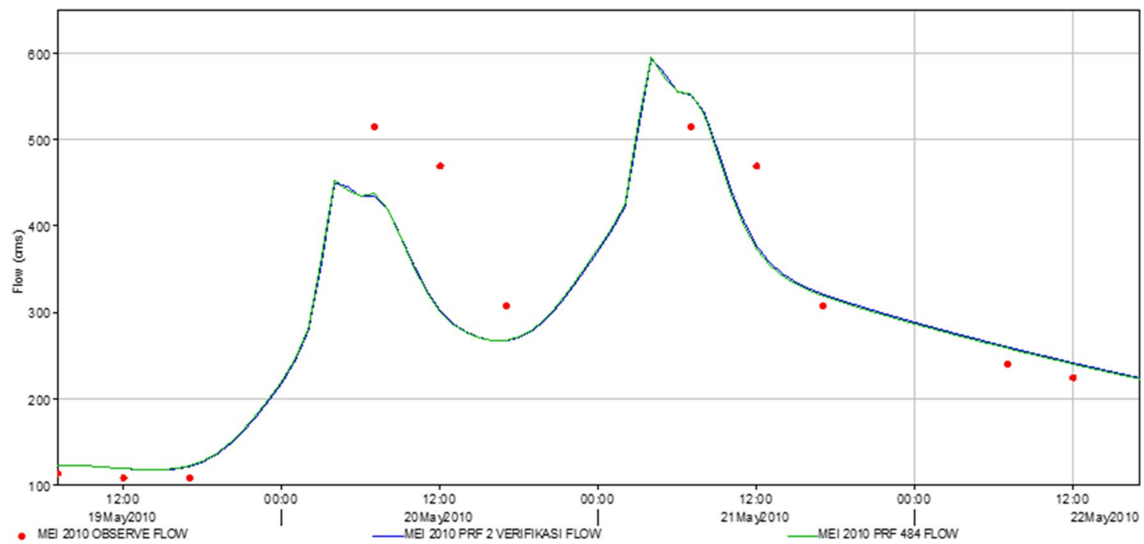


Fig. 19 Results of verification of PDA Cipasang watershed modelling in May 2010

Table 8 Objective function value of verification results

	March 2007		May 2010	
	Verification			
	PRF 484	PRF 2	PRF 484	PRF 2
RMSE	0.63	0.59	66.20	65.91
Correl	0.977	0.976	0.916	0.917
Delta peak (%)	43.04	41.46	15.55	15.35
NS	–		0.818	0.820

the PRF, according to the study, it is recommended to use the method of loss, namely, SCS curve number and the modeling done must be divided watershed modeling (consisting of several sub-basin) to produce the best and stable calibration analysis results.

- For the calibration analysis of flood events using PRF, the most suitable modeling method includes the method of losing the SCS curve number, the transform method using the SCS unit hydrograph, and the baseflow method using recession constant.
- The reason for using the SCS curve number loss method compared to deficit constant is that the results of modeling using deficit constant are unstable, so that it needs to be adjusted to the watershed again.
- Modeling for the analysis of flood events is also better to use modeling separately (made in sub-watersheds) rather than considering watersheds as a whole. This is evidenced by the unstable single-basin modeling results.
- Based on the results of the verification carried out, the objective parameter value produced shows comparable result with PRF 484, so it cannot be said that the modelling is better but by adding the varied PRF value makes the model more complete.

Conclusions

Conclusions that can be drawn from the research that has been carried out include several things that are conveyed as follows:

- Based on research conducted by the role of PRF is to make modeling more complete and better as indicated by the value of objective functions in Tables 6, 7, and 8.
- Based on the results of the PRF role test, the best way to determine the PRF value is to use a combination of slope grouping tables and a table of results of research conducted by Wanielista et al. (1997).

References

Fang X, Prakash K, Cleveland T, Thompson D, Pradhan P (2005) Revisit of NRCS unit hydrograph procedures. ASCE Proceedings, Austin, Texas

Khaddor I, Achab M, Soumali MR, Alaoui AH (2017) Rainfall-runoff calibration for semi-arid ungauged basins based on the cumulative observed hyetograph and SCS storm model: application to the Boukhalef Watershed (Tangier, North Western Morocco). JMES 8(10):3795–3808

Legates DR, McCabe GJ Jr (1999) Evaluating the use of "Goodness-of-Fit" measures in hydrologic and hydroclimatic model validation. Water Resour Res 35(1):233–241

Munajad R, Suprayogi S (2015) Kajian Hujan-Aliran Menggunakan Model HEC-HMS di Sub Daerah Aliran Sungai Wuryantoro Wonogiri, Jawa Tengah

Paimin S, Pramono IB (2009) Teknik Mitigasi Banjir dan Tanah Longsor. In: Ginting AN (ed) Balikpapan: tropenbos international indonesia programme. Retrievedfrom www.tropenbos.org

Pawitan H (2014) Perubahan Penggunaan Lahan dan Pengaruhnya Terhadap Hidrologi Daerah Aliran Sungai. Laboratorium Hidrometeorologi FMIPA IPB, Bogor

Pratiwi DT (2011) Analisis Hidrograf Aliran Menggunakan HEC-HMS (Studi kasus: DAS Citarum Hulu)

Sheridan JM, Merkel WH, Bosch DD (2002) Peak rate factors for flatland watersheds. Appl Eng Agric 18:65–69

Sitanggang GE, Suprayogi I, Trimaijon (2014) Pemodelan Hujan Debit Pada Sub Daerah Aliran Sungai Menggunakan Program Bantu HEC-HMS (Studi Kasus Pada Kanal Duri)

Wanielista M, Kersten R, Eaglin R (1997) Hydrology:water quantity and quality control (John Wiley & Sons Inc., New York). J Cent South Univ Technol 15(1):311–315. https://doi.org/10.1007/s11771-008-0370-7