Study of Modeling Method Selection in Flood Discharge Calibration Using HEC-HMS Software

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Abstract. Flood disaster management requires analysis and modeling, especially for the decision making of flood events. One way to analyze flood events is to use HEC-HMS software. HEC-HMS has three submodels: Loss, Transform, and Baseflow. In the flood discharge analysis, the selection of this sub-model is important because it is not certain that the method offered in this sub-model is suitable for all conditions, so it is necessary to choose which one is more suitable. Based on the results of the research, the SCS method can model well as evidenced by the good objective function values (RMSE (0.70 m; 49.05 m3/s), Correl (0.931; 0.992), and DELTA PEAK (16.88%; 13.75%). The verification results are also show similar results (RMSE (0.63 m; 66,198 m3/s), Correl (0.977; 0.916) and DELTAPEAK (43.04%; 32,754%). Therefore, it can conclude that the combination of benchmarking techniques that can be used for HEC-HMS modeling is the SCS curve number for loss submodel, SCS unit hydrograph for transform submodel and Recession constant for baseflow submodel.

1. Introduction
Flood disaster management requires analysis and modeling, especially analysing and decision making of flood events. In the flood discharge analysis process, the flood event calibration process is very important because this process tries to determine the physical condition of the watershed during a flood. With the results of this calibration process, an appropriate discharge plan can be determined. One method to perform a flood event calibration analysis is using the HEC-HMS software. HEC-HMS has three submodels: Loss, Transform, and Baseflow. In the flood discharge calibration analysis, the method selected in each of these sub-models is important because it is not certain that the methods offered in this sub-model are suitable for all conditions. This study tries to determine which method is the most universal and effective method to use as a basis for modeling the flood discharge analysis carried out. The analysis was carried out in 2 study areas, namely the Selorejo watershed and the Cipasang PDA watershed. The reason for using these two locations is the completeness of the data they have and as a comparison whether this modeling method is universal and suitable for use in various locations. Assessment of whether the calibration process is good is judged by the objective function used whether the modeling results are good enough or not. With this research, it is expected that the flood discharge analysis process will have an initial benchmark for selecting the method when using the HEC-HMS software.
2. Literature Study

Flood problems are a frequent problem in water quantity management, especially in developing countries. In addressing these issues, various methods have been developed to overcome flood problems, both structurally and unstructured. However, the method in overcoming these problems, it is necessary to have a computational analysis to support existing decision making. The analysis of these calculations develops from conventional methods to complex analysis.

At early stages analysis, Flood event are analyzed qualitatively. The analysis result are based on vulnerability factor that affects flood events. Based on their research, that vulnerability factor are maximum annual rainfall, basin shape, land use, and several other factors. This method is used because the historical data is not sufficient to do Quantitative flood analysis. In addition, the method of modeling flood events is still difficult to implement due to its complexity, which requires model assistance that was not as developed at the time as it is today. With the passage of time and the development of science and technology, the analysis of flood calculations has evolved.

Quantitative Analysis divided into two separate analysis. The first is by statistical analysis. This method only can be used if the historical data on the area of analysis is sufficient and long enough. There are studies that have performed analysis using this method in several rivers in Indonesia, and this study can provide results for specific return discharges in some rivers in Indonesia. For example, The 100-year Flood of Citarum basin is 377 m³/s. Due insufficient and incomplete historical data, new method of analysis was developed. This method is known as the Rain-Discharge Transformation method.

This methods are applied more often because of the availability of easily available data. Data used in this are rainfall data both long-term and short-term, as well as the physical condition of existing watersheds. To create a flood hydrograph using this method, three submodels are required: loss method, transformation method, and baseflow method to support existing analysis. Loss sub-model is a method for determining the effective rainfall value for runoff. The sub-model takes into account several processes of the water cycle: the value of rain lost due to atmospheric evaporation, vegetation blockage, and soil infiltration. The transformation submodel is a model for transforming existing valid rain into runoff hydrographs. The Baseflow submodel is to count the groundwater flow into a river as a bottom current or a flow that is always present in the river. You can use these three submodels to perform Rain-Discharge Transformation methods. The application has several computation models that use Rain-Discharge Transformation method to perform flood analysis, one of them is HEC-HMS.

Rain-Discharge Transformation methods are applied more often because of the availability of easily available data. For this method we use both long-term and short-term rainfall data. In the HEC-HMS model, the three submodels consist of several ways to perform the calculations. For example, the loss submodel consists of the SCS curve number. There are loss method that we can choose in HEC-HMS such as Deficit constant and initial constant. Other research has used SCS method for modeling, is Upper Citarum basin (Pratiwi, 2011) and WonogiriWuryantoro basin (Munajad and Suprayogi, 2015). Beside in Indonesia, SCS method has been applied in other nation, for example in Morocco, to be more precise, its in Bukarev basin (Khador, 2017). These four basin mentioned before use HEC-HMS model to analyze flood events at each study site. Although the location and type of basin is different, these four studies have similarities in modeling. That is, the SCS method is used for flood analysis, the SCS curve numbering method is used for the loss model, and the SCS unit hydrograph method is used for the transformation model.

Apart from the four watersheds mentioned above, all the authors made the statement based on surveys conducted by several sources. That is, the SCS method is used for flood analysis, the SCS curve numbering method is used for the loss submodel, and the transformation model. However, there is a problem that the results obtained when performing the SCS method vary. The SampeanBaru watershed showed poor results (Affandy, N.A. and Anwar, N, 2011), but the Wuryantoro watershed showed very good results using this SCS method (Munajad, R and Suprayogi, S. 2015). Because of these differences in results, it is necessary to conduct this study to confirm whether this SCS method is
not suitable to be applied as a standard for selecting methods and to find a combination of modeling methods that can be used as a standard for selecting methods.

3. Main Problems
The main problem in this study is that the flood discharge calibration analysis using HEC-HMS has a combination of methods for each sub-model. Based on the modeling results by several other studies, it shows varied results even though using the same method. Due to these differences, this study was conducted to verify these varied results and to try to determine the best combination of method selection as a standard for flood discharge calibration using HEC-HMS.

4. Goals
In general, this study aims to verify the modeling method using the SCS model in the selected study area. This study also tries to find a combination of other methods available at HEC-HMS to model flood discharge.

5. Research Methods
The study begins by conducting several reference or literature search on the flood analysis itself, especially in the calibration section of flood events. Research continues to find explanations about SCS method and application of this method in flood discharge calculation. Further research was conducted on modeling methods using HEC-HMS, especially from the perspective of determining existing modeling methods. Research on modeling method determination focuses on understanding and applying HEC-HMS loss, transformation, and baseflow methods.

This process followed the collection of field data from the basin used as the material for the analysis. Collected physical data from the basin in the form of land-use data taken from the Harmonized World Soil Database (HWSD). Beside that other physical data collected are watershed length, and basin slope. In addition to physical, hydrological data was also collected in the form of rainfall data at rainfall stations around the basin, which became an area of analysis and observation data that occurred on-site during floods. Field observation data in the form of water level and flood flow observations. The process was continued by modeling two research areas using HEC-HMS. Basin images of the study area were obtained from HEC-GeoHMS, in addition to physical data, input data for loss, transformation, and base flow model also collected in the previous process. On the other hand, rain modeling for flood events uses Thiessen Ploygon. In this polygon, each rain station has a weight ratio for each small basin under review.

After modeling has been carried out in the two study areas, the calibration process is carried out. The calibration is based on observational data obtained previously, for the Selorejo watershed the observation data is in the form of water level elevation in the Selorejo Reservoir while for the PDA Cipasang Watershed the form of flow rates. The calibration process is carried out in parallel between modeling using the SCS method and the Deficit Constant method. Another reason for modeling only using the Deficit Constant method is that other methods besides SCS and Deficit Constant data are difficult to obtain. The data obtained are only in the form of physical and topographic data, while for the land infiltration data in the location it is difficult to obtain. So a method is used that can make use of the physical data obtained.

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6. HEC-HMS modeling

Modeling using HEC-HMS software is used to simplify the complex process of analysing flood events due to the large number of sub-watersheds involved. In HEC-HMS modeling it is necessary to physically model the study area being reviewed. This includes the area, length of flow, and slope of land and channels of the sub-watershed. Apart from physical components, there are three main hydrological components to model a flood event, namely water loss (Losses), synthetic unit hydrograph (Transform), and baseflow. In the analysis of flood events, the Losses and Transform components in the form of a synthetic unit hydrograph are the most important main components while the Baseflow component has a smaller effect. Even so, the three components interact with each other in producing a starch hydrograph.

6.1. Loss Method.

6.1.1. SCS/NCRS Method. SCS method is one of method to calculate the amount of water loss due to land infiltration. Land infiltration rate represented by Curve Number (CN) parameter. The value of CN parameters depends on several factors regarding existing basin physical conditions. That factors are soil type, vegetation cover type, land use, hydrological conditions, previous soil moisture conditions, Antecedent Moisture Conditions (AMC), and basin climate. High CN value represent smaller penetration value and vice versa. SCS method estimates cumulative excess rainfall. Below is the loss / penetration equation for the SCS / NRCS method.
$$P_e = \frac{(P-I_a)^2}{P-I_a+S}$$  \hspace{1cm} (1)\\
$$I_a = \lambda \cdot S$$  \hspace{1cm} (2)\\
$$S = \left\{ \frac{25400-254 \cdot CN}{CN} \right\}$$  \hspace{1cm} (3)

Where:
- $P_e$ : Cumulative value of excess rainfall (mm)
- $P$ : Rainfall data (mm)
- $I_a$ : Initial Absorption (mm)
- $S$ : Potential storage in basin (mm)
- $\lambda$ : Coefficient (between 0.05 - 0.5)
- $CN$ : Curve Number

The relationship between $I_a$ and $S$ is empirically derived and the value of $\lambda$ is 0.2, and in HEC-HMS modeling, the standard $I_a$ value when not satisfied is also 0.2$S$. Therefore, different basins can have different $\lambda$ values. For basins with sub-basins of different types of soil and land cover, the CN composite value is determined using the composite CN formula as follows:

$$CN_c = \frac{CN_1 \cdot A_1 + CN_2 \cdot A_2 + \ldots + CN_n \cdot A_n}{\sum_{i=1}^{n} A_i}$$  \hspace{1cm} (4)

Where:
- $CN_c$ : Composite CN Value
- $CN_i$ : CN value in selected sub-basin,
- $A_i$ : Area in selected sub-basin, and
- $n$ : Number of sub-basin

6.1.2. Deficit Constant Method
Deficit constant method used to continuously calculate the loss of total rainfall and the water absorption capacity of the soil (recovery) value. Deficit Constant method consist of three major parameters. Those parameters are Initial deficit (mm), maximum deficit / maximum storage (mm), and constant rate (mm/hour). Initial deficit is the parameter that indicates initial condition of the calculation. By knowing this parameter we can determine the value/amount of water needed to fill the soil layer to reach maximum storage. The maximum storage parameter to express maximum amount of water that can be held by soil (expressed in thickness). We can determine the upper limit of layer thickness by multiplying between void ratio and soil storage value from CNSCS. The infiltration rate of this method will reach a certain value and become constant when the soil reaches saturated state. This value represented by saturated hydraulic conductivity (saturated hydraulic conductivity). You can use the following formula to calculate this value:

$$p_{et} = \begin{cases} p_t - f_c & \text{if } p_t > f_c \\ 0 & \text{if } p_t < f_c \end{cases}$$  \hspace{1cm} (5)

No spill will occur until the accumulation of rain in the leak area exceeds the initial volume shortage.

$$p_{et} = \begin{cases} 0 & \text{if } \sum p_t < I_a \\ p_t - f_c & \text{if } \sum p_t > I_a \text{ dan } p_t > f_c \\ 0 & \text{if } \sum p_t > I_a \text{ dan } p_t < f_c \end{cases}$$  \hspace{1cm} (6)

Where:
- $p_{et}$ : Effective rainfall at time $t$ (mm)
- $p_t$ : Rainfall at time $t$ (mm)
- $I_a$ : Initial deficit (mm)
Parameters that need to be determined are the initial deficit, maximum deficit or maximum storage, and a constant rate for loss modeling using the deficit constant method. The maximum shortage or maximum storage parameters are obtained from Equation 2.3, but the constant rate parameters can be determined based on Table 1.

**Table 1** The basis for determining the constant infiltration rate parameters (source: SCS, 2007)

| Hydrologic Soil Group | Group A | Group B | Group C | Group D |
|-----------------------|---------|---------|---------|---------|
| Inch/Hour             | >1.42   | 0.57-1.42 | 0.06-0.57 | <0.06   |
| Mm/Hour               | >36.1   | 14.5-36.1 | 1.5-14.5 | <1.5    |

By looking at the type of land in the watershed, it can be determined that the value of the Constant Rate in the watershed is based on Table 1.

6.2. SCS Unit Hydrograph

SCS Synthetic Unit Hydrograph method is transform method to convert rainfall data to a hydrograph. Using this method, we get dimensionless Hydrograph. In HEC-HMS software, the SCS Synthetic Unit Hydrograph consist of two major parameters namely lagtime and peak rate factor (PRF).

Lag Time value defined as amount of time passed from effective rainfall peak value to flood peak flow. Lagtime value estimation based on concentration-time values using formulas

\[ T_{lag} = 0.6 T_c \]  

Where:

- \( T_{lag} \): Time delay / Lag Time
- \( T_c \): Concentration time

\[ T_c = T_{Shallow} + T_{Sheet} + T_{Channel} \]  

Where:

- \( T_{Shallow} \): Time on the land (Minutes)
- \( T_{Sheet} \): Time at shallow flow (Minutes)
- \( T_{Channel} \): Time on channel (Minutes)

In the concentration-time value (\( T_c \)) calculation, TR-55 was used to estimate this value.

Beside lag time, Peak Rate Factor (PRF) value also affects the shape of UH. PRF value is a dimensionless parameter that affects UH shape. The standard PRF value for SCS hydrographs is 484. In this study, PRF values are equalized for each small basin with a standard value of 484.

6.3. Recession Constant Baseflow

This baseflow method used to describe the waterflow from underground natural reservoirs in basin. Formula to determine the baseflow using Recession Constant displayed below.

\[ Q_t = Q_0 k^t \]  

Where \( Q_0 \) is the base flow at starting time, \( Q_t \) represent baseflow at certain times, and \( k \) is the degradation constant. \( K \) value is defined as the ratio of the baseline flow at that certain time to the baseline flow of the previous day.

7. Study Location

7.1. Selorejo Watershed (source: Cahyono, C. and Wanny K. Adidarma, 2019)\(^{[3]}\)

Based on the calculations performed by the Geographic Information System (GIS) software, a topographic map as shown in Figure 3 is obtained, and the topographical characteristics are as follows:
- Watershed area: with DEM maps and digital river maps and with the help of GIS software, the Selorejo watershed area is 234.49 km².
- With the longest flowpath of the Selorejo watershed of 27.313 km

Figure 3. Topographic map of the Selorejo Watershed

Figure 4. Location of the Selorejo Watershed Rain Post

Figure 5. First Extreme Rain Event December 25-26, 2007

Figure 6. Second Extreme Rain Event March 10-31 2007

7.2. PDA Cipasang Watershed (source: Cahyono, C. and Wanny K. Adidarma, 2019)

Based on the calculations performed by the Geographic Information System (GIS) software, a topographic map as shown in Figure 7 is obtained, the area of the PDA Cipasang's watershed is 1216.3 km², with a watershed shape as shown in Figure 7.
In this analysis, there are several rainposts near the PDA Cipasang basin and only four rainposts are used. The location is shown in Figure 8. The four rainposts consist of Bayongbong, Leuwigoong, Tarogong, and Darmaraja. Based on rainfall data from four precipitation posts, the extreme rainfall that caused flooding was three events: April 20-21, 2010, May 19-22, 2010, and September 20, 2016. Only two were used to model flood events in the PDA Cipasang basin. That is, May 19-22, 2010 and September 20-22, 2016 (Figures 9 and 10).

8. Results

The data shown in Section 7 is processed and modeled using HEC-HMS software. The modeling process is performed by a combination of the SCS method, a loss submodel using the SCS curve number, a transformation submodel using the SCS unit hydrograph, and a base flow submodel using the recession constant. Then after modeling using the SCS method, a new model is created by replacing the Losses sub-model using the Deficit Constant. Following are the results of the comparison of modeling results using the SCS and Deficit Constant methods.

It can be seen in Figures 11 and 12 that the results are different. First, it can be seen that modeling using the SCS method shows good results for both locations. This is indicated by the results of the modeling approaching existing observation data. Meanwhile, it cannot be said when using the Loss method Deficit Constant for modeling. The Selorejo watershed showed unfavorable results. This is shown from the modeling results which are far below the observational data. Meanwhile, the modeling of the Cipasang PDA watershed shows the opposite, where the modeling results using Deficit Constant show good results. Apart from the graph of the modeling results, how well the modeling results can also be seen from the objective function used. This data can be seen in Table 2.
Table 2. Value of Objective Functions Modeling of Selorejo and PDA Cipasang Watershed

|                      | Selorejo December 2007 | PDA Cipasang September 2016 |
|----------------------|------------------------|----------------------------|
|                      | SCS                    | Deficit Constant           | SCS            | Deficit Constant |
| RMSE (m)             | 0.70                   | 2.44                       | 49.05          | 95.21            |
| Correl               | 0.931                  | 0.900                      | 0.992          | 0.973            |
| Delta Peak (%)       | 16.88                  | 82.86                      | 13.75          | 3.79             |
| NS                   |                        |                            | 0.983          | 0.937            |

Based on Table 2, the differences in modeling results can be more visible. For modeling in the Selorejo watershed based on Figure 11, it can be seen that the modeling results using the SCS method are much better than using the Deficit Constant. Whereas in PDA Cipasang the differences in modeling results can be seen in Table 2, where overall the results shown by the SCS method are slightly better than using Deficit Constant. Although the difference in peak values using Deficit Constant is better than SCS, the overall flood modeling method of SCS is more suitable. Based on the modeling results it can be concluded temporarily that the use of the SCS method is sufficiently capable of modeling flood events, whereas if using the new method in this case the Deficit Constant the results are less stable. This instability can be caused by several factors, but one thing that can be mentioned is that each watershed has its own character so that not all are suitable using the Deficit Constant method. Based on this provisional conclusion, a verification process was carried out to reinforce these findings. The verification process was carried out by using the SCS modeling method for other flood events in the two watersheds in the study area. The following is the result of the verification process.

Table 3. Value of the Objective Function on Verification Results

| Verification | Selorejo | PDA Cipasang |
|--------------|----------|--------------|
| RMSE         | 0.63     | 66.198       |
| Correl       | 0.977    | 0.916        |
| Delta Peak (%) | 43.04   | 32.754       |
| NS           | -        | 0.818        |
Based on the results shown in Figures 13, 14, and Table 3, the validation results show that modeling using the SCS method shows good results. Therefore, we can conclude that SCS can be used as a benchmarking technique for modeling with HEC-HMS to recommend a flood flow calibration process.

9. Conclusion
Based on the research and studies conducted, several conclusions can be drawn.

- Modeling in the Selorejo watershed shows that modeling using the SCS method shows good results. However, the opposite results are shown when using the Deficit Constant method.
- Modeling on the Cipasang PDA watershed shows that modeling using the SCS method shows good results as well. Similar results are shown when using the Deficit Constant method.
- Based on the verification results, modeling using the SCS method shows good results in the two watersheds in the study area.
- Based on the results of the initial modeling and verification process, it can be concluded that the SCS method shows good results so that it can be used as a benchmark for modeling using HEC-HMS.
- Although the modeling results on the Cipasang PDA watershed using Deficit Constant show good results, this method is very dependent on its own DAS because not all are suitable to be modeled using this method. This is indicated by the unfavorable results of the Selorejo watershed.

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