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Comparison Analysis of Measured Unit Hydrograph and Synthetic Unit Hydrograph of Buah Watershed

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Abstract. Buah Watershed is one of the Musi River tributaries located in Palembang City, South Sumatra. The cause of flooding in Buah Watershed is mainly due to land-use conversion of open space into residential areas that affect the ability of water infiltration and river discharge. The discharge is generally designed in the form of a hydrograph. The discharge hydrograph is a graphical presentation of the relationship between flow rate and time that describes the behaviour of the discharge within a certain period. There are two methods to obtain the hydrograph value in a watershed, Measured Unit Hydrograph (MUH) and Synthetic Unit Hydrographs (SUH). Therefore, this study aims to compare the results of hydrograph analysis between the GAMMA-I SUH Method, the SCS Method, and the Nakayasu Method towards the Measured Unit Hydrograph (MUH) in Buah Watershed. From the calculation of using the watershed, the characteristics of Buah Watershed by the SUH SCS-CN method had a discharge (Qp) of 4.852 m³/s at 0.52 Hours, SUH Gama I had a discharge (Qp) of 1.117 m³ / s, at 1,658 Hours, Nakayasu SUH had a peak discharge (Qp) of 1,60 m³ / s at 1,287 Hours. While the discharge from Measured Unit Hydrograph calculated from 3 rainfall events primary data as follows Qp_1 = 0,95m³ / s, Qp_2= 1,31 m³ / s and Qp_3 = 1,496 m³ / s. SUH Gama I has the peak discharge value (Qp) and peak time (Tp) closest to Measured Unit Hydrograph.

INTRODUCTION

Palembang city is one of the metropolitan cities in Indonesia and geographically located between 2° 52′ to 3° 5′ south latitude and 104° 37′ to 104° 52′ east longitude with an average elevation of 8 meters above mean sea level. Palembang City covers 400.61 km^2, which is administratively divided into 16 districts and 107 sub-districts. In terms of hydrological conditions, the city of Palembang is divided by the Musi River into two large parts called Seberang Ulu and Seberang Ilir. Palembang has 108 tributaries and 4 major rivers that flow into the city.

There are tweny one (21) sub-watersheds that are tributaries of Musi River, namely Gandus, Gasing, Lambidaro, Boang, Borang, Nyiur, Sekanak, Bendung, Lawang Kidul, Buah, Juaro, Batang, Sei Lincah, Keramasan, Kertapati, Kedukan Ulu, Aur, Sriguna and Jakabaring sub-watersheds.

According to [1], Palembang City has 25 road points and 43 high-risk flood areas (Buah Watershed). The Buah Watershed is a high-risk area and one of the critical watersheds in Palembang City. It has a total area of 10.79 km² and a length of the main river of 7.93 km. Land use is mainly residential, industrial, and swamp areas.

River runoff production and behaviour are functions of land use types and changes. Watershed geomorphology is related to a river basin's hydrological response such as; topography, catchment areas, basin shape, drainage slope and capacity, stream density, and hydrology [2]**.**

The increasing number of populations in Palembang city cause the land-use conversion of green open space into residential increases. Population growth also affects land demand [3]**.** Changes in river waterways are also contributing factors, namely sedimentation of channels by domestic wastes, inadequate physical, the capacity of waterways, and the conversion of swamps areas into impervious layers.

River discharge is an indicator of watershed function. In process management, particularly in the transformation of rain into streams. The discharge is generally designed in the form of a hydrograph. The discharge hydrograph is a

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graphical presentation of the relationship between flow rate and time that describes the behaviour of the discharge within a certain period.

Unit Hydrograph is commonly used for analysing and deriving flood hydrograph resulting from a known storm in a basin area. There are two methods to obtain the hydrograph value in a watershed, Measured Unit Hydrograph (MUH) and Synthetic Unit Hydrographs (SUH) methods [4]**.** A method for obtaining hydrograph from a watershed with a hydrometric measuring instrument lacks watershed data to analyse flood discharge in certain areas. This method is known as the Synthetic Unit Hydrograph Model (SUH) Gamma-I, SCS, and Nakayasu. Meanwhile, the Measured Unit Hydrograph (MUH) method requires primary watershed data such as rainfall data, flow data, and data about watersheds. Therefore, this study aims to compare the results of hydrograph analysis between the GAMMA-I SUH Method, the SCS Method, and the Nakayasu Method against the Measured Unit Hydrograph (MUH) in Buah Watershed.

RESEARCH METHODS

General Description

Geographically, the Buah Watershed is located at 2°58'17.7" LS - 2°58'57.2"LS 104°47'29.6"E - 104°47'44.0"E, which is one of the watersheds (DAS) in Palembang (Figure 1). The city of Palembang consists of two sub-districts, namely Kalidoni District and Ilir Timur II District. The area of the Buah Watershed analysed in this study is ±12,244 Km² which contains residential areas, trade and services, industry, and swamps.

FIGURE 1. Location of Buah watershed

Data Collection

Data collection includes the process of collecting data required for research, including:

Primary Data

Primary Data obtained from site surveys with direct measurements, such as:

- **Rainfall Measurement Data.** Rainfall data were obtained from direct measurements with a manual rain gauge placed precisely downstream of Buah watershed on Jalan Mayor (Laut) Wiratno, Sei Buah, Kec. Ilir Timur II, Palembang City, South Sumatra 30162. This tool is placed in an open area not

covered by trees and surrounding buildings with a height of ±70 cm from the ground level. Rainwater that falls on the funnel will be accommodated in the cylinder, and after the rain stops, it can be read how high the rain is. Rainfall research begins on June 1, 2020, until July 2, 2020.

- **Flow Rate Data.** For flow rate data, measurements were made at the time of the incident before, during, or after the rain. The cross-section of the river is divided into several sections, which are taken per 0.8 meters, so the speed measurement has six measurement points with the one-point method, namely at 0.6 of the water depth, using the *Current Meter type Flowatch FL-03*
- **Water Level Data.** Water level data and flow control were recorded manually for the downstream research area of Buah Watershed from the first day of data collection using measuring signs.
- **River Cross-Section Data.** Measuring the cross-section of the river is done in a simple way using measuring signs and paint *phlox*. Measurements were made with a gap of 80 cm to obtain a precise cross-sectional shape. Then this measurement is carried out while the watershed conditions are not flooded, or there is no rainfall to avoid difficulties when measuring the cross-section of the river.

Secondary Data

Secondary data is obtained from the existing data from relevant institutions to analyse watershed spatial characteristics using *software ArcMap 10.5*;

- **River Network Map**
- **Land Use Map**

RESEARCH METHOD

The analysis and calculation steps are divided into several parts of analysis in data processing work; before data collection, literature studies related to research are conducted. The next step is primary data collection, which includes measuring rainfall data, measuring velocity data using the *Current Meter*, measuring the cross-section of the river, and calculating the effective rainfall and direct flow. The next step is the analysis of Measured Unit Hydrograph (MUH) and Synthetic Unit Hydrograph (SUH). Determinating the characteristic data of the Buah Watershed in the form of the watershed area, the length of the main river, and the time of rainfall concentration. They were calculating peak discharge and peak time using the SUH Gamma-I, SUH SCS (*Soil Conservation Service)*, and SUH Nakayasu and calculating the volume of the hydrograph of each method of Synthetic Unit Hydrograph (SUH) that has been selected. After the analyses, a graph of the measured and synthetic flow hydrograph is created. The hydrograph's volume is controlled to get an effective rainfall as high as 1 mm on each hydrograph. The last step is calibrating the model. Model calibration is performed using graphical analysis. The next step is to calculate the percentage difference between each Synthetic Unit Hydrograph model and its Measured Unit Hydrograph.

Spatial Analysis Using ArcGIS 10.5

Watershed spatial analysis begins with processing and analysing topographical data to determine watershed parameters, including fractal characteristics and watershed morphometry. This process and analysis were carried out using geographic information system (GIS) software in ArcGIS to determine the boundaries of the watershed and sub-watershed, the river's order, the river's length for each segment, and the slope of the main river.

RESULTS AND DISCUSSION

Overview of Research Area

This research was conducted in the Buah River Basin, one of the watersheds in Palembang City with an area of 12,244 Km² and has the main river length of 6,810 Km, located in Ilir Timur 1 District.

Characteristics of the Watershed (DAS), as illustrated by the configuration of the river network (*main river)* and its tributaries. Based on the river order (*Stream Order),* According to Stahler (1945), Buah Watershed is shown in Figure 2.

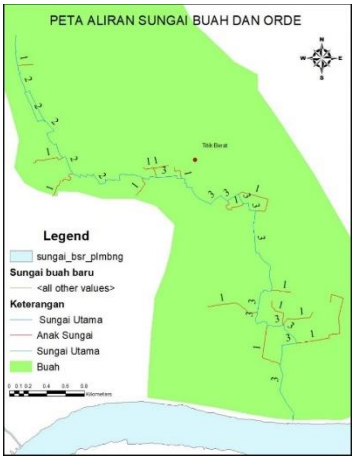

FIGURE 2. River Network and Order of Buah Watershed

Primary Data Collection

Rainfall observations were carried out at the research location using a manual rainfall gauge. The rain gauge is placed in an open place unobstructed by anything. So that rainfall will be received directly by this tool. This rainfall gauge is placed at a minimum height of 70 cm above the ground surface to prevent splash water from entering the ground. Measurement of rainfall is carried out by measuring the amount of water that is accommodated using a measuring cup with units of mm; the observation time is carried out every 30 minutes when it rains. After the measurement is complete, the rain gauge collected is discarded and cleaned for subsequent observations.

Rain measurements at the research location were carried out for ± 30 days starting from June 2, 2020 - July 2, 2020, but the results to be analysed were data with continuous rain with three events for a long time.

Discharge Measurement

Discharge is the amount of water that passes through the river in a certain period and is expressed units of m^3/s. By measuring the river discharge, the hydrological condition of a watershed will be known. The information obtained from the discharge measurement is:

1. The difference between the highest and the lowest discharge,
2. Changes in the daily discharge.

The discharge measurement is measured by measuring water level and Buah Watershed's velocity (DAS). The measurement of the discharge is calculated by using the average section method.

Effective Rainfall and Direct Flow

Effective rain or *excess rainfall* is part of the rain that becomes a direct flow in the river. This effective rain is equal to the total rain that falls on the ground minus the water loss. According to [5]**,** one of the methods to find water loss to calculate direct flow is the infiltration index.

The index value is the average water loss rate caused by infiltration, surface storage, and evaporation. To find the index, we need flow rate data. The measured discharge data in the Buah watershed has been calculated in the previous sub-chapter. The direct flow and effective rain can be calculated per one rain event, as shown in Table 1.

TABLE 1. Direct Flow and Effective Rainfall at the time of the first rainfall (23 – 24 June 2020)

Day - Hours		Rainfall (mm)	Discharge (m^3/s)	Direct Flow ($m^3/$)	Effective Rainfall (mm)
Thursday 23/06/2020	8:00	-	0,2144	0,0	
	9:00	-	0,2144	0,0	
	10:00	-	0,2144	0,0	
	11:00	-	0,2016	0,0	
	12:00	-	0,2016	0,0	
	13:00	-	0,2016	0,0	
	13:30	6	0,7	0,4856	1,17
	14:30	2,5	0,9222	0,7078	
	15:30	3,3	1,2012	0,9868	
	16:30	1	1,4048	1,1904	
	18:00	-	0,505	0,2906	
	19:00	-	0,316	0,1016	
Wednesday 24/06/2020	8:00	-	0,2616	0,0472	
	9:00	-	0,2616	0,0472	
	10:00	-	0,2576	0,0432	
	11:00	-	0,2496	0,0352	
	12:00	-	0,2416	0,0272	
	13:00	-	0,2376	0,0232	
	14:00	-	0,2336	0,0192	
Total of Direct Flow				4,0	

Measured Unit Hydrograph Analysis (MUH)

The measured unit hydrograph for the watershed is derived from pairs of rain data and flood hydrographs by separating the base flow based on effective rain by considering the magnitude of the *phi index* (Φ). The analysis carried out on the metric unit hydrograph obtained is the peak discharge, base time, peak time, and hydrograph pattern. The following is a presentation of the decrease in the hydrograph in Table 2.

TABLE 2. Results of Data MUH Calculation at the time of the first rainfall (23 – 24 June 2020)

Day - Hours		Rainfall (mm)	Discharge (m^3/s)	Direct Flow (m^3/s)	Effective Rainfall (mm)
Thursday 23/06/2020	8:00	-	0,2144	0,0	
	9:00	-	0,2144	0,0	
	10:00	-	0,2144	0,0	
	11:00	-	0,2016	0,0	
	12:00	-	0,2016	0,0	
	13:00	-	0,2016	0,0	
	13:30	6	0,7	0,4856	1,17
	14:30	2,5	0,9222	0,7078	
	15:30	3,3	1,2012	0,9868	
	16:30	1	1,4048	1,1904	
	18:00	-	0,505	0,2906	

Day - Hours		Rainfall (mm)	Discharge (m^3/s)	Direct Flow (m^3/s)	Effective Rainfall (mm)
Wednesday 24/06/2020	19:00	-	0,316	0,1016	
	8:00	-	0,2616	0,0472	
	9:00	-	0,2616	0,0472	
	10:00	-	0,2576	0,0432	
	11:00	-	0,2496	0,0352	
	12:00	-	0,2416	0,0272	
	13:00	-	0,2376	0,0232	
	14:00	-	0,2336	0,0192	
Total of Direct Flow				4,0	

From Table 2, the Runoff Volume is calculated to obtain the value of Flow Depth with the following calculation:

$$V_{Limp} = 4x3600 = 14280.48\ \text{m}^3$$

After the value of runoff is obtained, the flow depth is calculated, that is, the total volume divided by the area of the watershed:

$$Q_{Limp} = \frac{14280{,}48\ m^3}{12{,}244\ km^2 \times 1.000.000} = 1{,}166\ mm$$

A measured Unit Hydrograph is obtained from the calculation:

$$\text{Unit hydrograph ordinate} = \frac{Direct\ Flow}{1{,}166}$$

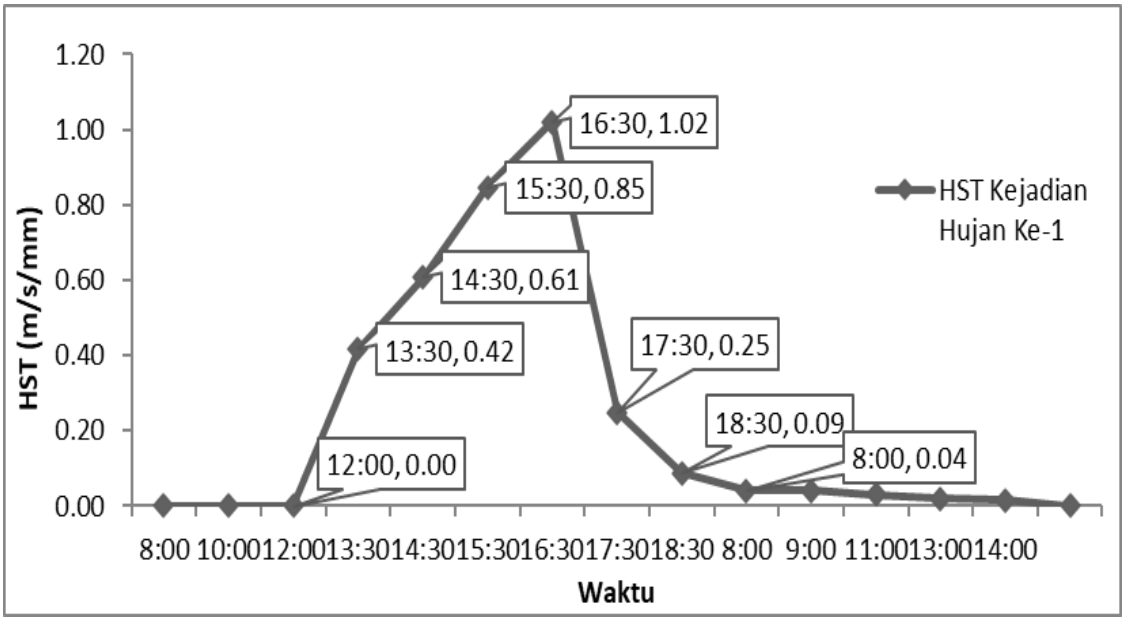

FIGURE 3. MUH on the first rainfall

From the graph above, the Measured Unit Hydrograph in Buah Watershed shows a peak discharge of Qp = 1.02 m³/s/mm with a base time (TB) of 11.5 hours or 690 minutes; the time reaches a peak (TP) of 7.5 hours or 450 minutes, recession side of 8.5 hours or 510 minutes.

Synthetic Unit Hydrograph (SUH)

Synthetic Unit Hydrograph is a hydrograph based on the synthesis of the parameters of the Watershed (DAS). Synthetic Unit Hydrographs will be compared with Measured Unit Hydrographs to determine which SUH method is closest to Measured Unit Hydrographs in Buah Watershed.

SCS Synthetic Unit Hydrograph Calculation (*Soil Conservation Service)*

Based on the spatial analysis using *ArcMapsoftware*, 10.5, several data were obtained to calculate the SUH SCS, namely the length of the main river (L), the slope of the river (Y), and the area of the rain catchment (A). And the potential retention is obtained from the calculation of the *curve number*. Therefore to calculate the interval time (T_L), concentration-time (T_C), rainfall duration (T_r), and peak discharge (Q_P), the Buah River Basin is shown in Figure 4.

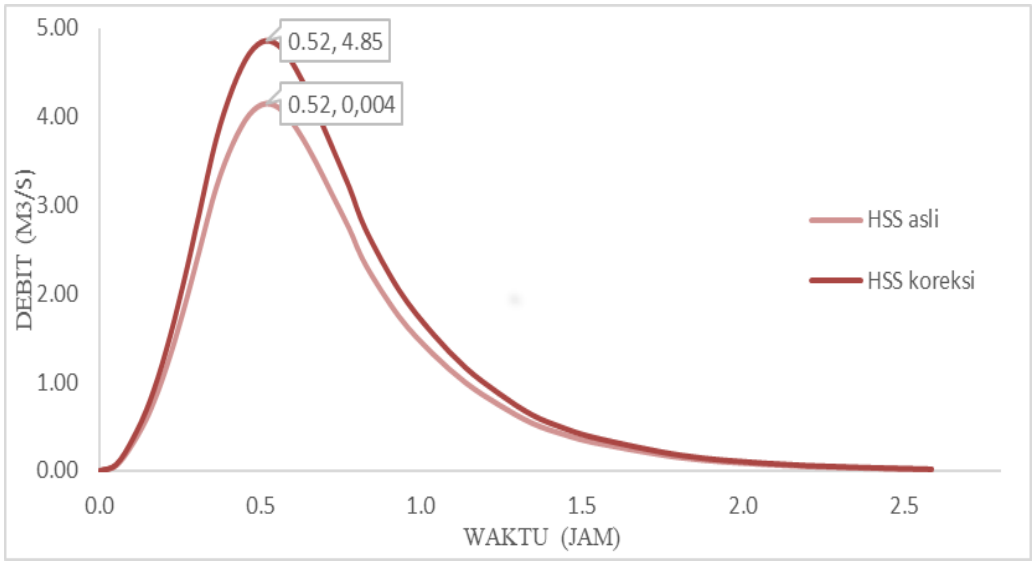

FIGURE 4. SUH SCS Buah Watershed

From the SUH SCS graph above, it can be seen that the peak discharge that occurred at Buah watershed was 4.85 m³/s, occurred at 0.52 hours or 31.2 minutes.

SUH Gama I Calculation

The initial stage of the Gama I SUH analysis is to analyse the watershed map. Topographic data (watershed maps) were obtained from analyses using *ArcMap Desktop* GIS version 10.5. These watershed map analysis results are in the form of watershed morphometric data (parameters), which are needed *for* the Gama I SUH model.

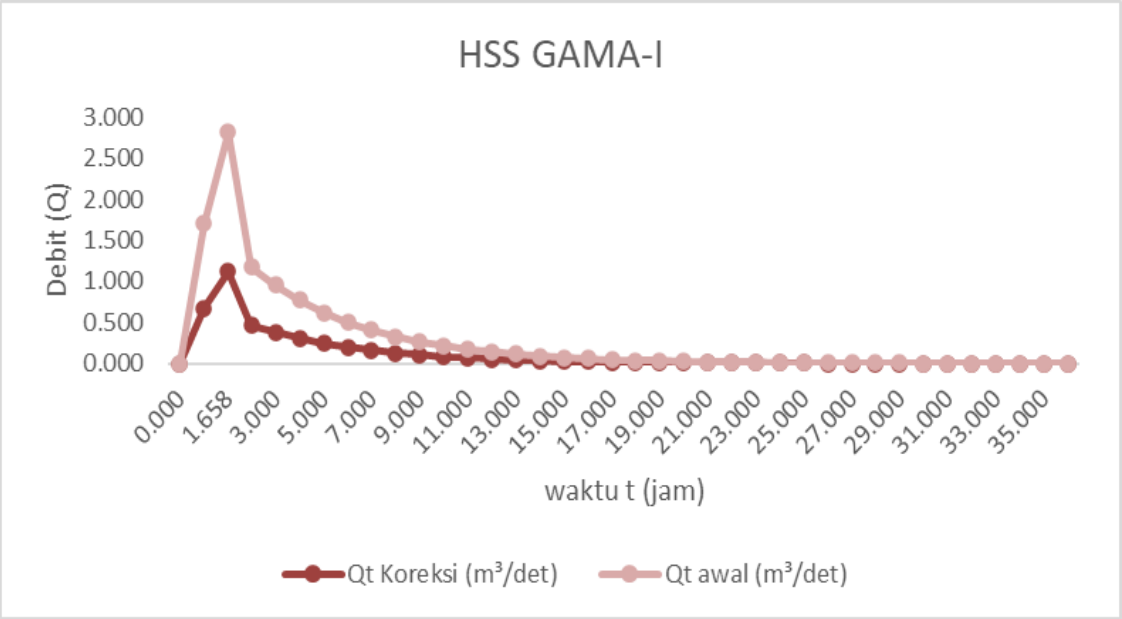

FIGURE 5. SUH Gama I

A triangular equation is used so that the upward curve above is a linear line to the top point of the curve to obtain an ascending curve in SUH Gama I.

In the descending curve, the discharge hydrograph equation is used

$$Qt = Qpe^{-t/K} = 1{,}286 \times e^{-\left(\frac{t-1{,}658}{4{,}707}\right)}$$

(after TR = 1.658 hours).

The maximum discharge after correction obtained from this calculation is 1.117 m³/s with Tp = 1.658 hours.

SUH Nakayasu Method Calculation

Based on spatial analysis using *ArcMap* 10.5, some data were obtained to calculate the Nakayasu SUH in Buah River Basin, including the watershed area (A) and the length of the main river (L) carried out in the discharge calculation is presented in Figure 6.

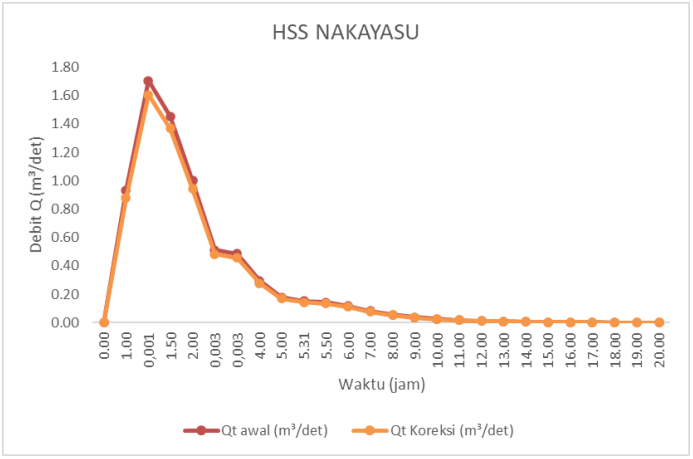

FIGURE 6. SUH Nakayasu of The Buah Watershed

In the ascending curve, an equation is used to arrive at the peak. This calculation results show that the maximum discharge after correction equals 1.60 m^3/ s with Tp = 1,287 hours.

MUH and SUH Analysis

Measured Unit Hydrograph (MUH) is used for comparison because it uses the measured rainfall and discharges data. Furthermore, a comparison of the three Synthetic Unit Hydrograph (SUH) calculation methods will be carried out towards Measured Unit Hydrograph. The comparison results of the three Synthetic Unit Hydrograph with the Measured Unit Hydrograph are presented in Table 3.

TABLE 3. Comparison Results of MUH and SUH

Hydrograph Model	Parameter		
	Qp	**Tp**	**Tb**
Nakayasu	1,60	1,29	15
SCS-CN	4,852	0,52	2,59
Gamma-I	1,117	1,658	25
MUH 1	1,02	3,5	18,5
MUH 2	1,23	0,55	21
MUH 3	1,42	0,30	13

Calibration Model

Calibration is carried out using graphical analysis using the SOLVER add-in in excel. Calibration is required to optimise parameter values to improve coherence between the measured and calculated hydrographs.

TABLE 4. Deviation of Peak Discharge and Peak Time

Parameter	**Measured Unit Hydrograph 1**	**Nakayasu**	**Δ (%)**
Qp	0,95	1,60	-67,84
Tp	4	1,287	67,83
Parameter	**Measured Unit Hydrograph 2**	**Nakayasu**	**Δ (%)**
Qp	1,31	1,60	-22,52
Tp	2	1,287	35,65
Parameter	**Measured Unit Hydrograph 3**	**Nakayasu**	**Δ (%)**
Qp	1,5	1,60	83,91
Tp	2	1,287	35,65

CONCLUSION

From the results of research, measurement, calculation, and analysis of the discussion of the Measured Units Hydrograph (MUH) and Synthetic Unit Hydrographs (SUH) of the Palembang City Watershed (DAS), which have been described in the previous chapter, it can be concluded that:

3. The results of the Measured Units Hydrograph analysis in the watershed of the three events of measurement in the field and the analysis of calculations are as follows:
    - Measured Units Hydrograph (MUH) of 1st (June 23, 2020) has a peak discharge (Qp) of 0,95m^3/ s, the time to peak (Tp) 4 hours (240 minutes), and a base (Tb) for 19 hours.
    - Measured Units Hydrograph (MUH) of the 2nd (June 28, 2020) was acquired, Qp = 1.31 m^3/ s, the time to the peak for (tp) 2 hours, and a time base (Tb) for 20 hours.

- Measured Units Hydrograph (MUH) of the 3rd (July 1, 2020) was acquired, Qp = 1.50 m^3/ s, the time to the peak for (Tp) 2 hours, and a time base (Tb) for 17 hours.

4. The results of the analysis using Synthetic Unit Hydrographs (SUH) in Buah Watershed:
   - SUH Gama, I had a peak discharge (Qp) of 1,117 m^3/ s, the time to the peak (Tp) for 1,658 hours
   - SUH Nakayasu has a peak discharge (Qp) of = 1.60 m^3/ s, the time to the peak (Tp) for 1,287 hours
   - SCS has a peak discharge (Qp) by 4.85 m^3/ s, the time to the peak (Tp) for 0.52 hours
5. Based on the Synthetic Unit Hydrograph analysis towards the Measured Units Hydrograph in Buah Watershed, it can be concluded that the peak discharge value (Qp) and peak time (Tp) are closest to Measured Units Hydrograph is SUH Gama I.

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