Analysis of Synthetic Unit Hydrograph Reability in Cikapundung Watershed, West Java Province, Indonesia

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ANALYSIS OF SYNTHETIC UNIT HYDROGRAPH REABILITY IN CW, WEST JAVA PROVINCE, INDONESIA

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Abstract: Synthetic unit hydrographs (SUH) that are most often used in Indonesia including SUH Nakayasu, SUH SCS, SUH Snyder and SUH ITB 1. Based on this background, a study was conducted to determine the most appropriate use of the SUH method for the characteristics of the CW. Hydrograph calibration was carried out using hourly rainfall data and 24-hour observation discharge data. The results of the analysis show that the Snyder SUH method is the most effective to be applied to the CW compared to the other three methods. This method shows a positive Nash-Sutcliffe efficiency (NSE) achieve of 0.74 with a correlation of 0.88. While the NSE value for SUH Nakayasu is -0.74 with a correlation of 0.93, the NSE value for SUH SCS is -1.61 with a correlation of 0.88 and the NSE value for SUH ITB-1 is -1.79 with a correlation of 0.87. Land cover in the Cikapundung Watershed in 2020 is dominated by settlements with an area of 50.64 km2, so the runoff coefficient value is quite large with a value of 0.46. The flood discharges for return periods of 2, 5, 10, 25, 50 and 100 years using the SUH Snyder method are 112.59 m^3/sec., 137.65 m^3/sec., 159.77 m^3/sec., 194 ,16 m^3/sec, 224.82 m^3/sec and 260.20 m^3/sec, respectively.

Keywords: SUH Snyder, Runoff Coefficient, Flood Discharge, and CW.

1. Introduction

The Cikapundung Watersehd (CW) with a catchment area of 144.32 km2 is located in the upper reaches of the Citarum River and it is one of the areas that provides water supply to the Citarum River, for the needs of the people of the city of Bandung and its surrounding districts. There is an imbalance between utilization efforts and conservation efforts in the CW, causing environmental problems. The problems that occur in the CW are basically caused by uncontrolled population growth which has resulted in increased exploitation of space and water resources in the last 20 years.

Infrastructure development in the upstream area of the Cikapundung River has reduced protected areas (forest and non-forest) (Sobirin, 2008). With this development activity, the designation of the area which was originally an open area to be function as a catchment area has then turned into an impermeable area, besides the use of groundwater in the upstream area is increasing. This activity has an impact on increasing surface runoff and decreasing ground water level so it affects the flow rate in the river (Widianto, 1999). Then agricultural cultivation that is not in accordance with conservation rules can cause a lot of critical land, higher levels of erosion resulting in sedimentation in riverbeds, reservoirs, drainage networks and other water infrastructure (Maria, 2008).

CW is a watershed with bird feather type where the shape of the watershed is not wide and the river flow is long so that the flood discharge is relatively smaller than the watershed which has a wide shape and short drainage distance. To obtain a hydrograph of an observation unit, a series of data are needed, such as data on maximum daily rainfall, actual river discharge data, and other parameters such as the characteristics of a watershed.

SUH is one way to estimate the magnitude of a flood discharge in a watershed. The planned flood with a certain return period can be calculated using flood discharge data or rain data. If the available flood discharge data is long enough (> 20 years), the flood discharge can be directly calculated using the probability analysis method. If the available data is only rain data and watershed characteristics, one of the recommended methods is to calculate flood discharge from the daily maximum rainfall data plan with a unit hydrograph superposition (Subramanya, 1984; Harto, 1993; Ramírez, 2000).

SUH has been widely developed by researchers and used nationally and internationally by many countries including SUH Nakayasu, SUH SCS, SUH Alex-Snyder and SUH ITB 1. Based on this background, a study was conducted to determine the use of the most suitable synthetic unit hydrograph method for the characteristics of the CW.

2 Literature Review

River Flow Pattern

There are several types of flow patterns that develop in the watershed (Howard, 1967). Howard divides flow patterns into eight types, namely dendritic, rectangular, parallel, trellis, radial, angular, multi-basinal and contorted flow patterns. The regional flow pattern is controlled by the slope, the type and thickness of the constituent rock layers, the geological structure, the type and density of vegetation, and natural conditions.

2.1 Watershed Types

There are three types of watersheds, including (Asdak, 2002):

1. Watershed type in the form of bird feathers which has the characteristics of small flood discharge due to the different arrival times of water from tributaries and relatively long flood times.

2. Distributed drainage watershed type which has the characteristics of a large flood discharge with a concentration at the meeting points of tributaries.

3. The type of parallel flow watershed which has the characteristics of a large flood discharge with a concentration at the meeting point of the river downstream.

2.2 Statistical Parameters

In statistical analysis data, there are four parameters which are useful in determining the right type of distribution to calculate the planned rainfall. Statistical parameters used in hydrological data analysis include standard deviation (Sd), skewness coefficient (Cs), Kurtosis coefficient (Ck) and coefficient of variation (Cv) (Soewarno, 1995).

2.2.1 Standard Deviation (Sd)

Standard deviation is a measurement value of dispersion and variability that most closest in statistical analysis of the data that has been collected.

$$Sd = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}} \qquad \text{.................................. (1)}$$

2.2.2 Skewness Coefficient (Cs)

Is a parameter that shows the degree of asymmetry of a distribution form.

$$Cs = \frac{\sum_{i=1}^{n} \{\log (Xi) - \overline{\log(X)}\}^3}{(n-1)(n-2)(\overline{Sd \log X})^3} \qquad \text{.................................. (2)}$$

2.2.3 Kurtois Coefficient (Ck)

The kurtois coefficient is an illustration of the sharpness of the data distribution curve, namely the degree of peak height of a frequency distribution.

$$Ck = \frac{\frac{1}{n} \sum_{i=1}^{n} \{(X_i) - \bar{X}\}^4}{Sd^4} \qquad \text{.................................. (3)}$$

2.2.4 Coefficient of Variation

Is a comparison value between the standard deviation with the average value of a distribution.

$$Cv = \frac{Sd}{\bar{X}} \qquad \text{.................................. (4)}$$

2.2.5 Rain Distribution

Rain distribution analysis can be done using historical data from rain data and discharge data. In statistics, it is known that there are several types of rain distribution including Gumbel distribution, Normal, Log Normal and Log Pearson Type III. Of the four methods, a compatibility test (Chi-Square and Smirnov-Kolmogorof) must be carried out before being selected to use in the calculation of planned rainfall.

In this study, the Log Pearson Type III method was chosen to analyze the distribution of rain in the Cikapunun watershed because this method has the smallest level of slope/error. This method is likened to a straight line equation with the following equation (Soemarto, 1999):

$$\text{Log } Xt = \text{Log } X + k \text{ Sd Log } X \qquad \text{.................................. (5)}$$

Rainfall plan with a certain return period is calculated using the antilog of Log Xt with the following equation:

$$Xt = 10^{\text{Log Xt}} \qquad \text{.................................... (6)}$$

2.2.6 Rainfall Intensity Analysis

Rain intensity is the amount of rainfall expressed in high concentrated rain in unit time. Rain intensity is one of the important parameters to calculate flood discharge. The calculation of the planned rainfall in this study uses the formula from Dr. Mononobe as seen below (Soewarno, 1995).

$$I = \frac{R_{24}}{t_c} \times \left[\frac{t_c}{t}\right]^{2/3} \qquad \text{.................................... (7)}$$

3. Research Methods

3.1 Research sites

The research is located in the CW, West Java Province, which is part of the Citarum watershed with a catchment area of 144.32 km2. The Cikapundung River has a length of + 32.83 Km which crosses 11 sub-districts in three districts namely West Bandung district, Bandung city and empties into the Citarum river which is located in Baleendah sub-district, Bandung district. Astronomically, the CW is located at coordinates 1070 37' 4.80" - 1070 38' 38.40" East Longitude and 60 49' 58.80" - 60 51' 10.80" South Latitude.

The climate type in the CW, West Java Province, belongs to the type B1 category (wet months between 7-9 months, and dry months less than 4 months). In general, what happens in areas that fall into the rainy zone part A, rain occurs almost throughout the year and the highest rainfall is from November to February. while the dry months occur from July to September (Chalid and Prasetya, 2020).

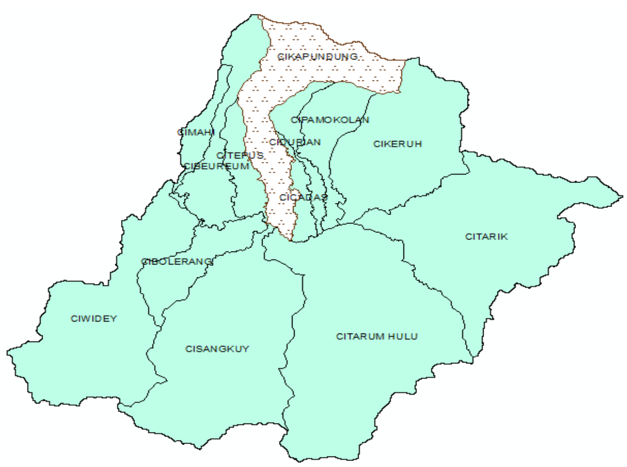


Figure 1. Research Location

3.2 Research Flowchart

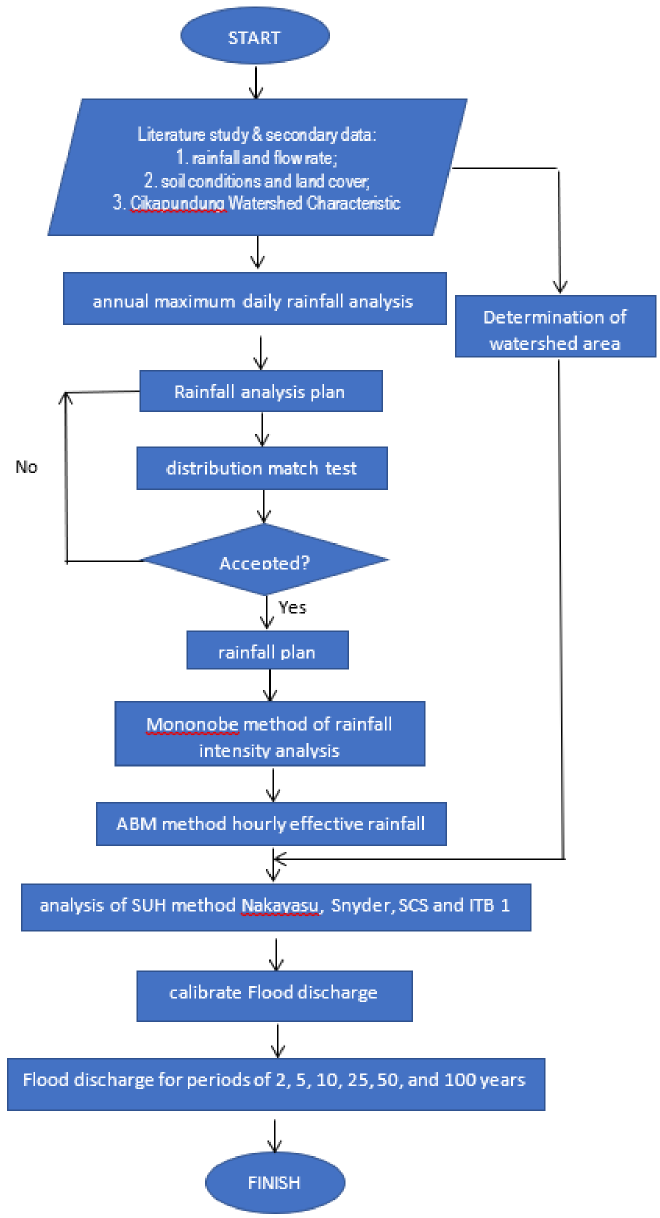


Figure 2. Research Flowcart

4. Results and Discussion

4.1 Rainfall Plan

The distribution of planned rainfall was calculated using the Log Pearson Type III method. The results of the calculation of rainfall for this method show that the rainfall with a return period of 100 years is 179.25 mm/day. The following shows a recapitulation of the planned rainfall for the Log Pearson Type III method from a return period of 2 years - 100 years.

Table 1. Rainfall Recapitulation Plan

No	Period	Log Pearson Type III Method (mm/day)
1	2	77,57
2	5	94,83
3	10	110,06
4	20	125,34
5	25	133,76
6	50	154,88
7	100	179,25

Table 2. Terms of Use Distribution Type

No	Kinds of Distribution	Condition		Calculation Results		Information
1	Log Pearson Type III Method	Cs ≠	0	Cs =	1,80	Fulfil
		Cv ≠	0	Cv =	0,25	Fulfil

4.2 Runoff Coefficient

Land use in the CW in 2020 is dominated by settlements and other buildings with an area of 50.64 km^2. Meanwhile, land use for open land is only 11.74 km^2 and for plantations is 37.68 km^2.

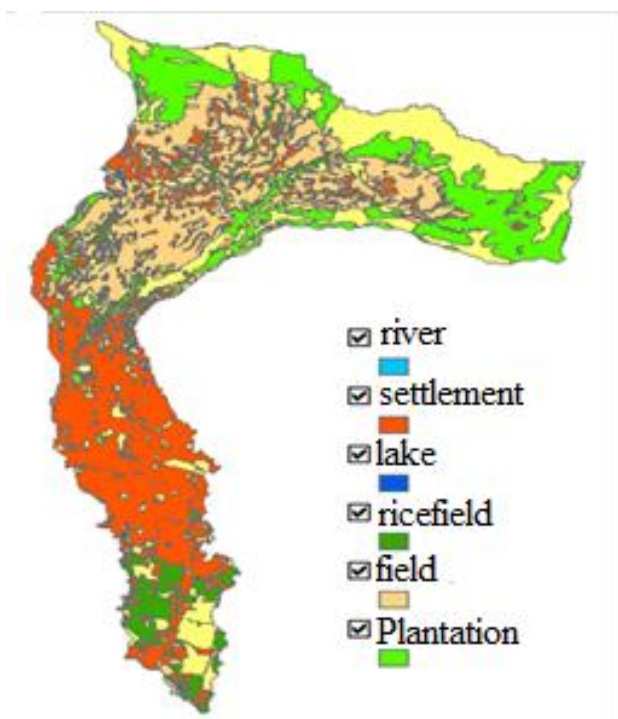


Figure 3. Land Cover CW in 2020

Table 3. Types of Land Use in the CW in 2020

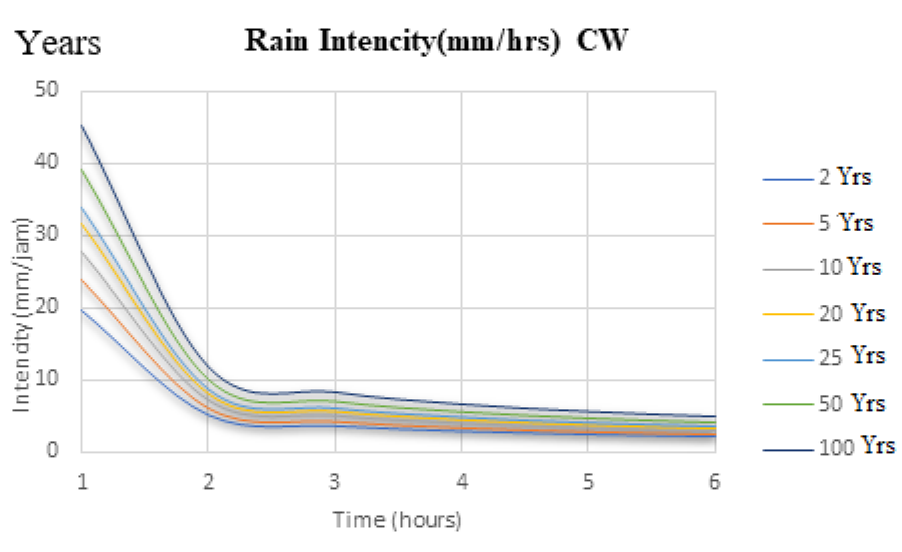
Type of land Use	Area (km^2)	C	Area x C
Open Field	11,74	0,40	4,70
Plantation	37,68	0,40	15,07
Field	34,56	0,20	6,91
Rice Field	9,32	0,15	1,40
River/Lake/Reservoir/Fond	0,38	0,10	0,04
Residential and Other Buildings	50,64	0,75	37,98
Total	144,32		66,10

To get the runoff coefficient value in the CW is by (Total Area x Coefficient) / Total Area = 66.10 / 144.32 = 0.46. Then the value of the runoff coefficient (C) of the CW in 2020 is 0.46.

4.3 Rainfall Intensity Analysis

There are many methods to calculate the intensity of rainfall, but in this study using the method of Dr. Mononobe which is a variation of short-term rainfall equations with the assumption that the average rain in Indonesia lasts approximately 6 hours.

To get the value of rainfall intensity obtained from the rainfall per return period multiplied by the coefficient of flow and the percentage value of the hourly rainfall distribution. The following is a graph of the intensity of rain for 6 hours for the CW in the image below:



Gambar 4. CW Rain intensity

4.4 Synthetic Unit Hydrograph Calibration

The hydrograph calibration uses hourly rain data for 24 hours. Daily rainfall data and observation discharge were taken on March 13, 2021 at 14.00 WIB until March 14, 2021 at 13.00 WIB. General data used to calibrate synthetic unit hydrographs including data on water level, observation discharge, base flow, direct flow, rainfall, flow coefficient and net rainfall. The following shows the graph of net rain and direct flow that occurs in the CW.

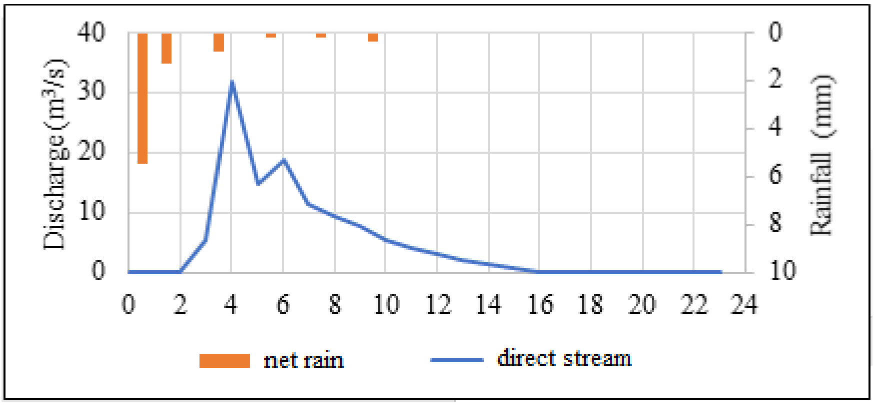


Figure 5. Rainfall Graph dan Discharge of Cikapundung River

Calculation of SUH calibration in the CW uses the following parameters:

- Watershed area (A) = 144.32 km^2
- Length of main river (L) = 32.83 km
- Effective rain (Ro) = 1.0 mm
- Flow coefficient (C) = 0.46

	Observasi		Nakayasu		SCS		ITB-1		Snyder-Alex	
t	Qobs	$(Qob-Qobr)^2$	Qm	$(Qob-Qm)^2$	Qm	$(Qob-Qm)^2$	Qm	$(Qob-Qm)^2$	Qm	$(Qob-Qm)^2$
0	0.00	23.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	23.51	1.53	2.35	3.04	9.25	1.18	1.38	0.00	0.00
2	0.00	23.51	8.45	71.32	11.99	143.68	17.69	312.82	0.12	0.01
3	5.52	0.45	23.30	316.12	26.17	426.49	36.61	966.89	12.65	50.82
4	31.71	721.57	44.01	151.37	38.77	49.84	44.01	151.37	31.16	0.30
5	14.94	101.78	39.64	610.09	44.01	845.46	43.83	834.55	19.97	25.35
6	18.76	193.40	32.29	183.15	41.71	526.88	39.25	419.81	7.88	118.20
7	11.51	44.42	27.96	270.43	35.54	577.12	32.67	447.77	5.23	39.44
8	9.38	20.50	21.65	150.70	28.35	359.87	25.88	272.21	2.47	47.74
9	7.70	8.11	17.99	105.86	22.30	213.28	20.11	154.01	1.27	41.27
10	5.55	0.49	15.08	90.87	17.60	145.26	15.43	97.62	0.82	22.36
11	3.96	0.79	13.30	87.22	14.05	101.78	12.45	72.11	0.93	9.20
12	3.15	2.89	11.75	73.89	11.44	68.65	10.21	49.90	1.15	4.02
14	1.29	12.68	8.82	56.74	7.61	39.98	6.09	23.10	0.80	0.24
16	0.20	21.63	6.03	34.05	4.44	18.03	3.22	9.10	0.02	0.03
18	0.00	23.51	4.35	18.93	2.44	5.94	1.59	2.53	0.00	0.00
20	0.00	23.51	3.23	10.43	1.33	1.77	0.76	0.58	0.00	0.00
23	0.00	23.51	2.08	4.34	0.52	0.27	0.24	0.06	0.00	0.00
Qobr	**4.85**	**1389.14**	**313.60**	**2412.32**	**333.39**	**3630.80**	**328.00**	**3873.11**	**86.39**	**359.32**

NSE	**-0.74**	**-1.61**	**-1.79**	**0.74**

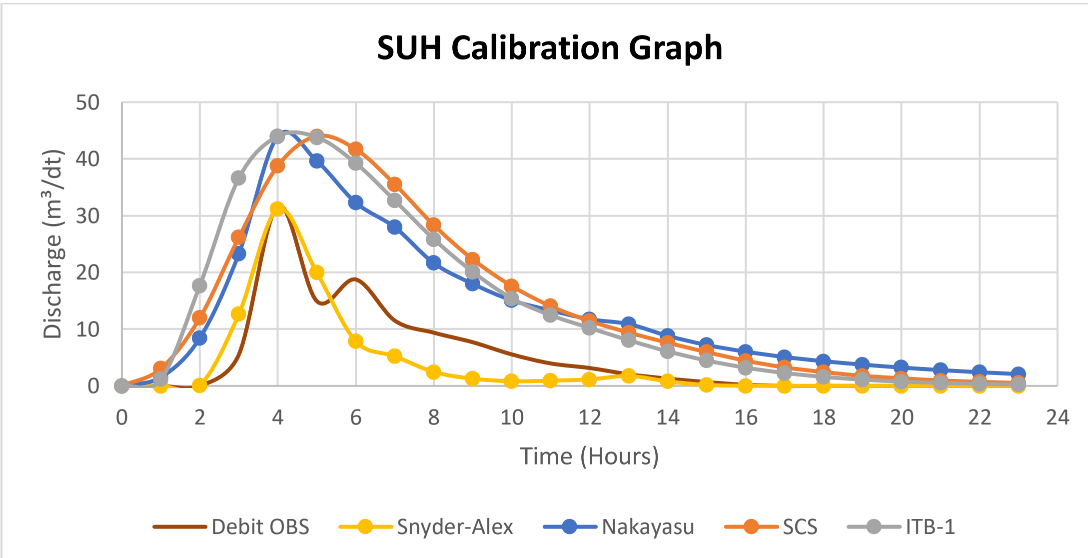


Figure 6. Recapitulation of SUH Calibration Graph

The four calibrated SUH methods, the Alex-Snyder SUH method was obtained with the best Nash-Sutcliffe efficiency (NSE) value of 0.74 and correlation value of 0.88. Therefore this method is the most effective method used for modeling flood discharge in the CW in the form of bird feathers.

3.5 Flood Discharge Alex-Snyder SUH Method

Common data used for modeling the Alex-Snyder SUH include the following:

- Watershed area (A) = 144.32 km^2
- Length of main river (L) = 32.83 km
- Length to center of gravity (Lc) = 16.42 km
- Unit rainfall (Ro) = 1.0 mm
- Unit rain distribution (Tr) = 1 hour
- Coefficient of time (Ct) = 0.55
- Peak coefficient (Cp) = 0.64

So it is calculated:

Time lag (tp) Ct (L.Lc)^0.3 = 3.65 hours

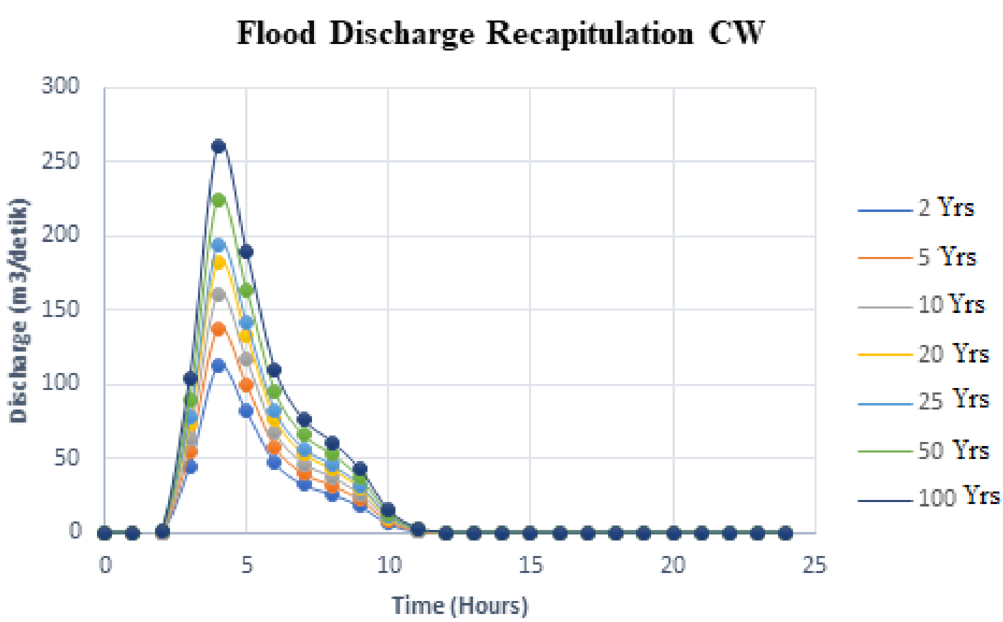
Effective rain (tc) tp/5.5 = 0.66 hours

Peak time (tpR) tp+(tc-Tr)/4 = 3.57 hours

qp 2.75 * Cp/tp = 0.482

qpR	qp * tp/tpR	= 0.494
Peak discharge (Qp)	qpR*A	= 71.27 m3/s
Time Base (Tb)	5.56/qpR	= 11.26 hours

Time (hours)	SUH Snyder	Flood Discharge (m^3/sec) Per Repeat Period						
		2 Yrs	5 Yrs	10 Yrs	20 Yrs	25 Yrs	50 Yrs	100 Yrs
0.00	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.00	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.00	0.0212	0.415	0.508	0.589	0.671	0.716	0.829	0.960
3.00	2.3080	45.229	55.292	64.176	73.086	77.994	90.309	104.519
4.00	**5.1558**	**112.599**	**137.651**	**159.770**	**181.950**	**194.169**	**224.829**	**260.205**
5.00	2.4354	82.098	100.364	116.491	132.663	141.572	163.927	189.720
6.00	0.5290	47.695	58.307	67.676	77.071	82.247	95.234	110.219
7.00	0.0737	33.016	40.362	46.847	53.351	56.934	65.924	76.296
8.00	0.0078	26.513	32.412	37.620	42.842	45.719	52.938	61.268
9.00	0.0007	18.452	22.558	26.183	29.818	31.820	36.844	42.642
10.00	0.0001	6.610	8.081	9.380	10.682	11.399	13.199	15.276
11.00	0.0000	1.310	1.601	1.858	2.116	2.258	2.615	3.026
12.00	0.0000	0.175	0.214	0.249	0.283	0.302	0.350	0.405
13.00	0.0000	0.018	0.022	0.026	0.029	0.031	0.036	0.042
14.00	0.0000	0.002	0.002	0.002	0.003	0.003	0.003	0.004
18.00	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22.00	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24.00	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000



Figurer 7. Recapitulation of Flood Discharge in the CW Snyder Method

4. Conclusion

Hydrograph calibration was carried out using hourly rain data for 24 hours. After the analysis, it was found that the Alex-Snyder SUH method was the most effective for the CW compared to the other three methods, only the Alex-Snyder SUH method showed a positive NSE value. The NSE value for SUH Nakayasu is -0.74 with a correlation of 0.93, the NSE value for SUH SCS is -1.61 with a correlation of 0.88, the NSE value for SUH ITB-1 is -1.79 with a correlation of 0.87 and the NSE value for SUH Alex-Snyder is 0.74 with a correlation of 0.88. The runoff coefficient in the CW in 2020 is 0.46. The flood discharges for return periods of 2, 5, 10, 25, 50 and 100 years using the SUH Alex-Snyder method are 112.59 m3/sec, 137.65 m3/sec, 159.77 m3/sec, 194.16 m3/sec, 224.82 m3/sec and 260.20 m3/sec.

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