

Increasing peak flow of snyder synthetic hydrograph units in the serenan sub-watershed of Bengawan Solo Watershed

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ABSTRACT

Changes in land use are closely related to the increasing number of people who are increasing from time to time. This land use change has an impact on increasing the runoff coefficient because the rain that falls will not be retained or seep and flows directly into the river. This is what causes an increase in peak discharge in a watershed. The purpose of this study was to determine the magnitude of changes in peak discharge that occurred in the Serenan watershed in 2015 and 2021 due to changes in land use. The method used in analyzing the peak discharge is the Snyder unit hydrograph, the results of this method will be compared with the measured unit hydrograph to determine the correlation between the two. To make a synthetic unit hydrograph, non-physical parameters are needed in the form of Ct and Cp values. The Ct value used in 2015 was 2.30 and in 2021 it was 2.00 while the Cp value in 2015 was 0.90 and in 2021 it was 1.10. The results of the analysis using the Snyder method showed that the peak discharge was 139.61 m³/s in 2015 and 194.56 m³/s in 2021. The analysis shows that the peak discharge increased by 54.95 m³/s and has a very strong correlation with the hydrograph of the measured unit.

Keywords: runoff coefficient; watershed; snyder hss; hs; ct and cp.

INTRODUCTION

A watershed or watershed is an area bounded by high points where water from falling rainwater collects in the area. The purpose of the watershed is to receive, store, and drain rainwater that falls on it through rivers (Triatmodjo, 2008). The watershed area is divided into several sub-watersheds, namely a land area that collects and stores rainwater and then distributes it to the main river through rivers or tributaries. Watersheds have characteristics that are closely related, one of which is humans and land use.

With the increasing number of residents who are quite intensive from year to year, it will have an impact on increasing land needs. So the efforts made by humans to meet their needs are to convert land use into non-forest. The conversion of land functions which are forest areas and agricultural land as well as rice fields which were formerly catchment areas into watertight built up areas such as residential and industrial lands causes negative impacts on land and water resources that occur in watersheds (DAS).

Changes in land use are closely related to runoff which can cause inundation. Asdak (2002) states that most of the rain that falls cannot be restrained by vegetation and cannot seep into the ground so that most of the rainwater will become surface runoff.

In the research of Nurhamidah et al (2018), it is stated that the amount of built up land is directly proportional to the runoff coefficient and the rate of surface runoff. This statement is supported by the results of the analysis of the surface runoff coefficient in the Batang Arau watershed which was initially 0.39 for 2006 to 0.41 for 2012, and the runoff discharge which was initially 327.20 m³/d changed to 339.51 m³/d. From the results of the analysis, it is concluded that land use changes greatly affect the runoff coefficient.

A similar study was conducted by Fauzi et al (2018) in the Penggung watershed. From the results of the study, it was found that the effect of land use area on peak discharge was 32.4%, with the land that had the most influence on peak discharge, namely built-up land.

Dharma et al. (2021) conducted a study with the aim of analyzing the peak discharge during high rainfall, analyzing the relationship of land use change to river discharge and analyzing the causes of

overflow. The method used in this research is the frequency distribution method for rainfall data analysis and peak discharge modeling with HEC-HMS. From the results of the study, it was found that the greater the change in land use, the greater the river discharge produced, this also resulted in river overflow due to the sediment that occurred.

The unit hydrograph is a direct flow hydrograph produced by rain that is spread evenly throughout the watershed. However, if a river does not have complete discharge measurement data, it can use another method, namely the reduction of a synthetic unit hydrograph based on the characteristics of a watershed. One of the popular synthetic unit hydrograph methods used in Indonesia is Snyder (Siswoyo, 2012).

Referring to the synthetic unit hydrograph Snyder, Barid, et al. (2020) conducted research on the Katulampa watershed using the Snyder HSS method and the ant algorithm as a solution to provide accurate calculation data so that it approximates field data. In this study, it was found that the Ct value was 1.55 and the Cp value was 0.44. The selection of these values has been carried out optimally because the calibration is close to 1.

Kristianto et al. (2019) also conducted research on the comparison of the measured unit hydrograph model with the synthetic unit hydrograph model. The method used is several synthetic unit hydrograph models, one of which is the Snyder HSS, then a comparison of the HSS model is carried out to determine the magnitude of deviations from the measured unit hydrograph. The results showed that the parameter values that have been optimized are the Ct value of 0.8 and the Cp value of 1.052. From the optimization results, the average deviation of peak discharge and peak time is 5%.

Gunawan et al. (2019) conducted a study on the evaluation of the peak discharge calculation method in the Air Bengkulu River Basin. This study uses 4 (methods) synthetic unit hydrographs, namely Snyder, Gamma 1, Nakayasu, and SCS. The results of the research that have been carried out, the peak discharge obtained by the HSS SCS method is 960.92 m³/second, Nakayasu produces a discharge of 995.87 m³/second, Gama I produces a discharge of 668.12 m³/second, and Snyder 1026.151 m³/second, the results of the analysis are considered to have similarities with unit hydrographs, so the use of synthetic unit hydrograph methods, namely Snyder, Gamma 1, Nakayasu, and SCS can be used to predict peak discharge in the Air Bengkulu watershed. The main goal in the researcher

RESEARCH METHODS

Research sites

The Serenan sub-watershed is part of the Bengawan Solo Hulu sub-watershed which includes Klaten Regency, Wonogiri Regency, Boyolali Regency, Gunungkidul Regency, Karanganyar Regency, and Sukoharjo Regency. The outlet point of the Serenan Sub-watershed is located at the coordinates 7°40'13.79"S - 110°46'48.03"E, the selection of this point is based on available debit post data due to data limitations.

In this study, rainfall and flow rate data are needed which are obtained through the official website of the Bengawan Solo River Basin Center. As for the watershed data and DEMNAS maps obtained through the <https://tanahair.indonesia.go.id> website, the data will be processed using ArcGis 10.2 software.

From the results of data processing, the area of the Serenan sub-watershed is 2714.7989 km² with a main river length of 40.7842 km.

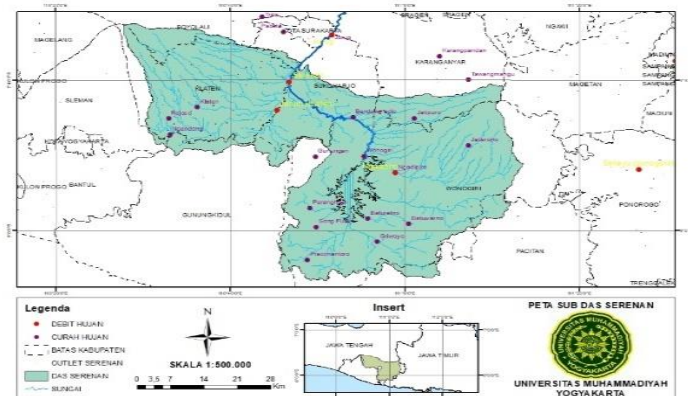


Figure 1. Serenan sub-watershed

Land Use

This study uses data from the Indonesian Earth Map which was downloaded through the website <https://tanahair.indonesia.go.id>. The data downloaded is in the form of land distribution in 2015 and 2021. The results of the data are processed using ArcGIS 10.2 Software, the output of the processing results in the form of land use and its area in each year.

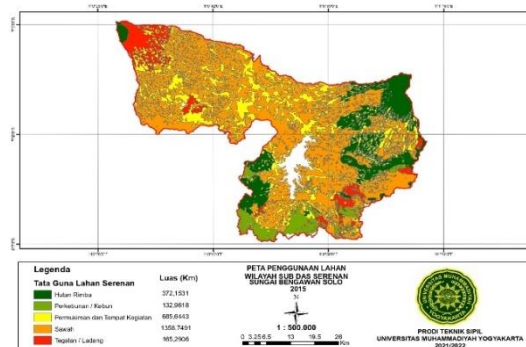


Figure 3. Land Use in 2015

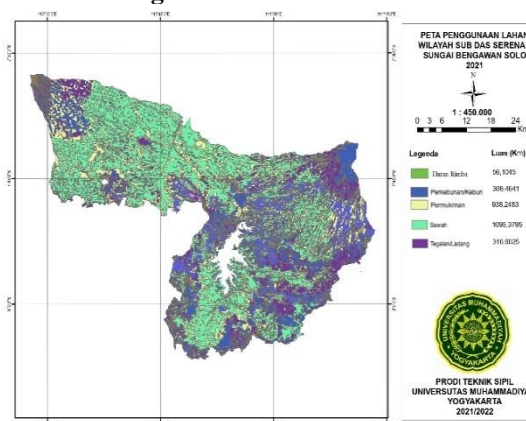


Figure 4. Land Use in 2021

Runoff Coefficient

The runoff coefficient is the percentage of the amount of water that is able to flow/run over through the soil surface from the total amount of rainwater that falls on a certain area. The runoff coefficient

value parameter is determined based on land cover, soil type, and slope slope (Fransedo and Akbar, 2019).

The runoff coefficient was calculated using the U.S. method. Forest Service. Later the results of this runoff coefficient will be used in calculating the effective rain to produce a discharge in the measured unit hydrograph.

$$C = \frac{C_1 \times A_1 + C_2 \times A_2 + \dots + C_n \times A_n}{A_1 + A_2 + \dots + A_n} \tag{1}$$

With:

C = coefficient of total land cover

C1-Cn = coefficient of each cover

Land

A = area of land cover

Table 1. Land Use in 2015

No	Land use	Large (Km ²)	
		Km	%
1	Jungle	372,15	13,70
2	Plantation/garden	132,96	4,89
3	Settlement	685,64	25,26
4	Ricefield	1358,75	50,05
5	Field Moor	165,29	6,09
Total		2714,7989	100

Table 2. Land Use in 2021

No	Land use	Large (Km ²)	
		Km	%
1	Jungle	56,10	2,07
2	Plantation/garden	308,46	11,36
3	Settlement	938,25	34,56
4	Ricefield	1095,38	40,35
5	Field Moor	316,60	11,66
Total		2714,7989	100

Rainfall data

This study uses rainfall recording data every 6 hours at each point of the rain post station. This data was obtained through the official website of the Bengawan Solo River Basin Center.

The rainfall data needed to analyze the discharge is regional rainfall data, so to convert point rain data into regional rainfall, the Thiessen method is used.

$$\bar{P} = \frac{A_1 \cdot P_1 + A_2 \cdot P_2 + \dots + A_n \cdot P_n}{A_1 + A_2 + A_3 + \dots + A_n} \tag{2}$$

With:

P = average rainfall,

P1, ... , Pn = rainfall at each station

A1, ... , An = area bounded by each polygon

Rain Intensity

Rain intensity analysis begins with changing the maximum daily rainfall data into hourly rainfall intensity. Calculation of rain intensity is done using the Mononobe method.

$$I_t = \frac{R_{24}}{24} \left(\frac{24}{t} \right)^{\frac{2}{3}} \quad (3)$$

Dengan:

- I_t = rain intensity for rain duration t
(mm/hour)
- R_{24} = maximum rainfall for 24 hours (mm)
- t = duration of rainfall (hours)

According to Van Breen (in Harisuseno, 2020), the duration of the rain that occurs in Java, Indonesia is 4 hours with an effective rain of 90% of the total rainfall for 24 hours.

Hydrograph Unit of Measure

The unit hydrograph is calculated based on the effective rain that has been distributed into several different intensities which will later be multiplied by the runoff coefficient to produce a direct runoff discharge. The calculation of the hydrograph is as follows:

$$Q_n = \sum_{m=1}^{n \leq M} P_m q_{n-m+1} \quad (4)$$

Dengan:

- Q_n = direct runoff hydrograph
- P_m = hujan efektif
- q_{N-m+1} = unit hydrograph
- n = ordinate sum of direct runoff hydrograph (1,2,3,...,n)
- m = number of consecutive rain duration (1,2,3,...,n)

Baseflow calculations can be done using the Synthetic Unit Hydrograph (HSS) Gamma 1 equation developed by Sri Harto (1993). Baseflow calculations with these equations can be carried out if detailed observational discharge data are available, but if the discharge data are incomplete, the baseflow calculation can use the following formula (Ramadhan et al, 2021).

$$Q_b = 0,475 \times A^{0,6444} \times D^{0,9430} \quad (5)$$

$$D = \frac{LN}{A} \quad (6)$$

Dengan:

- Q_b = Base Flow, (m³/sec)
- A = Large DAS, (Km²)
- D = Drain network density, (Km/Km²)
- LN = river length (Km)

Snyder Synthetic Unit Hydrograph

Synthetic unit hydrographs are used to develop unit hydrographs for other locations on rivers in the same watershed or for nearby watersheds with the same characteristics (Chow, 1998).

According to Triatmodjo (2008), the parameters developed in the Snyder method consist of parameters of time, lag, peak flow, base time, and standard duration of effective rain for the unit hydrograph associated with the physical geometry of the watershed with the following relationship:

$$T_p = C_t (L \times L_c)^{0,3} \quad (7)$$

$$Q_p = \left(\frac{C_p \times A}{t_p} \right) \quad (8)$$

$$T = 3 + \frac{t_p}{8} \quad (9)$$

$$t_D = \frac{t_p}{5,5} \quad (10)$$

If the effective rain duration t_r is not equal to the standard duration t_D , then:

$$t_{pR} = t_p + 0,25 (t_r - t_D) \quad (11)$$

$$Q_{pR} = Q_p \frac{t_p}{t_{pR}} \quad (12)$$

$$P_r = t_{pR} + \frac{t_r}{2} \quad (13)$$

With:

- t_D = Standard duration of effective rain (hours)
- t_r = Effective rain duration (hours)
- t_p = Time of center of gravity duration of rain effective tD peak hydrograph unit (Hours)
- t_{pr} = Time of center of gravity rain duration t_r to the top of the unit hydrograph (Hours)
- T = Base time unit hydrograph (Day)
- Q_p = Peak discharge for duration tD
- Q_{pR} = Peak discharge for duration t_r
- P_r = Time of the beginning of the rain to the top
- L = The length of the main river with respect to the point reviewed control (Km)
- L_c = Distance between control points to the point closest to the center of gravity of the watershed (Km)
- A = Large DAS (Km²)
- C_t = Slope dependent coefficient DAS
- C_p = The coefficient that depends on characteristics DAS.

To make it easier to describe, you can use the formula:

$$W_{50} = \frac{0,23 A^{1,08}}{Q_{pR}^{1,08}} \quad (14)$$

$$W_{75} = \frac{0,13 A^{1,08}}{Q_{pR}^{1,08}} \quad (15)$$

Where W_{50} and W_{75} are the widths of the hydrograph units at 50% and 75% of peak discharge, expressed in hours.

According to Siswoyo (2012) there are non-physical parameters obtained from the characteristics of the watershed, namely C_t and C_p . Gustama et al. (2018) states that the value of C_t is 0.75 to 3.00, while the value of C_p is between 0.90 to 1.40.

Correlation Between Hydrographs

The data suitability analysis was carried out by comparing the results of the unit hydrograph modeling discharge with the Snyder method hydrograph at the same time into the same graph.

According to Arun Goel (2011, in Mahyudin et al, 2014), there are 2 error rate criteria, namely Correlation coefficient (R) and Root Mean Square Error (RMSE), the calculation of Correlation coefficient (R) can use the equation:

$$R = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \quad (16)$$

Dengan:

- x = $X - X'$
- y = $Y - Y'$
- X = observation value
- X' = the average value of X
- Y = predictive value
- Y' = Y value average

With the following criteria:

- $R=0$: No correlation
- $0 < R \leq 0,25$: Very weak correlation
- $0,25 < R \leq 0,50$: enough correlation

$0,50 < R \leq 0,75$: Strong correlation

$0,75 < R \leq 0,99$: Very strong correlation

$R = 1,00$: Perfect correlation

RESULTS AND DISCUSSION

Land Use Change

The results of the analysis of land use in the Serenan watershed have five forms of land use including forest, plantations, settlements, rice fields, and dry fields with the following area:

Land changes that occur in the Serenan sub-watershed are indicated by a decrease in forest area by 11.6417% from 372.1531 Km² to 56.1045 Km² and a decrease in rice fields by 9.7013% from 1358.7491 Km² to 1095.3795 Km². In addition, there was an increase which was dominated by settlements as much as 9.3047% from 685.6443 Km² to 938.2483 Km². In addition, an increase in land area also occurred in the area of plantations/gardens as much as 6.4647% from 132.9618 Km² to 308.4641 Km² and an increase in land area in dry fields as much as 5.5736% from 165.2906 Km² to 316.6025 Km².

Runoff Coefficient

Changes in land use also affect the runoff coefficient. Changes in the runoff coefficient can be seen in the following table:

From the results of the analysis, it was found that there was an increase in the runoff coefficient of 0.06. The runoff coefficient in 2015 is 0.34 and in 2021 it is 0.4. This increase occurs due to changes in land that become impermeable to water, because of this change the amount of rainwater that becomes surface runoff will increase so that river discharge also increases. An increase in peak discharge will drastically change the shape of the hydrograph in a relatively short time.

Hydrograph Unit of Measure

Before getting the unit hydrograph discharge, complete rainfall data is required at each station. Preferred rainfall is January 13, 2015 and February 3, 2021.

From the results of the analysis will be obtained data:

a. Preferred Rainfall

Year 2015 = 44,94 mm/day

Year 2021 = 57,28 mm/day

b. Rain intensity

Year 2015 = 6,1832 mm/hour

Year 2021 = 7,8806 mm/hour

c. Rain distribution

For the distribution of rain using previous research data by Sobriyah 2005 (in Wardhani 2012). The percentage of hourly rain in the first hour is higher and decreases further into the following hours.

Table 5. Distribution of Hourly Rain

Time (t)	% Rain	(%Rain x C x It)	
		2015	2021
1	40,50	0,8489	1,2745
2	31,25	0,6550	0,9835
3	14,75	0,3092	0,4642
4	13,50	0,2830	0,4249

d. Basic flow

Q_b (baseflow) = 47,5996 m³/det

e. Peak Debit and Peak Hours

Peak debit (Qp) 2015 = 103,70 m³/sec

Peak hour (Tp) 2015 = hour to 18

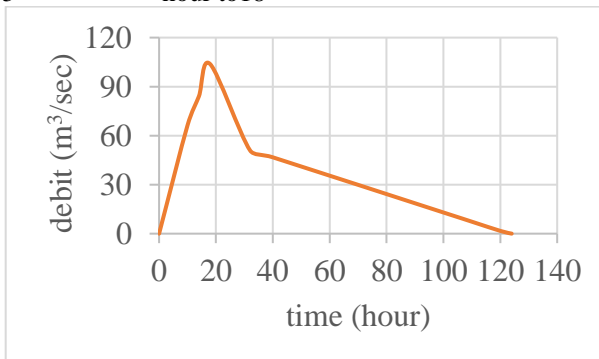


Figure 5. Graph of Unit Hydrograph 2015

Peak debit (Qp) 2021 = 173,37 m³/sec

Peak hour (Tp) 2021 = hour to 12

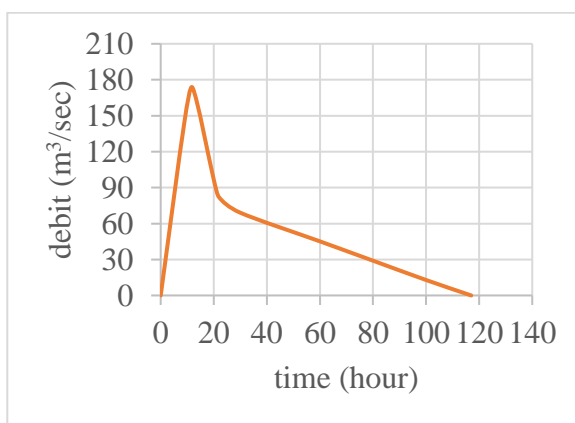


Figure 6. Graph of Unit Hydrograph in 2021

Snyder's Synthetic Unit Hydrograph

The data needed to calculate the Snyder Synthetic Unit Hydrograph are:

Watershed area (A) = 2714,799 Km²

River Length (L) = 40.7842 Km

Center of Weight (Lc) = 20.3921 Km

Effective Rain Duration (Tr) = 4 hours

a. Snyder Synthetic Unit Hydrograph Results 2015

Table 6. Snyder Parameters

Ct	2,30
Cp	0,90

Table 7. Snyder Calculation Results in 2015

Time (hour)	Debit of Snyder (m ³ /s)
0	0
10	69,81
13	104,71

20	139,61
40	59,23
80	31,02
100	16,92
124	0

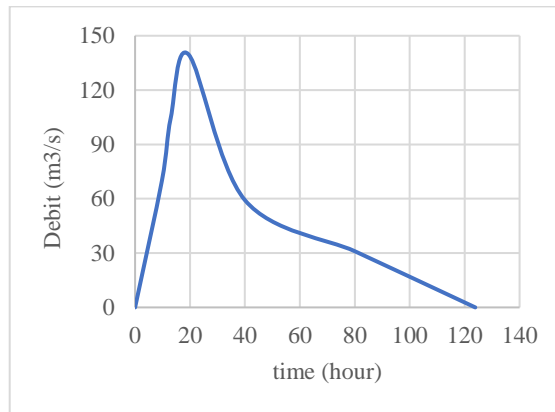


Figure 7. Graph of Snyder's Hydrograph Year 2015

a. Snyder Synthetic Unit Hydrograph Results 2021

Table 8. Snyder Parameters

Ct	2,00
Cp	1,10

Table 9. Snyder Calculation Results for 2021

Time (hour)	Debit of Snyder (m ³ /s)
0	0
9	97,28
12	145,92
17	194,56
35	83,09
65	52,69
80	37,49
117	0

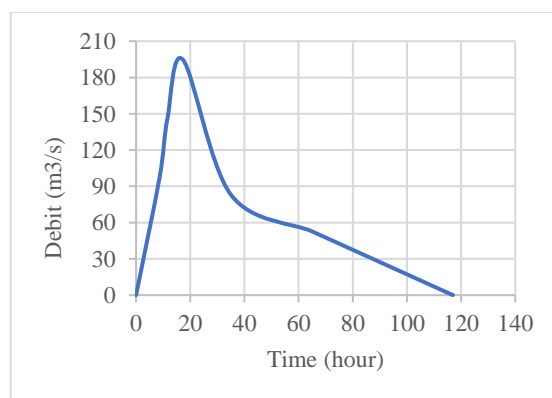


Figure 8. Snyder Hydrograph Graph for 2021

Validation Test

The result of the calculation of the correlation coefficient (R) in 2015 was 0.95 with a very strong category. Meanwhile, the correlation coefficient (R) in 2021 is 0.86 with a very strong category. High coefficient results on observational hydrograph data are considered the best model to determine the level of reliability in predicting synthetic unit hydrograph (HSS) parameters (Yani, 2019).

The comparison between the measured unit hydrograph and Snyder synthetic unit hydrograph is shown in the following figure.

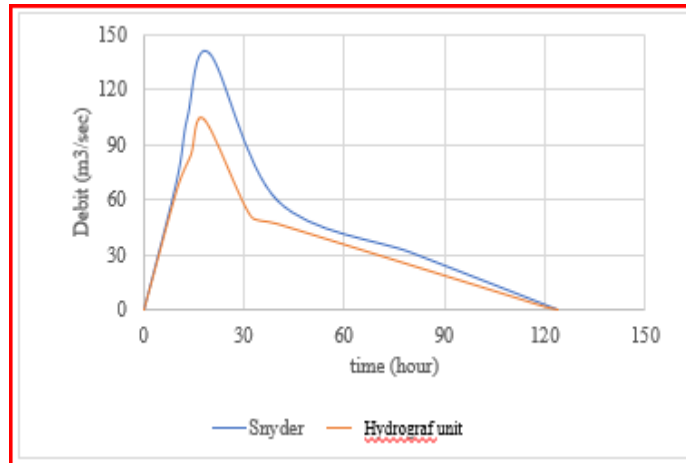


Figure 9. Comparison Chart for 2015

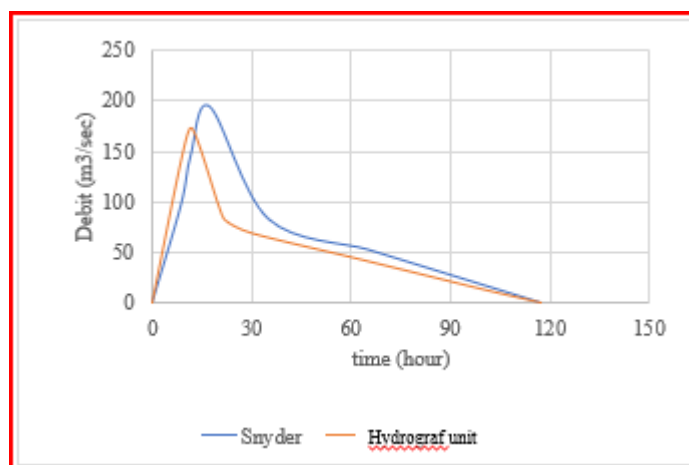


Figure 10. Comparison Chart for 2021

CONCLUSION

Changes in land use in 2015 to 2021 are dominated by a decrease in forest area of 11.6417% from 372.1531 Km² to 56.1045 Km², while the increase in land is dominated by settlements by 9.3047% from 685.6443 Km² to 938,2483 Km². From the land use change, the runoff coefficient value in 2015 was 0.34 to 0.40 in 2021. The results of the analysis of the peak discharge of the unit hydrograph in 2015 were 103.6983 m³/second with the 18th peak hour and the unit hydrograph in 2021 of 173.3722 m³/second with the 12th peak hour. Peak discharge increased by 69.6739 m³/second. The results of the hydrograph analysis of the Snyder unit in 2015 obtained a peak flow of 139.61 m³/s with a peak hour of 20 and in 2021 a peak flow of 194.56 m³/s with a peak hour of 17 was obtained. Peak discharge increased by 54.95 m³/s. The results of the HSS Snyder parameters in 2015 with a Ct of 2.30 and a Cp of 0.90 while in 2021 a Ct of 2.00 and a Cp of 1.10. The Snyder HSS parameter is considered the most optimal if applied to the Serenan sub-watershed because it

has been tested with the correlation coefficient (R) and obtained very strong results with values of 0.95 and 0.86.

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