Comparative Analysis of Flood Hydrograph Way Kandis River Basin with Synthetic Units Hydrograph (HSS) Snyder, Nakayasu, and Limantara Methods

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Abstract. Hydrological data is not available in most areas of Lampung Province. To decrease the unit hydrograph, then it's made a Synthetic Unit Hydrograph is created based on the physical characteristics of the River Basin. Way Kandis River which is a creek of Way Sekampung River is one of the watershed that does not have unit hydrograph so it is necessary to make HSS calculation from some existing method. The design flood debits calculated in this study were Q2, Q5, Q10, Q20, Q25, Q50, and Q100 using the HSS Snyder Method, the Nakowsasu HSS Method and the Limantara HSS Method. The peak debit (Qp) results on the highest 100 year (Q100) recalculation on the Limantara Q100 method = 615.44 m3 / sec HSS by a margin of less than 5 m3 / s through the Snyder Q100 method = 610.79 m3 / s. Lowest Method Nakayasu Q100: 437,40 m3 / s. The time to reach the longest peak (Tp) discharge on the Snyder method = 8 hours by 1 hour difference in each method. Nakayasu Method = 7 hours and Limantara Method = 6 hours. Of the three methods HSS can not yet predicted which approach approaches the flood hydrograph in Way Kandis watershed because there is no data for calibration. Therefore, further research is needed to obtain measurable flow data on Way Kandis River. Keywords: Watershed, Way Kandis River, Snyder, Nakayasu, Limantara.

1. Introduction

1.1 Background

Hydrological data is required as a preliminary information in every planning and design of water resources development. The quality of data to be used for a hydrological analysis shall be the optimal information obtained from hydrological outposts and is representative of a watershed. The transformation from rain to flow discharge is known as the unit hydrograph concept. This concept is widely used to estimate design floods. Way Kandis River is a river level / ordo 2. Way Kandis River empties into Way Sekampung River. In the Way Kandis River Basin there is no sufficient hydrological data to reduce the unit hydrograph, a synthetic unit hydrograph is based on the physical characteristics of the Way Kandis River Basin. Based on the above description, the authors conducted this study.

1.2 Purpose and objectives

The purpose of this study is to calculate the design flood discharge through synthetic unit hydrograph with Snyder Method, Nakayasu Method and Limantara Method based on rain data obtained from some rain stations around Way Kandis River Basin. While the objective of this study are :

a. Recognize the existence of rain stations affecting runoff flow in the Way Kandis River basin.

b. Calculate the design flood discharge using rain data affecting the Way Kandis River Basin with the Snyder Method, the Nakayasu Method and the Limantara Method.

c. Obtain comparison of flood discharge design results between Snyder Method, Nakayasu Method and Limantara Method.

d. The modeling results of some of these methods can be selected as basic data in determining the planning and design of civil buildings to be built on the Way Kandis River.

1.3 Scope of Problem

a. The study area in this research is Way Kandis River.

b. The data used in the calculation of design flood analysis is secondary data i.e. rain data from the rain stations affecting runoff on Way Kandis River Basin.
c. Synthetic Unit Hidrograph used is HSS Snyder Method, HSS Nakayasu Method and HSS Limantara Method.
d. The design flood debit calculated in this research is Q2, Q5, Q10, Q20, Q25, Q50, dan Q100.

2. Literature Review

2.1 Rain Measurement

The amount of rainfall occurring in a single watershed is a very important quantity in the watershed system as rain is the main input into a watershed. (Sri Harto, 2000) The most common mistakes in doing rain analysis are: (1) data completeness (2) data consistency (3) method of analysis. Therefore it is necessary to test the rain data.

2.2 Determination of the Rainy Area

The rain gauge only provides the depth of rain at the point where the rain station is located so that the rain on an area should be estimated from that point of measurement. If an area has more than one measurement station located scattered, the recorded rain in each station may be unequal. In hydrological analysis it is often necessary to calculate the average rainfall in the area, which is carried out by the following three methods : arithmetic mean method, Thiessen Polygon method and isohiet method. (Bambang Triatmodjo, 2013).

2.3 Hydrograph

Hydrograph is a curve that gives the relationship between flow and time parameters. These parameters can be either flow depth (elevation) or flow discharge; so there are two kinds of hydrograph that is water hydrograph and hydrograph discharge. The hydrograph of the water table can be transformed into a discharge hydrograph using a rating curve. Henceforth hydrograph is a debit hydrograph, unless otherwise stated. (Bambang Triatmodjo, 2013).

Hydrograph has three forming components:

a. Surface flow,
b. The intermediate stream, and
c. Ground water flow.

Hydrograph has a shape like a bell. Zero time indicates the beginning of hydrograph. The hydrograph peak is part of a hydrograph that describes the maximum discharge. Time to peak is the time measured from time zero to the peak discharge time. Rising limb is part of the hydrograph between the zero time and the peak reach time. Recession limb is part of a hydrograph that decreases between peak and bottom time. The base time is the time measured from zero to the time when the downside ends. The end of the downside is determined by approximation. (Bambang Triatmodjo, 2013).

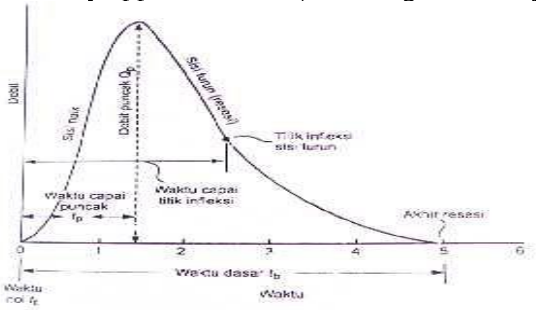

Figure 1. Flood Hydrograph Components

2.4 Unit Hydrograph

Unit hydrograph is a direct run off hydrograph generated by effective rainfall that occurs evenly across the watershed and with fixed intensity for a set time unit called the unit rain. Whereas the unit rain is the long rainfall such that the duration of surface runoff does not become short, even though the rainfall is short. So the rain of the selected unit is the same length or shorter than the hydrograph rising period (time from the starting point of the surface stream to the peak, time to peak). The runoff period from the unit rain is all about the same and has nothing to do with the intensity of the rain. (Suripin, 2003).

2.5 Flood Discharge Design

In determining the amount of flood discharge plan is done by transforming the rainfall data into debit data. As for the sequence in determining the amount of flood discharge of the plan, it can generally be described as follows :

2.6 Rain Data Selection

To provide reliable results, the probability analysis must begin with the provision of relevant, adequate and thorough data sets. After the value of daily rainfall is obtained, it is necessary to choose the maximum annual rainfall, then analyzed the probability of occurrence based on predetermined distribution pattern. Maximum flood discharge has correlation to maximum rainfall, therefore for flood discharge analysis used maximum daily rainfall as input data.

2.7 Rainfall Frequency Analysis

Rainfall frequency analysis is used to determine the specific rainfall period of the plan, which indicates the likelihood of rainfall to be matched or exceeded over a period of time. To select the appropriate type of distribution of a particular data series, it is necessary to investigate the statistical parameters. The terms are as follows :

a). Normal Distribution

The particular properties of this distribution are asymmetric values close to zero (Cs = 0), and the coefficient of kurtosis approaches three (Ck = 3).

b). Normal Log Distribution

Normal Log Distribution has an asymmetry value approaching 3 (three) times the coefficient of variation (Cs = 3 Cv), and Cs is always positive..

c). Gumbel Distribution

The nature of the Gumbel distribution, the asymmetry coefficient (Cs) = 1.1396, and the coefficient of kurtosis (Ck) = 5,4002.

d). Pearson Log Distribution III

This distribution is used when statistical data or basic statistical parameters do not show any distribution (as described above).

2.8 Distribution Suitability Test

This suitability test is intended to find out the truth of a Log Pearson Type III distribution frequency hypothesis. With this inspection will be obtained :

1. The truth between the observed results with the expected or theoretically derived model of distribution.
2. The truth of the hypothesis is accepted or rejected for use on subsequent calculations. There are two ways to test the suitability of Log Pearson Type III distribution, ie Smirnov Kolmogorov test (horizontal data test) and Chi Square (vertical data test).

2.9 Synthetic Unit Hydrograph

Synthetic Unit Hydrograph (HSS) has been used extensively to estimate the unit hydrograph form of a watershed that does not have a hydrometric station. There are several HSS methods that have been developed such as HSS Snyder, SCS, Nakayasu, Gama I, Gama 2, ITB 1, ITB-2 and Limantara..

2.10 HSS Snyder

In 1938, F.F. Snyder originating from America, has developed an empirical formula with an empirical coefficient that connects elements of unit hydrograph with the characteristic of a watershed. (CD Soemarto, 1987). These elements are the area of the drainage, the main flow length, the distance between the center of the drainage area and the outlet measured along the main stream.

tp = Ct (L. Lc)n .... (1)

Snyder also based his HSS counting method on the duration of 1 hour effective rainfall (tR) :

- If $t\mathcal{E} > tR$ then time goes up the unit hydrograph :

$t'p = tp + 0{,}25 * (t\mathcal{E} - tR)$ .... (2)

$Tp = t'p + 0{,}50 * Tr$ .... (3)

- If $t\varepsilon < tR$:
$Tp = tp + 0{,}50 * tr$ .... (4)
Peak discharge :

$$qp = 0{,}278 * \frac{Cp}{t'p} \quad \text{.................................. (5)}$$

and

$$Qp = qp * A \quad \text{.. (6)}$$

with :
tε : standard duration of effective rainfall (hours)
tr : effective duration of rain (hours)
tp : time from the center of gravity of effective rainfall tD to the peak of the unit hydrograph (hours)
Tp : time to reach the peak of flood (hours)
Qp : peak discharge (m3/dtk/mm)
qp : peak hydrograph unit (m3/dtk/mm/km2)
L : length of the main river to the control points reviewed (km)
LC : the distance between the control points to the point closest to the watershed
(km)
A : wide watershed (km)
Ct : coefficients that depend on the slope of the watershed, which vary from 1,1 - 1,4
Cp : coefficients that depend on the characteristics of the watershed, which vary from 0.58 to 0.69
2.11 HSS Nakayasu
Nakayasu synthetic unit hydrograph was developed based on several rivers in Japan (Soemarto, 1987). The use of this method requires some characteristic parameters of
the flow region, such as :
a) The grace period from the surface of the rain to the top of the hydrograph (*time of peak*)
b) The grace period from the surface of the rain to the top of the hydrograph
(*time lag*)
c) Hydrograph time span (*time base of hydrograph*)
d) Area of river basin
e) length of the longest channel
Bentuk persamaan HSS Nakayasu is

$$Qp = \frac{CA.Ro}{3{,}6(0{,}3Tp + T_{0,3})} \quad \text{.........................(7)}$$

with :
Qp = flood peak discharge (m3/s)
Ro = rain unit (mm)
Tp = the grace period from the beginning of the rain to the peak of the flood (hours)
T0,3 = time required by the decrease of discharge, from peak to 30% of peak discharge (hours)
CA= the area of the drainage to the outlet (km2)
To determine Tp and T0,3 we used the following formula approach:
Tp = tg + 0,8 tr …....................... (8)
T0,3 = α tg .... (9)
Tr = 0,5 tg to tg .... (10)
tg is the time lag that is the time between the rain until the peak flood discharge (hours) tg is calculated with the following conditions :
River with a long groove L > 15 km : tg = 0,4 + 0,058 L
River with a long groove L < 15 km : tg = 0,21 L0,7
The calculation of T0.3 uses the provisions:
α = 2 on a normal stream area

α = 1,5 on the slowly rising hydrograph section, and go down fast
α = 3 on the quick hydrograph riding section, and slow down
□□On the rise: 0 < t < Tp
Qa = Qp . (t/Tp)2,4 .... (11)
where Qa is runoff before reaching peak discharge (m3/s)
□□On the down curve (decreasing limb)
a. Hose value : Tp ≤ t ≤ (Tp + T0,3)

$$Qd_1 = Qp.0,3^{\frac{(t-Tp)}{T_{0,3}}} \text{ .... } (12)$$

b. Hose value : (Tp + T0,3) ≤ t ≤ (Tp + T0,3 + 1,5 T0,3)

$$Qd_2 = Qp.0,3^{\frac{(t-Tp+0,5T_{0,3})}{1,5T_{0,3}}} \text{ .... } (13)$$

c. Hose value : t > (Tp + T0,3 + 1,5 T0,3)

$$Qd_3 = Qp.0,3^{\frac{(t-Tp+1,5T_{0,3})}{2T_{0,3}}} \text{ .... } (14)$$

2.12 HSS Limantara

HSS Limantara was discovered by Lily Montarcih Limantara in 2006. Research locations in the watersheds in Indonesia are considered to represent : Java (6 Basin, 67 Sub Basin), Bali (2 Basin, 13 Sub Basin) Lombok (1 Basin, 5 Sub Basin) and East Kalimantan (1 Basin, 9 Sub Basin). Parameter watershed used in HSS Limantara there are 5 kinds, that is:

- Watershed Area (A)
- The length of the main river (L)
- The length of the river is measured to the point closest to the watershed (Lc)
- River slope (S)
- coarse coefficient (n)

Peak discharge equation :
Qp = 0,042xA0,451x L0,497x Lc0,356x S-0,131
x n0,168 ....(15)
The equation of the curve rises :
Qn = Qp [(t/TP)]1,107 .... (16)
The equation of the curve falls :
Qt = Qp x 100.175 (Tp-t) .... (17)
with :
Qp = peak discharge flood hydrograph unit (m3/s/mm)
A = Watershed Area (km2)
L = The length of the main river (km)
Lc = The length of the river is measured to the point closest to the watershed
s = River slope
n = coarse coefficient
Qn= debit on the equation of the rising curve (m3/s/mm).
Qt = discharge at the equation of the down curve (m3/s/mm)
Tp = time rises hydrograph or time reaches the top of the hydrograph (hours)
t = hydrograph time (hours)

The Limantara HSS can be applied to other watersheds that have similar characteristics with the watersheds in the study sites. The HSS Limantara technique specification is presented in the following table.

Table 1. Technical Specifications of HSS Limantara

Uraian	Notasi	Satuan	Kisaran
Luas DAS	A	Km^2	0,325 – 1667,500
Panjang sungai utama	L	Km	1,16 – 62,48
Jarak titik berat DAS ke *outlet*	Lc	Km	0,50 – 29,386
Kemiringan sungai utama	S	-	0,00040 – 0,12700
Koefisien kekasaran DAS	N	-	0,035 – 0,070
Bobot Luas hutan	Af	%	0,00 - 100

Source : HSS Limantara, 2009

To estimate the peak flood time (Tp) can be used a formula such as Nakayasu.

3. Research Methodology

In general, the methodology stages carried out in this research are : preparation phase, processing stage and data analysis then comparison of the calculation of Synthetic Unit Hydrograph and Hydrograph Unit measured.

4. Analysis And Discussion

4.1 Rainfall data

The rainfall data used in the calculation of rainfall in Way Kandis River Basin is taken from 4 rainfall stations with data length of each station from 1993 to 2016. The rain post used is as follows :

a. Sukaraja III Rain Post (R – 142)
b. Way Galih Rain Post (PH – 035)
c. Sidosari - Natar Rain Post (PH – 034)
d. Negara Ratu - Natar Rain Post (PH – 033)

4.2 Calculation of Rainfall Area

Calculation of rainfall area (Way Kandis watershed) using Thiessen Polygon method with the consideration that the rainfall recorders in the watershed is well spread so that it can get better rainfall area than other methods.

4.3 Rainfall Data Analysis

Before rainfall data is used in hydrological analysis, statistical analysis of rain data is first performed. Statistical analysis used to ensure that the rain data is feasible for further analysis includes :

a.Consistency test, from the analysis results it is known that for the level of significant (confidence level) 95%, then the value of $Q/\sqrt{n}$ critical = 0.767 and $R/\sqrt{n}$ critical = 0.886. Based on those preceding values where $Q/\sqrt{n}$critica l> $Q/\sqrt{n}$count and $R/\sqrt{n}$critical > $R/\sqrt{n}$count. From this result shows rainfall data used on rain stations in Way Kandis watershed consistent.

b. Outlier test, from result of analysis known value XH = 250,579 and XL = 10,880. For data outside the range will be immediately discarded.

Table 2. Maximum Rainfall Data

No	Year	Maximum Rain (mm)
1	2016	55,35
2	2015	29,29
3	2014	29,16
4	2013	62,35
5	2010	29,89
6	2009	26,62
7	2006	71,12

8	2005	35,12
9	2004	32,18
10	2003	34,69
11	2002	57,53
12	2001	61,81
13	2000	49,56
14	1999	44,56
15	1998	49,81
16	1997	44,56
17	1996	33,41
18	1995	71,24
19	1994	52,87
20	1993	46,79

4.4 Design Rainfall

The method commonly used for the calculation of rainfall design is Method E.J. Gumbel and Log Pearson Type III. To determine which method is appropriate, it is necessary to test the selection of frequency distribution.

Table 3. Determination of Distribution Types

No	Distribu-tion	Terms	Calculation results	
1	Gumbel	Cs ≈ 1.1396 Ck ≈ 5.4002	Cs = Ck =	1,766 3,953
2	Log Pearson III	no limits	Cs = Ck =	-0,045 2,094

Source: Calculation results

4.5 Reduction Factor

After obtaining the results of appropriate rainfall calculations using Log Pearson Type III distribution then before being used to calculate the flood discharge design should be multiplied by the reduction factor of the watershed area. From the calculation results obtained FR = 0.825 so Rain Design on each return period multiplied by the reduction factor.

Table 4. Rain Data Design used

No.	Return Period	Design Rain	Design Rain after multiplied by FR
	(year)	(mm)	(mm)
1	2	43,900	36,240
2	5	56,933	46,998
3	10	65,625	54,174
4	20	74,088	61,160
5	25	75,907	62,661
6	50	83,332	68,791
7	100	90,561	74,758

Source: Calculation results

4.6 Frequency Distribution Test

To test whether the selected distribution type matches the existing data, a distribution conformity test is performed. This test is done horizontally with Smirnov Kolmogorov method and vertically with Chi Square method. From Smirnov Kolmogorov test obtained

Dmaks = -0,0406 smaller than Dcritic = 0.2810. While from Chi Square test obtained c2 count = 4.05 smaller than c2α = 5.991 so that the type of distribution received.

4.7 Hours of Time Rainfall Distribution

Because in the vicinity of Way Kandis watershed there is no ARR, then calculation of rain distribution pattern using Mononobe formula.

$$I_t = \frac{Rt}{24}\left(\frac{24}{t}\right)^{2/3} \quad \text{.................................} \quad (18)$$

Table 5. Percentage of Rain Intensity

t (hour)	Rt	Percentage
1	0,5503	55,03%
2	0,1430	14,30%
3	0,1003	10,03%
4	0,0799	7,99%
5	0,0675	6,75%
6	0,0590	5,90%

Source: Calculation results

4.7 Runoff Coefficient

The runoff coefficient is the variable for determining the amount of surface runoff where the determination is based on the condition of the river basin and the rainfall characteristics that fall in the area. From the calculation results obtained by the average runoff coefficient for Way Kandis watershed is 0.653 so the calculation of the hour-time rain ratio is as follows :

Table 6. Effective Rain

Return Period (year)	Design Rain (mm)	Runoff Coeffisient	Effective Rain (mm)
2	36,240	0,653	23,669
5	46,998	0,653	30,696
10	54,174	0,653	35,383
20	61,160	0,653	39,945
25	62,661	0,653	40,926
50	68,791	0,653	44,930
100	74,758	0,653	48,827

Source: Calculation results

4.8 Snyder Method HSS

The parameters of the Watershed area from the analysis of topographic maps were obtained: A = 430 km2; L = 60 km; Lc = 25 km; Ct = 1.40; Cp = 0.65; n = 0.20. The results obtained :

Qp = 12,80 m3/s/mm

Tp = 6,57 hours

Table 7. Flood Debit Design of HSS Snyder

Return Period (year)	Flood Debit Design (m^3/s)
2	296,09
5	383,98
10	442,61
20	499,69
25	511,96
50	562,04
100	610,79

Source: Calculation results

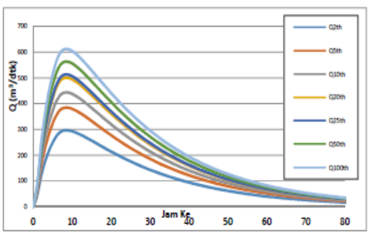

Figure 2. HSS Snyder's flood debit design hydrograph with various return periods

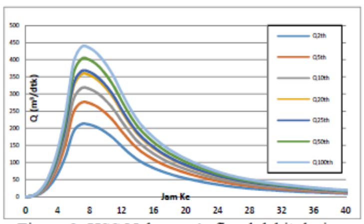

Figure 3. HSS Nakayasu's flood debit design hydrograph with various return periods

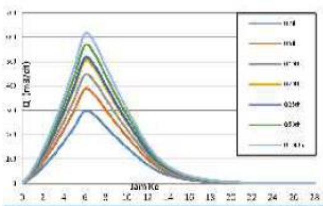

Figure 4. HSS Limantara's flood debit design hydrograph with various return periods

4.9 Nakayasu Method HSS

The parameters of the Watershed area from the analysis of topographic maps were obtained : A = 430 km2; L = 60 km. The results obtained :

Qp = 12,41 m3/dtk/mm

Tp = 6,21 jam

Table 8. Flood Debit Design of HSS Nakayasu

Return Period (year)	Flood Debit Design (m^3/s)
2	212,03
5	274,98
10	316,97
20	357,84
25	366,63
50	402,49
100	437,40

Source: Calculation results

4.10 Limantara Method HSS

The parameters of the Watershed area from the analysis of topographic maps were obtained : A = 430 km2; L = 60 km; Lc = 25 km; S =0,009; n (manning) = 0,035. The results obtained :

Qp = 16,43 m3/dtk/mm

Tp = 6,21 jam

Table 9. Flood Debit Design of HSS Limantara

Return Period (year)	Flood Debit Design (m^3/s)
2	298,34
5	386,91
10	445,99
20	503,50
25	515,86
50	566,32
100	615,44

Source: Calculation results

4.11 Comparison of 3 Flood Debit Methods

Highest Peak Debit (Qp) on the Limantara Method: 615.44 m3/s and the lowest peak (Qp) of the Nakayasu Method: 437.40 m3/s. Time to reach the longest Peak Debit (Tp) on Snyder Method : 8 hours and Time to reach the fastest Peak Debit (Tp) on the Limantara Method : 6 hours The total time from start of flood to low tide (Tb) is fastest on Limantara method = 24 hours. While the longest method of Snyder = 120 hours.

5. Conclusions And Recommendations

5.1 Conclusions

1. From several rain stations scattered around the Way Kandis River Basin, the authors use 4 rain posts because according to the calculation of Thiesson Polygon the four rain posts that have significant area calculation results especially PH-034 located in the middle of the watershed has the largest area with a weight of 36%.
2. Of the three Synthetic Unit Hydrographs (HSS) calculated, the largest HSS peak debit (Qp) is the Limantara method with Qp = 16.34 m3/s/mm. While the method of Snyder and Nakayasu method the result is almost equal to the difference not up to 1 m3/s/mm, Snyder method Qp = 12.80 m3/s/mm and Nakayasu method Qp = 12.41 m3/s/mm.
3. The peak debit (Qp) result on the highest return period 100 year (Q100) in the Limantara Q100 method = 615,44 m3/s. HSS with the difference not to 5 m3/s through Snyder Q100 = 610,79 m3/s method. Lowest Method Nakayasu Q100: 437,40 m3/s.
4. Time to reach the longest peak debit (Tp) on Snyder method = 8 hours with 1 hour difference in each method. Nakayasu Method = 7 hours and Limantara Method = 6 hours.

5. The total time from start of flood to low tide (Tb) is fastest on Limantara method = 24 hours. While the longest method of Snyder = 120 hours. Nakayasu method among others with Tb = 48 hours.

6. Recommendations

1. HSS using the Limantara method produces the largest Peak Debit (Qp). The difference is above 20% with the other two methods. This is probably due to the suitable Limantara method used for small to medium sized watershed that is below 500 km2. We recommend choosing another method if you want to plan simple water buildings to be cost efficient.
2. Highest Q100 is also on Limantara method but only difference of less than 1% with Snyder method. It is advisable to choose one of these two methods should have a strong technical justification for the costs incurred in accordance with the risk of danger to be borne.
3. Limantara method is suitable for the design of Early Warning System (EWS) if at any time on Way Kandis River will be installed the device. This is because of the time to reach the fastest peak (Tp) between the two other methods.
4. Snyder method is suitable for use in this river if the down time (Tr) becomes the most dominant factor in the calculation due to the total Time Base (Tb) up to 5 days.
5. Of the three methods of HSS, it is not yet possible to estimate which method approaches the flood hydrograph in the Way Kandis River Basin because

there is no data for calibration. Therefore, further research is needed to obtain measurable debit data on Way Kandis River to calibrate the HSS charts of the three HSS analyzed methods that approximate the measured hydrograph graph of measurement units on the Way Kandis River.

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