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An Analysis of the Influence of Variability Rainfall on Flow Rate Based on the Watershed Characteristics

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Abstract. Flood is one of natural phenomena that often occurs during the rainy season. In general, flooding occurs due to the inability of the river to accommodate the discharge that enters into it. The rain that descends in a watershed will turn into a stream. Thus, there is a relationship between rainfall and flow rate (discharge), which depends on the geometric conditions of watershed. The aim of this research is to determine the amount of discharge that outflow from the watershed due to the rain that descends in the area. The process of transformation rainfall into discharge is done by using Nakayasu synthetic unit hydrograph method. Derivation of this method is done by using different rainfall input i.e. single station and rainfall watershed. The results unit hydrographs are then used for design flood calculation in river.

1. Introduction
Flood is a natural phenomena that often occurs during the rainy season. In general, flooding occurs due to the inability of the river to accommodate the discharge that enters into it. The river's ability to accommodate discharge is called the river capacity. The magnitude of the river capacity is determined by the area of the wet cross section and the flow velocity. While the flow velocity depends on the basic slope of the river, the roughness of the river body, and the hydraulic radius. In short, the river capacity depends on the shape of the river geometry. The rain that descends in a watershed will caus the river discharge to increase. If the discharge coming into the river exceeds the river capacity, there will be overflow from the river.the overflow of this river is one of the causes of flooding in a region. The relationship between rainfall and discharge, which depends on the geometry of the watershed, is interesting to study especially assoiated the amount of discharge that outflow from watershed.

Research on the transformation of rainfall into discharge and its methods has been done by several researcher, among them, Sihotang, et al. (2011) conducted a study to calculate the design flood discharge at Gintung Dam using synthetic unit hydrograph of Nakayasu method with rainfall as its input. The calculation results show that the maximum discharge that enters the dam due to rain for return period 100 years is 224,401 m^3/s. Hasibuan, S.H. (2012) conducted a study to analyze flood design discharge at Bonai River, Kunto Darussalam Residence, Rokan Hulu District. Method was used to analyze is synthetic unit hydrograph of Nakayasu by rainfall in Pasar Kampar Station at year 2000 to 2009. The result of the research prove that flood design discharge at Bonai River for return period 0 years is 286,75 m^3/s. Suhariyanto, S (2014) analyzes the flow discharge occurring as a due to of falling rainfall in the Kali Sampean river basin using synthetic unit hydrograph of Nakayasu. The results showed that the rainfall that caused floods in river Kali Sampean in 2002 and 2008, is a rainfall with return period 100 years and produce flow discharge of 1.833,594 m^3/s.

Different from Sihotang, et al. in this study, rainfall data has been obtained from the rainstation for transformed into a discharge without having to select that the maximum rainfall data. The transformation process of rainfall into discharge will be done by using Nakayasu synthetic unit hydrograph. In Indonesia especially in Java Island this method is often used for discharge analysis. This is because the number and distribution of rainfall observation station is still lacking. The expected result of this research is to know the amount of discharge out of the watershed outlet due to input variation.

2. Theorical basic

In planning in the field of water resources, it is often necessary that the flood discharge data plan realistic. Flood plans with certain repeat periods can be calculated and flooding data or rainfall data. If flood discharge data is available long enough (more than 20 years), the flood discharge can be directly calculated with method of probability analysis. Medium if the data available only in the form of rain data and watershed characteristics , one of the recommended methods is calculating flood discharge from the maximum daily rainfall data plan with the superposition of unit hydrograph.

2.1. Watershed Characteristisc

Watershed or drainage basin is an area on the surface of the earth in which there is a drainage system consisting of one main stream and some of his tributaries, which function as a catchment area and steam water through one outlet. Several characteristics of watersheds that are important to examine as follows.

Drainge area. The drainage area is the most important watershed characteristic in watershed modelling. The drainage area reflect the volume of water that can result from falling rainfall in the area. Uniform or uniform rainfall for the entire drainage area is a common assumption in hydrological modelling.

Watershed length. The length of watershed is usually defines as the distance measured along the main river from the outlet to the watershed. The river usually will not reach the watershed limit, so it needs to be drawn the extension line starting from the edge of the river the the watershed limit by taking into account the flow drawn. Although the drainage are and the length of watershed are the size of the watershed but they reflect different aspects of the size. The drainage area is used as an indication of the potential for rain to produce a certain amount of water volume, while the length of the watershed is usually used in the calculation of the travel time required by water to flow within the watershed.

Watershed slope. Flood is a quantity that reflects the momentum of runoff and slope is an important factor in the momentum. The slope of the watershed reflects the rate of change of elevation within a certain distance along the main flow direction. The slope is measured by the elevation difference between the two main river ends divided by the length of the watershed. Different elevations do not always be or reflect the maximum elevation difference in the watershed. The highest elevation is usually located along the watershed and the edge of the river or main stream generally reach the watershed.

2.2. Unit Hydrograph (UH)

The flow hydrograph represents a time distributionof the flow (in this case the discharge) in the river in a watershed at a given location. A river flow hydrograph is an essential part of any water resources field. There is a close relationship between the hydrograph with the characteristic of a watershed, where the the flood hydrograph can show the watershed response to the rain input.

The unit hydrograph is direct runoff hydrograph produced by effective rainfall that occurs evenly across the watershed and with fixed intensity for a set time unit, that called the unit rain. The unit rain is a long rainfall such that the duration of runoff does not become short even though the rainfall becomes short. Thus 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). The runoff period from the unit rain ia all about the same and has nothing to do with the intensity of the rain.

The concept of unit hydrograph is based on linear systems theory and follow the principles of superposition and proportionality. For example, if one inch of excess rainfall produces a direct runoff peak of 100 cfs then two inch of excess rainfall with produce a direct runoff of 2 x 100 =200 cfs. Similarly if one inch of rainfall is followed by two inch of rainfall, the hydrographs from both rainfall pulses are simply added after accounting for the necessary time lag. The following figure demonstrates this concept.
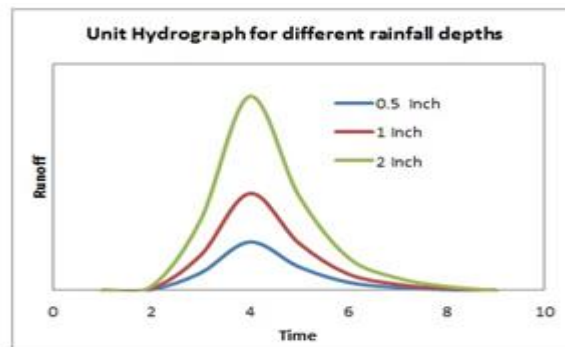

Figure 1. Unit hydrograph for different rainfall depth

Assuming that the watershed response to rain is linear, it is less price. Nevertheless, the use of unit hydrograph has yielded many satisfactory results for various condition. Thus, the theory of unit hydrograph is widely used in determining discharge or flood plans.

2.3. Synthetic Unit Hydrograph of Nakayasu
As indicate earlier, an effective collection of effective rainfall observation and direct runoff is required to derivation the unit hydrograph. Thus, the resultant of the unit hydrograph is specific to a particular watershed that determined by the point in the stream where the direct runoff observation is performed. If no direct observation is available, if no a unit hydrograph for another location at a stream in the same watershed or for a nearby catchment with similar charactristics is required, a synthetic unit hydrograph procedureshall be used.
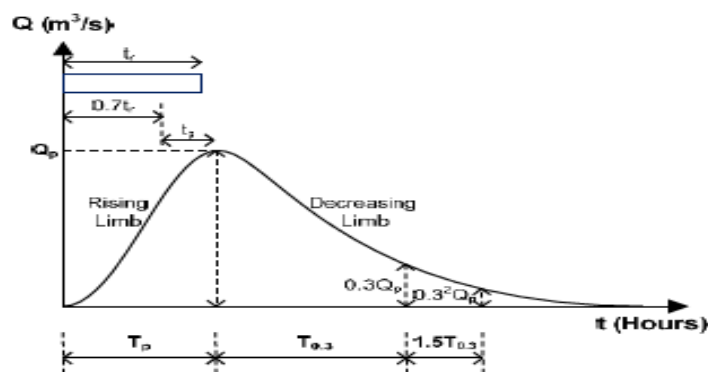
Figure 2. Scheme of Synthetic Unit Hydrograph of Nakayasu

Nakayasu has provided a synthetic unit hydrograph based on his research in Japan, as shown in Fig. 2. There are four variables have to be obtained, i.e. time lag (T_p), peak discharge (Q_p), rising limb curve (Q_a), and decreasing limb curve (Q_d). each variable will be explained as follows : time lag is the function of the time of concentration (t_g) and the duration of the effective rainfall (t_r). the equation of time lag is follows

$$T_p = t_g + 0.8\,t \tag{1}$$

Peak discharge is determined by some factors such as watershed area (*A*), watershed characteristic coefficient (*C*), unit rainfall (*R$_o$*), time lag, and time required to discharge reduction up to 30% peak discharge (*T$_{0.3}$*). The relationship among the variables is shown as follows

$$Q_p = \frac{C.A.R_0}{3.6\left(0.3T_p + T_{0.3}\right)} \tag{2}$$

The rising limb curve is the function of time lag, peak discharge, and time. The function of Q_a is expressed as follows

$$Q_a = Q_p \left(\frac{t}{T_p}\right)^{2.4} \tag{3}$$

The decreasing limb curve is influenced by time lag, peak discharge, and time required to discharge reduction up to 30% of the peak discharge. Its function is follows

$$Q_d = Q_p(0.3)^{\frac{(t-T_p)}{T_{0.3}}} \qquad , Q_d > 0.3 Q_p \tag{4}$$

$$Q_d = Q_p(0.3)^{\frac{(t-T_p)+0.5T_{0.3}}{1.5T_{0.3}}} \qquad , 0.3Q_p > Q_d > 0.3^2 Q_p \tag{5}$$

$$Q_d = Q_p(0.3)^{\frac{(t-T_p)+1.5T_{0.3}}{2T_{0.3}}} \qquad , 0.3^2 Q_p > Q_d \tag{6}$$

3. Methodology

The synthetic unit hydrograph parameter values can be analysed with various supporting data. The coefficient of surface flow depends on the data of land use, the area of the watershed, the length of the river flow is analysed from the topographic map. After the unit hydrograph can be calculated, the analysed the flow discharge data by using the proposed proposition of hydrograph is a constan base width argument, linearity proposition, and superposition proposition. For hydrograph analysis required is data in the form annual rain.

In general, available rainfall data in the form of daily rainfall data. In order to be used in the formula Nakayasu synthetic unit hydrograph, then the daily rainfall data needs to be converted into hour time rainfall data. In order to obtain carefulresults, the rain stations used to analyse the rain data are selected stations that are in the watershed and that is spreaded evenly. The rain data used is the rainfall data for the last 10 years. Of available daily rain data, one daily rainfall data is selected. Thus, within one year there will be 12 daily rainfall data.

The next step is to test consistency, calculate the everage rainfall by arithmetic method or Thiessen polygon. Then, see the appropriate distribution model, whether the data follows the normal distribution, log normal, log Piersen III, or Gumbel. After finding the appropriate distribution model, then calculated the rainfall design for certain return period. To convert daily data into hourly rainfall is used Mononobe method. Whereas Mononobe equation is as follows

$$I = \frac{R_{24}}{24}\left[\frac{24}{t_c}\right]^{2/3} \tag{7}$$

where *I* is rainfall intensity, *R$_{24}$* is daily rainfall, and *t$_c$* is time concentration or rain duration.

4. Results

The watershed data used in this research is secondary data [3]. The data is the result of measurement and recording obtained from various related agencies. Existing data include 1:50.000 scale topographic map, and data of discharge measurement, rainfall data,from six watershed in South Sulawesi. Based on data collected conducted data selection for further analysis and from topography map determined parameters of each watershed. From the topography map, the parameters of the watershed are determined as followed, after the unit hydrograph has been obtained, adjusted the unit hydrograph volume so that the value is equal to the runoff height of 1 milimeter on entire the watershed. The result obtained is a unit hydrograph representing each watershed as presented in Fig. 3

for the Jenalata watershed, whereas the parameters of the hydrograph forming for each watershed is presented in Table 1.

Table 1. Parameters of watersheds

No	Watershed Parameters	Names of Watershed					
		Jenelata	Noling	Kalaena	Maros	Walanae	Maloso
1.	Watershed Area (A)	227.6	595.5	933.3	274.2	2354	1476
2.	Watershed Area Upstream	117.13	297.7	422.27	135.79	1233.28	581.00
3.	River Slope	0.0227	0.00072	0.00194	0.00289	0.00068	0.00158
4.	River Length Main (L)	36.6	68.3	74.875	38	175	106
5.	Time rises hydrogrph (T_r)	2.45	2.68	3.05	2.28	24.07	3.82
6.	Peak Discharge (Q_p)	9.24	23.45	33.20	12.22	32.83	44.90
7.	Base time Hydrograph (T_b)	23.82	32.63	29.69	27.84	45.56	29.88

Based on the recorded discharge data obtained from each selected flood case and then sought the unit hydrograph with the steps as described previously. Of each flood case after its unit hydrograph is obtained, then averaged to obtain the measured unit hydrograph of each watershed reviewed as presented in Table 2.

Table 2. The main parameters of measured unit hydrograph

No	Watershed Names	Year of data recording until 1985			Year of data recording until 1999		
		Q_p	T_p	T_b	Q_p	T_p	T_b
1.	Jenelata	10.93	2.00	19.00	8.75	2.22	25.11
2.	Noling	32.77	2.22	22.85	30.75	2.00	22.58
3.	Kalaena	38.73	3.75	23.75	45.59	1.50	17.50
4.	Maros	13.31	3.57	25.86	-	-	-
5.	Walanae	-	-	-	-	-	-
6.	Maloso	-	-	-	54.86	3.60	23.20

When considered the performance of measure unit hydrograph compared to the Nakayasu synthetic unit hydrograph show a relatively large deviation, see Table 3.

Table 3. Value of measured unit hydrograph parameter and Nakayasu and its deviation

Parameters of hydrograph		Names of Watershed					
		Jenelata	Noling	Kalaena	Maros	Walanae	Maloso
Peak Discharge	measurable Nakayasu	10.93 10.1	32.77 15.29	38.73 22.04	13.31 11.79	- 24.99	- 25.25
	Deviation (%)	-7.59	-53.22	43.09	-11.42	-	-
Peak Time	measurable Nakayasu	2.00 1.89	2.22 3.27	3.75 3.55	2.57 1.95	- 7.91	- 4.91
	Deviation (%)	-5.5	47.29	-5.3	24.12	-	-

Thus, in order to for Nakayasu synthethic unit hydrograph usage to be optimized in South Sulawesi, the factors causing deviation on flood peak discharge are examined more closely. By not ignoring the deviations in the use of Nakayasu synthetic unit hydrograph, the use of the method of analysis with this model is considered very advantangeous to be applied by adjusting the parameters of forming

peak discharge, so the use of this model by itself will reduce the difficulty of determining the discharge, especially in rivers that have not available discharge pauge at the control point.
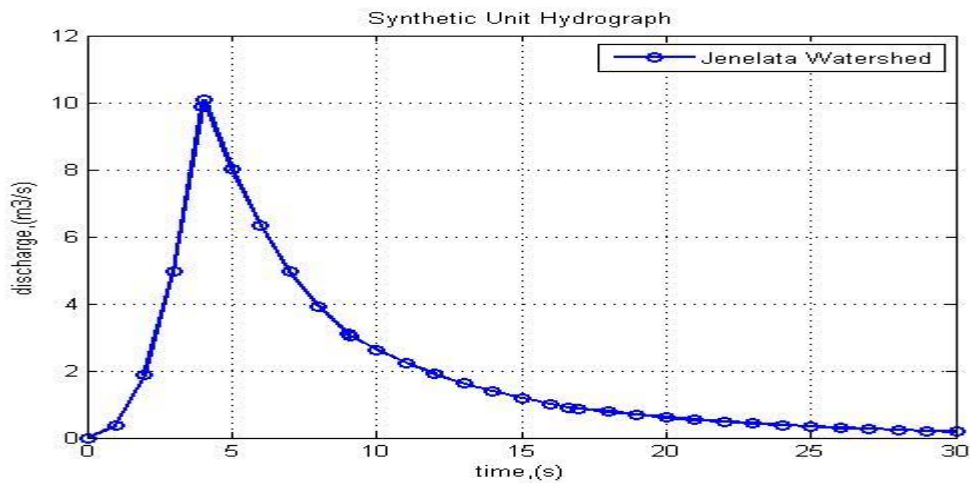

Figure 3. Nakayasu synthetic unit hydrograph of Jenelata Watershed

5. Resumes
The results obtained based on data analysis before 1985 compared with last year's data analysis result showed a small significant difference during that period the watershed did not change significantly. The most sensitive watershed physical factor to the hydrograph peak is the area of the watershed, while the length of the main river is very sensitive to the peak time. Of several watershed in South Sulawesi tested with Nakayasu, the results show considerable deviations to measurable hydrograph for each watershed observed, especially at their peak discharge values due to the uneven distribution of rainfall stations in each watershed.

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