IDF (intensity-duration-frequency) curve and unit hydrograph as signature of characteristic changing of Way Kuala Garuntang Watershed

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Abstract. There is direct relation between global warming and precipitation. Air capacity of water increase by 7% to increasing of 1°C of air temperature, causing more water vapor content in the air. This research aims to investigate how IDF Curve and Unit Hydrograph can be used as signature of characteristic changing of Way Kuala Garuntang Watershed. The study area is Way Kuala Garuntang watershed and rainfall data source is from automatic rainfall recorder of Stasiun BMKG Maritim Panjang, ARR Tipping bucket installed at Way Kuala Garuntang watershed, and 4 manual raingauges. From the research can be concluded that IDF Curve can be used as signature of characteristic changing of Way Kuala Garuntang watershed mainly the changing of rainfall intensity in various of return period. Meanwhile, due to average of IUH of 5 flood events in 1 year data serie, and significant differences of Qp between IUH and SUH, the Unit Hydrograph was not suitable as signature of characteristic changing of Way Kuala Garuntang watershed.

Introduction

There is a direct effect of global warming on precipitation [1], [2]. Rising temperatures will result in greater evaporation and the earth's surface will be drier, in such a way that it will result in increased intensity and duration of drought [3], [4]. Nevertheless, the capacity of water in the air increases by about 7% every temperature increase of 1°C, so there will be more moisture in the atmosphere. Therefore, storm events, extreme rain, blizzards, and tropical cyclones will increase in intensity. This will result in flooding with greater peak discharge and more frequently [5], [6]. From the wind change model, the rain pattern does not change much but will result in dry areas getting drier, and wet areas wetter. This pattern is the result of a model simulation and will be passed on in the future. In tropical and subtropical areas precipitation patterns are dominated by changes in sea water temperature, with El Nino as a good example [7].

Changes in the land use of Way Betung watershed (1991-2006) led to an increase in maximum daily discharge (Q_{max}) and lowered the minimum daily discharge (Q_{min}), raised river discharge fluctuations, and increased the annual flow coefficient. The best management of integrated water resources in Way Betung watershed is to increase the forest area by up to 30%. This lowers land erosion to the permitted level and decreases monthly run off fluctuations [8]. Way Betung watershed is geographically located very close to Way Kuala Garuntang watershed. Thus there will be hydrologic similarity in both watersheds.

Urban floods, flash floods, rob floods, land erosion, sedimentation in river estuaries and reduced river capacity are examples of problems with water-damaged power control. Flooding that occurs in watersheds flowing in Bandar Lampung city is one example of problems in watershed management. Urban flooding is caused by a combination of rain characteristics (high intensity, long duration, and large frequency, inter-storm period or time between two rain events, within storm pattern or pattern/variability of one rain event, season) and characteristics of river flow area (change in land use, damage to drainage system and reduction of river capacity) [9].

According to Bakri, et.al, accumulation of greenhouse gas mainly CO_2, CF_4, CH_4, and NO_2, that it was from anthropogenic activity since Industrial Revolution 1.0, causing damage of Ozon layer of stratosfer environment [10]. As an example of watershed characteristic, The Upper Sekampung Watersheds were dominated by class and subclass land capability of III-l2 about 17,630.51 ha (41.58%). All of the constrain for each land capability in this area is erosion hazard, especially land slope. From this research, cultivated land to coffee base crops were allowed in land capability II-l1. e1, III-l2, IV-l3, and VI-l4, with in adequate soil and water conservation practices. In contrary, the land capability of VII-l5 unsuitable for agriculture, they should be a nature or for conservation forest [11], [12], [13].

Observation and modeling of global temperature changes, 7% increase in water content per 1^0C increase in temperature, flood event in Bandar Lampung City, availability of rain and discharge data, and easier and more accurate to perform geospatial analysis, is a background of IDF Curve (Intensity-Duration-Frequency) research and Unit Hydrograph as a signature of characteristic changing of Way Kuala Garuntang watershed.

The objectives of this study include: 1. To get various I values (rainfall intensity) at various D (duration of rainfall), frequency (F) and for various data series lengths used in creating the IDF Curve; 2. To develop instantaneous unit hydrographs (IUH) and Synthetic Unit Hydrographs (SUH) in Way Kuala Garuntang watershed; 3. To analyse the IDF Curve and Unit Hydrographs as signature of characteristic changing of Way Kuala Garuntang watershed.

2. Research Methods

2.1. The research location
The research location is Way Kuala Garuntang watershed and surrounding areas.

2.2. Data Used
The data that is used in this study includes:
1. Rainfall data collected from automatic and manual raingauges;
2. IDF curve that is created from 12 years data series;
3. Daily rainfall data for 20 years data series (1991-2010);
4. Delineation of watershed in Bandar Lampung based on CITRA DEMNAS from Geospatial Information Agency downloaded in October 2020. This DEMNAS image has a resolution accuracy of 8 meters, compared to previous versions that have a resolution precision of 30 meters.

2.3. Procedure

2.3.1. IDF curve creation. A signature of characteristic changing of Way Kuala Garuntang watershed is done by comparing the intensity of rainfall for various years of the data series, at a certain duration and return period. As an overview, the duration selected for the peak discharge determination application is the same time as Tc (Time of Concentration) which is the time required by water from the furthest watershed point to the control point. The same duration of rain as this Tc is the duration that will cause the maximum discharge to flow at the control point. IDF curve creation can be done with the following procedures [14].

a) set a specific rain duration, in the study used 5, 10, 15, 30, 45, 60, 120, 360, and 720 minutes;

b) select the maximum rainfall at various durations;
c) the maximum rain depth is selected for each recording year, in such a way that there is a certain amount of data representing the entire recording year. In the data from an empty automatic rain station, the data filling is done from the manual rain station. Daily rainfall data is converted into rainfall data for various durations with Mononobe formula;
d) the depth of rainfall obtained can be converted to rainfall intensity by using a relationship of I = 60 p/t, with p is the depth of the rainfall and t is the duration;
e) calculate extreme *I* for various return period that in this study were used 2,5,10, 25, 50 and 100 years using frequency analysis method;
f) create a curve that states the relationship between the rainfall intensity and the duration of the rainfall for various return period, resulting in an IDF curve.

2.3.2. The developing of Unit Hydrograph. A signature of the change in watershed characteristics especially the response of watersheds to inputs in the form of rain that will provide an output in the form of discharge, carried out by a tool of unit hydrograph at a control point, in various flood events recorded. To obtain a measurable unit hydrograph in case of flooding, required data includes [15]:
a) AWLR Recording (Automatic Water Level Recorder). To obtain the AWLR recording it is necessary to install a water level recorder measuring instrument in the river that is reviewed.
b) Discharge measurement is done by measuring flow velocity for various water level. The measurement can be done with buoys or current meters. Rating curve should be established.
c) Daily rainfall data from manual rainfall station is used as a rainfall data comparison and filler for empty ARR data.
d) Numerical analysis to derivation of UH from measurable flood hydrographs was conducted with the Collins Method.

3. Results and Discussions
The discussion consist of: 1. Geospatial analysis; 2. IDF curve analysis, and 3. Instantaneous unit hydrographs and Synthetic Unit Hydrographs (SUH Gama I, Nakayasu and Snyder). Each of the above analysis activities is described in detail in the subcases below.

3.1. Geospatial Analysis

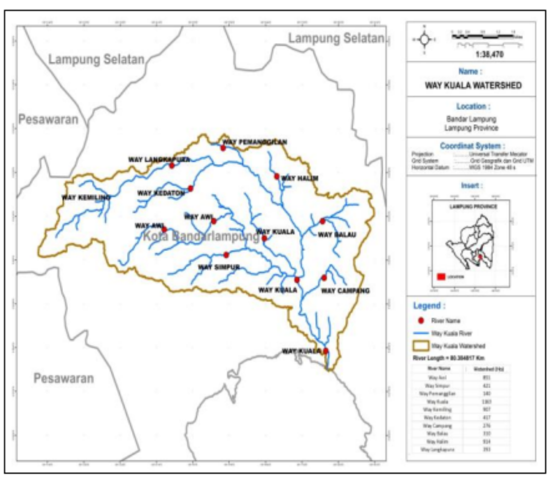

Figure 1. Delineation of Way Kuala Garuntang Watershed

The delineation of Way Kuala Garuntang watershed obtained from DEMNAS (Digital Elevation Model Nasional) imagery issued by Geospatial Information Agency, downloaded in October 2020

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which has a resolution precision of 8 meters. Delineation and river network as seen in Figure 1. Way Kuala Garuntang watershed has 10 tributaries. The area of Way Kuala Garuntang watershed is 58.76 km^2 or 5,876 ha. In the delineation of each tributary watershed obtained a total area or 5,792 ha or 57.92 km^2. The difference in the area is due to inaccuracies in the making of polygons to form watersheds in the delineation procedure.

3.2. Analysis of Design Rainfall

The design rainfall was analysed using frequency analysis. There are four manual raingauge stations whose data will be used to determine the average rainfall of Way Kuala Garuntang watershed.

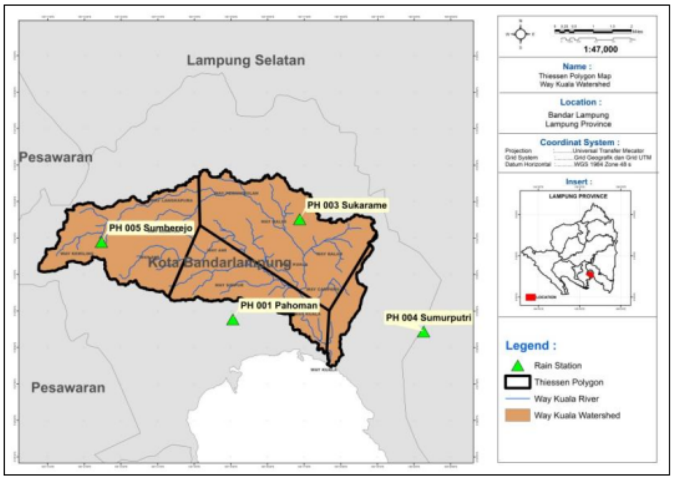

Figure 2. Area that is influenced by rainfall station using thiessen polygon method

Table 1. Average Annual Watershed Maximum Rain fall

Year	Maximum Rainfall (mm)	Year	Maximum Rainfall (mm)
1991	79	2001	64
1992	66	2002	68
1993	95	2003	71
1994	72	2004	75
1995	97	2005	72
1996	71	2006	82
1997	58	2007	44
1998	40	2008	94
1999	70	2009	73
2000	31	2010	77

Table 2. Rainfall redesigned at various return period

Return period (years)	2	5	10	25	50	200	200
Rainfall (mm)	69	80	81	85	87	90	92

3.3.IDF Curve Analysis

Table 3. Rainfall intensity for various durations and return period

No	t	Intensity (mm/hour), Return Period					
	(minute)	2	5	10	25	50	100
1	5	196	225	240	255	264	272
2	10	128	151	163	176	185	193
3	15	100	119	130	142	150	158
4	30	65	80	88	98	105	112
5	45	51	63	70	79	85	91
6	60	43	54	60	68	74	79
7	120	28	36	41	47	52	56
8	180	22	28	33	38	42	46
9	360	14	19	22	26	29	32
10	720	9	13	15	18	21	23

From the results presented in Table 3 can be stated that the IDF Curve can be used as signature of the change in characteristics of Way Kuala Garuntang Watershed. The amount of rainfall intensity rises significantly from low return period to high return period. This increase in rainfall intensity applies to all durations, ranging from the duration of 5 to 360 minutes used in this study. The increase in the duration of 5 minutes for example, the rainfall intensity on the 2-year return period is 196 $mm.h^{-1}$, and 272 $mm.h^{-1}$ on the 100-year return period, meaning there is an increase in rainfall intensity at this hypothetical time of 38.8%. The increase in rainfall intensity from the 2-year return period to 10 years was 22.5%. In small watersheds, which means Tc is also very short, then the increase in rainfall intensity at this short duration is an increase in the risk of disasters that need to be done mitigation and adaptation to changes in the intensity of this rainfall.

3.4. IDF Curve Analysis

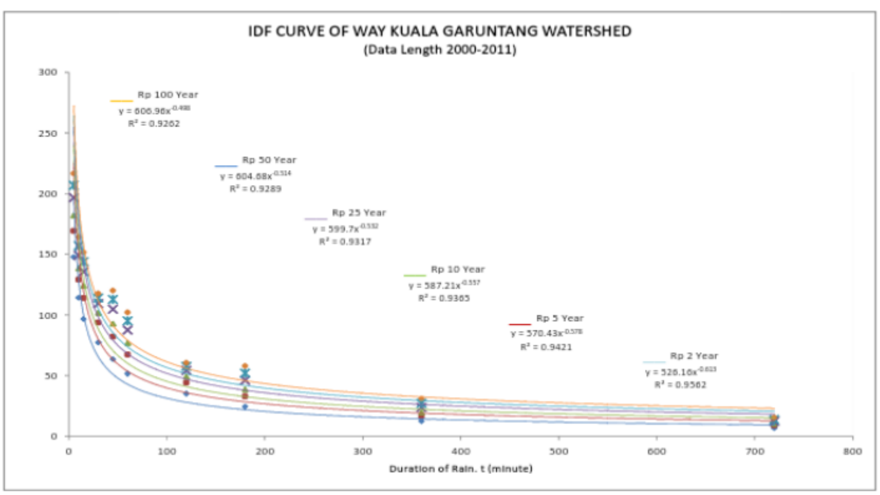

Figure 3. IDF Das Way Kuala Garuntang curve for 12 years data series

By reducing the length of the data series, the IDF Curve is generated for various data series year lengths of 11, 10, 9, to 4 years of data series. Assuming that the longer the year of the data series it will be the better to produce an overview of the change in rainfall intensity, it can be stated that the 12-year data series is the best depiction of the I value. Percentage of errors rainfall intensity results in year-long data series being reduced to rainfall intensity generated by the year's longest data series, can be seen in Figure 4. The shorter the year of the data series then the percentage of errors I to the intensity of rainfall results in the length of the year the maximum data series tends to get bigger. For example, if the used is 4 years of data series, when resetting F is 2 years then the error percentage is 25.1%.

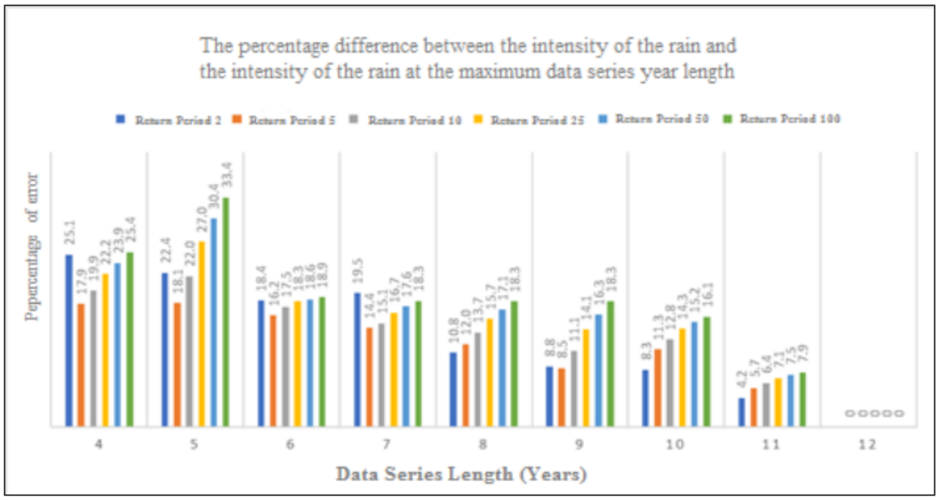

Figure 4. Percentage difference of rainfall intensity to maximum data series year length

The IDF curve is useful for determining the rainfall intensity value that will be used in determining the peak discharge of the design, especially in drainage channels. In a design, the amount of return period depending on the intent and purpose of use, the desired durability and especially the cost of being the main consideration in determining the return period. If rainfall intensity is determined based on the duration value = Tc or concentration time, Intensity will large enough then the dimensions of the building become large. Where D = Tc is the time that causes the possibility that $Q_{maximum}$ will be reached on a drainage channel. In relation to disaster risk management, structural management efforts are not the only scenario that must be implemented.

3.5. Unit Hydrograph

3.5.1. Instantaneous Unit Hydrograph (IUH). IUH are based on measurable data taken at the location specified in The Way Kuala Garuntang Watershed, in the form of discharge data and rain data at the same time and have adequate time steps, which is only possible if done with an automatic raingauge. The discharge data is the result of high calibration of water level and velocity. Although it is a black box model, observed unit hydrograph is able to explain the thorough response (integral response) of watershed to rain input. IUH of Way Kuala Garuntang watershed for almost every time step can be made. For longer time steps will be obtained smaller Qp, and have lower precision. For small to medium watersheds, it is necessary to have shorter *time step*, whereas for very large watersheds that have very long Tc, e.g. Tc up to 2 days, then the time step 1 hour is very adequate. In Figure 15 is IUH for a 10-minute step time for 5 flood events. This 10-minute step time is selected because it corresponds to the time step used at the discharge measurement time step.

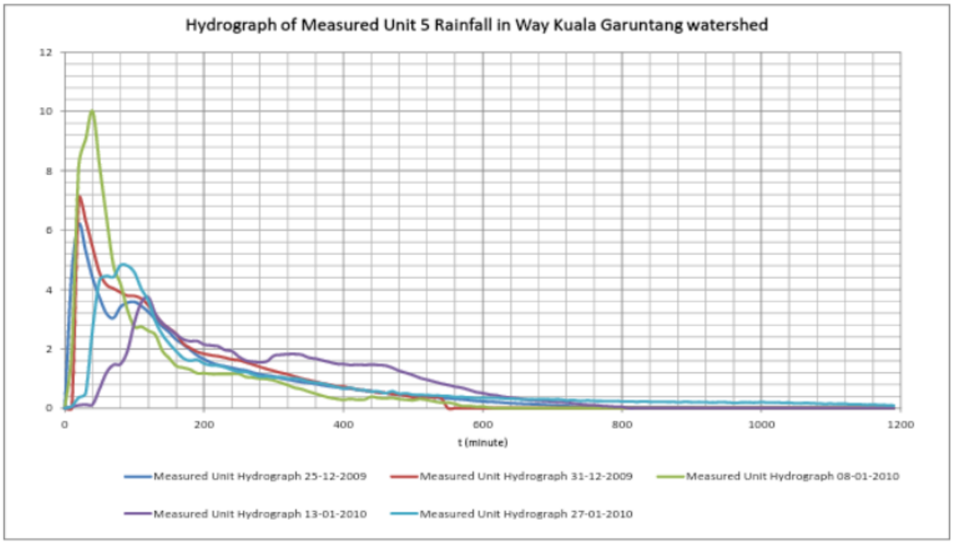

Figure 5. IUH 10 minutes time step of Way Kuala Garuntang watershed on 5 flood events.

Qp of the flood event on January 8, 2010 was the larger compared to 4 Qp of the other flood events. Qp of 10 $m^3.sec^{-1}$ and peak of discharge reached at time of 40 minutes. The rain event on January 8, 2010 was recorded at the manual rainfall station on January 9, 2010 at PH 001 Pahoman, PH 003 Sukarame, PH 004 Sumurputri and PH 005 Sumberejo as follows: 38 mm, 38 mm, 57.89 mm, and 0 mm respectively. IUH on January 8, 2010 was relatively high. As an illustration, if there is effective rainfall of 7 mm and occurs evenly in all watershed then the resulting peak discharge of 70 $m^3.sec^{-1}$.

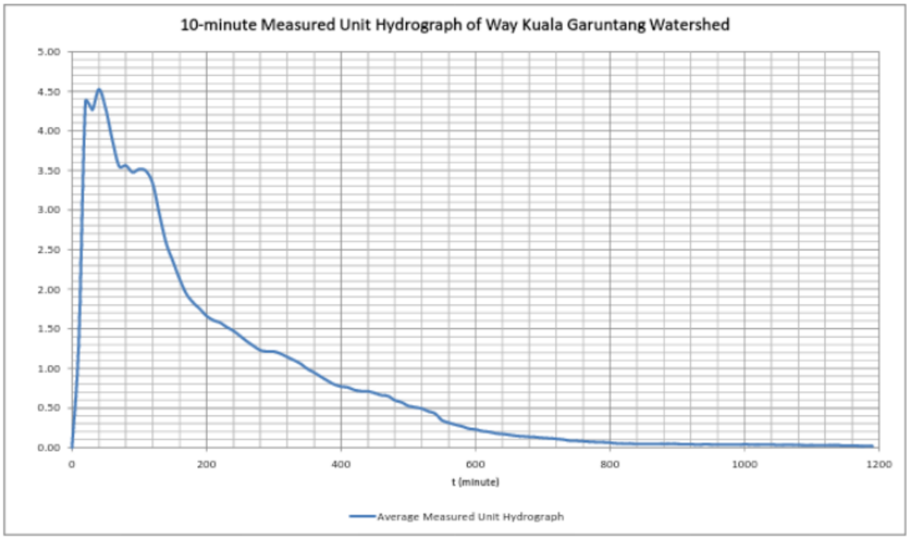

Figure 6. Average IUH for 5 flood events

Figure 6 is the average IUH of the 5 flood events with a 10-minute time step. Qp is obtained at 4.63 $m^3.sec^{-1}$ and occurs on the time leading up to the peak discharge of 40 minutes. The difference in shape, Qp and time to Qp as a result of various factors, among others: uneven rain distribution spatially and temporally, there is rainfall in most watersheds but precisely at the location of the rain station does not occur nor vice versa there is rain that is only centered on the rainfall-making station. In this study, observed unit hydrographs were calculated based on the time period of the minutes: 5, 10, 15, 30, 60, 120, minutes. A smaller time step will result in better measuring. while at a larger time step, the Qp recorded will become smaller. The difference in watershed response shown from the resulting UH difference, caused by several factors, including (1) Land use condition: Way Kuala Garuntang watershed is an urban watershed, so there is a tendency that the time to reach the peak is very fast, or better known as flash floods; (2) Catchment area: basically if all factors including rainfall depth, intensity, duration and frequency of rainfall remain, then runoff will always be the same, and not depending on the area the flow area, so the hydrograph is always comparable to the area of the drain; (3). Topographic conditions in the catchment area relatively gentle watersheds will respond to different inputs with hilly, steep-sloped watersheds.

An average hydrograph formed from several observed unit hydrographs can be considered a representation of a watershed and is a character of the watershed. So if it is known that rain with any amount and time period, then the flood hydrograph can also be calculated. In relation to this, IUH can be used as a tool in compiling an early warning system. But this early warning system has a prerequisite that is the existence of an automatic raingauge that in real time can be monitored. In the future, early warning systems will become cheap along with advances in information technology.

3.5.2. Analysis of IUH and SUH. From Figure 7 of the comparison of the average IUH with SUH Snyder, Nakayasu and Gama I can be seen some similarities and differences from each UH formed. Similarities include the shape, base time and peak time of each UH. While the difference lies in peak discharge and recession time. For SUH Snyder and Nakayasu have more similarities against IUH compared to Gama I.

On the figure 7 it reads that the peak discharge for the IUH at The Way Kuala Garuntang Watershed is 4.53 $m^3.sec^{-1}.mm^{-1}$ while the Gama I, Nakayasu and Snyder Synthetic Unit Hydrographs are 1.95, 2.95 and 3.05 $m^3.sec^{-1}.mm^{-1}$ respectively. From that number it can be estimated that SUH Nakayasu and Snyder are closer to IUH. This is likely due to the characteristic parameters of the watershed used in Gama I which is the result of empirical research for large watersheds flowing to the north coast of Java Island that are not similar with the Way Kuala Garuntang watershed area so that it is produced a very different graph with measurable conditions.

Qp between IUH and SUH has significant differences. This means that there is not an SUH that can be used as a representation of Way Kuala Garuntang watershed. Thus, the availability of measurable data that is only one year of the data series, with 5 flood events, and the absence of the suitability of the SUH mathematical model with IUH, then the Unit Hydrograph has not been able to be used as a signature of the characteristics changing of Way Kuala Garuntang watershed. However, this UH can be used as a character of Way Kuala Garuntang for existing conditions and can be used for other uses such as the preparation of early warning systems.

Table 4. Comparison of IUH and SUH of Way Kuala Garuntang watershed

No	UH	Qp ($m^3.sec^{-1}.mm^{-1}$)	Time to Qp (minutes)
1	IUH	4,52	40
2	SUH Snyder	3,05	60
3	SUH Nakayasu	2,95	120
4	SUH Gama I	1,95	60

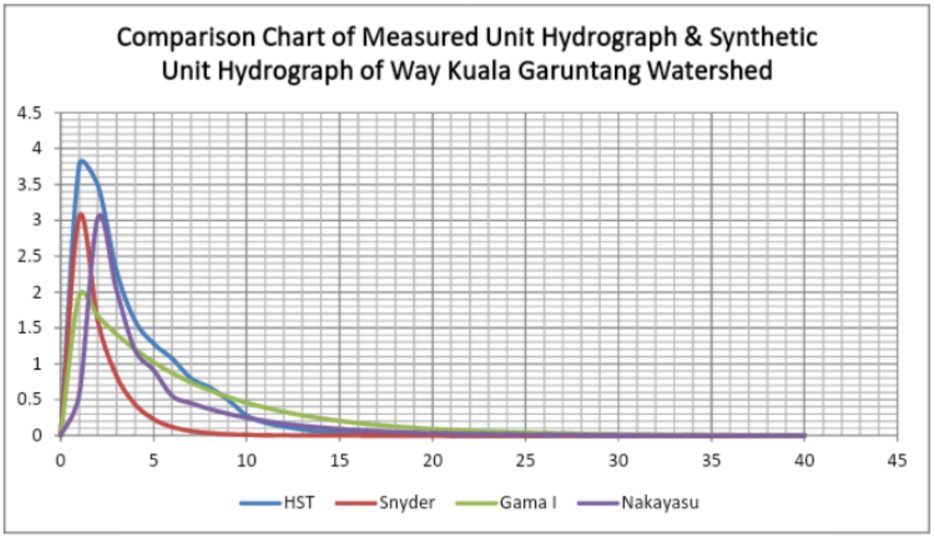

Figure 7. Comparison between IUH and SUH DAS Way Kuala Garuntang

The discrepancy between IUH and SUH is thought to be caused by the following factors:

1. Five flood events in one year of data are not enough to be used in an effort to produce average IUH;
2. SUH Gama I parameters (in north coast Java Island watershed), SUH Nakayasu (in Japan) and SUH Snyder (in North America) are different from Way Kuala Garuntang watershed parameters;
3. As well as a one-year flood event data series is not enough to be used as a sample.

Because the UH produced by IUH and SUH is different, and there is only one year of data series to create IUH, the Unit Hydrograph in Way Kuala Garuntang watershed cannot be used as a signature of characteristic changing of watershed.

4. Conclusion

1. From 12 years of data series (2000-2011) can be generated IDF Curves so that various I values (rainfall intensity) are obtained at various D (duration of rainfall), return period (F) and for various data series lengths used in creating IDF Curves;
2. Out of five flood events that occur in one year the data series is obtained in Instantaneous Unit Hydrograph (IUH), and from the parameters of waterhed formed Synthetic Unit Hydrograph (SUH) of Way Kuala Garuntang watershed. The average of IUH has significant Qp differences against SUH Snyder, Nakayasu and Gama I.
3. IDF curve can be used as a signature of characteristic changing especially changes in rainfall intensity that are significant enough for various return period. The average IUH of 5 flood events in one year data series, and incompatible with SUH makes the Unit Hydrograph not yet able to be used as a marker of changes in the characteristics of Way Kuala Garuntang watershed.

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