PERFORMANCE OF REPRESENTATIVE UNIT HYDROGRAPH DERIVED FROM DIFFERENT NUMBER OF CASES

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ABSTRACT

Unit Hydrograph (UH) theory is known as the old theory applied in designing water works. This has been developed by Sherman 80 years ago, but up to now its merit is still studied all over the world. Even the last publication was found in the year 2009. There are some numbers of questions following its applications. One major problem is the number of cases used in deriving observed UH to obtain the representative unit hydrograph. Studies have been done in some catchments in Central Java and in Yogyakarta special territory, by comparing design discharge calculated with representative UH derived from several cases and the discharge obtained from frequency analysis. The result showed that representative UH derived from 10 cases or more give more or less constant deviation.

Keywords: Unit Hydrograph, Representative Unit Hydrograph, Linearity.

1 INTRODUCTION

It has been quite interesting that by June this year (2012), the Unit Hydrograph (UH) theory has been in service for 80 years since it was first developed by Sherman (1932). Sherman's statement that *by making use of a single observed hydrograph one due to a storm lasting one day it is possible to compute. for the same watershed the runoff history corresponding to a rainfall of any duration or degree of intensity* has become the principle basis for this theory.

Unit hydrograph (UH) theory was first then developed by Sherman in 1932. UH is defined as the direct runoff hydrograph produced by the effective rainfall evenly spatially distributed and constant intensity in a specified unit of time. It has been early commented and emphasized among others by Clark (1945), Body (1959) that the principles of this theory are:

a) The hydrograph producing rain should be spatially evenly distributed. It means that rainfall has to occur at all over the catchment.
b) The rainfall intensity is constant in a unit Time, meaning that in a unit time of one hour; the rainfall intensity has to be constant.
c) Discharge is linearly proportional to the producing rainfall (linearity principle).
d) Whenever the occurrence of rainfall does not influence the transformation process of rainfall into discharge (principle of time invariant).
e) The period between the end of hydro-graph producing rain and the point of the end of the direct runoff is constant.

Having a deeper look at those principles, one may categorize UH as a linear time invariant model. Further looking at the assumptions of the UH theory, one may understand that this theory do not naturally represent the natural behavior of a catchment in transforming rainfall into hydrograph, since the nature is a non-linear time variant system. This fact has been commented and realized by any author in this matter, among others by Nalbantis et al (1995). The consequence of this assumption is that any UH derived from one pair of rainfall and the produced hydrograph will always differ from that derived from other pairs (cases). Then a big question is which UH should be selected to represent the catchment for the basis of the design of any water works.

There is a procedure of averaging observed hydrographs explained in some publications, which is done by averaging the time to peaks and the peak of each UH. This has been studied by Body (1962) that UH method only enables to indicate the peak discharge but not the time to peak. Therefore, the proper way to obtain average representative UH has to be obtained. In practice, the problem is not only the way to average the observed UH, but also the number of observed UHs to be averaged that one representative UH can be obtained. Inspired by the study done by Body (1962), Sri Harto (1993) showed that the different number of pairs for deriving observed UH will result in different observed UH. This result was obtained by selecting observed hydrograph sequentially in the order of magnitude as shown in Figure 1.

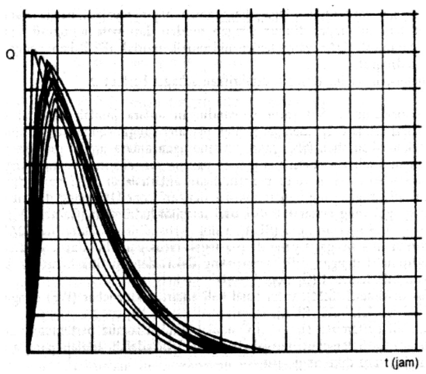

Figure 1. Average observed hydrograph derived from different number or cases

The peak of averaged UH tends to be smaller as the number of cases increase. Even, Revianti (2011) tried to further study the influence of magnitude sequential selection of pairs to derive representative UH. The study was done by averaging UHs from observed hydrograph either arranged from the highest to the lowest peak of observed hydrograph, from the lowest to the highest or based on the annual sequence of the occurrence. It showed that the average UHs derived from those were quite different, either their value of time to peak or the value of the peak discharge, as shown in Figure 2, Figure 3, Figure 4.

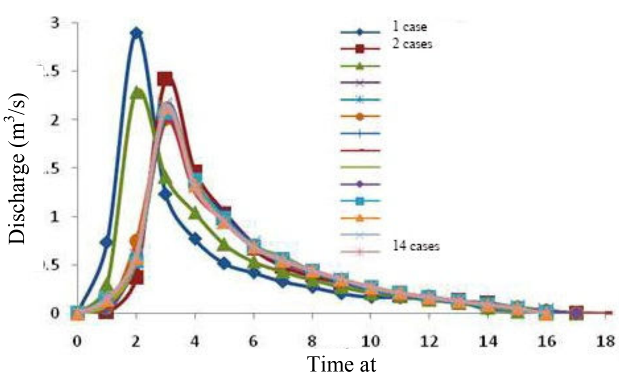

Figure 2. Representative UHs derived from different number of cases of the observed hydrograph, arranged from the highest peak to the lowest peak (Revianti, 2011)

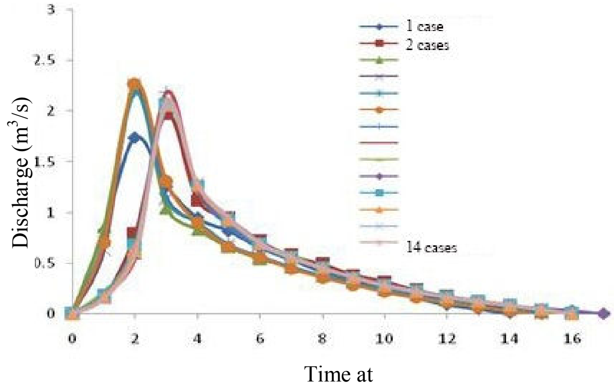

Figure 3. Representative UHs derived from different number of cases of the observed hydrograph, arranged from the lowest peak to the highest peak (Revianti, 2011)

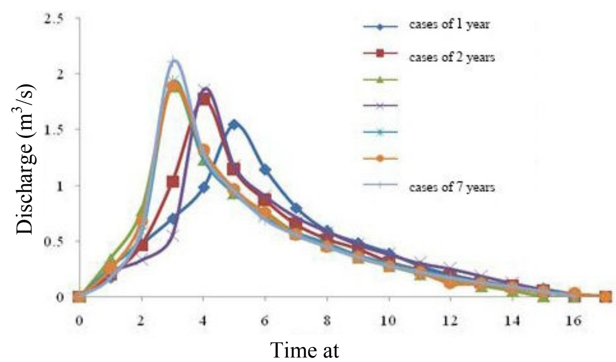

Figure 4. Representative UHs derived from different number of cases of the observed hydrograph, arranged sequentially (Revianti, 2011)

Having a look at those results, a big question remains, which UH will be chosen as UH representing the catchment for further analysis of obtaining design discharge.

2 CASES OF STUDY

The study of the performance of the UH was done as follows. The proper procedures for raingauge networks evaluation are based on Kagan's method (1972) and the consistency tests for all rainfall data have been done.

a) The existing networks are the starting problem to consider. There are indeed two opinions. One says that raingauges located with certain pattern will gave more accurate average rainfall estimates. The second says that in part of the catchment with higher rainfall variation, the raingauge density should be higher. No more information found elsewhere explaining this latter. Igel (2006) studied to see the possibility of knowing what density related to what rainfall variation, but no satisfactory result was found. Therefore, the existing network density and pattern is assumed to be the best that has to be used for analysis.

b) Ika (2006) studied five catchments in central Java where the areas vary from 42.5 km2 to 359.9 km2. While Revianti (2011) did in two catchments in Central Java and three others in Yogyakarta Special Territory, the areas are ranging from 23 km2 to 462.8 km2.
c) Observed UHs are obtained by Collin's method and the average UHs are obtained with the previous stated procedure. Each thus obtained averaged UH is supposed to be the representative UH based on that related number of pairs of data.
d) Ika (2006) applied hourly rainfall distribution derived from each automatic rain recorder available in each catchment. Revianti (2011) applied hourly rainfall distribution obtained by the other previous studies (Nomeritae, 2009, Ernie Rante Bungin, 2007 and Fatma Balany, 2008).
e) The design rainfall with a certain return period is obtained by frequency analysis from the available rainfall records. The assumption of the equal return period of rainfall and its produced hydrograph is still adapted.
f) Rainfall with a certain return period is applied to obtain design flood with the same return period by multiplying it with representative UHs.
g) The computed peak discharges are compared with the observed discharge of equal return period obtained from frequency analysis of observed data.

3 RESULT AND DISCUSSION

The results obtained from research procedures, either one done by Ika (2006) or by Revianti (2011) are presented if Figure 5, Figure 6, Figure 7, and Figure 8 respectively.

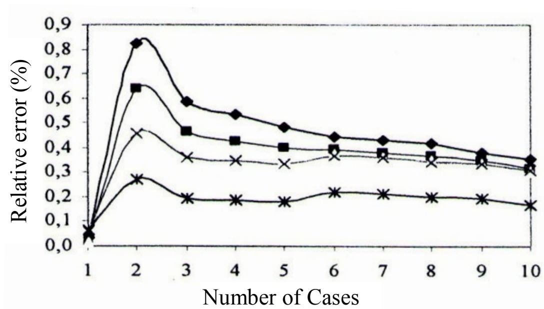

Figure 5. Relative error of computed discharge with different UH derived from different number of cases (Ika, 2006)

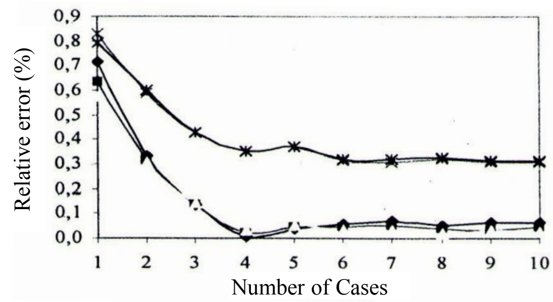

Figure 6. Relative error of computed discharge with different UH derived from different number of cases (Ika, 2006)

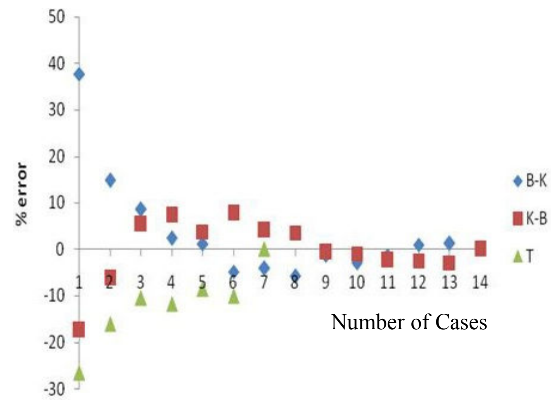

Figure 7. Relative error of computed discharge with different UH derived from different number of cases (Revianti, 2011)

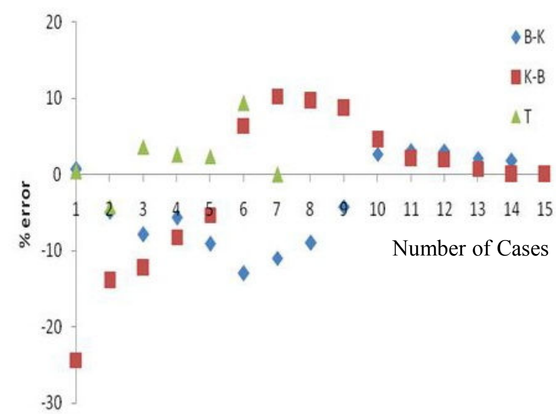

Figure 8. Relative error of computed discharge with different UH derived from different number of cases (Revianti, 2011)

Looking closer to those results, in depth discussion can be made.

a) It can be clearly noticed that the error of the computed peak discharge obtained by applying the representative UH derived from different number of cases decreases as the number of cases to derive UH increases. However, in general as the number of cases is equal or more than 10 cases, then the error shows a tendency stable. This may indicate that at least ten cases used to derive representative UH are considered acceptable.

b) Theoretical result has said so. Nevertheless, in practice there were unexplained reasons that one designer applied what so called representative UH derived from only one extreme flood ever recorded. The consequences of this are the possible large error in the value of design discharge or very high value of flood discharge.

c) Back to the basic assumption of the UH theory, the hydrograph producing rainfall has to be in constant intensity in unit of time, and the rainfall has to occur in the entire catchment. As has been stated by Sri Harto (1985) and elsewhere that the spatial and temporal variability of rainfall in the island of Jawa (and mostly in Indonesia) is very high. It means that evenly spatially distributed rainfall occur in the whole catchment can never be expected. Realizing this problem, Taylor and Schwarz (1952) did the analysis based on a certain number of cases, but no further stated information of how many cases should be used in such an analysis. This was also suggested by Body (1959). This has also been in general stressed by Body (1962). It is meant that the derived UH is obtained only by assuming that a hydrograph is produced by rainfall that occurs at most of all rainfall stations. This means that every UH is derived from possibly different pattern of rainfall in the catchment, or probably no rainfall at certain station (s), consequently they have different character. A study is now still in progress, trying to identify which is the 'commanding area' in a catchment that produced UH closer to the representative UH, whether it is influenced by topographical characteristic of the catchment or by spatial rainfall distribution. The constant rainfall intensity in a unit of time is also never met. Commonly the rainfall rate in a time unit (one hour) is averaged.

d) The selection of time rainfall occurrence that produces the corresponding hydrograph is also one important problem. One never knows when or which rainfall that really produced the selected hydrograph. As has been stated before that instead of the very high spatial variability of rainfall, also that time indicated by rainfall recorder does not always show the same time that rainfall occurs at major number of rainfall stations. Having one rainfall recorder in a catchment is already luck. Commonly the daily rainfall occurs on the day of the selected hydrograph is distributed by a certain method, or follows the distribution shown by the rainfall recorder.

e) The catchment daily rainfall obtained by Thiessen Polygon. This applicability of this method has also been studied by (Fatma Balany, 2008, 2012). The hourly distribution has an important role on the deriving UH. It was done by either direct derivation from the available rainfall recorder data in each catchment or application of previously available equations. It is quite questionable problem. Previously it has been stated that the spatial variation is very high, which strongly means the representativeness of each rainfall data at each rainfall station is low. Meanwhile, there is luck if there is one rainfall recorder presents in the particular catchment. Then it means that the representativeness of recorded data is also equally low. However, at least this recorded data may be influenced by the overall characteristics of rainfall data in that particular catchment. This has been studied by Sobriah (2003), Eddy Sukoso (2003) Mutia (2011), Erik Law (2012).

f) The separation of base flow from its total hydrograph is simply done by a straight line connecting the lowest point before the rising limb of the hydrograph and the lowest point at the recession limb. It is questionable, since the separation of the 'real' base flow from its direct runoff may occur before or after that lowest point. Early, Brater (1939) clearly explained that the influenced of the way to separate base flow may influence the value of the base time of UH. Other way of separating base flow was also introduced by Ninghu Su (1995)

g) Additional base flow to obtain total peak (design) discharge is done by the average base flow values of each observed hydrograph or by formula proposed by Sri Harto (1985, 2000). Ika (2006) has shown that both base flow values do not differ significantly.

h) Other problem encountered in this study is the equality of the discharge and the rainfall return period. Sri Harto (1985) had tried to explore the possible relationship between those two return periods. Theoretically, there should be a kind of functional relationship between them since the transformation of rainfall to hydrograph can be clearly understandable to follow the two basic concepts of hydrology. The study has tried to incorporate the role of strongly influential catchments parameters stated by previous researcher (Snyder, 1938), but still no acceptable results could be obtained. Therefore, while waiting for the proper solution, the assumption of the equality between the discharge return period and the rainfall return period is used instead.

4 CONCLUSSION

Having attention to the discussion and the results presented in the previous figures, although there are still unsolved problems encountered in the analysis, conclusions may be drawn.

a) Representative UH may be derived by the sequential value of the highest to the smallest observed hydrographs or from the smallest to the highest, or of the sequential of their occurrence. Consequently, different representative UH will be obtained.
b) Representative UH is recommended to be derived from at least ten cases.
c) Design discharge computed with representative UH derived from less than ten cases may invite overestimated value of peak discharge.

5 RECOMMENDATION

For further more accurate analysis, the previously indicated problems should be studied. They are among others:

a) Network evaluation has to be done in the area, to possibly rearrange or to improve the existing networks.
b) Obtaining proper equation for hourly distribution.
c) Searching the possible functional relationship between the discharge return period and the rainfall return period.

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