CALCULATION OF DESIGNED FLOOD IN WEAK DATA REGION IN VIET NAM USING WIN-TR55 MODEL

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Abstract: *Road transportation infrastructure is of great importance in the development of a nation. Viet Nam is facing many challenges in developing road infrastructure due to lack of rainfall and flow data required for calculation of designed flood, especially in mountainous areas. Furthermore, many water drainages have been damaged by heavy rain and severely affected by climate change. In this study, the Win-TR55 based on SCS method is employed for calculating storm runoff volume, discharge and hydrograph to estimate designed flood values for small watersheds. In order to use TR55, parameters for calculating designed flood including rainfall, soil type and land use map are required. This program is widely used in many countries, but has not been applied to the small basins in Viet Nam because of data missing. Tong Soong bridge on the National Highway No.31 crossing Dinh Lap district, Lang Son province, Viet Nam was selected as a case study. The study shows a great potential of the Win-TR55 method to estimate the hydrograph for small and medium watershed in Viet Nam.*

Keywords: *Win-TR55, designed flood, data missing, Tong Soong watershed.*

1. Introduction

Determination of design hydrograph is the key information for construction of transportation infrastructure. The size of these infrastructure systems strongly depends on the design hydrograph to make sure they will not be inundated by flood water in the future. There have been many methods developed to construct the hydrograph [1-2]. In general, these methods construct the designed hydrograph from the designed hyetograph based on the rainfall-runoff relationship. They can be classified into three groups. The first method so-called traditional method uses simple equations to formulate the rainfall-runoff relationship (e.g., runoff coefficient). The advantage of this method is that they can provide quick estimate of designed hydrograph. However, they do not explicitly account for the impact of watershed characteristics such as land use, topography and soil type or watershed conditions such as soil moisture. The second group of methods is based on physically-based hydrological models. These models can well simulate the water dynamics on the watershed but require those data that may be not available in remote regions. The third group of methods uses the conceptual hydrological models.These methods provide relatively accurate estimation of river flow from rainfall with affordable requirement of input data. In these methods, parameters of models are usually estimated from the watershed characteristics using GIS tools. For its accuracy and convenience to estimate, this study uses one of the methods in the third group known as TR55.

In Viet Nam, many studies have been done to develop unit hydrographs. For

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example, Le Dinh Thanh estimates the portable maximum flood (PMF) from the portable maximum precipitation [4]. Le Van Nghinh documented and applied different methods to calculate designed hyetographs and hydrograph [3]. Ngo Le Long considered the impact of climate change on the estimation of design hydrograph [5]. However, so far there have not been many studies on development of designed hydrograph for small watersheds where the time of concentration is usually less than 10 hours. In these watersheds, using daily rainfall to construct the hydrograph is not suitable due to coarse temporal resolution. Meanwhile, these small watersheds account for up to 70% of drainage structures. In that context, development of designed hydrographs for small watershed is an urgent need.

This study aims at applying the TR55 model based on SCS method to estimate the designed hydrograph for Tong Soong watershed, which is a small mountainous basin in Lang Son province, Northern Viet Nam. In this method, the SCS curve number is employed to estimate runoff and the SCS unit hydrograph is used to estimate the coordinates of hydrograph from runoff.

2. Methodology

This study employed the TR55 software to calculate design hydrographs for small drainage system for Tong Soong watershed. The software was developed in 1998 by the United States Department of Agriculture (USDA, 1999). The TR55 presents simplified procedures for estimating runoff and peak discharges in small watersheds. The model described in TR-55 begins with a rainfall amount uniformly imposed on the watershed over a specified time distribution. Mass rainfall is converted to mass runoff by using a runoff curve number (CN). Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed (USDA, 1999). The software calculates storm runoff volume using the SCS method and constructs hydrograph using tabular hydrograph method. The SCS method estimated by equation below:

$$Q = \frac{\left(P - 0.2S\right)^2}{P + 0.8S}$$

where Q is the runoff; P is the rainfall; S is the potential maximum retention after runoff begin. S is related to the soil texture and land cover conditions of the watershed through curve number (CN) parameter by:

$$S = \frac{100}{CN} - 10$$

CN can be determined from soil type, plant cover type, treatment, impervious areas, interception, hydrologic condition and antecedent runoff condition. CN also depends on whether impervious area is directly connected to the drainage system or whether flow over the previous area before reaching the drainage system.

Next, the hydrograph can be constructed for the watershed using tabular hydrograph method as below:

1) Divide the watershed into subareas with relatively homogeneous watershed characteristics

2) The hydrograph coordinate at time t of a subarea (q) is calculated by:

$$q = q_t A_m Q$$

in which q_t is the tabular unit discharge, which is determined from time of concentration (T_c) and ratio between initial abstraction and rainfall (Ia/P) with $I_a=0.2S$; A_m is the drainage area of subarea; and Q is the runoff on the subarea.

3) Finally, hydrograph at the outlet of the watershed is obtained from the hydrograph coordinates of subareas and time of travel from each subarea to the watershed outlet.

Clearly, there are three main parameters in the TR55 software including CN, Tc and Tt. In this study, these parameters were estimated from maps of topography, land use and soil type.

3. Study area

In this study, we constructed the design hydrograph for the Tong Soong watershed, which is a small watershed in Lang Son province, Northern Viet Nam (Figure 1). The watershed has an area of around 25km^2 and a catchment length of 7.14km. Located in a mountainous region, the watershed topography is quite steep with an average slope of 23.4°, which indicates that the time of concentration of this watershed is relatively small. More detailed description of the watershed characteristics can be found in Table 1.

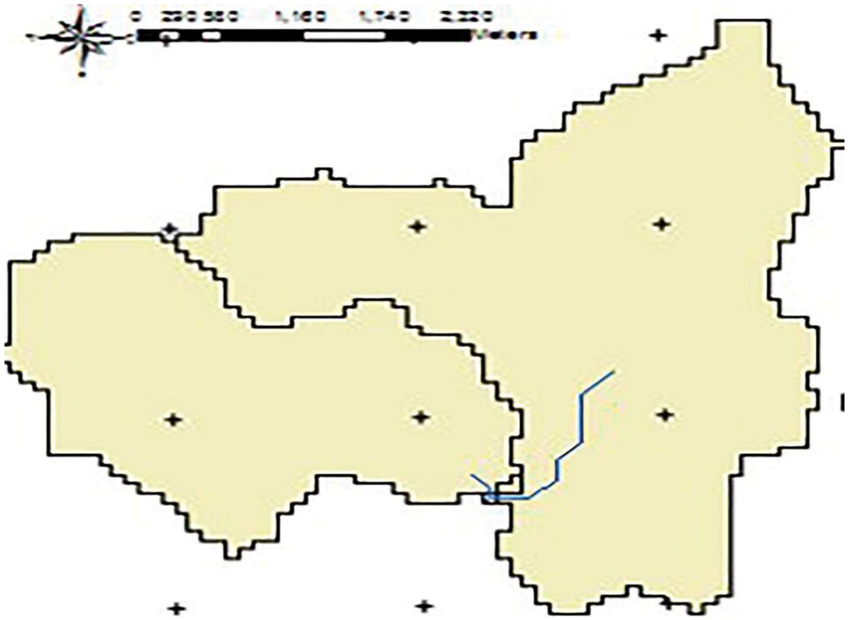


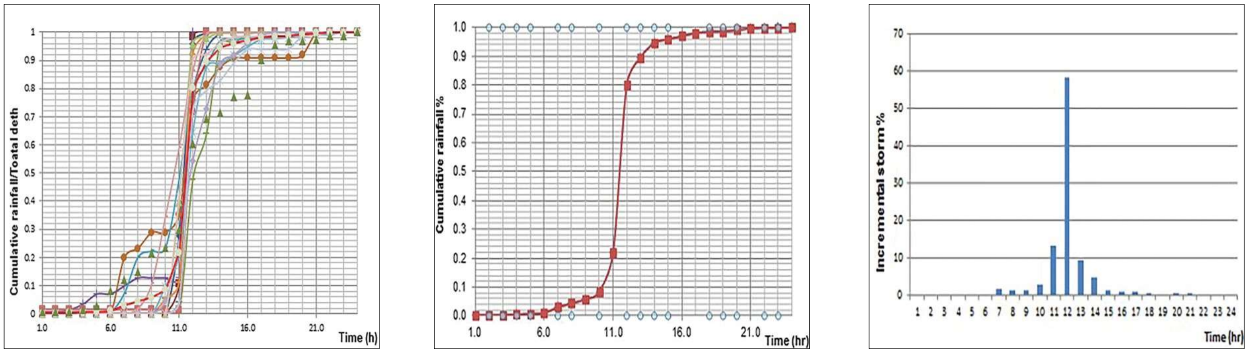
Figure 1. Watershed of Tong Soong Bridge

Table 1. Characteristics of Tong Soong watershed

No.	Characteristic	Symbol	Unit	Value
1	Design probability	P	%	2
2	Catchment area	A	km^2	19.48
3	Main flow length	L	km	1.8
4	Catchment length	Llv	km	7.03
5	Catchment averaged width	B	km^2/km	2.77
6	Catchment roughness			2.00
7	Catchment averaged slope	Sb	%	25.15
8	River bed slope	Sr	%	0.05

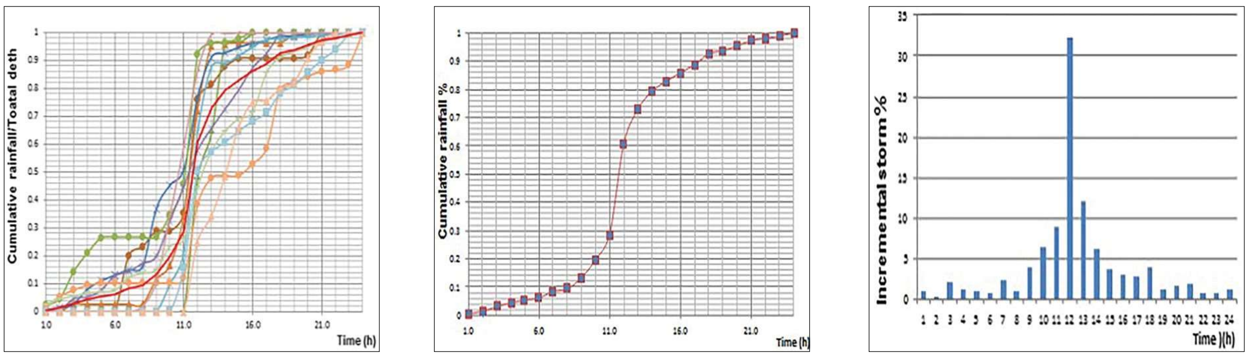
4.1 Determination of design hyetographs

In order to develop the design hydrograph for Toong song watershed, we collected hourly data over the period from 1975 to 2016 at Lang Son rain gauge. Subsequently, we determined the main rainfall events occurring over the 1975-2016 period and classified these events into two groups: events with total amount of 24-h rainfall lower than 100 mm (Type I) and events with 24-h rainfall higher than or equal to 100 mm (Type II). Figures 2a and 3a show the 24-hour dimensionless cumulative hyetographs of rain events 24-h rainfall lower and greater than 100mm, respectively. Based on these hyetographs, we selected the typical hyetograph of each group as shown in figures 2b and 3b. Figures 2c and 3c show the typical incremental hyetographs of each group. It is clearly seen that although the typical hyetographs of two groups are similar, the peak rainfall of type II is much higher than that of type I. Next, the design 24-h rainfall values with return frequencies of 1, 2, 5, 10, 25, 50 and 100 years were calculated based on 24-h rainfall datasets collected in the 1975-2016 period. Finally, the design hyetographs corresponding with the design 24-h rainfall values were obtained by mapping from two typical hyetographs type I and II. These design hyetographs were used as the inputs for TR55 to construct the design hydrographs.



(a) (b) (c)

Figure 2. Cumulative dimensionless hyetograph and design hyetograph in Lang Son (type I)



(a) (b) (c)

Figure 3. Cumulative dimensionless hyetographs and design hyetographs in Lang Son (type II)

4.2. Land use map and Curve number map

In order to estimate runoff from storm rainfall, the TR55 model uses the curve number (CN) method as mentioned in section 2. Determination of CN depends on the watershed characteristics including soil and land cover conditions, which the model represents as hydrologic soil group, land use, treatment, and hydrologic condition. Given those watershed data, the CN map can be constructed using GIS tools. Figure 4 shows the land cover and CN maps of the Toong song watershed. The figure indicates that there are three regions with CN values of 77, 71 and 70 in which the regions with CN values of 77 and 70 occupy nearly all watershed. Similar to the CN estimation, the time of concentration Tc and time of travel Tt were also calculated by GIS tool from the topography map.

4.3 Determination of design hydrograph

The 1-day hydrograph for the Tong Soong watershed was constructed from the daily rainfall with return periods of 1, 2, 5, 10, 25, 50 and 100 years using the TR55 method. Figure 5 shows an example of the design hydrograph at the outlet of the watershed corresponding with a return period of 50 years. Table 2 summaries the peak discharge and peak time at sub-basin, reaches and outlet of the watershed.

4. Conclusions

In this study, the TR55 method was explored and applied to estimate the designed hydrographs with return periods from 1 to 100 years. The initial results show that this method is suitable for calculation of designed hydrograph for small and medium watershed. Particularly, the calculation of time of concentration using this method, which accounts for the time traveling both on hill slope and on the river, is more accurate than the traditional methods. The accuracy of runoff simulation using combined GIS and TR55 was also confirmed in the study of Ramana (2014). The application of the TR55 method shows a great potential to derive hydrographs and develop a database of hyetographs and hydrographs for other mountainous regions having similar conditions in Northern Viet Nam. However, care should be taken as the procedures in TR-55 are simplified by assumptions about some parameters. These simplifications, however, limit the use of the procedures and can provide results that are less accurate than more detailed methods. The user should examine the sensitivity of the analysis being conducted to a variation of the peak discharge or hydrograph when using the method.

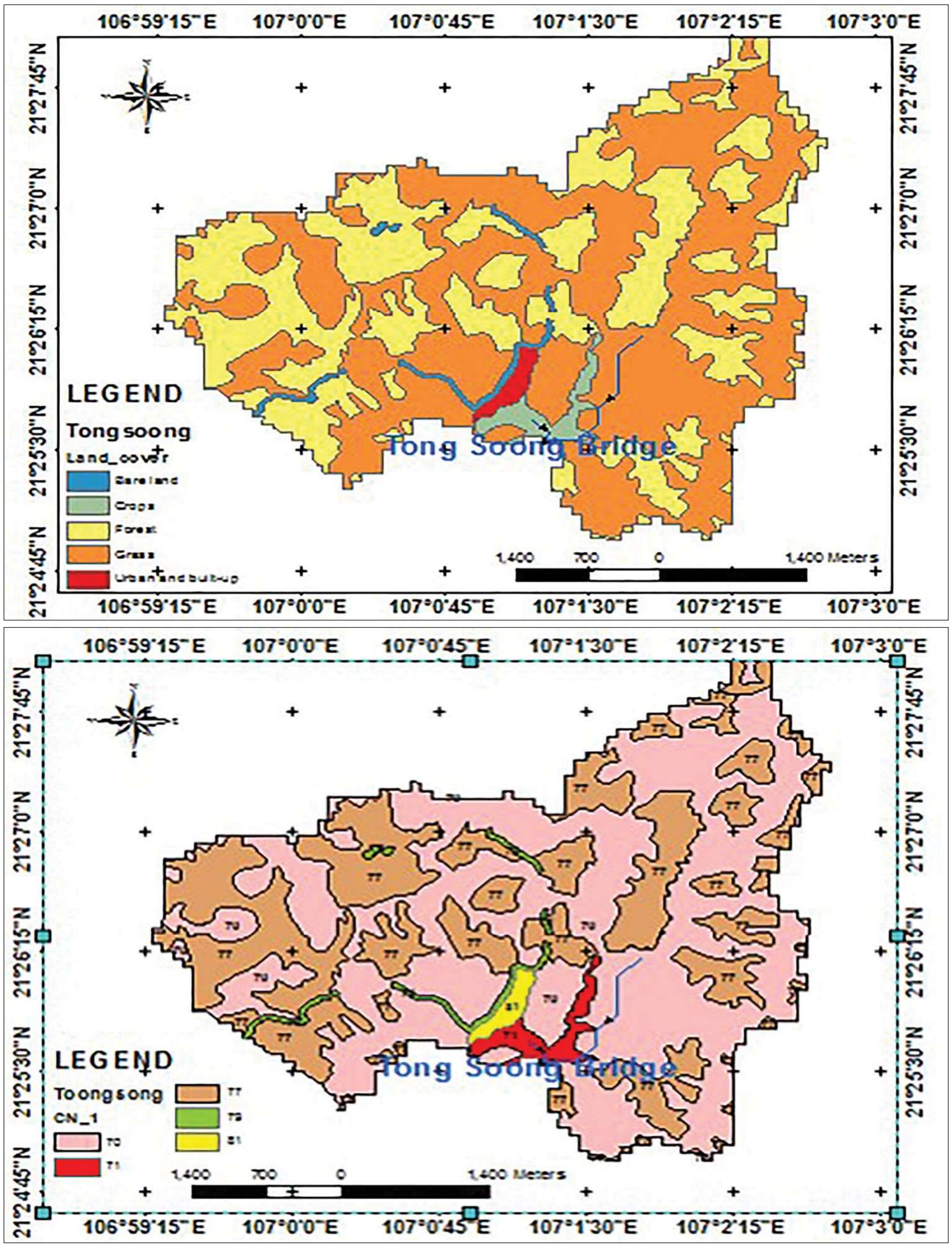


Figure 4. Land cover and Curve number map in Tong Soong

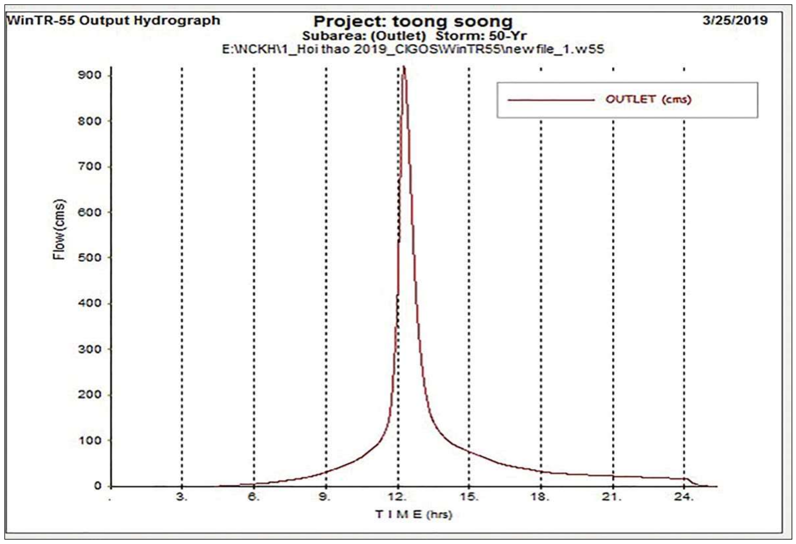


Figure 5. Design hydrograph at Tong Soong watershed

Table 2. Flood peak with different return periods at Tong Soong

Region: lang son Locale:

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cms) (hr)	5-Yr (cms) (hr)	10-Yr (cms) (hr)	25-Yr (cms) (hr)	50-Yr (cms) (hr)	100-Yr (cms) (hr)	1-Yr (cms) (hr)
SUBAREAS							
sub 1	75.86	82.05	228.38	306.51	364.87	422.24	72.04
	12.16	12.16	12.16	12.15	12.16	12.15	12.17
sub 2	118.94	128.36	359.06	483.43	574.75	666.47	112.36
	12.24	12.23	12.24	12.21	12.23	12.21	12.22
sub 3	0.40	0.44	1.20	1.60	1.90	2.20	0.38
	12.13	12.13	12.12	12.12	12.12	12.12	12.13
REACHES							
reach 1	75.86	82.05	228.38	306.51	364.87	422.24	72.04
	12.16	12.16	12.16	12.15	12.16	12.15	12.17
Down	75.85	82.02	227.80	306.06	363.75	421.67	71.85
	12.26	12.26	12.23	12.22	12.21	12.22	12.24
reach 2	118.94	128.36	359.06	483.43	574.75	666.47	112.36
	12.24	12.23	12.24	12.21	12.23	12.21	12.22
Down	118.75	128.27	358.49	482.76	574.12	665.18	112.36
	12.38	12.36	12.30	12.32	12.30	12.31	12.36
OUTLET	188.93	204.11	575.62	773.54	921.49	1068.16	178.92

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