



A Simple Method To Develop A Formula for Estimating Concentration Time of Drainage Design

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Abstract – Concentration time of rainfall is an important aspect to determine drainage design. A general rational formula is used to determine design flood or peak flow in urban drainage planning, especially for storm sewer design. The use of this balanced formula requires rainfall intensity, whose duration of rain is equal or more than the time of concentration. This time of concentration is determined using an estimation formula whose formation requires measurement data of the time of concentration. This study introduces how to measure the time of concentration using the concept of-rational-hydrograph, in which peak flow occurs at the time of concentration. To fulfill the aim of this research, an experimental of catchment area planted with *Zoysia Japonica* grass and showered with a rainfall simulator was conducted. The length of the flow path on the land, L, given in 5 variations, namely 50 cm, 100 cm, 150 cm, 200 cm, and 250 cm, was used. The slope of the land, S, is given in 3 variations, namely 2.8 %, 5,6%, and 8.8%. For each variation of L and S, the experimental catchment area was poured with a fixed rainfall intensity, which is 60 mm/hour. The flow was measured every 5 minutes intervals. Then, from the relationship of flow and time, a rational hydrograph was formed, from which the time of concentration, T_c, was deduced. This T_c value was treated as the measured T_c to form the T_c estimation formula using the regression formula. The formula is $T_c = 3.543 + 1.211 L - 17.119 S$, with the coefficient of determination $R^2 = 0.98$. These results show that the determination of T_c using the concept of the rational- hydrograph is acceptable. This formula applies to L and S values greater than zero and applies to land covered by *Zoysia Japonica* grass. Further research is needed for other types of land cover to validate the formula obtained in this research.

Keywords: concentration-time, rational hydrograph, estimation formula.

Introduction

In urban drainage planning, the magnitude of peak discharge due to rain must be determined in advance. This magnitude of peak discharge is generally determined using a rational formula. One variable in the balanced equation is rainfall intensity. The sensible formula requires the representative of rain duration. This rain duration is for determining the rainfall intensity, which is rain duration that is equal to or greater than the time of concentration. The time of concentration is defined as the length of time of the water flows from the farthest point in the catchment area to the observation point. The rational formula explains that if the rain duration is less than the time of concentration, then not all parts of the catchment area contribute to the flow at the same time. In other words, it can be understood that catchment area data cannot be used in a rational formula if the duration of rain is smaller than the time of concentration (Guo, 2003 and Ojha et al. 2008).

The above concept is explained in a rational hydrograph that peak discharge occurs when the duration of rain is equal to or greater than the time of concentration. Thus, the data of the time of concentration is essential (Moustafa, 1988), but measuring the concentration-time is challenging to do. Hydrologists suggested several empirical formulas to determine the time of concentration. This research introduces the method of measuring the

concentration-time using the concept of a rational hydrograph in an experimental catchment area. This innovative catchment area is planted with grass and showered by rain simulators. Discharge of rainwater over the catchment area is measured at certain time intervals. Then, based on the relationship between discharge and time, a rational hydrograph is made. The length of the time of concentration is obtained when the discharges steady. Furthermore, based on the measurement data that varies according to the extent and slope of the land, the formula for estimating the time of concentration is made using a regression formula.

An important variable used in storm sewer design is a time of concentration, T_c . It is defined as the time required for surface runoff to flow from the remotest part of the catchment area to the point under consideration (Butler, 2011). The characteristics of the catchment area control the time of concentration, land use, the distance of the waterway from the farthest point to the station being reviewed (Triatmodjo, 2008). Some empirical formulas for determining the time of concentration have been summarized by Chow (1988).

Meanwhile, rational hydrograph also another important variable for storm sewer designing need to be considered. The hydrograph of the rational formula shows the maximum flow reached when the whole catchment's areas contribute together, i.e., when the duration of rain is equal to or greater than the time of concentration, T_c (Butler, 2011). A rational hydrograph is shown in Figure 1 (Bedient, 2008)

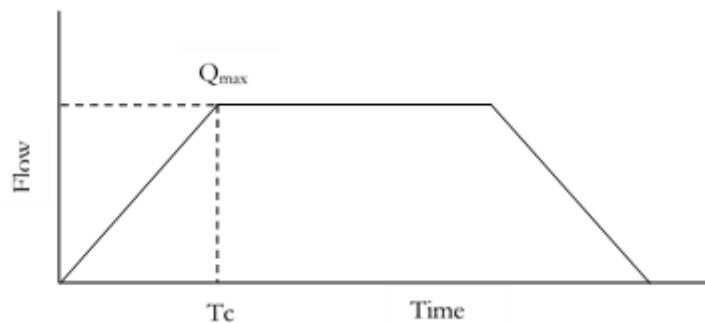


Figure 1 Rational Hydrograph

Materials and Methods

The material used in this study is rainfall simulators and Zoysia Japonica Grass, as well as a stopwatch for timekeeping. The research was conducted from August to October 2018. In this study, the time of concentration was measured using the concept of rational hydrograph, where the time of concentration occurs when peak flow occurs. The peak flow occurs when the flow starts to be equilibrium. Rational hydrographs are obtained from the relationship of flow with the time that occurs in the experimental catchment area planted with Zoysia Japonica grass, which is showered by rainfall simulators, as shown in Figure 2. Rainwater flowing over the innovative catchment area is collected downstream, and then the flow is measured at 5-minute intervals.



Figure 2 Rainfall Simulator and Experimental Catchment Area planted with Zoysia Japonica Grass

The length of the flow path on the land, L in centimeter, and slope of the land, S , in degree, are determined as the variables that determine the time of concentration, T_c in this study. By using the concept of the rational hydrograph, it is observed the time of peak flow, Q_{max} for each variation of L and S with constant rainfall intensity, $I = 60 \text{ mm/hour}$. The experimental catchment area was given an S with 3 variations, namely $S1 = 0.028$ (1°); $S2 = 0.056$ (3°); and $S3 = 0.088$ (5°). The length of the flow path on the land, L is adjusted by covering the upstream with plastic. The length variations given are 5 variations, namely $L1 = 50 \text{ cm}$, $L2 = 100 \text{ cm}$, $L3 = 150 \text{ cm}$, $L4 = 200 \text{ cm}$, $L5 = 250 \text{ cm}$. Then, based on the relationship between measurement data of T_c in various L and S conditions, the estimation formula of T_c is estimated using the regression formula.

Results

Time of Concentration

From the relationship of flow data and time data, rational hydrographs are obtained for each variation in L and S , as shown in Figures 3, 4, and 5. This rational hydrograph shows a change in flow pattern from rising limbs to equilibrium flow. The point indicates the time at which the equilibrium flow occurs is the time of concentration T_c .

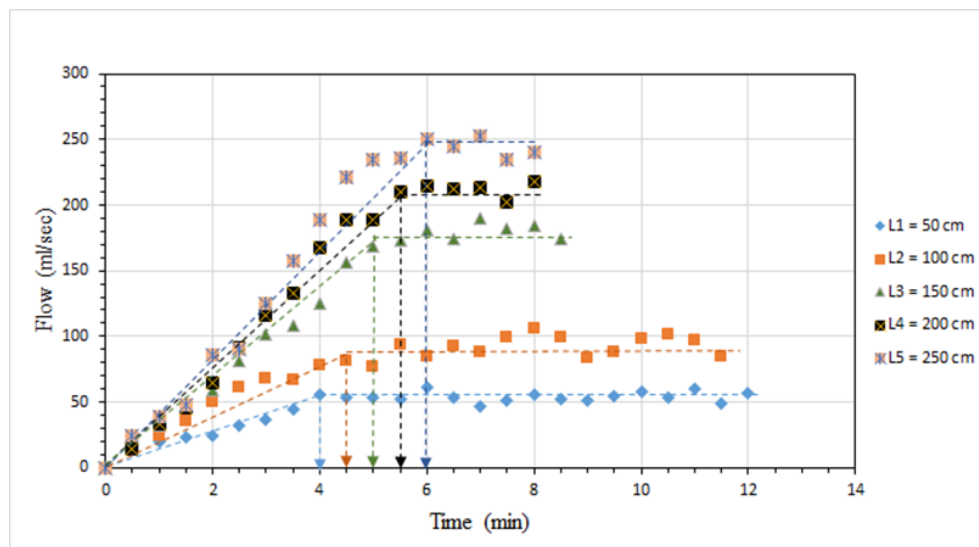


Figure 3 Rational Hydrographs and T_c occurred at Q_{max} at $S1 = 0.028$

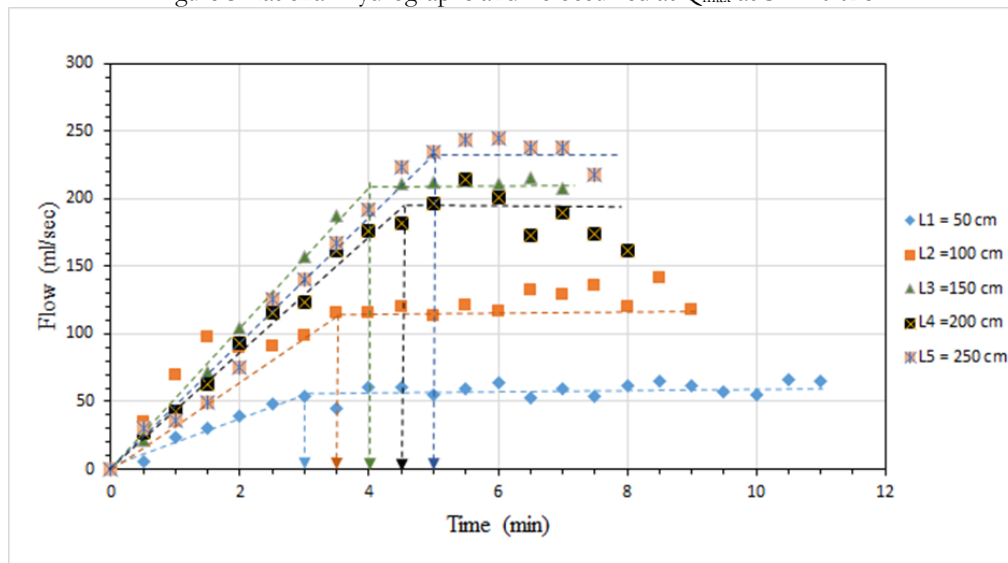


Figure 4 Rational Hydrographs and T_c occurred at Q_{max} at $S2 = 0.056$

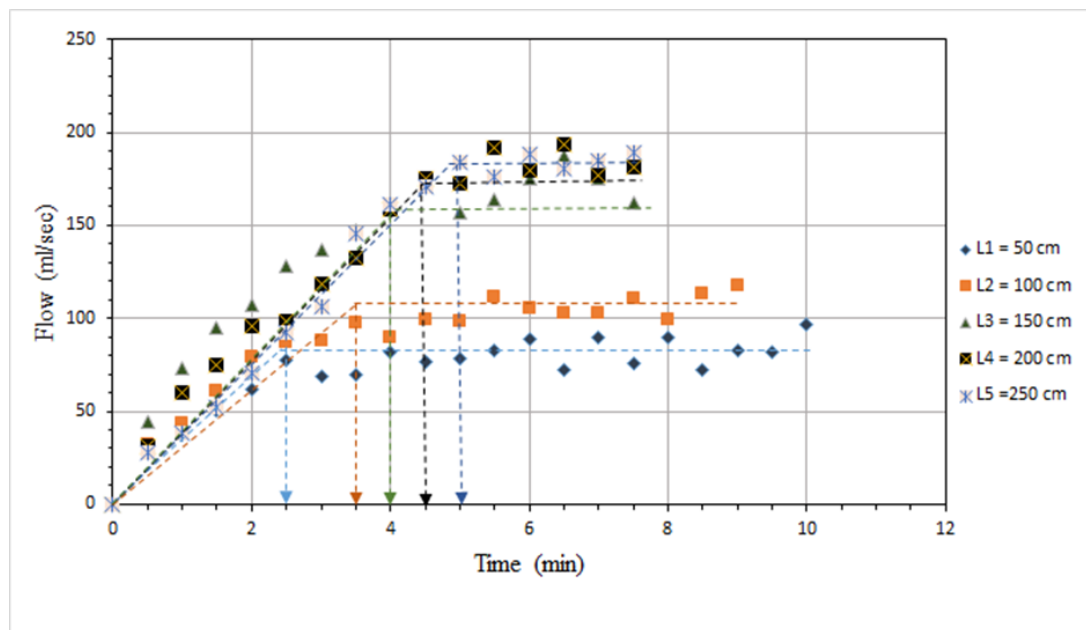


Figure 5 Rational Hydrographs and T_c occurred at $Q_{\max}$ at $S_3 = 0.088$

In general, the pattern of the rational hydrographs is relatively similar, i.e., there is a change in flow from a sharp rise to a horizontal. Graphically, the time of concentration is obtained at the intersection point between the upward regression line and the flat regression line, as shown in the three figures 3, 4. and 5.

As a resume, Table 2 shows the time of concentration T_c for each variation in the length of the flow path on the land L and the difference in the slope of the land S . These results show regularities that follow the physical meaning, namely, at the same value of L , the amount of T_c decreases as the value of S increases, and at the equal value of S , the amount of T_c decreases as the value of L decreases.

Table 2 Data of Observation Results Time of Concentration T_c (minutes)

The length of the flow path on the land (L)	The slope of the land (S)		
	$1^\circ = 0.028$	$3^\circ = 0.056$	$5^\circ = 0.088$
50 cm	4.0	3.0	2.5
100 cm	4.5	3.5	3.5
150 cm	5.0	4.5	4.0
200 cm	5.5	5.0	4.5
250 cm	6.0	5.5	5.0

The formula for Estimating Time of Concentration

Based on the relationship between data of the time of concentration T_c with the length of the flow path on the land L and slope of the land S as shown in Table 2 above, a formula is created to estimate the time of concentration T_c uses simple multiple regression analysis, as shown below.

$$T_c = 3.543 + 1.211 L - 17.119 S \dots\dots\dots (1)$$

Where:

T_c = time of concentration, min

L = length of flow path on the land, m

S = slope of the land (degree)

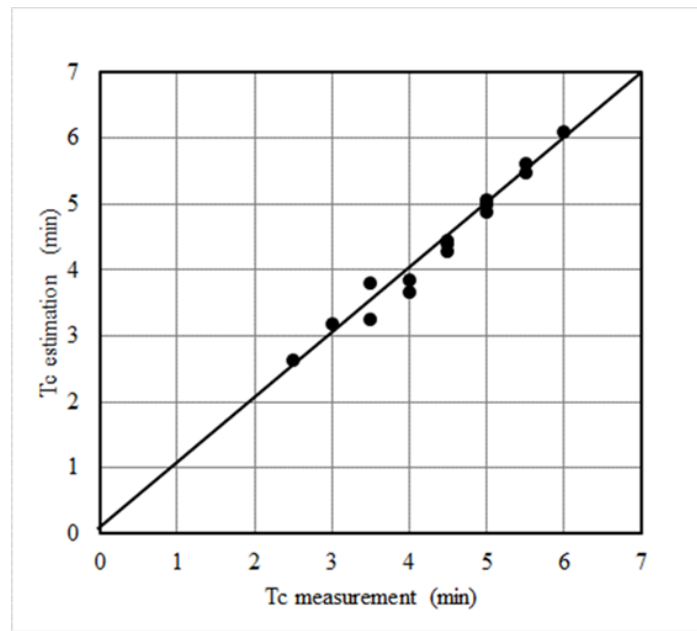


Figure 6 Relationship between observation T_c and estimated T_c using Formula 1

Figure 6 explains the relationship between the measured T_c value and the estimated T_c value calculated using Formula 1. The coefficient of determination of this formula is $R^2 = 0.98$. This value explains that Formula 1 has an accuracy of 98% to estimate the amount of T_c . This result also shows that the approach to determine observational data of T_c using the concept of the rational hydrograph is acceptable. This formula applies to values L and S greater than zero, and land covered with *Zoysia Japonica* grass. For this reason, it is necessary to research several types of land cover vegetation to obtain a formula for estimating the time of concentration based on variations in L values, variations in S values, and variations in land cover types.

Discussion

An estimation formula cannot be created if the measurement data of the variable that you want to estimate are not available. The above results show that measurement data of the time of concentration can be obtained using the concept of rational hydrograph, i.e., the time of concentration is the same as the time of peak discharge. Understanding the causes of estimation formula and improving the design and operation drainage system is a difficult task. Therefore by using the measured data as the dependent variable and including the independent variables that affect the time of concentration, a formula for estimating the time of concentration can be created. In this study, the formula was created using a simple regression formula; the independent variable is the length of the flow path on the land and the slope of the land. It is important to note that the formula obtained this research can improve efficiency and sustainably of a drainage system and also support decision-making proses (see Yu *et al.* 2019 and Kim *et al.*, 2016).

The accuracy of the formula created can be improved by increasing the number of variations in the length of the flow path on the land and land slope variations. The accuracy is an essential aspect in dealing with design and to apply the formula need further tests with different nature, *e.g.*, Leitch *et al.* (2018) and Salmasnia *et al.*, (2018). Then to apply this formula to urban drainage planning, this research also needs to be done on other types of land cover, including a land cover that is not planted with plants. This needs to be done because the type of land cover in an urban drainage catchment area generally consists of various kinds of land cover. The test could correct and adjust the formula based on the result of different land cover types. Thus, validation of the formula can be adopted widely.

Conclusion

Time of concentration, T_c , can be obtained from rational hydrographs, where T_c occurs when peak flow occurs. Based on the T_c data, the formula for estimating T_c is created using a simple multiple regression formula whose variables are the length of the flow path on the land L and slope of the land S . The determination coefficient of this formula $R^2 = 0.98$. This formula only applies to land covered by *Zoysia Japonica* grass. Further research is needed to create a T_c formula that can be applied to several types of land cover.

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