Estimates Time of Concentration in Rainfall, Runoff and Infiltration Application

by Zakki Fuadi Emzain

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ABSTRACT
Parameters that affect the hydrological processes in the urban drainage are rainfall, runoff, and infiltration. The process involves variables: velocity, distance and time. Time of concentration occurs in the hydrological process, that runoff and infiltration flow constant.

Time of concentration may occur in the process of absorption of the land, that is when it starts to rain, soaking into ground, and wet soil. The soil becomes saturated with water so that the maximum infiltration capacity and infiltration rate becomes constant. This condition is expressed by a constant value at the rate of infiltration. Water are flow over the surface of the ground as runoff, while the time of concentration occurs when rainwater flows to the ground because of a long point and slope of the land. Time of concentration becomes an important parameter in determining the design of urban drainage.

This study was conducted in laboratory observations using rainfall simulator plot tank. Determination of time of concentration inb rainfall, runoff and infiltration process uses a water balance concept that was a part of kinematic wave theory with Rainfall Simulator of Advanced Environmental Hydrology System. The size of the plot tank was 2,5 m x 1,2 m x 30 cm. Then, silica sand with 1000 micron up to 500 micron is used as a medium for the implementation of the experiment. This process uses the concept of water balance in the kinematic wave for urban drainage.

KEYWORDS
Time of concentration, rainfall, runoff, infiltration, kinematic wave, urban drainage

INTRODUCTION

Time of concentration is the result of kinematic wave concept with the theory of water balance. This process involves the relationship between rainfall, runoff and infiltration. Rain is the input while the discharge runoff and infiltration is the output of the process.

Rainfall that falls to the earth's surface will flow over the surface, pervasive and evaporate. Rainfall seeping into the ground is called infiltration. Infiltration and evaporation are water loss factor of the hydrological cyle, and infiltration is the sole factor in the loss of water in urban drainage (Richard, 1984).

This phenomenon of water balance occurs to be the concept of urban drainage. Water balance procces in urban drainage uses a concept kinematic wave which is a combination of continuity equation and momentum equation.
The correlation of water flow variable with time variable is to be the record for the condition of watersheds so that it will serve as the basis for the planning of urban drainage. The water flow variable is a dynamic equation between the velocity with the time, distance with the time, and the discharge of the time.

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The rain water which hits the ground when the rain starts to falls is the input which then becames the load to trigger the procces resulting in output. The rainwater that falls into the ground experiences a wide range of treatments an it moves over time.

The rainwater on the surface of the earth would flows over the soil surface and seep in to the soil. Over the soil surface, rain water cannot seep into the runoff will flow, while the rain water that can seep into the ground will result in infiltration. The variables of those to procceses depend on the condition of soil treatment, the topography, and the amount of rainfall.

MATERIAL AND METHODS

The correlation of time to rainfall, time to runoff and time to infiltration can be done by observation in the field and can be performed in laboratories. Observations in the field is the data recording of rainfall and runoff associated with discharge measurements at a certain distance and a certain slope at the outlet. The method based on this definition uses the watershed characteristics (e.g. area, slope and roughness of the channel) along with some attributes of rainfall to estimate the time of concentration (Tc). While the observations in the laboratory uses a rainfall simulator.

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Labolataroium observation in this study is functioning rainfall simulator with several variations of the slope and rainfall. Soil conditions were taken by using quartz sand. Slope variations used are the slope of 1%, 2%, 3%, while for the variations in rainfall are 13.56 mm / hr, 20.54 mm / hr, 24.45 mm / hr, 27.38 mm / hr, 34.23 mm/ hr.

Time of concentration is also used in the design of flood flow hydrograph analysis and models. The time of concentration was used as input data in Clark model of unit hydrograph as a method in HEC-1. Furthermore, (Hawley,1981) states that the urban development and the water level of the pond in city cause changes in the time characteristics of water into a runoff.

Hawley, 1981, developed a method to evaluate the effect of floodwaters on the time characteristics of runoff. Kinematic wave equation uses a time balance that is similar with the time of concentration. Thus, the time of concentration is an important parameter in hydrological analysis and it is a basic parameter to determine the design of drainage.
There are time of concentration formulas road map :

Kirpich (19940) : $tc = 0,0195\ x \left(\frac{L}{\sqrt{S}}\right)^{0,77}$

Richard (1984) : $\mathrm{tc} = 0,04690.\mathrm{L}_f^{0,4450}.\mathrm{i}_2^{-0,7231}.\boldsymbol{\phi}^{0,5517}.\mathbf{S}_{\mathbf{fm}}^{-0,2260}$

Akan (1986) : $Tc = \frac{pf.\phi.(1-Si)}{i(\frac{i}{k}-1}$

The time of concentration in overload flow uses the kinematic wave theory approach, (Bedient, 2008). Kinematic wave equation for time of concentration is: $Tc = 3,258\ (Lc/Sc)^{0,5}$ (1)

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The Kinematic wave equation has a role in determining a time of concentration of the drainage channel.

Different channel cross-sectional shape will affect the velocity of the water flow in the channel. In the Cross sections, the dimensions of the channel will affect the velocity of the water. The dimensions of the cross section include the channel slope, length, roughness, and shape, and they cause changes against time concentration. It is based on the continuity equation which has been used in generating maximum flow, maximum speed and time of concentration.

Determination of the time of concentration uses the basic equations of the theory of kinematic waves (Wong, 2009). The kinematic wave method was originally set for simple area e.g: the catchment area counter is relatively low, the shape is rectangular, and the water flows above ground level. The process of surface runoff calculations are based on the kinematic wave equation of continuity and momentum equations.

Kinematic wave describes the characteristics of the discharge change, velocity and water surface elevations with time at each distance in a uniform flow (uniform flow) and the flow is not fixed (unsteady flow) (Bedient, 2008, p. 270)

There are two equations needed to predict runoff flow phenomena (Badient, 2008, p. 269) as follows :

a. Continuity equation

Inflow = $\left(\boldsymbol{Q}-\frac{\partial \boldsymbol{Q}}{\partial_x}\frac{\Delta x}{2}\right)\boldsymbol{dt}+\boldsymbol{q}.\boldsymbol{\Delta x}.\boldsymbol{\Delta t}$

Outflow = $\left(\boldsymbol{Q}-\frac{\partial x}{\partial x}\frac{\Delta x}{2}\right)\boldsymbol{dt}$

Storage changes = $\frac{\partial A}{\partial t}.\boldsymbol{\Delta x}.\boldsymbol{\Delta t}$

With a flow rate q is width unity ($m^3/dt/m'$), and A is the cross-sectional area (m^2)

After separating Δx and Δt, after separating, the continuity equations becomes : $\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=\boldsymbol{q}$

For the A, the width unity, the average velocity of the continuity equations becomes : $\boldsymbol{y}\frac{\partial v}{\partial x}+\boldsymbol{v}\frac{\partial y}{\partial x}+\frac{\partial y}{\partial t}=\frac{a}{b}$

b. Momentum equation

With the assumption of uniform and steady flow and free air pressure can be ignored, then the channel bottom slope is parallel to the slope of the energy line. Momentum equation is taken from Newton's 2nd Law, that is:

F = $\frac{d}{dt}(mv)$,

$\frac{d(mv)}{dt}=m\frac{dv}{dt}+v\,\frac{dm}{dt}\rho A\Delta x, \frac{dv}{dt}=\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial x}$

The equation becomes :

$S_O-S_f=0$

In a state of uniform flow, Manning equation can be used :

$Q=\frac{So^{1/2}}{n}.A^m \rightarrow Q=\boldsymbol{\alpha}.\boldsymbol{A^m}$

Q is discharge (m^3/s), So is the slope of the channel base, n is the Manning rougness coefficient, A is the cross-sectional area flow (m^2), **α** and m are the kinematic wave parameters.

Continuity for flow on the surface runoff is :

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Continuity for flow on the surface runoff is:

$$\frac{\partial a_o}{\partial x} + \frac{\partial y_o}{\partial t} = i - f$$

The assumption of time of concentration with t = tc for x – xo = L, (Bedient, 2008, p. 283) is :

$$Tc = \left(\frac{L}{\alpha i_e^{m-1}}\right)^{1/m}$$

RESULT AND DISCUSSION

Infiltration rate is measured in units of length per time. The same unit applies to the rate of rainfall. The water depth of 1 cm per hour does not depend on the cross-sectional area of the water. That is the extent of the sectional area has indirect influence to infiltration rate.

When the tool was stared using slope variation and fixed intensity, the changes in the runoff happened throughout the time. Slope variations significantly affect the change of time to achieve a constant runoff value. For the value of runoff that occurs, the changes are not too significant because the media used is quartz sand which is not varied. This table below is the observation result of rainfall and runoff:

Table 1. The observation result of rainfall and runoff
Rainfall Intensity 13.56 mm/hr

Time	Slope and Runoff				
T (min)	Q-1%	2%	3%	4%	5%
0	0,000	0	0	0	0
5	0,021	0,58	0,58	0,58	0,58
10	0,026	0,57	0,57	0,57	0,57
15	0,026	0,57	0,57	0,57	0,57
20	0,039	0,56	0,56	0,56	0,56
25	0,061	0,54	0,54	0,54	0,54
30	0,085	0,52	0,52	0,52	0,52
35	0,061	0,54	0,54	0,54	0,54
40	0,085	0,6	0,6	0,4	0,4
45	0,085	0,5	0,8	0,5	0,38
50	0,085	0,5	0,7	0,42	0,38
55	0,085	0,2	0,6	0,4	0,38
60	0,085	0,2	0,5	0,4	0,35
65	0,085	0,2	0,5	0,38	0,35
70	0,085	0,2	0,4	0,38	0,35
75	0,085	0,2	0,4	0,38	0,35
80	0,085	0,2	0,4	0,38	0,35
85	0,085	0,2	0,32	0,38	0,35
90	0,085	0,2	0,32	0,35	0,32

The data in the table can be considered the result of runoff measurements on quartz sand media with variations in the slope and the rainfall intensity. Runoff at a certain time will approach a constant value.

The process can be seen in the following figure below.

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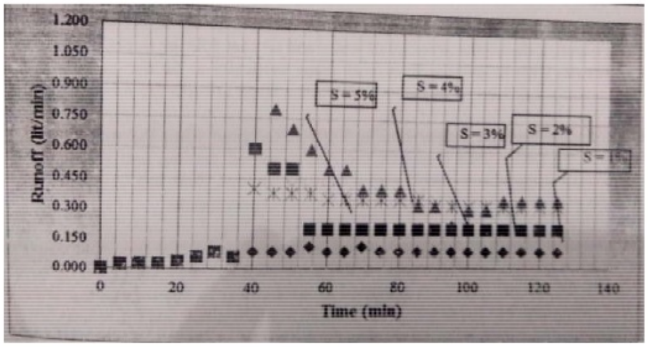

Figure 1. The observation result of rainfall(13,56 mm/hr) – runoff measurement, and variation slope: 1%, 2%, 3%, 4%, 5%. (Photograph courtesy of observation result).

Changes in the value of runoff are not significant to the study of media due to the same variation slope of the land, quartz sand. Rainfall that began falling on the surface of the land on the slope began to fill the pores of the pervious quartz sand. The longer of specified time fill to entire pore space. By that time the water will begin to fill the entire space in the media and start to flow. Runoff happened at first start at zero from thr start and then increased to a constant.

The slope is different and more increase will result in the pressure in the upstream and downstream land. Pressure that occurs is due to the presence of water and air that fills the pores of soil media. The media pressure upstream from now being filled with water vertically to fill the pores of media, and began to flow horizontally to fill the pores of the media with a slope towards the downstream area.

The process flow of water through the pervious soil affects the time when the media began to fill, drain, and then meet the media until it reaches the output started pooling and running flow. The storage with sequential volume also to runoff with a constant amount. Start stagnant water conditions and start to flow with a constant amount and that is the time of concentration.

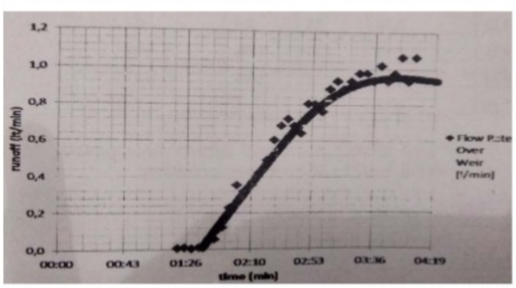

Figure 2. Runoff and time curve from Rainfall Simulator (Photograph courtesy of observation result)

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Time of concentration that occurs at a constant runoff will occur also at the time that occurs in the condition of the media in water saturated condition and there is no longer room for pervasive that fill and drain the water in the media. This event is named as infiltration. So that it is related to the water balance approaches which involves the relationship between rainfall, runoff and infiltration.

Water balance approaches between rainfall, runoff and infiltration. The infiltration calculation reduce rainfall to runoff. The infiltration of the calculation results can be seen in the following table:

Table 2. Infiltration calculation with Rainfall-Runoff Measurements, 3 %,1 lit/min

Time	Runoff	Rainfall-Runoff = Infiltration	Time	Runoff	Rainfall-Runoff = Infiltration
1	0,1	0,9	14	0,35	0,65
2	0,08	0,92	15	0,38	0,62
3	0,1	0,9	16	0,44	0,56
4	0,12	0,88	17	0,48	0,52
5	0,13	0,87	18	0,54	0,46
6	0,15	0,85	19	0,59	0,41
7	0,17	0,83	20	0,6	0,4
8	0,2	0,8	21	0,8	0,2
9	0,21	0,79	22	0,86	0,14
10	0,22	0,78	23	0,9	0,1
11	0,31	0,69	24	0,92	0,08
12	0,34	0,66	25	0,98	0,02
13	0,36	0,64	26	1	0

When connected between rainfall and runoff measurements process, we can find the time of concentration of the rainfall, runoff and infiltration. As follows:

Table 3. Time of Concentration in Slope and Rainfall

Slope	Time of concentration / Rainfall				
	1 lit/min	1,5 lit/min	2 lit/min	2,5 lit/min	3 lit/min
1%	0,92	1,5	3,5	6,67	7,17
2%	0,41	1,17	2,2	2,5	3,3
3%	0,33	1	1,3	1,5	1,7
4%	0,25	0,5	1,2	1,3	1,50
5%	0,17	0,3	0,83	1,67	0,33

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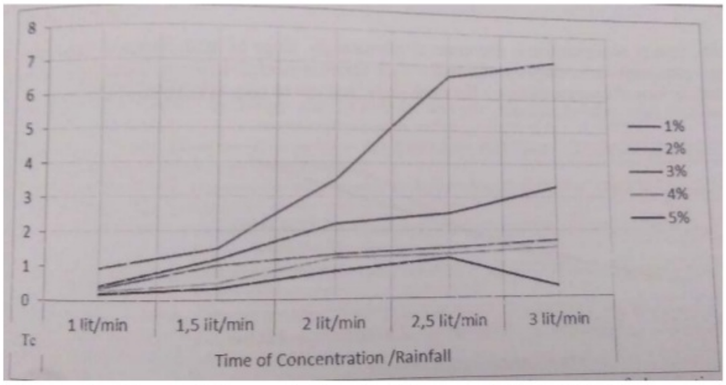

Figure 3. Time of Concentration in Slope and Rainfall (Photograph courtesy of observation result)

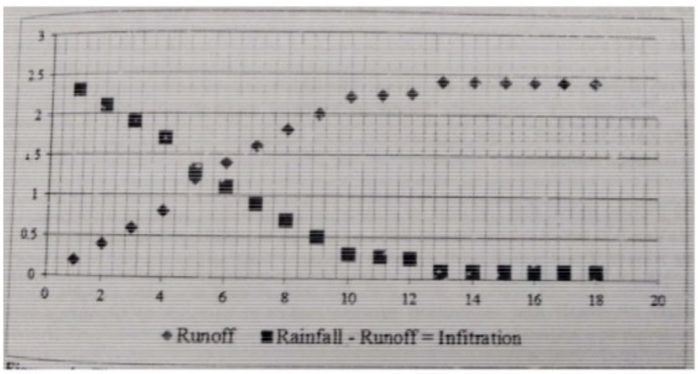

Figure 4. The curve of Runoff – Infiltration at 2,5 l/min of Raunfall (Photograph courtesy of observation result)

Conclusions

Variable slope variation will produce a different concentration on the same rainfall intensity. It is shown on the paragraph below:

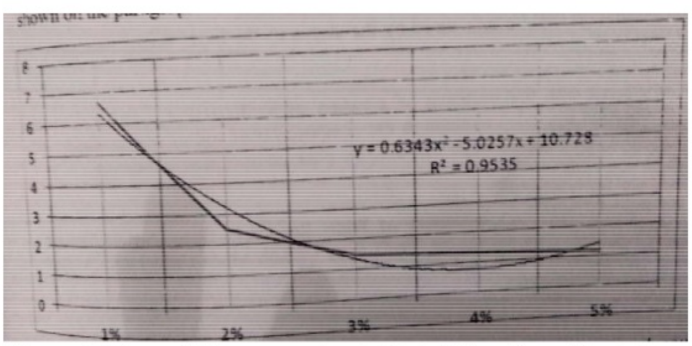

Figure 5. Time of Concentration in Rainfall to Slope Variations (Photograph courtesy of obsevation result)

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In the se, time of concentration is decreases in increasingly slope of land. Slopes of land affect the time of concentration in the same rainfall. And variable rainfall intesity variation will have a different the time of concentration on the same slope, and can be seen in the following figure:

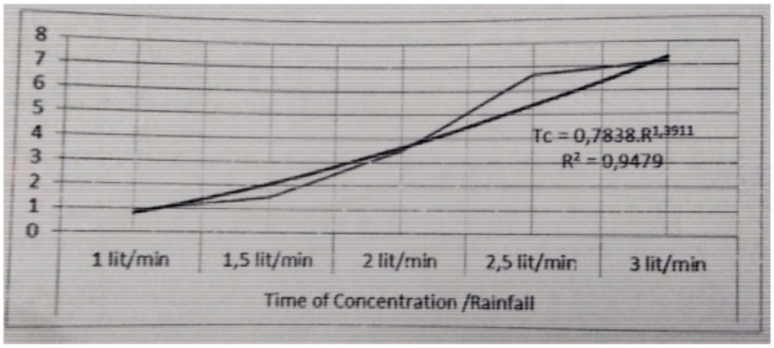

Figure 6. Time of concentration in Slope 1% to Rainfall Variations (Photograph courtesy of observation result)

Infiltration data generally depicted in the form of curves. The illustrated curve shows the relationship of infiltration and runoff water are commonly found in artifical rainfall intensity remains. Soil infiltration capacity begins at the start of the biggest rain, then decreases following the length of the rain so as to achieve a constant minimum.

It can be seen from the picture above that the time of concentration can also occur in infiltration. The infiltration curve shows that is pervious mediaand 80% of rainfall would be infiltrate so that the rest of the rainfall would be runoff. There are some factor that influence infiltration process beside rainfall and runoff condition, which are the type of soil, and the soil properties. The complexity and interaction of site factors on runoff and infiltration procces makes it difficult to identify a single component of the hydrograph that accuratelly characcterizes the entire runoff event.

So it can beconcluded that:

1. The time of concentration can occur in runoff events and infiltration procces.
2. The time of concentration can be determined on the incidence of rainfall, runoff and infiltration.
3. The time of concentration is influenced by the media where the rain falls, the behavior of both the behavioral land on the surface of the land or in the media field.
4. The time of concentration will be influenced by the slopes of the land, media treatment, and the rainfall.

This research can be continued wuth the treatment of a variety of media research fields. Variation medium density land in question is land, variations in the composition of soil or soil gradation. The selected plots were on similiar soil type and slope with similiar plant compositon and density.

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Bibliography

Akan, A. O (1986). *Time of concentration of Overland Flow*. The Journal of Irrigation and Drainage Engineering 283-292.

Bedient, W. C (2008). *Hydrology and Floodpain Analysis*. Canada: Prentice Hall, Pearson Education International.

Ben-Zvi, A. (2012). *Detention Storage Over 2d Labolatory Watersheds at Concentration Time*. Journal of Hydrologic Engineering, 105-1057.

Bondelid, T. R. (1982). Sensitivity of SCS Models to Curve Number Variation. Water Resources Bulletin Vol.12, No. 2, hal. 337-349.

Hawley, M. B. (1981). *A Planning Method for Evaluating Downstream Effects of Detention Basins*. Bulletin Vol.17 No. 5, hal. 806-813.

Ogbonna, S. U. ((2004). *Formula for the Time Concentration of Runoff*. Journal of Hydraulic Engineering, 576-579.

Richard H, M. S. (1984). *Estimating Urban Time of Concentration*. Journal Hydraulic Engineering, 887-904.

Wong, T. S. (2009). *Evolution of Kinematic Wave time of Concentration Formulas for Overland Flow*. Journal of Hydrolic Engineering, 739-744.

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