雨水利用と洪水緩和のための雨水貯留タンクの適用に関する研究

A study on application of harvesting tank for reusing rainwater and to flood mitigation

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Key Words: rainwater, harvesting tank, reusing rainwater, flood mitigation, frequency of rainfall

1. Introduction

Hanoi city which is on the North of Vietnam, is a capital, economy center and home to everyone from all over Vietnam. Accompanying the development of Vietnam, Hanoi city is broader and more developing day by day. However, because of fast development, Hanoi city is facing up to the fast rising of urbanization and unbalance causing many problems. Typically, there are two problems in Hanoi which are water shortage and flood. Because of the fast urbanization, there are many impervious areas and the drainage systems are overloaded when the permeable areas are decreasing and disappearing. Otherwise, Hanoi is being affected by underground water exploitation that causes the subsidence issue. Therefore in the rainy season, Hanoi has been always in a flooding situation. Moreover, the fast rising of population in Hanoi causes the unbalance of water usage. Although water treatment plants always work with full power, in somewhere near Hanoi center, the water shortage problem still exists. Both of the problems happen in the rainy season when the rainfall is the highest. Therefore if harvesting the rainwater from the impervious area as building rooftops, the discharge going into drainage systems will reduce and we can also use harvested rainwater for un-drinking water such as toilet flushing, cleaning, clothes washing, watering garden and firefighting. On my purpose, I want to study about rainwater harvesting tank (RHT) to evaluate the ability of RHT to mitigate flood.

2. Objectives

From the annual rainfall data list (from 1956 to 2013, 58 years), determining the rainfall model corresponding the years which have high rainfall, average rainfall and low rainfall condition (**Fig. 1**). In this paper, using the rainfall data of typical year in 58 years to calculate the tank volume depending on the un-drinking water and the capable harvesting area of building. On the other hand, the runoff discharge of each building and the discharge of flow in drains are also determined. Considering tank as a reservoir and using the calculated volume to do the calculation again. Therefore two main objectives; calculating the tank volume of the buildings for reusing rainwater in one year by using the data of un-drinking water demand and evaluating the effectiveness of tanks on the flood mitigation (**Fig. 2**)

3. Methodology

1) Determining the Designing Rainfall Model (DRM)

a) Choosing the rain gauge station

The chosen rain gauge station should be near the catchment (in 10km radius).

b) Choosing the design event of rainfall

Choosing the design frequency of rainfall to determine the DRM for the study catchment. By the DRM we can assess the rainfall potential. In fact, the annual rainfall is various, thus to evaluate accurate rainfall potential, I will calculate the DRM depending on years which have high rainfall, average rainfall and low rainfall. The higher rainfall is, the lower frequency is. Therefore I will choose the frequency value corresponding rainfall events case 1, case 2 and case 3 or rainfall of years 1973, 1985, and 1992

c) Determining method

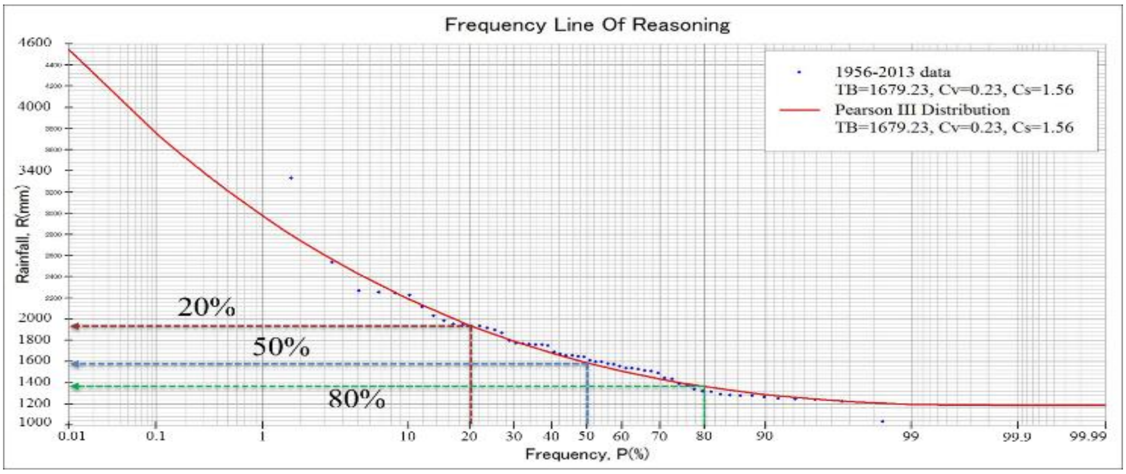


Fig. 1 Choosing rainfall events by frequency line of reasoning

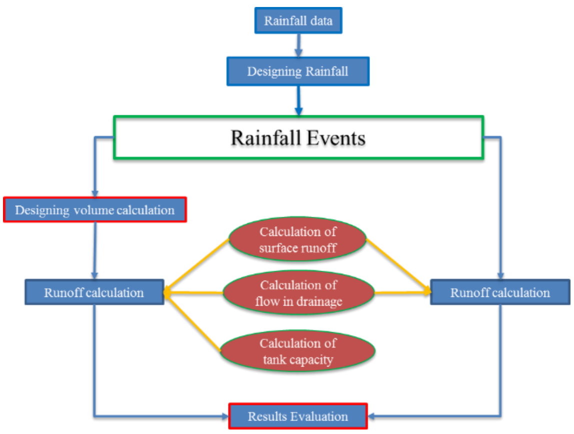


Fig. 2 Flow chart of the study

In this study, I use statistical probability method to calculate the DRM. From annual rainfall data, calculating and drawing the frequency line of experience by equation (1),

$$P_{x_i} = \frac{m_{x_i}}{n+1} \times 100\% \qquad (1)$$

where P_{x_i} is the experimental frequency of precipitation of observed year (%), m_{x_i} is total numbers of occurring values which are same or bigger than x_i, n is total of x_i.

After drawing the frequency line of experience, continue calculating and drawing frequency line of reasoning which was represented by equations,

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (2)$$

$$C_V = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{(n-1)\bar{X}^2}} \qquad (3)$$

$$C_S = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^3}{(n-3)C_V^3 \bar{X}^3} \qquad (4)$$

where X_i is rainfall of ith year (mm), $\bar{X}$ is average rainfall of total year (mm), C_V is the dispersion coefficient, C_S is the bias coefficient.

According both of frequency lines, the trend lines are almost similar, however using the frequency line of reasoning to do the calculation accurately. From the frequency line of reasoning, find out the rainfall corresponding 20%, 50% and 80% then from the annual rainfall data, choose year which has the most similar rainfall to use for calculating.

2) Calculating designing volume

Following the main objective, I calculate the tank volume depending on un-drinking water demand of each building and the capacity of building on harvesting rainwater. The calculation method is described by the model in (**Fig. 3**). From the water balance equation (5),

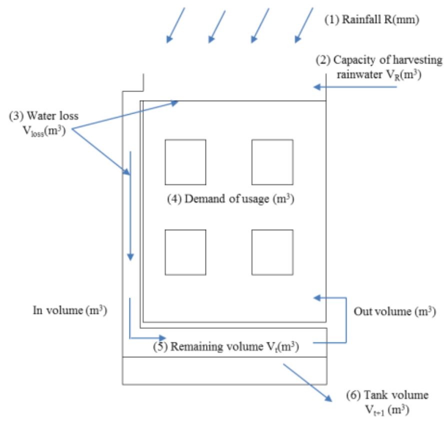


Fig. 3 Model of tank volume calculation

$$\frac{dV_T}{dt} = V_{in} - V_{out} \qquad (5)$$

the tank volume is described by the equation (6),

$$V_{t+1} = V_t + V_R - V_{loss} - V_{use} \qquad (6)$$

where V_{in}, V_{out} are input volume and output volume, V_T, V_{t+1} is volume of tank at time t+1 (m^3), V_t is volume of tank at time t (m^3), V_R is volume of harvested rainfall (m^3), V_{use} is volume of usage at time (m^3), V_{loss} = 10% of V_{use}, is loss volume at time (m^3).

3) Runoff calculation

a) Model description

EPA SWMM 5.1 is a dynamic rainfall-runoff simulation model used for single event or long term (continuous) simulation of runoff quantity and quality from primarily urban areas (USEPA, 2009). SWMM's conceptual framework is implemented through a set of connected objects, each performing a junction within the model. Rain gage can represent any given rain event. Sub-catchments receive the rainfall, and are described by areas, characteristic width and slope, percent imperviousness, depression storage, and soil properties. Sub-catchment can be divided into specific land uses. The infiltration of water can be describe by the Horton or Green-Ampt, and in this study, the Horton method is used. If water is not infiltrated, it becomes surface runoff and is transported through a series of conduits and nodes to a final outfall. Routing can be described by steady flow, kinematic wave routing, and dynamic wave routing. In this case, dynamic wave routing is used to calculate the runoff.

b) Surface runoff calculation

At the beginning, the rainfall excess which is the rainfall intensity less the evaporation and infiltration rate, were taken from Thuy Loi University, has to be calculated following the equation (7)

$$R_e(t) = R(t) - E(t) - I(t) \qquad (7)$$

where $R_e(t)$ is rainfall excess (mm/h), $R(t)$ is the rainfall (mm/h), $E(t)$ is evaporation loss (mm/h), $I(t)$ is infiltration loss (mm/h).

The entire process is repeated for each subwatershed and is modeled by two equations, continuity equation (8) and Manning's equation (9),

$$\frac{dV}{dt} = A\frac{dh}{dt} = AR_e(t) - Q(t) \tag{8}$$

$$Q(t) = \frac{1}{n}B\left(h - h_d\right)^{5/3} S_0^{1/2} \tag{9}$$

where $V = Ah$ is volume of water on the subwatershed (m^3), A is area of the subwatershed (m^2), h is the depth of water on subwatershed (m), $R_e(t)$ is the rainfall excess (mm/h), Q is the runoff flow rate from the subwatershed (m^3/h), h_d is the depth of maximum depression storage (m), B is the width of flow over the subwatershed (m), S_0 is the slope of the subwatershed (m), calculated as a function of the average depth of flow the final equation used to calculate the runoff is,

$$\frac{h_{n+1} - h_n}{dt} = R_e(t) - \frac{1}{n}\frac{B}{A}\left(h - h_d\right)^{5/3} S_0^{1/2} \tag{10}$$

where $h = (h_{n+1} + h_n)/2$ is the average depth of flow during time step n+1 (m).

The Newton-Raphson technique for numerically solving a simple nonlinear equation (10) is used to solve for h_{n+1}. The calculated value of h_{n+1} is then used in equation (9) to calculate the value of Q at the end of the time step.

c) Drainage systems calculation

Using the complete Saint-Venant equations, momentum equation and continuity equation to model the routing of flows through a sewer system.

$$\frac{\delta A}{\delta t} + \frac{\delta Q}{\delta x} = 0 \tag{11}$$

$$\frac{\delta Q}{\delta t} + \frac{\delta}{\delta x}\left(\frac{Q^2}{A}\right) + gA\frac{\delta h}{\delta x} + gA\left(S_f - S_0\right) = 0 \tag{12}$$

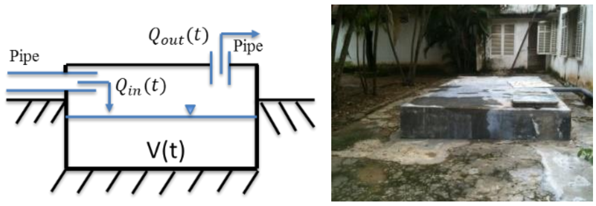
where Q is the flow rate (m^3/s), A is the cross-section area of flow (m^2), h is the water depth (m), x is the distance along conduit (m), t is time (s), g is the acceleration due to gravity (m/s^2), S_0 is the slope of conduit (m/m), S_f is the friction slope (m/m).

From equations (11) and (12), the basic flow equation used to calculate the flow in sewer system is,

$$gA\frac{\delta H}{\delta x} - 2v\frac{\delta A}{\delta t} - v^2\frac{\delta A}{\delta x} + \frac{\delta Q}{\delta t} + gAS_f = 0 \tag{13}$$

where v is the average flow velocity (m/s).

Essentially, the equation (13) contains two variables, *Q* and *H* (*v* and *A* are related to *Q* and *H*). Therefore, the continuity equation (11) is used to provide a second equation relating *Q* and *H* at each node. Finite difference approximations are used to numerically to solve the two partial differential equations.



(a) (b)

Fig. 4 (a) Level-surface reservoir model (b) Level-surface reservoir in fact

d) Calculating harvested rainwater volume

If a unit is modeled as a detention unit, as shown in (**Fig. 4**), flows are routed through the unit with a level-surface flow routing procedure (i.e., the modified Puls method). This method is based on yet another version of continuity equation (Viessman, et al. 1988),

$$\frac{dV}{dt} = Q_{in} - Q_{out} \tag{14}$$

where V is the volume of water in detention unit (m^3), Q_{in} is the inflow rate (m^3/s), Q_{out} is the outflow rate (m^3/s), t is time (s).

The equation (14) is approximated by the following finite difference relationship,

$$\frac{\left(V_{n+1} - V_n\right)}{\Delta t} = \frac{\left(Q_{n+1}^{in} + Q_n^{in}\right)}{2} + \frac{\left(Q_{n+1}^{out} + Q_n^{out}\right)}{2} \tag{15}$$

where n, n+1 subscripts indicating conditions at the end of time step n (or beginning of time step n+1) and the end of time step n+1, $\Delta t = t_{n+1} - t_n$ is time step (s).

At the end of any time step, the values of V_{n+1} and Q_{n+1} are unknown (the values for V_n and Q_n are known from the previous time step.) A second relationship between storage, V and discharge Q is needed to determine their values. Using a linear interpolation algorithm to approximate the relationship through a series of volume-discharge data pairs (each pair occurring at a particular depth). With two relationships (equation (15) and the user-supplied volume-discharge information) it is possible to solve for V_{n+1} and Q_{n+1} at each time step.

4) Study site description

The study site is Hanoi Water Resources University (a new name is Thuy Loi University) which is a part of Hanoi city center. Thuy Loi University includes office area (administrative building), public

service area (buildings of classes), living area (dormitories), and parks.

Table - 1 The calculated volumes

Buildings	Area (m^2)	Designing volume (m^3)	Tank Height (m)
A1	1255.25	504.13	0.40
A2	830.73	1036.41	1.25
A3	931.94	1314.51	1.41
A4	1052.18	1395.56	1.33
B1	692.68	979.37	1.41
B5	2063.09	1778.49	0.42
T45	3106.27	1778.49	0.46
D2	1457.05	1428.88	1.37
D3	1101.25	1996.16	2.13

Lang rain gage is located at No.8 PhaoDaiLang, DongDa dist., Hanoi, is about 3km far from Thuy Loi University. Therefore choosing the annual rainfall of Lang rain gage to calculate.

In this study, the observations is divided into smaller catchments. The parameters of catchment and sewer system are measured and reproduced by CAD software. From the CAD drawing, the

characteristic width and slope are calculated. Depression storage was taken to be the default value of 2mm and soil properties was taken from data of Thuy Loi University.

4. Results of calculation

Because having not enough space to show all the results, in this paper, I will show up an example result (case 1, the heaviest rainfall event of 1973).

1) Tank volume calculation

After doing the tank volume calculation depending on the demand of un-drinking water of each building, the results are shown in (**Table 1.**). If assume that the tank area is similarly to building area, the tank height equal tank volume divides to building area. Use the calculated results as the parameter to calculate again the discharge at Manhole.

2) Flow evaluation without tank

The discharge at flooding nodes receiving water from buildings are from 0.03 m^3/s to 0.5 m^3/s. In the example result, the peak of discharge in flooding node at T45 building is 0.16 m^3/s (**Fig. 5**)

3) Flow evaluation with tank

From calculating runoff without tanks, I found out the flooding nodes and did the calculation again with tank. The results are shown in (**Fig. 5**) The peak of discharge flow at 21:00 in 1973/7/23 is 0.11 m^3/s, comparing to case without tank (0.16 m^3/s), the discharge reduction is 0.05 m^3/s (1/3 of the discharge flow)

5. Conclusion

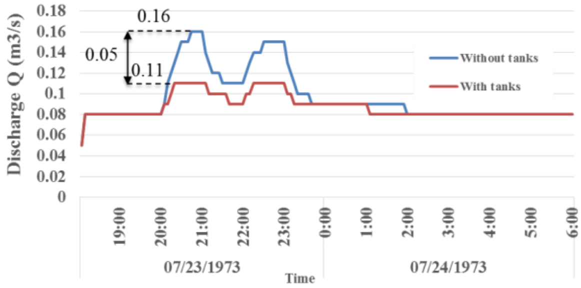


Fig. 5 Flow evaluation with tank of T45 building in the heaviest rainfall event 1973

The calculated tank volume provides enough water for each building in the years having high rainfall and low rainfall. Otherwise, the tank also can reduce the flow into drainage system despite heavy rain.

After finishing a rain event, the harvested rainwater volume is smaller than designing volume, by the condition initial volume equals zero. There is no discharge out from the tank, therefore the calculated tank volume is good for flood mitigation.

In the study, the runoff discharge was reduced (1/3 of the discharge flow), therefore the tanks is useful in the flood mitigation.

Because the designing volume is calculated depending on the demand of water usage of each building in calculating site, the volume might be big. Therefore to reduce the cost of building tank, we need to rebalance the using water from water treatment plants and the rainwater source.

Beside the advantages, the tank is too large, need more study to reduce the tank size. On the other hand, should use other methods besides using the tanks to reduce flooding in others areas without buildings.

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