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Calculating the volume of Tan Mieu lake in Thanh Noi area, Hue City, for the urban stormwater drainage system

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Abstract. Detention lakes, which are effective means of flood control, are highly effective in sustainable drainage solutions. Numerous factors diminish the regulating reservoir's function for urban drainages, such as the lake's small volume, an inadequate drainage system, and restricted outflow from the lake. Therefore, this study applies the method of limited rainfall intensity to calculate the stormwater flow into the lake and determine the volume of the detention lakes according to TCVN 7957: 2008 [1] to the sub-basin of Tan Mieu. It is confirmed that the volume of the lake in the region and the level of outflow from the lake, which are essential factors in flood mitigation, is not suitable for the rainfall characteristics of the area. The results show that with the planned outflow of $Q_x = 1/3 \times Q_t$, the lake's actual capacity is roughly a half of the required lake capacity. With the option $Q_x = 1/2 \times Q_t$, the actual volume of the lake is 1.2 times smaller than the calculated capacity. Therefore, increasing the lake's volume and outflow volume from the lake minimizes local flooding.

Keywords: detention lake, Tan Mieu Lake, urban drainage, limited rainfall intensity, Hue City

1 Introduction

In the 70s of the 20th century, numerous new technologies and drainage concepts were created to solve urban flooding sustainably. A sustainable drainage approach is to increase the rate of stormwater infiltration into the soil by reducing and slowing down runoff to reduce water flow in storm drains and water flow into rivers during heavy rains [2]. Detention lakes are highly effective in sustainable drainage solutions [2]; [3]; [4] because these lakes are constructed as low-lying basins to temporarily store large amounts of stormwater, thus reducing the risk of flooding.

The US Environmental Protection Agency highly appreciates the role of detention lakes; they said this is the best management method when stormwater overflows to help prevent and reduce the severity of floods and improve water quality. Various world authors have studied and applied detention lakes, such as Souza et al. [4], using the Storm Water Management Model

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– SWMM, confirmed the detention lake as an alternative, promoting increased stormwater infiltration into the soil and compensating for the lost infiltration due to urbanization. Ana et al. studied flood control using stormwater ponds in Mesquita, Brazil, utilizing the MODCEL model [5]. Khan et al. used the SWMM 5.1 software to analyze and calculate the hydrological benefits of onsite detention lakes for the sub-basin of the Mahiminside Mithi River watershed (India), an area with a rapid urbanization rate. This study has confirmed that the detention lake significantly reduces the flood peak and delays its appearance [6]. To determine the size and capacity of the detention lake, we used hydrological calculation methods to investigate the local characteristics and intended usage. These methods include the Colorado Urban Hydrology Process, UDSWMM, Modified FAA Method, and the V = KA approach.

In Vietnam (Fig. 1a), detention lakes have been studied and applied mostly in Hanoi and Ho Chi Minh City; these cities have a high rate of urbanization and increasingly heavy urban flooding. Sam et al. determined the location to build detention lakes for five drainage zones to minimize flooding in Ho Chi Minh City [7]. Truong et al. proposed solutions to prevent flooding in urban subdivision S2, Hanoi City planning. Quan et al. said that using detention lakes to reduce urban flooding in Hanoi has not yet brought desired effects. The reasons are that the number of lakes is small; their size is small; there is a lack of regulation works; the problem of maintenance and upgrading is delayed, etc. Quan et al. also provided the basis for calculating the detention storage volume, including the catchment area, the topography of the basin, the drainage system of the basin, and meteorological, hydrological, and geological characteristics [8]. Dong used different methods to calculate the volume of a detention lake for Nho Quan Town – Ninh Binh. These methods include calculation according to TCVN 7957-2008 Drainage – External networks and structures – Design standards, Calculation based on the total volume of the inflow hydrograph and the volume of the outflow hydrograph, Calculation based on triangular inflow hydrograph, Calculation based on regression method, etc. [9]. There are a few studies on urban flooding and inundation in Hue City with the following objectives: flood situation, flood trend forecasting, flood simulation in some main inner-city roads by data system on storm rain, topography, water infiltration capacity, and drainage coefficient of the drainage system. Mai et al. surveyed the status of using some lakes and ponds in the Thanh Noi area [10]; Ngoc et al. applied simulation technology in flood warnings due to rain in Hue City [11].

There are 38 lakes in the Thanh Noi area. They are linked by a chain of lakes and lake systems to form a self-flowing drainage system that drains a 520-hectare basin. These lakes are valued as natural detention basins and are now used for multiple purposes. The Thanh Noi area is regularly threatened by floods every year, so the use of the lake for flood mitigation should be given top priority, especially in the context of increasing extreme rainfall due to climate change.

So far, the lake system in the Thanh Noi area has been used to gather water and then route it into the region's principal drainage axis, the Ngu Ha River, before exiting to the Huong River in a self-flowing form based on the terrain slope. Each lake serves as a drainage for a sub-basin in the region's urban drainage system. Lake encroachment and sedimentation have taken place for a long time in the Thanh Noi area. Son and Dung revealed that the total area of ponds and lakes has decreased significantly to only 431,858 m^2, accounting for 8.3% of the area, which does not meet the standard required minimum water surface area compared with the natural area. The total area of the ponds and lakes decreased by 695,749 m^2 [12], [13]. Many lakes contribute to the area's advantage in holding a vast volume of stormwater and enhancing the potential to reduce the creation of urban flooding during rainy seasons. Simulation results by the SWMM model of flooding in Hue city from October 1 to 3, 2010, by Ngoc et al. on the flood depth at some roads in the Thanh Noi area show that flooding still occurs with a flood level of more than 0.5 m [11].

The research on the structure, exploitation, and effective use of the detention lakes in the Thanh Noi of Hue City still requires more attention, including the storage capacity and the connection efficiency among the lakes in the study area, even though the density of the lake is quite high.

Therefore, the objective of this study is to confirm that the storage volume of the detention lake in the sub-basin and the level of drainage outflow from the lake are the primary factors in minimizing flooding. This study focuses on assessing the required volume for Tan Mieu Lake by analyzing the characteristics of the sub-basin rainfall regime and drainage system. The study's results will clarify the level of efficiency of the lakes to urban drainage systems; the results also provide a basis for selecting measures to mitigate localized flooding during the rainy season in the Thanh Noi area.

2 Study area and method

2.1 Study area and data source

The Tan Mieu Lake (Fig. 1e) is located southwest of Thanh Noi and is the receiving point for the stormwater runoff on the sub-basin. It is bounded by Ton That Thiep Street in the west, Le Huan and Phung Hung Streets in the east, Thach Han Street in the north, and Yet Kieu Street in the south and belongs to the former Thuan Hoa ward, with coordinates ranging from approximately 16°28'8.04"N to 16°28'13"N. The Thanh Noi area (Figs. 1c, 1d) of Hue City (Fig. 1b) is between 16°29' to 16°27'N and 107°33' to 107°35'E, occupying an area of about 520 ha with an 11 km circumference. According to the survey, there are 38 lakes in the location with a total area of 431,858 m^2. Most lakes are only a few thousand to tens of thousands of square meters in size. The lakes usually have a square or rectangular shape; the average depth when formed is about 3–4 m. However, now, numerous lakes are deposited, so they are only 2 m to less than 3 m deep.

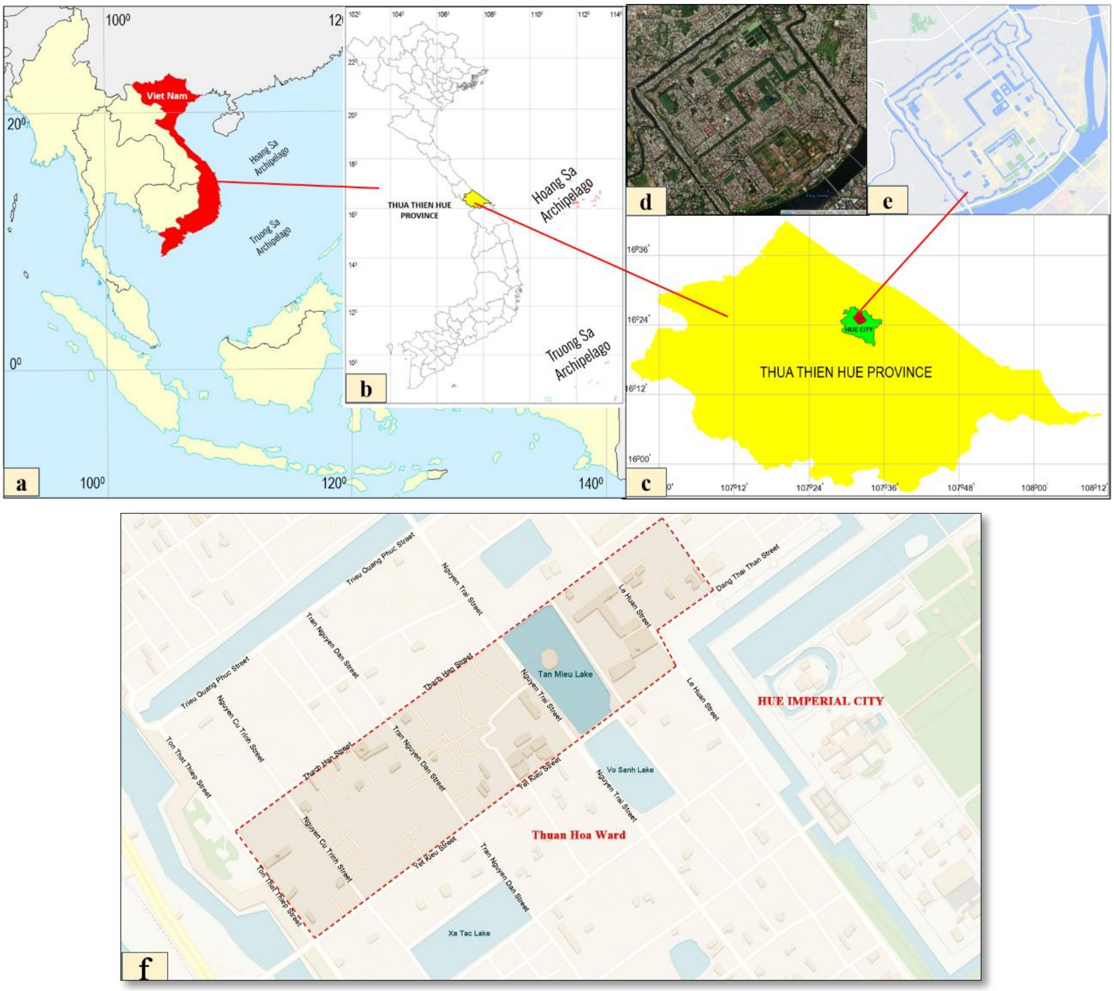

Fig. 1. Research locations: Vietnam in Southeast Asia (a); Vietnam (b); Thua Thien Hue province (c); Satellite image of lakes and ponds (d); Map of lakes and ponds in the Thanh Noi (e); Tan Mieu Lake sub-basin (f) (Edited from Google Map)

The study area is in a climate with much rain, seasonal concentration, and heavy rain in a short time (Table 1 and Table 2).

Table 1. The maximum daily rainfall corresponds to the guaranteed frequencies of Hue [14].

Guaranteed frequencies (%)	10	20	30	40	50	60	70	80	90
Rainfall (mm)	540	405	329	276	237	206	180	160	144

Table 2. Heaviest rainfall intensity by Rainy time in Hue city

Rainy time (min)	10	30	60
Rainfall (mm)	26	67	120

The Thanh Noi area is characterised by a relatively flat topography; the base elevation is only 1.8–3.5 m. Although the soil in Hue City has a reasonably significant capacity to hold water, it is quickly saturated due to a massive amount of rain occurring in a short period, and water permeability decreases sharply from the second rainy day of rainfall. As a result, the worn crust – the soil of Hue City – has only a moderate to poor ability to regulate water. Compared with other sites, the study area has a high level of vegetation cover. The density of buildings has increased many times over the last few decades; highways have been enlarged, restricting the area of garden houses, and other factors have contributed to increased surface runoff.

The study used the following data sources:

The Hue urban flood hazard warning data with different intensity storm rain scenarios by[11]; The data on the actual detailed investigation of the surface cover of the study area and data on the thorough fundamental analysis of the surface cover of the study area were used to calculate the runoff coefficient; The climatic constant in the formula for calculating the rain intensity and the formula for calculating the volume of the detention lake, according to TCVN 7957:2008; The diagram of the drainage system in the Thanh Noi area and the data on the drainage system in the Thanh Noi area from the Hue City of Hue Urban Environment Company (Table 3).

Table 3. The drainage system in the sub-basin of Tan Mieu Lake

Street name	Limit		Cement ditch (m) (B: <600)	Cement pipe (m) (φ: <600)	Water collection well (piece)	Drainage place
	from	to				
Yet Kieu	Le Huan St.	Ton That Thiep St.	632	444	69	Tan Mieu Lake
Thach Han	Phung Hung St.	Ton That Thiep St.	656	500	58	Tan Mieu Lake
	Phung Hung St.	Le Huan St.		319	22	Tan Mieu Lake
Masterpiece number 25 Thach Han St.			50			Tan Mieu Lake

2.2 Methods

TCVN 7957:2008 is used to calculate lake capacity because the study area has drained to the lake, and there is no pumping station, drainage – external networks, and structures – design criteria are required. The formula is as follows:

$$W = K.Q_t.t_t \quad (1)$$

where Q_t is the volume of rainwater flowing into the lake (m^3/s); t_t is the rain time of the catchment area with culverts serving drainage to the outlet dumping into the lake (s) (based on the hydraulic spreadsheet of the rainwater drainage network); K is the coefficient, which depends on ∝ and can be determined from the following formula, according to (TCVN 7957 : 2008) (Table 4).

$$K = (1 - \alpha)^{1.5}.$$

where $\alpha = \frac{Q_x}{Q_t}$; and Q_x is the volume of outflow exiting the lake (outflow); Q_t is the rainwater flow into the lake (inflow).

Table 4. Determine the coefficient *K* according to ∝

∝	*K*	∝	*K*	∝	*K*
0.10	0.50	0.40	0.42		
0.15	1.10	0.45	0.36	0.70	0.13
0.20	0.85	0.50	0.30	0.75	0.10
0.25	0.69	0.55	0.25	0.80	0.07
0.30	0.58	0.60	0.21	0.85	0.04
0.35	0.50	0.65	0.16	0.90	0.02

Determine the values of Q_x, Q_t, K, and t to calculate the volume of the detention lake.

Step 1. Calculate the volume of storm rain runoff flowing into the lake according to the limit intensity method (TCVN 7957 : 2008), according to the formula

$$Q_t = q.F.\psi.\alpha \quad (2)$$

where F is the catchment area that the drainage system pipe (ha); ψ is the coefficient of distribution of showers. Take ψ = 1 when the area of the calculated basin is less than 200 ha; α is the runoff coefficient; q is the calculated rainfall intensity by the limit intensity method, according to the formula:

$$q = \frac{A(1+C\lg P)}{(t+b)^n} \ (L/s/ha) \quad (3)$$

where P is the return period in the year; t is the calculation storm duration; A, b, C, and n are the climate constants in the precipitation intensity formula

Substituting (3) into (2), we have the following formula for calculating Q_t:

$$Q_t = F.\psi.\alpha.\frac{A(1+C\lg P)}{(t+b)^n} \ (l/s \ or \ m^3/s) \quad (4)$$

Step 2. Determine the calculation of storm duration (t) (min). The calculation is as follows:

$$t = t_m + t_c + t_r \quad (5)$$

where t_m is the time for stormwater runoff to flow from the furthest point to the drainage ditch, also known as the time to concentrate water on the surface. Take t_m = 5÷10 min; t_r is the time for stormwater runoff to flow to the nearest stormwater collection well in the trench.

$$t_r = 1.25\frac{l_r}{v_r}$$

where l_r is the length of the trench (m); v_r is the speed of stormwater in the trench (m/min); 1.25 is the factor that considers the possibility of increasing the flow rate during the rainy process; t_c is the time for water storm to flow in the pipe from the collection well to the calculated cross-section.

$$t_c = r\Sigma\frac{l_c}{v_c}$$

where l_c (m) is the calculated length of pipe; v_c (m/min) is the speed of water in the line; r is the terrain dependence coefficient (r = 2 when the terrain is flat; r = 1.2 when the landscape is steeper than 3%).

Substituting the values t_r and t_c into (5), we have the formula to calculate the calculation storm duration (t) as follows:

$$t = t_m + r\Sigma\frac{l_c}{v_c} + 1.25\frac{l_c}{v_r} \quad (6)$$

Step 3. Determine Q_x (flow out of the lake) according to the following options:

$$Q_x = \frac{1}{3}Q_d; \ Q_x = \frac{1}{2}Q_d$$

where Q_d is the peak flow (m^3/sec).

Step 4. Find the value $\propto$ from that to deduce K to calculate the volume of the detention lake according to the design rainfall.

Step 5. Compare the results of calculating the volume of the detention lake according to the design rainfall with the existing volume of the lake.

Applying specific calculations to the sub-basin of Tan Mieu Lake

The constant value in calculating the rainfall intensity of Thua Thien Hue province according to TCVN 7957–2008 is as follows:

A = 1,610; C = 0.55; b = 12, and n = 0.55.

Choose P = 2 (years); r = 2 (due to the flat topography of the study area); t_m = 5 min.

The average distance between two rainwater harvesting holes is about 50 m.

The storm drain has been designed with v = 1 m/s; the average runoff coefficient calculated over the study area is 0.5.

Assuming that $Q_d = Q_t$.

3 Results and discussion

Using the method of limiting rainfall intensity, we calculate the rainfall intensity from the storm duration value (t) of sub-areas in the Tan Mieu sub-basin, according to the following formula

$$q = \frac{1{,}610 \times (1 + 0.55 \times \lg 2)}{(t+12)^{0.55}} \quad (7)$$

and the calculated stormwater flow pouring into Tan Mieu Lake was computed according to equation (8)

$$Q_t = F \times 1 \times 0.5 \times \left(\frac{1{,}610 \times (1 + 0.55 \times \lg 2)}{(t+12)^{0.55}} \right) \quad (8)$$

Substituting the values (t) into (8), we have the values of Q_t. The results are shown in Table 5.

Table 5. Calculation results of stormwater flow to the lake and time to concentrate stormwater into the lake of the main storm drain to Tan Mieu Lake sub-basin

Drain pipe	l (m)	F (ha)	Q_t (L/s)	V (m/s)	T_r (min)	t_c (min)	t (min)	d (mm)
A	1,156	12	625	1	17.03	38	169	<600
B	1,076	13	677	1	18.75	35	171	<600
C	359	8	806	1	5.2	11	46	<600
D	50	1.8	376	1	1	2	8	<600

The results obtained are as follows:

The total time for rainwater in the catchment area to pour into the lake is 394 min (6.5 h).

The total incoming flow is 2,484 L/s = 2.48 m^3/s.

With the planned outflow of $Q_x = \frac{1}{3} \times Q_t$, then ∝ = 0.33. Looking up Table 5, we have $K = 0.5$

So, the required volume of the lake is as follows: $W = 0.5 \times 2.48 \times 23{,}640 = 29{,}314$ m^3

With the planned outflow of $Q_x = \frac{1}{2} \times Q_t$, then ∝ = 0.5. Looking up Table 5, we have $K = 0.3$.

So, the required volume of the lake is as follows: $W = 0.3 \times 2.48 \times 23{,}640 = 17{,}588$ m^3

Tan Mieu Lake is 25 m wide, 200 m long, and 3 m deep. So, the storage capacity is 15,000 m^3.

The result shows that the assessment of the required volume of the lake located in the sub-basin depends heavily on the parameter of the outflow from the lake. In both options for calculating the outflow from the lake, the results show that the amount of stormwater entering the lake exceeds the current storage volume of the lake. With the option $Q_x = 1/3 \times Q_t$, the required volume exceeds the actual volume twice. So, it can be assumed that this is one of the basic causes of local flooding in the study area. The survey shows that the situation of the lakes in the area being deposited and encroached at a high level is prevalent. Therefore, the drainage efficiency in other sub-basins in the Thanh Noi area is similar. Compared with the flood simulation results using the SWMM model, Ngoc's flooding situation in Hue City from October 1 to 3, 2010 [11] about the depth of flooding on some roads in the Thanh Noi area, and the actual survey results of some floods in 2018, 2020, and 2021 show that the areas with many roads suffered from flood deeper than 0.5 m when many lakes are infringed upon, and strongly sedimented. The flooding of the roads is related to the shrinking of the lake's volume. If the lake has an ideal storage capacity, urban flooding will be minimized in terms of inundation time, flooded area, and depth.

There are many ways to determine the reservoir volume. In conclusion, Dong used a range of techniques and then compared them. Each technique has a unique set of drawbacks. The SWMM mathematical modelling method uses the gradual trial technique to calculate the volume of the conditioning reservoir because it is based on the actual process of inflow and outflow and yields the best and most logical results (this method requires meticulous design and takes much time). Unlike the SWMM method, according to TCVN 7957:2008, the reservoir volume calculation method gives the slightest error in the flow rate and is easy to apply. Therefore, it is now used by many designers [9], [15]. With this method, it is only necessary to make a hydraulic calculation table to determine the values such as inflow, outflow, storm duration, and the lake area and volume; however, there are still errors.

The increase in extreme rainfall due to climate change requires the design, structure, and calculation of detention lake capacity and location in a detailed and complete manner to minimize local flooding in the direction of urban drainage sustainability. The mathematical modelling method SWMM has proven outstanding advantages in calculating sustainable urban drainage and designing regulating lakes, so it is becoming increasingly popular [5]; [11] [16].

The volume of outflow from the lake depends on the current use of the lake. The underground pipe linking lakes in the Thanh Noi area is often blocked by garbage, the roots of aquatic plants in the lake, or the nets to raise fish in the lake; these factors obstruct the outflow [11] [12] [13] [17]. Therefore, to increase drainage efficiency, it is necessary to ensure the volume of the lake and the ability to drain stormwater from the lake or the capacity of the pumping station to serve the drainage.

The results of calculating the volume of the conditioning reservoir according to TCVN 7957:2008 in this study are at the introductory level. The research results would be more accurate if the following is considered, namely the hydraulic calculation for a branch pipe in the sub-basin, more sub-basins included in the study, and using the SWMM mathematical modelling method to get more bases and data for conclusions about the required reservoir capacity in the sub-basins in the region. This is also the direction of future research.

4 Conclusions

Local flooding in the Tan Mieu Lake sub-basin, Thanh Noi area, Hue City, continues. Sustainable urban drainage attaches importance to the effectiveness of the detention lake. The Tan Mieu Lake in the region is a detention lake in urban drainage, but its current volume fails its function if it is considered according to the two options: $Q_x = 1/3 \times Q_t$ and $Q_x = 1/2 \times Q_t$.

Tan Mieu Lake and the lakes in the Thanh Noi area have favourable terrain for stormwater to flow to the lake to reach the most extensive flow. The flow obtained from the secondary pipes, open ditches, and drains to the lake has the shortest time. Particularly, with the state "Combined with the drainage system of the area, the inflow and outflow of the lake are reasonable", it is at an inefficient level.

To improve the drainage function of the lake, the solutions that need to be implemented soon are as follows: dredging the lake bed periodically to increase the suitable storage capacity, selecting types of lake use for economic purposes and tourism but not obstructing the outflow from the lake when draining, and inspecting the pipe system connecting the lakes before the stormy season to minimize the blockage of outflow from the lake.

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