Study on Optimal Starting Time of Detention Ponds and Water Resource Reuse

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***Abstract*—Adopting the SWMM（Storm Water Management Model） developed by the U.S. Environmental Protection Administration, this study presumes the condition of a regional drainage system and simulates the starting of a detention pond in different time based on the change of water levels. Because the pattern of rainstorms is unpredictable, five types that have occurred most frequently in Taiwan are used for analysis--normal distribution, logarithmic normal distribution; Pearson type III distribution, Log-Pearson type III distribution and Extreme-Value type I distribution. The purpose is to acquire the best timing for starting the detention pond, with the regional drainage system fully loaded, and the optimal value of water storage without causing a flood. Another goal is to recycle the water resource by planning the reuse of flood water. As the results of the simulation show, different rain types produce different solution sets. If the optimal solution can be located without the threat of a flood, we can prolong the duration to fill up a detention pond on its designed capacity and reduce the effects caused by the uncertain factors in a rainstorm. Moreover, the storms can be turned into excellent water resource. This study has demonstrated the procedures to strike the best timing of starting the detention pond. It has to be remembered, however, that the change of data on hydrology and underground hydrology in a specific region will definitely affect the results of simulation. To put it into practice, one should closely attend to the existing situation of the region.**

Keywords-Detention pond; Optimal time; Water resource; Discharge hydrograph

I. INTRODUCTION

The extensive cultivation of land in the city has affected the natural permeability of land. The aquiclude expands and prevents water from infiltrating into the soil during a rain. This leads to more runoffs on the surface. When a rainstorm comes, the number of runoff increases so fast as to go beyond the capacity of existing drainage system. As the urban areas have developed rapidly in recent years and acquiring budget and land to expand the drainage system is rather difficult, the concept of regional drainage planning has been modified. The focus should be on how to reduce the runoff caused by rainfall in the catchment area. One solution is to build detention pond to defer the occurrence of flood peak in the lower reaches and to decrease flood flow. Furthermore, detention pond will contribute to the reuse of water resource in the city. Since the city space is limited and water shortage has become a problem these years, reusing rain water will benefit the development of a city. For this reason, the present study proposes to control the starting time of detention pond to reduce flood peak and allow for more efficient use of water resources. As Fig. 1 shows, the blue line represents the inflow hydrograph; the green line represents the outflow hydrograph; the black lines indicate the cubic measure of detention pond. These data have been essential for building a detention pond in the hillside. Now, the starting time is added. The red dotted line is the discharge hydrograph at the optimal starting time. This line and the inflow and outflow hydrographs form the orange and the purple areas. The two areas will be equal. It means storm water is taken by regional drainage system before starting time (T_1). Once detention pond is started at T_1, it will absorb the water immediately and reduce peak flow. The process creates a new discharge hydrograph, which crosses with inflow hydrograph at T_2 to form a new area.

Many factors determine the function of detention pond. They include the strength of rainfall (x_1), duration (x_2), pattern of rainfall (x_3), the capacity of a detention pond (x_4), the location (x_5), number (x_6), starting time (T_1), etc. A simple math formula will describe the relationships. f represents the function of detention pond; x_1, x_2, x_3, x_4, x_5, x_6 are variables; T_1 is the optimal starting time.

$$f = f\,(T_1, \chi_1, \chi_2, \chi_3, \chi_4, \chi_5, \chi_6 \ldots) \qquad (1)$$

The present study focuses on variable T_1 to explore the effect of starting time on the operation of detention pond.

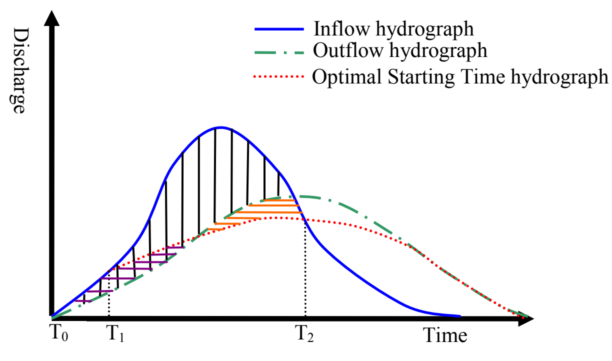

Figure 1. The inflow and outflow hydrograph and the optimal starting time of a detention pond

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Previous studies on detention pond tend to focus on hillside development. According to "The Regulations of Water and Soil Conservation Technology," (2002) [1], detention facilities aim at reducing peak flow, deferring flood peak, or facilitating infiltration. The purpose is to reduce the impact of peak flow caused by the development of hillside on areas of the lower reaches. As for flood control facilities in the rural area, most of them are used for flood discharge. Given that most part of a city has been developed and the use of land is confined, the best planning for flood control is to build detention pond, as is described in A Proposal for Reviewing the Drainage System of Kaohsiung City (2001) [2].

There have been many studies on detention pond. Some examine the pattern of outlet. Another uses diagrams to calculate its design capacity. Others investigate optimal location and sizing of detention ponds. All these studies adopted the flood hydrograph drawn at the beginning of rainfall. In other words, the runoff is allowed to enter detention pond as soon as the rain starts. Since the ponds are usually located in the upper reaches of hillside, nobody is there to control the starting of the pond. Under such circumstances, storm water flows in and out of the pond freely only to extend the duration of flood peak. Detention pond in urban area, however, is not always located on the upper reaches. Many factors, such as regional condition, flood pattern, existing drainage system, and so on, have to be considered. At this point, the time of starting deserves special attention. After the optimal design capacity of detention pond is decided, the next step is to control the time of starting to discharge the storm water in the drainage system. This will enhance safety against the uncertainty of rainstorm and prevent flood effectively.

This study adopted the SWMM (Storm Water Management Model) developed by the U.S. Environmental Protection Administration between 1969 and 1991. It presumed the condition of a regional drainage system and simulates the starting of detention pond in different times based on the change of water level. Moreover, as rainstorm pattern is unpredictable, five rain types of highest probability in Taiwan were used for analysis. The researcher created the rainfall hyetograph according to the definition of PDF (Probability Density Function) and the analysis made by Li and Chang (2002) [3]. Then, the data of hydrology and underground hydrology of the region drainage system were put into the SWMM to implement the RUNOFF module. The result and the data of the drainpipe were put into the model again to implement EXTRAN module. This process showed if the regional drainage system is able to sustain the rainfall of the five rain types of probability distribution and does not produce overflow. When overflow occurred, the researcher located detention pond on the manholes and simulated for the result. In this way, the optimal location of detention pond was identified. In this location, the researcher shifted the starting time of the detention pond based on the level of inflow water and implemented the EXTRAN module. The results showed the change of water level in detention pond under different inflow level and the overflow on manholes. The control of water level led to several solution sets, among which one will find the optimal starting time of detention pond when the regional drainage system is fully loaded.

II. Instrument and Procedure

SWMM had been developed before GUI (Graphic of User Interface) was invented. Despite of the lack of user friendly interface, the model is widely used because it has been successfully adopted worldwide in planning city underground drainage and simulating water quality. This study used 4.4H version of SWMM (1988) [4] as the instrument to explore the optimal starting time of detention pond to discharge flood.

A. Storm Water Management Model

1) Framework

SWMM consists of a few modules (See Fig. 2). The website of the Water Resources Agency (2002) [5], Ministry of Economics and the study by Su et al. (1998) [6] describe the model, the principle, and the function as follows:

a) Input sources: the sources include runoff and hydrology. Runoff involves the amount of rainfall and the meteorological conditions before rainfall. The two factors determine the surface and underground runoff. Hydrology refers to existing land use, land form, and infiltration.

b) Central cores: the cores are made up of RUNOFF, TRANSPORT, and EXTRAN. TRANSPORT can calculate routing, pipe flow, flow, and pollutant flow. EXTRAN deals with more complicated calculation of hydrology except that of pollutants.

c) Correction devices: the devices include storage and treatment. This module can control water quality more effectively. It also calculates basic cost.

d) Receiving water: although SWMM does not have water-receiving model, its output can be linked to WASP or DYNHYD of EPA to calculate receiving water.

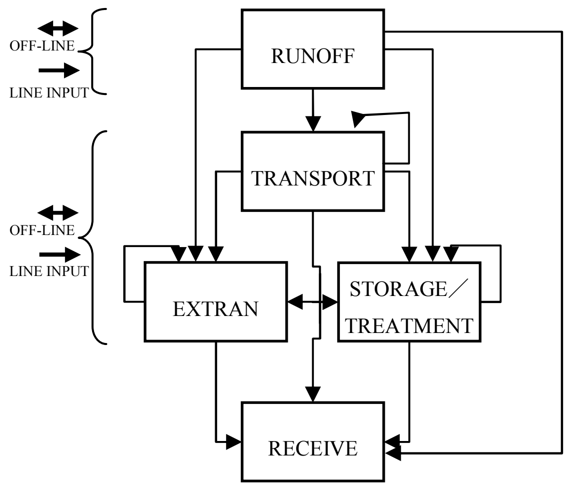


Figure 2. The Framework of SWMM

2) Introduction to the model

a) RUNOFF

After rain falls to the ground, it infiltrates, stays to become routing, flows into side ditch, or goes into the transport through manholes. The water amount in the transport increases all the time. The total amount also changes along with the flow route. This makes the operation of drainage system rather complicated. The SWMM, therefore, divides the condition into surface runoff and transport based on the dynamics and features of water flow and then makes proper hypotheses to simplify the formula. To acquire correct flow speed and depth, the Siant-Venant one-dimensional unsteady flow formula can be used:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad (2)$$

$$\frac{1}{g}\frac{\partial V}{\partial t} + \frac{V}{g}\frac{\partial V}{\partial x} + \frac{\partial y}{\partial x} = S_o - S_f \quad (3)$$

Eq. (2) and Eq. (3) show the formula of one-dimensional gradually varied unsteady flow without side flow.

Q： discharge $[L^3T^{-1}]$；
V： average speed of cross section $[LT^{-1}]$；
t： time axis [T]；
x： space axis along the flow；
y： depth of water [L]；
g： gravitational acceleration $[LT^{-2}]$；
n： Manning coefficient $[TL^{-1/3}]$；
R： hydraulic radius[L]；
S_o： bottom slope；
S_f：energy line (can be calculated with Manning formula)

$$S_f = \frac{V^2 n^2}{R^{4/3}} \quad (4)$$

b) EXTRAN

EXTRAN and TRASPORT serve the same purpose. The difference is that TRANSPORT adopted the treatment of steady flow and cannot consider the reverse water effect. Moreover, the two models deal with surcharge flow differently. EXTRAN analyzes the whole formula and displays the reverse. The formula is

$$\frac{\partial Q}{\partial t} = -gAS_f + 2V\frac{\partial A}{\partial x} + V^2\frac{\partial A}{\partial x} - gA\frac{\partial H}{\partial x} \quad (5)$$

Q： pipe flow $[L^3T^{-1}]$；
V： flow speed in the pipe$[LT^{-1}]$；
A： cross section of flow $[L^2]$；
H： water head [L]；
S_f： friction slope

$$S_f = \frac{K}{gAR^{4/3}} Q|V| \quad (6)$$

$$K = g\left(\frac{n}{1.49}\right)^2 \quad \text{for US} \quad (7)$$

$$K = gn \quad \text{for metric}$$

Eq. (6) confirms the direction of S_f by means of the absolute value of speed and guarantees that friction goes against water flow.

$$Q_{(t+\Delta t)} = Q_t - \frac{K\Delta t}{R^{4/3}}|V_t|Q_{(t+\Delta t)} + 2V(\frac{\Delta A}{\Delta t})_t \Delta t + V^2[\frac{A_2 - A_1}{L}]\Delta t - gA[\frac{H_2 - H_1}{L}]\Delta t \quad (8)$$

Calculate $Q_{(t+\Delta t)}$ of Eq. (8) to get

$$Q_{(t+\Delta t)} = \frac{1}{1+\frac{K\Delta t}{R^{4/3}}|\overline{V}|}\left[Q_t + 2\overline{V}(\frac{\Delta A}{\Delta t})_t \Delta t + \overline{V}^2[\frac{A_2 - A_1}{L}]\Delta t - g\overline{A}[\frac{H_2 - H_1}{L}]\Delta t\right] \quad (9)$$

$\overline{V}$, $\overline{R}$, and $\overline{A}$ are weighted averages of pipe at time t. $Q(t+\Delta t)$, H_1 and H_2 are unknown numbers of Eq. (9). $\overline{V}$, $\overline{R}$, and $\overline{A}$ are also related to Q and H. So, the correlation of Q and H can be displayed with a continuity equation at a specific point:

$$\frac{\partial H}{\partial t} = \frac{\sum Q_t}{A_{St}} \quad (10)$$

The above can be written in the form of difference method

$$H_{(t+\Delta t)} = H_t + \frac{\sum Q_t \Delta t}{A_{St}} \quad (11)$$

From Eq. (9) and Eq. (10), the Modified Euler method can be used to calculate the flow and water head of every section at a certain time.

B. Discussion on the optimal

In seeking solutions for engineering problems, one has to consider more than one variable. The variables and their interaction will lead to a huge solution set. To identify the best solution, try and error is feasible for most cases.

This study explored the optimal starting time of detention pond. With SWMM, however, the time variable cannot be put into the model directly to obtain the result. For this reason, the researcher utilized the change of inflow level to get the timing indirectly. If the result of model implementation is function g, g will contain all the input data. Input data for RUNOFF module of SWMM include the area of watershed（x_1）, permeability area（x_2）, acquiclude area（x_3）, acquiclude area ratio（x_4）, weir width（x_5）, surface slope（x_6）, pattern of land use（x_7）, etc. Input data for EXTRAN module are shape of the transport cross section（x_8）, the width of cross section（x_9）, depth（x_{10}）, slope（x_{11}）, length（x_{12}）, and number of manholes（x_{13}）. As this study used the height of the weir to control the inflow level and accordingly identify the best timing, the height of the weir is referred to as variable λ. Other data are fixed, and function g can be presented as

$$g = g(\lambda, \chi_1, \chi_2, \chi_3, \chi_4, \chi_5, \chi_6 \ldots) \quad (12)$$

The change of λ will lead to different solution sets g, namely, g_1, g_2, g_3, etc. By limiting certain conditions, one will find possible solutions and furthermore acquire the optimal one by setting principles and priority.

Researches on the starting time of detention pond are rather limited. The data cannot be used to simulate with the SWMM directly. This study, therefore, changes water level by using weir to control the time the water enters detention pond. The flood and the storage in different time are recorded. The recorded data offer possible solutions. The principles and priorities to identify the best solution are as follows:

1) No flood occurs in the region.

2) The time when water flows into detention pond is the time for starting.

3) Detention pond will not be started until the regional drainage system is fully loaded. This is to reduce the effect of uncertain rain type.

4) Once started, detention pond will achieve maximal storage after a period of time when the height of the weir is zero.

III. SIMULATION AND DATA ANALYSIS

This study simulated with the maximal rainfall in one hour for the standard regional drainage system. Flood occurred after the rainstorm. A detention pond would be established in order to extend the duration of flood peak, reduce the flow, and control the flood. The result of the simulation can be put into practice. One can use this method to identify the optimal starting time of detention pond in different regions to achieve maximal storage without overflow.

A. Create the regional rainfall hyetograph

The researcher studied the frequency distribution rain types in Taiwan and picked up five types that often occur on the island. The hydrology data of the rain types are processed with the probability density function and the control of duration to form the rainfall hyetograph of equal probability. As regional flood is essential for the simulation, the researcher presumed that rainfall mean was 206.7 mm/hr; standard deviation 100.9 mm/hr; skewness coefficient 1.67. These were data of regional hydrology. The rain last for 60 minutes; the storm hydrograph was 70.9 mm/hr every five years; total rainfall was 5105 m^3. With these data, the researcher obtained the five rainfall frequency distribution types, the density of rainfall, and the duration.

B. Collect data on the typical sewage system

This study presumed a region in the urban area. In the west lies a river, from which water flows out. The region is flat without steep slope and has a typical sewage system. As Fig. 3 shows, the system has four manholes and three culvert pipes. The outlet allows water to flow into the river in the way of free outfall. The manholes are numbered as 1001, 1002, 1003, and 1004 (outlet). The flow area from 1001 to 1003 is 2.4 hectares respectively. If 50% of the area is aquiclude, the total flow area of the drainage system will be 7.2 hectares. As this simulation focused on storm water, the evapotransporation is presumed to be zero.

The surface heights of the manholes are 8.20 m, 8.00 m, 7.80 m, and 7.60 m ; the bottom heights are 6.20 m, 6.00 m, 5.80 m, and 5.60 m. The starting water level is presumed as 0 m; the first culvert is marked as 102, which is linked to manhole 1001 and 1002 with a concrete pipe (diameter : 1.2 m, length: 100 m, Manning coefficient : 0.014, slope: 0.005) ; the second culvert is marked as 203, linked to manhole 1002 and 1003 with another pipe (diameter: 1.2m, length: 100m, Manning coefficient : 0.014, slope: 0.005) ; the last culvert is 304, linked to manhole 1003 and 1004 with a concrete pipe (diameter: 1.2 m, length: 100 m, Manning coefficient : 0.014, slope : 0.005). It was presumed that a rainstorm occurred in a specific time. The five frequency distribution rain types were used for simulation. The operation delayed for two minutes. The simulation last for 60 minutes. Total rainfall is 5,105 m^3。 The researcher carried out the RUNOFF module and obtained the flow hydrographs of the manholes. Then he simulated the transport of the culverts with the EXTRAN module.

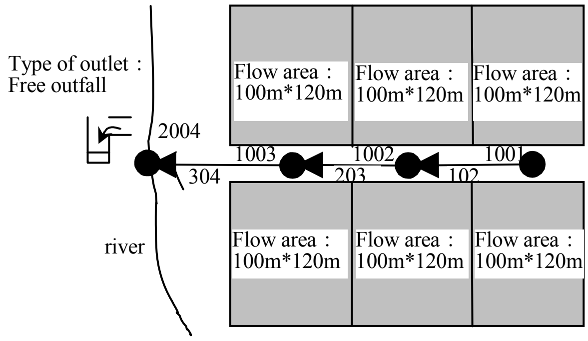


Figure 3. The transport of typical urban sewage system

C. The placement and simulation of detention pond

The foregoing simulation of the typical urban sewage system (see Fig. 3) led to flood. One considered using detention pond to solve the problem. Three detention ponds were placed in the manhole 1001, 1002, and 1003. The water level, controlled by the weir along with the five frequency distribution rain types, raised by 10 cm each time. The EXTRAN simulation was carried out. The results showed the connection between the location and the starting time of the detention ponds. In the normal distribution rain type without flood, the best location of detention pond was in 1002. When there was no flood and the detention pond was started 24 minutes later, the flood peak was postponed, which maximized the drainage. Starting detention pond when the drainage system is fully loaded enhances safety in face of the unknown rainfall and achieves higher water storage as well (with the highest water level of 4.8 m). In the same way, for the logarithmic normal distribution rain type, the detention pond was started 38 minutes later and the water level reached 4.08 m; for Pearson type III distribution rain type, the timing was 39 minutes with a water level of 4.02 m; for Extreme-value type I distribution rain type, the timing was 29 minutes with a water level of 4.08 m. In the three rain types, the best location for the detention pond was all in manhole 1002. In the case of Pearson type III distribution rain type, flood occurred no matter where the detention pond was located. The maximal water storage (4.13 m) appeared in 1002. In short, as far as the simulated drainage system was concerned, the best location for the detention pond was 1002 regardless of the rain types.

Detention pond would be located in manhole 1002. Considering the total rainfall of the five frequency distribution rain types (5,105 m^3) , the detention pond would be 30 m long, 30 m wide, and 6 m high and the capacity would be 5,400 m^3. It is the area of the underground of a high-rise and the height of two floors. Such a design resulted from the limited space of the urban area. If detention pond is built on the foundation of the high-rise, it will effectively absorb and store storm water. The water resource can be reused for many purposes such as watering plants or flushing the toilet.

D. *Simulation Results and Discussion*

1) *Results*

a) *The drainage system without detention pond*

Without detention pond, overflow occurred in the manholes and caused flood except in manhole 1003 with the normal distribution and the Extreme-value rain types.

TABLE 1. OVERFLOW IN THE MANHOLES WITHOUT A DETENTION POND

Distribution rain type	Overflow in the manholes								
	1001 (2m deep)			*1002 (2m deep)*			*1003 (2m deep)*		
	Time of highest water level		Duration of the flood	Time of highest water level		Duration of the flood	Time of highest water level		Duration of the flood
	time (min)	height (m)	(min)	time (min)	height (m)	(min)	Time (min)	height (m)	(min)
Normal distribution	26	2.00	8.7	25	2.00	11.6	30	1.92	0
Logarithmic normal distribution	8	2.00	7.6	8	2.00	9.7	7	2.00	3.6
Pearson type III distribution	5	2.00	4.3	4	2.00	8.8	4	2.00	0.2
Log-pearson type III distribution	3	2.00	5.9	2	2.00	7.5	2	2.00	4.5
Extreme-value type I distribution	8	2.00	8.0	8	2.00	10.2	12	1.99	0

b) *The drainage system with the detention pond*

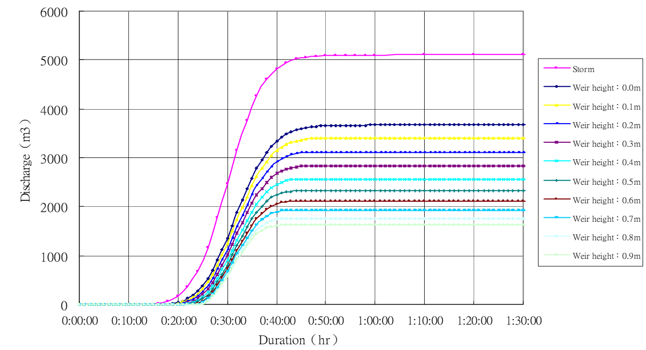
After the flood occurred, detention ponds were placed in the manholes. Considering the connection between starting time and water storage, detention pond should be located in 1002 in order to eliminate flood and maximize storage. Once placed, the detention pond was started at the 24th minute for normal distribution rain type; for logarithmic normal distribution, Pearson type III distribution and Extreme-value type I distribution, the starting times were 6 minutes, 2 minutes, and 6 minutes respectively. In these cases, the detention pond was not started until regional drainage system is full and no overflow occurred. Slight overflow occurred only for 0.6 minute in 1001 under Pearson III distribution rain type, as Table 2 shows.

TABLE 2. OVERFLOW IN THE MANHOLES WITH DETENTION POND

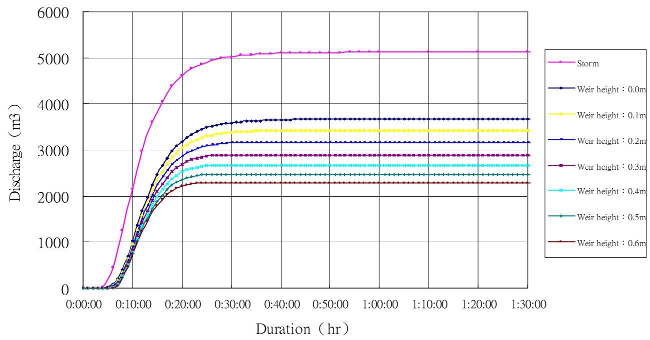
Distribution rain type	Overflow in the manholes									Detention pond
	1001 (2m deep)			*1002 (2m deep)*			*1003 (2m deep)*			
	Time of highest water level		Duration of the flood	Time of highest water level		Duration of the flood	Time of highest water level		Duration of the flood	Starting Time
	time (min)	height (m)	(min)	time (min)	height (m)	(min)	Time (min)	height (m)	(min)	(min)
Normal distribution	30	1.48	0	30	1.39	0	30	1.48	0	24
Logarithmic normal distribution	10	1.83	0	10	1.29	0	7	1.68	0	6
Pearson type III distribution	6	1.03	0	6	1.01	0	6	1.19	0	2
Log-pearson type III distribution	4	2.00	0.6	4	1.11	0	4	1.46	0	0
Extreme-value type I distribution	12	1.52	0	12	1.32	0	10	1.66	0	6

c) *Starting time optimization of detention pond*

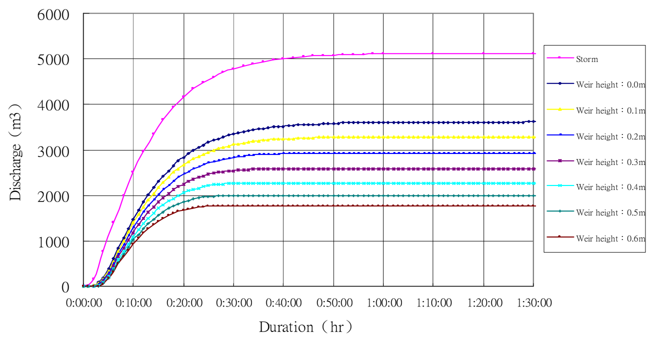
Rising the weir by 10 cm every time to control inflow level, the researcher simulated the starting time of detention pond to get the best solution from the many solution sets. The change of water amount at different starting time can be found in Fig. 4: (a) refers to normal distribution, (b) logarithmic normal distribution, (c) Pearson type III distribution, (d) Log-pearson type III distribution, and (e) Extreme-value type I distribution. Without causing overflow, different controlled level leads to different storage in detention pond. The earlier detention pond is started, the larger is the storage. But, if the drainage system has not been fully loaded, it will be a waste and cause danger in view of the unknown rainfall. By controlling the water level, one controls the time of inflow. The higher the controlled level is, the later the inflow starts. The delay of starting is the key to optimal starting time of detention pond.



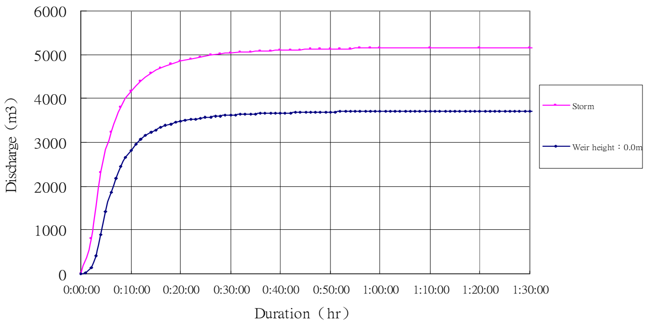
(a) refers to normal distribution



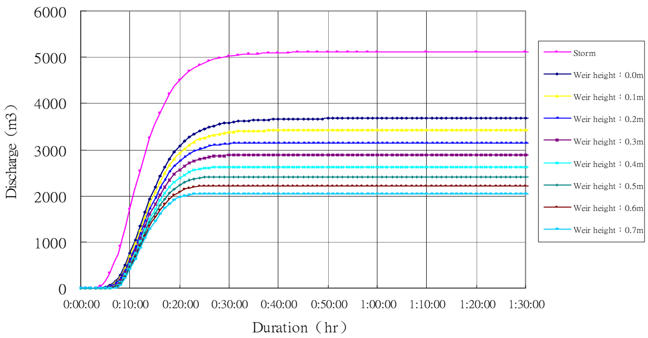
(b) logarithmic normal distribution



(c) Pearson type III distribution



(d) Log-pearson type III distribution



(e) Extreme-value type I distribution

Figure 4. Rainfall of five distribution rain types and storage at different starting time

2) Discussions

After the SWMM is implemented, the following three points were discussed.

a) The accuracy of rainfall hyetograph

The five rain type distributions form the "equal probability" hyetograph, which is derived from the probability density function (PDF) along with the designed duration. But, as PDF is continual distribution, the values are taken from $-\infty$ to $+\infty$. Although thirty sets of data were adopted according to the defined value, there might be some errors. After the implementation of RUNOFF, the rainfall in five rain type distribution were 5,103 m^3,5,118 m^3, 5,112 m^3, 5,150 m^3 and 5,111 m^3. Compared with the designed rainfall 5,105 m^3, there were errors of 2 m^3, 13 m^3, 7 m^3, 45 m^3, 6 m^3 respectively. All the errors were less than 1%, which was tolerable. As Table 3 displays, the rainfall hyetograph is reliable.

TABLE 3. ERRORS OF FIVE FREQUENCY DISTRIBUTION RAIN TYPE HYETOGRAPH

Distribution rain type	**Rainfall（m^3）**		**Error of rainfall (m^3)**	**Absolute error (%)**
	Original design	***RUNOFF result***		
Normal distribution	5,105	5,103	2	0.04
Logarithmic normal distribution	5,105	5,118	13	0.25
Pearson type III distribution	5,105	5,112	7	0.14
Log-pearson type III distribution	5,105	5,150	45	0.88
Extreme-value type I distribution	5,105	5,111	6	0.12

b) The appropriateness of locating detention pond in manhole 1002

On the premise of no overflow, the researcher simulated all the possibilities in the region. Among the many solution sets, when the starting time (controlled with the weir) was fixed, 1002 was the best choice for all the five rain type distributions. As Table 4 demonstrates, in normal distribution rain type and weird height 0.8 m, no overflow was found in 1001 and 1002. At this time, 1002 stored 1,764 m^3 of water, more than the 1,485 m^3 by 1001. In other rain types, the storage of 1002 always surpassed that of 1001: 3,249 m^3>2,556 m^3, 2,916 m^3>2,115 m^3 and 2,871 m^3>2,268 m^3. In Logarithmic normal distribution rain type, all the manholes had overflow and the largest storage 3,717 m^3 was still found in 1002. In summary, manhole 1002 was the most appropriate location for detention pond in this regional drainage system.

TABLE 4. COMPARISON OF STORAGE AT DIFFERENT LOCATION WITH THE SAME WEIR HEIGHT

Distribution rain type	**Weir height（m）**	**Storage（m^3）**			**note**
		Manhole 1001	***Manhole 1002***	***Manhole 1003***	
Normal distribution	0.8	1,485	1,764	Overflow	
Logarithmic normal distribution	0.1	2,556	3,429	Overflow	
Pearson type III distribution	0.2	2,115	2,916	Overflow	
Log-pearson type III distribution	0.0	1,782	3,717	3,654	Overflow
Extreme-value type I distribution	0.3	2,268	2,871	Overflow	

c) Verification of the optimal starting time of detention pond

In the foregoing simulation, the change of starting time was represented by the change of weir height. Theoretically, the weir height should be zero when detention pond is started. But, SWMM does not offer such a function. Therefore, it is presumed that if the entrance is big enough, detention pond will gradually achieve maximal storage from the moment it is started with zero weir height until the highest water level is reached.

In normal distribution rain type, detention pond was started at the 16th minute with zero weir height and achieved maximal storage at the 58th minute. The duration was 42 minutes. If the previous hypothesis is valid, one can say that in normal distribution rain type, if the detention pond of this region is located in manhole 1002, the optimal starting time is the 24th minute. In 66 minutes, it will achieve maximal storage 3,672 m^3, keeping up to 68 % of storm water. The optimal starting times for the other four rain types are the 6th, 2nd, 0, and the 6th minute respectively. In 50, 89, 77, and 52 minutes, there will be maximal storage 3,672 m^3（68%）, 3,672 m^3（67%）, 3,672 m^3（68.8%）, and 3,672 m^3（68%）respectively. As Table 5 shows, Log-pearson type III rain type will cause overflow in 1001.

TABLE 5. OPTIMAL STARTING TIME AND MAXIMAL STORAGE FOR FIVE DISTRIBUTION RAIN TYPES

Distribution rain type	**Detention pond (30m*30m*6m , capacity 5,400 m^3)**					
Five distribution rain types	***Starting time (min)***	***Time of maximal storage (min)***	***Water level (m)***	***Storage (m^3)***	***Storage rate (%)***	***note***
Normal distribution	24	66	4.08	3,672	68	
Logarithmic normal distribution	6	50	4.08	3,672	68	
Pearson type III distribution	2	89	4.02	3,618	67	
Log-pearson type III distribution	0	77	4.13	3,717	68.8	Overflow
Extreme-value type I distribution	6	52	4.08	3,672	68	

As Table 5 clearly demonstrates, when a rainstorm arrives and the entrance of detention pond is big enough, starting the detention pond in different time will lead to maximal storage, which is approximate to the maximal capacity of the pond. Optimizing the starting time will share the burden of the drainage system, reduce the danger of a fully loaded system, and accordingly ease the impact of flood peak.

This study explored the optimal starting time of detention pond with presumed conditions and established a pattern of simulation. In reality, the government agency has its own criteria for designing rain types. For example, the Housing and Urban Development Bureau of Taiwan Provincial Goverment adopts Huff method and the Hydraulic Engineering Office uses Pilgrim and cordery method and Keifer and chu method. After collecting regional data, they conduct rain type design to obtain regional rainfall hyetograph, which, combined with SWMM, will lead to optimal starting time of detention pond more accurately.

IV. THE REUSE OF WATER RESOURCE

In 1992, a United Nations conference known as Earth Summit was held in Rio de Janeiro of Brazil. The summit produced the Rio Declaration on Environment and Development, which stipulated 27 principles to guide future sustainable development around the world. As the third principle of the document stated, "the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations." On December 22, 1992, the United Nations declared that March 22 would be the World Day for Water. States were invited to devote the Day to concrete activities related to the conservation and development of water resources. Moreover, the 2003 UN World Water Development Report warned against the impact of global water crisis, from which no region could spare: "Water supplies are falling while the demand is dramatically growing at an unsustainable rate. Over the next 20 years, the average supply of water world-wide per person is expected to drop by a third." Such a warning is particularly significant for Taiwan since the island is facing the shortage of water supply currently.

A. water resourc e reuse OF Detention Ponds

Taiwan enjoys abundant rainfall, about 2.6 times the world's average. Due to the limitation of natural environment, however, only 12 billion tons runoff are intercepted, stored, and utilized, including eight billion tons in the rivers and four billion tons in the dams. This accounts for only 18% of the total runoff and the rest just flows into the sea. Managing water resource in this way has caused flood or shortage of supply, which seems incredible to other countries. Western countries have made policies for ecological flood control. Buildings and construction sites must facilitate rain water to infiltrate and be stored in order to absorb partial flood and prevent damage. The researcher thus suggests related construction regulations of Taiwan should require buildings to have the ability to control and discharge flood. The owners or caretakers of buildings should also be given the responsibilities of maintaining and operating the facilities of flood control and discharge. Moreover, the urban green spaces and athletic fields of school should serve multi-functions; that is, the part above the ground is designed for recreational, exercising, or earthquake-resistant parks while the underground is developed for parking and storage of storm water. If the building is situated in flood-prone area, the government should allow higher capacity utilization above the ground to encourage the use of the underground for flood storage purpose. Then, the stored water will add to the many water resources that the government is developing. Meanwhile, when the "Rainwater Collection and Dual-mode Water Supply System" is set up and put to use, the wastewater of livelihood and the stored rainwater will be utilized. This will raise the cycling rate of water resource and the household use of original water on plants, toilet, and car-washing will drop.

In our daily life, mere toilet-flushing accounts for 35 percent of total water use. The government should set up the intermediate water system in office, school, residence, and hotel. The waste water can be used on toilet-flushing, car-washing, plant-watering, street-cleaning, landscape-maintaining, and river or lake refilling. Once the intermediate water system is established, it will reduce the threat of water shortage and turn the rainstorm into financial gains. Japan, which is also an island nation, has had great success in using the intermediate water system to supply water for industry and community.

Detention pond effectively reduces the crisis caused by flood peak. Combined with the intermediate water system, detention pond becomes a rainwater storing cistern and the water supply center of the community. The daily waste water from nearby household can be processed through this system to form a community-based water recycling system. It is cost-saving and resembles the pattern used in school or factory. It will benefit the government and the people as well as water resource.

B. Evaluation of economic benefits

According to Taiwan Water Corporation (2002), the daily per capita water consumption is 290 liters, which is much higher than the 250 liters in western countries. A water user has to pay the basic fee, consumption fee, business tax, and waste disposal fee. The consumption fee is NT$7 per degree/per ton under 10 degrees, NT$9 per degree from 11 to 30 degrees, NT$11 per degree from 31 to 50 degrees, and NT$11.5 per degree over 51 degrees. The basic fee comes from the diameter of the water meter—NT$17 for 13mm, NT$34 for 20mm, NT$63 for 25mm, etc. Moreover, the users are required to pay 5 percent of the water bill as business tax. The waste disposal fee is regulated by local environmental protection agencies.

Based on the foregoing calculation, if a household with four persons use about 35 degrees of water every month, it has to pay NT$500 (basic fee: NT$20, water consumption: NT$305, business tax: NT$17, waste disposal: NT$4.1 (in Kaohsiung)* 35=NT$144). As 35 percent of total livelihood water consumption is on toilet flushing, if the household uses the water in detention pond to cover the 35 percent, it will save NT$175 a month. If the community has 1,000 households, NT$175,000 will be saved per month and NT$2,100,000 per year, as long as the detention pond is big enough plus the intermediate water system. Take the detention pond in this study as an example. With a capacity of 5,400 m^3., the pond can serve 440 households. It not only helps conserve water but also creates substantial wealth. Table 6 demonstrates the total benefits.

TABLE 6. EVALUATION OF TOTAL BENEFITS OF RAINWATER COLLECTION AND DUAL-MODE WATER SUPPLY SYSTEM

Project	Water consumption before deployment (m^3/month)	Water consumption after deployment (m^3/month)	Water saved (m^3/year)	Money saved (NT$/year)
Deployment of Rainwater Collection and Dual-mode Water Supply System	About 5615	Average 2444	38,052	437,598

V. CONCLUSIONS

During a rainstorm, the arrival of flood peak greatly challenges the discharge system. Prolonging the duration of flood peak by changing the starting time of detention pond significantly reduces the probability of flood. This study adopted the SWMM developed by the U.S. Environmental Protection Administration to simulate for the optimal starting time of detention pond with the regional drainage system fully loaded and for the maximal water storage devoid of overflow. The simulation is conducted with the five rain types occurring most frequently in Taiwan--normal distribution, logarithmic normal distribution; Pearson type III distribution, Log-Pearson type III distribution, and Extreme-Value type I distribution.

The following conclusions can be drawn from the analysis:

(1) The results will vary with regions. Due to the difference in data of hydrology and underground hydrology, the results in different regions will not be the same. The rainfall hyetography should be constructed on regional hydrology and underground hydrology to serve practical purposes.

(2) The location of the detention pond will influence the result. Even if land acquirement is not a problem, where the detention pond is situated will strongly influence the effect of detention. One has to simulate in different sites in order to identify the best one.

(3) Fixed rainfall leads to fixed storage of storm water. If total rainfall remains the same, the water storage of detention pond will be fixed accordingly regardless of rain type. Water storage is related to drainage system rather than rain types.

(4) The arrival time of flood peak decides the starting time of detention pond. After simulating the five distribution rain types, the researcher found that, with total rainfall fixed, the faster the flood peak arrives, the stronger it will be, which is the main cause of flood. Therefore, the detention pond should be started in different times for different rain types. The order is Log-Pearson type III distribution, Pearson type III distribution, Logarithmic normal distribution; Extreme-Value type I distribution, and normal distribution.

(5) With the use of detention pond, water consumption will drop by a third. Processed through the Rainwater Collection and Dual-mode Water Supply System, storm water can be used in our daily life. The evaluation of economic benefits indicates that the cost of using water also drops by a third. In the long term, the construction cost of detention pond will be refunded. Meanwhile, it corresponds with the government's policy of utilizing water resource sustainably.

The foregoing discussion manifests the key factors to be considered in building the detention pond in urban regional drainage system. It also establishes the mechanism of starting the detention pond at the optimal timing. This mechanism breathes new life into the building of urban detention pond. Instead of allowing runoff to flow in and out freely, we need a better way to control flood. The stored storm water along with the "Rainwater Collection and Dual-mode Water Supply System" best exemplifies the reuse of water resource. Such a design can be incorporated into community planning to achieve highest value of water use. In the meantime, the water bill will drop by a third. Water used to be considered a disaster rather than wealth. Now it has proved to be wealth rather than disaster and contributes to higher living quality. Using water in this way conforms to the global trend of water resources development. After all, water is the most important "strategic material" in the 21st century. Whoever possesses it will be the winner.

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