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RAINWATER UTILIZATION TO REDUCE FLOODING IN LOW-LYING AREAS OF TAIPEI CITY, TAIWAN

Andrew Lo

Key words: stormwater, rainwater catchment systems, rainwater drainage systems, wet ponds, dry ponds.

ABSTRACT

She-Zih is a low-lying area in Taipei City where the Tanshui River and Keelung River meet. Average elevation is about 2.5 m. Perennial flood events occur very often. The only flood prevention facility is the 6 m levee built around the perimeter to overcome 20-yr flood events. The main cause of the flooding problem is the instantaneous extreme high rainfall events that often exceed the drainage capacity of She-Zih. Current solutions to relieve this water hazard, suggested by the Water Resources Agency, include channel widening and many water pumping installations. At present, all emergency facilities are insufficient to combat unexpected heavy storms. Therefore, this study attempts to design drainage systems using the available limited land space, along with rainwater catchment systems, in order to achieve the expected flood prevention goal. These study results may provide adequate references for residents and government agencies to design future flood prevention management plans and strategies.

This study gathers information from previous literatures to understand initially the effect of storm runoff in this low-lying area, the flood mitigation benefits of building rooftop catchment systems and the drainage systems. Scaled-down rooftop simulation experiments are then conducted with different rainfall intensities and retention rates to evaluate their effects on flood mitigation. Study results indicate that for low intensity rain, a 55% and 69% flood retention efficiency may be obtained using the lower capping device (2.5 cm) and the higher capping device (5.0 cm), respectively. For medium intensity rain, a 58% and 70% flood retention efficiency may be obtained using the lower capping device and the higher capping device, respectively. For high intensity rain, a 46% and 63% flood retention efficiency may be obtained using the lower capping device and the higher capping device, respectively. In addition, eight locations are selected for temporary retention ponds construction in order to enhance the flood mitigation effect. Stored flood water may then be drained out through pumping or connecting drainages ditches.

I. INTRODUCTION

Water-related disasters such as floods, droughts and water-borne diseases affect more than 200 million people each year and claim more lives than war. The damage done by water-related disasters thwarts sustainable development and perpetuates poverty [5]. Over the last 10 years, disasters of hydrological, meteorological and climatic origin have been responsible for over 90% of all deaths due to natural disasters. For the last 30 years, the number of lives lost to natural disasters has decreased to about 60,000 per year, but the numbers of people affected and estimated economic losses have been steadily increasing. Between 1991 and 2000, the figure averaged about 210 million people per year, seven times more than the people affected by conflict. Moreover, 98% of the people affected are from developing countries.

More than 2,000 water-related disasters on all scales occurred during the last decade. Asia and Africa were the most affected continents, with floods accounting for half of these disasters and water-borne and vector-disease outbreaks accounted for a significant fraction of remaining disasters. In term of lives claimed, floods accounted for 15% of all deaths related to natural disasters. The economic cost of water-related natural disasters, especially for developing countries, is considerable. Asia accounts for one-third of economic losses caused by water-related disasters.

In Taiwan's rainfall-abundant watershed with steep terrain, torrential storms may result in accelerated soil erosion and runoff causing irreversible damages downstream. Up till now, the most popular flood mitigation strategy always focuses at the end treatment method using engineering structures (e.g. large dams, levees and dykes). So far, no major breakthrough has emerged. Stormwater collection using scattered small infiltration enhancement structures and retention ponds have proven more effective on storm runoff reduction and flood control [2].

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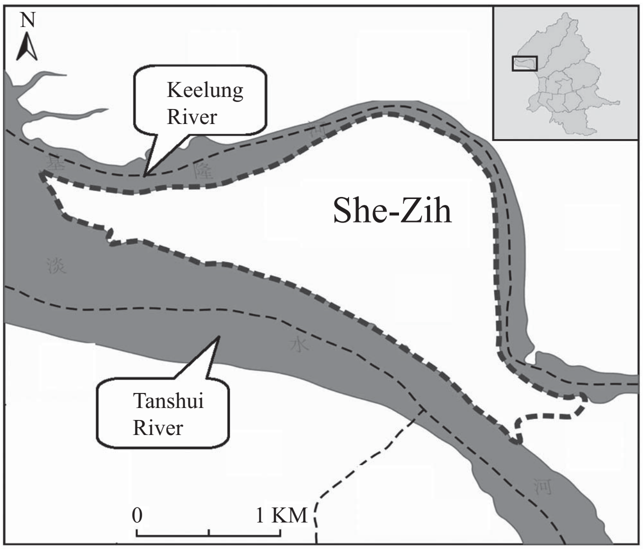

Fig. 1. Location of She-Zih area, northwestern edge of Taipei City.

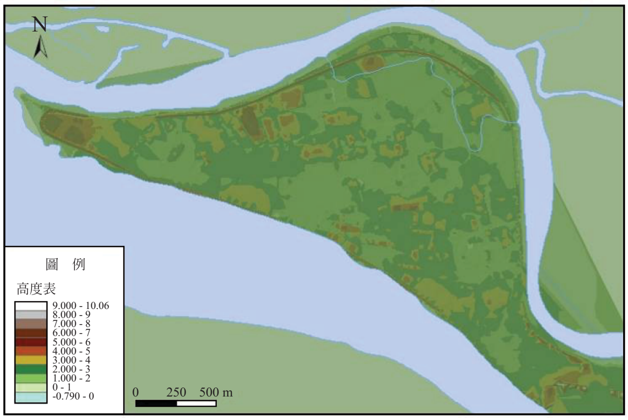

Fig. 2. Elevation (m) above mean sea level at She-Zih.

Table 1. Distribution of land use types at She-Zih.

Land use type	Area (ha)	% Total
Agricultural	170.00	52.69
Residential	24.91	7.72
Industrial	25.58	7.93
Commercial	1.66	0.51
Abandoned	43.82	13.58
Public facility	6.97	2.16
Waterway	5.38	7.67
Buddhist temple	0.73	0.23
Storehouse	3.46	1.07
Transportation	20.28	6.28
Miscellaneous	19.89	6.16
Total	**322.67**	**100.00**

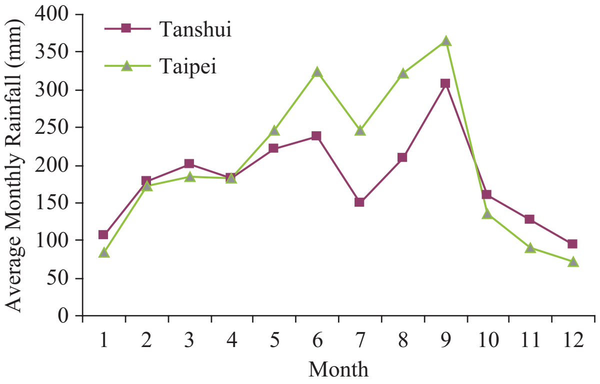

Fig. 3. 1979-2008 average monthly rainfall at Tanshui and Taipei City.

She-Zih is a low-lying area in Taipei city and has been classified as a flood retention district with strict inhibition to development in the early days. However, due to recent changes in environmental conditions, local residents have questioned the need for restriction and wanted urban development in this area. This study, therefore, attempts to gather necessary hydrologic information through scaled-down rooftop simulation experiments and to evaluate the appropriate rainwater management strategies for flood mitigation in this study area.

II. GENERAL DESCRIPTION OF STUDY SITE

She-Zih is located at the northwestern corner of Taipei City where the Tanshui and Keelung River meet (Fig. 1). It is a low-lying flood-plain area with average elevation of about 2.5 m above mean sea level (Fig. 2). The mean annual temperature, rainfall and relative humidity is about 15-30°C, 1,850 mm and 71-80%, respectively. The mean annual rainfall at the nearby stations of Taipei City and Tanshui is shown in Fig. 3. Rainfall is concentrated in summer months resulting from typhoon passages. Heavy rainstorms often lead to frequent floods in this area. Therefore, this area has been classified as a flood retention district with strict inhibition to development in the early days.

As a result, the current population at She-Zih is about 10,800. It is experiencing a declining population growth and small family size. The total area of She-Zih is about 322 ha. The major land use type (Table 1) in this area is agriculture (53%), followed by abandoned-land (14%), industrial (8%), residential (8%), and transportation roads (6%). Transportation is not very convenient with road width averaging only about 5 m. However, there are more than 10 Buddhist temples over 100 years old.

Flood prevention programs have been initiated as early as 1970. Since then, 4,170 m of earth levee and 1,649 m of concrete levee (a total of 5,819 m) has been constructed along the shoreline. Some of the levees are as high as 6 m to provide needed flood protection of 20 years return period. In addition, there are 9 pumping stations scattered in the entire area and 6 portable heavy-duty water pumps readied for emergencies.

Table 2. Different usage of runoff retardation facilities.

Facility type	Detention	Retention	Infiltration	Eco-environment sustainability	Water quality improvement	Recreation
Dry pond	✓					
Wet pond	✓	✓		✓		
Wetland		✓	✓	✓	✓	✓
Bio-retention storage		✓	✓	✓	✓	
Gravel-pore storage		✓	✓			
Rooftop rainwater catchment		✓				
Underground storage		✓				
Infiltration enhancement		✓	✓	✓	✓	✓

Fig. 4. Rooftop drain outlet and capping device.

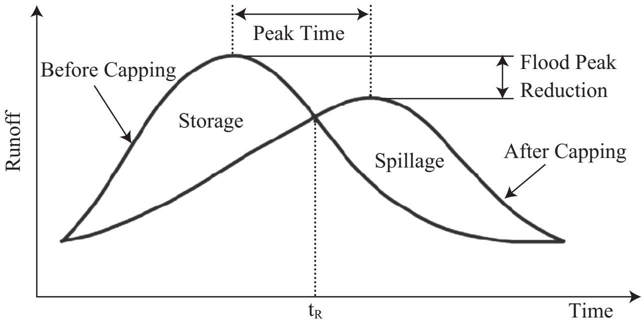

Fig. 5. Runoff hydrograph before and after capping the drains (t_R = maximum storage time).

Fig. 6. Aluminum metal box and plastic tubing used in simulation experiment.

Still, during intense and prolonged rainstorms, flooding may occur and inundate land areas with inefficient drainage. Submerged land may last for days to weeks and cause serious property damage. After a typhoon passage in September 1963, a record flood stage of above 3 m (1-storey) high was recorded. As such, more effective storm water discharge mechanisms are necessary to alleviate flooding problems at She-Zih.

III. RUNOFF RETARDATION FACILITIES

There are many different types of runoff retardation facilities. According to their usage, they can be classified as: dry pond, wet pond, wetland, bio-retention storage, gravel-pore storage, rooftop rainwater catchment, underground storage, and Infiltration enhancement [1].

Most runoff retardation facilities may be used for storm detention, storm retention, infiltration, sustaining eco-environment, water quality improvement, and recreational purposes. Table 2 categorizes the different usage of these facilities. Various runoff retardation facilities should be combined in the actual implementation of flood control work. The selection should be able to adapt to different local conditions in order to achieve optimum effectiveness.

IV. ROOFTOP RAINWATER CATCHMENT SYSTEMS

Rooftops of residential housing can be used to retard rainwater and runoff. Level rooftops with surrounding retaining walls can store rainwater temporarily if the drains are capped (Fig. 4). The storage capacity is directly proportional to the construction area. The collected rainwater may be discharged subsequently without any damage to the building structure. However, this delayed release of storm water may result in significant reduction of flood-peak and substantially postpone the flow concentration time (Fig. 5). Therefore, it is very effective in controlling floods in densely paved urban cities. In the USA, many state governments have included and implemented rainwater catchment in their building construction codes [4].

In order to confirm the effective use of rooftop rainwater catchment systems for flood mitigation, a simulation experiment was designed to evaluate the flood-peak reduction and flow concentration time lag for different storm sizes. An aluminum metal square box 80 × 80 × 10 cm is used to represent a scale-down version of the traditional flat roof housing in She-Zih area (Fig. 6). Four 1-cm diameter drainage holes are installed at all corners. Each drainage hole is connected with plastic tubing delivering spillage water to a measuring bucket.

Table 3. Effectiveness of rooftop catchment systems.

Rainfall intensity (mm/hr)	Storage water level height			
	2.5 cm (Low)		5 cm (High)	
	Flood peak reduction (%)	Flow concentration lag time (hr)	Flood peak reduction (%)	Flow concentration lag time (hr)
15 (Low)	55	0.17	69	0.25
20 (Medium)	58	0.20	70	0.30
25 (High)	46	0.10	63	0.17

Each drainage hole can be capped to retain water at two height levels, one at 2.5 cm and another at 5 cm. Cut-off plastic tubing sections (5 mm in thickness, 2.5 cm in diameter, 2.5 cm in height) are used as capping devises (Fig. 6). The 2.5 cm and 5 cm capping levels are established using one tubing section and two stack-up sections, respectively. The capping devises are not firmly glued to the metal box. Stored water may seep through the metal and plastic interfaces, allowing slow drainage during storm events. Water above the retention level may then be drained out of the box. On the whole, rainwater catchment experiments are conducted at three storage height levels of 0, 2.5, and 5 cm.

Artificial rainwater is delivered to the metal box using a sprinkler system at three rainfall intensities, namely low (15 mm/hr), medium (20 mm/hr) and high (25 mm/hr), for a duration of 30 minutes. A uniform distributed rainfall pattern is selected, with 25% of the total rainfall amount applied during the first 10 minutes, followed by 50% total for the second 10 minutes, and the remaining 25% total at the last 10 minutes. Flood-peak reduction and flow concentration lag time can be determined by comparing runoff hydrographs between 0 and 2.5 cm as well as 0 and 5 cm water storage level heights. Experimental results are listed in Table 3.

Obviously, results in Table 3 indicate that high storage level using a higher capping device of 5 cm is more effective in mitigating flooding. More than two-thirds of the flood peak flow reduction is obtained with only 5 cm storage during the low and medium intense storms. Flood peak flow decrease of about 63% is achieved with the same storage capacity for more intense storms. The smaller storage capacity (2.5 mm) may be able to reduce about half of the flood peak flow. Better results (about 58%) are obtained at medium intensity rains. With more intense storms (medium rainfall intensity), more flood water can be stored on the roof. As such, flood peak can be further lowered with more flood peak flow reduction. For high intensity rainfall, due to higher leaking rate, slightly less flood water can be stored on the roof, resulting in higher flood peak and less flood peak flow reduction. However, postponement of flow concentration time is less effective using rooftop catchment systems. Most treatments result in less than 15 minutes delay in flow concentration. Only during low and medium intensity storms with 5 cm storage capacity, the lag time can exceed more than 15 minutes. Results obtained from the simulation experiment should be closely replicated themselves in full-size, scaled-up roof catchment systems with larger storage spaces. The flood peak flow reduction will be significantly higher and the flow concentration lag time will be much larger.

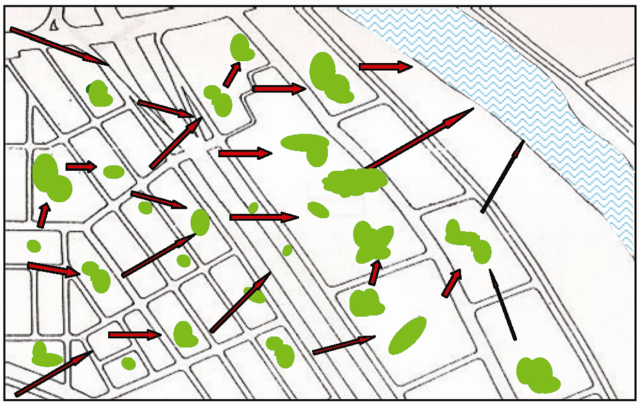

Fig. 7. Schematic diagram of scattered low-impact runoff retardation facilities [1].

V. OTHER FLOOD MITIGATION STRATEGIES

For reducing the flood hazard at She-Zih, using rooftop catchment systems may not be adequate since the dwelling land area comprises only about 6% of the total land area. Other runoff retardation facilities may be used to achieve comprehensive flood control in the study area. The most appropriate solution is to construct many scattered dry ponds and wet ponds at the abandoned land use areas (Fig. 7).

In urban areas, runoff coefficient increases significantly with abundant land paving and building construction, resulting in flood peak increase. An effective way to mitigate flood is to use permeable road pavement. It can minimize storage construction land use and also enhance groundwater recharge. However, dry pond is suitable for use in less populated cities and towns with only limited road pavement and sufficient abandoned land areas. Its regulative mechanism is restricted to a certain time period. It can store rainwater and runoff during heavy storms. After the rain stops, the collected rainwater and runoff may be drained out slowly. In addition to retarding flood via temporary storage, it may also provide space for other purposes such as creation parks, golf courses or parking lots [3].

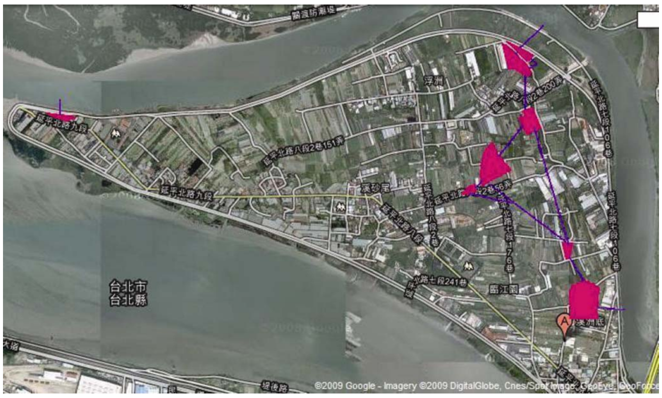

Fig. 8. Locations of the 8 temporary retention ponds.

Wet ponds combine the existing and man-made ponds and lowlands. Both ponds and lowlands usually maintain low water flow, which may be able to reduce flooding. They may provide stability to the aquatic ecological system if continuous steady inflow and outflow is maintained. They are also beneficial for stabilizing the stream base flow and its ecologic environment. The open aquatic environment may contribute also to the aesthetic as well as water-friendly effects.

As a recommendation to mitigate flooding problems resulting from more than 350 mm intense storms, eight man-made temporary retention ponds with 1 m depth and area ranging from 1,121 to 16,755 m^2 should be installed (Fig. 8). Criteria for choosing these locations are:

1. Zero or less than zero meters above mean sea level.
2. Surrounding runoff concentration areas.

The 1-m depth consideration is based solely on safety reasoning. The total area of all 8 retention ponds is about 60,000 m^2, providing a total storage of about 60,000 m^3. Assuming a total of 80 ha impermeable surface in the study area, an intense 100 mm/hr rainstorm lasting for an hour will generate about 80,000 m^3 runoff volume. The total storage capacity of all the dry ponds will reach as much as 75% which may contribute significantly in mitigating flooding problem in the study area. Stored flood water may then be drained out through pumping or connecting drainage ditches.

VI. CONCLUSION

This study successfully verifies the effectiveness of using rooftop catchment systems to mitigate flood problems at She-Zih. Rooftop storage can significantly reduce flood peak flows and prolong the flow concentration time. However, to comprehensively control floodwater, other low-impact runoff retardation technologies such as dry ponds and wet ponds are also suggested to increase its storm water storage capacity. Although the effectiveness of this technology is only limited to a certain size of storm events, it can easily control ordinary flood with satisfactory results. Usually small-scale runoff retardation facilities may not be able to prevent large storm runoff events. However, they may mitigate the problem to a certain extent. Besides flood control benefits, the runoff storage should increase the availability of water resources. Water stored in ponds may provide for non-potable uses such as irrigation, toilet flushing, landscaping, and groundwater recharge.

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