Investigating flood mitigation strategies applying to urban planning from a perspective of managing runoff – A case study of Dali River in Taiwan

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1. Introduction

Global climate change is very likely to increase the uncertainty of future water resources, and in particular there will be more extreme patterns in rainfall (Gelt et al., 1999; Serrat-Capdevila et al., 2007; Gallo et al., 2013). The report released by the United Nations and World Bank indicating that more people in urban area will suffer in the next 20 years for the influence of climate change, the extreme heavy rainfall caused by urban floods is more likely to expand its economic losses risk of today's 50 times. United Nations Office for Disaster Risk Reduction (UNISDR) stated in the Global Assessment Report on Disaster Risk Reduction 2015 that global economic losses might increase up to $300 billion every year. Due to global climate change and impermeable surface in urban settlement, the torrential rain and surface runoff put cities in increasing risks and threats than ever before.

Flooding is a challenging issue in the worldwide (Line and White, 2007). Traditional flood management relies on structural engineering measures largely including reservoirs, levees and flood walls, improvements to channels and the floodways (Thampapillai, 1985). However, multiple weaknesses have been identified. The risk of building damage and the loss of life are possible wherever development is allowed in hazardous areas. Nonstructural measure is an alternative approach reducing potential damage without influencing the current of flood event including education, land use management, emergency response and others (Minea and Zaharia, 2011). In particular, the hydrologic control of surface water in urban runoff management highly relies on land use management.

Taiwan is an island country, and may be the place on Earth most vulnerable to natural hazards, with 73 percent of its land and population exposed to three or more hazards (World Bank, 2005). With the global climate change, there is an increasing rainfall in warmer world and will likely intensify typhoons in south-western Pacific where Taiwan located. In order to cope with serious flood issues, we have relied on hydraulic engineering heavily. According to Special Act for Flood Management in Taiwan, project of flood-prone areas have been budgeted 3.8 billion US dollar for eight years since 2006. Nevertheless, urban development changes land-use coverage directly which affects overall performance of hydraulic engineering and eventually leads to flood disaster (Beighley et al.,2003; Haase et al.,2009).

Taiwan has confronted critical flood resulted from urbanization with a typical imbalanced land use and water environment planning in previous days. Under complicated relationship between land use change and water balance, the issues are required involving various professional fields such as hydraulic engineering, civil engineering and urban planning. Hydraulic engineering stressed flood management by utilizing model simulations and facilities selections to appraise non-engineering flood mitigation measures (Water Resources Agency, Ministry of Economic Affairs, 2008). And Risk management, of spatial planning, emphasized that restriction should be worked out in high risk zones such as flood plain area, river buffer zone, and flood tendency area. Storm water management in Taiwan has been a challenge task for intense rain fall in a myriad of planning failures such as excessive urbanization and land use out of control result in the increasing of surface run-off. Structural measures of flood management couldn’t handle the runoff cause by climate change and rapid urban growth. Non-Structural measures like Sponge City, LID and Runoff Allocation Policy are gradually being taken seriously. However, these measures have their own suitable scale to be applied. A master plan that measures the total amount of runoff in the river basin scale to guide the urban planning is needed.

This paper tried to apply the concept of Runoff Allocation Policy on land-use Planning. We define the framework of "Runoff Responsibility" by identifying the causes of flood. As basing on this framework, we chose Taichung Dali River Basin as empirical area. Moreover, different flood mitigation strategies are applied in scenario analysis for the same flood-control performance. The map of "Runoff Responsibility" can be regarded as the master plan to guide the land use planning.

2. Data and Methodology

2.1 Study area

This place should account the drainage capacity of drainage channels such as rainwater sewers, urban drainage and irrigation drainage. There are still many land development cases. And some areas are about to be developed, such like High-speed rail portal specific area etc. This study area about 4,200 hectares. It is located in Wu Xi Creek, Dali Creek and rafting Creek intersection in Taichung City, Taiwan. It's including 4 districts and 10 drainage channels (See Fig. 1). The region faces land development and changes in land patterns. Therefore, we must conduct a review of the flood protection standard. Exploring the flood-resistant capacity of the land, trying to introduce engineering and non-engineering measures.

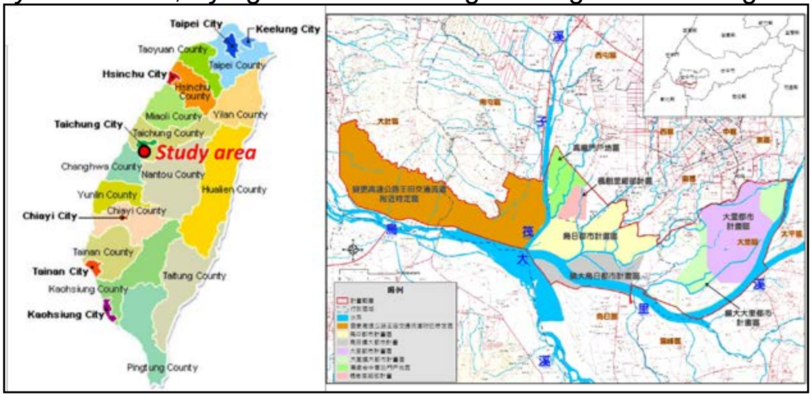


Figure 1:Study area

2.2 Data set

•Flood control system

The study area includes Dali Creek Mainstream, Tai Hang Stream, Tze Zi Stream, Dry Creek, Tau Tau Hang Stream and Caohu Stream. First, we must know the local flood control system, including: regional drainage system, storm sewer system, farmland drainage system, important water conservancy structures.

The river situation survey items include: flow, river type etc. The ever-increasing population and changing patterns of land use in the region have led to widespread floods and heavy rains. There includes 3 storm sewer systems. Therefore, this study explored the flood season in the 100-year recurrence period, taking the 1.5-meter-high effluent as the review standard (See Fig. 3).

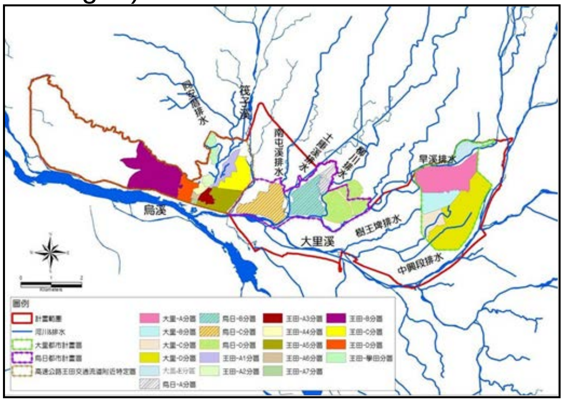


Figure 2: Drainage drainage system diagram

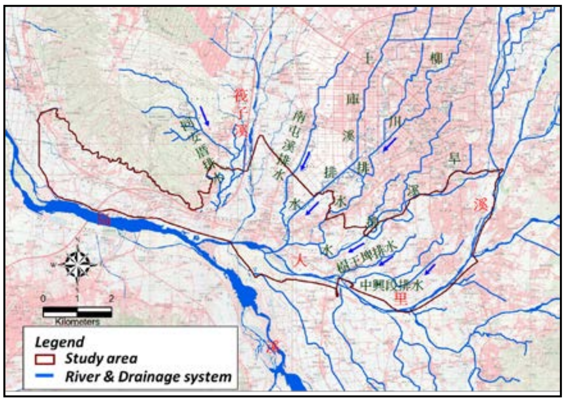


Figure 3: River & Drainage system

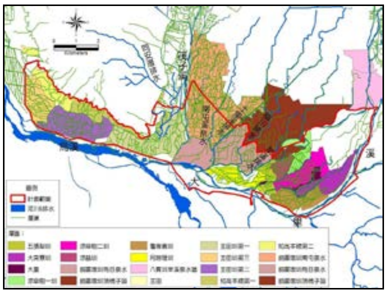


Figure 4: Irrigation canal distribution map

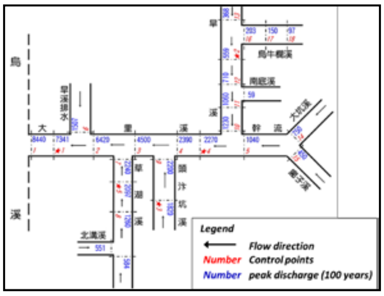


Figure 5: Peak discharge distribution map

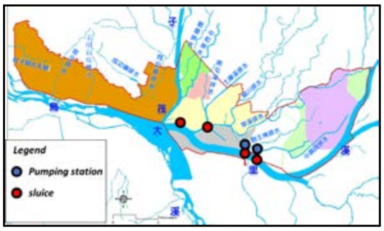


Figure 6: Important water structures

Major flooding event

This study collected floods caused by major typhoons. And explore the main causes of flooding, including seven reasons : (1) instantaneous rainfall is too large, (2) curvature of the river is too large, (3) external water level is too high, so that the internal rain can not be ranked, (4) This area is located in the low-lying area, (5) pumping too late, (6) the drainage system is not remediation, (7) Insufficient drainage system and (8) the drainage system is blocked.

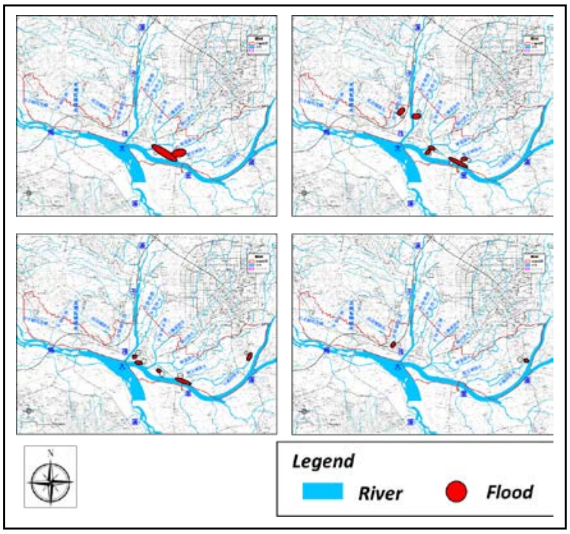


Figure 7: Distribution of major flooding events

Table 1: Table Type Styles

Year	Typhoon	No.	Flooding range(ha)	Flooding depth(m)	Flooding reasons	Improve the situation
2004	Minnesota Typhoon	1	15	0.5~1	(1), (2)	Unimproved
		2	22	>1.5	(1),(3),(4)	Improved
2008	Card Rose Typhoon	3	40	0.5~1	(1),(3)	Unimproved
		4	13	>1.5	(1),(3),(4)	Improved
		5	0.2	<0.5	(1),(3)	Unimproved
		6	2	>1.5	(1),(4)	Improving
		7	1.5	>1.5	(1),(5)	Unimproved
		8	7.5	0.5~1	(1),(6)	Unimproved
2012	Sula Typhoon	9	0.1	<0.5	(1),(7)	Unimproved
		10	0.13	<0.5	(1),(7),(4)	Improved
		11	0.1	0.5~1	(1),(8)	Improved
		12	1.5	<0.5	(1)	Improved
		13	0.3	<0.5	(1),(7)	Unimproved
2014	Suli typhoon	14	0.4	<0.5	(1),(7)	Unimproved
		15	0.3	0.5~1	(1),(7)	Improved

Flooding reasons :
(1) instantaneous rainfall is too large, (2) curvature of the river is too large, (3) external water level is too high, so that the internal rain can not be ranked, (4) This area is located in the low-lying area, (5) pumping too late, (6) the drainage system is not remediation, (7) Insufficient drainage system and (8) the drainage system is blocked.

Methods

This study uses hydrological simulation is SOBEK. It was developed by Dutch WL | Delft Hydraulics. It is a suite of programs that integrate rivers, urban drainage and watershed management. SOBEK has three modes: SOBEK Rural, SOBEK Urban and SOBEK River. Three sets of models include rainfall runoff, river calculus, water quality model, sand transport and other environmental conditions. This software can be applied to the calculation of water quality in rivers and urban sewer systems and simulation of urban flooded areas, providing considerable help to water conservancy and water resource managers in their management, decision-making and analysis.

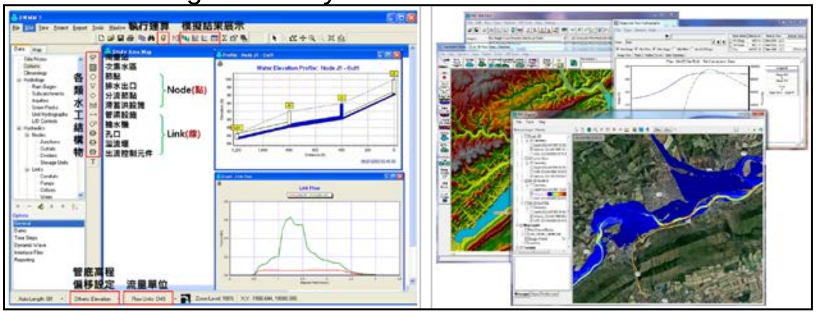


Figure 8: SOBEK.

2.3 Analysis

•Hydrology and Water Analysis

For hydrological simulation, first enter the elevation map and the status of land use, and then enter the surrounding channels, rainwater sewer system and other related information. In addition, adding rainfall and flooding area, flooding depth and other data in the area, and input information on drainage system engineering status.

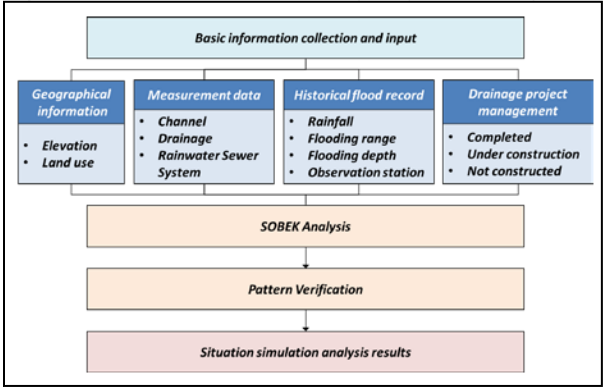


Figure 9: Hydrological simulation flow chart

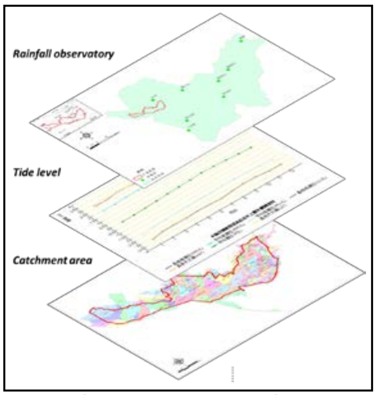


Figure 10: Enter data

Flooding simulation results

In this study area, the urban planning area is expected to reach a 50-year recurrence interval. In some important areas, such as the specific area of the high-speed rail, it is the benchmark for expected 100-year recurrence interval. For non-urban planning area mining 5-year recurrence interval, most of the current status of the land for the agricultural area. The follow-up plan will be put forward for land runoff sharing in flooded areas in the context of a 50-year recurrence interval (See Fig. 11).

In the context of the 50-year recurrence simulation results. Owing to the change of land use zoning (Expressway near the special traffic area Wangdi, Wuri urban planning area and urban planning area), there is a lack of water capacity leading to rainwater sewer systems, resulting in flooding of some areas in these areas.

Analysis results will use the Chi-Square Test for Goodness-of-Fit Test or use K-S test. The results from "cumulative probability value" would compare with the results of "hypothetical theoretical probability". Except through " Chi-Square Test " and " K-S test " to view the simulation results, also through the past results of flooding view simulation results are correct. Hydrological simulation results passed the test.

Chi-Square Test

$$\chi^2 = \sum_{i}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

k= The number of data packets (k=1+3.3 log(n), n= Number of data)
O*i*=Observed value
E*i*=Expected value

K-S test

$$D_\alpha = \max| F_{gi}(x) - F_{oi}(x)| \text{ , } i = 1, 2,\ldots\ldots, n \qquad (2)$$

$$K_\alpha = \frac{1.36}{\sqrt{n}} \qquad (3)$$

Fgi(x)： Observation of the cumulative probability of distribution

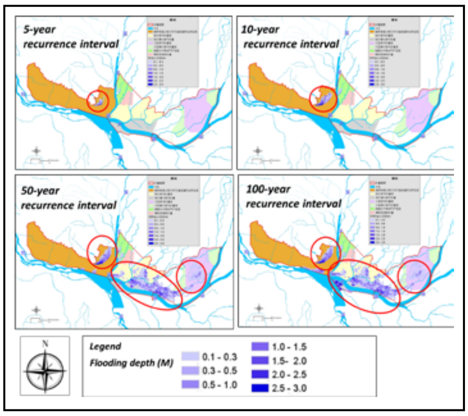


Figure 11:Hydrological simulation flow chart

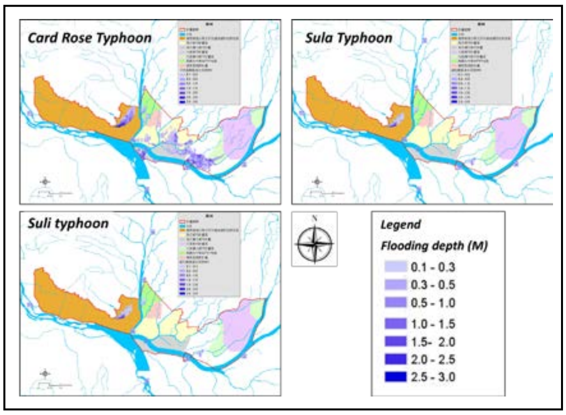


Figure 12: Past typhoon flooding range.

2.4 Results

Runoff sharing plan for land use planning

The land use plan has 3 items in the project package. The packages are: (1) to increase the connection of urban small-medium-sized detention basin, (2) to extend the surface runoff time in urban areas, and (3) to reduce the burden on storm drains and regional drainage. The scale of the planning plan includes large-scale and medium-scale, and the strategic direction is mainly to increase large-scale medium-sized stagnant storage space in the city. The operation flow of land use plan is divided into four steps, which are as follows: (1) Runoff inventorying and screening, (2) Runoff sharing space acquisition, (3) Runoff sharing planning, and (4) Land strategy zoning.

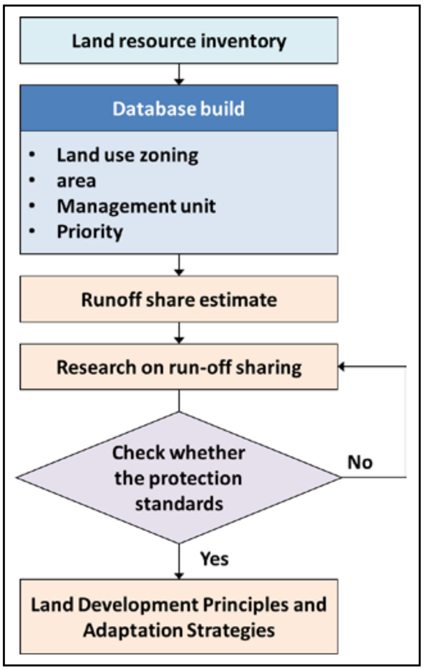


Figure 13: Runoff distribution operation process.

1. Space inventory and screening: Including: (1) land for public facilities, (2) public non-public land, (3) public utilities, and (4) farmland water conservancy associations. The

main reason for inventorying public land is that it will be proposed as a model operation area in the future. Another reason is that private land is not easy (See Fig. 14).

2. Space acquisition: Assessment of the feasibility of "public facilities land", "public non-public land", "public enterprise", "farmland water conservancy".
3. Runoff distribution planning: Based on the results of flooding simulation, we propose a scheme of runoff sharing. And assess whether the program can solve the flooding problem. If it can not be solved, then assess whether other land assistance.
4. Land Strategy Zoning: Develop different regional development strategies and adaptation strategy.

Space screening

In Taiwan, land use zoning and use status are different. Not all lands have flood detention capacity and can be used as detention facilities. Therefore, we must exclude inappropriate land. Filter conditions:

1. Taiwan announced environmentally sensitive, including: slopes, sites etc.
2. The shape of the land is narrow and the status quo has been used as a ditch or road.
3. There have been plans for detention facilities, and non-idle, non-low-use land.

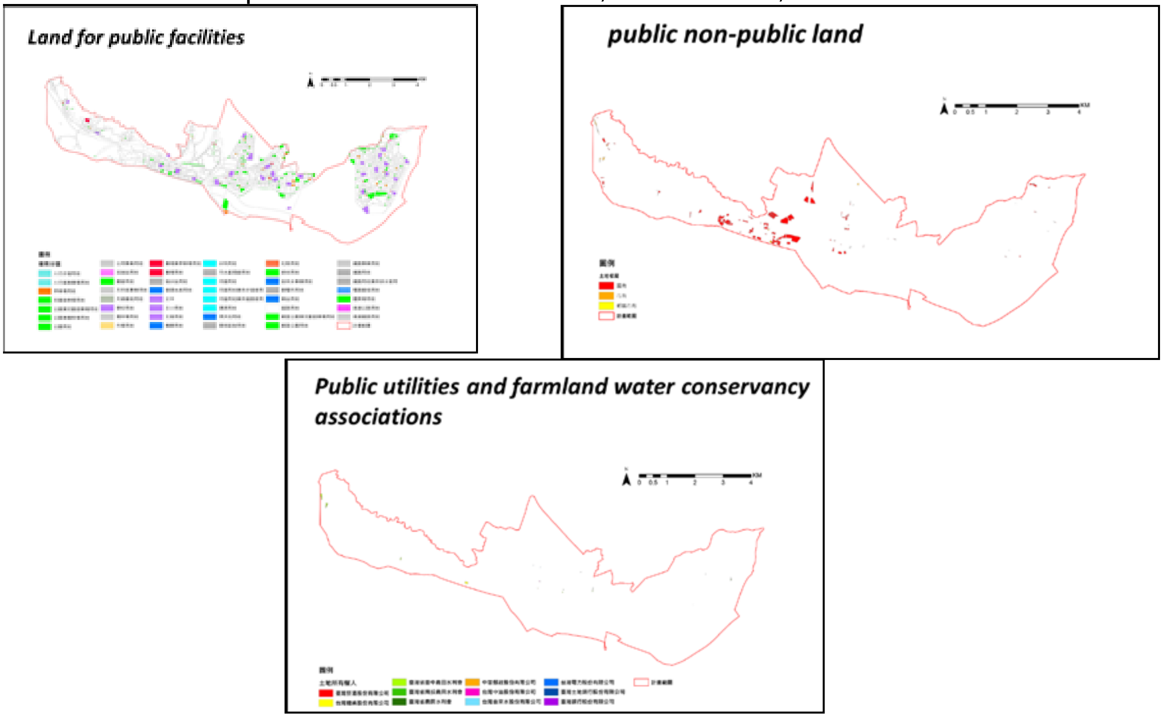


Figure 14: Space inventory and screening

Estimated water storage potential of land

In this study, we review the relevant literature to understand the water storage capacity of different land so as to estimate the water storage capacity of land. Calculated as follows:

$$V = A \times D \tag{4}$$

V: Storable volume (m^3)
A: Available area (m^2)
D: Permeable depth (m)

Table 2: Water Storage Potential Estimation Table

Land use zoning	Available ratio (%)	Permeable depth (m)		Storable volume (m3)	
School (Primary, Secondary)	30		0.3		Area×30%×0.3m
School (high school or above)	30	Min	0.3	Vmin	Area×30%×0.3m
		Max	0.5	Vmax	Area×30%×0.5m
Park (> 5 hectares)	68	Min	0.3	Vmin	Area×68%×0.3m
		Max	0.5	Vmax	Area×68%×0.5m
Park (< 5 hectares)	65		0.2	Area×65%×0.2m	

Land use zoning	**Available ratio (%)**	**Permeable depth (m)**		**Storable volume (m3)**	
Flat parking	70	Min	0.1	Vmin	Area×70%×0.1m
		Max	0.3	Vmax	Area×70%×0.3m
Children's playground	65		0.2	Area×65%×0.2m	
Institutions, markets, social education institutions, postal services	15		0.3	Area×15%×0.3m	
Square, sports stadium	70		0.3	Area×70%×0.3m	

Table 3: Reserves Of Different Types Of Land In The Study Area

Land category	**Storable volume (m^3)**	
	Min	**Max**
Land for public facilities	218,319.51	275,020.69
public non-public land	1,230,669.19	
Public utilities and farmland water conservancy associations	64,810.23	

Feasibility assessment of land use

This study will select a few indicators as a viability assessment of land use. Respectively: land can be water storage, land acquisition costs, stagnation performance etc. After the index is assessed, six grades will be given to the land, namely:

- Level 1: Fully public and the land ownership is the municipal public utility land.
- Level 2: City land but not utility land.
- Level 3: Fully public and the land ownership is state-owned land for public facilities.
- Level 4: State-owned but not public-owned land.
- Level 5: Public part of the public part of the privately owned land.
- Level 6: Public utilities and water conservancy land.

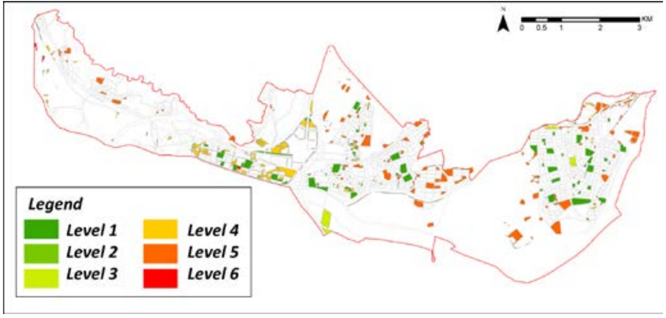


Figure 15: Land availability map.

Runoff distribution program planning

In this study, we plan to propose a plan of runoff sharing under the background of 50 years of floodplain simulation. The planning principles are as follows:

1. The principle of "partitioning the same sewer system with flooded areas". The area where there is no sewer system planning is based on the principle of "the same drainage catchment area as the flooded areas".
2. Land situated in the same sewer system section or drainage catchment area will be given priority in areas flooded with waterways, taking into account the waterway flow direction. The land located upstream of flooded areas is the next priority.
3. Reference to the feasibility assessment results, select the higher feasibility for the program.
4. According to the above principle, selecting suitable land can’t be selected, and the second most feasible alternative site for public facilities or public non-public land will be selected as the plan.

There are 15 sites in this study that need to explore runoff sharing solutions. The land program in this area can’t share the flooding volume. The analysis shows that there is serious flooding in the upper reaches of the area, and the area is located in the lowland area. Therefore, the runoff can’t be effectively shared. The proposed upstream should effectively solve the problem of flooding.

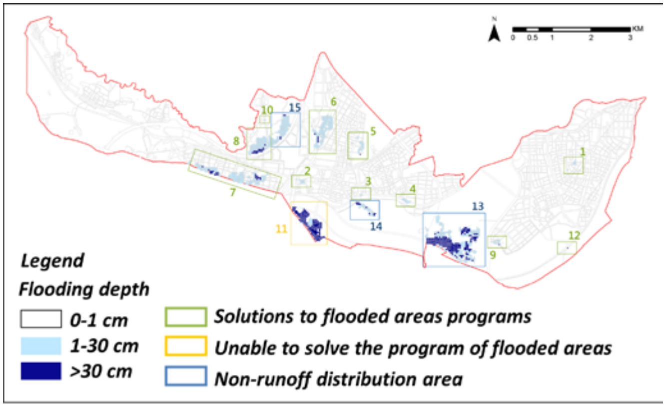


Figure 16: Runoff distribution program location..

Table 4:Program 1

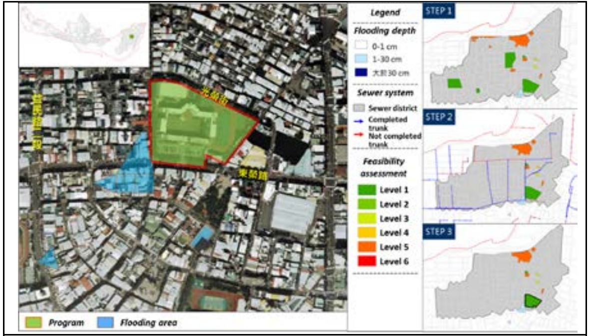
			
Flooding simulation results			
Flooding area (m)	9,077.34	Flooding volume (m^3)	257.23
Land use zoning	School land	Storage fluid volume(m^3)	2,587.44
Not enough to share			
Area (m^2)	0	Volume (m^3)	0

Table 5 :Program 2

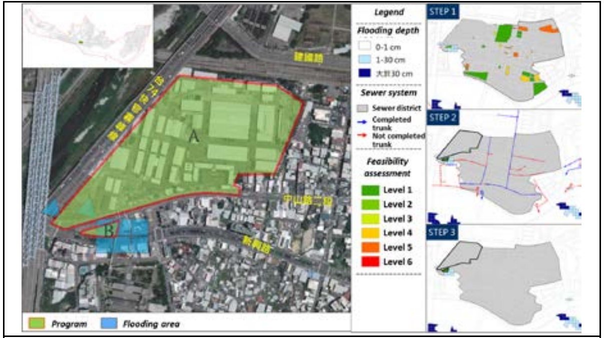
			
Flooding simulation results			
Flooding area (m)	11,790.90	Flooding volume (m^3)	999.64
Land use zoning	Authority land	Storage fluid volume(m^3)	1,300.00
Not enough to share			
Area (m^2)	0	Volume (m^3)	0

Table 6:Program 9

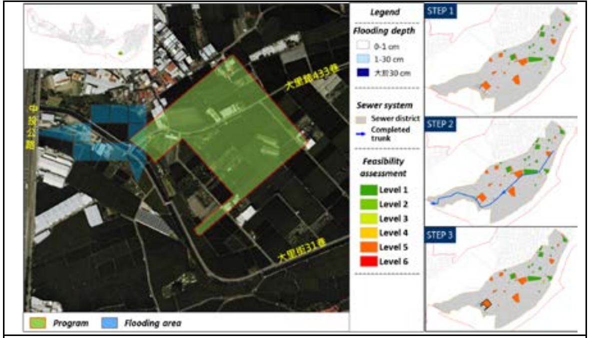
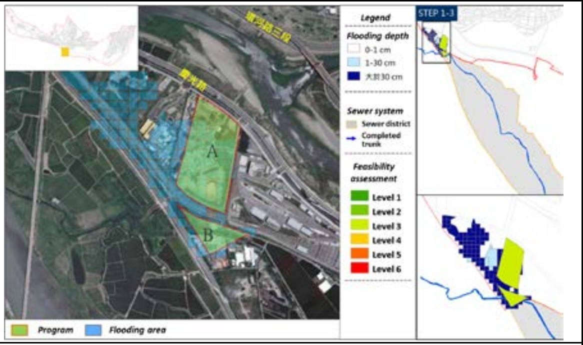
			
Flooding simulation results			
Flooding area (m)	20,484.12	Flooding volume (m^3)	3,227.42
Land use zoning	Park land	Storage fluid volume(m^3)	101,344.25
Not enough to share			
Area (m^2)	0	Volume (m^3)	0

Table 7:Program 10

			
Flooding simulation results			
Flooding area (m)	242,228.16	Flooding volume (m^3)	279,926.14
Land use zoning	Stadium land	Storage fluid volume(m^3)	140,908.25
Not enough to share			
Area (m^2)	70,723.11	Volume (m^3)	36,611.85

2.5 Conclusion

There were 15 sub-regions in the study area and 12 proposed solutions were sufficient to solve the flooding problem. There are 2 agricultural areas with 10-year recurrence as a protection standard, so there is no flooding situation. One of the 15 sites can not solve the flooding problem and needs assistance from other regions. Due to the increased incidence ratio of extreme precipitation events from Global Climate Change, flooding continues to worsen. Therefore, the plan proposes development strategies in different regions.

Land strategy zoning is to consider the submergence potential areas and the important object of protection to be divided. Water potential areas are identified by hydrological simulations with a 50-year recurrence interval and are divided into: (1) non-flooded areas (no flooded areas), (2) low flooded areas (0 Cm <depth of submergence ≤ 29 cm), (3) areas of high flooding potential (depth of submergence ≥ 30 cm). Important protection targets are populated areas.

Through the above two indicators, the land strategy zoning is divided into four categories, namely: (1) high flooding potential areas and important protected areas, (2) low flooding potential areas and important protected areas, (3) high flooding potential areas and non-critical protected areas, (4) non-flooded areas Flooding potential areas and non-important protected areas.

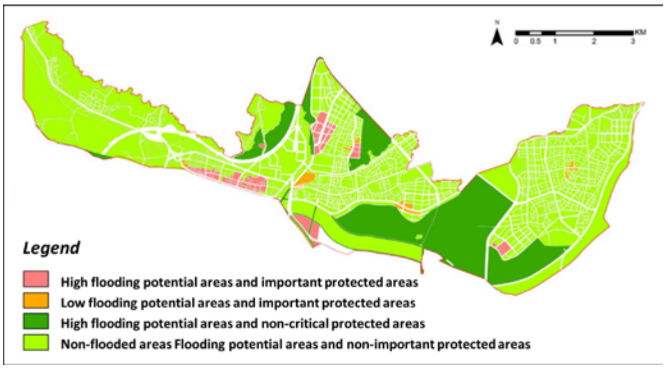


Figure 17: Runoff distribution program location..

Table 8 : Strategy zoning advice

Strategy zoning	Development concept
High flooding potential areas and important protected areas	• Land use planning should take the overall development approach and guide the urban development to reduce the cost of facility protection. • Strengthen the flood control and flood control capability of the developed regions.
Low flooding potential areas and important protected areas	• Strengthened regional capacity for adaptation to ease the impact of disasters. • Strengthen the flood control and flood control capability of the developed regions.
High flooding potential areas and non-critical protected areas	• Development behavior should be strictly controlled and afford higher development costs. • Other non-flooded areas need to support runoff distribution responsibility. • Strengthen regional capacity to adapt to mitigate the impact of disasters.
Non-flooded areas Flooding potential areas and non-important protected areas	• Land use planning should take the overall development approach and guide the urban development to reduce the cost of facility protection. • Development needs to achieve zero runoff to avoid increasing the burden on the downstream catchment.

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