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URBAN FLOOD RESILIENCE: A CHRONOLOGY OF POLICIES TO PREVENT FLOODING IN TAIPEI

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ABSTRACT

Floods caused extensive damage during the 1960s while Taipei was experiencing fast urbanization. In the early 1970s, Taiwan's central government planned a new town, the Linkou New Town, to move people from Taipei's area of high risk for flooding. Numerous levees and dikes, flood pumping stations, and gates have been built in Taipei since the 1970s. However, high density development occurred along the flood-prone areas of Taipei's major rivers after the completion of major flood control facilities in the 1990s. Flash floods, along with the failure of pumping stations along the Keelung River, caused by Typhoon Nari in 2001 flooded downtown Taipei. This research finds that coordination problems between different governmental agencies have resulted in inefficiency and ineffectiveness of flood prevention policies. Additionally, a new method combining non-structural measures, land-use and environmental planning, along with retreat planning in order to reduce risk should be gradually adopted in Taipei. Land-use and environmental planning should play a proactive role in reducing Taipei's flood risk and damage.

INTRODUCTION

Taipei is the capital as well as the economic, political, and cultural center of Taiwan. However, Taipei is also the most vulnerable among Taiwan's major cities. According to the United Nations report World Urbanization Prospects: The 2011 Revision (2012), Taipei City is third on the list of the world's top 10 urban areas with 750,000 or more inhabitants exposed to three or more natural hazards, with the highest risk of cyclones, floods, landslides, and earthquakes. For instance, Typhoon Nari flooded most of Taipei City in 2001, causing 94 deaths and approximately $800 million of damage. Over the last forty years, Taipei has promoted flood resilience mainly through engineering and other structural interventions aimed at reducing flood risk. The engineering strategy of using flood control facilities such as levees, dikes, flood control gates, and pumping stations created a "flood control paradox" (Wiering and Immink 2005). Strengthening levees encouraged more intensive land use and development which resulted in higher damage when floods did occur. Numerous levees and dikes, flood pumping stations, and gates have been built since the 1970s.

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High density development occurred along the flood-prone areas of Taipei's major rivers after the completion of major flood control facilities in the 1990s. Despite Taipei improving flood control facilities during the past four decades, the lack of integration between flood control engineering and land-use planning remains. Taipei is still vulnerable to floods due to lack of resilience planning policy and strategies. The issues surrounding Taipei's flood resilience elicits several questions: What has been done and what still needs to be done to promote flood resilience in Taipei? How can Taipei achieve more effectiveness in flood resilience through land-use planning? To respond to these questions, this articles first reviews the history of Taipei City's development in order to help understand the relationship between urbanization and flooding. Second, this research analyzes the reasons and areas of historic floods in Taipei. Third, this article summarizes and analyzes a chronology of steps implemented to prevent floods in Taipei since the 1960s. Finally, it recommends strategies of urban flood resilience in Taipei.

Brief history of Taipei City development

There are three major development periods in Taipei City (see Table 1): China's Qing Dynasty (1683-1895), the Japanese Colonial Period (1895-1945), and the Taiwan Retrocession (ongoing since 1945).

During the period of China's Qing Dynasty, the first governor of Taiwan[1] developed Taipei as a political, military and commercial center by building railways connecting Taipei with other cities of Taiwan. In order to protect the city from invasion, walls and gates were constructed in 1884. Taipei city development was mainly concentrated on the area within these walls. The population was under 50,000 in 1895, and Taipei was still a small, underdeveloped city.

This transition also merged the three settlements of Man-Ka, Da-Dao-Cheng, and the Taipei walled-city into one modern city (Tzeng 2009). In addition, the building of the Governor-General Office of Taiwan[3] was built during 1912-1919. Most of Taiwan's high-ranking central government agencies were developed around this core area of Taipei, known as Bo-Ai special district. The population was 164,329 at the end of 1920.

Table 1. Taipei city's major historical phases and their legacies

Major historic phases	Legacy
China's Qing Dynasty (1683-1895)	• A growth boundary within walls to protect invasion • Taipei railroad station development • Settlements in the west side along the Tamsui River • Taipei was still a small, underdeveloped city; the total population was under 50,000 as of 1895
The Japanese Colonial Period (1895-1945)	• The walls of Taipei was torn down in order to expand city development • Taipei's first city planning plan in 1905; a revised city planning plan of 1932 • "City Beautiful Movement" in Taipei, planning for boulevards, parks, and sanitary systems • Taipei became the dominant political, economic, cultural center of Taiwan • The population increased to 335,397 in 1945
The Taiwan Retrocession (ongoing since 1945)	• The first city plan developed by the KMT was in 1951 to accommodate 300,000 veterans and expand to the east, north, and south side • Taipei attracted enormous rural migrants from southern Taiwan in the 1970s because of economic bloom • Taipei polycentric development pattern since the 1980s • Population of Taipei grew from 1 million in 1966 to 2.72 million in 1990 • Taipei mass rapid transit system began operation in 1996. The daily ridership increased from 82,678 in 1996 to 2 million in 2014

During the Japanese colonial period,[2] Taipei became the dominant political, economic, and cultural center of Taiwan (Huang 2008). The Japanese government established the Governor-General Office of Taiwan in Taipei in 1895. The goal of the Japanese government was to develop Taipei into a modern city in order to demonstrate the strength of the Japanese. At the time, the Japanese were influenced by the western planning theory of the "City Beautiful Movement" in the early years of the twentieth century. Large urban parks, wide boulevards, a newly developed grid road system, and administrative buildings were planned and built in Taipei (Huang 2008). Plans for urban development began to be issued in 1899. In 1905, Taipei's first city plan was implemented to expand its boundary in order to accommodate the goal of 150,000 people living within 1,800 hectares.

The construction of roads, parks, and sanitary systems was the primary focus of Taipei's first city plan of 1905. The walls of Taipei built during China's Qing Dynasty were torn down in 1905 and replaced by roads to expand development. Taipei city expansion went beyond the wall boundary to develop a new functional area of markets, schools, and shrines in today's Xi-Men-Ting (Japanese West Gate District) and a new residential area outside the south gate.

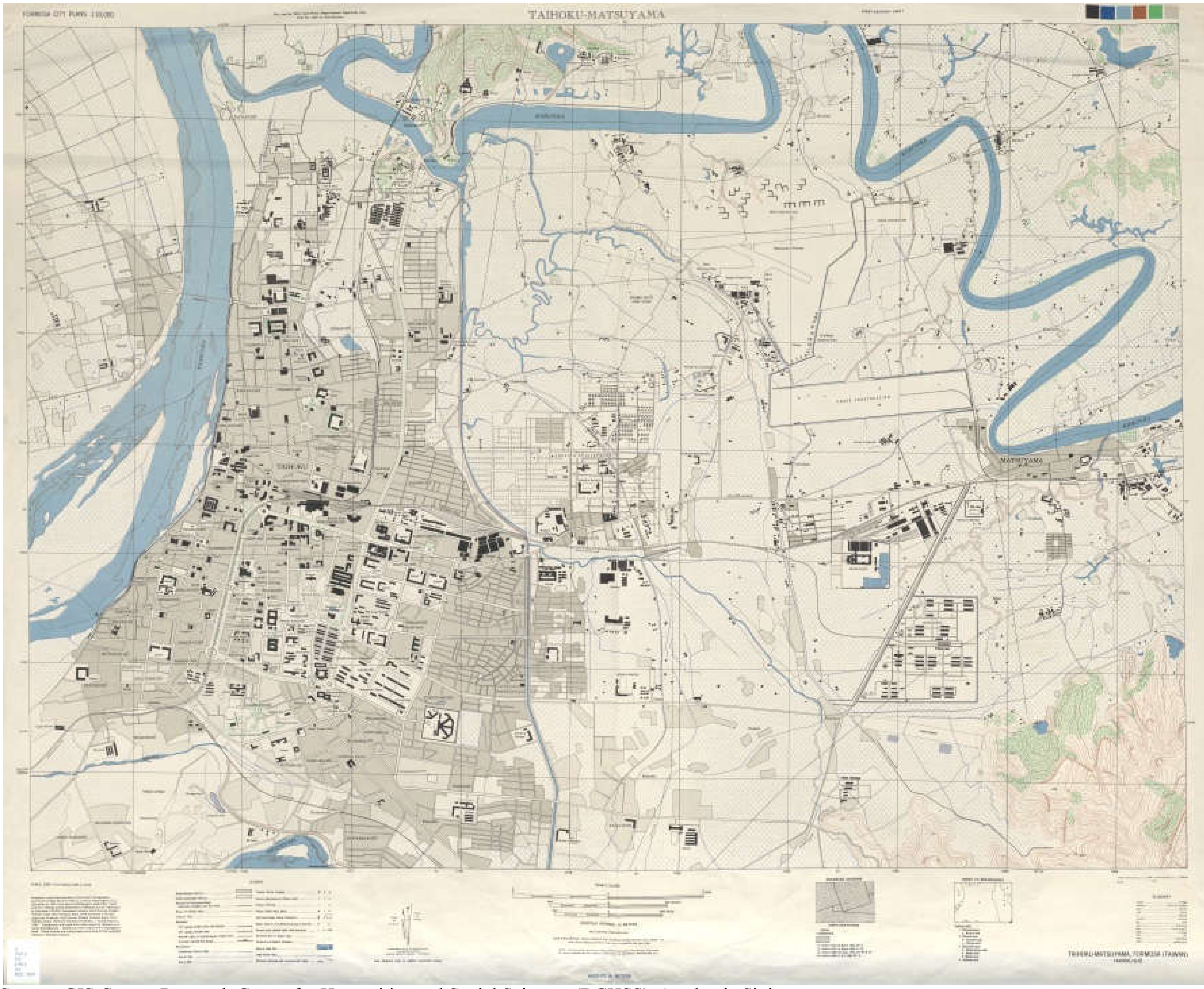
The population increased quickly in the 1930s. In the revised city plan of 1932, the goal was to accommodate 600,000 people within 6,676 hectares. In 1945, the last year of the Japanese colonial period, the population increased to 335,397. During the five decades of the Japanese colonial period, the population grew approximately seven-fold. The city expanded to the east, north, and south to the borders of two major rivers, the Keelung River and Xindian River (see Figure 1). The Japanese defeat in World War II in 1945 terminated the Japanese occupation of Taiwan, which was handed over to the Kuo-Min-Tang (KMT), the Nationalist Party led by General Chiang, and the ruling party of the Republic of China. Approximately 300,000 Japanese departed from Taiwan, one-third of them from Taipei, (Huang 2008). Taipei was designated a provincial city after Taiwan's retrocession in 1945. However, after the KMT lost control of Mainland China to the Communist Party in the Chinese Civil War in 1949,[4] approximately two million political refugees relocated to Taiwan, with 300,000 of them settling in Taipei (Huang 2008). Taipei was declared the provisional capital of the Republic of China (R.O.C.) in 1949 and became the political and economic center of Taiwan in the 1950s.

[1] Taiwan was under China's Qing Dynasty rule from 1683 to 1895, officially established as China's province in 1887. Ming-Chuan Liu was the first governor of Taiwan.

[2] Japanese occupied Taiwan from 1895 to 1945.

[3] This building is now the Taiwan's White House, the Presidential Hall.

[4] The Chinese Civil War fought between forces loyal to the KMT's ('Kuo-Min-Tang', Nationalist Party in Chinese) Republic of China and forces loyal to the Communist Party of China from 1927 to 1949.



Source: GIS Center, Research Center for Humanities and Social Sciences (RCHSS), Academia Sinica

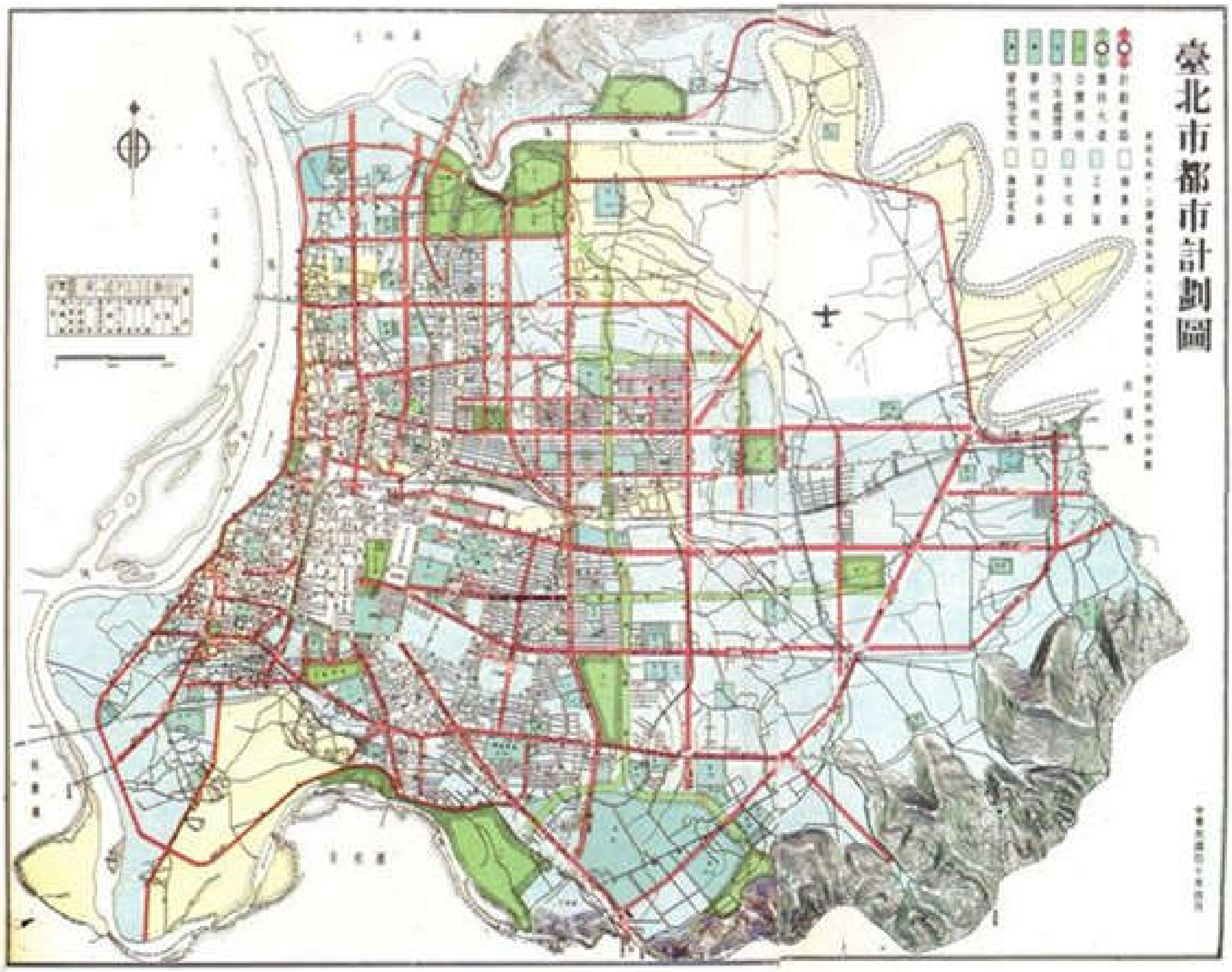
Figure 1. Taipei city development in 1945, the last year of the Japanese Colonial Period

The first city plan developed by the KMT was in 1951 (see Figure 2), based on the Japanese planning for parks, boulevards, and expansion to the east, north, and south side of Taipei to accommodate veterans following General Chiang.In the 1960s, the KMT gave up the idea of returning to Mainland China, and the central government changed its national policies and adopted economic development-oriented strategies in Taiwan. In 1973, Taiwan's Premier Ching-Kuo Chiang, a son of General Chiang, announced "Ten Projects for National Construction", aiming to complete major infrastructure to pave the way for Taiwan's industrialization (Huang 2008). As part of Taiwan's industrialization and economic miracle from the 1960s to the 1980s, most companies and headquarters were located in Taipei, which became a gateway to the international market and was described as an interface city in the global economy (Huang 2008; Chou 2005; Hsu 2005). Because of the economic boom, Taipei also attracted an enormous number of rural migrants from southern Taiwan in the 1970s. Consequently, the population of Taipei grew from 1 million[5] in 1966 to 2 million in 1974, and reached its peak of 2.72 million in 1990. In addition, planning for Taiwan' first mass rapid transit system, known as Taipei MRT or Taipei Metro, began in 1975 to solve the traffic congestion accompanying the economic growth of the 1970s. The initial network design was approved in 1986 and construction began in1988. The first line, 10.5-kilometers with 12 stations, began operation in 1996. In less than 20 years, the total length increased twelve times, from 10 kilometers with 12 stations to 121 kilometers with 109 stations, and the daily ridership increased from 82,678 in 1996 to 2 million in 2014 (see Figure 3). During this period, the transit-oriented development of Taipei MRT helped make Taipei a modern and convenient city.

Urbanization as a result of potential floods in Taipei Basin

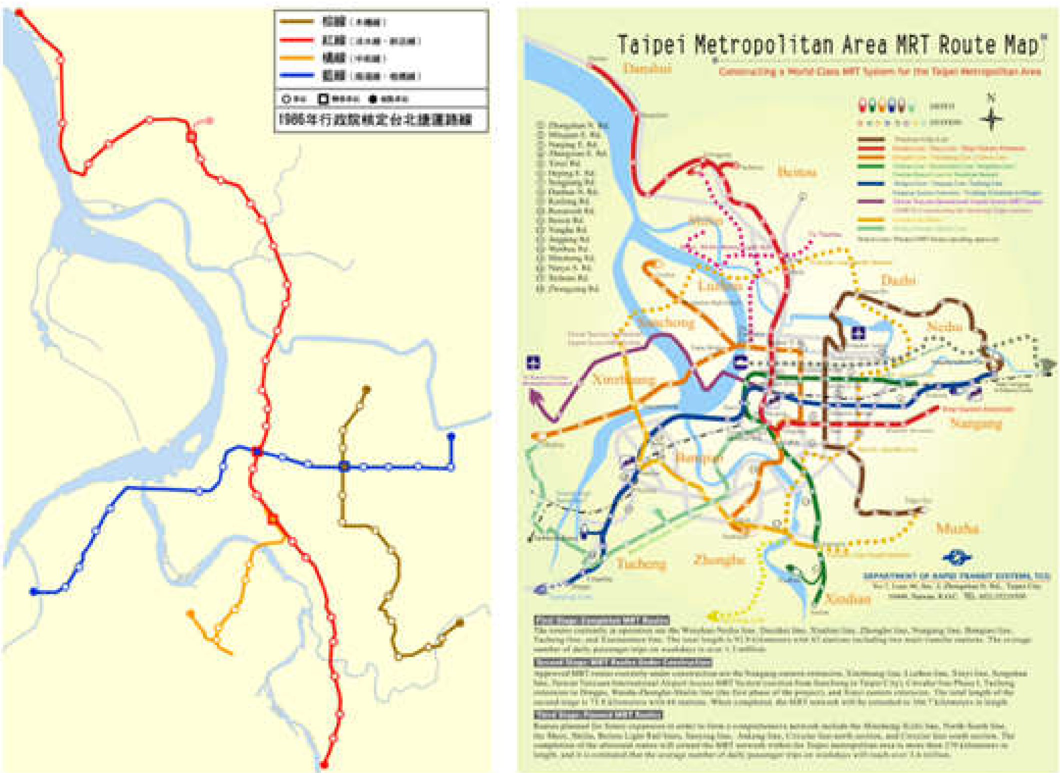
The Taipei Basin (see Figure 4) belongs to the two administrative entities of Taipei and New Taipei City (previously known as Taipei County).

[5] Because the population of Taipei city broke through 1 million in 1966, Taiwan central government elevated Taipei's status to special municipality in 1967, and made Jingmei, Muzha, Nangang, Neihu, Shilin, and Beitou townships subordinate to Taipei in 1968 (Taipei City Government 2014).



Source: GIS Center, Research Center for Humanities and Social Sciences (RCHSS), Academia Sinica

Figure 2. Taipei's city plan in 1951, the first plan in the Taiwan Retrocession Period



Source: Taipei City Government

Figure 3. Taipei mass-rapid transit system in 1986 (left) and in 2013 (right)

Geologists believe that the Taipei Basin was once a large lake in ancient times and eventually formed a basin after long years of sedimentation. Development of the Taipei Twin Cities has been inseparable, especially now with the extension and development of traffic networks (Taipei City Government 2014). Taipei City, currently with a population of 2.7 million and 100% of them living in urban areas, is the capital city as well as the cultural, economic, and political center of Taiwan. New Taipei City, with a population of 3.95 million and 94% of them living in urban areas, is the most populous and fastest-growing city in Taiwan (see Table 2). Taipei Twin Cities grew fast. The population of the Twin Cities was only 2.3 million in 1965. However, the total population tripled during the past four decades. Taipei Twin Cities, with 6.7 million people and continuing to grow, now accounts for 30% of the total population in Taiwan. The GDP of the Taipei Twin Cities accounts for more than half of Taiwan's GDP of $489 billion in 2013.[6] The GDP per capita in Taipei City is approximately $48,400, more than double that of Taiwan's GDP per capita $20,952. Taipei Twin Cities are also the economic core of Taiwan. However, this fast development may cause environmental vulnerability. Case studies around the world have found that as a city becomes more urbanized, the city also becomes more prone to flooding due to reduced wetlands and infiltration, and increased impermeable areas and surface runoff (Brody *et al*. 2007; Swan 2010; Howe and White 2010; De Roo *et al*. 2001; Weng 2001).

The disappearance of irrigation water tunnels and rivers

Since Taipei's rapid urbanization and development, most of the farm lands have been converted into residential and commercial zones. Consequently, the impermeable land areas increased. As Swan (2010) indicates, increasing a catchment's impermeable surface area will generally lead to higher levels of runoff and a subsequent increase in peak storm flows. In Taipei, the irrigation systems, with the combined functions of irrigation and flood control, were converted into roads after the 1970s. The resulting increased runoff also led to increased flooding. This situation also happened in other Asian countries. For instance, as Engkagul (1993) indicates, the disappearance of the irrigation system in the Chao Phraya Plain of Thailand caused severe floods because of the decrease in water storage areas. In addition to the farms and irrigation systems being converted into development lands and roads, the displacement of rivers with a man-made river and highways in Taipei increased floods. The highway construction, Sun Yat-Sen Highway, through Taipei in the 1970s removed some of the branches of the Keelung River (see Figure 5). This development resulted in less flood retention space and more stormwater runoff which caused more floods. Further, because of the frequent flooding along the curving downstream of the Keelung River, the lower reaches of the river were reshaped and replaced by a man-made river, with the length of 1,828 meters, width of 150 meters, and depth of 5 meters.

Source: Taiwan's Water Resources Agency, Ministry of Economic Affairs

Figure 4 Topography of Taipei Basin: Taipei (left) and New Taipei City (right)

The reshaping of the river also resulted in more intensive and impermeable land developments in floodplains along the man-made river, which led to even more potential for flood damage.

[6] The GDP in Taipei metropolitan area is approximately $300 billion in 2012.

Table 2. Population and urban development in Taipei Twin Cities

Taipei Twin Cities	Population (million)	Land area (km²)	Population density (persons/km²)	Housing units	Urban planned area as % of total area	Population in urban planned area as % of total population
Taipei City	2.68	271	9,884	935,535	100	100
New Taipei City	3.91	2,052	1,927	1,546,874	60	94

Note

- Taipei City's population of 2,686,516; New Taipei City's population of 3,954,929 as of the end of 2013.
- Most housing units are condominiums in the Taipei Twin Cities

Source: Taiwan National Development Council's 2014 Urban and Regional Development Statistics; the Ministry of the Interior's 2014 Housing Stock Statistics.

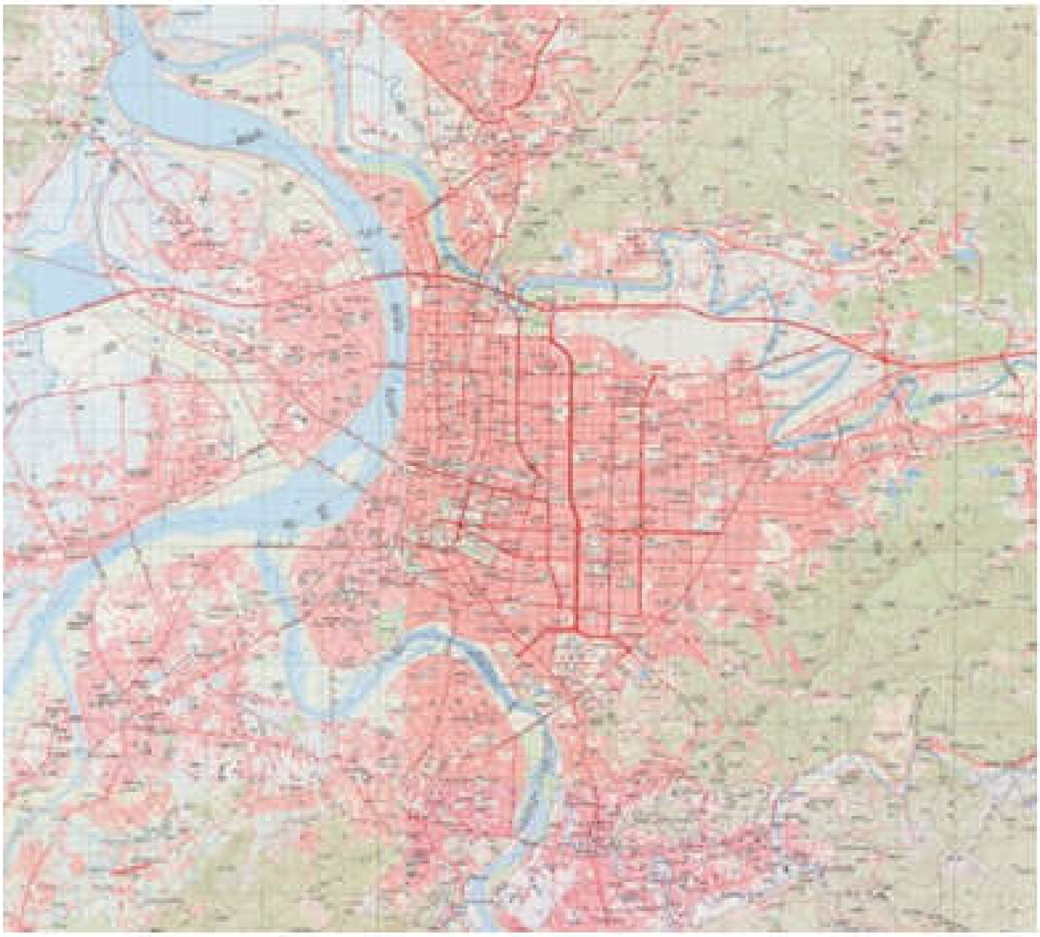
Source: GIS Center, Research Center for Humanities and Social Sciences (RCHSS), Academia Sinica

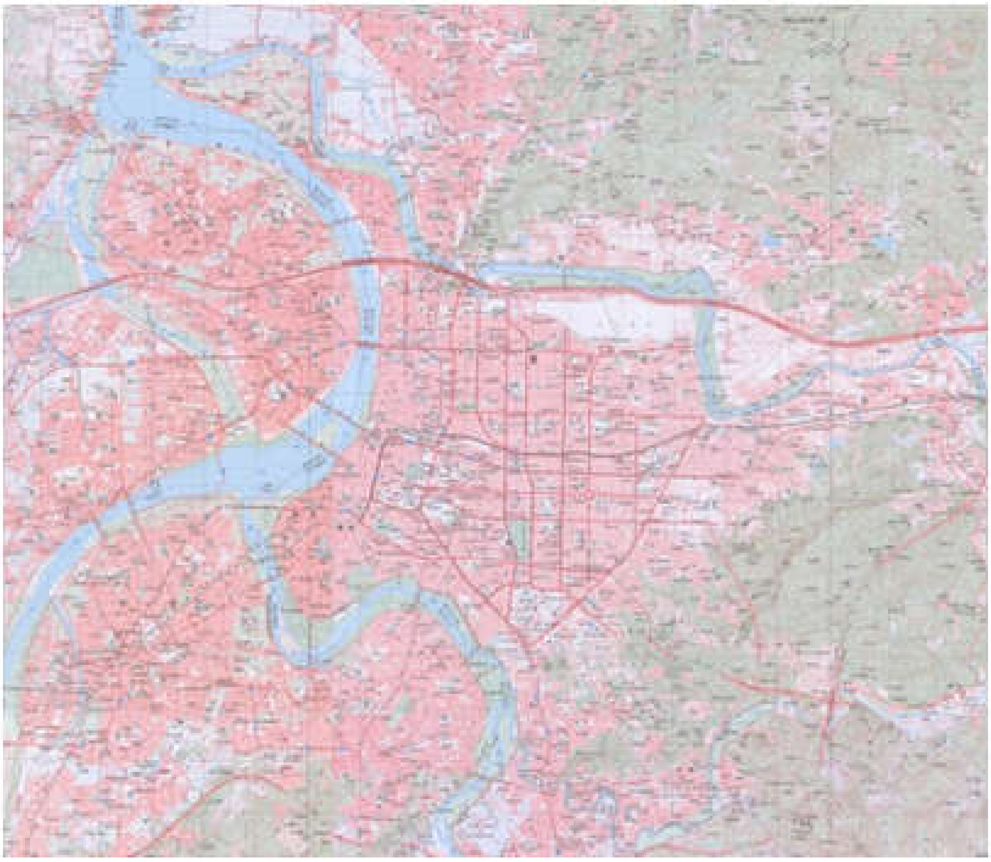
Figure 5. The vanished river, existing highway, and intensive urban development in floodplains after reshaping and removing parts of the river in the 1990s (aerial photograph was taken in 2013)

The reshaping of the river was intended to reduce floods. However, the history of flooding in Taipei from 1991-2012 indicates that this area, also known as Shezi Island of Taipei's Shilin district, was a most flood-prone area (see Figure 6).

Extreme weather and rainfall threaten Taipei more frequently

Taipei's topographic characteristics also make it more vulnerable. Taipei is situated at the center of the Taipei Basin in Northern Taiwan. Geologists believe that the Taipei Basin was once a large lake in ancient times and eventually formed a basin after long years of sedimentation (Taipei City Government 2014). Nowadays, there are four main rivers in the Taipei Basin: Tamsui River, Keelung River, Dahan River, and Xindian River. Tamsui River is formed by the confluence of the Keelung River from the northeastern side, the Xindian River from the southeastern side, and the Dahan River from the south.





Source: GIS Center, Research Center for Humanities and Social Sciences (RCHSS), Academia Sinica; Taipei City Government

Figure 6. Taipei city expansion adjacent to rivers and floodplains, from the top: aerial photographs of urban development in 1985, and 2003 (in red areas)

The topographic characteristics of the floodplain and the growing frequency of extreme weather events, such as more rainfall occurring over shorter periods and increasing precipitation intensity, have resulted in Taipei becoming increasingly threatened by typhoons and floods (Chang *et al*. 2013). The extreme rainfall associated with tropical cyclones is expected to increase by up to a third, reaching 2 to 3.15 inches (or 50 to 80 millimeters) per hour, indicating a higher level of flood risk in South East Asia (The World Bank 2013).

During a thirty-five year period 1971-2006, eleven severe typhoons caused flooding problems in Taipei, presented in Table 3. These floods mainly resulted from the overflowing of the Keelung River and the failure of the drainage system. The highest flooding reached 8.5 meters caused by Typhoon Nari in 2001. The amount of the 24-hour duration rainfall and damage have increased during the past three decades. Hence, Taipei has experienced fast-growing urbanization as well as increased vulnerability to flooding. If the current trends of global climate change are to continue unchecked, Taipei could be completely flooded by the end of the 21st century. Wang (2009, 2013) predicts that more than 50% of the Taipei area will be flooded and suggested the relocation of the capital city and evacuation of at least one-third of the population to safer places (Wang 2009; 2013).

Typhoons often flood Taipei. According to Taiwan Central Weather Bureau, 75% of heavy rainfall events, caused by typhoons from 1975 to 2014, resulted in drainage failure and river overflowing. In order to reduce flood risk, some projects have been done by the Taiwan central government. However, some coordination problems remain among various agencies. For instance, Taiwan's Soil and Water Conservation Bureau, the Water Resource Agency, and the Construction and Planning Agency manage different sections of each river and its watershed. Coordination problems for flood prevention and control exist among these central governmental agencies and local governments (see Table 4). Over the past four decades, a lack of resilience policy in flooding prevention has remained. The engineering strategy for flood prevention prevailed over the retreat and land-use planning strategy for reducing the risk of flooding (see Figure 7 and 8).

The risk awareness of floods in the 1960s

Taipei has experienced the fastest urbanization and development since the 1960s. However, the devastating floods caused by typhoons has occurred during the same period. In 1962, more than 41 square miles (10,712 hectares) in Taipei were flooded by a typhoon event. In 1963, more than 56 square miles (14,588 hectares) in Taipei were flooded by Typhoon Gloria.

Table 3. Severe flood events caused by typhoons in Taipei

Flood events caused by typhoons	Rainfall (millimeters within 24 hours)	Flooded area (hectare)	Highest flood depth (m)	Spatial distributions and characteristics
1971 Bess	150-200	6,500	3.4	Flooded areas were mainly in downstream areas where the Tamsui and Keelung Rivers converge and with low flood protection. The flood occurred in area of low development. These events caused damage and loss to agriculture and affecting flood prices. The flood type is river overflow and inundation by the sea.
1972 Betty	200-300	7,053	3	
1977 Vera	150-200	1,998	1.6	
1978 Ora	200-300	2,602	2.2	
1987 Lynn	500-700	3,332	7.5	Location of flooded areas changed from low flood protection area to mid-stream. The flooded areas with medium development. The total flooded areas declined, but the urban areas flooded increased. The flood was caused by river overflow and drainage failure.
1996 Herb	200-300	1,000	1.2	These flooding events were located in the high density areas of Taipei. The damage and losses were huge and affected all major urban activities such as transportation and commerce. These floods were due to drainage failure and river overflow.
1997 Winnie	150-200	-	1.1	
1998 Zeb	400-500	291	7.5	
1998 Babs	200-300	286	3.8	
2000 Xangsane	400-500	441	7.5	
2001 Nari	500-600	6,640	8.5	

Source: Chang et al. 2013; Typhoons Affecting Taiwan 2010

A chronology of policies implemented to protect Taipei from flooding

This section surveys current practices, developing a chronology of various steps implemented by national and local governments to protect Taipei from flooding. Flooding is a major threat to Taipei because Taipei is developed in a basin, a river mouth, and low-lying topography in a coastal zone. Flood inundation along riversides caused by the heavy precipitation that is associated with rainstorms and typhoons frequently occurs in lowlands and floodplains (Shih *et al*. 2014; Chen *et al*. 2006; Hsieh *et al*. 2006 ; Pan *et al*. 2012).

These devastating floods resulted in raised awareness of flood risk, and made the Taiwanese central government aware of Taipei's flood risk. In order to balance the fast urbanization with prevention from flood damage, two strategies were adopted: moving people from floods to Linkou New Town and building a man-made floodway to divert floods. The latter was more emphasized initially. Building a floodway was adopted for flood risk reduction. Dikes, flood prevention gates, pumping stations, and storm sewer systems are the major elements for reducing the flood risk in Taipei. However, these structural measures and hard infrastructure have their limitations when floods exceed the design standards.

Table 4. Various polices implemented by national and local governments to protect from flooding

Central and local governments	Ministry of Economic Affairs	Ministry of the Interior	Council of Agriculture	Taipei City Government	New Taipei City Government
Agency or Department	Water Resource Agency	Construction and Planning Agency	Soil and Water Conservation Bureau	Department of Urban Development	Urban and Rural Development Department
Central and local governments	Central	Central	Central	Local	Local
Flood prevention	Taipei flood control and river management	Taipei storm sewer construction	Taipei watershed management and erosion control of sleep land in the upstream	Ecological environmental planning; waterfront planning; conservation of floodplain	Creating a green city; city of rivers; expanding riverside parks and green spaces
Project	Riverside levees; strengthening of rivers; flood diversion system	Storm sewer	Upstream watershed conservation	Riverside park and open space planning	Riverside park and open space planning

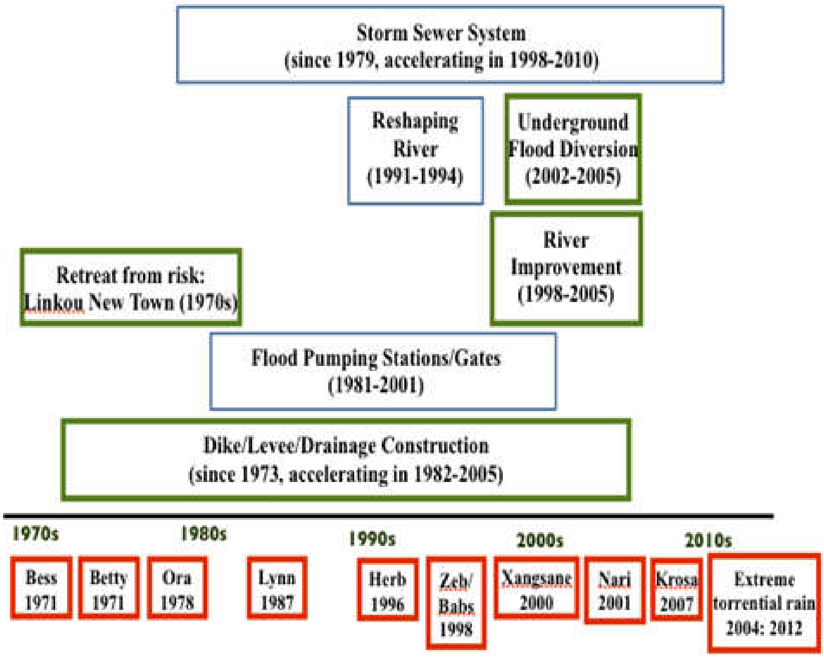


Figure 7. A chronology of policies implemented to protect Taipei from flooding

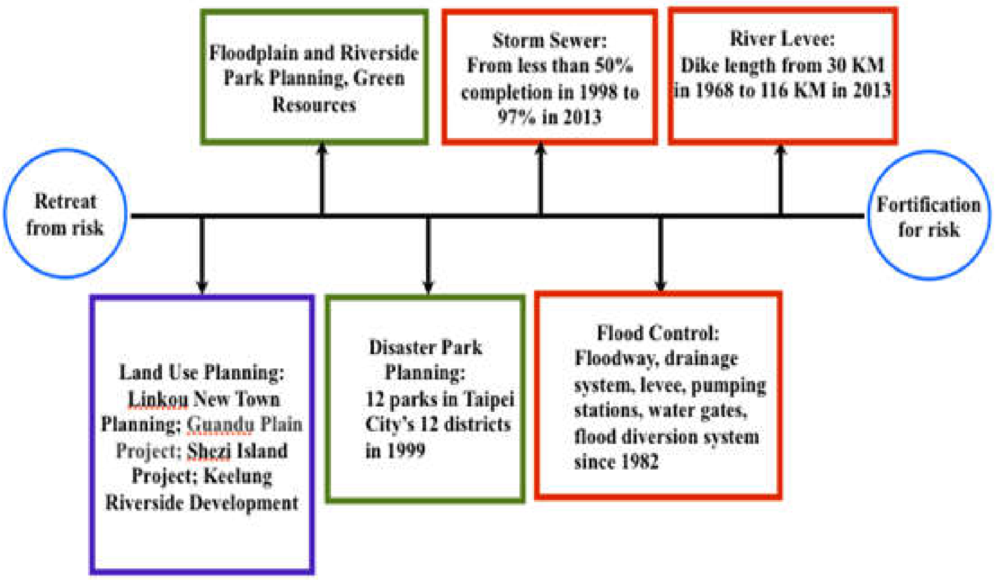


Figure 8. From fortification to retreat, the lack of land-use planning remains

The rapid urbanization without sufficient floodplain management resulted in highly developed and densely populated zones along riverbanks. The existing hydraulic facilities were thus unable to provide adequate flood protection (Shih *et al*. 2014). Land-use planning and retreat from risk needed to be gradually adopted (Huang 1989; Chang *et al*. 2013; Wang 2003).

The retreat planning in the early 1970s

The retreat policy was adopted in the early 1970s in Taipei, most notably in the development of Linkou New Town. This was designed to move people from Taipei's areas of flooding. The Linkou New Town plan was initiated in the late 1960s by the Urban and Housing Development Committee (UHDC)[7] and the United Nations' Advisor Group[8] working together in Taipei to implement the idea of Ebenezer Howard's "Garden City". The policy of the Linkou New Town plan was to relocate population to outer Taipei to prevent flood damage and to accommodate its population growth. This major national project, with its planned goal of relocating 200,000 people within 72 square miles (18,750 hectares), was implemented in the 1970s. The goal of the plan was not only to accommodate Taipei's population growth, but also to reduce flooding risk and damage as well as the expense of costly flood control facilities. Hence, Linkou New Town in the late 1960s and early 1970s was a retreat model to prevent or reduce damages from flooding in Taipei.

However, the lack of adequate facilities, public transportation, water supply, clear water, decent public schools, and cultural activities has discouraged people from living in Linkou New Town. Additionally, the Taipei real estate market did not soar until the 1990s. Linkou New Town did not gain much comparative advantage in housing market in the 1970s. Moreover, the windy and cold weather also discouraged people from living there. Thus, the development of Linkou New Town in the 1970s was not viewed as a successful case to accommodate Taipei's population. Since the 1970s, there is still a lack of a retreat and resilience policy in flooding prevention. The engineering strategy for flood prevention prevailed over the retreat and land-use planning strategy for reducing the risk of flooding. Furthermore, the existing hydraulic facilities were unable to provide adequate flood protection. A new strategy combining non-structural measures, land-use planning, and retreat from risk needed to be more emphasized in Taipei (Huang 1989; Chang *et al*. 2013; Wang 2003; Sui 2011; Shih *et al*. 2014).

Numerous investments in engineering structures in the 1980s

Due to the devastating floods in the 1960s and 1970s, constructing a man-made floodway was initiated and approved in 1979.

The Erchung Floodway, which is 7.7 kilometers long, 450-700 meters wide, was completed in 1984 to reduce Taipei flood risk. This man-made floodway helped to reduce flood areas along the Dahan River in New Taipei City. However, flooding did not stop; the water just went elsewhere. Although flooding around the Dahan River was reduced after the construction of the Erchung Floodway, the flooding was shifted and concentrated in different locations, mainly along the Keelung River. For example, the flooding areas, 13 square miles, caused by Typhoon Lynn in 1987 were located along the Keelung River.

Taiwan's Water Resources Agency is the major authority for the construction of Taipei flood control facilities. Taipei's comprehensive flood control project began in 1982, the biggest flood control measure in Taiwan (see Table 5). To present, five major flood control projects have been completed in Taipei including: Keelung River Overall Improvement Project; Yuansantze Flood Diversion Project; River and Sea Dikes Construction Projects; Taipei Area Flood Control Project; and Keelung River Control Project. In general, these flood control projects have adopted the 200-year-flood frequency (a flood with the probability of 0.5% annually or once in every 200 years) as protection criteria. This has resulted in developing dikes as high as 9.5 meters along major river banks. In Taipei City, river levees have been extended from 31 kilometers in 1968 to 117 kilometers in 2013 (Taipei City Government 2014). Taipei's flood control projects lasted from 1982 to 1996 with a total budget of approximately \$3.49 billion. Since the 1980s, numerous dikes, pumping stations, and water gates have been constructed to prevent flooding, with huge public expenditures associated with this. The latest phase of the Taipei flood control project, Keelung River Flood Control and Overall Improvement Project, spent approximately \$1.46 billion from 1998 to 2005 to improve river dredging, bank protection, dike and water gate construction, and reconstruction of pumping station bridges. The scope of flood control facilities has increased dramatically during the past three decades. The total length of dikes was tripled from 1977 to 2006 to approximately 117 kilometers. There are only a few unprotected places remaining for the extension of dikes.

Since the 1980s, flood protection efforts have mainly focused on river levees and flood diversion systems (see Table 6). There are still huge public expenditures for engineered hard infrastructure to prevent floods. Rather than increasing adaptive capacity or retreating from flood risk, Taipei has done flood control projects and engineered infrastructure to diminish the flood risk. Numerable levees, flood pumping stations, and gates have been constructed since the 1970s. However, flash flooding with the failure of Yu-Chun pumping station along the Keelung River, caused by Typhoon Nari in 2001, flowed from a levee gap and flooded downtown Taipei.

Many pumping stations were submerged and paralyzed by flooding water. The flooding areas were estimated at approximately 26 square miles. This flood was one of the most severe floods ever in Taipei. The lowlands along the Keelung River were almost entirely inundated. The Taipei rail transit system and the mass-rapid transit system were filled by the deluge.

[7] Previously UHDC is now the Department of National Spatial Planning and Development, National Development Council, Executive Yuan

[8] Unite Nations' Advisor Group in urban planning and housing in Taiwan includes Mr. Donald. Monson, Mr. Karl J. Belser, Mr. Edmund T. Ames, Mrs. Astrid Monson, Mr. Samuel S. Zadik, and Mr. Eric R. Gold.

Table 5. Major flood control projects in Taipei since the 1980s

Year	1982 ~ 1996	1998 ~ 2001	2002 ~2005
Project	Taipei Area Flood Control Project	Keelung River Flood Control Early Stage Project	Keelung River Overall Improvement Project
Budget	$3.49 billion	$407 million	$1.05 billion (including $250 million for the Yuansantze Flood Diversion Project)
Flood control criteria	200-year Flood	10-year Flood	200-year Flood
Structure construction	Construction of Dikes, pumping stations, water gates; straightening of channel curves; flood forecast system.	River dredging; bank protection; dike & water gate constructions; reconstruction of pumping station bridges.	Yuansantze flood diversion; construction of dikes, water gates and pumping stations; reconstruction of bank protection bridges; water & soil conservation; flood forecast and inundation alarm system establishment.

Source: Taiwan's Water Resources Agency, Ministry of Economic Affairs

Table 6. Major steps taken to prevent floods since the 1980s

Flood protection	Levee	Storm Water Management	Flood Diversion
Starting year	1982	2000	2005
Content	River dike construction	Storm sewer system construction	Yuansantze flood diversion construction
Measurement (as of 2013)	116 kilometers	522 kilometers	81% flood from upper Keelung River is diverted into the tunnel; 1,310 cubic meters per second (CMS)

Source: Taiwan's Water Resources Agency, Ministry of Economic Affairs

Table 7. Improvement of storm sewer systems in Taipei Twin Cities

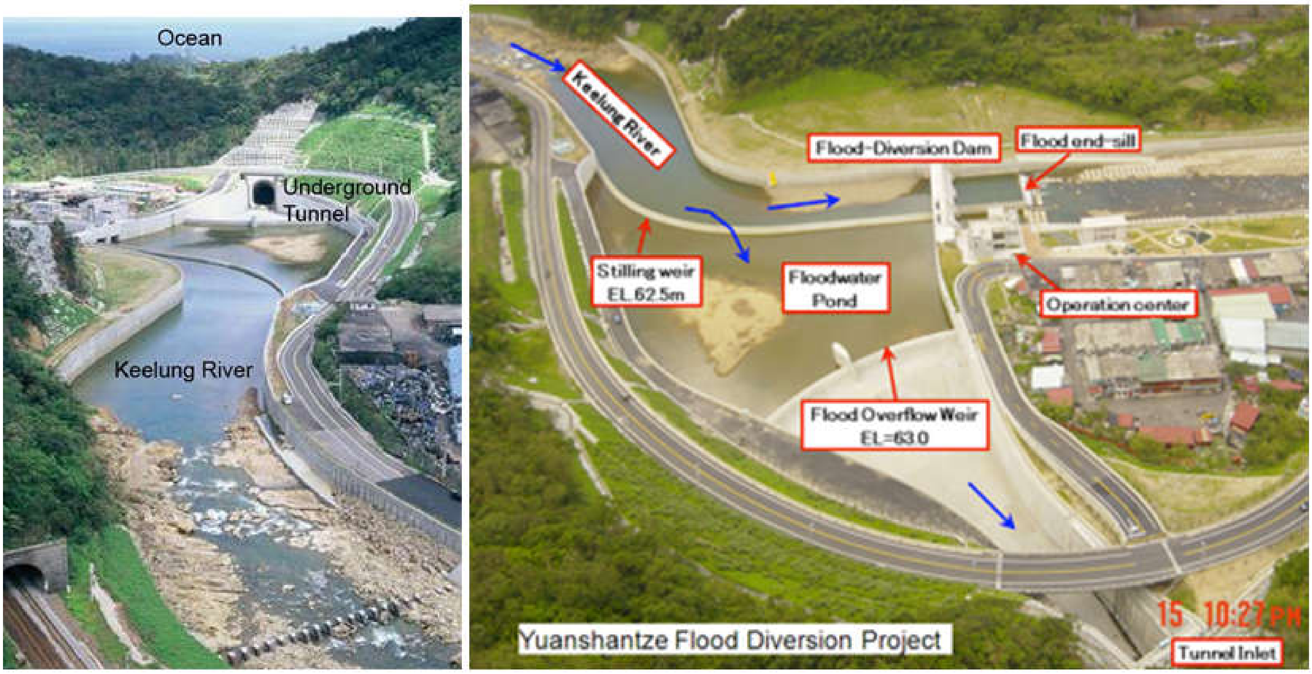
Storm sewer improvement	Taipei City	New Taipei City
Total planning area (hectare)	26,182	58,326
Planning length (km)	540	767
Constructed length (km)	522	608
Percentage of completion (%)	96	79

Source: Taiwan's Construction and Planning Agency, as of the end of 2012

The hard infrastructure failed to control this major flood. Because of this flood, the Yuansantze flood diversion system, costing $250 million and starting in 2002, was constructed with a water tunnel 2.45 kilometers long and two meters in diameter to let the overflow run through the tunnel into the ocean (see Figure 9). This engineering system project was constructed in 2005 to help mitigate flood risk in Taipei. 3.4 The improvement of storm sewer systems in the late 1990s Building storm sewer systems is another strategy used to address flood risk in Taipei (see Table 7). However, because storm sewer improvement is not obvious to the public, the political leaders delayed its implementation. Until 1998, the percentage of completed storm sewers in Taiwan was less than 50%.

It is estimated that every 1% of storm sewer improvement will cost approximately $67 million. Taiwan's Construction and Planning Agency has improved storm sewer systems as a strategy to reduce flood risks. In Taipei City, the goal is a total length of 540 kilometers of storm sewers. Currently, Taipei City is at 96% completion. New Taipei City is at 79% completion (National Development Council 2014).The improvement of storm sewer systems has reduced the flood risk since the late 1990s.

However, some storm sewer systems were designed to use the principle of gravity, allowing the water to flow from higher to lower places. Downtown Taipei is the low-lying area of the Taipei Basin. Hence, the effectiveness of storm sewer systems in downtown is diminished because of the gravity design and Taipei's topology. Drainage depending on pumping stations at outlets of the storm sewer system has been implemented. Many pumping stations were built along the Keelung River and Tamsui River. Currently, there are 65 permanent and 21 provisional pumping stations in Taipei City. However, the design of the storm sewer system in Taipei was based on a 5-year flood frequency. The maximum capacity of full operation of the storm sewers is rainfall of 3 inches (or 78.8 millimeters) per hour. The radius of the storm sewers ranges from 0.7 to 1.5 meters. When a severe typhoon hits, these storm sewers and pumping stations do not function well. Since the inflow discharge is greater than the sewer capacity, inundation usually occurs. Notable historic floods in Taipei caused by typhoons, and then the failure of pumping stations, were caused by Typhoon Zeb of 1998 and Typhoon Nari of 2001. Typhoon Zeb made the storm sewer system and pumping station dysfunctional and resulted in serious inundation in Taipei. (Hsu 2000). Nari Typhoon also flooded Taipei, 26 square miles inundated.



Source: Taiwan's Water Resources Agency, Ministry of Economic Affairs

Figure 9. The Yuansantze underground flood diversion system: flood water in Keelung River runs through the underground tunnel directly into the ocean

Strengthening the early-warning system is another option to reduce damage. An automatic remote surveillance system has been used to strengthen the early-warning system of storm sewers. The early-warning system for flooding is improving in Taipei. However, there are still many pumping stations along the rivers without the automatic remote surveillance system. According to Taipei's Hydraulic Engineering Office, these 86 pumping stations were allocated into 6 zones to be managed in groups, with an automated monitoring system set up for each zone.

The first automatic remote surveillance system was established in 2007. At present, there are still 26 stations along the Keelung River bank and 50 stations alongside the Tamsui River that have not been implemented completely. Storm sewer systems and pumping stations will help reduce flood risks when they are in full function. However, flash floods and the heavy rainfall caused by typhoons can still cause the systems to fail. In addition, storm sewer improvement and flood control improvement belong to two different central governmental agencies and the absence of full integration of these agencies still remains an issue.

Accommodation of flood by environmental planning strategy in the 2000s

In addition to these structural measures used to prevent Taipei from flooding, some non-structural policies have been included since the 2000s. For instance, there is increasing green space in Taipei. Taipei promoted the adoption of green space to improve the quality of life and provide the city more permeable surfaces to retain water. It is estimated that each citizen in Taipei City shares a park or green field area of 5 square meters, a 6-time increase compared to 0.72 square meters in 1968. Currently, each resident shares an average of 51 square meters of green space including the parks, green fields, plazas, sport locations for children, athletic complexes, educational squares, riverside parks and scenic areas under the control of Taipei City Government, in addition to reserved areas and national parks (Taipei City Government 2014). However, it is increasingly difficult to plan more parks and green spaces because Taipei's urban planning focused on meeting the demands of socioeconomic growth (Chang *et al*. 2013). Also, there is little space left for it in Taipei.

In order to have a more comprehensive flood prevention policy, Taipei City has changed the strategy of flood control and fortification since the 2000s. Taipei's Comprehensive Flood Control Project was initiated in 2003 to include conserving upstream water flow, minimizing mid-stream flooding, and controlling downstream flooding. Hence, the policy of Taipei's Comprehensive Flood Control Project mainly concentrates on its objective of launching a new water management mechanism for "retaining upstream water resources, minimizing midstream flood risks, and preventing downstream flooding" (Taipei City Government 2013). In addition, Taipei's Hydraulic Engineering Office, under the Department of Public Works, began a plan of water control and environmental protection in 2001 to reduce flood risks. For example, the ecological and flood control of Dagoi Stream Park was implemented in Taipei's rapidly urbanized district of Neihu.[9] The combination of park development and flood mitigation planning is an example of an integrative strategy to reduce flooding. In addition, in 2005 the project's committee gathered experts and officials from various government agencies to discuss working together on incorporating watershed conservation upstream, flood mitigation midstream, and flood defenses downstream into a comprehensive flood management system in Taipei City (Sui 2011).

[9] Neihu means "Inner Lake" in Chinese. Nowadays, the Neihu Science Park is located here.

Hence, since the 2000s, land-use and environmental planning has gradually become a major strategy for flood risk reduction in Taipei. The Comprehensive Water Control Management Commission was established under the Taipei City Government in 2006 as an integrative organization to coordinate with different departments for flood prevention and reduction.

Concluding Remarks

Taipei is vulnerable to flooding. Floods caused extensive damage during the 1960s while Taipei was experiencing fast urbanization. After the 1960s, Taiwan's central government and Taipei city government implemented flood control projects, including floodways, levees, flood diversion systems, flood control gates and pump stations, and storm sewer systems. In the early 1970s, Taiwan's central government planned a new town, the Linkou New Town, to move people from Taipei's area of high risk for flooding. The idea of Ebenezer Howard's "Garden City" was realized in Taipei not only to accommodate population growth, but also to prevent flooding damage. However, the engineering strategy of using flood control facilities such as levees, dikes, flood control gates, and pumping stations created a "flood control paradox" (Wiering and Immink 2005). Strengthening levees encouraged more intensive land use and development which resulted in higher damage when floods did occur. Numerous levees and dikes, flood pumping stations, and gates have been built since the 1970s. High density development occurred along the flood-prone areas of Taipei's major rivers after the completion of major flood control facilities in the 1990s.

This articles also finds that coordination problems between different governmental agencies hampered the effectiveness of flood prevention policies. For instance, a river and its watershed management in Taipei is divided into at least three sections, and each section has three different central government agencies primarily in charge of river management, soil and forest conservation of watershed, and flood prevention policy. This has resulted in inefficiency and ineffectiveness.
Starting in the 1970s, the construction of engineering structures has been the primary strategy for flood prevention, rather than land-use planning. Urban planning played less of a role in flood risk reduction than in the past. However, historic floods indicate that the existing hydraulic facilities were unable to provide adequate flood protection. Hence, a new method combining non-structural measures, land-use and environmental planning, along with retreat planning in order to reduce risk should be gradually adopted in Taipei. Land-use and environmental planning should play a proactive role in reducing Taipei's flood risk and damage. Taipei should promote planning policies regarding accommodating water, rather than mainly through engineering and other structural interventions aimed at reducing flood risk. The integration between flood control engineering and land-use planning should be strengthened to reduce flood risk in Taipei.

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