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Resilience in Space:

An experimental analysis of resilience in urban flood management in the Taipei Basin

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Abstract

The existing paradigm of flood management in the Taipei Basin prioritizes structural measures over non-structural measures. This strategy is not sufficiently flexible, particularly in light of increasingly frequent extreme weather. Resilience theory is concerned with the capacity of a system to absorb disturbance and retain its same functions. This study offers new insight by conceptualizing resilience in urban flood management. In particular, it demonstrates to what extent resilience theory as used in research on social-ecological systems was useful in developing a better plan for urban flood management. The study comprises a resilience assessment of flood management in Taipei based on guidelines in a workbook for scientists published by the Resilience Alliance. This study identified the external shocks to the flood management system in the Taipei Basin include typhoons, evidence of increasingly frequent extreme weather, groundwater mining and resulting land subsidence, and rapid urbanization. This study also includes a historical profile of major flooding and hydraulic projects from 1960 to 2010 and analyzes phases in terms of an adaptive cycle. The study concludes that resilience theory was an effective approach to investigating external shocks and stress to the system. Furthermore, the qualitative approach to apply resilience was a useful discourse for envisioning a better urban flood management system. Combining the historical profile and the adaptive cycle provided a new metaphor for examining urban flood management, though further research is needed for effectively applying to spatial issue.

Keywords: Adaptive cycle; Resilience; Social-ecological systems; the Taipei Basin; Urban flood management

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Abbreviations

CORFU	Collaborative Research on Flood Resilience in Urban Areas
NCP	National Contact Point
RA	Resilience Alliance
SRC	Stockholm Resilience Center
SESs	Social-Ecological Systems
TEIC	Taiwan Environmental Information Center
UNISDR	United Nations International Strategy for Disaster Reduction
WRA	Water Resources Agency

Websites

Collaborative Research on Flood Resilience in Urban Areas http://www.corfu7.eu/
National Fire Agency, the Ministry of the Interior http://www.nfa.gov.tw
Resilience Alliance http://www.resalliance.org/
Stockholm Resilience Center http://www.stockholmresilience.org/
Sustainable Scale Project http://www.sustainablescale.org/
Taipei City Government Hydraulic Engineering Office http://www.heo.taipei.gov.tw
Taiwan's Central Weather Bureau http://www.cwb.gov.tw
The Flood Resilience Group http://www.floodresiliencegroup.org/
The Taipei Flood Reporting Online Database http://rain.tcg.gov.tw/flood
The Tenth River Basin Management Bureau http://www.wra10.gov.tw/
Taiwan Environmental Information Center http://e-info.org.tw/
United Nations International Strategy for Disaster Reduction http://www.unisdr.org/
Water Resource Agency http://www.wra.gov.tw/

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1. Introduction

> Climate change is expected to cause more severe and more frequent natural hazards. As our cities and coasts grow more vulnerable, these hazards can lead to disasters that are far worse than those we have seen to date. We have a moral, social and economic obligation to build *resilience*[1] by 2015. Implementing the Hyogo Framework for Action will also help us reach the Millennium Development Goals.
>
> Ban Ki-moon, Secretary-General of the United Nations (UNISDR, 2007)

In the first few months of 2011, the world witnessed a series of severe natural disasters. Flooding and earthquakes wrought particular devastation. In early January, parts of Queensland, Australia, experienced heavy flooding, with three quarters of the state declared a disaster zone (Hurst, 2011). In February, a 6.3-magnitude earthquake rocked Christchurch, New Zealand — the country's worst natural disaster since 1931 (BBC News, 2011). Then, on March 11, a temblor measuring 9.0 struck northeastern Japan, triggering a tsunami that devastated coastal towns and cities and caused a nuclear crisis (BBC News, 2011). In late March, unseasonal cold weather and heavy rains swept southern Thailand and stranded thousands of tourists (BBC News, 2011). In April, more than 60 tornadoes ripped through North Carolina, USA — the highest number of twisters in a single storm in that state since 1984 (BBC News, 2011). Natural disasters have become a daily staple of media reports from developing and developed countries alike. Seeking innovative strategies to cope with such catastrophes is without doubt one of the most urgent challenges of our era. As advocated by the UN International Strategy for Disaster Reduction (UN/ISDR), resilience will likely be pivotal in developing solutions, since it concerns the efficiency of a system in resisting, absorbing, accommodating and recovering from natural hazards (UNSIDR, 2009).

Resilience is a prevailing theme of the discourse on disaster preparedness, response, recovery and mitigation (Klein et al., 2003, UNISDR, 2007). This became all the more true after Hurricane Katrina wreaked havoc on New Orleans in 2005 (Tierney and Bruneau, 2007, Revkin, 2010). The UN/ISDR has adopted the term resilience in campaigns including the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters, and the agency's 2010-2011 World Disaster Reduction Campaign, "Making Cities Resilient: 'My city is getting ready.'" However, the application of resilience remains tenuous in terms of context.

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[1]Italics added.

The concept of resilience emerged in the 1960s and early 70s from studies of population dynamics and ecological stability theory in the field of ecology (Folke, 2006). According to Holling's definition, "resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Holling 1973:17). The use of this term has stretched considerably from its original meaning, however, and has come to influence a number of other disciplines. An excellent example of this is Adger's definition of social resilience as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change" (Adger 2000:374).

Underlying this finding, Adger (2000) raised the possibility that ecological and social resilience may be linked through their dependence on ecosystems. This perspective on resilience informs research into social-ecological systems (SESs); by this view, all resources consumed by humans are seen as embedded in a complex system and social and ecological factors cannot be approached independently (Walker et al., 2002 , Walker et al., 2004). Some researchers term this "coupled human-environment systems," although the term SESs is more common. In brief, SESs is an emerging research field that focuses on the interplay between social and ecological systems. Ostrom's (2009) research examines the multiple effects and interrelatedness of social elements in an environment is an example in this field.

In this context, resilience is perceived as a way to achieve long-term sustainability (Walker et al., 2002). The Resilience Alliance (RA) and Stockholm Resilience Center (SRC) are two key research institutions advocating this perspective. The RA is an extensively networked research organization that seeks new ways to learn about and apply resilience theory, while the SRC is a transdisciplinary research center that connects resilience theory to SESs, ecosystem service management and long-term sustainability. One of the RA's approaches is developing guidelines that will enable others to assess the resilience of SESs and develop policy and management tools that support sustainable development (RA, 2007).

Although this application of resilience theory has given rise to a vibrant research scene, why it should be the proper approach for exploring resilience in a wide variety of contexts has yet to be answered. Thus, the present study challenges this approach to resilience by questioning whether it is applicable to spatial issues. The study selects one type of disaster for investigation: flooding, specifically in urban areas.

This study therefore aims to contribute to two fields of research, namely resilience and urban flood management, and to offer new insight gained by conceptualizing resilience in urban flood management. By "flood management", I mean measures to reduce the effects of flooding. For example, measures can be modifying susceptibility to flood damage (legislation, zoning and land-use planning), modifying flood waters (flood defence infrastructure) and modifying the impact of flooding (detection of the likelihood of flood formation, early warning, public evacuation and insurance)(Kundzewicz, 2002). The study seeks to demonstrate to what extent resilience theory as used in SES research was useful in developing a better plan for urban flood management. The study used flood management in the Taipei Basin to test this perspective on resilience.

1.1 Structure of this study

Chapter 2 systematically reviews the literature on the concept of resilience. Chapter 3 homes in on social-ecological resilience to explore resilience in urban flood management. The RA's inquiry suggestions for conducting resilience assessments, published in *Assessing Resilience in Social-Ecological Systems – A Workbook for Scientists* (2007), served as a guide for this part. Due to the limitations of time and scope, I then select the elements of external shocks, historical profile and adaptive cycle for further discussion. To test the applicability of social-ecological resilience to urban flood management, the study focuses on flood management in the Taipei Basin as a case study. Chapter 4 offers a brief history of flood management in the basin, while Chapter 5 analyzes the applicability of social-ecological resilience to this region. Further discussion and conclusions about applicability are presented in Chapter 6. The structure of this paper is listed below (Figure 1).

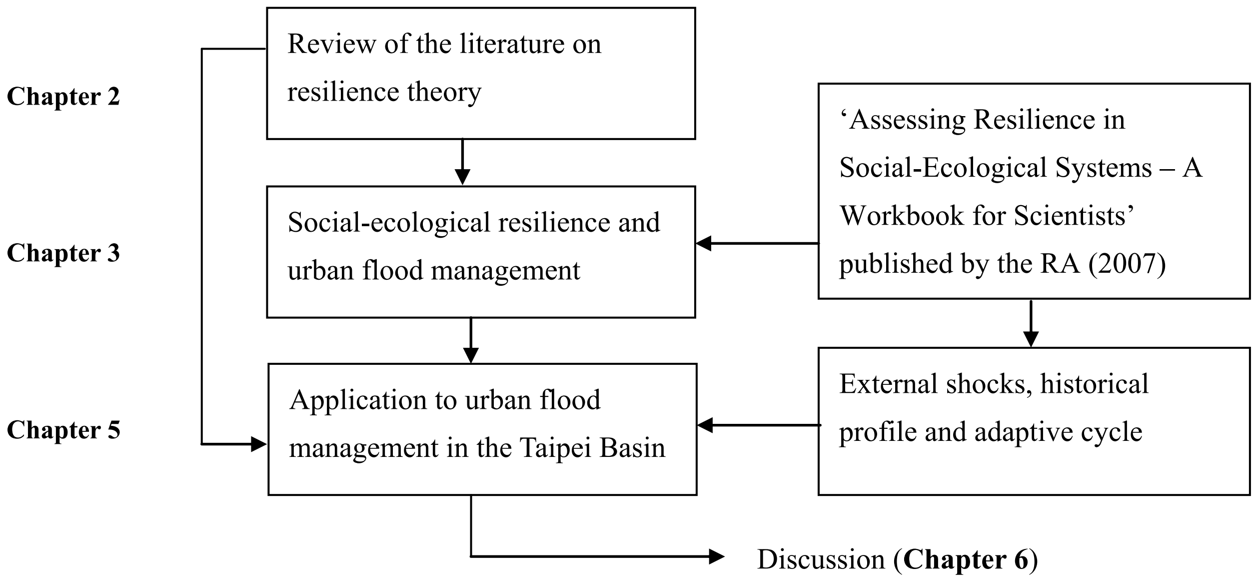

Figure 1: Conceptual framework for this study

1.2 Motivation for this study

Four key considerations motivated this study. Firstly, given the complexity of floods, coping strategies should be placed in the context of sustainability. Kundzewicz (2002) argues that floods destroy human heritage and thus jeopardize the quality of life. Additionally, inappropriate measures for flood defense may become impediments to better options in the future.

Secondly, viewing flood protection policies within this context likely has implications for flood management in the Taipei Basin, where authorities have long prioritized structural solutions over non-structural ones (Teng et al., 2006). "Structural" solutions refer to attempts to control floodwaters with dikes and floodwalls. By contrast, "non-structural" measures usually refer to source control, watershed management, legislation and regulations such as zoning rules, flood warning systems and flood-related databases (Kundzewicz, 2002). The history of flood management in the Taipei Basin has been a process of containing flooding by building ever higher and longer dikes along the city's rivers and ignoring the rivers' natural systems. Between 1968 and 2009, the total length of the basin's dikes increased from 30.96km to 116.76km (Taipei City Government, 2010).

Yet as most of Taiwan's major flooding infrastructure was built in the 1970s, engineers hardly factored in the potential for extreme weather brought about by climate change. The current flood management paradigm of building ever higher dikes is not flexible enough to cope with the high uncertainty that an increase in extreme weather poses. Taiwan in particular is located on the major route of typhoons in the northwest Pacific and sees an average of three or four of the storms annually.

Thirdly, although resilience seems an attractive concept for describing the degree of disturbance that a system can tolerate before a regime shift is required, there are obstacles to translating this into an operational tool for policymaking and management (Klein et al., 2003). In order to advance resilience in urban flood management, it is necessary to have a clear initial understanding of what resilience is and what its determinants are. To refer back to the introduction, this study focuses on analyzing resilience as understood in SESs research.

Lastly, resilience is not today a dominant discourse within Taiwanese flood management. However, in 2011, an urban flooding research team from Taiwan will participate in the Collaborative Research on Flood Resilience in Urban Areas (CORFU) project, a joint, interdisciplinary program launched by European and Asian partners. CORFU aims to provide adequate measures to improve flood management in cities (NCP, 2010). Participating countries will share case studies from Barcelona, Spain; Beijing, China; Dhaka, Bangladesh; Hamburg, Germany; Mumbai, India; Nice, France; Seoul and Songdo, South Korea and Taipei, Taiwan in hopes of advancing the discussion of strategies for living with floods. My study therefore offers a preliminary analysis to envision flood resilience in the context of urban flood management in the Taipei Basin.

1.3 Research questions

This study aims to demonstrate to what extent resilience theory as used in SES research was useful in developing better plans for urban flood management. To that end, it proposes a hypothetical solution of incorporating resilience into the discourse on urban flood management. The main research questions are formulated as follows:

1. *Which definition of resilience is most useful for exploring urban flood management?*

2. *To what extent is resilience as it is understood in SES research applicable to spatial issues, particularly urban flood management?*

In order to test applicability of the second research question, I relied on Resilience Alliance's *Assessing Resilience in Social Ecological Systems – A workbook for Scientists* (Version 1.1 Draft for Testing and Evaluation) (2007) to guide my assessment of the resilience of current flood management in the Taipei Basin. To provide crucial background, the study addresses the following questions:

3. *What is the current configuration of the flood management system in the Taipei Basin?*

4. *How useful is a historical profile of flooding and adaptive cycles in identifying the barriers to and opportunities for a better flood management in the Taipei Basin?*

1.4 Research methodology

This study conducts a resilience assessment of flood management in the Taipei Basin. As a guide to the assessment process, I used the RA's 2007 workbook for scientists as well as a framework proposed by Walker et al. (2002) for analyzing resilience in social-ecological systems.

To support the assessment process, this study relies largely on *secondary data* collected by other researchers and government departments for statistical purposes. The advantages of secondary analysis lie in having access to good quality data and an opportunity for longitudinal analysis (Bryman, 2008). Background information gathered for this study is mainly from published research on flood management and resilience theory, and from newspapers and government documents. This study presumes the validity and reliability of the data: Since my aim is to test whether social-ecological resilience is applicable to spatial issues, I argue that the secondary data provide sufficient evidence to support my investigation.

In addition to secondary data, this study includes two personal communications — one from a scholar in this field and another from a government agency — as primary data to support the discussion.

As a Mandarin Chinese speaker, I had access to a wide variety of original material and data on the subject. Part of the resilience assessment required putting together a historical profile, for which most sources were in Chinese. The profile covers flooding events and major flood-prevention infrastructure in the Taipei Basin between 1960 and 2010. For this section, I included all instances of flooding listed by the Tenth River Basin Management Bureau and the Taipei Flood Reporting Online Database. A database of typhoons, including their duration, track and intensity, is available through Taiwan's Central Weather Bureau. Data on the number of people and homes affected is available through the National Fire Agency under the Ministry of the Interior. Most documents concerning hydraulic policies and construction projects are public in Taiwan and can be found on the websites of government agencies.

2. Conceptualizing resilience

Research Question 1*:*
Which definition of resilience is most useful for exploring urban flood management?

Resilience is derived from the Latin word *resilio* and literally means "to jump back" (Klein et al., 2003). The origin of the concept is contested: Some academics say it has its roots in ecology, while others point to physics (Manyena, 2006). In this study, "resilience" refers to the concept as used in the field of ecology and in Holling's (1973) oft-cited "Resilience and Stability of Ecological Systems" based on observations on the population dynamics of predators and prey in ecosystems. Nevertheless, the term has evolved considerably from its original meaning and has been applied, for example, to social systems (Adger, 2000). There is a trend toward more metaphorical uses, describing the ability of a system to recover and return to its original state (Klein et al., 2003).

2.1 The evolution of the concept of resilience

Even prior to Holling's findings, studies on resilience can be found in the disciplines of psychology and psychiatry in the 1940s (Manyena, 2006). These studies sought to analyze the effects of adverse conditions or events on child development, such as whether children raised in adverse circumstances are more likely to withstand stressful situations in the future (Masten et al. 1990). I do not discuss this conception of resilience here.

Based on an inductive approach and his experience observing disturbance at multiple scales in natural systems, Holling (1973) introduced the concept of ecological resilience equilibriums as a challenge to the dominant view of stable equilibriums. He defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973:14). This approach to resilience was later termed "ecological resilience".

Pimm (1984), meanwhile, defines resilience as the speed with which a system returns to its original state after perturbation. This perspective of resilience became known as "engineering resilience". The different approaches of Holling and Pimm have become two dominant paradigms. The two approaches show different research emphasis (Figure 2). Gunderson (2000) argues that the difference reflects separate perspectives on stability and the way to understand and operationalize resilience. In engineering resilience, he says, there is an implicit assumption of global stability, in which only one steady state or equilibrium exists. By contrast, the concept of ecological resilience presumes the existence of multiple stability domains, in which it is possible for a system to experience perturbation before transitioning among stable states (Gunderson, 2000). Carpenter et al. (2001) argue that these two approaches can help natural resource managers imagine the persistence of a given system and break the myth of achieving stability.

Resilience = disturbance which can be absorbed before state change

Resilience = rate of recovery from perturbation [resilience + resistance = stability]

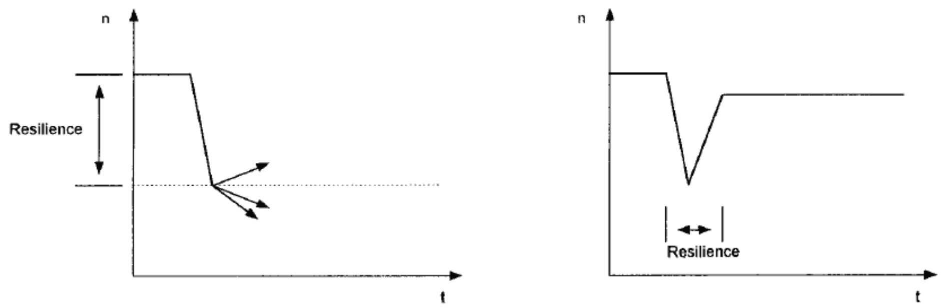

Figure 2: Two definitions of resilience. The graph on the left represents Holling's (1973) focus on the magnitude of disturbance that a system can absorb. The one on the right represents Pimm's (1984) focus on recovery speed/time. Source: Adger (2000: Fig. 1)

These two contrasting views of stability are so fundamental that they produce alternative paradigms that reflect either a focus on *efficiency* of functions (engineering resilience*)* or maintaining the *existence* of functions (ecosystem resilience) (Holling and Gunderson, 2001: 28).

In addition to these two key perspectives on resilience, Folke (2006) summarizes the concept's evolution from the more narrow interpretation to the broader social-ecological context (Table 1). The emergence of social-ecological resilience

(SER) reflects a research trend in which our understanding of resilience in natural systems is applied to the interplay between social and ecological systems. In this area of research, resilience is perceived as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al., 2004).

Table 1: The sequence of resilience concepts. (Folke et al., 2006)

Resilience concept	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological/ecosystem resilience social resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibrium, stability landscapes
Social-ecological Resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity transformability, learning, innovation	Integrated system feedback, cross-scale interactions

The concept of resilience as applied in this area has three key components: (1) the amount of change the system can undergo and still remain within the same domain of attraction; (2) the system's capability to self-organize; and (3) the degree to which the system can learn and adapt (Carpenter, 2001; Folke et al., 2002). Domain of attraction refers to a dynamic system that contains an "attractor" that enables the state of the system to move (Figure 3). Gallopin (2006) argues that the concept of domain of attraction is key to resilience because SESs usually have more than one attractor, meaning that when an unexpected shock affects the system, the state of the system shifts from domain to domain. Resilience thus is the capacity of a system to absorb disturbance and retain the same function (Walker et al., 2004).

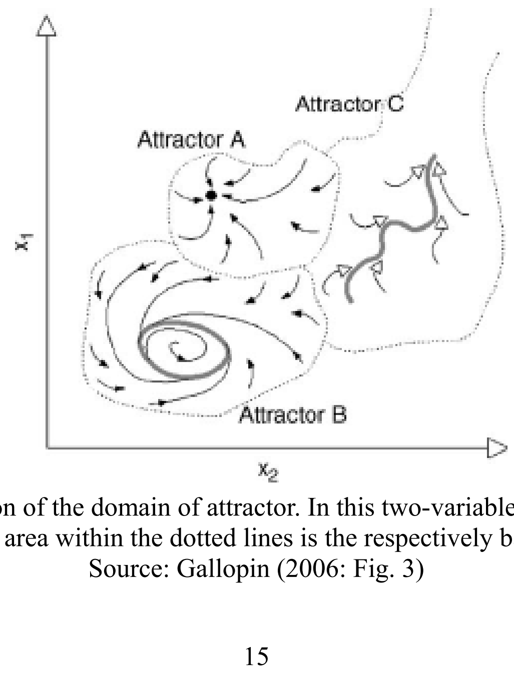

Figure 3: The illustration of the domain of attractor. In this two-variable system, there are three attractors and the area within the dotted lines is the respectively basin of attraction.
Source: Gallopin (2006: Fig. 3)

In practical applications, the concept of resilience often follows the broader definitions of social resilience and SER. For example, in the disaster prevention field, the UNISDR has offered the following definition:

> Resilience means the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
>
> UNISDR, 2009

However, as resilience is increasingly viewed as a viable approach to tackling overarching issues both in practice and in academia, there is a risk of misinterpretation. In particular, when it comes to research into global environmental change, resilience has been discussed parallel to concepts such as vulnerability and adaptation.

Janssen et al. (2006) analyzed 2,286 publications produced between 1967 and 2005 that mention resilience, vulnerability and adaptation and explored the co-author links and citation relationships. The analysis revealed a strong scholarship network that indicates increasing integration of the different knowledge domains. However, the increasing linkage between these terms also raises the risk of ambiguity and overlapping concepts.

To better understand this integration, Gallopin (2006) systematically reviewed the fundamental attributes of these concepts (vulnerability, resilience and adaptive capacity) and developed a framework to describe the conceptual relationships among them. Gallopin found that these concepts are strongly related and concluded that research on the dynamics of global SESs can be "epistemologically very messy," and should therefore be carefully examined (Gallopin, 2006: 301).

Without doubt, resilience is an evolving concept. Understanding resilience perspectives from multiple fields requires further research. In my study, I share the perspective that resilience has multiple levels of meaning: 'as a metaphor related to sustainability, as a property of dynamic models, and as a measurable quantity that can be assessed in field studies of SES' (Carpenter et al., 2001: 765). The following section focuses on SER for further discussion.

2.2 The emerging research on social-ecological resilience

Social-ecological resilience (SER) is an emerging conception of resilience that attempts to bridge the natural sciences and social sciences and facilitate interdisciplinary research. The SRC research institute sees resilience as a new framework for analyzing uncertainties, with implications for sustainable development policies (SRC, 2007). This research niche falls under the umbrella of SES research. One common trait of research under this umbrella is a strong emphasis on developing a conceptual framework to describe a given issue and generate solutions. For example, the general framework Ostrom's (2009) developed is a research effort for analyzing the sustainability in SESs to reverse the deterioration of natural resources around the world. The basic assumption underlying the SES perspective is that "humans must be seen as a part of, not apart from, nature" (SRC, 2007).

Thus, by viewing humans as the major driving force of planetary change, it fundamentally shifts the research focus to a broader socioeconomic context. This approach underpins the development of SER research. The key questions in this area of research are: *Does social resilience exhibit characteristics similar to ecological resilience?*

The development of social resilience offers a view of how SER has evolved. Klein et al. (2003) notes that Timmerman (1981) was one of the first to discuss the resilience of society to climate change. In their view, Adger (1997, 2000) follows the same definition of social resilience as Timmerman (1981). Adger explores the potential links between ecological and social resilience as illustrated in the following quotation:

> Market liberalization and the privatization of mangroves in this case reduce ecosystem as well as social resilience. This loss of resilience is associated with negative impacts on livelihoods and, in the context of the institutions of common property management, collective institutional resilience is also undermined.
>
> Adger (2000:348)

Although there is no consistent definition of resilience in ecology, the application of resilience to social sciences is gaining ground (Klein et al., 2003). The concept's appeal lies no doubt in including ecological and social factors from various scales to disentangle complex questions concerning the management of natural resources.

However, as Adger (2000) notes, the concept of resilience should not be transferred uncritically from ecological systems to social systems. The development of the adaptive cycle is seen as the best example of transferring this concept to social system.

2.3 Resilience and Adaptive Capacity

Understanding the interaction of people and natural systems by examining only limited factors is no easy task. Almost a decade ago, the Resilience Project aimed to develop an integrative theory that would embrace the complexity of such issues (Holling, 2001). The project borrowed Einstein's words, "as simple as possible but no simpler," to argue that complexity can be approached through a smaller number of controlling processes rather than a larger number of interacting factors (Holling, 2001). The work that emerged from this project was elaborated in the book *Panarchy: Understanding Transformations in Human and Natural Systems* (Gunderson and Holling, 2001). The authors write:

> The theory that we develop must of necessity transcend boundaries of scale and discipline. It must be capable of organizing our understanding of economic, ecological, and institutional systems. And it must explain situations where all three types of systems interact. The cross-scale, interdisciplinary, and dynamic nature of the theory has led us to coin the term *panarchy* for it. Its essential focus is to rationalize the interplay between change and persistence, between the predictable and unpredictable.
>
> *Panarchy*, Holling and Gunderson, p.5

Thus, the adaptive capacity understood as "the resilience of the system" (Holling, 2001) is seen as a way to understand a dynamic system. By this view, all systems, including flood management systems, exist and function at multiple scales of time, space, social organization and interaction at cross-scales. The four stages of the adaptive cycle are (Figure 4):

The ***exploitation*** stage (r) is one of rapid expansion, as when a population finds a fertile niche in which to grow.

The ***conservation*** stage (K) is one in which slow accumulation and storage of energy and material is emphasized, as when a population reaches carrying capacity and stabilizes for a time.

The ***release*** (Ω) occurs rapidly, as when a population declines due to a competitor, or changed conditions.

Reorganization (α) can also occur rapidly, as when certain members of the population are selected for their ability to survive despite the competitor or changed conditions that triggered the release.

Sustainable scale project, 2003

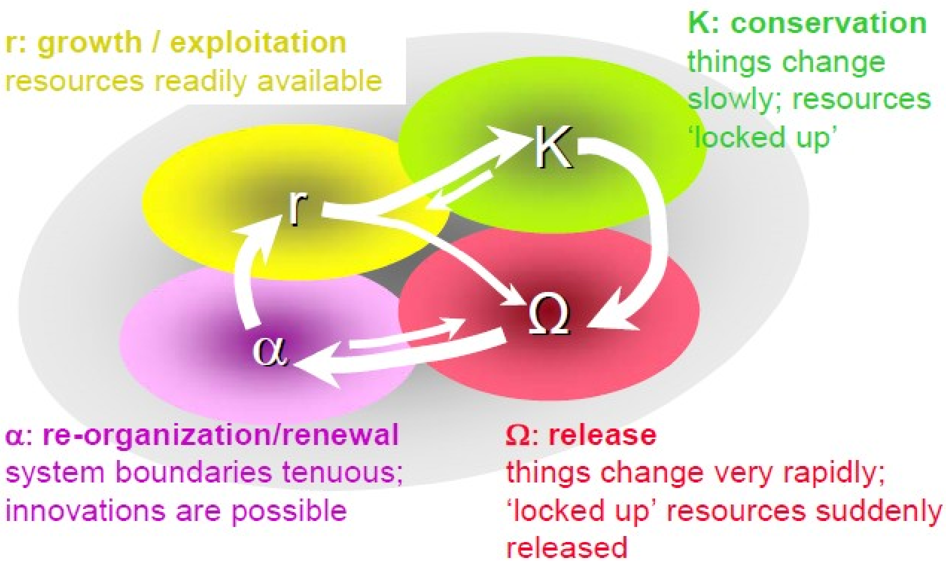

Figure 4: The adaptive cycle. The model of adaptive cycle was derived from the dynamics of ecosystem. For an ecosystem and SESs, the system's dynamics can be represented by an adaptive cycle with four distinct phases: growth or exploitation (r), conservation (K), collapse or release (omega) and reorganization (alpha) (RA, 2007).

Applying the concept of adaptive cycles to social systems is a sophisticated attempt to combine theories from ecology and human institutions. It is an evolving concept and still an evidence-based approach. As Walker et al. (2004) have noted, the metaphor of the adaptive cycle does not imply a fixed and regular cycle. Applying this concept also reflects a strong emphasis on the actions of humans, "because human actors base their actions not only on their past experience but also on their capacity to *plan for the future*[2]" (Chapin et al., 2009:23). However, the effectiveness of applying adaptive cycles to social systems remains hypothetical, though a number of empirical experiments have been conducted. In the RA's workbook, SESs are perceived as systems that are never static and tend to move through the four, recurring phases of the adaptive cycle (RA, 2007).

[2] Italicized in the original.

3. Resilience and Urban Flood Management

In the first part of this chapter, I briefly review the body of research on resilience and flood management — mainly the quantitative approach of operationalizing the concept. Next I enter the main discussion of this study: a social-ecological resilience approach to urban flood management.

3.1 Existing research on resilience in flood management

Applying resilience to flood management is not entirely new. Recent research on resilience in flood management took place in the Netherlands and the UK. For example, the Flood Resilience Group (FRG), established in 2007, is a multidisciplinary research group affiliated with the UNESCO-IHE and the Delft University of Technology. Their aim is to integrate scientific knowledge and practical applications to advance flood resilience in urban environments. The group's work includes (1) quantifying the impacts of changing drivers for urban flood risk, (2) assessing the restorative and adaptive resilience of urban flooding systems, and (3) transition management and adaptive management for urban flooding systems.

Similarly, the Dutch government's "Room for the River" plan incorporates the resilience strategy by allowing some flooding. Vis et al. (2003) compared current flood risk management in the Netherlands — a resistance strategy that favors raising dikes — with two alternative resilience strategies that focus on minimizing the consequences of floods. They evaluated the financial impact of flood damage and found that the initial costs of the two resilience strategies were high, but produced benefits in the long term. Additionally, resilience is considered more flexible in offering landscape development (Vis et al., 2003).

So far, Bruijn (2005) has produced the most comprehensive exploration of resilience in flood management. Brujin used a quantitative approach to explore resilience in the context of flood risk management in lowland rivers. Brujin determines the resilience of a flood management system by quantifying three aspects: the amplitude of the reaction; the gradualness of the increase in reaction to increasingly severe flood waves; and the recovery rate (Bruijn, 2005). She used three case studies to test the theoretical framework: the lower Rhine River, the undiked part of the Meuse River and the lower Mekong River.

In her findings, Brujin characterizes resilience strategies as strategies that allow flooding yet aim to minimize the impact. Resilience strategies can also direct floods to less vulnerable areas, or limit flooding through compartmentalization. To illustrate the main difference between resilience and resistance strategies, Brujin notes that resilience strategies consider the entire discharge regime, whereas resistance strategies may focus on a single design discharge.

Building on Brujin's (2005) findings, Zevenbergen et al. (2008) developed a framework to explore the complex spatial-temporal relations of urban flood management. They concluded that urban flood management should focus on the feedback loops that interact across differing spatial scales (from the building, street level and city to the catchment), and that participatory design is a key temporal dimension to reducing flood impact.

To sum up, research into flood resilience tends to take an operational approach to resilience. Bruijn (2005), for example, applies a quantitative approach to flood management resilience. This approach is partially a result of the researcher's background in hydraulics-related fields. It raises the question of whether resilience should be used to reframe flood management with a focus on allowing flooding (while reducing the impact) or quantifying the recovering rate. In the following section, I describe the approach to resilience in flood management that I used in this study.

3.2 Applying social-ecological resilience to urban flood management

Research Question 2:
To what extent is resilience as it is understood in SES research applicable to spatial issues, particularly urban flood management?

In contrast to the quantitative approach to operationalized resilience described above, I take essentially a qualitative approach to exploring the resilience of Taipei's flood management. In this approach, resilience is a concept or perspective that is intended to help us understand a system rather than a scientific hypothesis that should always be tested with quantitative data (Norberg and Cumming, 2008).

After considering various approaches, I decided to use an SER approach to discuss resilience in urban flood management for two reasons: Firstly, urban flood management usually involves issues across spatial and temporal scales and should therefore be viewed from an SES perspective. This approach also echoes Kundzewicz's (2002) argument that flood management should be placed in the context of sustainability. Secondly, as engineering resilience focuses on *efficiency* — reflecting a traditionally engineering-centric approach to urban flood management, such as how to contain floodwaters — it seems that an SER model is more likely to generate a regime shift toward a more desirable state. In particular, this approach to resilience is useful in analyzing the adaptation process (Nelson et al., 2007). With these considerations in mind, SER seems the best choice to explore resilience in urban flood management.

The next step, then, is to test how applicable SER is for urban flood management. By "flood management" I mean measures to reduce the effects of flooding. Measures may be either structural or non-structural (Table 2).

Table 2: Structural and non-structural measures in the urban flood management. (Andjelkovic, 2001)

Structural Measures	**Non-structural Measures**
Protection against flood; Modify flood; Reduce pollution.	Emergency responses measures; Flood preparedness measures; Local and state legislation; Financing; Environmental impact assessment.

I followed the RA's resilience assessment workbook to test applicability, but did not follow it in its entirety. This study does not, for example, discuss inventions in resilience management. In the following section, the study identifies the factors that should be included in a framework (Walker et al., 2002) for analyzing a participatory approach to SES resilience. The Taipei Basin then serves as a case study to test applicability.

3.2.1 The conceptual framework for Urban Flood Management

The conceptual framework for conducting resilience assessments of urban flood management is listed below (Figure 5). The framework is modified from the model Walker et al. (2002) present for analyzing a participatory approach to SES resilience. In order to apply it to the context of urban flood management, I added other factors, using the RA's workbook as a guide.

In Step 1, the first priority is to specify the boundaries of the system. Step 2 includes three aspects; exploring the external shocks is key in this step. Plausible policies and visions for the future are crucial in the last step of the stakeholder's evaluation. A historical profile of major events and developments is created in Steps 1 and 2. Between Steps 2 and 3, scenarios should be envisioned. I include three categories of scenarios: low-resilient, medium-resilient and high-resilient. These scenarios are not predictions but rather potential developments (RA, 2007).

Step 3 is the most important part of the process, the resilience analysis. In this step, the study should develop a conceptual model of change. Phases in system dynamics, critical scales and cross-scale connections should be identified and connected to the adaptive cycle. The most difficult part of this is understanding the dynamics at scales below and above — linked to the concept of panarchy. In the last step, policy and management actions should be evaluated after stakeholder meetings.

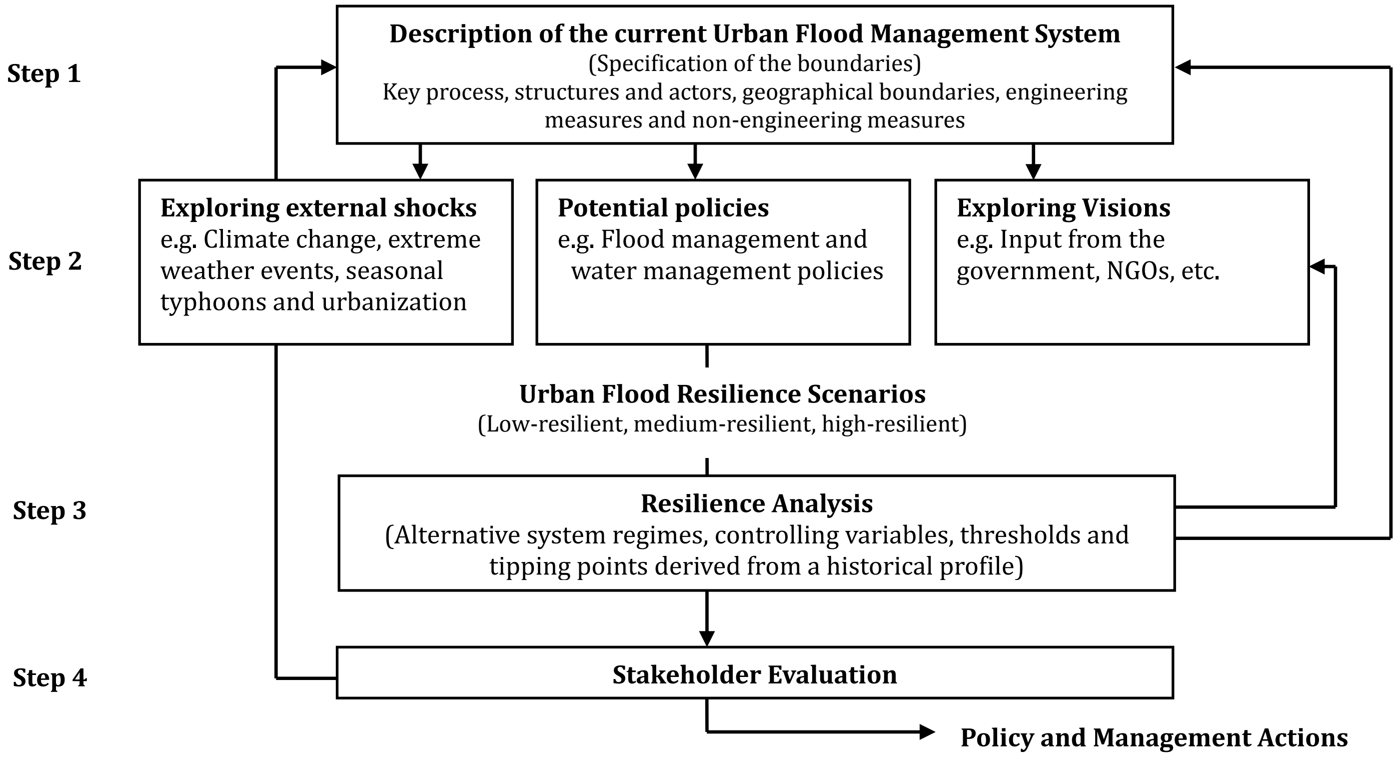

Figure 5: A conceptual framework for Urban Flood Management, modified from the framework for analyzing SES resilience proposed by Walker et al. (2002).

3.2.2 Application to the Taipei Basin

Before applying this form of analysis to the Taipei Basin, two matters of definition require discussion. Firstly, to demarcate approximate boundaries for the flood management in the Taipei Basin, I first defined the *system boundaries* using the geographical boundaries of the Taipei Basin. However, to identify multi-scale patterns in the spatial and temporal factors involved in the system, geographical boundaries only help determine the system's location. Following the RA's workbook, I then set further boundaries for my study based on the government agencies involved and the measures of flood management (engineering and non-engineering solutions). Thus, the boundaries are not only geographical. Government agencies involved in flood management in the Taipei Basin include the Taipei City Government Hydraulic Engineering Office (local-level), the Tenth River Basin Management Bureau (regional) and the Water Resources Agency (national).

Secondly, the RA's workbook says it is structured to guide scientists through the process of applying resilience to complex resource problems in a region. Thus, the question is whether urban flood management in the Taipei Basin constitutes a complex resource problem. Based on the review in the following chapter, the emerging regime shift in water management that seeks to incorporate "watershed conservation upstream, flood mitigation midstream and flood defenses downstream" demonstrates that urban flood management in the Taipei Basin is indeed a complex resource issue (Taipei City Government, 2007). Chapter 4 reviews the kinds of flood management measures employed in the Taipei Basin.

4. Fortress City: Taipei's enthusiasm for building dikes

> 'Florida has its hurricanes; California, its earthquakes.' So reads the caption beneath a photograph of the San Francisco calamity in a 1963 geography of the Golden State. Although that may sound like an obvious insight, in fact, there is nothing natural or predestined about this state of affairs. … The problem with such a view is that it effectively naturalizes a particular set of geographies of risk, instead of asking how these historically specific hazard profiles came to be. Florida, like California, was not born risky. *It was built that way.*[3]

Acts of God, Ted Steinberg, p.47

Research Question 3:
What is the current configuration of the flood management system in the Taipei Basin?

According to the Tenth River Basin Management Bureau, 300 years ago, the Taipei Basin was still a lake. At that time, the area was home to Katagalan tribes (Aborigines), though Han Chinese began moving into the region as well in the 18th century. Today the lake is gone and the basin is Taiwan's largest metropolitan area,

[3] Italics added.

falling into the administrative areas of Taipei City and New Taipei City, with a population of nearly 6.5 million people.

The basin experienced its most rapid period of urban transformation in the last four decades of the 20th century: significant rural-urban migration in the 1960s and 70s, floodplain deregulation and rapid urban sprawl in the 70s, development stretching into the foothills in the 80s and development along the Keelung River in the 90s (Chen and Chen, 2007). Once a region highly vulnerable to floods, the city transformed itself by building ever longer and higher dikes along its waterways to contain floodwaters (Figure 6). Yet as the frequency of extreme weather increases, it is necessary to start asking whether the Taipei Basin was "born risky" or "built that way."

Figure 6: The fortress city. Huanhe North Road is a street along the Danshuei River in Taipei City. On the riverside, the dike is usually with the height approximately 7-8 meters (on the right side of this picture).

4.1 Background

Taiwan is an island located in the Western Pacific Ocean in East Asia, with a total area of 36,000km^2 (Figure 7). The population is approximately 23 million. The climate is marine tropical, dominated by monsoons. Average annual precipitation is 2,500mm, with most precipitation concentrated into the summer months (June, July and August), accompanied by typhoons. The island has a Central Mountain Range running north-south along its length, is mostly mountainous in the east and has gently sloping plains in the west. The central range is the major watershed for rivers. As the east-to-west width of the island is very narrow, however, rivers are relatively short, with steep bed slopes. Only nine rivers have watershed areas exceeding 100km^2 (Teng et al., 2006). These conditions make the rivers prone to midstream and downstream flooding.

Earthquakes and typhoons are the two natural hazards that most often affect Taiwan (Chang, 1996). Located on the major track for typhoons in the northwest Pacific, in the last century alone, around 350 typhoons barreled into Taiwan, in some cases triggering flood disasters (Teng et al., 2006). On average, three or four typhoons strike Taiwan per year, with annual economic losses estimated at NT$200 billion (approximately US$6.9 billion) (EPA, 2010).

The Taipei Basin, located at the northern tip of Taiwan, is home to Taipei City, the capital, which, together with the surrounding New Taipei City, comprises Taiwan's largest metropolitan area. An estimated 6.5 million people live in the Taipei region. The basin includes the downstream floodplains of the Danshuei River. Translated literally, "Danshuei" is Mandarin Chinese for freshwater. The Danshuei River is the third-longest river in Taiwan, with a length of 159km and a watershed of 2,726km^2. The river basin has three main tributaries: the Dahan, Sindian and Keelung rivers (Figure 7). There are two upstream reservoirs, the Shihmen and Feisui reservoirs, located on the Dahan and Sindian rivers, respectively. In addition to serving as water supplies for the region, these reservoirs provide flood mitigation during typhoon season. In the following two sections, I briefly reviewed the structural and non-structural solutions to flooding in the Taipei Basin.

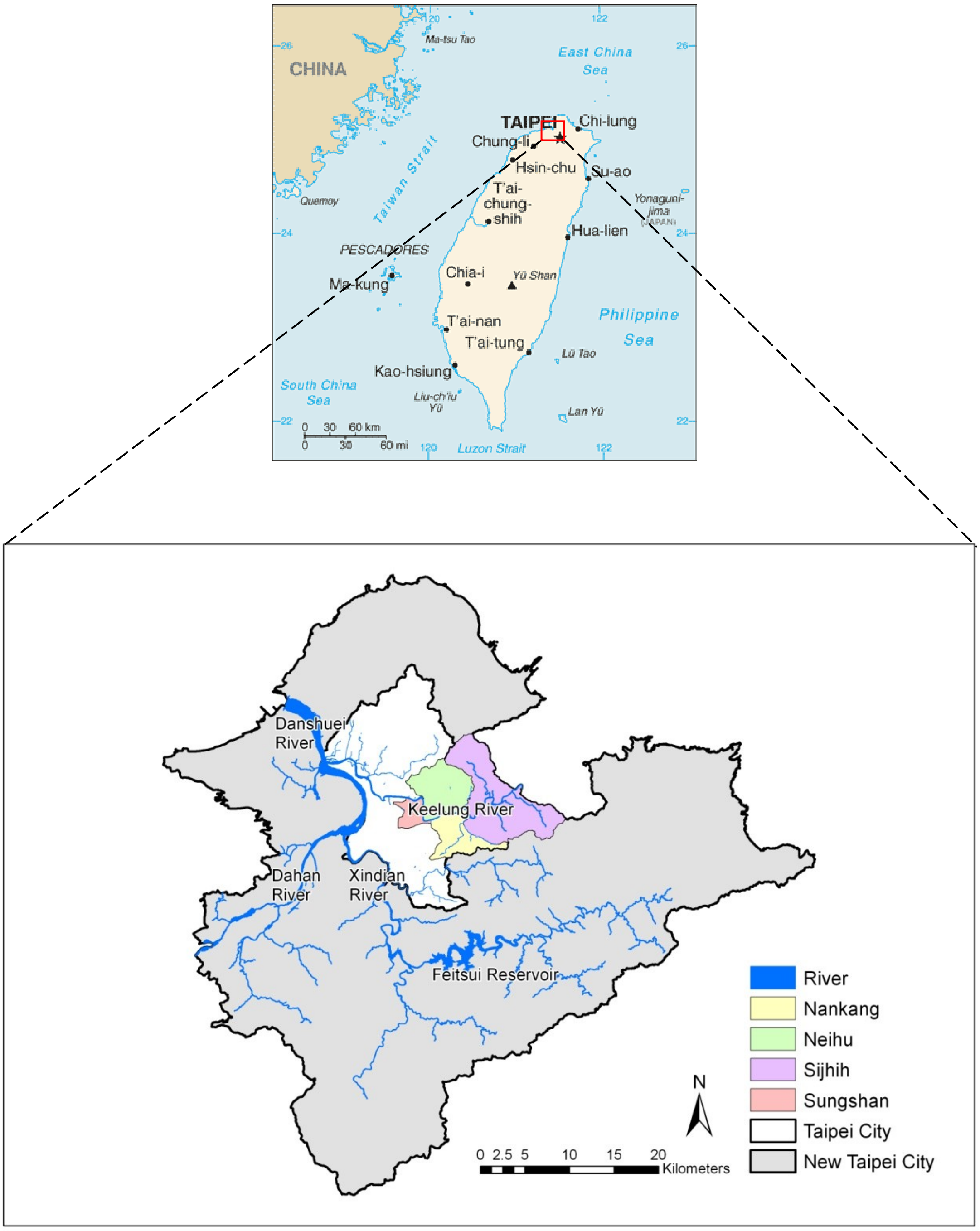

Figure 7: The Taipei Basin. The major rivers in the Taipei Basin are the Danshuei River and its three main tributaries: the Dahan, Sindian and Keelung rivers. The Taipei Basin mainly located in administration boundaries of Taipei city and New Taipei City.

4.2 Building higher and longer dikes

The history of constructing river levees along the Danshuei River can be traced back to the Japanese Colonial Period (1895-1945). Following a spate of severe floods in the 1930s in the Sanchong district of Taipei, the Taiwan Governor-General's Office, the highest government agency in Taiwan during the Japanese occupation, planned a series of comprehensive flood management projects for the Taipei Basin, such as bolstering the role of forests upstream (Sanchong District Office, 2009). Levees were constructed along the Danshuei River, but mainly on the east bank, since the city’s economic hub was located to this side. The outbreak of the Pacific War at the end of 1941 interrupted further levee construction, meaning that districts along the west bank, such as Sanchong and Luzhou, were left susceptible to serious flooding during typhoons.

The practice of building river levees to contain floodwaters continued in the post-war period, with unfinished pre-war projects receiving first priority. However, it was not until serious flooding brought by typhoons in the 1960s (such as Typhoon Gloria in 1963, Elaine in 1968, and Elsie and Flossie in 1969), that the government started to develop comprehensive regional planning for flood management. This was the origin of the massive flood-reduction structural project called the Taipei Area Flood Control Project (TAFCP), considered Taiwan’s largest flood mitigation effort to date (The 10th River Bureau) (Figure 8).

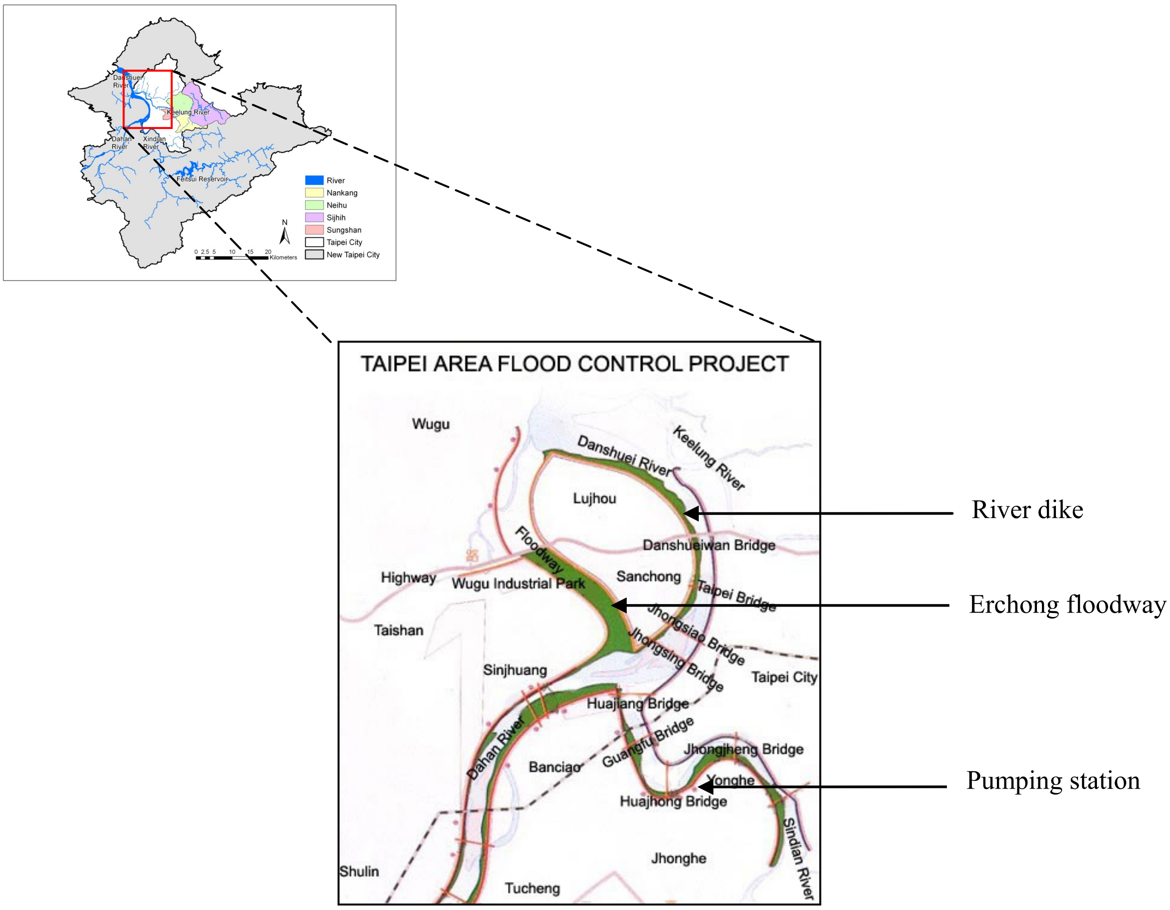

Figure 8: Taipei Area Flood Control Project. TAFCP is the largest flood mitigation project in Taiwan which mainly structural measures. The green color shows the new green belt of the city.
Source: The 10th River Bureau, WRA

Although this project was first planned in the 1960s, it was postponed until the early 80s because of the high costs. The overall budget for TAFCP was US$3.3 billion (Teng et al., 2006). The construction of the TAFCP from 1982 to 1996 relied heavily on engineering infrastructure such as river levees and drainage and diversion systems. The Erchong diversion channel, for example, was built to divert 6500m^3/s of upstream floodwater from the 25,000m^3/s design flow of the Danshuei River (Teng et al., 2006). In brief, structural measures have been the major solution for flooding in the Taipei Basin.

Flood-prevention infrastructure has gradually and continually increased in terms of the length of dikes and number of pumping stations (Figure 9). This trend — particularly the reliance on pumping stations — reflects the fact that structural measures have been the main solution to flooding in the Taipei Basin. Pumping stations pump floodwaters from the city into the river during typhoons, when gravity outlets to the river are sealed. To date, major rivers in the Taipei Basin are guaranteed with 200-year flood protection. 200-year flood is a statistical term that means it has a flood return period of 200 years or it should only happen every 200 years on the average.

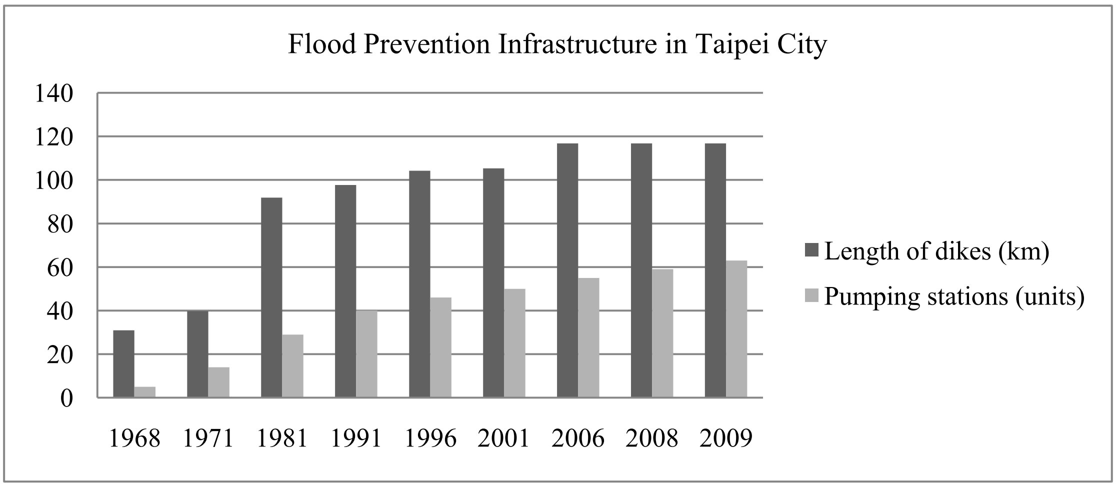

Figure 9: Flood prevention infrastructure in Taipei City. By the end of 2009, the length of dikes in Taipei Basin was 116,756m. Data Source: Taipei City Statistical Abstract – Flood Prevention Facilities.

4.3 Non-structural measures of flood management in the Taipei Basin

In addition to the structural measures mentioned in the previous section, non-structural measures are gaining importance. Chen et al. (2006) argue that non-structural measures for flood mitigation are an indispensable complement to structural solutions in Taiwan. In recent years, the development of non-structural measures to manage flooding has greatly improved in terms of technology and early warning systems. For example, in the Taipei Basin, a flash flood routing model for the Danshuei River Basin transmits data automatically to a monitoring center to conduct simulated water condition analysis (Hsu et al., 2003, Lee et al., 2006). Furthermore, a countrywide database has been created to bring information on inundation potential together with land-use management, flood warning systems, emergency responses and flood insurance programs. The goal is to reduce the social and economic impact of flooding and facilitate policy implementation (Chen et al., 2006).

Legislation and regulations are also increasingly important to flood management in the Taipei area. A few examples include new regulations for restricting floodplains along the Danshuei River (June 30, 1999), the Special Act Governing the Management of the Keelung River Basin (announced on October 31, 2001), the Special Act for Flood Management (promulgated on Jan. 27, 2006) and the Special Act Governing the Management of Shihmen Reservoir and its Catchment Area (promulgated on Jan. 27, 2006).

Without doubt, non-structural measures present a potential regime shift in flood management for the Taipei Basin. The ongoing discussion of Strategic Integrated Flood Mitigation Planning in Taipei City is another example. 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 (Taipei City Government, 2007). Chen Shen-Hsien, general-director of the Water Resources Agency at the time, strongly endorsed the concept of integrated and comprehensive flood management. Chen said in an interview that the government's ad-hoc strategy for flood management was outdated and must give way to holistic water management (Gau and Su, 2007).

4.4 The risk of extreme weather

In 2009, Typhoon Morakot devastated southern and eastern parts of Taiwan — an example of increasingly common extreme weather. Morakot struck on Aug. 8, and in the span of a few days, brought the most severe flooding ever recorded in Taiwan. In Xiaolin Village in the mountains of Kaohsiung, the torrent triggered a massive mudslide that buried nearly 500 people alive (Lu, 2009). This event not only sparked concern that Taiwan can expect more extreme weather of this kind, but also raised the question of how the Taipei Basin would have fared had the downpour struck farther north. Were such heavy precipitation to hit the Taipei area, the outcome would likely be more than massive flooding; if the Shi-Men Dam upstream on the Dahan River collapsed, it could destroy the city (TEIC, 2010). In response to the concerns, the Water Resources Agency again turned to engineering solutions, such as increasing the capacity of the dam by evacuating sediment though a bypass tunnel (TEIC, 2010).

However, an official at the Taipei City Government Hydraulic Engineering Office conceded that the uncertainty of climate change poses a risk that engineers cannot effectively factor into structural measures (personal communication, April 11, 2011). The official said the office's strategy to deal with the risks of extreme weather relied largely on advances in non-structural measures such as early-warning monitoring and flood evacuation plans.

5. Assessing resilience in the flood management of the Taipei Basin

> The aim of resilience management and governance is to keep the system within a particular configuration of states that will continue to deliver (on some societally determined time scale) desired levels of ecosystem goods and services, and to either prevent the system from moving into un-desirable configurations from which it is either difficult or impossible to recover, or move from a less desirable to a more desirable configuration.
>
> Resilience Alliance's workbook, p.15

Research Question 4:
How useful is a historical profile of flooding and adaptive cycles in identifying the barriers to and opportunities for a regime shift in flood management in the Taipei Basin?

After a brief review of flood management in the Taipei Basin, the current preference for structural defenses seems to be a rather undesirable configuration that is not sufficiently flexible to cope with more frequent extreme weather. For instance, most flooding infrastructure has not effectively factored in the potential for extreme weather brought about by climate change. I use this chapter and the discussion in chapter 6 to answer the research question 4.

Based on the discussion in Chapter 3, in this chapter I discuss the results of my analysis of flood management resilience in the Taipei Basin. I identified the main external shocks to the urban flood management system in Taipei: seasonal typhoons with extreme precipitation, groundwater mining that has led to subsidence, and rapid urbanization. To help assess the system's resilience, I provide a historical profile of flooding events and major hydraulic projects. Later in this paper I connect this profile to the adaptive cycle to help identify factors that would facilitate a regime shift from an emphasis on structural measures to a configuration more capable of handling extreme weather.

5.1 Resilience to what? Exploring the external shocks

Based on academic journals, newspapers and government reports (Chen and Chen, 2007; TEIC, 2010; EPA, 2010), I identified four key sources of external shocks to this system. Among these, seasonal typhoons and evidence of increasingly frequent extreme weather can be considered exogenous factors. The other two — the falling level of groundwater and rapid urbanization — hinge on economic development and are therefore essentially internal. I describe these shocks in the following sections.

5.1.1 Seasonal typhoons and extreme weather

Typhoons are common external shocks to the system in the summer and autumn. In recent years, attention has shifted from normal typhoons to extreme precipitation brought by typhoons. However, the body of research that focuses on extreme weather specifically in the Taipei Basin is not sufficient to describe the future potential for such weather. This study therefore relied on research at the national level and a single typhoon event in 2009.

Typhoons with unusually severe rainfall are becoming more common in Taiwan. In 2008, a climate change conference organized by the Central Weather Bureau invited academics to discuss the increasing frequency of extreme weather and its implications. Liu et al. analyzed meteorological data from 1960 to 2005 and found a statistically significant shift in the intensity of precipitation from light rain toward heavy rain (Liu et al., 2008). Tu et al. (2008) identified an abrupt shift in the number of typhoons since 2000. Between 1970 and 1999, an average of 3.3 typhoons hit Taiwan per year. Between 2000 and 2006, however, an average of 5.7 typhoons struck per year. They also found a consistent northward shift in the main track for typhoons in the northwest Pacific-East Asian region, as well as an increase in the frequency of typhoons in the Taiwan-East China Sea region (Tu et al., 2008).

5.1.2 Groundwater level

Groundwater plays a fundamental role in supporting economic development in many urban areas in the developing world (Foster et al., 1998). Due to its low cost and high quality, groundwater is often the preferred source for public water supplies and private domestic and industrial use. Taipei is no exception. As a result of groundwater mining, the city has already experienced significant subsidence. Since 1968, the government has regulated the massive groundwater pumping that lay behind the subsidence across the entire Taipei Basin (WRA, 2009). However, from 1960 to 1970, ground subsidence was more than 10cm (Chang, 1996). More recently, Chen et al. (2007) analyzed groundwater levels from 1975 to 2003 and concluded that post-pumping subsidence is largely irreversible and poses a particular risk for flood-prone areas of the city. Although groundwater mining in the Taipei Basin is now strictly regulated, this factor remains crucial to understanding the system as a whole.

5.1.3 Urbanization

Rapid urbanization without proper regulation of land use is the main problem if Taipei is to deal with flooding (Teng et al., 2006, Hsieh et al., 2006). Since the late 1980s, real estate developers eager to cash in on a booming housing market have managed to evade new regulations and proceed with large housing projects in the foothills (Hsiao and Liu, 2002).

Sijhih District in New Taipei City is one example. The population in Sijhih has rapidly increased since the 1960s (Figure 10). The potential for flooding was not taken into consideration by urban planners and resulted in over-development along the Keelung River. After 1961, improvements in transportation and traffic flow, coupled with economic growth, led to new communities being built on the valley slopes along the Keelung River. Hsieh et al. (2006) analyzed the transformation of land-use patterns in this area and found that the zoned for building in 1996 (563ha) was 4.2 times the area in 1961 (134ha); the area of land used for roads increased almost proportionally to the decrease in land used for agriculture (Figure 11).

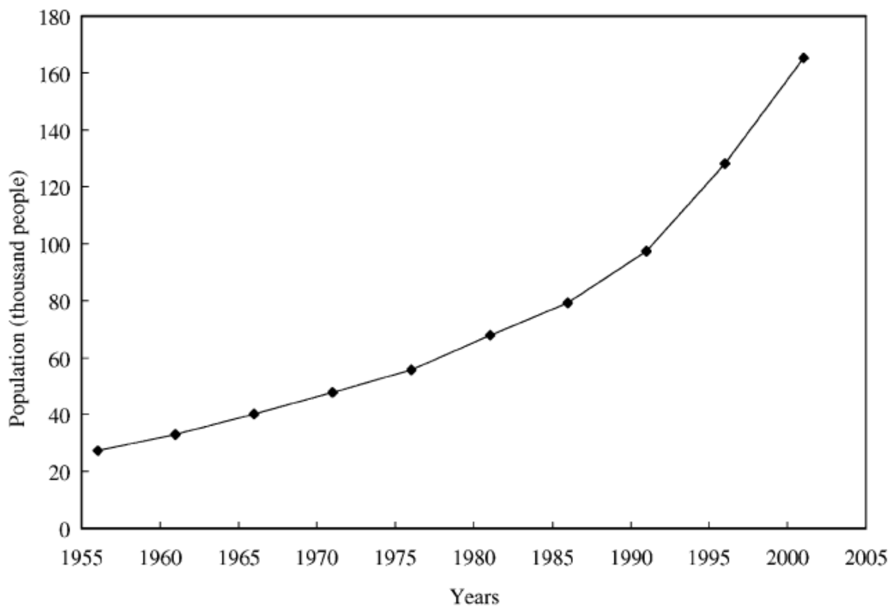

Figure 10: The growing population of Sijhih District (Hsieh et al., 2006)

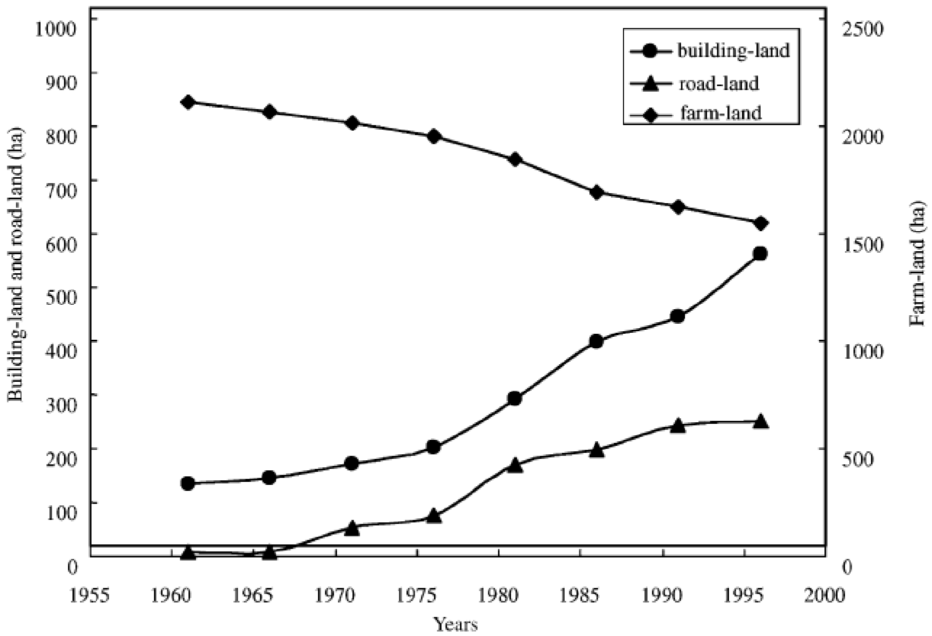

Figure 11: The change in land use in Sijhih District (Hsieh et al., 2006).

To get a wider picture of flooding and urbanization, Chen and Chen (2007) analyzed the population growth rate (PGR) of each district in Taipei City from 1960s to 1990s and compared the areas that had flooded during comparable storms events. The temporal and spatial relationships indicated that the flooded areas moved further upstream, with some correlation between high-PGR districts and flooding (Figure 12).

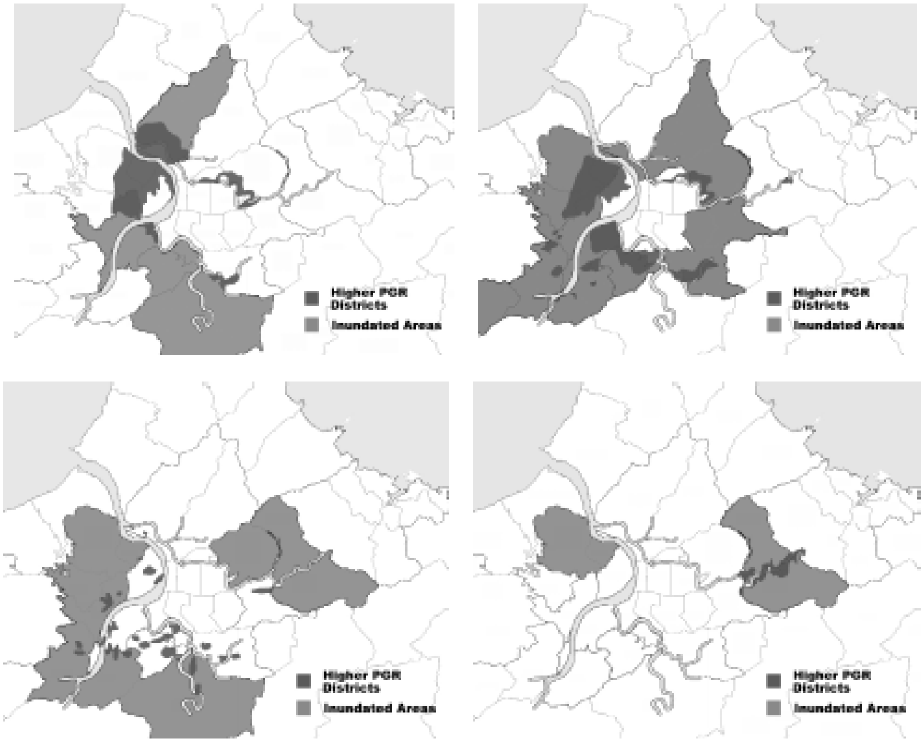

Figure 12: The transformation of the flooding pattern and urbanization in Taipei City. Maps of high-PGR districts during the 1960s, 70s, 80s and 90s are marked with light color, and flooded areas (resulting from Typhoon Elaine in 1968, “the 6-3 flood” in 1984, Typhoon Abe in 1990 and Typhoon Xangsane in 2000) are marked with dark color (Chen et al., 2007).

5.2 Historical profile of flooding (1960-2010)

I summarize the history of flooding in the basin as well as major infrastructure and water management policies (Figure 13), using Chen and Chen’s (2007) three periods in Taipei’s flooding history based on the type of flooding experienced (Table 3). The typhoons listed on the left side indicate that a typhoon resulted in serious flooding in the Taipei Basin; typhoons that struck Taiwan but did not cause severe flooding in Taipei are not listed. Since Typhoon Nari in 2001, there has been no serious flooding in the basin in conjunction with typhoons. The death toll from floods has also greatly decreased since the 1980s. However, in the early 2000s, the number of people who died in Typhoon Xangsane (2000) and Typhoon Nari (2001) brought the death toll up again (Figure 14). In contrast to the death toll, the number of homes affected by typhoons has greatly decreased since the 1970s (Figure 15).

Table 3: A characterization of flooding in the Taipei Basin. Modified from Chen and Chen (2007).

Period	**1960-1980** **Initial period**	**1981-1995** **Transformation period**	**1996-present** **Urban flood period**
Location of drainage	Downstream, river converge and low flood protection areas	Most areas are with low flood protect area and some midstream areas	Upstream, edge of plains around the Taipei Basin and low areas behind the embankment
Inundation type	River overflow	River overflow and drainage flood	Drainage flood, basement flooding and river overflow

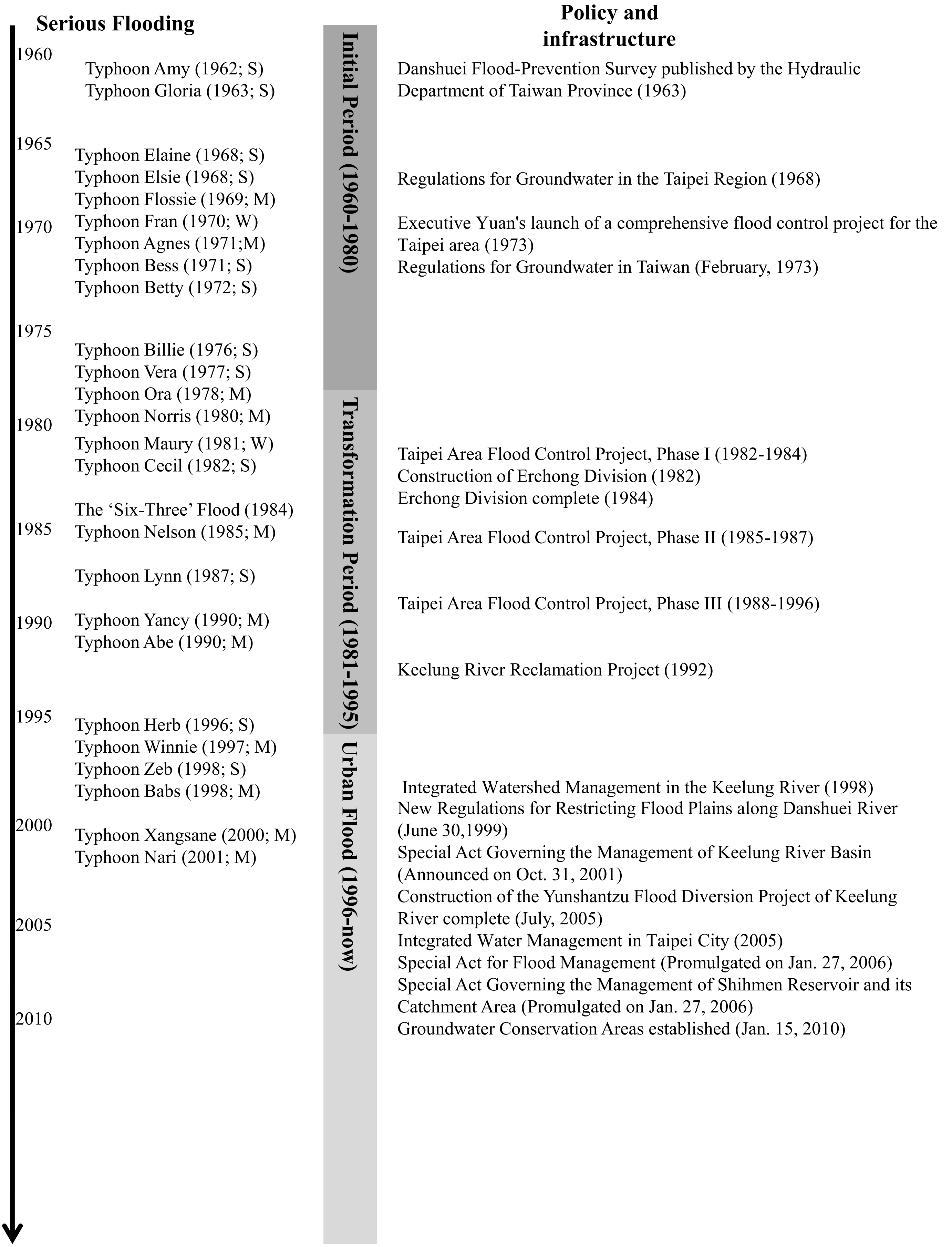

Figure 13: Historical profile of flooding and major hydraulic projects and policies.
Typhoon Amy (1962; S) means this typhoon arrived Taiwan in 1962 with the strong strength.
S: strong; M: medium; W: weak. Data Source: Taiwan’s Central Weather Bureau

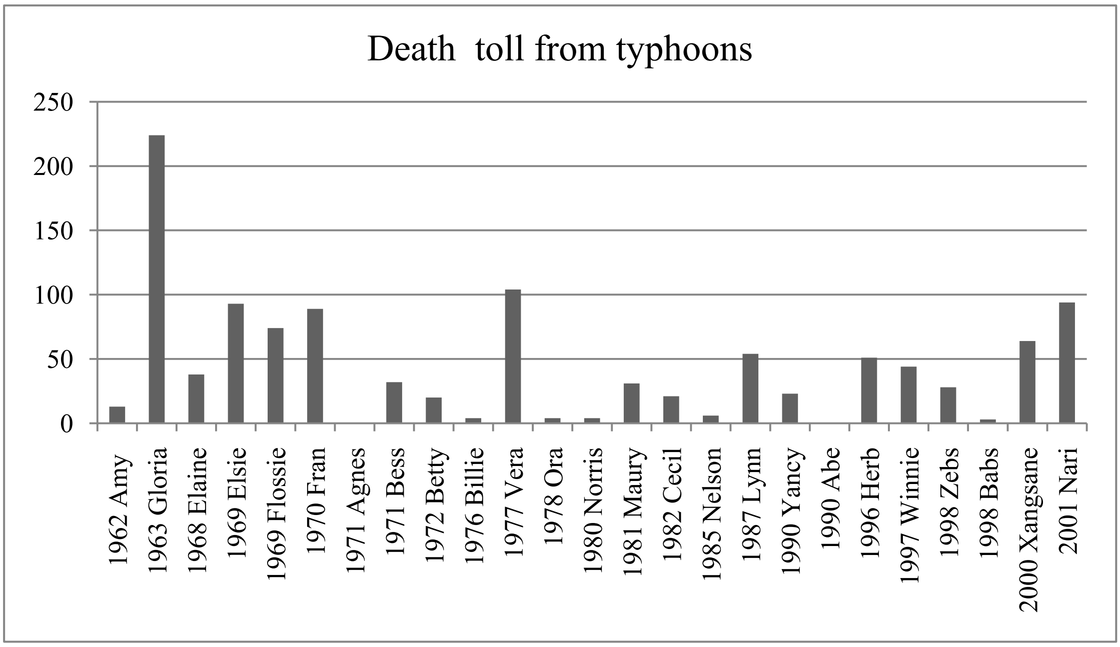

Figure 14: Death toll resulting from typhoons.
Data Source: National Fire Agency, Ministry of the Interior

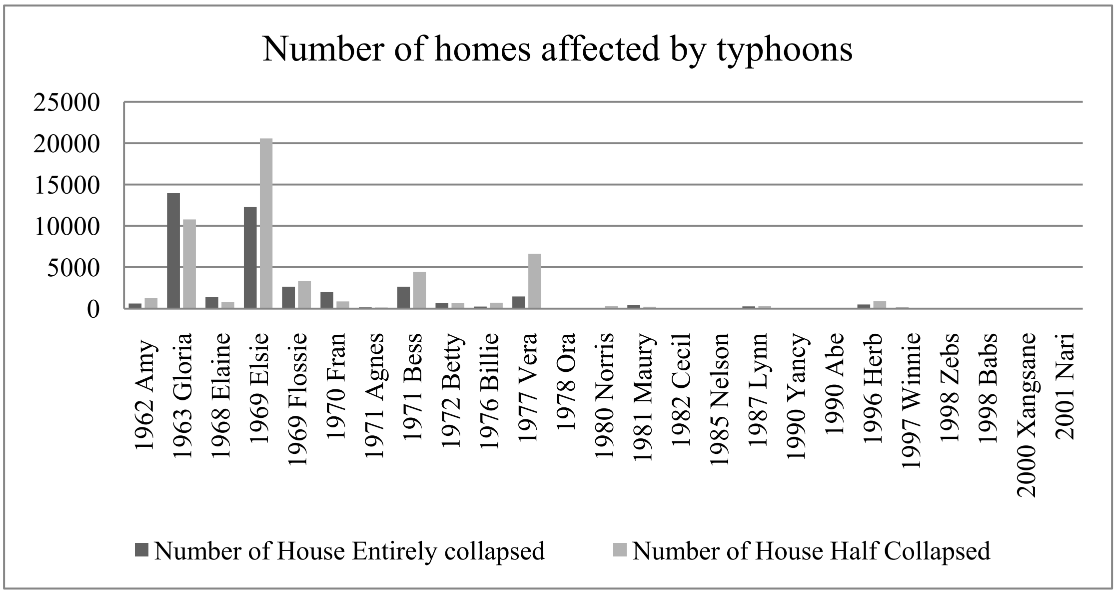

Figure 15: Number of homes affected by typhoons.
Data Source: National Fire Agency, Ministry of the Interior

5.3 Identifying adaptability attributes based on the historical profile

> The purpose of theories such as panarchy is not to explain what is; it is to give sense to what might be. We cannot predict the specifics of future possibilities, but we might be able to define the conditions that limit or expand those future possibilities.
>
> *Panarchy*, Holling and Gunderson, p.32

With this historical profile as a backdrop (Figure 13), the next step is to test the applicability of the adaptive cycle to flood management in the Taipei Basin. Chen and Chen's (2007) three flooding periods again provided a reference (Table 3). I examine severe floods from 1960 to today and connect them to the adaptive cycle (with four phases r, K, Ω and α) to describe the transformation of flood management in the Taipei Basin.

The initial period (1960-1980): the exploitation phase (r)
In this period, the frequency of serious flooding caused by typhoons was much higher than the following two periods. Flood defenses had not yet been built to cover the entire Taipei Basin. To refer back to Chapter 4, as resources were limited, the city prioritized flood defenses on the east bank of the Danshuei River to protect economically vital areas, while leaving districts to the west, such as Sanchong and Luzhou, unprotected. Most flooding in this period was therefore river overflows in downstream areas with little flood protection. Massive rural-urban migration in the 1960s and 70s driven by rapid economic development meant that living space in Taipei City was soon inadequate. Rural areas were rapidly urbanized, but the economic losses mainly hit the agricultural sector. This period is characterized by rapid urbanization and the accumulation and retention of economic capital in the area. I therefore connected it to the exploitation phase (r). A clear regime emerged in which engineering was used to keep floodwaters at bay. This resulted in a rapid decrease in the number of homes affected by typhoons (Figure 15).

The transformation period (1981-1995): the conservation phase (K)
The transformation period was a period of massive structural work to combat flooding. The comprehensive flood control project TAFCP, mentioned in Chapter 4, is the most obvious example. I consider this period the conservation phase (K) because of the strong emphasis on engineering measures with a fairly predictable approach to floodwater. It is also a period of transformation in that engineering measures began to transform the river landscape at this point. One of the projects, the Keelung River

Reclamation Project, aimed to straighten the section of the river that meandered through the Nankang, Neihu and Sungshan districts (Figure 7). The work started in 1991 and shortened the river by 5.3km. The project involved building higher dikes and redeveloping a 5.6km^2 area that had been inhabited by some 13,000 squatters (Chung, 2002).

The urban flood period (1996 to today): another exploitation phase (r)
In the urban flood period, the location of flooding has moved to upstream areas and the edge plains of the Taipei Basin. Economic damage has rapidly increased in urban areas. Government authorities still rely on engineering measures, such as the construction of the Yunghantzu flood division project of the Keelung River. However, this period is characterized more by non-structural measures, such as the Special Act for Flood Management (Figure 13). The new approach of integrated water management — "watershed conservation upstream, flood mitigation midstream and flood defenses downstream" — is another example. This period seems to be another exploitation phase (r), though with more non-structural measures. Although it possesses the characteristics of an exploitation phase, it is ongoing and requires further observation.

Several serious flooding events in each period: the release phase (Ω):
Release phases occur rapidly when the system faces changing conditions. In this study, I consider serious flooding events in each period to be release phases. For example, the severe flooding events in the 1960s and 70s led the government to develop comprehensive regional planning for flood management. Flooding along the west bank of the Danshuei River provided strong motivation to build the Erchong Division and gradually increase flood defenses to 200-year flood along the river. Additionally, massive flooding in the 1980s and 90s (e.g. during Typhoon Lynn in 1987, Herb in 1996 and Babs in 1998) prompted the integrated watershed management and flood control plan for the Keelung River. In the urban flood period, the worst flooding was in 2001, when Typhoon Nari flooded the city's metro system, shutting it down for weeks and causing NT$1.4 billion (approximately US$41 million) in damage (Chung, 2002).

6. Discussion

This study demonstrates that resilience theory as used in SES research is useful in developing better plans for urban flood management in the Taipei Basin. Based on the resilience assessment exercise in Chapter 5, I will now turn to the applicability of resilience theory for spatial systems such as flood management in Taipei.

6.1 Identifying external shocks

Resilience theory, being system-oriented, proved useful in identifying external shocks to the flood management system in the Taipei Basin. In particular, it was effective for considering the high uncertainty posed by extreme weather. By investigating in what ways the system is resilient and how it can be weakened or bolstered, I was able to put together an overview of flood management in the basin and identify four main external shocks, namely, seasonal typhoons, the evidence of increasingly frequent extreme weather, falling level of groundwater and rapid urbanization (Chapter 5.1). This then led to doubts that the system — a product of decades of building ever higher dikes along the rivers — is flexible enough to cope with the increased threat of extreme weather (Chapter 4.4).

Although I identified external shocks based on secondary research, identifying external shocks usually involves public participation and stakeholders' meetings (Figure 4). Thus, developing a resilient flood management system is more likely to include bottom-up initiatives translated into top-down policy decisions. In Taiwan in particular, embracing the concept of resilience could help reverse a long-term, narrow-minded approach to flooding. According to Hsu Chan-chuan, a spokesperson for Taiwan's Water Watch Alliance: "The [water management] agencies are mainly staffed with engineers, and their minds turn to blocking rivers whenever it comes to flood control" (Tsai, 2009). Water Watch Alliance is a local grassroots group that monitors the government's budget for flood management projects.

6.2 Envisioning a better system

This study found that using the metaphor of resilience helped to reframe flood management in the Taipei Basin. Since the study used a qualitative approach to apply resilience to urban flood management, resilience theory was a useful discourse for envisioning a better system. Unlike the concept of sustainability, resilience can be positive or negative: An undesirable state can also be resilient (Carpenter et al., 2001). The assessment in Chapter 5 revealed that flood management in the Taipei Basin is in an undesirable but resilient state, lacking the flexibility to effectively handle new challenges, such as increasingly extreme weather. At the same time, the effectiveness of the structural measures, as illustrated by the drop in death tolls (Figure 14) and damaged homes (Figure 15), points to the resilience of the system. Like any other system, however, Taipei's flood management may lose this resilience.

The current system may be resilient in terms of efficiently draining floodwater from the city, but it does not seem resilient in terms of retaining enough rainwater for times of drought. Taiwan faces the ironic dilemma of suffering both periodic severe flooding and droughts. As a result, it needs an innovative strategy to balance the need for preventing flooding with the need to avoid water shortages (Liu, 2011). This is particularly problematic as Taiwan's rivers are relatively short, with steep bed slopes, meaning that they are prone to flooding yet drain quickly in times of drought. This study found that resilience theory would be a useful discourse for policymakers and urban planners to reframe their analysis of flood management in Taipei, in particular, with the participatory scenario building (Figure 5).

6.3 The gaps between historical flooding and adaptive cycle

The historical profile (Figure 13) provided an overview of the changes in flooding patterns and the development of hydraulic policies in the Taipei Basin. By next connecting this profile to the adaptive cycle (Chapter 5.3), I sought to reframe urban flood management in a new perspective. The analysis revealed an emerging regime shift, in which the emphasis is moving from structural measures toward more inclusive, non-structural measures.

The profile was a useful tool to learn from past policies, but was not sufficient to analyze the cross-scale connections in this study. Specifically, there are three obstacles.

Firstly, this study faced a classic dilemma of scientific approaches. Such approaches work best under highly reduced and controlled conditions, yet in the real world, it is almost impossible to find such ideal situations. In particular, urban flood management is a complex spatial issue. Thus it is difficult to decide how many factors are sufficient for a historical profile and a study to conclude a cross-scale connection between various variables. Additionally, there is a risk that emphasizing the historical profile analysis could lead to post hoc conclusions. Gunderson, one of the editors of *Panarchy,* acknowledges this dilemma. In a personal communication, Gunderson said: "The historical profiling is an important exercise. It allows the researcher to ask questions about what types of external forces and stresses can come to bear on the system, and what transformations have been undertaken" (April 11, 2011). He acknowledged, however, that it is difficult to identify specific stages of the adaptive cycle, even for academics. This study was therefore an attempt to contribute to an evolving field by exploring these questions.

Thirdly, although I considered severe flooding events in Taipei's history to be the release phases (Ω) of the adaptive cycle, major hydraulic policies and projects usually take several years following such events. Unlike ecological systems, the release phases (Ω) were usually rapid, meaning that flood management in Taipei resembles other social systems that are more complex. Further research is needed to investigate the mechanisms and facilitators of linking flood management to adaptive cycle.

7. Conclusion

This study applied resilience theory as understood in SES research to a flood management system. Resilience was a useful qualitative approach and metaphor for understanding the system and envisioning movement toward a more flexible paradigm. In the early stages of the assessment, this was a helpful approach to exploring the external shocks and disturbances to the system. However, the concept is not yet sufficiently developed to apply it effectively to spatial issues. The key findings of this study are listed below.

Firstly, performing a resilience assessment of flood management in the Taipei region was indeed a meaningful exercise. Resilience proved to be an effective aid to exploring the configuration of flood management in the Taipei Basin, allowing the researcher to investigate external shocks and stress. Resilience is useful in considering both past and future threats to the system and encouraging a long-term approach to solutions. In particular, this study found that the long tradition of prioritizing structural flood defenses in Taipei could actually increase the city's vulnerability to extreme rainfall. Incorporating resilience theory into flood management planning could help avoid this kind of negative consequence.

Secondly, the study found that the approach taken in SES research is a qualitative approach to conceptualizing resilience. The qualitative inquiry process should be considered an indispensable companion to the current quantitative and engineering-oriented approaches in the Taipei Basin. A qualitative assessment revealed that the basin has experienced a dramatic transformation in landscape over the past century. Looking back even farther, 300 years ago, the basin was a lake with a limited population. Yet this historical view is largely absent from the current discourse: Urban planners and policymakers seldom incorporate it into their discussion of the city's flood management.

Due to the limits of the scope of this paper, this study only examined major flooding from 1960 to 2010; however, I found a qualitative assessment useful for understanding and interpreting past events. The qualitative and metaphorical approach of resilience could help realize a transformation in the flood management paradigm. The priority must be to think of flexible strategies for handling extreme weather in light of the massive structural measures already in place. Envisioning a resilient system also echoes the ongoing discussion of Strategic Integrated Flood Mitigation Planning in Taipei City. Resilience is a helpful concept for incorporating "watershed conservation upstream, flood mitigation midstream and flood defenses downstream."

This study was also an attempt to view flooding in Taipei as an adaptive cycle. As Taipei will serve as a case study in the CORFU project, Taiwan should share not only its advances in structural and non-structural flood management, but also the capital's history of living with floods.

Thirdly, in terms of influencing policy, a qualitative approach is useful if it can be supplemented with a quantitative approach. In Taiwan, flood management agencies are staffed mainly with hydraulic engineers. Therefore, the quantitative approach is more likely to apply resilience within the current institutional setting. The quantitative approach to flood resilience (Bruijn, 2005) could therefore serve as a reference. Inevitably, most quantitative approaches require data to evaluate. This study only applies a qualitative approach to the resilience of flood management in the Taipei Basin; quantifying flood resilience could be the next step.

To sum up, while resilience is widely seen as an innovative strategy to cope with natural disasters, it should be examined in different contexts. This study contributed to two research fields, resilience and urban flood management, by conceptualizing the resilience of flood management in the Taipei Basin. This qualitative approach was effective in identifying the risks posed by extreme weather. Combining the historical profile and the adaptive cycle provided a new metaphor for examining urban flood management. Further research is needed, however, before resilience theory can be effectively applied to spatial issues. This is consistent with Adger's (2000) finding that the concept of resilience should not be transferred uncritically from ecological systems to social systems. Lastly, I viewed this study as an experimental analysis with the goal of contributing to the discourse on flood management in Taiwan.

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