Developing a Sponge Catchment Management Framework with Natural Flood Management in Guiyang, Southwest China

Final Thesis

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March 2023

Acknowledgement

It was an honour that UNNC accepted me as a part-time PhD student. I officially registered as a part-time PhD student in Sep 2018. As a part-time PhD student, I knew finishing this PhD was challenging. There were many academic discussions between supervisors and me in the last five years, whether day or night, workday or holiday (Appendix 4). We strictly followed our research plan, including the first annual review in June 2020, the second annual review in June 2022, and the third annual review in November 2022. I want to thank my supervisors, colleagues, friends, and families. I could not get this far without their help, support, hard work, and sacrifice.

During the last five years, I focused on academic training during my off hours (Appendix 5). As the first author, I published several SCI papers (Appendix 6). I also attended international research meetings to give presentations (Appendix 7) while obtaining national engineer certifications by examination (Appendix 8). In addition, I profoundly improved my academic thought and engineering skill by applying for related patents (Appendix 9) and as a journal reviewer (Appendix 10).

In the last five years, we experienced Covid-19 and an unpeaceful world. I was also lucky to be a father and moved to a new department in my company. I deeply understand that UNNC granting me a PhD is only a fresh start in the academic world. I will continue researching urban-rural-catchment areas by collaborating with teachers, colleagues and friends to contribute to UNNC and FoSE.

I sincerely appreciate Faith Chan, Meili Feng, Colin Throne, Jun He, Nicholas Hamm, Tengwen Long, Yu-Ting Tang, Claire Shi, Yuan Zhang, Emily O'Donnell, James Griffiths, Michael Hutchins, Gang Li, Yangfan Sang, Lucia, Neil, Sitong Liu, Feng Xu, Runtian Xu, my parents, wife, and child.

Yunfei
March 2023

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Declaration

I (Yunfei Qi) confirm that this thesis is my own. UNNC Research Ethics Panel fully approved this research, in January 2021, before the research conduction (Please ref Appendix 2 Ethics Approval Form). Although part of the content refers to my previously published papers, I confirm that suitable references have been annotated in the final thesis. The contributions of these published papers from authors are as follows:

The first review paper, *"Addressing Challenges of Urban Water Management in Chinese Sponge Cities via Nature-Based Solutions"* (doi:10.3390/w12102788), is related to Chapter 2. The contributors are Yunfei Qi, Faith Ka Shun Chan, Colin Thorne, Meili Feng, etc. I review literature about Urban Flood Management, Nature-Based Solutions, and Sponge City Programme. I also carry out planning, collecting information, and writing this paper. Other authors give comments and suggestions.

The second research article paper, *"Exploring the Development of the Sponge City Program (SCP): The Case of Gui'an New District, Southwest China"* (doi.org/10.3389/frwa.2021.676965), is related to Chapters 3 and 4. The contributors are Yunfei Qi, Faith Ka Shun Chan, Meili Feng, Colin Thorne, etc. I am responsible for planning, collecting information, conducting interviews, and writing this paper. Other authors give suggestions to this paper via review work.

The third research article paper, *"Sponge City Program (SCP) and Urban Flood Management (UFM)—The Case of Guiyang, SW China"* (doi.org/10.3390/w13192784), is related to Chapters 3, 4, and 5. The contributors are Yunfei Qi, Faith Ka Shun Chan, Meili Feng, etc. I am responsible for planning, collecting information, conducting interviews, and writing this paper. Other authors provide comments and editorial support by reviewing the manuscript before submission.

The fourth research article paper, *"Developing a "Sponge Catchment Management Plan (SCMP)" framework at the catchment scale: the case of Guiyang, SW China"* (doi.org/10.1002/rvr2.33), is related to Chapters 3, 6 and 7. The contributors are Yunfei Qi, Faith Ka Shun Chan, Meili Feng, Colin Thorne, etc. The contribution of the other authors is providing further comments.

Table of Contents

List of Tables

List of Figures

List of Appendixes

Abstract

Catchment flood events have become more challenging for humans due to rapid and intensive urbanisation and climate change. Before 2010, Low Impact Development (LID) had inspired China to consider the ecological transformation of urban plans and construction. Then, China officially announced to start Sponge City Programme (SCP) in 2013. The SCP can store part of the initial rainwater while enhancing sustainable urban development by providing a variety of co-benefits. However, the designing characteristics of SCP infrastructures are mainly to reduce urban pluvial risks at specific locations. In 2021, the damaging flood events in Zhengzhou (China) and Oberhausen (Germany) reflected the necessity of managing floods at a catchment level. The inborn features of SCP have brought concerns to authorities and academics in managing larger-scale fluvial floods after many fluvial flood events. Natural Flood Management (NFM) is an environmental-friendly principle to improve flood adaptation on upstream-rural and downstream-urban catchments using Nature-Based Solutions (NBS). Enlightened by NFM, this research developed an innovative catchment managing framework that merges the Natural Flood Management (NFM), Grey-Leading Infrastructures (GIs), and Sponge City Programme (SCP), namely Sponge Catchment Management Framework (SCMF). The proposed SCMF novelty provides an opportunity to expand sponge concepts to a catchment scale by integrating NFM and GIs. This research also evaluated the SCMF via a Guiyang case study, Focus Groups (FGs) and Semi-Structured Interviews (SSIs) to understand stakeholders' perspectives on SCMF. The SCMF and research results can contribute to other sponge cities to improve flood resilience on a catchment scale.

Keywords: Sponge City, Sponge City Programme (SCP), Sponge Catchment Management Framework (SCMF), Natural Flood Management (NFM).

Chapter 1. Introduction

1.1 Research background

Flood is one of the natural water cycle processes. Humans can only mitigate a flooding process rather than complete control (Chan et al., 2013a). When people respect flood, it may give a present. Otherwise, it can be a dangerous natural disaster due to possible severe damage to humans (Ferguson and Fenner, 2020). Academics classify flood events as underground, pluvial, fluvial, coastal, and other combinational processes (Qi et al., 2020). If intensive rain exceeds a catchment-containing capacity, a runoff volume may cause fluvial flood events to affect urban and rural areas in a holistic catchment. This research focused on the fluvial flood on a catchment scale.

Because of the agricultural productivity requirement and traffic convenience in the terrain aspect, numerous cities and villages are on flood plains (Antonarakis and Milan, 2020). However, moving these socioeconomic activities out of floodplains is unrealistic. Thus, the continually developing flood-prone areas keep increasing the flood risk to riverside property and residents (Chan et al., 2013b). People have widely used artificial interventions to reduce fluvial flood risks in history. They include building reservoirs, dykes, flood channels, and sluices to change natural water paths and water storage capacity in catchments (Qi et al., 2020).

Due to the high density of infrastructures, buildings, and populations in urban areas, Urban Flood Management (UFM) has always attracted much attention worldwide. For instance, North American countries have developed Stormwater Best Management Practices (Stormwater BMPs) and Low Impact Development (LID). European countries have developed Sustainable Drainage Systems (SuDs) and Nature-Based Solutions (NBS). Meanwhile, Asian-Pasific counties have initiated Water Sensitive Urban Design (WSUD), Low Impact Urban Design and Development (LIUDD), and Active, Beautiful and Clean (ABC) Waters Programme. These practices have contributed to UFM and enlightened other following counties.

The China National Government (CNG) has constructed many Grey-Leading Infrastructures (GIs) to protect people over the last several decades. Many concrete-making dykes, reservoirs, and water gates have enhanced the flood-defence abilities at river mainstreams (Chan et al., 2018b). In 2019, the total length of river dykes above Grade V was 320,000 km. The constructed reservoirs reached 98,221 nationwide, having 899.1 billion m^3 of full water storage capacity. In addition, there were 8,392 flood diversion sluices, 18,513 drainage water sluices, 57,908 water supply-controlling gates, 5,217 tidal barrages, and 13,902 water diversion helping water management (MWR., 2019).

Entering the 21st century, the CNG started the ecological transformation of water management. In 2010, the LID pilot work of the Guangming New District launched in Shenzhen to use Ecosystem Services (ESs) principles in urban planning and construction (Xia et al., 2017). After summarising the pilot experience of LID, the CNG formally proposed and vigorously promoted Sponge City Programme (SCP) in 2013 (Qi et al., 2021b). The Ministry of Housing and Urban-Rural Development (MUURD) published *"National Technical Sponge City Guidelines - Building LID System (trial)"(National SCP Technical Guidelines)* in 2014.

The *National SCP Technical Guidelines* require cities to transform traditional UFM into more ecological (Guiyang City Government., 2016a). The CNG initially hoped SCP could effectively solve wide-range flood issues in pilot sponge cities (Nguyen et al., 2020). However, there were some unfortunate flooding events occurred in selected sponge cities, such as Shenzhen (2013, 2014), Beijing (2012), Ningbo (2013, 2020), and Wuhan (2016, 2020) (Li et al., 2017). Another frightening flood was in Zhengzhou from July 17 to July 23, 2021. The "*Investigation of Zhengzhou 7.20 Raining Hazard*" recorded that Zhengzhou City and nearby 2,068 km^2 of catchment accumulated over 600 mm during this intensive rainfall. Consequently, this catchment flood seriously inundated this plain sponge city, causing over 380 casualties and an economic loss of 40.9 billion yuan (Council, 2022). These flood events raised severe concerns about whether sponge cities can withstand extreme rainfall (Qi et al., 2021a). Overdependence on SCP and lack of CFM may not be enough to improve urban flood resilience. The CNG and local governments have also reconsidered the SCP and Catchment Flood Management (CFM) relationship.

The SCP can partially enhance the UFM ability up to a one-in-30-year rain return period. However, small-separated SCP infrastructures are not specifically designed to alleviate large-scale fluvial floods (Chan et al., 2018c). Scattered SCP infrastructures, such as green roof buildings, community rain gardens, and rainwater storage tanks, can not cope with catchment-scale flood discharges caused by intensive rainstorms (Zheng et al., 2022). The current SCP mainly aims to manage initial rainwater in urban communities (Lashford et al., 2019). The current SCP practices mainly help mitigate waterlogging issues at a relatively site-specific scale (Jia et al., 2017).

1.2 Research aim and objectives

This research aims to make an original scientific contribution by proposing a Sponge Catchment Management Framework (SCMF) in Chapter 1.4 to further enhance Catchment Flood Management (CFM) in catchments with sponge cities. This research provides an opportunity to improve CFM on the catchment scale by achieving the following specific objectives:

First, to help researchers deeply understand the Sponge City Programme (SCP) in China, this research critically reviews worldwide Urban Flood Management (UFM) and Nature-Based Solutions (NBS) practices in Chapter 2. The review output can help readers understand the concepts, history and development of worldwide UFM and SCP.

Second, Chapters 4 to 5 analyse the Guiyang SCP plans, implements and challenges, aiming to find the issues faced by several implemented SCP projects and the future challenges and opportunities via a Case Study of the Nanming River Catchment in Guiyang, Focus Groups (FGs), and Semi-Structured Interviews (SSIs).

Thirdly, according to the conditions of Guiyang, this research further explores the proposed Sponge Catchment Management Framework (SCMF) via integrating Natural Flood Management (NFM), Grey-Leading Infrastructures (GIs), and Sponge City Programme (SCP) and for the Nanming River Catchment in Chapter 6 to both improve Rural Flood Management (RFM) and Urban Flood Management (UFM).

In addition, Chapter 7 suggests pathways to build, pilot, and continuously optimise SCMF by analysing the public and experts' perspectives on SCMF found by Focus Groups (FGs) and Semi-Structured Interviews (SSIs). Based on the SCMF proposed for Guiyang, the research results and suggestions may become one future direction of catchment ecological transformation for more sponge cities in China.

1.3 Research methods

Guiyang is the first batch pilot sponge city. The city is in southwest China with mountainous terrain and Karst landform features. Taking Guiyang as a case study is meaningful for researching SCP in mountainous areas. Meanwhile, the researcher is a senior engineer in the water department in Guizhou province. The researcher knows many professionals in Guiyang and Guizhou Province. That is the reason this research choose Guiyang as a case study.

Guiyang is the capital of Guizhou Province. Urban socioeconomic development has been rapid in recent years. The case study of Guiyang has great reference significance for the SCP. However, the Guiyang City Government (GCG) has not yet taken an SCP postassessment for Guiyang. No official evidence exists of whether these SCP practices can successfully reduce urban flood risks. More importantly, these SCP infrastructures are still at a small scale compared to the whole metropolitan area of 380 km^2. The SCP development in Guiyang has some constraints, primarily that the requirement flood control standard of SCP measures only reaches or is under a one-in-30-year rain return period (Guiyang City Government., 2019). The flood control standard of SCP is far less than the flood standard of Guiyang City (one-in-100-year rain return period). In addition, implemented SCP facilities are fragmented and not designed to mitigate fluvial floods in the Nanming River Catchment (Guizhou Water Resources and Hydropower Institute., 2016b).

This research involved 30 nonprofessional participants and 32 professional interviewees. They were landowners, residents, government officials, academics, planners, engineers, and developers. Focus Groups (FGs) can warm the talking atmosphere to improve interview efficiency when interviewing nonprofessional interviewees. Thus, this research chose FGs to collect residents' perspectives in the Nanming River Catchment. Semi-Structured Interviews (SSIs) can evoke sensitive interviewees to participate and answer questions. Therefore, this research selected SSIs to collect data from professional interviewees. UNNC Research Ethics Panel fully approved this research, in January 2021, before the research conduction (Please ref Appendix 2 Ethics Approval Form).

1.4 The proposed Sponge Catchment Management Framework (SCMF)

According to *National SCP Technical Guidelines*, SCP infrastructures mainly absorb the initial precipitation to reduce urban pluvial (urban surface flood or waterlogging) risks (Lancia et al., 2020). If Guiyang suffers from large-scale fluvial floods, it is still imperative that the constructed SCP infrastructures cannot deal with catchment floods (O'Donnell et al., 2020). So unless SCP is better connected to the broader CFM, it could become a *"shop window"*. In other words, SCP alone cannot cope with the catchment flood threat to cities. Regarding traditional flood control, the Guiyang City Government (GCG) has invested a lot in building reservoirs, flood walls, and drainage tunnels on the Nanming River. However, expanding such grey projects to further improve the flood management capacity is facing problems such as insufficient construction land, high project investment and related negative ecological impact (Qi et al., 2021b). Therefore, relying on small-scale SCP projects and build-up Grey-Leading Infrastructures (GIs) to deal with the flood threat from the Nanming River Catchment is inadequate (Qi et al., 2023).

Local decision-makers of Guiyang need an innovative ecological flood management framework to solve the challenges that local SCP and GIs face. Using Guiyang as the context, this research proposed a Sponge Catchment Management Framework (SCMF). SCMF is a broader-scale, more sustainable and more investment-friendly flood management framework. The application scope of SCMF covers urban and rural areas of the Nanming River Catchment. Because a management strategy needs to utilise structural and non-structural measures, the horizontal level includes structural and non-structural factors. The structural side focuses on the engineering measures, while the non-structural side highlights the soft ones. One side supports another side horizontally. Only using structural or non-structural aspects is not very effective, except using them simultaneously. Thereinto, NFM, GIs and SCP are integrated vertically on the left side; the vertical right side focuses on encouraging collaboration management, improving plans and technical standards more compatible, and strengthening communication among stakeholders, school education and public participation (Figure 1).

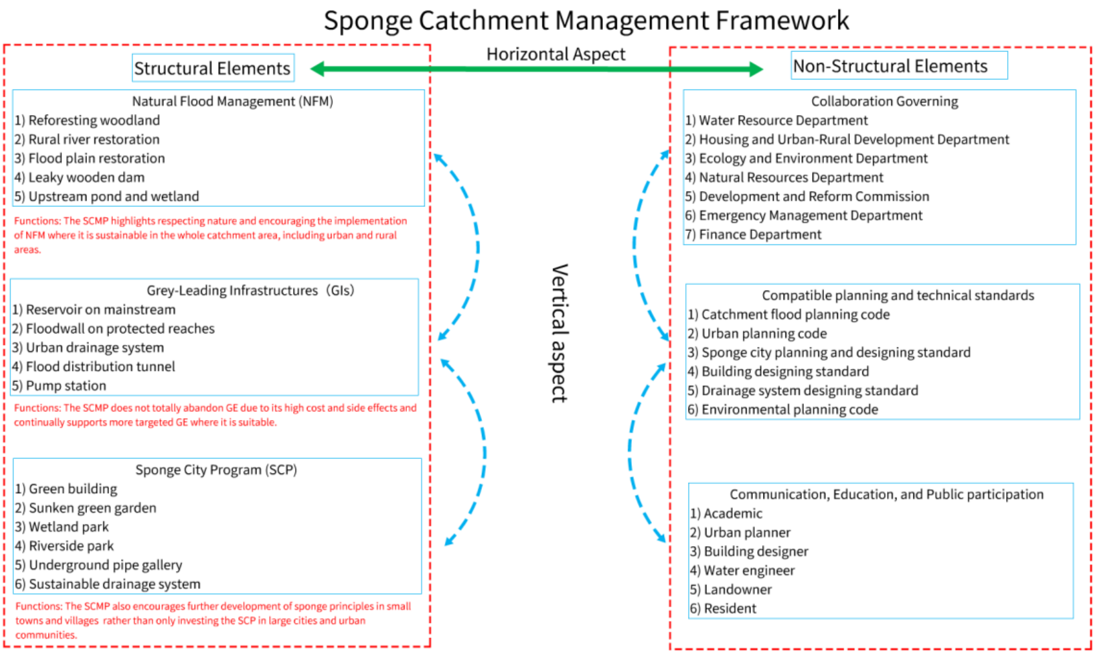


Figure 1 The basic structure of Sponge Catchment Management Framework (SCMF). (Yunfei Qi).

1.5 Thesis structure

This research follows the storyline of reviewing previous worldwide achievements, identifying Guiyang case results, finding potential solutions and giving future suggestions. First, Chapter 1 (Introduction) outlines this research to help readers understand the main research contents. Chapter 2 (Critical review) critically reviewed the development of worldwide Urban Water Management (UWM), Nature-Based Solutions (NBS), and the Sponge City Programme (SCP) in China. Chapter 3 (Research methods) described the conditions of Guiyang and the Nanming River Catchment while narrating the concepts of several interview methodologies and why this research selected FGs and SSIs. In Guiyang and the Nanming River Catchment context, Chapter 4 used FGs and SSIs to deeply understand the Guiyang SCP plans and related SCP designs, historical local flood events, and the flood management performance of GIs and SCP. Based on the research results, Chapter 5 discussed the Guiyang SCP implementational challenges in governance, planning, technical standards, design, land use, maintenance, and funding. Chapter 6 further explained the Sponge Catchment Management Framework (SCMF) proposed in Chapter 1 in the context of the Nanming River Catchment. In addition, Chapter 7 discussed how to implement an SCMF in Guiyang. This research suggested collaboration governance, multiple planning integration, strengthening basic research, revising technical standards, improving project land use, operation, maintenance and investment, and encouraging public participation and school education in the future SCMF implementation. Finally, Chapter 8 primarily summarised this research and gave a vision of outlooks (Figure 2).

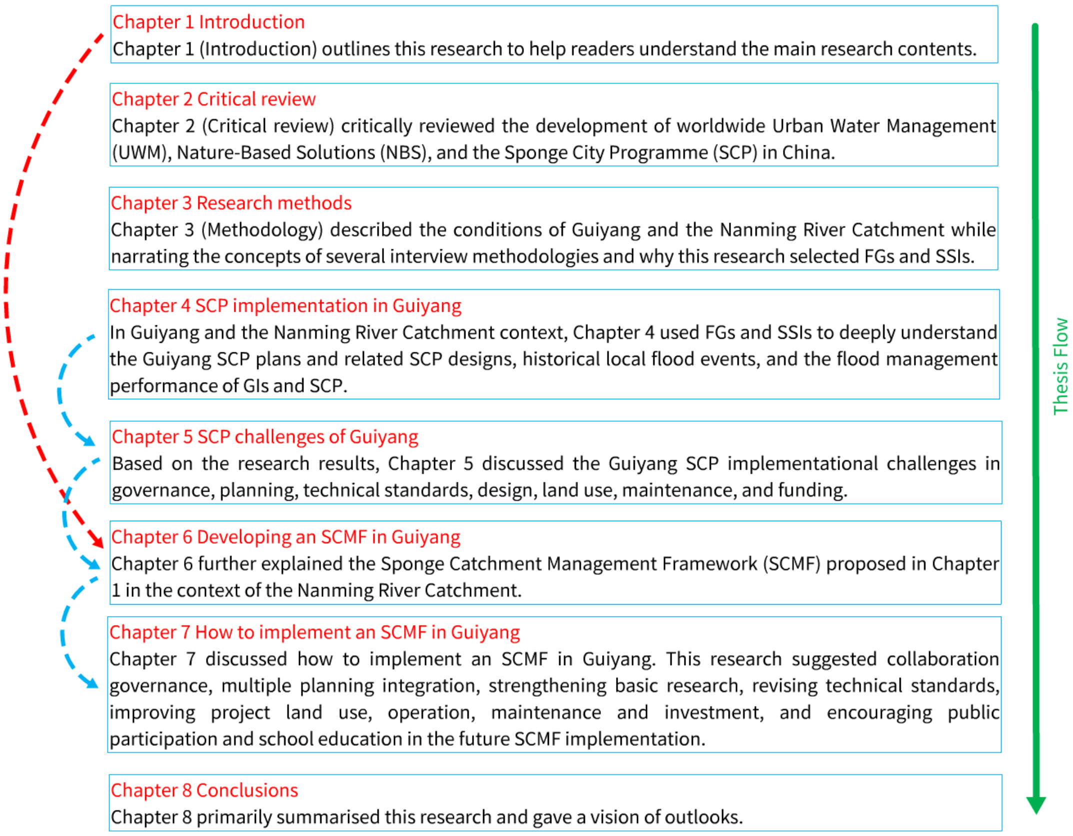


Figure 2 The chapter flow of this research. (Yunfei Qi).

Chapter 2. Critical review

2.1 Urban Water Management (UWM) progress in human history

People implemented drainage systems in ancient cities 5,000 years ago, including in the Chinese, Mesopotamian, Persian, Indus, and Minoan civilisations. The primary purpose of these drainage systems was to reduce local flooding and wastewater issues (Ashley et al., 2015). For centuries, drainage systems of masonry channels formed the rudiments of urban drainage technology. Ancient Romans also built drainage systems to discharge rainwater from low-lying areas to protect cities from intensive rainfall (Chen et al., 2021). *"Water Towns"* in China use the plain river networks to help east coast cities withstand storm surges and typhoons.

Modern sewerage systems appeared primarily to deal with sewage problems brought about by rapid urbanisation in Western Europe in the 19th century (Ellis and Lundy, 2016). One example was London's sewer system, aiming to solve large-scale Thames River pollution. At that time, the population was densely concentrated in the urban area of London along the Thames River. Arbitrarily discharged domestic and production sewage is directly discharged into the Thames River. The Thames River was a main part of London's drainage system. As a result, London residents suffered several epidemics, including the "*Cholera Outbreak on Broad Street"* in 1853 and the "*Great Stink"* in 1857. Concerns about public health and quality of life in these public health events led to social initiatives to create a modern sewerage system. Then, Joseph Bazalgette designed London's first modern sewerage system (Lashford et al., 2019). The explicit goal of the sewerage system was to reduce the health threat to the public by draining wastewater far away from the water supply source.

After *World War II*, the urban economy developed very fast in Western Countries. Urban scientists, planners, and designers began to rethink the Urban Water Management (UWM) issues to reduce urban flood risks and improve people's lives. Several UWM practices, such as Management Practices (Stormwater BMPs), Sustainable Drainage Systems (SuDs), Low Impact Urban Design and Development (LIUDD), etc., were emerging worldwide. These UWM practices include one primary principle: using low-impact and restoring measures by mimicking the natural hydrologic process in urban areas to improve people's life quality. After the 2010s, Nature-Based Solutions (NBS) summarised previous concepts, principles, programmes, and practices into systematic ecological solutions for urban planning and UWM. In 2013, the China National Government (CNG) initiated the Sponge City Programme (SCP), enlightened by the explored evidence of LID. For more details about these practices, readers can refer to Chapters 2.2.1 to 2.2.6.

Natural-Based Solutions (NBS) aim to deliver positive outcomes for human society through natural solutions while mitigating negative impacts on nature (Wendling et al., 2018). NBS is a summarised umbrella concept highlighting the limitations of Grey-Leading Infrastructures (GIs) and the advantages of natural solutions (Dushkova and Haase, 2020). Therefore, this umbrella concept embraces more specifically focused concepts, principles, and programmes (Gulsrud et al., 2018). Figure 3 depicts the NBS circular. Tables 1 and 2 encompass specific contents, including Stormwater Best

Management Practices (Stormwater BMPs), Sustainable Drainage Systems (SuDs), Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Low Impact Urban Design and Development (LIUDD), Active, Beautiful and Clean (ABC) Waters Programme, Natural-Based Solutions (NBS), and Sponge City Programme (SCP), when cities face water-related issues worldwide. Integrating natural solutions with GIs to solve water issues in urban areas is essential to these principles. There are overlaps among each other and supplements for each other. This NBS circular has structural and non-structural aspects of improving sustainable social development (Han and Hyun, 2019). Briefly, these basic principles include core ideas as follows:

1) Simulating or restoring natural hydrological processes by protecting or restoring water ecosystems in urban areas;

2) Improving urban waterbody quality and urban landscapes;

3) Mitigating urban flood risks;

4) Improving urban residents' life quality by providing more sustainable Ecosystem Services (ESs);

5) Providing additional co-benefits, such as carbon capture, well-being, and biodiversity.

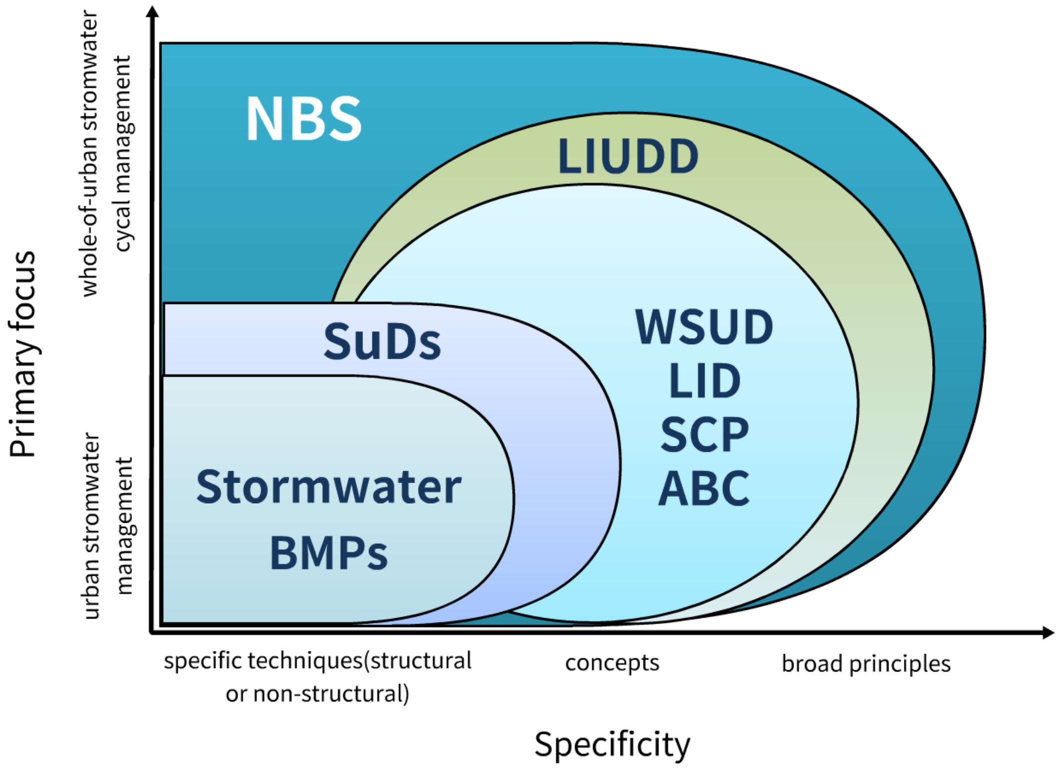


Figure 3 Relationships within various Urban Water Management (UWM). (Yunfei Qi).

Table 1 The development of worldwide Urban Water Management (UWM) practices

Beginning Time	Term	Countries	Citations
The 1970s	Stormwater Best Management Practices (Stormwater BMPs)	The United States and Canada	(Fletcher et al., 2014)
The 1970s	Sustainable Drainage Systems (SuDs)	The United Kingdom	(Lashford et al., 2019)
The 1990s	Low Impact Development (LID)	The United States and Canada	(Ishaq et al., 2019)
The 1990s	Water Sensitive Urban Design (WSUD)	Australia	(Cook et al., 2019)
The 1990s	Low Impact Urban Design and Development (LIUDD)	New Zealand	(van Roon, 2011b)
The 2000s	Green Infrastructure	The United States and Canada	(Artmann et al., 2019)
The 2000s	Active, Beautiful and Clean (ABC) Waters Programme	Singapore	(Goh et al., 2017)
The 2010s	Blue-Green Infrastructures and Blue-Green City	The United Kingdom	(Kozak et al., 2020)
The 2010s	Nature-Based Solutions (NBS)	Europe	(Seddon et al., 2020)
The 2010s	Sponge City Programme (SCP)	China	(Zevenbergen et al., 2018)

Table 2 Main features of various principles and programmes

Items	BMPs	LID	SuDS	WSUD	LIUDD	ABC	NBS	SCP
Start	The 1970s	The 1990s	The 1970s	The 1990s	The 1990s	The 2000s	The 2010s	The 2010s
Origin	United States, Canada	United States, Canada	United Kingdom	Australia	New Zealand	Singapore	Europe	China
Main Scale	City	City	City	City	City	City	Rural and urban areas, including catchment	City
Focus	Practices and techniques	Urban planning	Techniques	Urban planning	Urban planning	Urban planning	Principles and measures both in urban and catchment areas	Urban planning and designing principles
Original Definition	BMPs are a structured approach or practice to reduce and prevent pollution.	LID is a design approach simulating nature and reducing the cost of urban water management.	SUDS is a principle to reduce urbanisation's impact on sustainable urban development by optimising urban drainage systems.	WSUD is a philosophical approach to urban planning and design, including urban water management.	The term "low impact" means reducing the effects of human activities on natural processes. "Design and development" refers to practices that ensure people's actions will not essentially disturb or destroy these natural processes.	It creates beautiful and clean waterbodies as recreational spaces for people.	NBS is inspired and supported by nature. It is a cost-effective solution to cope with urban-related issues.	SCP originates from LID. It focuses on the strategy of integrated urban water management.
Original Aim	To prevent pollution.	To recover nature hydrology.	Reduce the potential impact of surface water drainage.	To manage the water balance, improve water quality and protect the ecosystem.	LIUDD offers pathways to accommodate human activities within ECC and helps assess how to work with natural cycles within ECC	It aims to transform Singapore's waterways and waterbodies into beautiful recreational spaces.	It improves urban sustainable development and resilience to climate change by restoring the ecological ecosystem.	Mitigating urban waterlogging; improving urban water quality; restoring urban water ecosystem function; utilising rainwater as a resource; improving the urban microclimate.
Measures	Both non-structural and structural aspects.	It includes smaller-scale measures, bio-retention systems, green roofs, swales etc.	Water practices and technologies work together to form a management system.	WSUD encompasses several urban water management, including water supply, sewerage and urban flood management.	LIUDD uses Water supply, sewerage, and urban flood management combined with cultural integration.	ABC Water Programme creates more recreational opportunities through green spaces and water bodies.	NBS explores the role of grey, green, and blue infrastructures, particularly hybrid approaches.	Consistent with principles behind LID, SCP measures include bio-retention, green roofs, permeable pavement, ponds, wetlands, etc.
Citations	(Di Matteo et al., 2017)	(Ishaq et al., 2019)	(Lashford et al., 2019)	(Beecham et al., 2019)	(van Roon, 2011a)	(Neo et al., 2022)	(Pontee et al., 2016)	(Xia et al., 2017)

2.2 Urban Water Management (UWM) in modern cities

2.2.1 Stormwater Best Management Practices (Stormwater BMPs)

The United States and Canada first used Best Management Practices (BMPs) to control industrial water pollution (Di Matteo et al., 2017). In 1977, the term was first used in the *"United States Clean Water Act"* to describe extensive waste disposal programmes, plans, and procedures to control toxic pollutants in industrial wastewater discharges. The "*Section 404 Programme"* covered dredging and landfill permits and mentioned BMPs in enforcement exemptions (Zhang and Chui, 2018). BMPs have protected surrounding urban lands contaminated by fertilisers, sediment, pesticides, and other chemical contaminants.

Over time, people found that urban surface runoff also threatened the environment because it could carry pollutants from the impermeable urban underlying surface, such as roads and parking lots, flowing into nearby waters (Rentachintala et al., 2022). In 1987, Stormwater BMPs first appeared in the "*United States Clean Water Act Amendment",* which aimed to propose the Nonpoint Source Management Demonstration Programme. In the water quantity aspect, the United States and Canada have promoted Stormwater BMPs to control urban stormwater runoff quantity since the 1990s (Wagner, 2008). Since then, Stormwater BMPs have become principles for improving water quality and quantity in North America.

In 2014, the United States Environmental Protection Agency (US EPA) developed a "*Siting Tool of BMPs"* to guide practitioners in adopting BMPs (The United States Environmental Protection Agency, 2014). The "*BMPs Siting Tool"* made BMPs more than just principles but also real exemplary construction projects implemented by the US EPA. Since then, Stormwater BMPs have been developed into principles, techniques, devices, and projects to manage water quality and quantity (Villarreal et al., 2004). According to the "*BMPs Siting Tool",* the considerations in selecting Stormwater BMPs include but are not limited to 1) site conditions, such as soil types, land and river slope, and underlying conditions; 2) current and planning land use on-site and surrounding; 3) priority stormwater management objectives, such as water quality or quantity; and 4) future site development or redevelopment objectives, such as providing resident, business, recreation, or flood detention areas.

Stormwater BMPs have structural and non-structural categories (Bureau of Watershed Management., 2006). Structural Stormwater BMPs are engineering contents such as artificial ponds, wetlands, and urban discharge systems, which can help mitigate urban development impacts on urban water (Jia et al., 2013). Non-structural BMPs are broader planning and design managing approaches that can reduce stormwater-generating urban flood risk (Bureau of Watershed Management., 2006). The benefits of Stormwater BMPs do not end with controlling pollutants and urban flood risks (Rentachintala et al., 2022). Stormwater BMPs can restore urban ecosystems while providing additional co-benefits, such as increasing property value, improving socioeconomic development, and giving permanent habitats for wildlife and recreational areas for residents.

2.2.2 Low Impact Development (LID)

Based on practical knowledge and experience of BMPs, America and Canada developed Low Impact Development (LID) as an urban planning principle in the early 1990s (Zhang et al., 2019b). LID focuses on comprehensive urban land development and building design approaches (e.g. green roofs and community rainwater gardens) by managing rainwater close to its source. However, LID is not an unattainable *"zero-impact"* development (Jia et al., 2013). The primary LID objective is to promote rainwater storage, infiltration, evaporation, and treatment by recreating predevelopment nature-hydrological conditions through LID planning and design principles (Di Matteo et al., 2017). LID encourages planners and designers to mimic natural hydrologic conditions via distributed rainwater storage in urban landscapes to improve UWM (Wagner, 2008). LID also employs Green Infrastructure to create water recycling functions in site drainage systems (The United States Environmental Protection Agency, 2014). In addition, LID helps recharge groundwater and river base flow. LID preserves rainwater as a processible resource.

In the 21st century, LID has transformed to use on a larger scale. According to the US EPA, LID includes holistic (urban-scale) and isolated (site-scale) strategies (Bureau of Watershed Management., 2006). Although isolated LID practices can partially store initial rainwater to mitigate urban flood risks, a holistic LID strategy can maximise its benefits on a larger scale (Zhang and Chui, 2018). There are five core requirements of LID: 1) conserving natural areas wherever possible; 2) minimising the development impact on sites' natural hydrology; 3) reducing the discharge rate of urban surface runoff and prolonging water discharge duration from GIs; 4) implementing GIs as patchworks of natural areas to improve urban flood protection, water ecosystem, air and water qualities in urban areas; and 5) encouraging proper maintenance and public education to increase LID long-term development. Some examples of LID designs are vegetated swales, bio-retention ponds, recovering green spaces, planting shrubs and trees, rain gardens, and rain barrels.

A related but not interchangeable term is Green Infrastructure. The US EPA noted that Green Infrastructure is a relatively flexible term used in various LID contexts (The United States Environmental Protection Agency, 2014). Green Infrastructure represents an environment-friendly public or private infrastructure directly using or mimicking natural water processes, such as infiltration, flow and evapotranspiration, at a site where the water generates (Rentachintala et al., 2022). Building designers can use Green Infrastructures at individual small-scale landscapes in place of, or in addition to, Grey-Leading Infrastructures (GIs) to support LID implementation (Villarreal et al., 2004). It is worth mentioning that Shenzhen, China, began to learn from LID experience and carry out LID pilot projects in Guangming New District in approximately 2010. Relevant LID pilot results and expertise contributed significantly to the proposed SCP in China.

2.2.3 Sustainable Drainage Systems (SuDs)

More green spaces were replaced by asphalt pavement and concrete buildings, leading to impervious surfaces. British cities have decreased their ability to absorb rainwater in the last several decades. The rainwater instead directly flowed into urban drainage systems. Direct drainage rainwater often overloads aged drainage systems, while traditional urban drainage systems have the probability of being blocked or damaged by flooding debris, causing floods. Similar to other developed countries, increasing urbanisation and global climate change have caused more frequent damaging floods in British cities (O'Donnell et al., 2018). It was necessary to transform traditional drainage systems into more environment-friendly and sustainable designs. Thus, since the 1990s, Sustainable Drainage Systems (SuDs) have become increasingly widespread in the United Kingdom.

SuDs are a collection of a series of environmentally optimised drainage systems. SuDs guide urban drainage planning and design by simulating the natural water cycle to reduce the project's impact on the natural environment while meeting the urban functional requirements. (Ashley et al., 2015). Meanwhile, SuDs are also part of the United Kingdom's Blue Green Cities (BGCs) (Ballard et al., 2015). Constructed SuDs can recharge or store rainwater in natural-source water bodies at given sites as much as possible to recharge underground aquifers by permeable soil and vegetation or flowing into nearby streams and lakes through grass ditches.

In the late 1990s, Robert Bray Associates designed Oxford Services Motorway Station as one of the pioneering constructed SuDs in the United Kingdom (Yazdanfar and Sharma, 2015). This motorway service station comprised swales, permeable paving, filter strips, and ponds (Ellis and Lundy, 2016). The SuDs in Oxford Services Motorway Station can collect, treat and store rainwater falling on parking areas and green roofs (Lashford et al., 2019). Then it releases the water at a controlled rate into the nearby water bodies (Chen et al., 2021). In 2010, formal legislation strengthened SuDs in British society. The *"Flood and Water Management Act 2010"* required that all building design, construction, operation, and maintenance meet SuDs provisions and standards (O'Donnell et al., 2017). In the early 2010s, SuDs contributed to the Newcastle-Upon-Tyne Blue Green Cities (BGCs) pilot project as an essential guiding principle.

2.2.4 Water Sensitive Urban Design (WSUD)

In the early 1990s, Water Sensitive Urban Design (WSUD) originated in Australia in the Asia-Pacific region (Hoban, 2019). In 1992, Mouritz initiated using the term WSUD. Whelans and Halpern Glick Maunsell proposed the first formal WSUD guidance in 1994. The Council of the Australian Government agreed to implement the National Water Initiative in 1994, which still encompasses *"24 guidelines"* in water quality, underground water, sewerage systems, diffuse and point pollution, and water recycling aspects (Radcliffe, 2019). Since then, all Australian States have committed to compiling regional WSUD guidelines (Cook et al., 2019). The WSUD has gradually transformed Australian urban planning principles to achieve multiple urban development objectives.

WSUD has already become a cornerstone of urban planning in Australia (Wong, 2015). Many prominent Australian cities such as Sydney, Melbourne, Perth, Canberra, Adelaide, and Brisbane have used WSUD to guide urban master plans (Beecham et al., 2019). WSUD integrates various proactive processes, such as land use planning, urban planning, urban landscape design, architecture design and water management (Wong, 2006). WSUD focuses on restoring natural water cycles (including rainwater, surface water, and underground water) to minimise water ecosystem degradation while meeting people's living, aesthetic and recreational appeals (Ashley et al., 2013). WSUD's principles are as follows: 1) protecting streams, rivers and wetlands in the urban environment; 2) improving water discharge quality from the urban environment into natural waterbodies; 3) encouraging water recycling to save water resources; 4) integrating rainwater treatment with urban landscapes to reducing water treatment pressure for sewage plants, provide recreation places for citizens, and provide habitat for wild animals; 5) reducing flood peak discharge from the urban environment while increasing infiltration and groundwater recharge; 6) integrating waterbodies into urban landscapes to enhance planning, designing, visual, social, cultural and ecological values to cities; and 7) easy implementation and low cost, allowing for wide application.

2.2.5 Low Impact Urban Design and Development (LIUDD)

Sustainable development ideas have also emerged strongly in New Zealand since the late 1980s. Across the Tasmanian Sea, as a neighbour of Australia, New Zealand developed Low Impact Urban Design and Development (LIUDD) enlightened by WSUD (van Roon, 2011b) in the 1990s. The New Zealand Parliament issued the "*Resource Management Act 1991",* officially embedding LIUDD into legislation (van Roon, 2009). In 2003, New Zealand funded a six-year LIUDD programme within the Sustainable Cities Portfolio.

People have a long history of changing urban landscapes without considering the following negative consequences. The term *"low impact"* means reducing the effects of human activities on natural processes in air, land, and water so that natural resources can still be available and sufficient for future use (van Roon, 2007). *"Design and development"* refers to the ideas, measures, and practices that ensure people's activities will not essentially disturb or destroy these natural processes. LIUDD attaches great importance to Ecological Carrying Capacity (ECC) as a critical element of sustainable urban development (van Roon, 2009). The ECC's effects and measures are complex because people's needs go beyond basic food and shelter requirements (van Roon, 2011a). Therefore, there is a need to create cities with innovation, economic growth, and low flood risks to improve social well-being, life quality and cultural identities (van Roon, 2011b). LIUDD considers the effects of humans living in urban ecosystems both now and in the future, which offers pathways to accommodate human activities within ECC and helps assess how to work with natural cycles within ECC.

In addition to essential urban planning and building design principles in Stormwater BMPs, LID, WSUD, and SuDs, LIUDD also considers race and cultural issues. The race and cultural factors affected by urban planning and design, such as indigenous communities, traditions, and cultures, are critical factors in the successful LIUDD implementation. Therefore, LIUDD is a multidimensional policy-making process weighing various scales over time, space, race, and culture (van Roon, 2009). Implementing cultural integration for LIUDD to transition into different local communities smoothly is essential. Recognising this, the New Zealand Government takes dialogues and inclusions among diverse ethnicities, communities, and cultures as a significant part of LIUDD (van Roon, 2007). LIUDD also encourages experts to move away from conventional thinking and into broader and various local contexts (van Roon, 2011a). Local LIUDD groups can expand their understanding, knowledge and social networks to achieve LIUDD goals by communicating and learning with experts and other stakeholders.

2.2.6 Active, Beautiful and Clean (ABC) Waters Programme

Urban Water Management (UWM) pioneering transitions have also profoundly influenced Southeast Asia. In the mid-2000s, Singapore initiated the Active, Beautiful and Clean (ABC) Waters Programme to provide a better living environment for the public through more sustainable water management (Goh et al., 2017). In 2001, the Singapore Government unveiled the *"Parks and Waterbodies Plan"* as an essential part of the *"Singapore Master Land-Use Plan"*. Then, the Singapore Urban Redevelopment Authority spearheaded the *"Parks and Waterbodies Plan"* to improve people's living quality. In 2004, one significant policy change was opening reservoirs for water sports and other leisure activities (Iftekhar et al., 2019). The successful initiatives gave confidence to the government to move towards a larger-scale programme to harness water bodies' potentialities.

In 2006, the Singapore National Water Agency officially launched the ABC Waters Programme. This programme aims to improve water quality and residents' life quality. It has transformed a part of Singapore's rivers, channels and reservoirs into urban leisure places, where residents can be close to urban water bodies and naturally become spontaneous water managers. As the slogan indicates, the core ideas of the ABC Waters Programme have three aspects. *"Active"* means creating new urban recreational spaces for residents. *"Beautiful"* refers to transforming a concrete waterway into beautiful and vibrant water bodies as urban landscapes. *"Clean"* represents improving water quality and fostering a better water-human relationship through holistic water management and public education. (Yau et al., 2017) The ABC Waters Programme's design features focus on urban surface flood mitigation and surface runoff treatment (Lim and Lu, 2016). Regarding land use, the ABC Water project increases land-use efficiency by allowing traditional single-function water infrastructure to perform multiple functions, such as recreation and education.

The ABC Waters Programme has developed a master plan to coordinate multiple departments to ensure success. In addition, the master plan divides Singapore into eastern, central, and western catchments with unique physical characteristics. For example, east and central catchments have more commercial and residential land use, while western catchments are primarily industrial land. Consulting companies compiled ABC Waters Programme for each catchment in line with its characteristics. The ABC Waters Programme plans to finish over a hundred potential ABC projects before 2030 (Goh et al., 2017). There were also several sub-programmes to support the ABC Waters Programme. The Singapore National Water Agency published the *"ABC Waters Design Guidelines Handbook"* to cultivate experts in programme implementation. The Singapore National Water Agency also initiated ABC Waters Education Programme to encourage social organisations and residents to participate. Another initiative was ABC Waters Learning Trails, which encouraged primary and secondary school students to explore and learn about implemented ABC Waters projects. In addition, Our Waters Programme enabled public and private sector members to organise events or develop their own ABC Waters projects in select water bodies (Liao, 2019). These sub-programmes successfully support the implementation of the ABC Waters Programme.

2.3 Nature-Based Solutions (NBS)

These pioneering Urban Water Management (UWM) practices have profoundly influenced European Nature-Based Solutions (NBS). Traditional UWM has been an anthropocentric notion for the last fifty decades (Zimmermann et al., 2020). People focus mainly on what nature can give us (Ferreira et al., 2020). Scientists have started to rethink the relationship between nature and cities when humans face more health, food security, water, energy, urbanisation, and climate change challenges.

One traditional solution to these challenges is to rely singularly on technological strategies. Another alternative solution is to form a systematic nature-friendly principle to sustain and increase the delivery of Ecosystem Services (ESs) to humans (Wendling et al., 2018). In the past 30 years, European practitioners have tried to find solutions to various challenges through the sustainable use of nature (Cohen-Shacham et al., 2016). At the beginning of the 21st century, NBS appeared as a concept to encourage proactive management of nature to enhance ESs while keeping a balance with nature

The International Union for Nature Conservation (IUCN) defines NBS as policies and measures for managing urban ecosystems based on protection, restoration and sustainable development (O'Donnell et al., 2020). NBS can improve cities' resilience to meet various social and environmental challenges and simultaneously provide multifaceted co-benefits, including improving human health and ecological diversity (IUCN, 2016). The IUCN definition emphasises that access to nature can help cities adapt to changing external environments.

The European Commission (EC) has described the NBS concept in more social and economic terms (Faivre et al., 2017). The EC explains how NBS can ensure urban sustainability and resilience by providing social, economic and environmental benefits through locally specific natural measures (Turconi et al., 2020). This definition has more to do with social orientation. Specifically, the EC's NBS practices are derived from different background conditions with different characteristics (Debele et al., 2019). Meanwhile, NBS projects must use targeted solutions to solve specific local issues.

The Unified Nations (UN) defined NBS as active urban water environmental management actions (Mendes et al., 2020). NBS aims to better balance the urban water cycle by restoring or simulating natural water cycle processes (rainfall, infiltration, evaporation and runoff), thereby improving water quality, ensuring urban water security, and reducing urban flood risk (UN, 2018). The UN hopes NBS can positively affect climate change and water-related risk management (Dushkova and Haase, 2020). The UN aims to promote more sustainable urban development by restoring a more undisrupted and natural urban water cycle. However, the UN's NBS definition focused more on urban water management and less on social and economic aspects.

These NBS pilot projects have collected practical evidence of NBS implementation to develop better solutions through continuous modification and integration of NBS designs (Artmann and Sartison, 2018). Although values from ESs can immediately benefit humans and the economy, NBS focuses on balancing the long-term benefits between humans and nature via sustainable solutions that respond to climate change and natural hazards (Turconi et al., 2020). NBS goes beyond the traditional category of ecological protection and pays more attention to the relationship between nature, people and society. NBS focuses on solving poverty, food security, and social and economic development through natural methods (Seddon et al., 2020). NBS is a systematic ecological-social-economic principle summarised from previous practices

(Raymond et al., 2017). Thus, despite its broad definition, the NBS's significant strength lies in its ability and early measures to integrate the social sphere by linking nature and the economy conceptually and practically.

In the flood management aspect, NBS encourages the integration of green (natural solutions) and grey (engineering solutions) measures (Figure 4). Integrating green and grey solutions help improve the current inadequate design standards of flood management while providing more co-benefits. These green and grey infrastructures include widespread wetlands, ponds, sunken rain gardens, green roofs, ecological river banks and corridors that increase the absorption and transport of rainwater along grey urban drainage channels. One classic example is Hamilton City. Hamilton City reconnected natural floodplains with naturally restored rivers to increase floodwater storage capacity and transport rainwater to mitigate flood issues (Faivre et al., 2017). This green and grey measure has proven to be more resilient to climate change. In addition, this hybrid measure can provide more cost-benefits than a single grey measure (raising flood barriers) or a single green measure (totally restoring natural flooding spaces without engineering infrastructures).

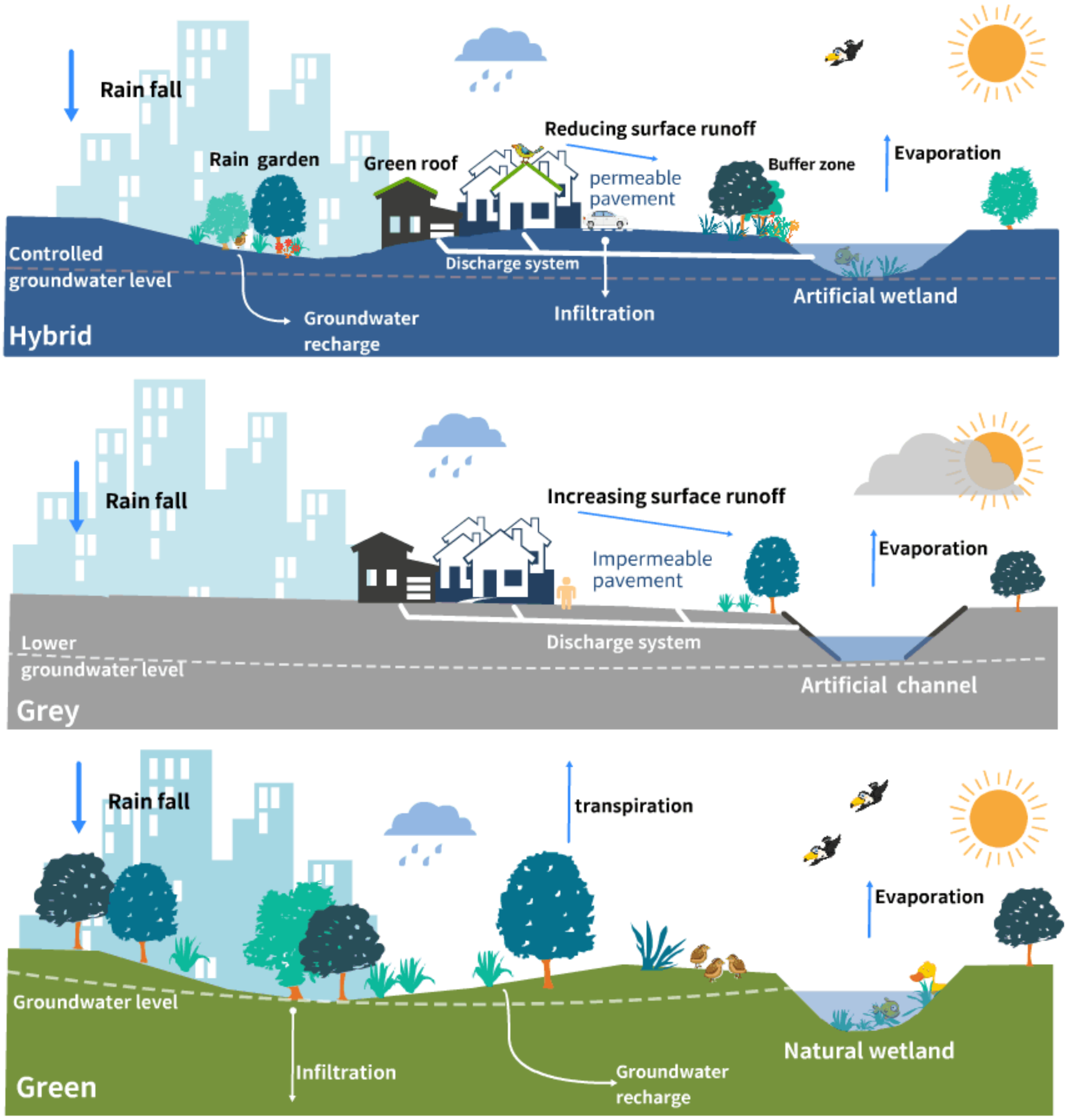


Figure 4 Green and grey measures with the NBS concept. Yunfei Qi drew the figure by adapting from (Kabisch et al., 2017)

2.4 Urban Water Management (UWM) and Sponge City Programme (SCP) in China

2.4.1 Development of UWM and related laws in China

Since the Reform and Opening Up, China's coastal and riverside cities have developed rapidly (Nguyen et al., 2019). In the 1980s, only 19.2 % of China's population lived in cities. By 2015, this proportion had exceeded 60% (Shao et al., 2016). Similar to the development history of western countries, rapid urbanisation has led to urban water problems. *"Big city diseases"* of water have come one after another, such as water supply shortage, flooding, water environment pollution, and water ecosystem deterioration (Chan et al., 2013a). Before the 2000s, traditional Urban Flood Management (UFM) relied mainly on Grey-Leading Infrastructures (GIs) in China (Nguyen et al., 2020). Although urban drainage systems have contributed to reducing inundation frequencies and urban water pollution, outdated GIs cannot solve all urban water issues due to rapid urban growth (Jia et al., 2017). The Ministry of Housing and Urban-Rural Development (MHURD) surveyed 351 cities to understand the urban flood conditions in 2014. A survey showed that over 62.3% of these cities suffered from urban flood events between 2008 and 2013 (Li et al., 2017). For instance, the Beijing flooding event caused widespread damage; seventy-nine people died on July 21 2012 (Wang et al., 2013). Over 20 million people were affected by flooding in China in July 2020 alone. (China Daily., 2020). These urban flood events' geographical spread, frequency, and severity convinced the CNG that only using the GIs in UFM was insufficient. It is necessary to propose new innovative UFM strategies.

The first breaking point of UWM in China was in 2002. The CNG initiated Water-Saving Cities (WSC) to encourage all social sectors in pilot cities to save water usage. However, Water-Saving Cities (WSCs) only focused on mitigating water supply shortage (Shang et al., 2017). Between 2003 and 2007, the focus of UFM gradually moved to deal with urban water pollution. Several megacities, such as Beijing, Shanghai, and Guangzhou, began implementing Better Urban Stormwater Management (BUSM) by upgrading water pollution treatment works and urban drainage systems (Li et al., 2019a). Between 2008 and 2010, the CNG started Urban Water Resources Optimisation (UWRO) to spatially optimise the water resources among various regions and cities (Chang and Su, 2020). In 2010, Shenzhen began experimentally implementing Low Impact Development (LID) (Lancia et al., 2020). In 2013, the CNG initiated the Sponge City Programme (SCP), enlightened by the principles and practices of LID and NBS (Qi et al., 2021a) (Figure 5).

Meanwhile, CNG has also issued several water-related laws and policies to support the ongoing transformation of water management strategies. The China National Congress promulgated the "*China Water Law"* in 1988 (the latest amended in 2016). The "*China Water Law"* is still China's most basic water management law. In 1997, the China National Congress enacted the "*China Flood Control Law"* (the latest amended in 2011). In the urban planning aspect, the China National Congress also promulgated the "*China Urban and Rural Planning Law"* in 1986 (the latest amended in 2019) and the "*China Land Management Law"* in 1987 (the latest amended in 2019). These two laws stipulate that urban and land plans must be compatible with flood control plans.

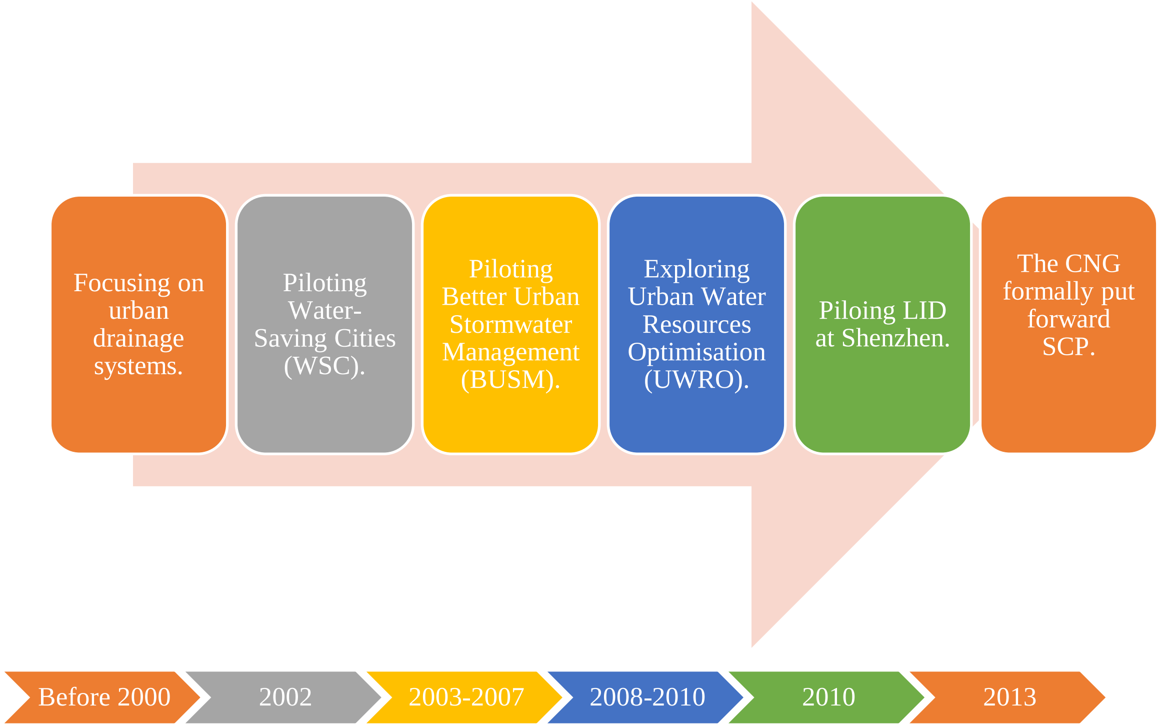


Figure 5 Development of UWM in China between 2000 and 2013. (Yunfei Qi).

2.4.2 Development, concept, and stage objectives of SCP in China

The idea of SCP originated from an ancient Chinese practice of *"Water Town"*. For instance, traditional Chinese farmers have utilised paddy fields as flood buffers in suburban areas of Ningbo (Tang et al., 2018). In 2003, Chinese researchers Yukong Jian and Dihua Li first used the term *"sponge"* as a metaphor for urban wetlands in the book *"The Road to a Cityscape: Talking to the Mayor" (Shao et al., 2016)*. In April 2012, the *"Low-Carbon Development Forum"* clearly proposed sponge city principles. In December 2013, President Xi stressed the statement at the *"Conference of Urbanization":*

"We should prioritise retaining limited rainwater resources and then use natural forces to manage water, to construct sponge cities with natural functions."

After that, the CNG officially initiated the Sponge City Programme (SCP) as a new national-level urban development strategy for urban planning, building design and water management (Zhang et al., 2019a). In October 2014, the MHURD issued *"National Technical Sponge City Guidelines - Building LID System (trial)" (National SCP Technical Guidelines)* (MHURD., 2014). In December 2014, according to President Xi's speech on strengthening SCP construction at the "*CPC Central Committee economic work conference*", the Ministry of Finance (MF), the MHURD and the Ministry of Water Resources (MWR) issued the *"Notice of Central Funding Supporting Pilot Work of Sponge City"* to support SCP pilot work by central government subsidiary funding (MF, 2014).

The CNG selected 30 SCP pilot cities in 2015 and 2016, respectively (MHURD., 2014). In 2015, the CNG picked the first batch of 16 pilot sponge cities, including Baicheng, Qian'an, Jiaxing, Zhenjiang, Wuhan, Chizhou, Pingxiang, Xiamen, Jinan, Changde, Hebi, Nanning, Suining, Chongqing, Xian (including Xixian New Area), and Guiyang (including Gui'an New Area) (MF, 2015). In 2016, the CNG selected the second batch of 14 pilot sponge cities, including Beijing, Shenzhen, Dalian, Tianjin, Ningbo, Shanghai, Qingdao, Zhuhai, Fuzhou, Sanya, Xining, Qingyang, Yuxi, and Guyuan (MF, 2016). In October 2015, the General Office of the State Council issued the *"Guidance on Promoting SCP Construction" to* point out the general SCP objectives as follows:

"Minimising urban development impact on the environment by comprehensively taking actions such as "water infiltration", "water retention", "water storage", "water purification", "water usage" and "water discharge" through SCP construction. The sponge cities aim to absorb 70% of the rainfall for reuse. By 2020, over 20% of the urban constructed areas must meet SCP requirements. By 2030, local governments should transform more than 80% of urban into sponge spaces." (General Office of the State Council., 2015)

In March 2016, the MHURD issued the *"Temporary Provisions of Preparing Sponge City Special Plans"*, requiring all pilot cities to hurry up compiling local special SCP plans by the end of October 2016 in amenable with approval procedures. In October 2018, the MHURD issued the *"National Sponge City Post-Evaluation Standard (GB/T 51345-2018)" (National SCP Assessment Standard)* (MHURD., 2018). In 2020, the MHURD public comments on another two national standards, *"Sponge City Special Planning and Design Standard (Exposure Draft)"* (MHURD., 2020b) and "*Sponge City Monitoring Standard (Exposure Draft)" (MHURD., 2020a)*. In 2021 and 2022, the MF, MHURD, and MWR issued *the "Notice of implementing Systemic and Whole Area Demonstration Work of Sponge City in the Fourteenth Five-Year Plan"* (MF., 2021) *and the "Notice of implementing Second Batch of Systematic and Whole Area Demonstration Work of Sponge City in the Fourteenth Five-Year Plan"* to support enlarging pilot SCP work by central government subsidiary funding (MF., 2022). Table 3 chronicles the development of SCP at China's national level.

Table 3 SCP development in China

Timeline	The development of SCP in China	Citations
2012	*"Low-Carbon Development Forum"* clearly proposed the concept of a sponge city.	(Xiang et al., 2019)
2013	The CNG formally put forwarded the SCP.	(Chan et al., 2018b)
2014	The MHURD released "*National Technical Sponge City Guidelines - Building LID System (trial)" (National SCP Technical Guidelines).*	(MHURD., 2014)
2014	The MHURD and MWR issued the *"Notice of Central Funding Supporting Pilot Work of Sponge City".*	(MF, 2014)
2015	China chose 16 pilot sponge cities as the first batch.	(MF, 2015)
2015	The General Office of the State Council issued the *"Guidance about Promoting SCP Construction"*, which pointed out the general objective of SCP	{General Office of the State Council., 2015
2016	China chose 14 pilot sponge cities as the second batch.	(MF, 2016)
2016	The pilot sponge cities started to compile local special SCP plans.	(Li et al., 2017)
2018	The MHURD published the *"National Sponge City Post-Evaluation Standard (GB/T 51345-2018)"(National SCP Assessment Standard)*	(MHURD., 2018)
2020	The MHURD solicited public comments on another two national standards, *"Sponge City Special Planning and Design Standard (Exposure Draft)"* and *"Sponge City Monitoring Standard (Exposure Draft)"*.	(MHURD., 2020a)
2021	The MF, MHURD, and MWR issued the*"Notice of implementing Systemic and Whole Area Demonstration Work of Sponge City in the Fourteenth Five-Year Plan".*	(MF., 2021)
2022	The MF, MHURD, and MWR issued the *"Notice of implementing Second Batch of Systematic and Whole Area Demonstration Work of Sponge City in the Fourteenth Five-Year Plan".*	(MF., 2022)

SCP is a systematic programme. The SCP uses the metaphor of *"sponge"* to absorb initial rainfall and release rainwater back into the runoff after soil infiltration and purification (Figure 6) (Shen et al., 2020). The SCP can mitigate urban flood risks while storing water resources, improving the urban environment, increasing biodiversity, and providing co-benefits to residents by capturing rainwater. It is a form of urban planning, building design and urban water management principles within an urban scale. SCP infrastructures utilise a set of NBS to catch, store and purify rainwater by mimicking the natural water cycle.

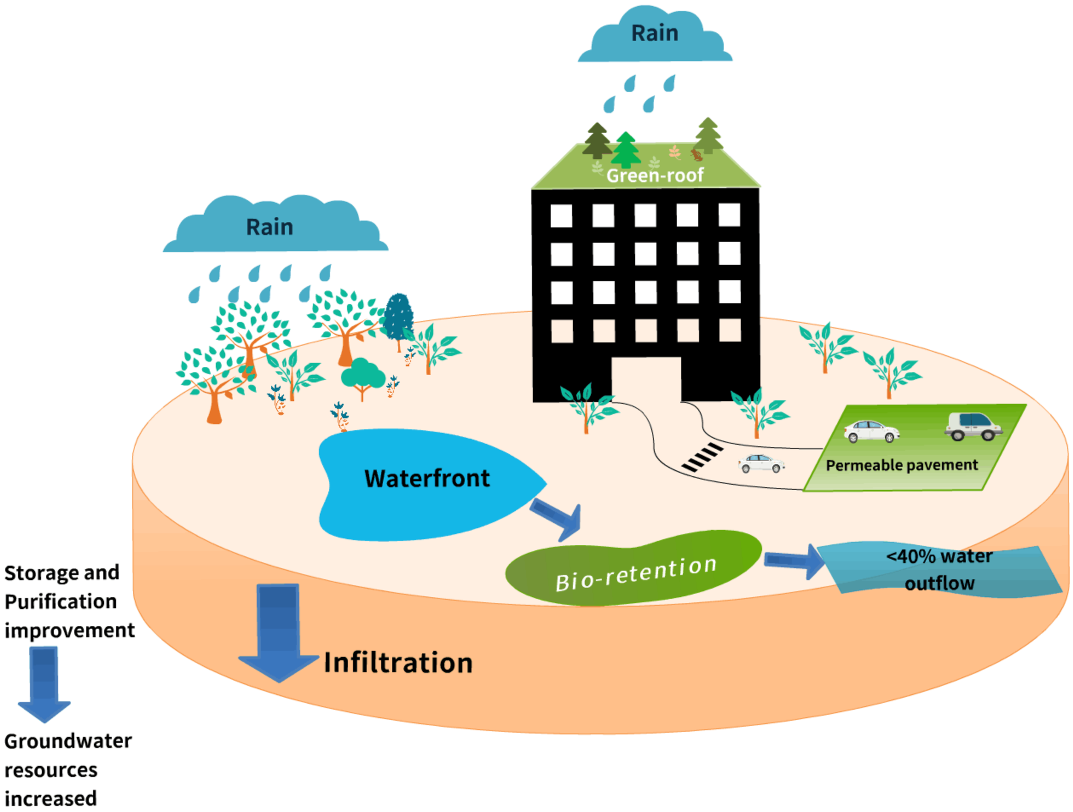


Figure 6 Sponge City idea and concept. (Yunfei Qi)

The core of SCP is to restore urban hydrological characteristics that remain unchanged as far as possible after a site development, including surface runoff, flood volume, flood peak, peak occurrence time, etc. The SCP adopts *"infiltration"*, *"retention"*, *"storage"*, *"purification"*, *"usage"*, and *"discharge"* measures in urban hydrological cycles to absorb rainwater at site sources and realise water slowly (Xia et al., 2017). Figure 7 illustrates the peak flow and time duration in natural conditions, traditional cities, and sponge cities. The gaps between the peak flows represent the expected SCP implementation's ideal effectiveness. Chapter 2.4.5 will critically review specific SCP measures in *National SCP Technical Guidelines*.

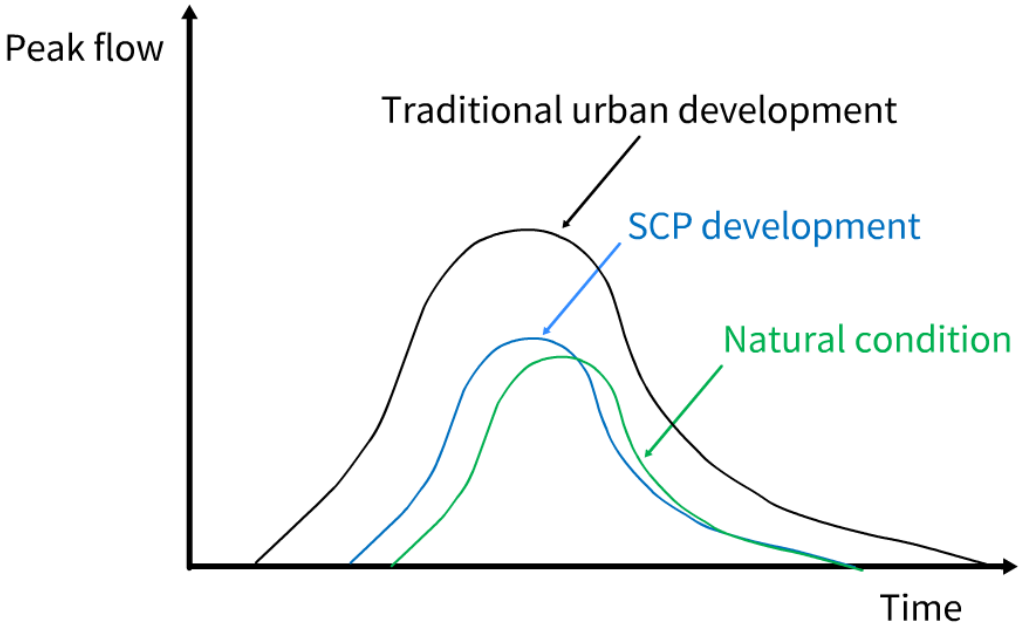


Figure 7 Hydrological characteristics in sponge cities. (Yunfei Qi).

SCP generally adopts the annual rainfall volume capture ratio to access the annual runoff control target. Before urban land development, natural landforms are often considered green spaces. Ideally, the annual runoff control target in built-up urban areas should be close to the natural landforms. Under normal circumstances, the green space's annual runoff discharge ratio is between 15% and 20%. Additionally, referring to previous practices in developed countries, the sponge cities' optimal annual rainfall volume capture ratio is between 80% and 85% (Wang et al., 2018). Figure 8 illustrates the annual rainfall volume capture ratio.

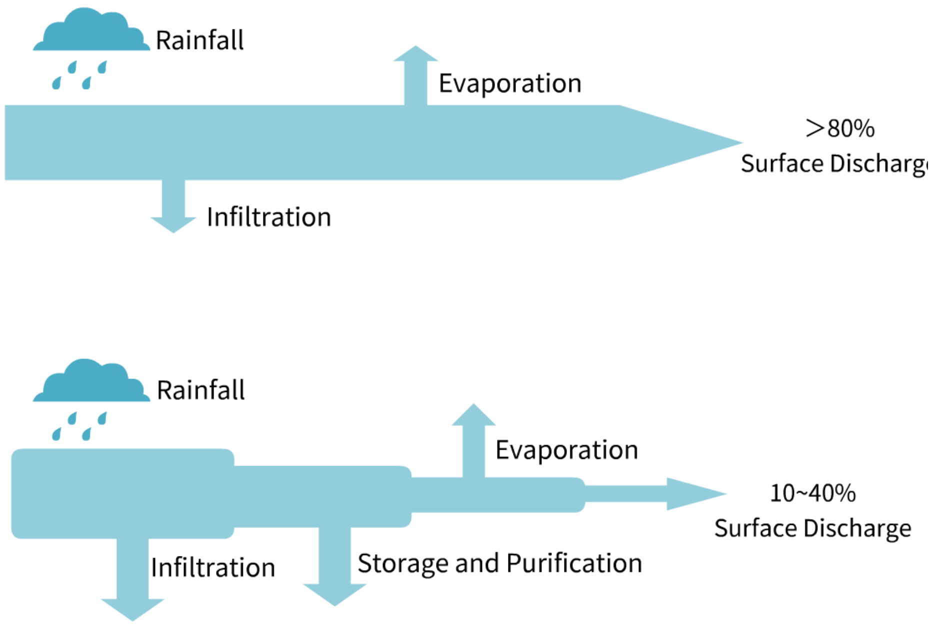


Figure 8 The sketch diagram annual rainfall volume capture ratio. (Yunfei Qi).

The corresponding one-to-one relationships exist between the annual rainfall volume capture ratio and design rainfall (Table 4). Taking Beijing as an example, when the annual rainfall volume capture ratio is 80% ~ 85%, the corresponding design precipitation is 27.2 mm ~ 33.5 mm, which corresponds to the one-hour rainfall that occurs one-in-0.5-year and one-in-one-year, respectively. Taking Guiyang as another example, when the annual rainfall volume capture ratio is 80% ~ 85%, the corresponding design precipitation is 26.2 mm ~ 32.1 mm, corresponding to the one-hour rainfall that occurs one-in-0.5-year and one-in-one-year, respectively. Sponge cities' annual runoff control target can mainly achieve by controlling moderate and small rainfall events (MHURD., 2018). The CNG has set three phased objectives for SCP as follows:

1) From 2015 to 2018, the short-term development aimed to promote SCP with small-scale SCP projects (green buildings, comprehensive pipe corridors, community ponds and parks, and urban wetlands) in the 30 chosen pilot sponge cities;

2) From 2018 to 2020, the medium-term development aimed to expand SCP up to more than 20% of sponge city areas according;

3) From 2020 to 2030, the long-term development plans to integrate SCP into urban master planning to transform more than 80% of urban areas into sponge areas (MHURD., 2014).

Table 4 The corrosion relationships between the volume capture ratio (%) of annual rainfall and design rainfall (mm) (MHURD., 2014)

Cities	The corresponding relationships between the volume capture ratio (%) of annual rainfall and design rainfalls (mm)				
	60%	70%	75%	80%	85%
Jiuquan	4.1	5.4	6.3	7.4	8.9
Lasa	6.2	8.1	9.2	10.6	12.3
Xining	6.1	8.0	9.2	10.7	12.7
Wunumuqi	5.8	7.8	9.1	10.8	13.0
Yinchuan	7.5	10.3	12.1	14.4	17.7
Wuhehaote	9.5	13.0	15.2	18.2	22.0
Haerbin	9.1	12.7	15.1	18.2	22.2
Taiyuan	9.7	13.5	16.1	19.4	23.6
Changchun	10.6	14.9	17.8	21.4	26.6
Kunming	11.5	15.7	18.5	22.0	26.8
Hanzhong	11.7	16.0	18.8	22.3	27.0
Shijiazhuang	12.3	17.1	20.3	24.1	28.9
Shenyang	12.8	17.5	20.8	25.0	30.3
Hangzhou	13.1	17.8	21.0	24.9	30.3
Hefei	13.1	18.0	21.3	25.6	31.3
Changsha	13.7	18.5	21.8	26.0	31.6
Chongqing	12.2	17.4	20.9	25.5	31.9
Guiyang	13.2	18.4	21.9	26.2	32.1
Shanghai	13.4	18.7	22.2	26.7	33.0
Beijing	14.0	19.4	22.8	27.2	33.5
Zhengzhou	14.0	19.5	23.1	27.8	34.3
Fuzhou	14.8	20.4	24.1	28.9	35.7
Nanjing	14.7	20.5	24.6	29.7	36.6
Yibin	12.9	19.0	23.4	29.1	36.7

Cities	The corresponding relationships between the volume capture ratio (%) of annual rainfall and design rainfalls (mm)				
	60%	70%	75%	80%	85%
Tianjin	14.9	20.9	25.0	30.4	37.8
Nanchang	16.7	22.8	26.8	32.0	38.9
Nanning	17.0	23.5	27.9	33.4	40.4
Jinan	16.7	23.2	27.7	33.5	41.3
Wuhan	17.6	24.5	29.2	35.2	43.3
Guangzhou	18.4	25.2	29.7	35.5	43.4
Haikou	23.5	33.1	40.0	49.5	63.4

2.4.3 Current SCP governance in China

The SCP is a complex programme that involves urban planning, design, water, landscape, natural resources, environment, emergency rescue, and government funding departments. Table 5 shows the responsibilities and roles of SCP governing at the national level. The CNG heads all ministries having authority in SCP. For instance, the National Development and Reform Commission (NDRC) approves SCP project construction, while the MF provides government subsidies for SCP projects. The MHURD is accountable for compiling SCP technical standards and supervising urban planning and building construction. The MWR manages water-related planning and construction. The Ministry of Natural Resources (MNR) governs national resource-related affairs, including land, forest, and grassland. The Ministry of Ecology and Environment (MEE) manages the ecosystem and pollution. The Ministry of Emergency Management (MEM) takes responsibility for emergency rescue work. The Ministry of Education (ME), the Ministry of Human Resources and Social Security (MHRSS), the Ministry of Transport (MT), and the Ministry of Agriculture and Rural Affairs (MARA) govern juvenile education, vocational and adult education, transportation, and agricultural and rural affairs, respectively (Chan et al., 2018b). Figure 9 illustrates SCP project planning, investment, and building procedures.

Table 5 The national governing system of SCP at China's national level (Wu et al., 2020)

Top governing authority	Ministry	Roles/Duties
China National Government (CNG)	NDRC	Approving the SCP project implementation.
	MF	Funding the SCP projects
	MHURD	Governing the SCP technical standards, city planning, and building construction in urban areas
	MWR	Governing the water-related planning and construction
	MNR	Governing the national-resources-related affairs
	MEE	Governing the ecological and environmental affairs

Top governing authority	Ministry	Roles/Duties
	MEM	Governing the emergency rescue affairs
	ME	Governing the education
	MHRSS	Governing the public, vocational and adult education
	MT	Governing the transportation
	MARA	Governing agricultural production and rural affairs

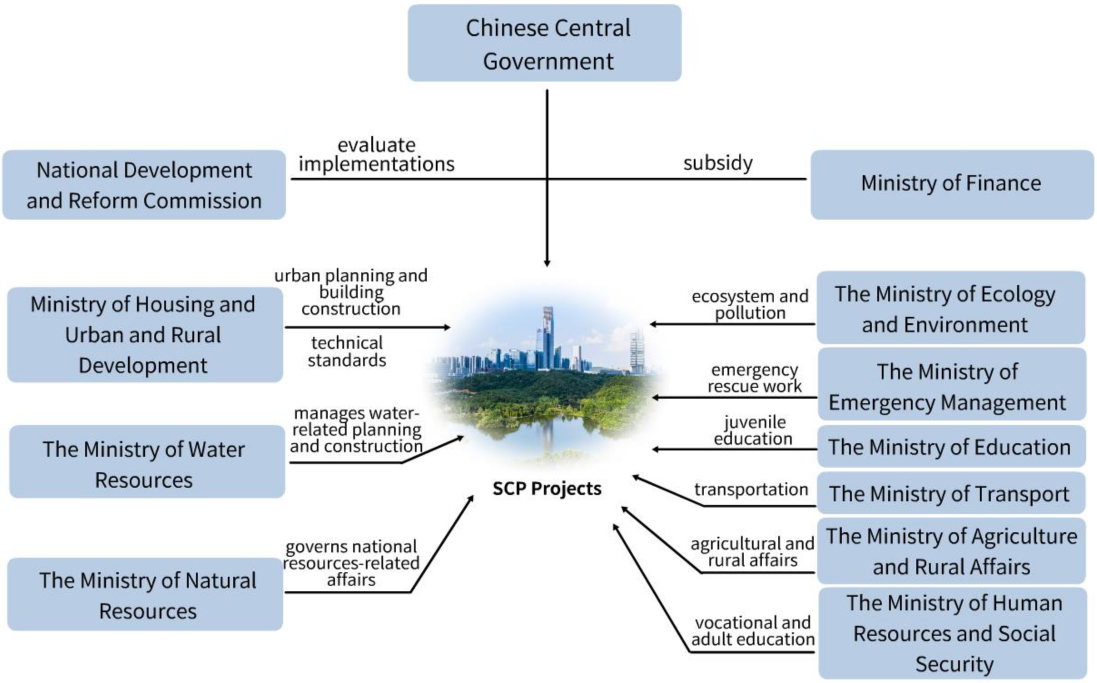


Figure 9 The governing stream of SCP. (Yunfei Qi).

2.4.4 SCP technical and assessment standards in China

The MHURD released *"National Technical Sponge City Guidelines - Building LID System (trial)" (National SCP Technical Guidelines)* in 2014. The *National SCP Technical Guidelines* intend to guide the new urbanisation process by promoting LID development. It rigidly regulates reducing urban surface runoff discharge from natural rainfall sources, prioritising using natural drainage systems and building ecological drainage facilities. It encourages using urban green space, communities, roads, parks, and water systems so that the hydrological characteristics of urban built-up areas are close to those before land development. The *National SCP Technical Guidelines* technically guide local governments and experts to build sponge cities.

The *National SCP Technical Guidelines* absorbed the worldwide Urban Water Management (UWM) experience and relevant policies, regulations, and engineering practices to apply in the following three aspects: 1) provide SCP typical measures for SCP plans; 2) guide SCP in stages from planning to operation; 3) guide and coordinate relevant departments in SCP implementation (MHURD., 2014). According to *National SCP Technical Guidelines*, the SCP has three main contents: 1) Protecting the original characteristics of the urban water ecosystem, such as lakes, rivers, ponds, wetlands, and urban green spaces to cope with rainfall. 2) Ecological restoration. The traditional GIs urban development model has damaged the urban water ecological environment. The SCP should restore these damaged ecological areas by ecological measures into ecological spaces. 3) Low-Impact Development (LID). The SCP requires cities to restore natural hydrological characteristics to a certain extent by controlling the intensity of urban development, preserving green spaces and reducing impermeable urban spaces (MHURD., 2014). In addition, sponge cities should appropriately enlarge urban water body areas in natural rivers and lakes to increase rainwater storage, infiltration, detention, and purification.

The *National SCP Technical Guidelines* also highlight the building steps of SCP projects. As Figure 10 illustrates, the SCP project building has four steps: 1) plan; 2) design; 3) build; and 4) operation and maintenance (Li et al., 2017). In each step, invited experts must review and evaluate SCP projects according to the general standards in the *National SCP Technical Guidelines* to ensure that SCP projects comply with the requirements.

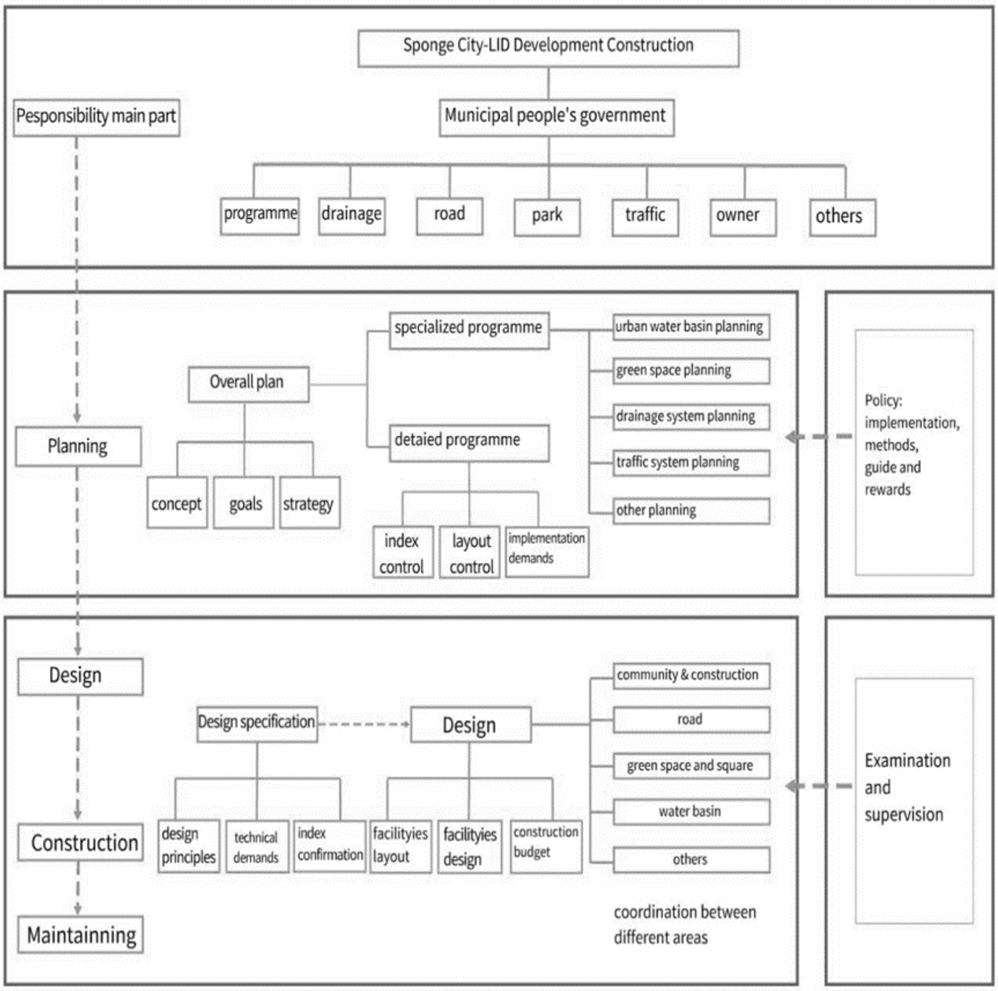


Figure 10 SCP construction process (MHURD., 2014). (Yunfei Qi).

Based on the statistical analysis (from 1983 to 2012) of rainfall in nearly 200 Chinese cities, the *National SCP Technical Guidelines* summarise the corresponding relationships between annual rainfall volume capture ratios and design rainfalls for some typical Chinese cities (mentioned in Chapter 2.4.2). In addition, the *National SCP Technical Guidelines* divide China's mainland into five areas to establish the minimum annual rainfall volume capture ratios. Namely I areas (85% ~ 90%), II areas (80% ~ 85%), III areas (75% ~ 85%), IV areas (70% ~ 85%), and V areas (60% ~ 85%) (Figure 11) (MHURD., 2014). Sponge cities must follow the standard to set local annual rainfall volume capture ratio in specific SCP implementation.

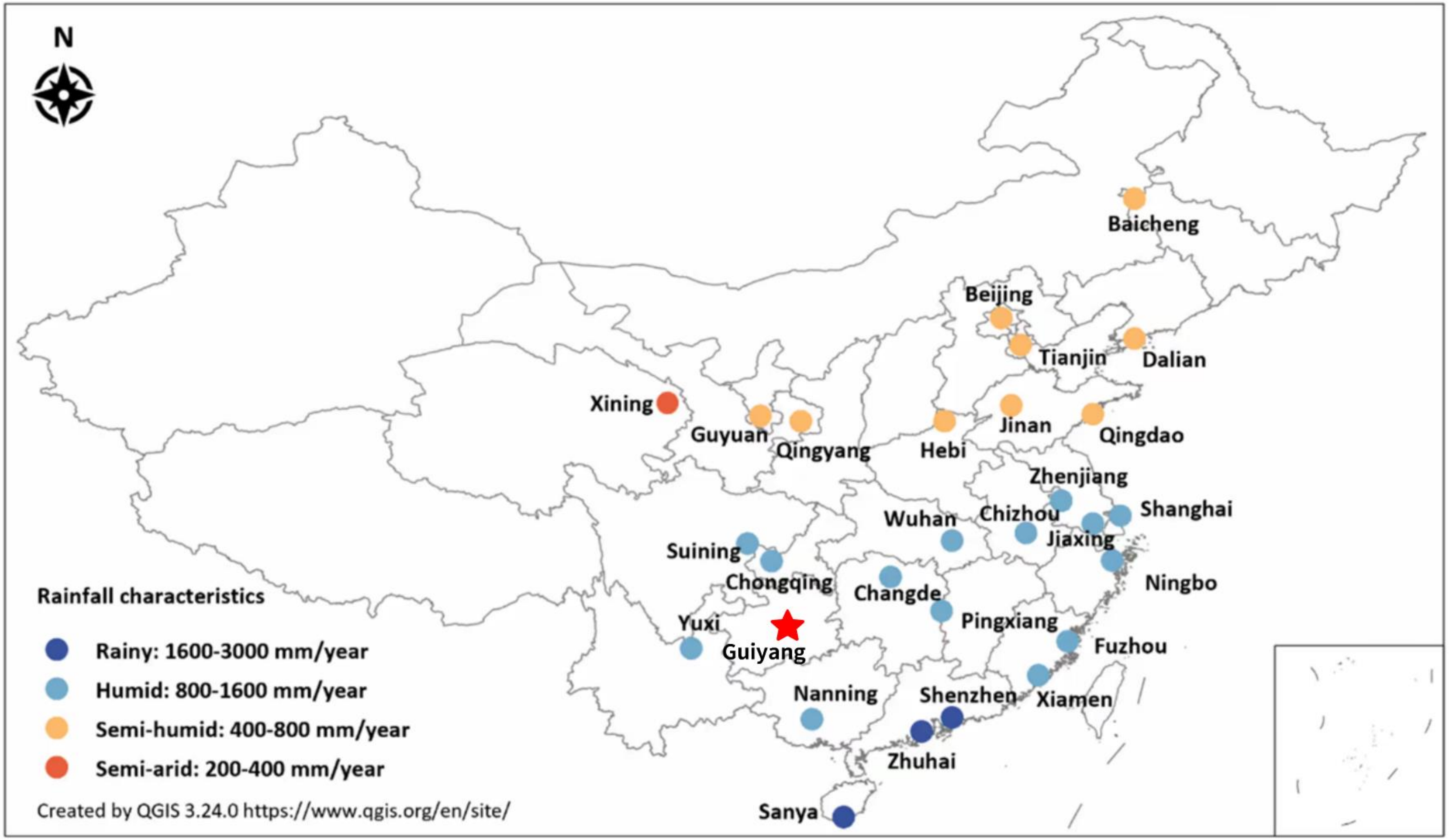


Figure 11 Annual rainfall volume capture ratio in China *(MHURD., 2018)*

To assess the construction effectiveness of the 30 pilot sponge cities, the MHURD released the *"National Sponge City Post-Evaluation Standard (GB/T 51345-2018)" (National SCP Assessment Standard)* for the sponge city construction effect in 2018. The standard evaluates the effectiveness of SCP in terms of annual rainfall volume capture ratio, the reducing effectiveness of flood source, waterlogging management, urban water quality improvement, protection of natural water shoreline, containment of the downward trend of groundwater level, and mitigation of Urban Heat Island Effect (UHIE) (Table 6). In 2020, the MHURD solicited public comments on another two national standards, *"Sponge City Construction Special Planning and Design Standard (Exposure Draft)"* and *"Sponge City Construction Monitoring Standard (Exposure Draft)"*. Because these two standards are still exposure drafts, this research does not review them.

Table 6 The major aspects of National SCP Assessment Standard (MHURD., 2018)

Assessment contents		**Requirements**
1． Annual rainfall volume capture ratio		1) Annual rainfall volume capture ratio. The annual rainfall volume capture ratio in building areas must exceed the lower limit in Table 4 and the corresponding calculated runoff volume.
2. Effectiveness of source emission reduction projects	Residential and commercial areas	1) Annual rainfall volume capture ratio. The annual rainfall volume capture ratio in building areas must exceed the lower limit in Table 4 and the corresponding calculated runoff volume. 2) Runoff pollution control (suspended solids SS). New buildings should not be less than 70%. Reconstruction buildings should exceed 40% in meeting the relevant planning requirements. 3）Peak runoff control. Under the flood return period of drainage systems, New buildings' peak runoff discharge should be less than the predevelopment peak runoff discharge. The peak runoff discharge of reconstruction buildings shall not exceed the original peak runoff discharge before renovation. 4) The hardening ground rate. New buildings should not be more than 40%; The hardened ground rate of the reconstruction buildings should not be greater than the original hardened ground rate before the reconstruction and should not be greater than 70%.
	Roads	1) Roads should be designed following planning and design requirements of runoff pollution control, waterlogging prevention, and flood drainage
	Parking lots and squares	1) The annual rainfall volume capture ratio in building areas must exceed the lower limit in Table 4 and the corresponding calculated runoff volume. 2) Runoff pollution control (suspended solids SS). Newly parking lots and squares should not be less than 70%. Reconstruction parking lots and squares should exceed 40% in meeting the relevant planning requirements. 3）Peak runoff control. Under the flood return period of drainage systems, New parking lots and squares' peak runoff discharge shall not be more than the original peak runoff discharge before site development. The peak runoff discharge of reconstruction parking lots and yards must be less than the original before renovation.
	Parks and green spaces	1) The surface runoff volume. The surface runoff volume controlled by the new parks and green spaces shall not be lower than the 90% annual rainfall volume capture ratio. According to the technical and cost-benefit analysis, the runoff volume controlled by the reconstruction parks and green spaces shall not be lower than the 90% volume capture ratio of annual surface runoff. 2) Parks and green spaces should take in rainfall runoff from surrounding areas.
3. Waterlogging control		1) Grey-Leading Infrastructures (GIs) and Green Infrastructures should be reasonably connected to play the role of flood peak detention, peak dislocation and peak cutting.

Assessment contents	Requirements
	2) Under the rainfall conditions corresponding to the design return period of discharge systems, there should be no water accumulation. 3) Waterlogging shall not occur in the case of heavy rain under the return period of the waterlogging prevention standard.
4. Urban water quality	1) Gray-Leading Infrastructures (GIs) and Green Infrastructures should be reasonably connected to control runoff pollution, confluence overflow pollution and water purification. 2) No direct wastewater discharge in the dry season. 3) Control the mixing and overflow pollution from stormwater and wastewater on rainy days. It should not make the receiving water body appear black and smelly. 4) Water is not black and smelly. 5) Water quality should not be inferior to that before SCP implementation. The water quality of the downstream section should not be inferior to that of the upstream inflow in the dry season.
5. Natural ecological patterns management and protection of ecological water shoreline	1) Before and after urban development, it should not reduce the total area of natural water areas. The natural topography, landform and landscape patterns should be protected and restored to the maximum extent. It should not change or occupy the natural flood passage, flood plain, wetland, woodland, grassland, and other ecologically sensitive areas. 2) In the urban planning areas, except for production shorelines such as harbours and necessary engineering flood control shorelines, the ecological shoreline rate of urban water bodies should be more than 70%.
6. Curbing the declining trend of groundwater levels	1) Sponge cities should curb the declining trend of groundwater.
7. Mitigation of Urban Heat Island Effect (UHIE)	1) In summer, the average daily temperature in the suburbs should show a downward trend compared with the historical summer period.

2.4.5 Typical SCP infrastructures

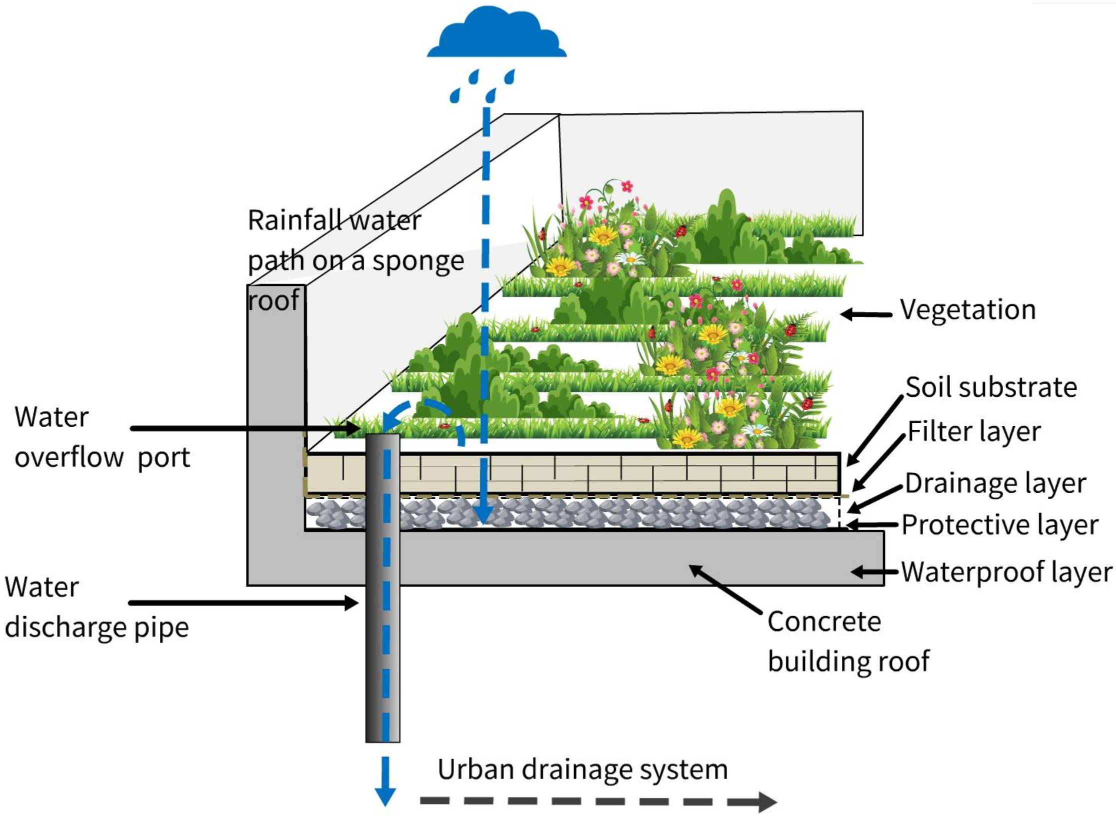
In urban planning, the *National SCP Technical Guidelines* encourage cities to restore urban water ecological environments, including identifying ecological patches, building ecological corridors, and connecting various ecological patches into a whole network. In the design aspect, the *National SCP Technical Guidelines* recommend applying to urban green spaces, green roofs, rain gardens, sponge roads, wetland parks, sponge water systems, etc. Chapter 2.4.5 will review the three typical SCP facilities.

Green roof

The *National SCP Technical Guidelines* recommend green roofs (Figures 12 a, b, and c) covered by vegetation and plants. Green roofs are also called planting roofs, roof greening, etc. Green roof advocates planting suitable plants on the roof to achieve the following objectives: 1) reduce surface runoff discharge from buildings; 2) reduce energy consumption to mitigate the UHIE; 3) improve urban water and air quality; 4) improve wildlife habitat and plant life; 5) create recreational areas. The practical application of green roofs can trace back to historical buildings one hundred years ago. In the early 1960s, modern green roof systems began in Germany, intending to reduce the energy consumption of buildings (Wright et al., 2020). In the last 30 years, the United States has conducted many studies on green roof design (O'Donnell et al., 2018). The United States Environmental Protection Agency published *"Green Roofs for Stormwater Runoff Control"* in 2009. Modern green roofs first came to China during the 1980s. Green roofs are increasingly popular worldwide thanks to the pioneering experience from Germany and the United States.

Green roofs are divided into simple and garden types according to the planting substrate's depth and the landscape's complexity according to the *National SCP Technical Guidelines*. Vegetation requirements and roof loadings determine the planting substrate depth (MHURD., 2018). The soil substrate of simple green roofs is generally no more than 150 mm. The soil substrate of garden roofs can exceed 600 mm when planting trees. A typical green roof structure includes plant, soil substrate, filter, drainage, protective, and waterproof layers. Green roofs are suitable for flat and slope roofs ≤15° (MHURD., 2014). The *"Technical Specification of Planting Roofs (JGJ155-2013)"* has more specifications in structure loading, waterproofing, space, slope, and planting conditions.

(a) (b)



(c)

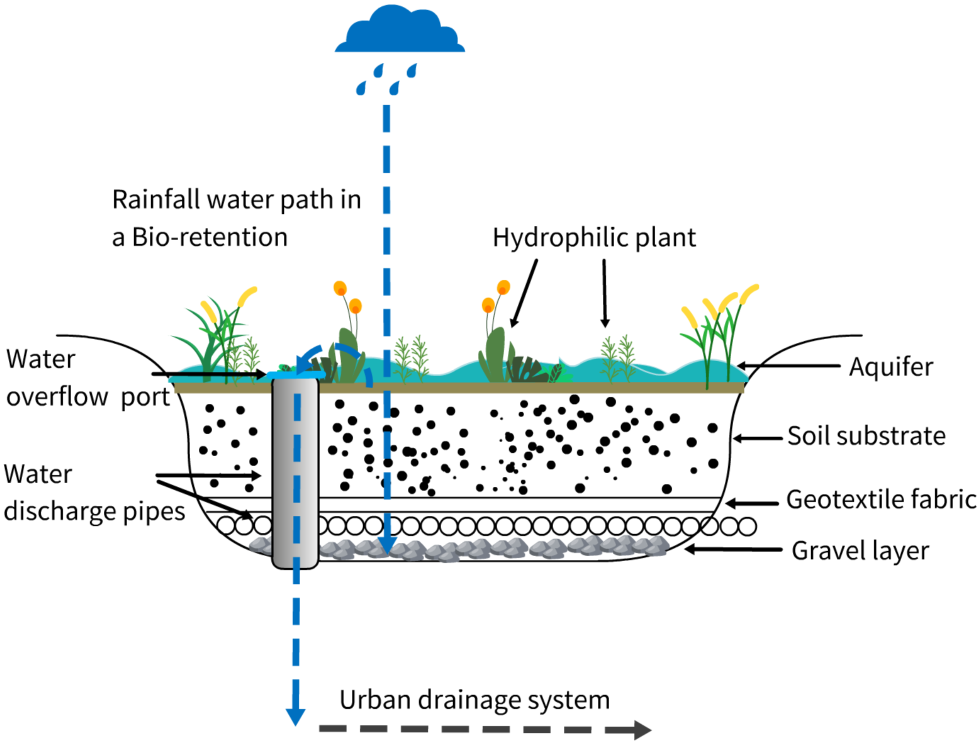
Figure 12 The green roofs were constructed in Guiyang (a) and (b). (Yunfei Qi). A typical structure of a green roof (c) (MHURD., 2014)

Bio-retention area (Rain garden)

Bio-retention (Figures 13 a, b, and c) is the process that removes contaminants from rainwater runoff. Bio-retention aims to reduce surface runoff and remove runoff pollutants (Su et al., 2019). In the bio-retention process, the grass space and ditches first direct rainwater into planting treatment areas consisting of a sand bed, top hydrophilic plants, a filter layer, and bottom soil. The filter layer usually consists of soil amendments, such as coconut husk, water treatment residue, and biochar. The sand bed is distributed around ponding areas to slow runoff velocity (Xiang et al., 2019). Then, the ponding areas store the rainwater. After several days, the stored water in the ponding areas exfiltrates into the underlying soils (Zhang et al., 2018). The *"National SCP Technical Guidelines"* suggests applying bio-retention areas (rain gardens) as a relatively cheaper and feasible SCP measure surrounding residential buildings, streets and parking lots (Zhou et al., 2018). According to different applicational contexts, bio-retention areas may include grass ditches, grasslands, flower beds, tree pools, hydrophilic-plant ponds, and underground drainage pipes.

(a)

(b)



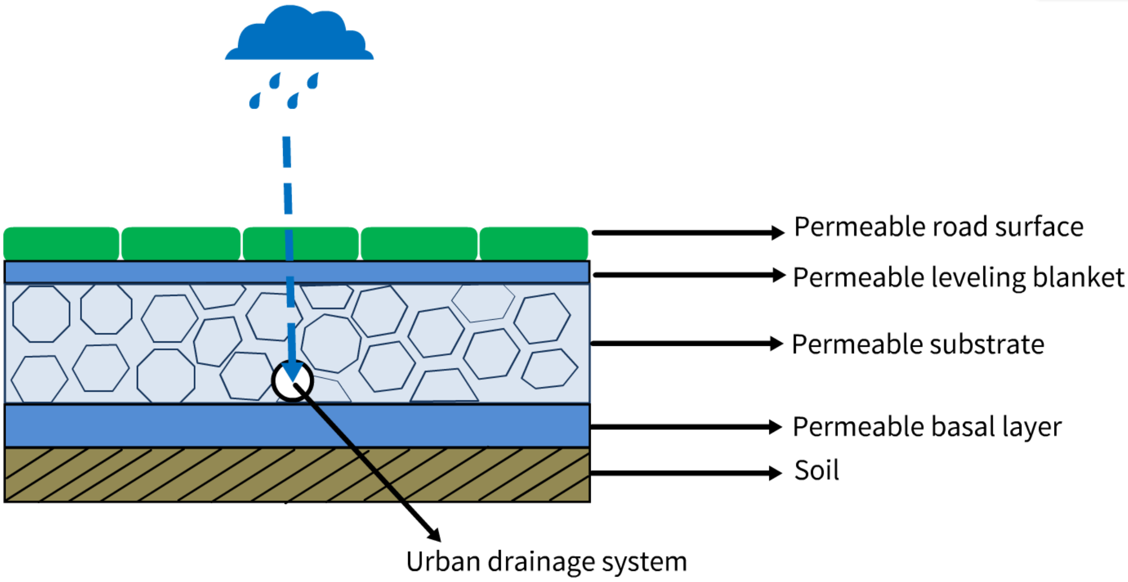
(c)

Figure 13 A rain garden (a) and a tree pool in Guiyang (b). (Yunfei Qi). A typical structure of a rain garden (c) (MHURD., 2014)

Permeable pavement

Permeable pavement (Figures 14 a, b, and c) is an SCP technology that uses porous materials to build ground pavement for increasing rainwater infiltration and purification (Li et al., 2019c). Urban permeable pavements contribute to constructing sponge roads, parking lots, side walkways, and squares (Li et al., 2019b). Designers choose different types of permeable pavement according to the vehicle load on the road. There are four types of permeable pavement: permeable brick, grass-brick, permeable concrete paving, and permeable asphalt (Ma et al., 2020). Suppose a sponge area replaces traditional pavements with porous pavements. In that case, the performance of flooding reduction may be better than only using distributed green roofs or rain gardens (Griffiths et al., 2020). For instance, permeable pavement construction on the Tianjin University campus in China reduced the total runoff by nearly 35.6% (Nguyen et al., 2019). However, the planning of urban permeable pavement should be adapted to local conditions, considering the problem of particle blockage and material life cycle. Concerning particle clogging issues, permeable concrete paving performs better than permeable brick and asphalt (Jia et al., 2017). Thus, porous pavement is unsuitable in highly polluted regions or with low soil permeability (Liang et al., 2020). For more details, readers can refer to "*Permeable Brick Technical Standard (CJJ/T188)*", "*Permeable Asphalt Technical Standard (CJJ/T190)*", and "*Permeable Concrete Technical Standard (CJJ/T135)*". There are many other kinds of sponge measures with various characteristics, referring to Table 7.

(a) (b)



(c)

Figure 14 A permeable asphalt walking street in Guiyang (a). *A grass-brick parking lot in Guiyang* (b). (Yunfei Qi). A typical structure of a *permeable pavement* (c) *(MHURD., 2014)*

Table 7 SCP technical measures (Jia et al., 2017)

Sponge Infrastructures	Functions					Control Objectives			Disposal or Concentration		Costs		Removal Rate for Pollutants (%)	Landscape Effectiveness
	Water Reuse	**Recharging Underground Water**	**Surface Flood Reduction**	**Rainwater Purification**	**Water Transmission**	**Runoff Volume**	**Runoff peak**	**Runoff Pollution**	**Dispersal**	**Relative Concentration**	**Construction Costs**	**Maintaining Costs**		
Green Roof	○	○	△	△	△	☆	△	△	√	-	High	Mid	70 to 80	Easily seen
Permeable Pavement	○	☆	△	△	△	☆	△	△	√	-	Low	Low	80 to 90	-
Permeable Cement	○	○	△	△	△	△	△	△	√	-	High	Mid	80 to 90	-
Permeable Asphalt	○	○	△	△	△	△	△	△	√	-	High	Mid	80 to 90	-
Sunken Green Space	○	☆	△	△	△	☆	△	△	√	-	Low	Low	-	Occasionally seen
Simple Bio-Retention	○	☆	△	△	△	☆	△	△	√	-	Low	Low	-	Easily seen
Integrated Bio-Retention	○	☆	△	☆	△	☆	△	☆	√	-	Mid	Low	70 to 95	Easily seen
Permeable Pond	○	☆	△	△	△	☆	△	△	-	√	Mid	Mid	70 to 80	Occasionally seen
Wet Pond	☆	○	☆	△	△	☆	☆	△	-	√	High	Mid	50 to 80	Easily seen
Seepage Well	○	☆	△	△	△	☆	△	△	√	√	Low	Low	-	-
Rainwater Wetland	☆	○	☆	☆	△	☆	☆	☆	√	√	High	Mid	50 to 80	Easily seen
Impounding Pool	☆	○	△	△	△	☆	△	△	-	√	High	Mid	80 to 90	-
Regulating Pond	○	○	☆	△	△	○	☆	△	-	√	High	Mid	-	Occasionally seen
Regulating Pool	○	○	☆	○	△	○	☆	△	-	√	High	Mid	-	-
Rainwater Tank	☆	○	△	△	△	☆	△	△	√	-	Low	Low	80 to 90	-
Dry Grass Ditch	○	○	○	△	☆	☆	○	△	√	-	Low	Low	35 to 90	Easily seen
Transfer-Type Grass Ditch	△	○	○	△	☆	△	○	△	√	-	Low	Low	35 to 90	Occasionally seen

Sponge Infrastructures	Functions					Control Objectives			Disposal or Concentration		Costs		Removal Rate for Pollutants (%)	Landscape Effectiveness
	Water Reuse	Recharging Underground Water	Surface Flood Reduction	Rainwater Purification	Water Transmission	Runoff Volume	Runoff peak	Runoff Pollution	Dispersal	Relative Concentration	Construction Costs	Maintaining Costs		
Wet Grass Ditch	○	○	○	☆	☆	○	○	☆	√	-	Mid	Low	-	Easily seen
Permeable Canal	○	△	○	○	☆	△	○	△	√	-	Mid	Mid	35 to 70	-
Vegetation Buffer Zone	○	○	○	☆	-	○	○	☆	√	-	Low	Low	50 to 75	Occasionally seen
Initial Rainwater Treatment	△	○	○	☆	-	○	○	☆	√	-	Low	Mid	40 to 60	-
Artificial Infiltrating Soil	☆	○	○	☆	-	○	○	△	-	√	High	Mid	75 to 95	Easily seen

☆—High; △—Relative high; ○—Low; Landscape

Chapter 3. Research methods

Guiyang is a first-batch pilot sponge city with mountainous terrain and Karst landform features in southwest China. Taking Guiyang as a study case is meaningful for researching SCP in mountainous areas. The author knows many professionals in the water department because he is a senior water engineer in Guiyang. Therefore, this research selected Guiyang as the research case. Specifically, this research selected the Nanming River Catchment as the research catchment. Focus Groups (FGs) can warm the talking atmosphere to improve interview efficiency when interviewing nonprofessional interviewees. Thus, this research chose FGs to collect residents' perspectives in the Nanming River Catchment. Semi-Structured Interviews (SSIs) can evoke sensitive interviewees to participate and answer questions. Therefore, this research selected SSIs to collect data from professional interviewees. This research involved 30 nonprofessional participants and 32 professional interviewees. They were landowners, residents, government officials, academics, planners, engineers, and developers.

3.1 Research case study

3.1.1 Social-economic development of Guiyang

Guiyang is the capital city of Guizhou Province. It is in the Southwest of China. The city circle includes six districts (Nanming, Yunyan, Huaxi, Wudang, Baiyun, and Guanshanhu Districts) and three counties (Xifeng County, Kaiyang, and Xiuwen), one sub-city (Qingzhen City), and one new district (Gui'an New Distinct) (Figure 15). The Nanming River originates south of Guiyang and flows through the city area to the north (Figure 16). Guiyang has been the core of the fastest developing economic region in Southwest China, as the *"Central Guizhou Economic Zone"*, taking an essential role in the *"Pan-Pearl River Delta Economic Circle"* (Guiyang City Government., 2016b) (Figure 17). The city has maintained a buoyant economy and population growth (Table 8). From 1990 to 2021, the urbanized areas increased from 43.9% to 75.4% (Statistics Bureau of Guiyang., 2019). An increase of over one million people and 50,000 companies will occur by the 2030s (Guizhou Provincial Statistics Bureau., 2019).

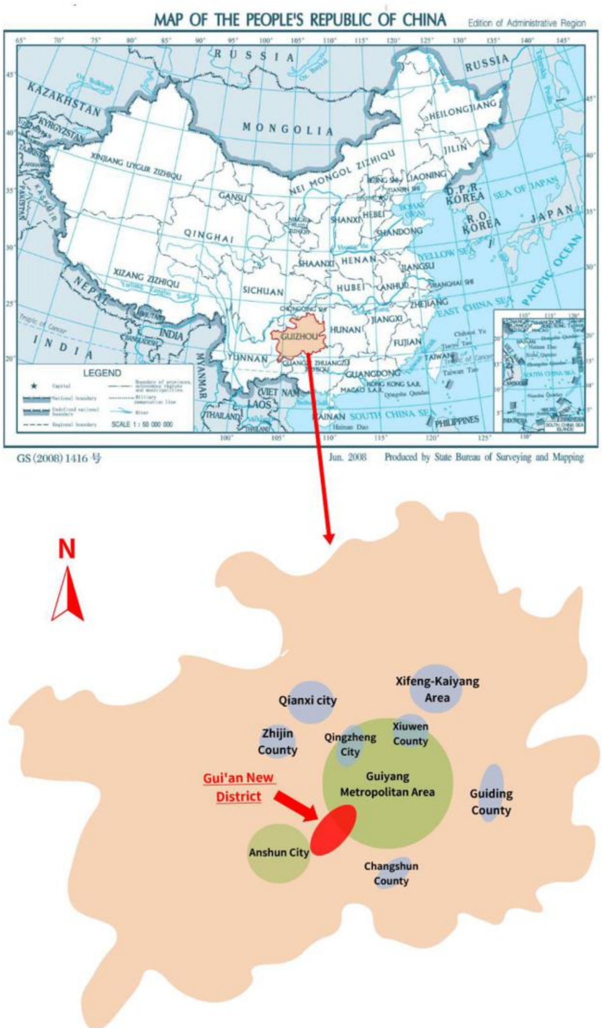
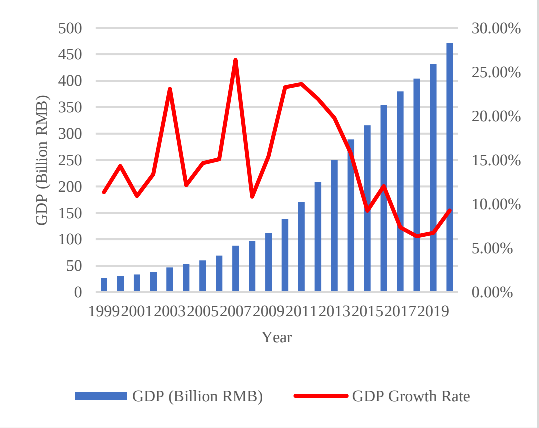


Figure 15 The location map of Guiyang. Yunfei Qi drew and adopted the figure from (State Bureau of Surveying and Mapping., 2008).

(a) (b)

Figure 16 Nanming River in Guiyang CBD (a and b). (Yunfei Qi).



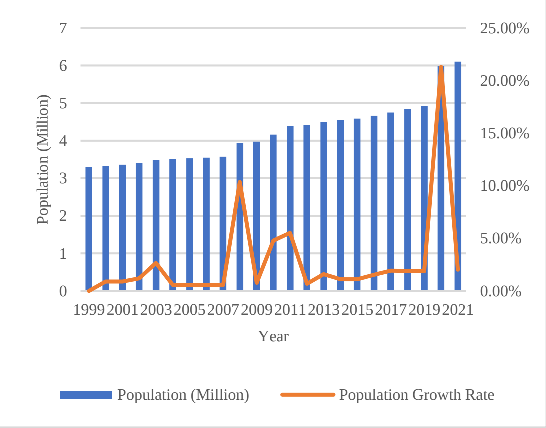


Figure 17 Guiyang GDP and GDP growth rate (a); Guiyang population and population Growth (b). Yunfei Qi drew the figure and adopted data from (Statistics Bureau of Guiyang., 2019).

Table 8 The Economy and Population Development of Guiyang. Sources: (Statistics Bureau of Guiyang., 2019)

Year	GDP (Billion Yuan)	Annual GDP Growth Rate	Population (Million People)	Annual Population Growth Rate
1999	23.8	/	3.3	/
2000	26.5	11.34%	3.33	0.91%
2001	30.3	14.34%	3.36	0.90%
2002	33.6	10.89%	3.4	1.19%
2003	38.1	13.39%	3.49	2.65%
2004	46.9	23.10%	3.51	0.57%
2005	52.6	12.15%	3.53	0.57%
2006	60.3	14.64%	3.55	0.57%
2007	69.4	15.09%	3.57	0.56%
2008	87.7	26.37%	3.94	10.36%
2009	97.2	10.83%	3.97	0.76%
2010	112.2	15.43%	4.16	4.79%
2011	138.3	23.26%	4.39	5.53%
2012	171	23.64%	4.42	0.68%
2013	208.5	21.93%	4.49	1.58%
2014	249.7	19.76%	4.54	1.11%
2015	289.1	15.78%	4.59	1.10%
2016	315.8	9.24%	4.66	1.53%
2017	353.8	12.03%	4.75	1.93%
2018	379.8	7.35%	4.84	1.89%
2019	403.9	6.35%	4.93	1.86%
2020	431.1	6.73%	5.98	21.30%
2021	471.1	9.28%	6.10	2.01%

3.1.2 Terrain, climate, and hydrological features of Guiyang

Terrain characteristics

Guiyang locates in the middle of the Yunnan-Guizhou Plateau. The average altitude of Guiyang is approximately 1100 meters. The general topography is high in the southwest and low in the northeast. The Miaoling Mountain crossing the whole city creates an ups-down terrain, including alternate erosion hills and basins, valleys, and low-lying land. The relative height difference is 100~200 meters. The highest peak is in Miaowo Top, Shuitian Town, 1659 meters above sea level, and the lowest is in the downstream Naming River, 880 meters above sea level (Guizhou Water Resources and Hydropower Institute., 2016a).

Climate characteristics

Guiyang is in the Ferrel Cell, which means the westerlies influence the weather year-round. It belongs to the humid and mild climate of the subtropical region. Guiyang has an average annual temperature of 15.3℃. The annual high temperature is 35.1℃, and the annual low temperature is -7.3℃. The annual rainfall is 1129.5 mm, and the average relative humidity is 77%. In addition, Guiyang has an annual average of 235.1 cloudy days, 1,148.3 hours of sunshine, and 11.3 days of snowfall. (Guizhou Water Resources and Hydropower Institute., 2016c). The annual precipitation in Guiyang ranges from 1,760 mm (the maximum year was 1954) to 718 mm (the minimum year was 1981). April to September is the rainy season, with abundant rainfall of 891 mm, accounting for approximately 79.1% of the annual total precipitation. The highest monthly rainfall is in July, averaging 300 ~ 400 mm (Guizhou Provincial Meteorological Bureau., 2020). This precipitation pattern increases the potential risk of flash floods and urban flooding.

Hydrological characteristics

The Tongmuling in Huaxi District is the watershed boundary of the Yangtze River and Pearl River Catchment. The rivers in the southern Tongmuling belong to the Pearl River Catchment, and the rivers in the north belong to the Yangtze River Catchment. There are 98 rivers over 10 kilometres in Guiyang, including 90 in the Yangtze River Catchment and 8 in the Pearl River Catchment (Guizhou Water Resources and Hydropower Institute., 2018). The main rivers include the Wujiang River, Nanming River, Maotiao River, Yachi River, An Liu River, Yuliang River, Gusa River, Xifeng River, Yang Shui River, and Mengjiang River (Figure 18).

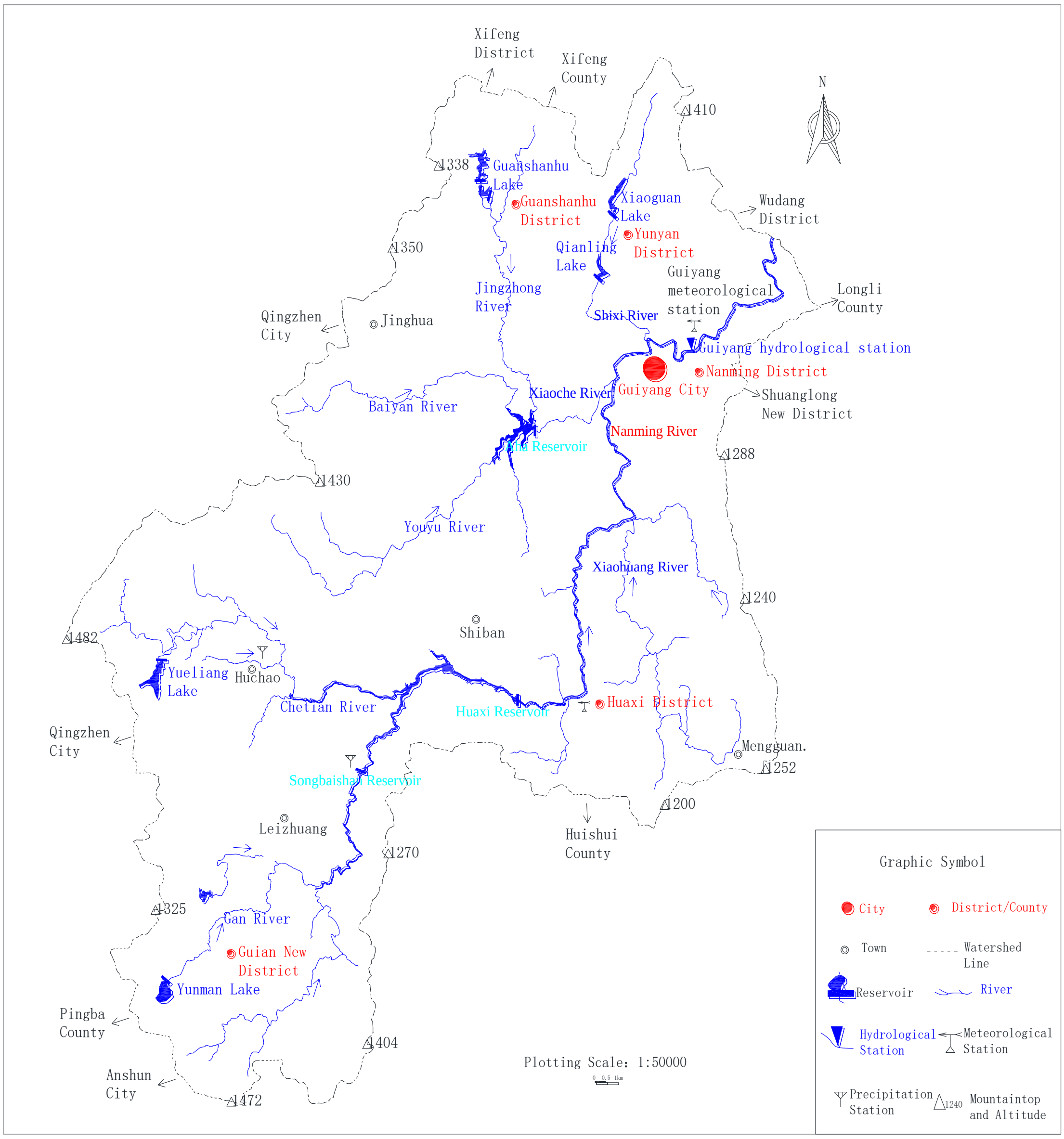


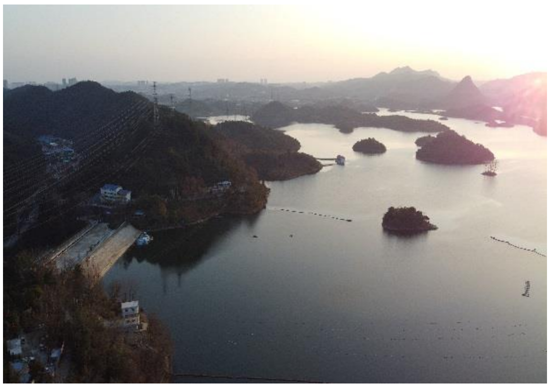
Figure 18 The sketch map of the Naming River Catchment. Yunfei Qi drew the figure and adopted information from (Guiyang City Government., 2018)

3.1.3 Development of flood management and SCP in Guiyang

Before the 1980s, the Guiyang City Government (GCG) focused on controlling fluvial floods to protect farmland and urban areas along with the mainstream Nanming River rather than reducing urban surface floods. Thus, the GCG built the traditional GIs, such as Songbaishan, Huaxi, and Aha Reservoirs, on the Nanming River upstream to reduce fluvial floods and provide water supply to the downstream (Figure 19 a, b and c). During 1980~1995, the GCG started to build more GIs in urban areas, such as floodwalls alongside urban reaches of the Nanming River (Figures 19 d, e and f). The floodwalls partially prevented the high flood level due to fluvial discharge (Guizhou Water Resources and Hydropower Institute., 2016b). Since 1995, the GCG has heavily invested in the urban underground drainage system to mitigate urban waterlogging issues (Figures 19 g and h) (Guiyang City Government., 2018).

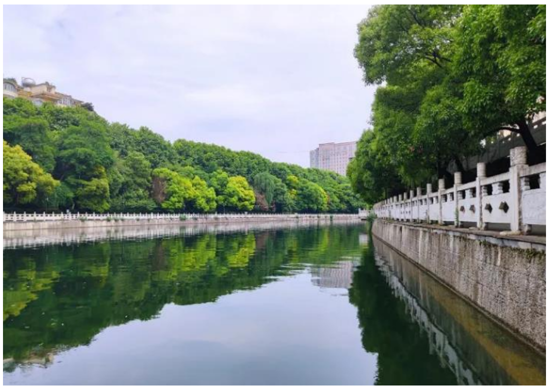
(a)

(b)



(c)

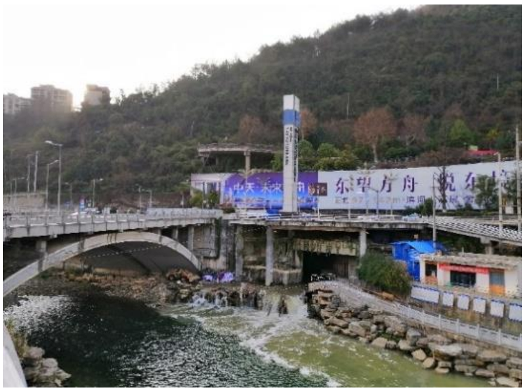
(d)



(e)

(f)

(g)



(h)

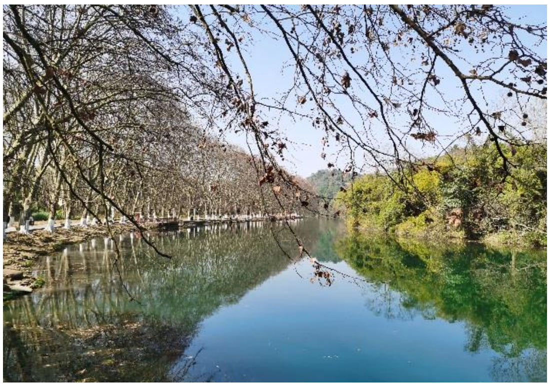
Figure 19 Huaxi Reservoir (a); Songbaishan Reservoir (b); Aha Reservoir (c); A hydraulic pressure dam on the Nanming River (d); Floodwalls on the Nanming River (e and f); Guancheng River Underground Flood Discharge Tunnel (inlet) (g); and Guancheng River Underground Flood Discharge Tunnel (outlet) (h). (Yunfei).

Under the national flood management laws described in Chapter 2.4.1, the Guizhou Provincial Government has also formulated flood management laws and regulations to regulate flood management at the provincial level. For instance, the Guizhou Provincial Government issued the *"Guizhou Provincial Flood Control Regulation"* in 2003 (the latest revised in 2017) (Guizhou Provincial Congress., 2017). In 1997, the Guizhou Provincial Government published the *"Guizhou Provincial River Administration Regulation"* (the latest revised in 2019) (Guizhou Provincial Congress., 2019).

At the municipal level, the Guiyang City Government (GCG) also compiled laws and regulations according to national and provincial policies. In 1996, the GCG published the "*Guiyang Municipal Flood Control Regulation"* (the latest revised in 2006) (Standing Committee of the Guiyang People's Congress., 2006). The GCG also published the *"Guiyang Municipal River Administration Regulation"* in 1997 (the latest revised in 2004) (Standing Committee of the Guiyang People's Congress., 2004). Although these flood management laws and regulations lag behind many aged reservoirs' construction, these legal provisions provide the legal basis of flood management for new-building Grey-Leading Infrastructures (GIs) and SCP infrastructures in Guizhou Province and Guiyang City.

After the China National Government (CNG) initiated the SCP in 2013, the Guizhou Provincial Government and Guiyang City Government (GCG) realised the urgency of transforming Urban Flood Management (UFM) because urban floods occurred more frequently (Guizhou Provincial Government., 2016). Following the national SCP policies and technical standards, the Guizhou Provincial Government published *"Guizhou Provincial Technical Sponge City Guidelines"* in December 2015. In August 2016, the Guizhou Provincial Government proposed the *"13th Five-Year Plan for Sponge City Construction Development of Guizhou Province"* to encourage cities of Guizhou Province to implement SCP. In June 2017, the Guizhou Provincial Government issued the *"Notice on Accelerating Sponge City Implementation for Guizhou"* to accelerate SCP implementation in Guizhou Province (Guizhou Provincial Government., 2017b).

At the municipal level, the Guiyang City Government (GCG) proposed the "*Sponge City Special Plan of Guiyang Central Urban Areas (2016~2030)" and "Sponge City Construction Plan of Guiyang Central Urban Areas (2019~2025)"* to guide SCP implementation (Guiyang City Government., 2016a). According to *"Sponge City Construction Plan of Guiyang Central Urban Areas (2019~2025)",* GCG planned to construct more SCP infrastructures in Guiyang. During the pilot SCP stage, the GCG finished contracting 38 sponge communities, 31 sponge roads, 34 sponge parks, and 14 sponge rivers before 2018. (Guiyang City Government., 2019). During the initial stage of the SCP, the GCG built SCP infrastructures supported by governmental funding. For example, the GCG constructed Huaxi Wetland Park, Guanshan Lake Park, Yueshan Lake Park, and Dongling Park (Figure 20). Indeed, these parks are Guiyang's current *"sponge name cards*" (Guizhou Water Resources and Hydropower Institute., 2018).

(a) (b)

(c) (d)

Figure 20 Huaxi Wetland Park (a); Guanshan Lake Park (b); Yueshan Lake Park (c); and Dongling Park (d). (Yunfei Qi).

However, these SCP infrastructures are still at a small scale compared to the holistic city areas of 380 km^2. The SCP in Guiyang has some constraints, primarily that the flood standard of SCP measures only reaches or is under a one-in-30-year rain return period (Guiyang City Government., 2019). These SCP projects are fragmented and not designed to mitigate fluvial floods (Guizhou Water Resources and Hydropower Institute., 2016b). The GCG also does not sufficiently recognise the importance of social stakeholders' participation (e.g., experts, engineers, developers, and residents). In addition, the GCG has not yet taken the SCP postassessment for Guiyang. Thus, no official evidence exists of whether or how much these SCP practices reduce urban flood risks. Generally, the primary flood management strategy of the Nanming River is the *"integration of water storage and drainage via GIs and SCP"* (Guiyang Municipal Government, 2015b). Table 9 describes the development of flood management in Guiyang.

Table 9 The development of flood management in Guiyang (Guizhou Water Resources and Hydropower Institute., 2018)

Elements	Time				
	Before the 1950s	**1950 ~ 1980**	**1980 ~ 1995**	**1995 ~ 2010**	**2010 ~ current**
Flood management strategy	There were a few large-sized water projects.	The government began to build reservoirs on urban upstream reaches.	The government began to build floodwalls and levees on urban upstream reaches.	The urban drainage system has been gradually improved. However, technical standards are still relatively low (one-in-1 to one-in-5-year rain return period).	The local government has started implementing ecological flood management (e.g. SCP).
Measures options	No flood management strategy.	A Fluvial-source strategy focusing on controlling fluvial flood source	Measures of this stage concentrated on preventing fluvial flooding in riverside areas.	Enhancing an inner-urban flood strategy aiming to solve urban waterlogging issues	The ecological strategy hopes to improve the landscape and flood management.
Investment	Limit government investment support	Government investment from the GCG			Exploring the Public-Private-Partnerships (PPP) investment model
Integration with urban spatial planning	-	-	-	It piloted merging flood management into urban spatial planning.	Integrating flood control plans with urban master plans
Climate change consideration	-	-	The government started to consider local characteristics.		The government has realised the significance of climate change.
Social participation	The government led all projects.			The GCG led most projects.	The government understands the significance of stakeholder engagement but still leads most projects.
Flood warning system	-	-	-	The government set up simple flood warning systems based on meteorological forecasts, but it was difficult to realise the real-time disaster warning.	Explore online flood warning systems with big data technology.
Emergency management	There is no emergency rescue management system.			Each department carries out different rescue work independently. For instance, the Fire Department is in charge of emergency firefighting, while the Water Department is responsible for flood emergencies.	The CNG initially established the Emergency Management Department.

3.2 Selected interview methods

The research interview is a well-established and effective method to collect first-hand data. The interview is widely used in fieldwork as a qualitative approach to gather preliminary data before an in-depth survey. There are a variety of interview methods, including Structured Interview (SI), Unstructured Interview (UI), Semi-Structured Interview (SSI), and Focus Groups (FGs) (Edwards and Holland, 2013, Bjørnholt and Farstad, 2012). Researchers widely use these methods in social science (Qu and Dumay, 2011). Different interview methods suit different arenas of study, cultural backgrounds and various types of information (Galletta and Cross., 2013). Collecting data requires planning, preparation, talking, intensive listening, and noting. Even when the interviewer and interviewee have the same language and cultural background, the real meanings of answers can be biased by misleading or misunderstanding. The interview method is the art of questioning and interpreting answers. This research chose the Semi-Structured Interview (SSI) and Focus Groups (FGs) to collect data. This chapter explains why this research chose these two interview methods.

Structured Interview (SI)

The degree of interview structure is the classic way to clarify the interview method. The SI is also called a Standardised Interview. SI must prepare guidelines and questions in advance, and the interviewers give the same questions to interviewees (Galletta and Cross., 2013). The primary aim of SI is to minimise the interviewer's bias and find the objective reality (Catherine et al., 2019). However, the SI is based on the assumption of truth talkers. The SI may lose the main advantage of an interview. That is, it cannot capture the flexible and deep detail of information.

Unstructured Interview (UI)

On the other hand, the UI interview seems informal. This interview method makes interviewees feel relaxed to share more stories (Catherine et al., 2019). The purpose of an unstructured interview is not to ask questions on a prepared list but to feel the deep natural perspectives of interviewees. Because more engagement provides a better opportunity for the interviewers to build trust with interviewees, the collected data are more likely close to the profound reality (Galletta and Cross., 2013). However, personal relationships, characters, social powers and authorities can influence the answers (Qu and Dumay, 2011). For example, it is difficult for less professional and powerful interviewers to obtain sensitive and profound information from professionals and government officials. Meanwhile, the UI requires interviewers to have solid professional experience, listening and talking skills, and high emotional intelligence.

Semi-Structured Interview (SSI) (used in this research)

Because SSI has the advantages of SI and UI, SSI is more prevalent in the research world. The SSI requires flexible interview guidelines, from relatively loose to highly scripted (Galletta and Cross., 2013). SSI is not aimless talks, which is the same as the SI. Although the interviewers need to prepare an interview guide in advance, it allows participants to talk about the topics they feel are essential. More importantly, the SSI can reveal the hidden aspects of human and organisational behaviour. It is usually a convenient and effective way to collect interview data (Catherine et al., 2019). It also requires skilled interviewers to modify the style to evoke profound answers from interviewees. It also allows respondents to answer questions their way (Nicholas et al.). The flexibility is close to UI if researchers want to understand how respondents perceive the questions. The SSI produces situated understanding that depends on personal relationships, characters, social powers and authorities.

Focus Groups (FGs) (used in this research)

In FGs, the interviewers host several people in a flexible and exploratory discussion that emphasises interaction between all participants rather than only between the interviewers and interviewees. The advantages of FGs are convenience and time-saving (Nicholas et al.). Because the interviewer acts as a moderator in FGs, there are fewer biases from the interviewers than in individual interviews (Catherine et al., 2019). However, the FGs are unsuitable for topics that people are reluctant to discuss and share with others or for which the interviewees' roles are sensitive.

In summary, SSI and FGs can be used for various studies. They are reasonably informal, flexible, and more easily obtain profound information. This research involved government officials, professionals, and residents. Thus, the SSI can evoke sensitive interviewees to participate and answer questions. In addition, when interviewing ordinary residents, the FGs improve interview efficiency. The SSI and FGs are more sustainable with this research, and this research selected these two methodologies.

3.3 Data collection

UNNC Research Ethics Panel fully approved this research, in January 2021, before the research conduction (Please ref Appendix 2 Ethics Approval Form). Appendix 3 shows the basic question guide or list prepared before each interview.

The Focus Groups (FGs) and Semi-Structured Interviews (SSIs) are more than just regular chats. Researchers must formulate questions, recruit participants, select appropriate interview sites, translate records, and transcribe data (Nicholas et al.). The Focus Groups (FGs) and Semi-Structured Interviews (SSIs) in this research involved residents, officials, scholars, planners, engineers, real estate developers, etc. Because the interviewees' knowledge, experience, and professional fields are very different, not all of them understand flood management's basic concepts or principles. Therefore, the interviewers would illustrate SCMF and its related contents before conducting formal interviews to promote the targeting and effectiveness in communication between interviewers and interviewees. Figures 21 (a), (b), (c), and (d) represent NFM measures in catchments. Figures 21 (e), (f), (g), (h), and (i) are typical SCP measures. Figures 21 (j), (k), and (l) belong to GIs.


(a)


(b)


(c)


(d)

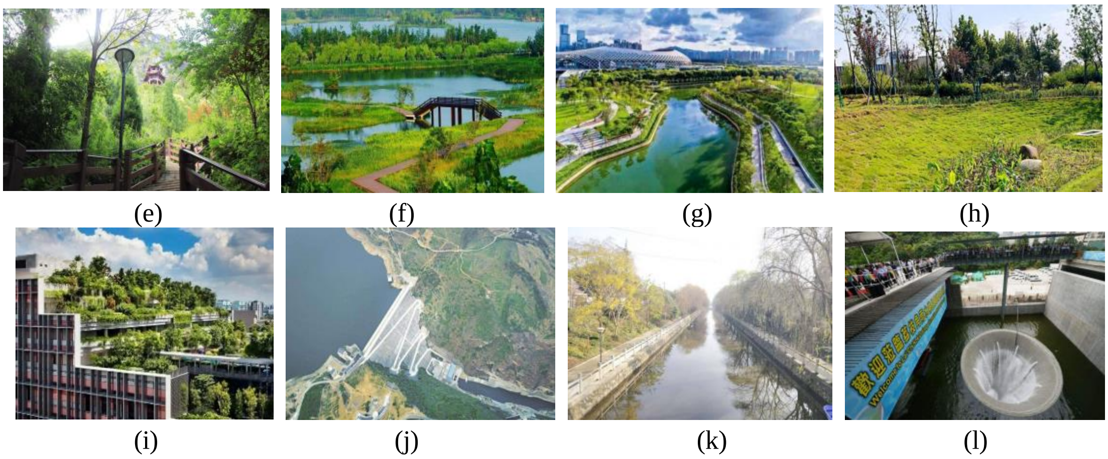


Figure 21 NFM: Woodland creation (a); Leaky wooden dam (b); Natural pond (c); Natural floodplain (d); SCP: Forest park (e); Wetland park (f); Riverfront park (g); Rain garden (h); Green roof; GIs: Concrete dam (j); Floodwall (k); Flood drainage tunnel (l). Yunfei Qi collected and sorted out the figures from http://www.mwr.gov.cn/ and https://www.gov.uk/.

This research generally followed six steps in interviews (Table 10). The first step was to identify interviewees. The second and third steps were analyzing media information and official documents to understand catchment conditions and historical flood events. The secondary data analysis could be a triangulation for the subsequent interview results. In step four, this research classified respondents; and assigned them to various FGs and SSIs. Then, the interviewers explained the basic principles of SCMF to the selected interviewees before conducting interviews. In step five, the researchers worked on recording, translating, coding, and analysing interview data. In the last step, the interview results reflected challenges and opportunities for improving Catchment Flood Management (CFM) under the proposed SCMF.

Table 10 Interview steps, points, and aims

No.	Steps	Points	Aims
1	Selection of interviewers	The interviewers should have professional knowledge to gain the participants' trust.	Ensure the interviewees have experience in SCP, water conservancy, construction and other industries.
2	Media data collection and analysis	This research identified relevant published or open-access media information, literature, and government report to validate the interview results of SSIs and FGs.	Cross-verify the follow-up interview results.
3	Data collection from the governmental reports		
4	Choice of interviewees	The FGs invited 30 residents and landowners along the river and waterlogged areas.	Verify the impact of local flood disasters; Understand residents' preferences for different projects.
		The SSIs invited 32 representative professional Interviewees in Guiyang.	Understand the current situation of NFM, SCP and GIs and the possibility of developing SCMP through interviews with professionals.
5	Principle explanation, record interviews, translation, code	Translation and making coding patterns	Record the critical information related to the research and use it as the primary data for subsequent analysis.
6	Obtaining research conclusions and providing suggestions	Post-data analyses and reflections	Look for opportunities and steps to promote the SCMP pilot in Guiyang.

The FGs is a group interview where interviewers invite targeted participants to exchange thoughts in group activities and meetings. Because the characteristics of FGs are more like an idea exchange talk meeting, researchers do not necessarily invite too many interviewees (Galletta and Cross., 2013). This research targeted 30 interviewees living at the riverside or in waterlogging areas as the non-professional category to collect perspectives. SSIs can help researchers collect critical information from professional and authoritative interviewees via open person-to-person communications (Catherine et al., 2019). Meanwhile, this research invited 32 experienced and representative officials, scholars, engineers, planners, and housing developers in the professional category. The author is a senior water conservancy engineer in Guiyang. Thus, many experienced interviewees know the author. It is easier to establish a trusting relationship between interviewers and interviewees. Based on the working experience and knowledge background, this research selected participators in SSIs (Table 11).

China has the world's highest technical and practical infrastructure design and construction capacity. Therefore, this study mainly focuses social aspect rather than the engineering aspect. Many interview questions (in Table 10 Aims) are more about non-structural elements in SCMF. If SCMF can take the lead in making breakthroughs in the non-structural part, SCMF may have the opportunity to pilot in Guiyang.

UNNC Research Ethics Panel fully approved this research, in January 2021, before the research conduction (Please ref Appendix 2 Ethics Approval Form). Appendix 3 shows the question guide or list prepared before each interview. Because of the impact of COVID-19, most interviewers used the telephone, WeChat and QQ to interview the interviewees. The interview ways did not reduce the interviews' effectiveness but also improve efficiency. Each interview took about 25 to 35 minutes. In this research, most respondents like the forms of communication. They were willing to give insightful and honest opinions. Most of the time, researchers and interviewees talked in Mandarin. After the interviews, the researchers translated the interview data into English for code with NVivo. All interviewees had agreed to this research before each talk. All respondents were anonymous. After this research, the researcher will delete all interview-related data according to the requirements of moral approval to protect personal privacy. In addition, all data from reports were legal and authoritative. Most governmental information referenced by this research was on official websites. This research gave them clear referring indications.

Table 11 The basic information of interviewees and coding patterns

Type	Occupation	Interviewee Background	Responsibility	Participate ID	Title/Position	Age
Non-professional interviewees	Residents	\	\	ID (R 1 ~ 5)	\	18 ~ 30
				ID (R 6 ~ 10)	\	30 ~ 40
				ID (R 11 ~ 15)	\	40 ~ 50
				ID (R 16 ~ 20)	\	50 ~ 60
				ID (R 21 ~ 25)	\	60 ~ 70
				ID (R 26 ~ 30)	\	70 ~ 75
Professional interviewees	Officials	Guiyang Municipal Government	overall management	ID (P 1)	Secretary	43
				ID (P 2)		40
		Guiyang Water Resources Bureau	Managing public affairs related to the department	ID (P 3)	Bureau Head	47
				ID (P 4)	Chief Engineer	53
		Guiyang Housing and Urban-Rural Development Bureau		ID (P 5)	Deputy Bureau Head	43
				ID (P 6)	Deputy Chief Engineer	51
		Guiyang Ecology and Environment Bureau		ID (P 7)	Bureau Head	49
				ID (P 8)	Chief Engineer	43
		Guiyang Natural Resources Bureau		ID (P 9)	Deputy Bureau Head	44
				ID (P 10)	Chief Engineer	49
		Guiyang Development and Reform Commission		ID (P 11)	Bureau Head	46
				ID (P 12)	Deputy Chief Engineer	54
		Guiyang Finance Bureau		ID (P 13)	Deputy Bureau Head	46
				ID (P 14)	Chief Engineer	39

Type	Occupation	Interviewee Background	Responsibility	Participate ID	Title/Position	Age
	Academics	Hydraulic Professor	Academic research	ID (P 15)	Professor	43
		Hydrological Professor		ID (P 16)		44
		Urban Planning Professor		ID (P 17)	Associate Professor	46
		Architecture Professor		ID (P 18)		40
		Landscape Professor		ID (P 19)	Professor	59
	Planners	Urban Architectural Planner	Making relevant plans	ID (P 20)	Senior Engineer	53
		Urban Road Planner		ID (P 21)		59
		Urban Landscape Planner		ID (P 22)		37
		Water Conservancy Planner		ID (P 23)		33
		Water Resource Planner		ID (P 24)		40
	Engineers	Urban Planning Engineer	Engineering design and consultation	ID (P 25)	Senior Engineer	54
		Project Consulting Engineer		ID (P 26)		57
		Construction Engineer		ID (P 27)		34
		Environmental Engineer		ID (P 28)		31
		Project Cost Engineer		ID (P 29)		36
	Housing developers	Architectural Engineering	Investing in the development of commercial or residential areas	ID (P 30)	General Manager	46
		Architectural Engineering		ID (P 31)	Deputy Manager	41
		Architectural Engineering		ID (P 32)	Department Manager	36

Chapter 4. SCP implementation in Guiyang

4.1 Current Guiyang SCP planning and typical design

4.1.1 The main principles, contents and objectives of Guiyang SCP Planning

There were two published SCP plans in Guiyang, *"Sponge City Special Plan of Guiyang Central Urban Areas (2016~2030)"* and *"Sponge City Construction Plan of Guiyang Central Urban Areas (2019~2025)",* which will be further mentioned in Chapter 4.1.1. This research calls these two plans jointly as *Guiyang Municipal SCP Plans in this research*. The *Guiyang Municipal SCP Plans* have two main contents. The first part is SCP construction planning, which defines the plans' scope, main tasks and objectives according to the top SCP plans, urban master plans, and special plans. Considering the current development of Guiyang, *Guiyang Municipal SCP Plans* attempt to optimise the SCP zones and SCP facilities' layout to develop phased implementational suggestions. The second part elaborates on typical SCP infrastructure designs of Guiyang, such as a sponge community, sponge road, sponge park, and sponge river, to guide more SCP projects further. The interviewee ID (P1), an official in GCG (Guiyang City Government), described the main contents of *Guiyang Municipal SCP Plans* as follows:

"It is an honour that the CNG supported Guiyang as one of the pilot sponge cities. Following the national and provincial SCP requirements, standards, and planning, the GCG invited top planning companies to compile the Guiyang Municipal SCP Plans to push the SCP implementation. The SCP is a systematic work, which requires the planning comprehensively includes urban planning, building and landscape designs, environmental protection, water supply and flood management contents." ID (P1)

In the Urban Flood Management (UFM) aspect, the GCG hopes the *Guiyang Municipal SCP Plans* can transform traditional Urban Flood Management (UFM) from traditional Grey Leading Infrastructures (GIs) flood management to dispersive ecological flood management. Interviewee ID (P2), an official in GCG, specifically stated the core principles of *Guiyang Municipal SCP Plans* as follows:

"The Guiyang Municipal SCP Plans reduce urban surface flood risks by strengthening rainwater infiltration, retention, storage, purification, and reuse in urban areas. The planning emphasises building SCP infrastructures and *using natural urban mountains, rivers, forests, fields and lakes to restore the natural circulation of urban water bodies."* ID (P2)

The *Guiyang Municipal SCP Plans* cover the central urban area of Guiyang, with a total area of 1230 km^2 (East from Xiao Bi Town, Yong Le Town, Dong Feng Town; West to Zhu Chang Town, Jin Hua Town, Jiu An Town, Shi Ban Town; South from DangWu Town, Meng Guan Town; North to Mai Jia Town, Sha Wen Town, Du La Town). Considering Guiyang's catchment conditions and water discharge areas, the *Guiyang Municipal SCP Plans* divide Guiyang's central urban area into twenty-one sponge zones (Figure 22). Except for four sponge zones out of the Nanming River Catchment, the Nanming River Catchment includes the last seventeen sponge zones.

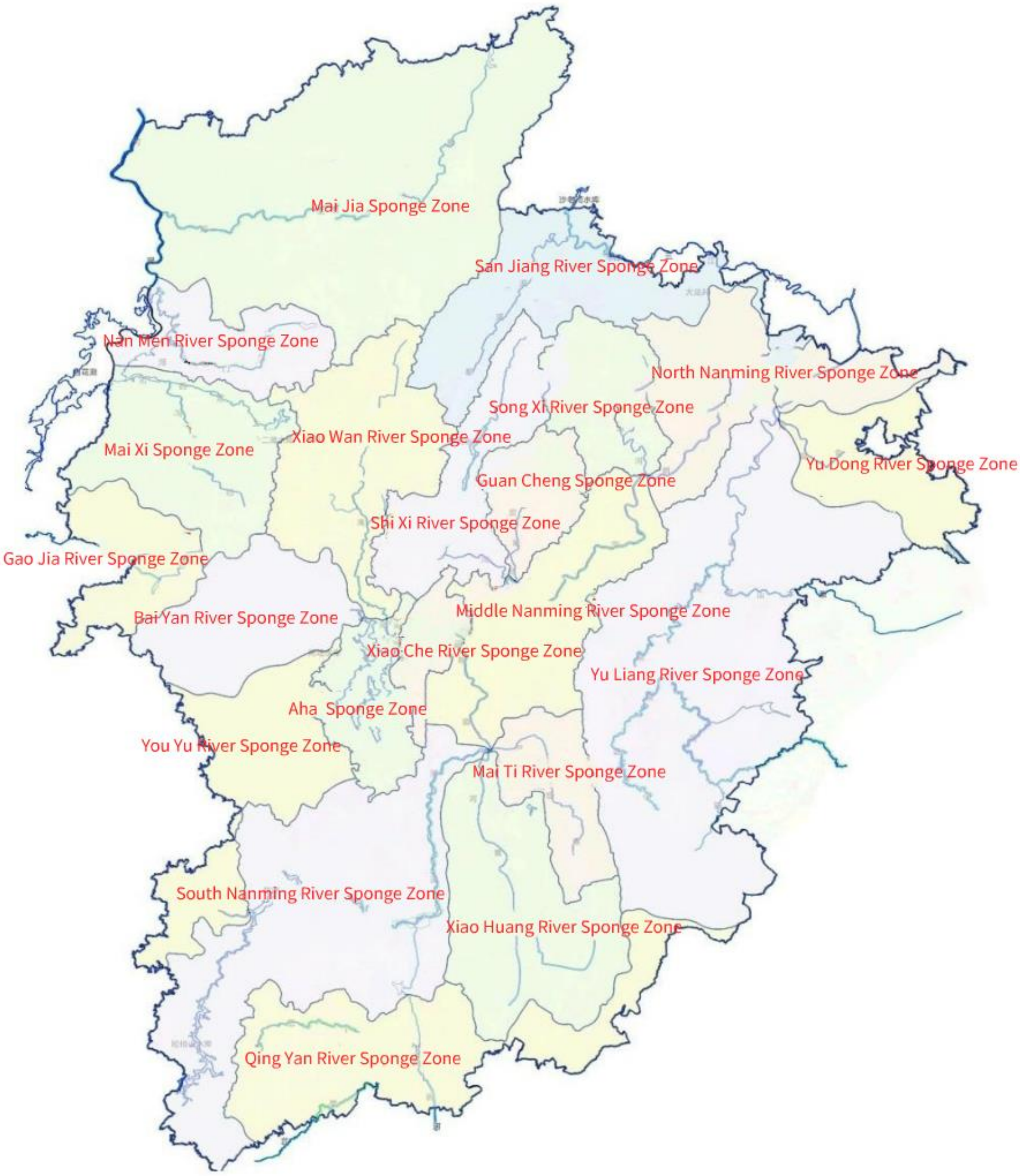


Figure 22 The twenty-one sponge zones in Guiyang (Guiyang City Government., 2019)

The overall objective of *Guiyang Municipal SCP Plans* is to build Guiyang into an "ecological sponge", "mountain sponge", and "green sponge" with the characteristics of karst landforms in southern China. Following *"A* Guidance *about Promoting SCP Construction"* issued by the General Office of the State Council, *Guiyang Municipal SCP Plans* have three planning periods, including the short-term (from 2018 to 2020), medium-term (from 2020 to 2025) and long-term (from 2025 to 2030).

The short-term objective is to build a demonstration city of *"an ecological civilisational sponge city"* combined with *the thousand*-gardens *city programme*, environment management, urban waterlogging management, community retrofit and construction, and urban road construction. In the first planning term, *Guiyang Municipal SCP Plans* vigorously promoted demonstrational sponge communities, roads, parks, and rivers to achieve the planning target of a 75% annual rainfall volume capture ratio in more than 20% of built-up urban areas. The medium-term (2020-2025) is to intensively push SCP in urban construction, operational, and management aspects. By 2025, the planning target requires a 75% annual rainfall volume capture ratio in over 30% of constructed urban areas, and the SCP will have overall effectiveness before 2025. The long-term (2025-2030) target is that 80% of built urban areas can absorb and reuse 75% of the local rainwater (Guiyang City Government., 2016b).

The *Guiyang Municipal SCP Plans* provide critical indexes for 2020 and 2025 in Guiyang's SCP development (Table 12). The *Guiyang Municipal SCP Plans* determine each sponge zone's annual rainfall volume capture ratio (i.e., the most crucial index) according to the various land-use conditions. The annual rainfall volume capture ratio in the *Guiyang Municipal SCP Plans* in 2020 and 2025 is up to 75.3% (more than 75%), which meets the *National SCP Technical Guidelines and Guizhou Provincial SCP Plan*. Based on the index requirements in *Guiyang Municipal SCP Plans,* urban and building designers can select specific SCP infrastructures for each sponge zone.

Table 12 Key index of Guiyang Municipal SCP Plans (Guiyang City Government., 2019)

Objective	No.	Index	2020	2025
Improving water ecology	1	Volume capture ratio of annual rainfall	≥75%	≥75%
	2	The standard area of sponge city	≥20%	≥30%
	3	The proportion of ecological river shoreline	≥30%	≥35%
	4	The proportion of water coverage	≥3%	≥3.5%
	5	Urban vegetation coverage	≥45%	≥45%
	6	UHIE	effective mitigation	
	7	Treatment rate of urban sewage water	≥85%	≥90%
Improving water environment	8	Urban water bodies' quality	IV	
	9	The pollution control of urban surface runoff	TSS reduction rate: 60% COD reduction rate: 30%	effective control
	10	The discharge water standard of treatment	IV	
Moderate utilisation of water resources	11	Sewage water reuse rate	≥20%	≥25%
	12	Rainwater reuse rate	7.67 million m^3	14.13 million m^3
	13	Water reuse rate	≥2%	≥3%
	14	The leakage rate of the urban pipe network	≤13%	
Ensuring water safety	15	The water quality of the drinking water source	100%	100%
	16	The standard rate of source water	≥99%	100%
	17	Waterlogging standard	one-in-30 ~ 50-year rain-return period	
Improving governing	18	The management of SCP planning and construction	Guiyang Municipal SCP Plans require these documents	
	19	The design and protection of urban blue and green lines		
	20	The technical standard for SCP		
	21	The investment mechanism for SCP		

Objective	No.	Index	2020	2025
	22	The postassessment mechanism for SCP	to be published	
	23	The industrialisation of SCP	before 2020.	
Display degree	24	The connecting and large-scale demonstration rate of SCP	≥20%	≥30%

4.1.2 Typical SCP design in Guiyang

The SCP implementation is systematic work. The typical designs in *Guiyang Municipal SCP Plans* can guide urban and building designers in SCP design. Interviewee ID (P17), a professor from a university, talked about the typical SCP designs in *Guiyang Municipal SCP Plans* as follows:

"SCP implementation involves many industries and specialities. For example, the SCP building design work is unlike traditional designs but may involve urban planning, structure, landscape, environment, drainage design and funding knowledge. Traditional civil designers need time to improve their skills. Thus, Guiyang Municipal SCP Plans combine problem-oriented case designs, such as sponge communities, roads, parks, and rivers, to guide designers to adapt SCP principles quickly." ID (P17)

Guiyang Municipal SCP Plans illustrate the Rui Da Jia Yuan, Qing Long Avenue, Huaxi Lake Park, and Ma-Ti River design cases. Chapter 4.1.2 will critically introduce these typical SCP infrastructures in Guiyang.

Typical SCP community design (Rui Da Jia Yuan Sponge Community)

The SCP residential and commercial building designs mainly mitigate nonpoint source pollution and waterlogging risks. It must also comprehensively consider building safety, functionality, and landscape to improve residents' quality (Randall et al., 2019). The Rui Da Jia Yuan is a typical sponge community in Guiyang. This typical sponge community prioritises using green roofs, sunken green spaces, grass ditches, permeable pavement, and underground stormwater tanks as SCP facilities according to the community and surrounding conditions. Interviewee ID (P26), an architectural engineer from a housing developer, introduced Rui Da Jia Yuan as follows:

"Building structural safety is the bottom line in engineering. Meanwhile, the designers must focus on building functions so residents can live conveniently. Beyond that, we designed environmental-friendly landscapes in this sponge community, such as green roofs, sunken green spaces, grass ditches, and ponds. We also designed permeable pavements and underground rainwater tanks based on landscape design. The layout of these SCP facilities ensures more rainwater collection to reduce the surface runoff discharge from the community. Although these SCP facilities increased the total cost of community construction, they increased the housing sales."

The volume capture ratio of the annual rainfall in the community's overall layout must meet the requirement in *Guiyang Municipal SCP Plans* (the annual rainfall volume capture ratio is more than 75%). Figure 23 illustrates the sponge community layout in Rui Da Jia Yuan. Rui Da Jia Yuan has a total area of 25,000 m^2. According to the different underlying surfaces, including green roofs, sunken green spaces, grass ditches, and ponds, the volumetric runoff coefficient of the community is 0.41 (less than 0.65), which meets the requirement of the sponge zone (Figure 23). The 21.9 mm of rainfall corresponds to 75% of the annual rainfall volume capture ratio (Table 12). Therefore, the minimum required water storage volume is 224.6 m^3 (25,000 m^2×21.9 mm×10^{-3}×0.41=224.6 m^3). According to the design calculation, all sponge facilities in this community have a total water storage capability of 711 m^3 (more than 224.6 m^3), meeting the minimum water storage volume requirement. Figure 24 illustrates the water flow in this sponge community.

Figure 23 The layout of SCP facilities in a typical SCP community (Rui Da Jia Yuan)

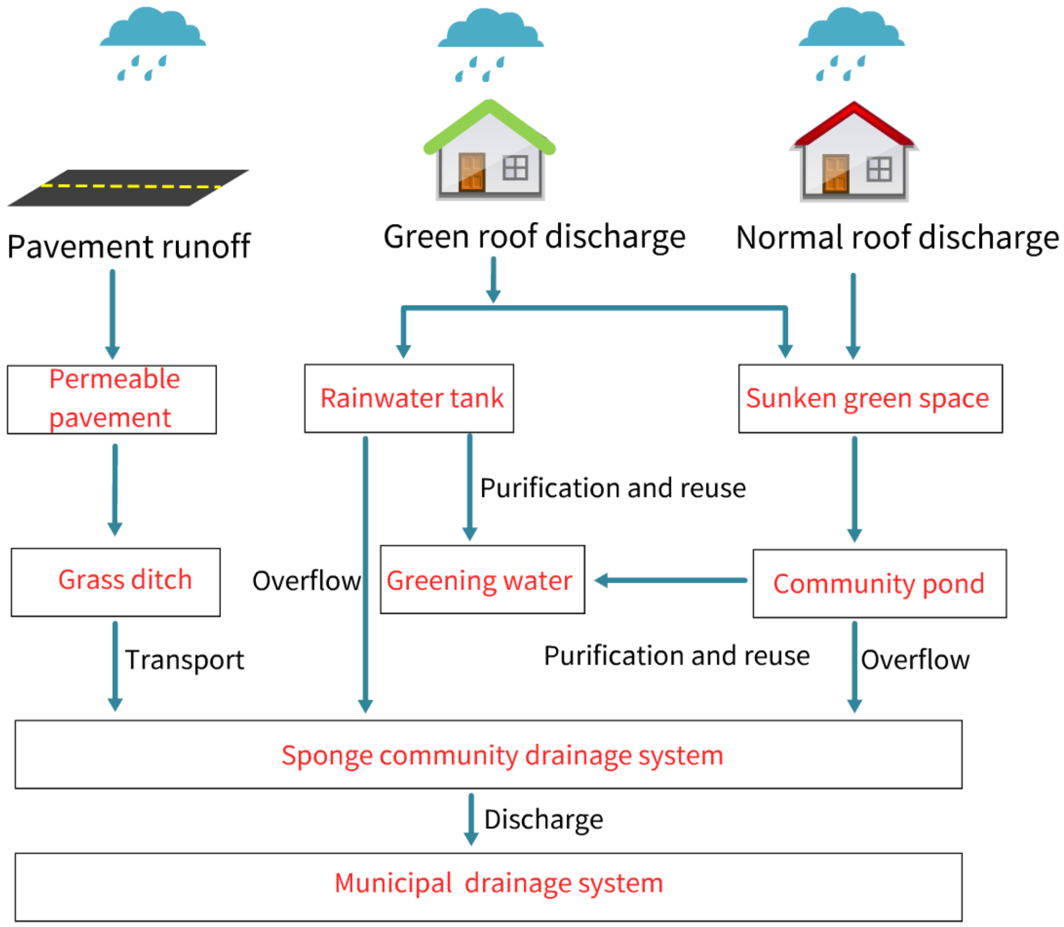


Figure 24 Runoff path in a typical SCP community (Rui Da Jia Yuan)

(1) Green roof

National SCP Technical Guidelines suggest that green roofs are suitable for flat roofs with enough roof load and waterproof conditions or pitched roofs with a slope ≤15°. The Rui Da Jia Yuan used green roof designs for roofs with slopes ≤10%°. When the roof slope is between 10% ~ 30%, the designers set anti-slip structures to realise green roofs. The roof drainage slope is more than 2% when the soil is ≥ 300 mm thick. It also has stormwater collection systems to collect the outflows. The water drainage pipes and electricity cables are above the waterproof layer to avoid water damage to the buildings and cables. The roof rainwater buckets are the external drainage type. The soil does not cover rainwater hoppers, and there are surrounding grids protecting rainwater hoppers (Figure 25a).

(2) Sunken green space

The community squares and sidewalks without large car load capacity adopt permeable pavement. The sunken green space is 150 mm ~ 200 mm lower than the surrounding ground. The surrounding surface water can dispersedly flow into the sunken green space. The designers choose drought-waterlogging-resistant vegetation plants in the green space. The spacing of the overflow rainwater outlets is 25 m ~ 50 m, and they are 100 mm~ 150 mm higher than the green space.

(3) Grass ditch

The community increases the use of natural surface drainage forms such as grass ditches to infiltrate, detain, and transport surface runoff and reduce rainwater pipe use. There is flood risk when the longitudinal slope is less than 0.3%. Therefore, the range of the longitudinal slope is 0.3% ~ 0.4%. The plant ditch's ideal vegetation height is between 100 and 200 mm. The gravel porosity should be 35% ~ 45%, and the effective grain size should be more than 80 %. When rainwater infiltration is considered, a geotextile should be set up (the infiltration coefficient should be greater than 5×10^{-6} m/s). In contrast, a seepage prevention canal should be set up when infiltration is not considered (Figure 25b).

(4) Permeable pavement

Asphalt waterproof roll material is applied to cement pavement construction joints. The material and construction requirements of permeable brick should meet the *"Environmental Road Surface of Urban Roads"*. The structural layer of permeable pavement within the scope of the fire lane should meet the load requirements. Meanwhile, sand-free and large-hole concrete (base porosity ≥15% set transverse 10 mm width shrinkage joints. The permeable brick hole clearance rate should reach 20 %. The permeable bricks are laid with 2 mm ~ 3 mm seams filled with medium-coarse sand (Figure 25c).

(5) Rainwater tanks

This SCP community sets purification and filtration treatment devices on the nearby roof to collect the initial rainwater. The made-up or concrete tanks can be used as underground tanks to collect initial surface water in the community. The purified water can be reused for irrigating green land and road washing (Figure 25d).

(a)

(b)

(c)

(d)

Figure 25 Green buildings with green roofs and balconies (a) and (b); a rain garden with underground water tanks (c); a permeable sidewalk with tree pools and green spaces on both sides (d) (Yunfei Qi).

Typical SCP road design (Qing Long Sponge Avenue)

Qing Long Sponge Avenue is located in the Baiyun District of Guiyang (Figure 26). It is a 40-meter-wide and 4.6 km-long urban main road connecting Dong Lin Si Road and Qing Long North Avenue. Qing Long Avenue belongs to the Mai Jia River drainage area, and the target volume capture ratio of annual rainfall is 65%. Interviewee ID (P26), an urban planning engineer, introduced this sponge road as follows:

"The permeable brick or asphalt concrete made the sidewalk surface on both sides of the road. The designers designed the central separation belt into a sunken green belt. The sunken green belt has tree pools to collect and detain the surface water from sidewalks and the road. Meanwhile, overflow outlets are in the sunken green belt at an interval of 120 m. The designers also set grass ditches and bio-retention zones outside the sidewalks where the condition is suitable (there are enough spaces on both sides, and the road section is not close to other buildings and infrastructures.)." ID (P26)

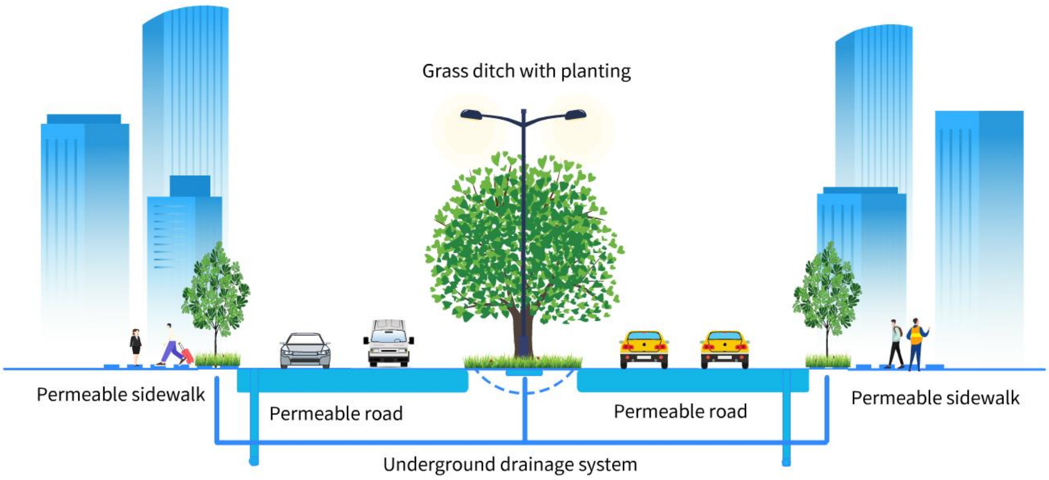


Figure 26 The cutaway view of Qinglong Avenue

Qing Long Sponge Avenue has a total area of 184,000 m^2. According to the areas of different underlying surfaces, including sunken green belts, tree pools, bio-retention areas, and grass ditches (Figures 27 a, b, c, and d), the volumetric runoff coefficient of Qing Long Avenue is 0.63 (less than 0.7). The volumetric runoff coefficient meets the requirement of the sponge zone. The annual rainfall volume capture ratio is 65%, corresponding to 15.8 mm of rainfall (Table 12). The minimum water storage volume requirement is 1,831.5 m^3 (184,000 $m^2 \times 15.8$ mm$\times 10^{-3} \times 0.63 = 1,831.5$ m^3). According to the sponge facilities' areas and water storage capability, this sponge road can hold 7,360m^3 of rainwater (more than 1,831.5m^3), meeting the minimum requirement. Figure 28 illustrates the water flow in this sponge road.

(a) (b)

(c) (d)

Figure 27 Tree pools (a) and (b); bio-retention areas (c); a grass ditch and in a sunken green belt (d). (Yunfei Qi).

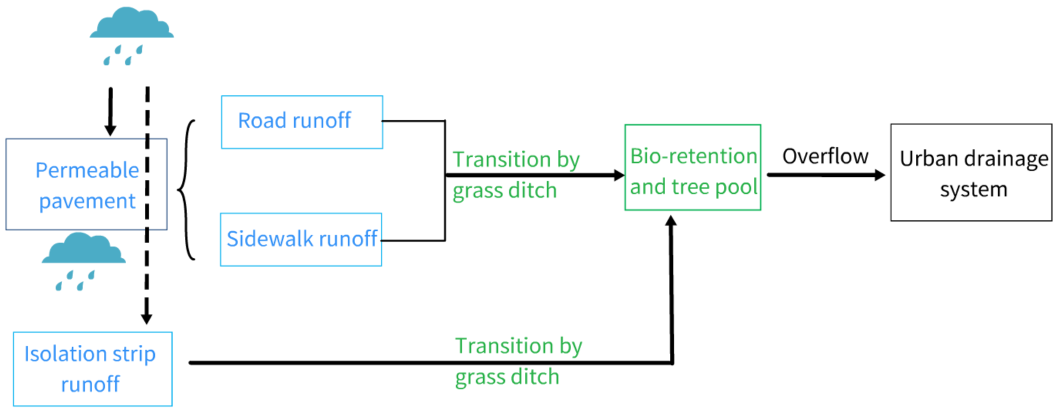


Figure 28 The water pathway of the Qing Long Sponge Avenue

Typical SCP park design (Huaxi Lake Sponge Park)

Huaxi Lake Sponge Park is located west of the Huaxi District of Guiyang, with a planning area of 882,200 m^2 (Figure 29). Huaxi Lake Sponge Park belongs to the drainage zone of the southern section of the Nanming River. The project site has an irregular north-south belt layout. The overall terrain of the site is relatively variable, showing the vertical characteristics of high in the west, low in the east, high in the north, and low in the south. The current site is mainly farmland, fishponds and village dwellings. The ecological environment is relatively good. The existing village dwellings in the southeast of the site are aged. Interviewee ID (P21), an urban planner, introduced this sponge park supplementally as follows:

"The developer plans to remove the aged village buildings via compensation and resettlement. Meanwhile, designers renovated these farmlands into reserved landscapes. In this sponge park, the designers mainly set up SCP facilities, such as sunken green spaces, rain gardens, permeable pavement, and rainwater wetlands, in open spaces." ID (P21)

Figure 29 The design sketch of Huaxi Lake

The designers recommend that SCP parks' planting configuration follow the local plants' priority characteristics. Fully combined with the current situation of the site and the suitable habitat conditions of plants gives play to the comprehensive functions of plants to reduce runoff, reduce the flow rate, purify water and form landscape. Different planting areas have different flooding conditions. The planting space is divided into the water storage area, the buffer area and the edge area, and the flooding risks decrease successively. Plant selection considers the flooding and drought resistance of different plants. Plants with developed roots and strong purification capacity are selected according to different zoning and landscape requirements. Plants that are beautiful, resistant to flooding and have strong decontamination ability are chosen. Different types of aquatic plants are matched according to water depth to ensure the landscape effect. When designing the energy dissipation facilities of the water inlet and overflow outlet, the designers use landscape measures to optimise the impact.

Huaxi Lake Sponge Park has a total area of 882,200 m^2. According to the areas of different underlying surfaces, including rain gardens, sunken green areas, permeable pavement, and rainwater wetlands (Figure 30), the volumetric runoff coefficient of Huaxi Lake Sponge Park is 0.18 (< 0.2), which meets the requirement of sponge zone (Figure 22). The annual rainfall volume capture ratio is 90%, corresponding to 43.4 mm of rainfall (Table 12). The minimum water storage volume requirement is 6,891.7 m^3 ($882{,}200\ m^2 \times 43.4\ mm \times 10^{-3} \times 0.18 = 6{,}891.7\ m^3$). According to different sponge facilities' areas and water storage capabilities, this sponge park can hold 7,085 m^3 of rainwater (more than 6,891.7 m^3), meeting the minimum requirement. Figure 31 illustrates the water flow in this sponge park.

Figure 30 The layout of Huaxi Lake (Yunfei Qi)

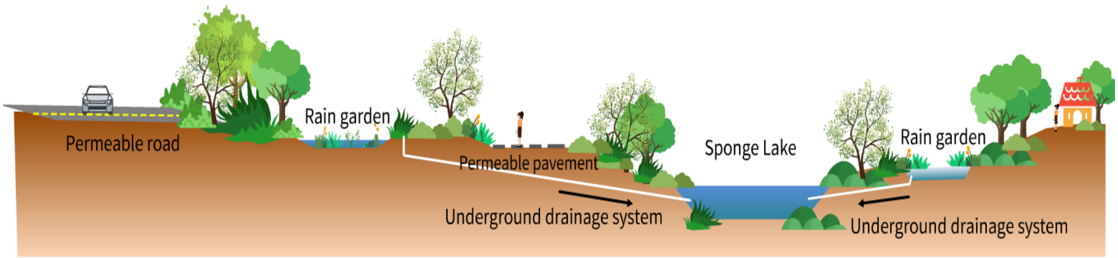


Figure 31 The cutaway view of Huaxi Lake (Yunfei Qi)

Typical SCP river design (Ma-Ti Sponge River)

The Ma-Ti Sponge River originates near Niulang Guan, Huaxi District, and flows 12.4 km into the Nanming River, with a catchment area of 26.1 km^2 and a high river slope. The terrain of the Mati River Catchment is high in the south and low in the north. The Mati-River belongs to the Mati-River SCP zone. The flood control standard is a one-in-100-year rain return period. Many housings occupied parts of the river surface, affecting the river's flood flow pathway. Most of the current river banks are grey, which decreases their ecological restoration ability and flood resilience. Meanwhile, these river banks are lined with farmlands, houses and even abandoned factories. The existing vegetation species are small and lack biodiversity. Interviewee ID (P3), an official from the Guiyang Water Resources Bureau, introduced this sponge river as follows:

"The designers plan to use ecological banks, wetland parks, riverside green spaces and sunken green spaces in this sponge river. We also built the NiuLang Guan Sewage Treatment with a planned scale of 20,000 tons/day to treat the urban sewage water into replenishment water for the Ma-Ti River. The treatment standard is IV. In addition, there are six underground rainwater tanks along the Ma-Ti River, each with a water storage volume of 5000 m^3. The rainwater collection systems entirely use the underground municipal rainwater discharge on both sides of the river, which will not occupy the open land area. The municipal rainwater discharge pipes collect the rainwater and then transfer it into underground rainwater tanks for storage and filtration. After that, the rainwater is discharged into the river as river replenishment water, municipal road pouring and greening water."

The Ma-Ti Sponge River has a total area of 393,000 m^2. According to the areas of different underlying surfaces, including riverside ecological revetments, wetland parks, and sunken green spaces, the volumetric runoff coefficient of the Ma-Ti Sponge River is 0.6 (less than 1.0), which meets the requirement of sponge zone. The annual rainfall volume capture ratio is 70% (Figure 22), corresponding to 18.4 mm of rainfall (Table 12). The minimum water storage volume requirement is 4,338.7 m^3 (393,000 $m^2 \times 18.4$ mm$\times 10^{-3} \times 0.6 = 4{,}338.7$ m^3). According to sponge facilities' areas and water storage capability, this sponge river can hold 171,100 m^3 of rainwater (more than 4,338.7 m^3), meeting the minimum requirement.

The sponge river bank is a kind of ecological shoreline with prominent environmental characteristics that can strengthen the original ecological conditions. It mainly reflects the natural wild interests by integrating the urban and water environment relationships. It enhances the natural landscapes of natural rivers. The ecological shoreline also needs to meet the residents' leisure requirements. A series of hydrophilic spaces can be designed on both sides of the river, such as hydrophilic platforms, steps, and walking paths. Due to the limitation of the building areas, the sponge river section crossing vital infrastructures or next to buildings should remain grey. Figure 32 illustrates the water flow in this sponge river.

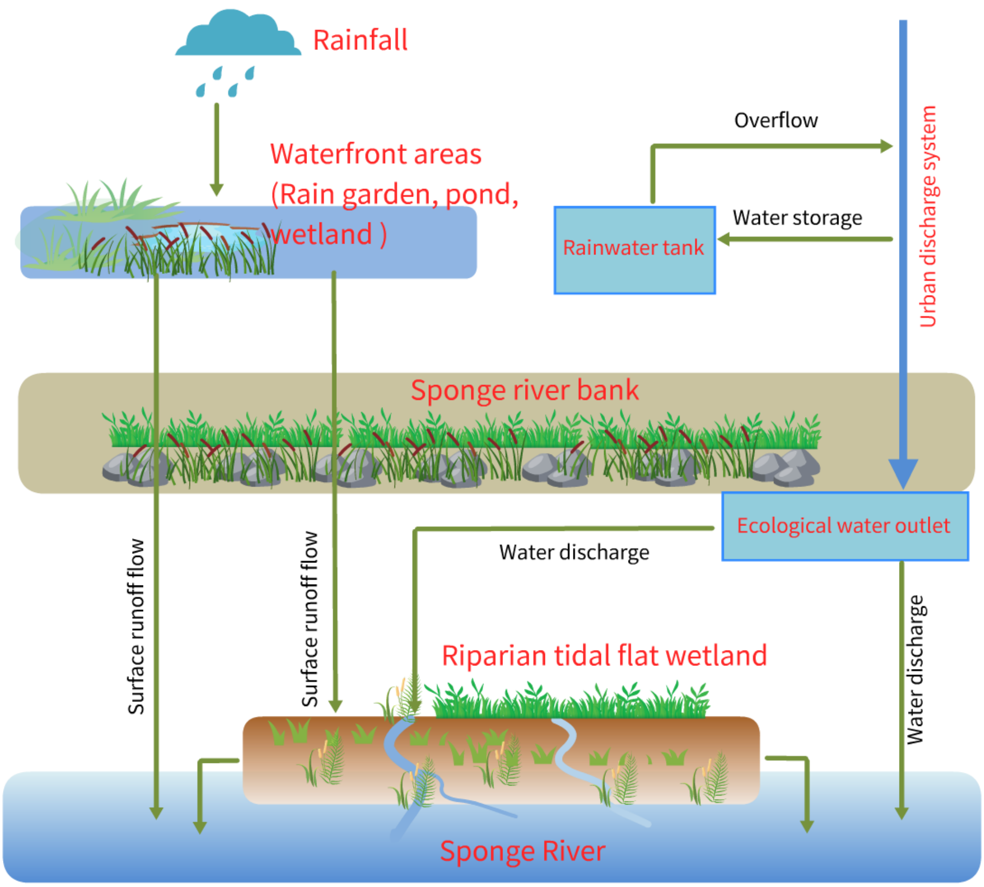


Figure 32 Water pathway of the Ma-Ti Sponge River (Yunfei Qi)

4.2 Public awareness of SCP in Guiyang

Based on the results and analysis of the historical floods in Guiyang, this research interviewed public perspectives on SCP in Chapter 4.2. This Chapter explored residents' attitudes toward various natural hazards, awareness channels, self-protection awareness in emergency events, participation opportunities, and willingness to take project costs.

The results show that 45% of FGs respondents considered floods significant disasters in Guiyang. Most middle-aged and elderly residents had vivid and clear memories of the 1996 flood. Landslide disasters ranked second; 25% of FGs respondents said Guiyang is the most prone to landslides. Fire hazard ranked third. Most people had seen buildings or forest fires at some point, but only 15% saw it as a significant hazard. Earthquake hazard ranked fourth. Only 10% of respondents said earthquakes were their most scary event. Guiyang is not in an earthquake zone. People learned from the media that earthquake damage is terrible, but they never experienced an earthquake themselves.

Approximately 68% of FGs respondents considered flooding events an infrequent occurrence. In addition, 32% of participants believed that flood risk had increased over the past decade due to climate change, building construction and urbanisation. The interviewee, ID (P6), said the reasons were as follows:

"Most people living along the Nanming River have experienced flooding events. Other residents on higher ground are aware of the flood problem, mainly through the media. People living by the river are more afraid of floods than those living on high ground. Where people live affects their awareness level of natural disasters. In addition, knowledge, education, and work experience also affect people's awareness." ID (P6)

When the researchers asked how they heard about the term *"sponge city"*, approximately 75% of respondents said they saw (or heard) it on WeChat, Weibo, or Tiktok. However, most respondents had never actively obtained SCP information or knowledge. Regarding the relationship between urban planning and flooding, over 80% of residents believed that the SCP's principal effect was to improve urban environments and landscapes. They failed to recognise that SCP principles and constructed SCP infrastructures could help flood management. Interviewee ID (R11) gave a typical response as follows:

"I understand the importance of flood defences. Dams and flood walls are, of course, built to control flooding and keep residents safe. As for green roofs, rain gardens and wetland parks, I think they provide a place for us to relax. I do not understand how these green spaces can store rainwater to reduce flood risk." ID (P11)

When asked how they would handle an emergency during supposed flood events, 90% of respondents chose to dial the emergency call number (119, 110, or 120). In addition, the residents' self-rescue preparedness was also very low. When asked if they had a plan for self-protection, understood escape routes, or had prepared emergency water, food, and medicine, 86% of participants said it was unnecessary. An official, ID (P2), gave the following reasons:

"The CNG has relatively strong and centralized authority to carry out emergency rescue work. Government-led rescue missions also have many successful, inspiring, and touching stories. The media widely publicized these success stories and heroes. Most residents believe the government is willing and able to protect them from natural disasters. Because of these widely spread government emergency management cases, more people have gradually lost their sense of self-protection." ID (P2)

At the same time, this research found that the government did not take the initiative to identify residents' perspectives and demands in the SCP planning and design stages. Most public participation channels were official websites, but official online participation could not effectively collect residents' deep and true perspectives to solve local problems. Almost all FGs residents never participated in any online engagement activities. Interviewee ID (R9) directly expressed the response as follows:

"When the local government is planning or constructing SCP projects, plan or project review teams usually consist of experts and officials but usually do not include residents. Planning or design teams often ignore the real feelings of local people. The project review process does not respect residents' views, which is not conducive to raising public awareness of the SCP and improving the SCP projects. The government should solicit more residents' opinions through various channels such as community surveys, schooling, brochures, and invitations to visit projects." ID (R9)

The SCP infrastructure also requires operation and maintenance. Various local SCP features diversify this SCP work. The SCP operation and maintenance can be as simple as removing garbage from urban water bodies or as complex as maintaining ecological bio-diversity in rain gardens. The FGs identified another challenge in maintaining SCP facilities on private land and buildings. Residents ID (R13) and ID (R22) responded to this issue as follows:

"Public SCP infrastructures, such as wetland parks, are generally well maintained. The maintenance of public SCP infrastructures belongs a clear responsibility of the local government. However, on private land, housing, apartments, and communities, SCP facilities are difficult to maintain. The residents of our community share a common view that they do not have a mandatory responsibility to maintain SCP facilities on our property." ID (R13)

"We are grateful to the government that public SCP infrastructure is usually well maintained. On the other hand, people's awareness needs more improvement. For example, many residents have sealed the green balcony to obtain a lot of indoor space; the community transformed the public green space into an impervious parking lot. It is necessary to enhance residents' awareness of maintaining private SCP facilities." ID (R22) (Figure 33)

(a) (b) (c)

Figure 33 Operation and maintenance status of SCP facilities in public (a) and private (b and c) buildings. (Yunfei Qi).

4.3 Historical flood events in the Nanming River Catchment

Before specifically understanding the flood performance of GIs and SCP in Guiyang, Chapter 4.3 recorded the interview results about historical flood events of the last 30 years in the Nanming River prior to cross-validating these interview results with government reports.

According to the "*13th Five-Year Special Plan for Water Supply and Discharge of Guiyang"*, the history of major flood events that caused massive losses are associated with the Nanming River (Guiyang City Government., 2015a). Historical flood events can reflect the flood characteristics of cities. Respondents from riverside communities ID (R11), ID (R16), and ID (R21) recalled Guiyang's flood history as follows:

"There were three huge flood events in Guiyang that left a deep impression on me. The three floods occurred in the summers of 1991, 1996 and 2014, respectively. The 1991 floods mainly damaged a lot of farmland because the city was not growing so large in the early 1990s." ID (R11)

*"The 1996 flood was the worst I have ever experienced, and the several days of heavy rain caused the flood. The water of the Nanming River overflowed its banks flooding many landmarks, including Fountain Square and JiaXiu Pavilion (*Figure 34 a*). Many shops, schools, companies, and government offices closed for nearly a week. This flood event damaged many public facilities and houses. The whole city had no traffic, water supply or electricity before the flood receded. The 1996 flood seriously affected our normal life."* ID (R16)

"2014 was also a rainy year. Unlike previous major floods, the local government issued advance flood warnings through cellphone text messages. As a result, the 2014 flood event did not affect our lives much. Although this flood inundated many urban roads and parking lots, our city weathered the flood event well that year." ID (R21) (Figure 34 b, c and d)

(a)

(b)

(c) (d)

Figure 34 The high water at the river reaches JiaXiu Pavilion in the Nanming River (a), the submerged Er Qi Street (b), the submerged Qing Yun Road (c), and the submerged Meng Guan (d). (Yunfei Qi).

A government report, *"Comprehensive Water Resources Planning for Guiyang"*, verified interviews with residents. On July 1 1991, the intensive rainfall caused direct economic losses of 90 million yuan; the major losses were along the Nanming River mainstream. This flood event was a two-peak flood caused by one-in-50-year return period rainfall of 112.0 mm in 24 hours. The total economic losses were 90 million yuan, and agriculture suffered 70% (58 million yuan) of the losses due to the underdeveloped urban economy and small urban areas in the early 1990s. (Guizhou Water Resources and Hydropower Institute., 2016c).

On 2 July 1996, another intensive rainfall with a one-in-100-year return period caused the most destructive flood in Guiyang's recorded history. This single-peak fluvial flood caused by heavy rainfall of 197.3 mm in 24 hours affected more than 929,022 people, resulting in 89 deaths, 1,124 injuries and 8,671 housing collapses. The direct economic loss caused by this flood event was 3.26 billion yuan, accounting for 11.8% of Guiyang's GDP in 1996. Considering the yearly inflation ratio, the losses would reach over 12 billion yuan. The magnitude of the flooding loss left everyone reeling (Guizhou Water Resources and Hydropower Institute., 2016a).

The rain intensity on July 16 2014, was 201.7 mm in 24 hours. Although the rainfall intensity was slightly higher than on July 2 1996, the flooding on July 16 2014, had minor consequences. The water level of the Nanming River is controlled below the top of the city's flood walls. This flood event inundated parts of the underground parking lots, while most public facilities were safe to open. Moreover, the flood caused no casualties (Statistics Bureau of Guiyang., 2019) (Table 13).

These historical flood data are from the Guiyang Meteorological Station and Guiyang Hydrology Station. These two stations recorded precipitation and water flow as official data. The two authoritative stations are located in downtown Guiyang, beside the Nanming River. The Guiyang Meteorological Station uses typical rainfall measurement methods, including rain buckets and automatic rain gauges. Guiyang Hydrology Station uses mechanical water gauges and doppler radar flow detectors to monitor and record the river and flood peak flow. The official, scholar, and engineer, ID (P4), ID (P27), and ID (P15) explained why the three flood losses differ:

“Heavy seasonal rainfall is the main cause of the floods in the Nanming River Catchment. The rainfall intensity, frequency, and length in the catchment are the main reasons for historical flood disasters in Guiyang.” ID (P4)

"Guiyang has two kinds of floods. The first is river (fluvial) flooding, which can cause great damage to riverside areas. The other is small-scale urban surface flooding (known as waterlogging in China), caused by old and relatively low design standards of urban drainage systems. Waterlogging can affect low-lying communities, roads and parking lots. However, current urban drainage design standards only prevent flood events up to a one-in-5-year return period for rainfall. River and urban surface flooding usually co-occur in a single intensive rainfall event. For example, the floods of 1991, 1996 and 2014." ID (P27)

"Compared with urban surface floods, river floods have caused more damage to Guiyang. Therefore, the focus should be on catchment-scale flood management to the co-reduce river and urban flooding. In this regard, the constructed reservoirs in the upper Nanming River have played key roles in river flood control." ID (P15)

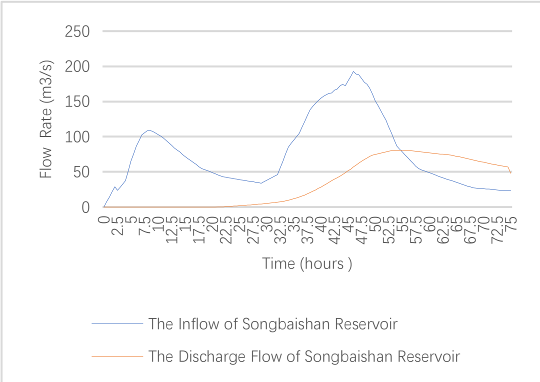
Table 13 Guiyang’s historic flooding and damage data. Yunfei Qi adopted data from (Guizhou Provincial Statistics Bureau., 2019).

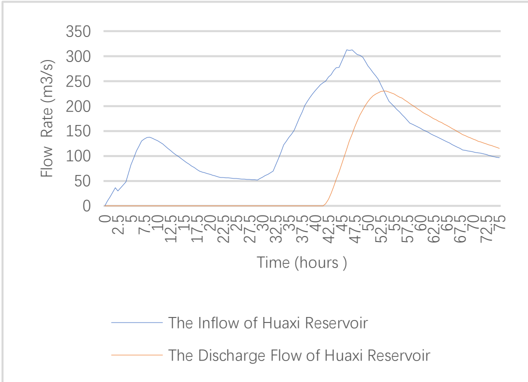
Rank	Date	Flooding Type	Flood Peak Flow (m^3/s)	Rainfall in 24 Hours (mm)	Economic Losses (Billion Yuan)	Flooded Houses or Infrastructures	Casualties
1	2 Jul 1996	Fluvial and urban surface flood	888	197.3	3.26	8,671 housing collapsed	89
2	1 Jul 1991	Fluvial and urban surface flood	569	112.0	0.09	no statistics	/
3	16 Jul 2014	Fluvial and urban surface flood	868	201.7	0.495	Many streets and parking lots	/

4.4 The flood management performance of the GIs and SCP

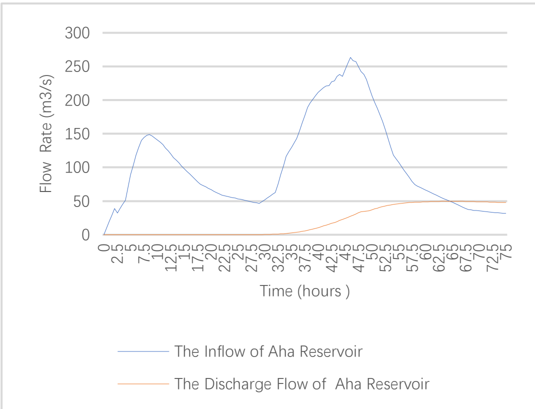
Chapter 4.4 will analyse the flood management performance of GIs and SCP from professional and non-professional groups’ perspectives. Meanwhile, this research will find governmental reports to validate these interview results. The flooding events in the Nanming River are usually fluvial flash floods, given Guiyang's mountainous slope in the catchment. A governmental report, *“Flood Control Planning for Guiyang”,* described the performance of Grey-Leading Infrastructures (GIs) in flood management as follows:

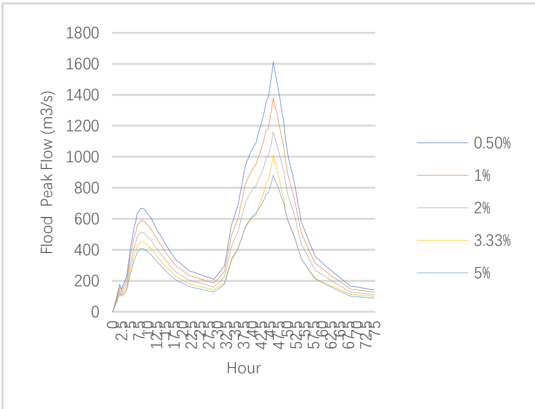
The Songbaishan Reservoir, Huaxi Reservoir, and Aha Reservoir mentioned in Chapter 3 have a total water storage capacity of 147 million m^3. The catchment area above the three reservoirs covers 505 km^2, accounting for 67% of the areas above Guiyang Hydrology Station (753 km^2) (Guiyang City Government., 2015b). These upstream reservoirs can reduce the flood peak flow of the Nanming River by 20~50% in one-in-100-year return period precipitations (the flood standard of Guiyang city is one-in-100-year) (Figures 35 a, b, and c) (Guizhou Water Resources and Hydropower Institute., 2016b). For instance, the peak flow of the Guiyang Hydrology Station on July 16 2014, was 868 m^3/s. If the GCG had not built the three reservoirs in the upstream catchment, the peak discharge flood at the measuring point of Guiyang Hydrology Station would have reached 1,380 m^3/s on that day (Guizhou Water Resources and Hydropower Institute., 2016c) (Figure 35 d). If this were to happen, the entire urban area along the Nanming River would be flooded entirely (Guiyang City Government., 2018).





(a) (b)





(c) (d)

Figure 35 The natural inflow and discharge flow regulated by the Songbaishan Reservoir (a); The natural inflow and discharge flow regulated by the Huaxi Reservoir (b); The natural inflow and discharge flow regulated by the Aha Reservoir (c); The flood flow at the Guiyang Hydrological Station without reservoir regulation (d). Yunfei Qi collected data (Guizhou Water Resources and Hydropower Institute., 2016b) and drew the figures.

During 1980~1995, the GCG started to design and build floodwalls along the Nanming River mainstream (Guizhou Water Resources and Hydropower Institute., 2016b). The constructed 12 km^2 of floodwalls on the mainstream restrain fluvial flood water discharged from upstream reservoirs in the river channels to partially reduce the risks of the flood water overflowing into urban areas by enhancing fluvial flood control capability at urban reaches (Guizhou Water Resources and Hydropower Institute., 2016a).

Since 1995, the GCG has heavily invested in the urban underground drainage system to prevent urban surface floods (waterlogging issues) (Guiyang City Government., 2018). However, the technical standard only required the urban drainage system to meet a one-in-5-year rain return period. In reality, debris and trunks from the surrounding hills and garbage from the nearby communities could easily block the urban drainage system, reducing the flood discharge ability (Guiyang City Government., 2016a). That means the urban drainage system can only deal with one-in-1-year and partly one-in-5-year rain intensity. Consequently, urban surface flood risks increased because the drainage system could not cope with the rapid urbanisation process (Guizhou Provincial Government., 2017a).

Therefore, the GCG implemented the centralised urban underground flood tunnels to mitigate the urban waterlogging issue (Guizhou Water Resources and Hydropower Institute., 2018). Chapter 3 has mentioned a representative engineering project, the Guancheng River Underground Flood Discharge Tunnel. In 1998, the GCG built this urban underground flood tunnel in the Fountain Place area connecting to the downstream Nanming River (Guiyang City Government., 2015b). This 3.3 km-long underground flood tunnel can increase 100 m^3/s to the CBD's water discharging ability directly into urban downstream reaches, significantly reducing the waterlogging risk of the Fountain Place area. The strengthened GIs is the major reason the flood on July 16 2014 had fewer consequences than on July 2 1996. (Guizhou Water Resources and Hydropower Institute., 2016b). Some water academics and engineers, ID (P16), ID (P26), and No. ID (P29) mentioned the contributions of these GIs:

"Guiyang successfully withstood the flood event on July 16 2014, thanks to underground flood discharge tunnels built in the late 1990s. After constructing Guancheng River Underground Flood Discharge Tunne, Fountain Place has hardly suffered great losses from serious waterlogging events." ID (P16)

"According to our engineering experience over the years, the most effective flood control measures in the Nanming River are still to use reservoirs to store water in the city's upper reaches and use tunnels to discharge flood in the urban areas." ID (P26)

"However, GIs are costly. For instance, the floodwall costs more than 200 million yuan per kilometre. In addition, there is no urban space for large-scale GIs in the Nanming River. It is impossible to build a new reservoir on the Nanming River. It is necessary to rethink the traditional GIs flood management." ID (P29)

Regarding the flood performance of SCP, the GCG has not yet taken an official SCP postassessment for the pilot stage. There was no direct official evidence of whether these SCP practices could successfully reduce urban flood risks. Thus, the interview method combined with governmental document analysis is suitable for identifying the flood management performance of SCP in Guiyang. According to *Guiyang Municipal SCP Plans,* GCG planned to construct more SCP infrastructures. By adopting SCP measures, the *GCG* has built 38 sponge communities, 31 sponge roads, 34 sponge parks, and 14 sponge rivers up to 2020. (Guiyang City Government., 2019). However, these SCP infrastructures are still at a small scale compared to the whole city area of 380 km^2. Official ID (P5) and resident No. ID (R17) expressed typical worries about SCP infrastructures in flood management:

"The SCP infrastructure has to some extent improved the city's flood control capacity below one-in-30-year rain return period. However, the completed SCP infrastructure coverage is still very small compared to the city size (380 square kilometres). Even large-scale wetland parks have not shown sufficient flood control capacity as we expected. For instance, Huaxi Wetland Park flooded surrounding streets due to heavy rainfall on July 16 2014." ID (P5)

"When rainfall is not intensive, permeable roads, green gardens, and wetland parks can retain a large part of the initial rainwater. If the rain intensity is too strong or the rainy period is over three days, water will wash out of gardens and wetlands to flood nearby urban areas." ID (R17)

Another governmental report, *"Guiyang Municipal Flood Control Plan"*, gives the reasons. The Guanshan Lake holds only 0.15 million m^3 of water, much less than a medium-sized reservoir (a reservoir has a water storage capacity of more than 10 million m^3). The limited water storage capacity means that even the large SCP infrastructures, such as wetland parks, have a lower capacity to mitigate flood risks (Figures 36 a and b) (Guizhou Water Resources and Hydropower Institute., 2018). In addition, interviewees ID (P28) and ID (P18) mentioned the issues of *urban drainage systems* nearby constructed SCP infrastructures (Figures 36 c and d):

"The current urban drainage systems connecting with SCP infrastructures are ageing. The construction standard of these ageing drainage systems is relatively low. In most current circumstances, it can only drain rainwater under a one-in-one-year rain return period, which is far less than the technically required SCP flood control standard. These urban drainage systems can not meet current urban flood management requirements." ID (P28)

"Branches, household garbage, and soil can easily block urban drainage systems, coupled with the lack of daily maintenance of urban drainage systems, leading to frequent urban waterlogging events." ID (P18)


(a)


(b)

(c) (d)

Figure 36 Che Tian River Wetland Park (a); Yun Man Wetland Park (b); underground water storage tank (c); waterfront path (d). (Yunfei Qi).

"Guiyang Municipal Flood Control Plan" recorded another long historical fluvial flood, which can further verify that SCP has a relatively low ability to mitigate fluvial floods. In the 1950s, the green space rate of the Nanming River Catchment was 95%, and the reservoirs were not constructed then. This damaging flood in 1952 was a one-in-50-year rain return period, which submerged an area of 15 km^2. The flooding area accounts for 10% of the current central urban area (Guizhou Water Resources and Hydropower Institute., 2018). This historical flood event verifies that even if the SCP can restore the green space rate to pre-urbanisation, Guiyang will still suffer severe flood disasters without GIs.

The interviews, governmental reports, and the characteristic curve diagram of flood control in Guiyang prove that the construction of SCP infrastructures on the urban scale is insufficient to deal with flood events, especially under catchment-sized intensive precipitation. Factors affecting the formation of flood disasters in a city include rainfall intensity, rainfall duration, catchment topography, river system discharge capacity, and other natural and uncontrollable factors, as well as constructed SCP infrastructures, the water storage capacity of upstream reservoirs, construction standards and operation conditions of urban drainage pipes, land cover type and other artificial controllable factors. However, it should be noted that a city can not completely develop into sponge areas or unlimitedly invest in GIs. A flood control system for a sponge city at the catchment scale conforming to the systematic and integral natural water ecosystem can maximize the coupling of SCP and GIs measures. Therefore, given the high cost of urban land, natural flood control measures in the urban upstream catchment are a good choice to optimise the effect of SCP and GIs measures. Chapter 5 will try to identify additional challenges of current SCP, and Chapters 6 and 7 will discuss how to develop holistic catchment-friendly flood management.

Chapter 5. SCP challenges of Guiyang

In Guiyang and the Nanming River Catchment context, Chapter 4 used FGs and SSIs to deeply understand the Guiyang SCP plans and related SCP designs, historical local flood events, and the flood management performance of GIs and SCP. To solve the problems encountered by SCP implementation in the proposed Sponge Catchment Management Framework (SCMF) in Chapter 1, Chapter 5 further discussed the Guiyang SCP implementational challenges in governance, planning, technical standards, design, land use, maintenance, and funding.

5.1 Governing challenges in SCP

Governance arrangements are key to long-term policy implementation and management (Ongaro et al., 2018). A country's history and development conditions shape the characteristics of its governance arrangements (Hegger et al., 2014). China's governance framework has five levels: national, provincial, city (or municipal), county (or district), and township governments (Yang et al., 2018). This system of governance is a strict top-down arrangement in which the higher government strictly commands the lower government. For instance, there are five levels of government in this research case: the China National Government (CNG), Guizhou Provincial Government, Guiyang City Government (GCG), Nanming District Government, and Guan Shui Community Office. Governments at all levels manage different departments at that level separately. Several respondents have issued the following characteristics and challenges in SCP governance:

"National, provincial and municipal governments have almost total control over SCP decision-making. For instance, these top-three-level governments control most government funding, land sales, pollution permits, and water right. There are fewer and fewer opportunities for the county or town governments in decision-making. Meanwhile, non-state actors almost cannot participate in political activities." ID (P1)

"Lower levels of government have less power regarding urban planning. In most cases, county and town governments are the just players in implementing these top-down policies. Centralised political systems offer fewer opportunities for county and town governments in policy- and plan-making. The possible downside is that these top-down decisions are too general and are hard to implement with local conditions" ID (P2)

"For instance, the county and town are not required or can not compile SCP plans for their areas. They must obey the uplevel SCP plans without questions. Although this absolute top-down governance can improve the governing efficiency, it may sacrifice the individual county or town's benefits to the top regions." ID (P20)

These summarised interview results pointed out potential governing challenges to the ongoing SCP. 1) Power centralisation: SCP governance is power-centralised. For instance, the NDRC has to approve large infrastructures if a project needs investment or subsidies from CNG. However, the top CNG does not clearly understand all local conditions, such as geography, precipitation, population, and economic development (Yang et al., 2018). 2) Cross-bureau governance: Take Guiyang as an example. Guiyang Development and Reform Commission, Finance Bureau, Housing and Urban-Rural Development Bureau, Water Resources, etc., manage different aspects of SCP. Guiyang has no clear organization to lead and cooperate with different bureaus, which may reduce the efficiency and efficiency of SPC. 3) State-control governance in SCP-related water affairs: The National departments dominate water management in China. The advantage is this state-dominated water management can decrease the water supply price compared to completely marketable goods such as oil, natural gas, coal, and iron. On the other hand, nonstate participants have fewer opportunities to advise or participate in SCP-related water affairs.

5.2 Planning, technical-standard, and designing challenges in SCP

The multiple-department governance issue of SCP, mentioned in Chapter 5.1, also challenges SCP planning. In China, the urban master plan is usually at the highest level in various urban plans. Meanwhile, each department or industry has its special plan. All special plans are subordinated to one urban master plan. Officials ID (P5) and ID (P6) from the Guiyang Housing and Urban-Rural Development Bureau expressed the following:

"SCP is not exclusive to any one department but involves many departments. SCP special planning is on the same level as other industry special planning. The cross-department attribute of SCP has led to constraints from various special plans on SCP planning. Conversely, the SCP itself has difficulty influencing other special plans." ID (P5)

"At the same time, different special plans have the coordination problem. The disharmony within various special plans deeply affected SCP planning. Without a coordinated and systematic SCP plan, it is difficult for SCP to develop in the long run." ID (P6)

Another challenge comes from the SCP technical standards. The *National SCP Technical Guidelines* and *National SCP Assessment Standard* provide a unified national evaluation standard for SCP construction. However, China is a country with a very large territory. These national guidelines are challenging to use in SCP design in all cities (Jia et al., 2017). Architectural design professor ID (P17) believes the SCP standard is too general to apply to particular sponge cities with considerable climate, hydrology and socioeconomic differences.

"The National SCP Technical Guidelines guide engineers in planning and designing SCP projects. However, the national technical standards are too general and vague for all sponge cities. Common indexes (such as greenspace coverage and building ratio) are relatively easy to control. However, technical standards do not sufficiently consider local precipitation, hydrology, geography, demography, economy, history, culture, and heritage conditions. The lack of consideration for specific local conditions in technical standards is a barrier to implementing local-targeting SCP projects." ID (P17)

Chapter 2.4.4 mentioned that the *National SCP Assessment Standard* divides China into five regions (I, II, III, IV, V). The prescribed reduction rate of surface runoff is the same for all cities in one region. For example, Guiyang and Ningbo, Shanghai, Fuzhou and other coastal cities are all in the region (III) (the required surface runoff reduction rate is 75% ~ 85%). However, Guiyang is in an underdeveloped mountainous inland region with a lower population and construction density than other large cities on the east coast. Unlike coastal cities in the region (III), typhoons rarely affected Guiyang. Guiyang faces higher fluvial flooding and waterlogging risks. Therefore, the neglect of local elements in SCP technical standards is an obstacle, and the fewer local standards in specific cities impact the accurate implementation of

SCP. SCP needs to modify the idea that one solution fits all in technical standards. The professor of environmental engineering ID (P18) expressed a similar perspective as follows:

"According to local urban conditions, the local governments take responsibility for regional water issues. However, the implemented SCP lacks localised technical standards even in pilot sponge cities. For example, as a pilot sponge city, Guiyang has had no technical SCP guidelines until now. The GCG only issued the Guiyang Municipal SCP Plans to guide the SCP implementation macroscopically." ID (P18)

In addition, it is vital to constantly revise technical standards to increase flood control standards for urban drainage systems to cope with urban flooding. Other Asian cities, Hong Kong and Singapore have flood protection standards of over one-in-50 years in urban drainage systems (Chan et al., 2018a). Compared with them, Guiyang needs to improve flood control standards of existing urban drainage systems connected to SCP infrastructures (Guizhou Water Resources and Hydropower Institute., 2018).

Most designers are highly focused on the needs of their clients (government or housing developers) regarding SCP plans and designs. The government and developers represent the public and commercial needs, respectively. The designer chose a *"one-way street"* concentrating on public or commercial interests is far from sufficient in SCP. The difficulty lies in fully integrating public SCP designs (roads, drainage systems, dams, banks and wetland parks) into commercial SCP designs (commercial and residential buildings). Interviewee ID (P13) explained the difference as follows:

"At present, architectural design companies are all profit-oriented. Government or real estate developers are customers of these architectural design companies. When the government entrusts architectural design companies to design SCP infrastructures, it is more important to consider that it can bring more public services. However, when real estate developers entrust architectural design companies to design SCP communities, developers will consider saving costs or driving up house prices through SCP landscapes. The purpose of SCP design with public attributes is completely different from that of business behaviour." ID (P13)

The protection of culture and heritage is an example of this aspect. It was a challenge to balance the historic urban character with the design of the modern SCP building. National and local SCP technical guidelines do not explain the dimensions of harmonizing cultural and historical features with SCP planning and designing. For instance, Qingyan Ancient Village locates in the sponge area, South of Guiyang. This urban planning academic interviewee, ID (P17), talks about the difficulties of implementing green roofs in heritage reserves:

"Qingyan Ancient Village is a famous tourist attraction in Guiyang. It is also a cultural relic protection area. In Qingyan Ancient Village and nearby areas, the government strictly protects the angle roof design of ethnic style. But this kind of large angle pitched roof design is difficult to coordinate with the green roof design. The modern green roof concept is difficult to apply to large-angle pitched roofs." ID (P17)

By querying the"Architectural Feature Guideline of Gui'an New District", designers must use the sloping-roof design on single-storey, multi-storey or high-rise buildings in the Qingyan Ancient Village and its surrounding areas. However, green roofs are mainly fit for building tops with slopes of less than 15 angle degrees (Beecham et al., 2019). Figure 37 shows the sloping roofs of Qingyan Ancient Village and the High-Speed Railway Station sloping roof in Gui'an New District. Although these ancient and modern sloping roofs offer harmonious building styles, they sacrifice an opportunity to use green roofs on top of new buildings.

(a) (b)

Figure 37 Sloping roofs in Qingyan Ancient Village (a) and Gui'an High-Speed Railway Station (b). (Yunfei Qi).

5.3 The urban land-use and project maintenance challenges in SCP

Chapter 2.4.2 mentioned that CNG requires local governments to transform at least 20% of urban spaces into sponge areas before 2020, and the rate must reach 80% before 2030 (General Office of the State Council., 2015). Following national requirements, GCG has also set the same objectives to transform 20% of urban areas into sponge areas in 2020. Then the required rate is 25% in 2025 and up to 80% in 2030. Like the annual rainfall volume capture ratio, the sponge cover rate is also rigid as the top-prioritised criterion. In addition, the SCP has set other goals in wastewater treatment, carbon absorption, ecological restoration, reducing the UHIE and developing intelligent cities (Long et al., 2020). The SCP objectives are very encouraging, but that seems ambitious in one timetable, as presented by interviewee ID (P23) below:

"SCP technical guidelines and plans underestimate urban land use challenges. The SCP remains highly dependent on subsidies in the pilot stage. Without subsidies from the central government, Guiyang would not have been able to build more large-scale SCP infrastructures to meet the SCP planning objectives. The challenge of urban land use will increase the uncertainty of Guiyang Municipal SCP Plans." ID (P23)

The ambitious sponge area ratio target is conducive to speeding up the implementation of SCP. However, planning more SCP areas means fewer urban land sales. Urban land sales revenue is the current most important source of fiscal revenue for local governments. Due to the unbalanced economic development of different Chinese cities, the completion of SCP objectives in various cities is uncertain. Interviewee ID (P21) indicated as follows:

"Land use affects the spatial expansion of sponge cities. Because the population continues to move into Guiyang, urban land is becoming increasingly scarce and precious. However, most SCP infrastructures are designed on the urban ground, requiring much urban land.

Unfortunately, Guiyang's location in the mountainous southwest region has limited the development of its manufacturing and service industries. Therefore, Guiyang's industry income tax is relatively low, and the land sales income accounts for over 50% of the fiscal revenue for GCG. The local government still relies heavily on revenue from land sales. Fewer land sales mean less revenue for local governments, which is unacceptable and unsustainable." ID (P21)

In addition, the high cost of demolition in existing built-up cities is an additional massive obstacle to SCP development. The demolition compensation cost is typically high in Chinese cities (Table 14). The demolition cost of Guiyang is relatively cheaper than other developed Chinese cities compared to Guangzhou and Ningbo. However, considering the relatively low local government income, it is still a challenge for GCG to demolish the existing building for new-building SCP infrastructures on a large scale.

Table 14 Land expropriation cost in three Chinese cities that has undertaken the SCP. Yunfei Qi adopted data.

Land types	**Guangzhou (Baiyun) (RMB/666 m^2)**	**Gui'an New Distinct in Guiyang (RMB/666 m^2)**	**Ningbo (Yinzhou) (RMB/666 m^2)**
Rural Residential Land	350,000	74,000	90,000
Industrial Land	300,000	56,900	75,000
Cultivated Land	260,000	35,000	65,000
Other Agricultural Land	220,000	34,020	55,000
	(Guangzhou Municipal Peoples Government, 2017)	(Gui'an new district management committee office, 2017)	(People's government of Yinzhou district, Ningbo city, 2014)

The main buildings of SCP facilities have different uses, and their property owners and socioeconomic attributes are also different. According to the actual situation of Guiyang, the SCP facilities are divided into two categories according to ownership rights. They are public sponge infrastructures and nonpublic sponge facilities, respectively. Public sponge infrastructures refer to local government-owning municipal sponge infrastructures, such as sponge roads, parks, squares, and sponge facilities in public schools, stadiums, hospitals, and nursing homes. The local government is in charge of investing in and constructing these public sponge infrastructures on public land. Nonpublic sponge facilities are invested in and constructed by corresponding private property owners on nonpublic land plots, mainly including the sponge facilities in commercial buildings and residential communities developed by housing developers. Professors ID (P17) and ID (P18) representatively expressed the existing challenges in SCP project maintenance as follows:

"For public SCP facilities funded entirely by the government, such as using the Build-Transfer (BT) model to build public sponge facilities. In the BT mode, construction and

operation are separated (two companies take charge of construction and operation, respectively.). The remaining problems during construction will usually cause interference with project operation and maintenance. A third-party operational company hired by the local government through government authorisation or government service purchase carries out project maintenance. Maintenance funds are from the government's annual budget. Whether the financial budget is sufficient during the operation of the facilities directly affects the operation and maintenance of public sponge facilities." ID (P17)

"For the public SCP facilities in Public-Private Partnership (PPP) construction mode, one project company manages the infrastructure construction and operation. The government need to pay operational fees to private investors in accordance with the project performance, project appraisal, and the PPP contract agreement. Suppose the operating income of the PPP project is not enough to pay for the operation and maintenance costs, and the government can not pay enough operational fees. In that case, the private investors will not be willing to run and maintain the public SCP infrastructures for a long time." ID (P18)

Nonpublic SCP facilities are mainly constructed by housing developers who purchase land use rights according to the land contracts signed with the government. After the SCP facilities completion, the property owners (the building buyers) bear the SCP operation and maintenance cost. Most of the time, building buyers do not directly maintain SCP facilities. Building buyers often contract a property management company to operate and maintain sponge facilities. Indeed, the property management company manages the operation and maintenance of nonpublic sponge facilities. In this mode, the government, housing developers, housing buyers, and property companies entrust the chain relationship. Housing developer ID (P30) expressed the existing challenges in this aspect:

"Property management companies' operation and maintenance of SCP facilities are inconsistent with its goal of pursuing financial profit. For example, according to the SCP design, sunken gardens should retain water, but too much-detained water harms plant survival. Too many SCP facilities in communities mean that property management companies must recruit more professional personnel and equipment to maintain SCP facilities. It will increase the companies' operating costs. Thus, the initiative of the property management company to operate sponge facilities is not high. Meanwhile, there is a lack of feasible and efficient policies to supervise nonpublic sponge facilities. The management of nonpublic sponge facilities is at a higher risk." ID (P30)

5.4 Funding (subsidy) challenges in SCP

After urban land use barriers, the greatest challenge for further implementation of SCP is the funding issue (Zimmermann et al., 2020). According to the *"Notice of Central Funding Supporting Pilot Work of Sponge City" released in 2014, CNG provided* 400 to 600 million yuan for each sponge city pilot city from 2015 to 2018 (MF, 2014). An estimated 160 million to 180 million yuan per square kilometre is required to turn a whole city into an entire sponge. (Xiang et al., 2019). The current government subsidy is far from enough. Interviewee ID (P13) also pointed out that the lack of funds is still the critical problem hindering SCP's continuous development:

"The SCP requires a considerable investment to build. The first phase of pilot SCP is highly dependent on CNG subsidies. Lacking additional government subsidies will limit the SCP promotion. The government and investors must create more win-win investment models to implement more and larger SCP projects." ID (P13)

The NDRC and MF drafted the Public-Private Partnership (PPP) policy on large public infrastructures in the early 2010s (Dai et al., 2017). Although the CNG has promoted the PPP investment model in SCP pilot work since 2016 (Zhang et al., 2019a), the interviewee ID (P14) considered this a minor step rather than an achievement.

"The PPP does not apply to all infrastructure investments and all potential investors. Unlike sewage treatment plants and power stations, wetland parks do not generate steady economic returns for investors. Therefore, investors' willingness to invest in SCP infrastructures is very low. Questions remain about investment policies and the willingness to cooperate between public and private investors. They can not reconcile in most cases." ID (P14)

Moreover, the potential return on investment is different across regions and infrastructures. A classic contradiction is the investment return. Public investors demand maximising public benefits from investments, such as improvements to urban landscapes, ecosystems and flood defences. Instead, private investors focus on the economic benefits (in most cases, at least an 8% return on investment.) (Zhang et al., 2019a). The interviewee from Guiyang Development and Reform Commission, ID (P11), mentioned this contradiction as follows:

"The different requirements of investment return rate make it hard to achieve cooperation between the public and private investors. In Guiyang, GCG has used the PPP investment model to construct several wetland parks, costing over 2 billion RMB in the last ten years. However, public and private investors' project cost and return requirements have not been resolved now." ID (P11)

Although the CNG has constantly improved PPP policy in the last decade, the PPP model is still hard to use in SCP. Public investors are typically state-owned companies, but private companies are usually private-owned small companies. The imbalance of company size and the difference in company attributes make state-owned enterprises unwilling to do business with private enterprises. In recent years, the willingness of private investors to invest in PPP projects has continued to decline. Evidence is that PPP projects decreased by 26 %, and newly constructed PPP projects fell by 62% in 2020 compared to 2019 (Sohu News., 2020).

The total withdrawal of help from the central subsidies is unrealistic in the short term. Therefore, CNG has prolonged the governmental subsidies by issuing the *" Notice on Carrying Out Systematic Whole-Area Demonstration Work of Sponge City Construction" and the " Notice on Carrying Out the Second Batch of Systematic Whole-Area Demonstration Work of Sponge City Construction During the 14th Five-Year Planning Period"*. However, this short-term subsidiary policy worried private investors. The housing developer ID (P31) expressed his concerns as follows:

"As private investors, reasonable financial return is our primary appeal. Since SCP projects do not provide stable cash flow returns, private investors are wary of investing in these projects. There are subsidies from the government now, but they won't last forever. When the

government cancels the subsidy policy, SCP projects will not be attractive to private investors. The future SCP funding policy may become a significant obstacle to scaling up the SCP.” ID (P31)

In General, to solve the problems encountered by SCP implementation in the proposed Sponge Catchment Management Framework (SCMF) in Chapter 1, Chapter 5 discussed the Guiyang SCP implementational challenges in governance, planning, technical standards, design, land use, maintenance, and funding. The first challenge is in governing. National, provincial and municipal governments have almost total control over SCP decision-making. For instance, these top-three-level governments control most government funding, land sales, pollution permits, and water right. There are fewer opportunities for the county and town governments in decision-making. The possible downside is that these top-down decisions are too general to implement with local conditions. The second challenge is in SCP planning, technical-standard, and design. Different special plans have coordination issues. The disharmony within various special plans deeply affected SCP planning. Without a coordinated SCP plan, it is difficult for SCP to develop in the long run. Third, most SCP infrastructures require a lot of urban open land. Land use affects the spatial expansion of sponge cities. Unfortunately, Guiyang's mountainous location has limited manufacturing and service industries. Land sales income accounts for over 50% of the government's fiscal revenue. Fewer land sales mean less revenue for local governments, which is unacceptable and unsustainable. Fourth, the greatest challenge for SCP is the funding. The CNG provided 400 to 600 million yuan for each pilot city from 2015 to 2018. However, it required an estimated 160 million to 180 million yuan per square kilometre to transform a city into an entire sponge. The current government subsidy is far from enough. According to the SCP implementational challenges in Guiyang, Chapter 6 will explore holistic sponge flood management for the Nanming River Catchment.

Chapter 6. Developing an SCMF in Guiyang

The flood events in China's sponge cities mentioned in Chapter 1 drive Chinese policymakers to rethink China's flood management strategy. Small-scale and distributed SCP infrastructures that lack connection with the river catchment lack the overall flood management capacity (Qi et al., 2023). Technically, the SCP facilities are not designed to alleviate large-scale fluvial floods. They mainly retain initial rainwater within an urban community scale (Chan et al., 2018c). Scattered SCP measures, such as green roof buildings, sunken community spaces, and rainwater storage tanks, can not cope with catchment-scale flood discharges caused by intensive rainstorms (Zheng et al., 2022). The current SCP practices mainly mitigate waterlogging risks at a specific-site scale (Jia et al., 2017). In the case of Guiyang, Chapter 4.4 has recorded the relatively low flood management performance of SCP mentioned in the context of Guiyang. Chapter 5 has set forth other challenges in SCP implementation in Guiyang.

It is not new to consider catchment conditions in water management, but it has become the focus of attention in the past few decades. The European Commission adopted the *"EU Water Framework Directive"* in 2000. Furthermore, the *"EU Water Framework Directive"* requires member countries to strengthen catchment water management (European Commission., 2020a). To cope with a series of extreme flood events in 2002, the European Commission launched the *"EU Flood Directive"* to assist member countries in dealing with catchment flood threats. Both the *"EU Water Framework Directive"* and the *"EU Flood Directive"* require all member countries to meet the mandatory assessment by 2015 (European Commission., 2020b).

Meanwhile, the UK Environment Agency (EA) proposed Catchment Flood Management Plans (CFMPs) (Environment Agency., 2021a) to help Catchment Flood Management (CFM). CFMPs focus on using Natural Flood Management (NFM) and working with natural processes. Because the risks of climate change and catchment floods are similar between Britain's mountainous areas and Guiyang, CFMPs and NFM may help Guiyang sustainably manage inland fluvial flood risks on the catchment scale. Therefore, at the beginning of Chapter 6, this research will study CFMPs and Natural Flood Management (NFM). Then, Chapters 6.2 and 6.3 will further discuss the proposed SCMF in the context of Guiyang. Chapter 7 will suggest potential solutions to mitigate the recorded SCP challenges in implementing Guiyang's SCFM pilot work.

6.1 Natural Flood Management (NFM) lessons under Catchment Flood Management Plans (CFMPs)

6.1.1 The initiation of catchment-scale and natural approach for flood risk management in Europe

In 2004, the annual cost of flooding in the UK was estimated at £1.1 billion, while the total asset value at flooding risk in England and Wales was approximately £200 billion. The UK Climate has predicted that the individual precipitation in winter will continue to increase in Britain. These phenomena indicate that flooding is expected to increase in the United Kingdom. Flood risk is a comprehensive product of flood damage and probability, meaning that flood risks will depend on environmental change and socioeconomic development. Concrete and metal limit GIs flood management because they are expensive and environmental-unfriendly. In addition, the UK Government may not fund GIs in flood-risk areas if the risk assets do not offset the costs. For instance, there is a high risk of flooding in short and steep catchments such as Holnicote in southwest England. However, the total value of flood-risk properties in Holnicote is not high, so the local authority is reluctant to invest in expensive GIs. Therefore, British scholars began to pay attention to low-cost, natural and watershed-based flood management strategies at the beginning of 2000. "*Foresight Future Flooding*" proposes two of the most sustainable ways to manage flood risks: catchment-wide storage and better land-use planning (Government Office for Science., 2004). The Department for Environment Food and Rural Affairs (Defra) also published "*Making Space for Wate"* in 2005, which has the recognition of the importance of managing water at the catchment scale (Department for Environment Food and Rural Affairs (Defra). 2005).

6.1.2 Coproduction with CFMPs and NFM

The Department for Environment Food and Rural Affairs (Defra) and the National Assembly for Wales initiated the idea of Catchment Flood Management Plans (CFMPs) in the early 2000s (Falconer and Harpin, 2005). The CFMPs are a series of catchment plans to implement Catchment Flood Management (CFM) by promoting collaborative work between various stakeholders within river catchments (Falconer and Harpin, 2005). Most importantly, CFMPs aim to manage the flood reach up to one-in-100-year rain return period in a whole catchment by linking urban flood management with fluvial flood management.

According to the "*Flood and Water Management Act 2010"* (UK Parliament, 2010), CFMPs encourage environmentally friendly, cost-effective, and sustainable flood management practices. Considering the potential impacts of climate change, CFMPs require surveying the flood risks across a catchment (The UK Parliament., 2010). Meanwhile, the planning catchments are divided into various subareas for requiring to reduce flood risk to an acceptable level. Within subareas, particular actions, including Natural Flood Management (NFM), are recommended (Iacob et al., 2017). As early as 2009, the UK Environment Agency (EA) carried out many projects under CFMPs in 10 major basins in the UK, including the Dee, Anglian, Thames, and Humber River Catchments (Environment Agency., 2009).

At the beginning of the 2010s, the UK proposed Natural Flood Management (NFM) (Holstead et al., 2017). To mitigate flood risks, the NFM adopts low-impact measures to restore the natural water process in the upper and middle catchment areas (Bark et al., 2021). It also provides a variety of co-benefits to the environment, biodiversity, agricultural products, and public health (Ferguson and Fenner, 2020). The NFM is a natural subset of CFMPs. The UK Environment Agency (EA) has released the *"Working With Natural Processes-Evidence Directory"* to guide the implementation of NFM projects.

NFM is a natural and sustainable catchment flood solution for decision-makers (Environment Agency., 2021b). According to Guiyang's terrain, geology, soil type, climate and water system, different places and landscapes need to choose various NFM measures to achieve the purpose of flood management and provision of co-benefits as follows:

Woodland Creation

Woodland Creation uses tree planting to reduce flood risk while improving water quality. Models studying the water-retarding and flood-reduction effects of trees at the catchment scale show that forests have flood control effects. Nevertheless, their effects depend on the scale of floods and the distribution and quantity of plantings. Woodland creation suggests that planting the entire small watershed (approximately 10 km^2) could reduce the flood peak of minor and major floods by an average of 50% and 36%, respectively. Directional planting along river channels, combined with wood damming, is expected to reduce the flood peak by 8 to 10% in catchments under 100 km^2. The forestland reduces the flood peak by intercepting, absorbing and evaporating the surface runoff formed by precipitation. The coniferous woodland catchment can reduce the amount of flood entering the stream by 10%. However, the influence of broad-leaved trees is relatively small.

Sediment Management

Strong surface runoff will increase the risk of soil erosion and sediment increase in the catchment area. Sediment deposition will reduce streams' cross-section and water-carrying capacity, thus increasing flood risks. Controlling soil erosion upstream is crucial for flood management and ecological conservation in a catchment. Planting riparian trees and allowing natural river channel adjustment can reduce surface runoff by sediment control. These measures are also essential for large catchments where strategies of reducing the source runoff production or improving connectivity between water bodies will likely impact flood management.

Water storage

The Parrett Catchment model in Somerset suggests that flood peaks can be reduced by using 2% ~ 3% of the land as storage facilities. However, high land and construction costs may make large-scale manual storage impossible. If farmers can use the stored flood for irrigation, this may change positively. In Northumberland, a project encouraged local farmers to use pools near the runoff source to irrigate. The effectiveness of water storage has been shown as a runoff source reduction method.

River Restoration

River Restoration can increase the river length while reducing the river slope. It is usually used in restoring flood detention areas to increase water storage ability and help reduce flood risks. GIs, such as culverts and weirs, must be removed to recover the natural water process.

Washland

Washlands are land that allows being inundated to reduce flooding downstream. This NFM measure involves natural areas such as floodplains to channel water. Washland sites are widely used in European flood mitigation programmes. The biodiversity benefits of washlands are significant depending on seasonal water management. Flood-compatible agriculture may be feasible in some areas. The washland created on productive land can also maintain food production capacity, which varies from farm to farm.

6.2 Developing a Sponge Catchment Management Framework (SCMF) in the context of Guiyang

6.2.1 The reasons for proposing SCMF in Guiyang

When the ratio of impervious catchment surfaces exceeds 10%, the natural attributes of the river decline, the artificial features are enhanced, and the characteristics of the highly urbanized catchment appear. The higher urbanization rate brings more catchment-scale water issues. However, the SCP focuses on site-specific water issues in urban areas. SCP alone is insufficient in flood management for the southern cities in China because of the long and intensive rainy season. These cities usually simultaneously face both fluvial and waterlogging challenges. Facing the water issues in urbanization, practitioners may consider expanding the SCP from the inner city with expensive land value and tight space to its suburban and rural catchment, from the highly urbanized area to its surrounding river catchment. With the catchment perspective, practitioners can find broader implementational spaces to solve the water issues.

Qihua Cai, the director of the Water Resources Strategy Research Institute of China, proposed the idea of a sponge catchment at the National Water Security Strategy Research Forum on March 22, 2016. Six academicians attended this form to support this forum. The forum proposed the development of an ecological sponge catchment by Catchment Flood Management (CFM). In the face of a high degree of urbanisation, the sponge domain should go forwards from an urban perspective to the catchment. Based on the water cycle process of the catchment as the main line, a sponge catchment is giving full play to the catchment's natural water cycle. A sponge catchment has more profound content in flood management than an independent sponge city. The sponge catchment idea gives a new connotation and a broader view of SCP and UFM. Enlightened by CFMPs in the UK and NFM in Leeds, this research proposed the Sponge Catchment Management Framework (SCMF) to promote wholely water management in Chapter 1.4.

SCMF requires holistic thinking. The main SCMF objective is to mitigate the negative impact of humans on natural features rather than only building fragmented landscapes. The SCP challenges mentioned in Chapters 4 and 5 may be solved well by systemic methods and the integration of ecological technologies with the idea of harmonious coexistence between humans and water. A good way to achieve this flood management transformation is to change one-objective flood control to multiple-objectives flood management, environment and human well-being improvement.

In the SCMF, it needs to coordinate the integrated relationship among catchment, rural and urban areas and the mutual relationship among macro-scale Catchment Flood Management (CFM), middle-scale Urban Flood Management (UFM) and Sponge City Programme (SCP), and micro-scale buildings, communities, and drainage projects. Similar to SCP, SCMF will involve various stakeholders. Thus, breaking the tendency of independence among various stakeholders is necessary. SCMF should comprehensively integrate policy, administration, plan, design, construction, education, and social communication. Therefore, the SCMF must include structural and non-structural aspects (Figure 1). Following the problem diagnosis, objective determination, plan formulation, and effect evaluation process, the SCMF must integrate structural and non-structural contents by adopting the "source-process-end" CFM. Chapter 6.2.2 will further explain the proposed SCMF in the context of the Nanming River Catchment in Guiyang.

6.2.2 The SCMF in Guiyang

Chapter 6.2.2 applies the SCMF proposed in Chapter 1 to Guiyang and its Nanming River. The SCMF is an umbrella frame including horizontal and vertical aspects. The SCMF has structural to non-structural elements in the flat part to achieve flood managing objectives. Vertically, the structural features include NFM, GIs and SCP to manage flood in the catchment area (Figure 1). The SCMF arranges the structural factors from the upstream to downstream of the Nanming River. In the SCMF, NFM is a natural complement to GIs and SCP.

Specifically, the GCG must first emphasize respect for nature while encouraging the NFM implementation in suburban and surrounding rural areas. The GCG must also promote the further development of the SCP in small towns around the city, not just in central urban areas. Although GIs are costly with ecological side effects, GCG can not abandon GIs. Under the SCMF, the GCG must continue to support targeted GIs in appropriate places.

Non-structural factors (Figure 1) have collaborative management, making consistent technical standards, and encouraging the improvement of public participation. First, many departments have participated in flood-related affairs in Guiyang. Top-down flood management is not conducive to effective SCMF implementation. Therefore, cooperation in governance is needed by breaking down barriers among various departments. Second, NFM is relatively new in Guiyang. Therefore, GCG and related departments must encourage revising technical standards to promote SCMF further. Third, public participation and stakeholders' support is the basis for successfully implementing SCMF in Guiyang.

The SCMF horizontal structural and non-structural elements support each other. The structural elements are the basis of SCMF. Flood management involves infrastructures and people. Only using structural measures can not effectively improve catchment flood adaptation. Therefore, this research emphasises improving non-structural elements by management.

The SCMF to be implemented in Guiyang integrates the structural and non-structural elements in the Nanming River Catchment to effectively enhance the flood resistance capacity of the catchment area and bring other co-benefits to Guiyang: 1) The SCMF can help CCG to formulate plans and projects; 2) In the emergency rescue work, it can help the local authorities understand the flood risk to improve the rescue efficiency; 3) It can assist the water company in carrying out water-related activities; 4) The SCMF can help land owners, land developers, farmers and residents to use land reasonably; 5) It can protect and beautify the catchment environment through natural measures; 6) The SCMF also can improve public awareness of flood risk and related-flood response plan. Finally, SCMF can help Guiyang build a sponge catchment area, as shown in Figure 38.

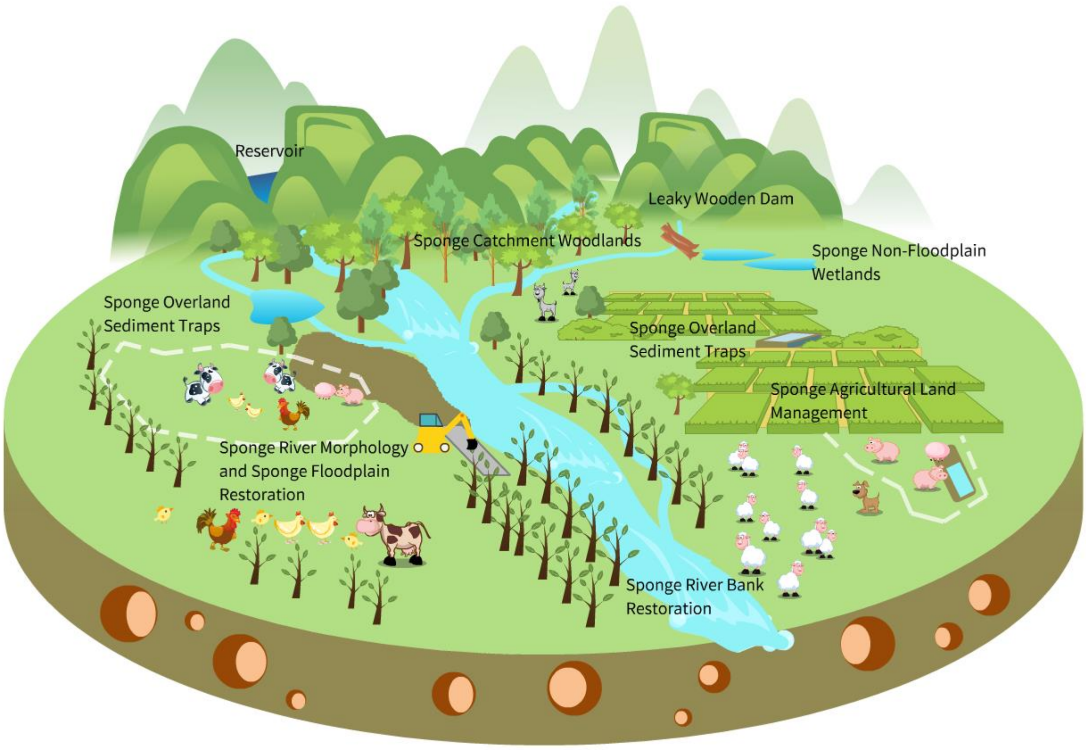


Figure 38 Sponge Catchment Management Framework (SCMF) diagrammatic drawing, including NFM, GIs, and SCP. (Yunfei Qi).

6.2.3 Suggested NFM measures in Guiyang's SCMF

Under the SCMF, the NFM measures have three primary groups, including woodland creation, land management, and river and floodplain restoration, to coproduce the catchment flood mitigation. Different NFM measures in a catchment have different effects on flood risk reduction. NFM measures in an upstream catchment and dispersed across catchment areas generally have greater uncertainty than those targeting specific areas and those closer to the flood risk receivers (people, property along rivers, and downstream cities) (Figure 39). Chapter 6.2.3 will introduce three primary NFM measure groups of planting woodland, land and soil management, river and floodplain restoration for sponge catchments.

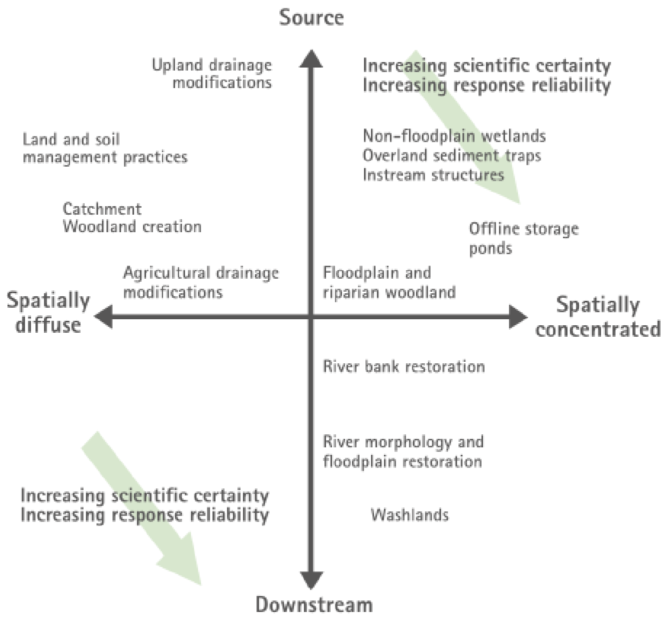


Figure 39 An NFM mechanism in a catchment. (Yunfei Qi).

Sponge Woodland Creation

(1) Flooding Woodlands

Flood woodlands (Figures 40 a and b) have the most significant potential to enhance flood management in a sponge catchment. However, the value of flood woodlands in the Sponge Catchment Management Framework (SCMF) varies depending on their location and size within sponge catchments. The effect of numerous flood woodlands throughout a sponge catchment is likely similar to a vast floodplain.

Planting conifers, mixed tree species or short-wheel-irrigated forests on flood plains are common in creating flooding woodlands. These trees can reduce flood risks and provide wood fuel for fossil fuel replacement. Local governments and landowners can use the natural landscape of flooding woodlands to restore river channels and riverside ponds. However, planners should carefully site extensive flooding forests to avoid synchronised flood peaks.

(a) (b)

Figure 40 Flooding woodlands in a sponge catchment (a) and (b). (Yunfei Qi)

(2) Sponge Stream Woodlands

Sponge Stream woodlands (Figures 41 a and b) are often planted as buffers between streams and nearby land. Sponge stream woodlands on either side of streams are usually tens of metres wide, which can increase contact between trees and moving water. They can provide the benefits of penetration, hydraulic roughness, evapotranspiration, and the possibility of wooden debris (a leaky wooden dyke that allows an overflow outside itself, thus delaying the water flow downstream). Because of their proximity to streams and usually washed by water flow, it is better to select hardwood species when planting riparian woodlands. Planners should also carefully choose where to plant trees. For example, high species planting should not be done if there is a risk of wind blowing, and wood debris should not be encouraged near upstream of bridges or culverts where washed-away wooden debris can block streams by chance.

(a) (b)

Figure 41 A planting of riparian woodlands (a); Riparian woodlands (b). (Yunfei Qi)

(3) Sponge Catchment Woodlands

Sponge catchment woodlands over a wider catchment are suitable for planting on soil prone to having water flow channels. These water flow channels may dry in the normal season but have water flow in the rainy season or intensive rainfall. Unlike flood woodlands, riparian woodlands, and urban landscape trees, sponge catchment woodlands focus on larger and more dispersive water flow channels in catchments to comprehensively enhance Catchment Flood Management (CFM)

Typically waterlogged soils suffer from soil compaction in a sponge catchment. Therefore, planting species for catchment woodlands should preferably have deeper root systems to maximize soil stability and penetration. The tree species, spacing, density, and spatial structure of sponge catchment woodlands also affect their ability to absorb water and mitigate flooding. However, planners should not plant too many trees above the natural tree line to avoid affecting natural tree growth. Rationally planning sponge catchment woodlands and utilizing their soil storage, hydraulic roughness, and evaporation can comprehensively increase CFM function.

Sponge Agricultural Land Management

(1) Sponge Agricultural Land Management

Traditional agricultural land management practices that result in soil erosion, soil compaction, and reduced tree coverage increase the production of surface runoff and the potential for associated agriculture pollutant infiltration. Using heavy machinery, high stocking density, and preserving soil without crop vegetation in the rainy season may cause flood risks.

Sponge agricultural land management can reduce flood risks and soil pollution posed by traditional agricultural land management practices via retaining and storing runoff in agricultural land. At the same time, sponge agricultural land management can increase agricultural production by reducing soil compaction and improving root penetration. Practices often include improving soil structure, optimizing crop structure, and optimizing farm location to increase soil infiltration, reduce soil erosion, and reduce runoff and sediment transport. Specific measures of sponge agricultural land management include controlling breeding density, crop rotation in the rainy season, soil compaction mitigation, soil ventilation, using light machinery to compact soil, field buffers, and low hedges (Figures 42 a and b).

(a) (b)

Figure 42 A soil aerator (a); Planted hedgerow (b). (Yunfei Qi)

(2) Sponge Agricultural and Upland Drainage Modifications

The CNG encouraged agricultural mechanization and agricultural policy to improve agricultural water supply and drainage systems to maximize the growth and yield of crops. Many field surface and underground pipes drain excess water and reduce soil saturation. These farmland drainage systems increase the connectivity between catchment surface runoff and river networks. At catchment levels, such a quick agricultural drainage system may decrease the peatland quality and associated crops. This NFM measure alters traditional farmland drainage systems to benefit farmers in flood management by simulating the natural flow path over the soil and the natural hydrological connectivity. Typical measures include blocking drainage on highland fields, terracing modification, and dry farmland conversion to paddy fields.

Modified drainage systems on farms produce complex hydrological responses that can positively and negatively impact runoff. These effects may also change over time with gradual changes in soil characteristics. For example, sponge farmlands can increase water storage potential in fields and thus reduce peak river flows. However, runoff that overflows farmland may increase the river's peak flow when reaching farmland water storage caps. In addition, agricultural drainage and associated subsoil treatments can also increase or decrease the peak drainage flow and the time to reach peak flow, depending on the soil type and moisture.

Although the impact of improving the farmland drainage system is complex, more and more evidence shows that the agricultural and highland drainage system transformation can help the catchment area cope with catchment flood events (Figures 43 a and b).

(a) (b)

Figure 43 Terraced paddy fields (a); A field drainage system with wooden interventions (b). (Yunfei Qi)

(3) Sponge Non-Floodplain Wetlands

Sponge non-floodplain wetlands (Figures 44 a and b) are usually saturated areas where groundwater is mostly near the surface. Due to the hydrological and geological characteristics of the site, there are many types of sponge non-floodplain wetlands, including peatland and salt marsh. It is worth noting that there is no direct connection between the sponge non-floodplain wetland and nearby rivers, lakes or coast.

Sponge non-floodplain wetlands can serve as landscape-type water storage areas that can slow and hold rainwater and then release it during drought, thus helping to reduce the impact of catchment flooding and drought. In addition to assisting Catchment Flood Management (CFM), sponge non-floodplain wetlands can capture sediment and retain pollutants to improve water quality. They also support a variety of livestock and crops as productive areas. Some sponge non-floodplain wetlands can help mitigate the effects of climate change by efficiently storing carbon.

To increase the productivity of the land, farmers removed many non-floodplain wetlands in the Nanming River catchment over the last century. Due to nutrients, water management, invasive species, and pollutants, many surviving wetlands are in poor condition. Despite the decline in shape and extent, scholars increasingly recognize the role of non-floodplain wetlands. However, the scale of sponge non-floodplain wetlands and their flood management impact will depend on many factors, such as their location in flood paths, vegetation types and conditions, catchment slopes, and pre-flood soil saturation.


(a) (b)

Figure 44 A Non-floodplain wetland (a); A series of Non-floodplain wetlands (b). (Yunfei Qi)

(4) Sponge Overland Sediment Traps

Sponge sedimentation ponds (Figure 45) can take many forms but usually involve excavating surface runoff channels. Thereinto, sponge overland sediment traps are also known as the rural NFM. It preserves sediment by simulating natural hydrological conditions before runoff is discharged (drainage water through gravel outlets). The Sponge overland sediment traps are to reduce diffuse pollution and obtain flood benefits by reducing surface runoff. Combined with other runoff management functions, they can effectively control sediment discharge to the river network, thus maintaining the ability of the river to transport flood. Due to the small scale of sediment traps, a small number are unlikely to produce significant flood management benefits. Only planning more sponge sediment traps has an apparent impact on flood reduction.

Figure 45 A series of constructed sediment traps. (Yunfei Qi)

Sponge River and Floodplain Restoration

(1) Sponge River Bank Restoration

Natural riparian erosion is an important fluvial process that can maintain river sediment supply, restore habitat, and reduce flow energy. However, human activities along rivers have increased bank erosion unnaturally. For instance, livestock can destabilize riverbanks by eating vegetation; settlements along rivers can increase river soil erosion; and engineering straightening channels can increase flow rates and thus increase riverbank erosion.

Sponge riverbanks (Figures 46 a and b) provide valuable habitats for wildlife and plants. Sponge riverbanks provide shelter and food to protect the ecosystem from contaminated surface runoff. The root system of vegetation in sponge river banks helps maintain the river bank's stability, alleviates the river bank erosion and sediment deposition caused by human activities, and ensures that the river flow crossing section does not shrink.

Restoration of unnaturally high erosion rates should focus on sponge riverbank management to allow riverbanks to regrow and be naturally stable. Examples are installing fencing for livestock, planting seedlings and trees, and sowing seeds, which can be simple. However, river erosion can occur quickly in some cases, so sponge bank management must be coupled with engineering interventions to stabilise the bank.

(a) (b)

Figure 46 River bank restoration (before) (a) and (after) (a). (Yunfei Qi)

(2) Sponge River Morphology and Sponge Floodplain Restoration

Traditional grey-leading river projects increase agricultural or infrastructure land by straightening rivers and building embankments (Figure 47 a). These GIs usually directly or indirectly alter natural river courses and separate rivers from the natural floodplains, reducing the likelihood of water flowing into the floodplain. However, these traditional measures may narrow the channel sections, reduce the raw water storage, and increase river flood discharge. Current research has established that greater environmental uplift and recovery of lost river functions, including biodiversity and the capacity of streams to cycle nutrients, process pollutants, and sequester carbon, are achieved when incised river channels are reconnected to their floodplains.

Large-scale NFM projects usually use sponge river morphology and floodplain restoration. They usually require a certain degree of engineering measures to restore the shape of degraded rivers, such as engineering bank removal or channel adjustment. Sponge river morphology and floodplain restoration require recovering straightened river bends, lowering, breaking, or removing barriers, and directly connecting to floodplains (Figure 47 b). They are rarely implemented alone but in combination with other NFM measures, such as planting banks, creating wetlands, or removing artificial structures.

When the engineered channel disconnected from its floodplain is fully reconnected, this is referred to as a pre-disturbed condition. In many cases, returning a river to its completely natural state is impossible. However, in many riverside village settings, it is not possible to fully reconnect due to the development of the former floodplain. In those places, a partial reconnection is the best that can be achieved. This is river restoration in which a narrower floodplain is created with a river-wetland corridor.

(a) (b)

Figure 47 Removing an artificially raised bank (a) and replacing the concrete channel with NFM measures (b). (Yunfei Qi)

(3) Sponge Instream Structures

Historically, people often removed wood debris in rivers to reduce the possibility of river blockage. With increasing recognition, such structures can increase hydraulic resistance by blocking overflows and strengthening river connections to floodplains. Sponge instream structures are traditionally known as leaky wooden dams but are also known by many other names (Figures 48 a and b). Sponge instream structures are often made of sizeable local cut trees. The design of the sponge instream structures varies in complexity, from one or two logs on either side of streams to dozens of stacked logs anchoring the banks. These sponge instream structures can simulate the natural hydraulic conditions of the river to improve the ecological diversity of animal habitats. However, the use of sponge instream structures is highly uncertain. In some cases, it may increase the flood risk of some objects by creating bridge obstructions and narrowing the water crossing sections. Therefore, designers must understand the influence of sponge instream structures on water level and flow direction.

(a) (b)

Figure 48 Leaky wooden dams (a) and (b). (Yunfei Qi)

(4) SpongeWashlands and Offline Storage Ponds

Sponge washes and non-linear ponds are areas near rivers or streams where flood water is directed when rivers have high flow. Floodwaters can naturally flow in and be temporarily stored in scours and non-linear ponds. They can reduce flood peaks by diverting water from rivers and streams. Then, after the flood water passes downstream, the diverted water is naturally discharged back into the rivers.

Sponge washlands and non-linear ponds work like naturally controlled floodplains. Traditional artificially manipulated floodplains require water gates and pumps to divert water through artificially controlled entrances and exits, which means it is more like a GIs. Riverbanks usually separate sponge washlands and non-linear ponds with rivers. The off-line ponds naturally divert water through natural inlets and outlets. Scours differ in that sponge washlands have no distinct inlet and outlet. Sponge washlands raised the rivers' natural banks to a height that allowed water to overflow riverbanks during periods of high flow. Some key is the location of sponge washlands, where the riverbanks are subdivided into small pieces to maximize water retention. Planners can also use a combination of multifaceted NFM measures to attenuate flow, such as planting water-friendly trees in sponge washes and non-linear ponds, to intercept flow (Figure 49).

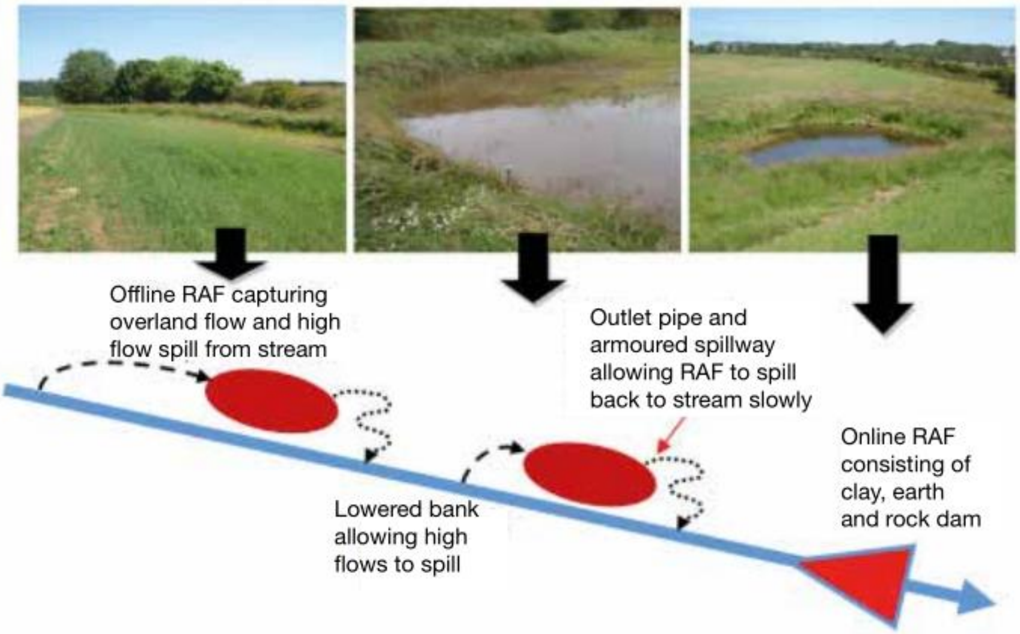


Figure 49 Offline storage areas and other attenuation features. (Yunfei Qi)

Generally, the NFM measures under SCMF can improve soil infiltration and water detention/storage capacity for flood reduction. The upper catchment often acts as the source of flooding. In intensive rainfall, upland soils may saturate rapidly; thus, surface runoff can quickly form and drain. Although the storage volume of one NFM project is limited, the total water detention/storage volume is considerable if people dispersively settle a series of NFM projects in a holistic catchment. According to the location and distribution in the catchment area, NFM can be one or a combination of many measures (Table 15). The combined use of planting woodlands, land management, and river and floodplain restoration can provide an opportunity to strengthen Catchment Flood Management (CFM) based on integrating SCP and GIs. In addition, multiple benefits, such as improving water quality, increasing biodiversity, storing carbon dismiss, and providing recreational places, can result from these NFM measures. However, careful planning of the NFM measures is necessary to ensure not to increase in the flood drainage synchronization of various NFM measures.

Table 15 NFM measures in SCMF. Yunfei Qi sorted the table and collected information from (Wilkinson et al., 2019)

NFM measure groups	NFM measure types	Main functions
Sponge Woodland Creation	Flooding Woodlands	catchment flood reduction and water storage
	Sponge Stream Woodlands	catchment flood reduction
	Sponge Catchment Woodlands	catchment flood reduction
Sponge Agriculture Land Management	Sponge Agricultural Land Management	catchment flood reduction
	Sponge Agricultural and Upland Drainage Modifications	catchment flood reduction
	Sponge Non-Floodplain Wetlands	catchment flood reduction and water storage
	Sponge Overland Sediment Traps	catchment flood reduction and water storage
River and Floodplain Restoration	Sponge River Bank Restoration	catchment flood reduction
	Sponge River Morphology and Sponge Floodplain Restoration	catchment flood reduction and water storage
	Sponge Instream Structures	catchment flood reduction
	Sponge Washlands and Offline Storage Ponds	catchment flood reduction and water storage

6.3. Moving beyond technical knowledge to understand stakeholders' deep values in an SCMF

6.3.1 The perspectives of residents in the SCMF

The purpose of government investment in public infrastructures is to maximize public benefits. The SCMF project is also to improve flood management, disaster reduction, environmental quality, and carbon capture management, and finally, provide a better living environment for the residents in catchments. Therefore, fully understanding the demands of residents is fundamental for the scientific decision-making of projects in catchments. A local government official ID (P2) expressed the following views in the interview:

"The starting point of government investment in public infrastructures is to improve the people's living standards so as to obtain greater support from the people for the government. Policymakers must understand the needs of residents for public infrastructure before making policy and investment decisions. Before piloting SCMF, We should know which specific solutions residents prefer and what services these solutions can provide residents." ID (P2)

As described in Chapters 3.2 and 3.3, before each interview, the interviewers would explain the basic principles of SCMF and show real project pictures to the interviewees to obtain more accurate feedback. Chapter 6.3.1 will exhibit many typical interview results of non-professional interviewees. By analyzing the interview results, this research has analyzed people's perspectives on different SCMF measures. More than 85 % of residents chose specific measures of NFM and SCP. Among them, parks are the most popular infrastructure for residents. The following part excerpts the representative interview results of two residents, ID (R1) and ID (R20):

"Visually, we prefer green infrastructure. Mountain, riverside, and wetland parks bring us visual enjoyment and inner pleasure. Green infrastructures allow us to feel a natural, healthy, pastoral life. Both NFM and SCP you introduced are the types we like. We can imagine we jog and play with our children in these parks." ID (R1)

"Conversely, we don't like GIs built from concrete. The artificial traces of GIs are too obvious, giving us a very unnatural feeling. GIs can not integrate with the surrounding natural landscapes. Because grey infrastructures give us a sense of depression, aggravating our tense feelings about urban life. We feel uncomfortable with the pictures of GIs." ID (R20)

However, not all NFM initiatives were universally welcomed by non-professional interviewees. When asked about river dredging or leaky wooden dams, two interviewees, ID (R11) and ID (R21), gave similar and representative answers:

"More than a decade ago, the Guiyang Municipal Government carried out several phases of river dredging projects in the mainstream Nanming River. Dredging projects have significantly improved water quality and landscape for the first few years, but these positive effects only last three or five years. Several years after the project implementation, the river's water quality began to blacken and stink again. Meanwhile, similar river dredging projects have not significantly reduced the river flood risk. The frequency and severity of fluvial flooding did not decrease before and after the river dredging projects. The often flooded urban areas along the river remain constantly threatened by flooding." ID (R11)

"In our view, green infrastructures should be green and vibrant. The leaky wooden dams look like a pile of cut-down logs. Although you explained how leaky wooden dams work, we still can not understand how leaky wooden dams can positively impact the local ecology. Nor do we believe that leaky wooden dams can effectively reduce flood risk. We will not invest in leaky wooden dams on our land or farms unless the government gives us enough subsidies." ID (R21)

This research found that compared with traditional GIs, green infrastructures are more likely to arouse positive associations among respondents. Because the appearance of green infrastructures often implies that they can provide interviewees with environmentally friendly, healthy, and high-quality living conditions, the impression of green infrastructures is an essential factor influencing the preferences of non-professionals. These basic green perceptions benefit from the CNG and local governments' continuous promotion of green concepts and culture through multiple channels in recent years. When the researchers asked how the respondents learned about green ideas, the response of ID (R3) confirmed the positive influence of the government on the people in terms of propaganda in recent years:

"Most of our knowledge about sponge cities comes from WeChat Public Accounts, WeChat Moments, Sina Weibo (like Facebook) and Titok (a short video platform). Except for older people who often watch TV and print newspapers, more young people now use mobile phones as the primary channel to get news and information. For example, we use smart mobile phones to know Sponge City Programme, Carbon Peaking and Carbon Neutrality Goals, and Ecological-Civilization Society are the most popular topics in recent years. Although we are non-professionals, we also know that SCP can provide us with a higher-quality living environment. We fully support green infrastructures, especially the SCP and NFM measures you introduced in SCMF." ID (R3)

Regarding flood management, only 30% of non-professional respondents understand that SCP and NFM-related infrastructure can play a role in storing stormwater to help flood mitigation. Most respondents' acceptance of flood management positively correlates with the matching degree between the measures and the nearby natural environment. Residents tend to focus on this coordination degree rather than flood control efficiency. For example, residents prefer environmentally friendly flood management such as wetland parks, riverside parks and mountain parks to dams and flood walls. On the other hand, most residents view GIs as *"dead looks-like*" and damaging the natural environment. These interview results suggest that the public already has a solid green consciousness, directly impacting their preference for flood infrastructures and management.

Meanwhile, there were apparent differences among different groups. Wealthier and older respondents prefer healthy, quiet, leisurely living places with better landscapes and medical conditions. This trend suggests that personal wealth and age play a significant role in infrastructure preferences. One nearly retired resident, ID (R17), gave the following view:

"I have three years to retire. My first consideration is using my pension to choose a retirement community with a good environment and medical conditions. Flood risk is not our primary consideration when choosing a retirement community. We believe the government and developers will manage flood well when planning and designing communities." ID (R17)

Most middle-class people chose communities more concerned with property values and children's education than flood risk. The resident, ID (R6), typically expressed as follows:

"As wage earners, we are most concerned about the property's value when we buy a house. Since the house's value are more than 60% of our family's total assets, the preservation and steady appreciation of the house significantly impact our family. Of course, if NFM and SCP can increase the value of the property we buy, we are happy to accept them. Because the local government and housing developers have never introduced relevant information to us, flood

risk is not a factor when we choose a house over time. As for the best way to reduce the flood risks in our communities, we paid little attention before we bought a house." ID (R6)

The main assets of middle-class Chinese families are in real estate, so it makes sense for them to pay more attention to property values. In addition, Chinese families also pay great attention to their children's education. Many young couples make their children's education another primary concern. Resident ID (R12) representatively stated as follows:

"I am a licensed architect, and my wife is a college teacher. We know something about the flood control functions of traditional infrastructures, such as dams and flood walls. At the same time, we know that SCP and NFM can bring us many additional co-benefits. However, parents pay more attention to their children's education. Our primary concern is whether a community has better public elementary and junior high schools. In other words, flood risks to the community are not our primary consideration." ID (R12)

Housing rent pricing, job opportunities, and commuting convenience are common concerns for relatively low-income, single, and young respondents. A recent college graduate, ID (R4), replied as follows:

"For us just entering the workforce, the convenience of work is the number one factor we consider, followed by the rent price and commuting convenience. If a community is too far from the workplace, we won't live there even if it has an excellent natural environment and low flood risk." ID (R4)

In general, residents prefer green infrastructures. However, residents' awareness of NFM and SCP is still insufficient in flood management. Housing prices, education, commuting, environment and other factors are the primary considerations for residents choosing a house and supporting or opposing SCMF rather than flood risk.

6.3.2 The perspectives of professionals in SCMF

In most urban areas of Guiyang city, the urban drainage systems only reach a rainfall intensity of one-in-5-year rain return period. Although the *National SCP Technical Guidelines* require sponge cities to raise the protection standard to a one-in-30-year rain return period, the *Guiyang Urban Flood Control Plan* requires the city area to meet the standard of a one-in-100-year rain return period. It is challenging to meet flood control standards of plans only using SCP infrastructures. For instance, intensive rainfall can quickly fill green roofs, rain gardens, and community ponds, then produce urban surface runoff. In the Guiyang case, grey infrastructures still play essential roles in river flood control; the SCP project mainly improves the urban landscape. Chapter 6.3.2 will exhibit many typical interview results of professional interviewees. Professional interviewee ID (P3) expressed similar perspectives as follows:

"Upstream reservoirs, flood walls in urban reaches, and urban drainage systems are the main infrastructures to protect Guiyang from flood damage. Small and scattered SCP infrastructures have limited flood storage capacity. Therefore, making grey infrastructure greener is a credible way to manage urban flooding sustainably today at this stage." ID (P3).

Although NFM and SCP outperform GIs in improving aesthetics and environmental sustainability, most professionals still consider traditional infrastructures superior to NFM and SCP in flood control efficiency. Policymakers, planners, and designers continue to trust GIs with irreplaceable flood protection capabilities, especially when dealing with catchment flooding events caused by intensive rainfall. A common finding among the interviews was that planners and designers would not risk replacing conventional flood control infrastructures with NFM or SCP on a large scale without the strong support of the technical standards. The interview results also evidenced that up to 78% of the professional respondents favoured GIs' flood prevention efficiency. Experienced urban planner ID (P20) and water engineer ID (P27) gave representative statements as follows:

"When planning a city or a river catchment, flood control safety is the primary consideration. We deeply understand that NFM and SCP can enhance the ecological sustainability of catchments and urban ecosystems. We also understand the potential negative environmental impact of GIs. But it is impossible to achieve flood control with pure green infrastructures alone because flood control standards for urban watercourses usually exceed one-in-100-year rain return period." ID (P20)

"No policymaker, planner, or designer will take the risk of replacing traditional GIs with good-looking green infrastructures on a large scale. We see NFM and SCP are ecological compensation measures for GIs. When a major flood control problem is solved in a city or a catchment, we will adopt green infrastructures to replace traditional flood control infrastructures under technical guidance." No. 27 (P)

Interestingly, professional and non-transfer respondents had similar views on leaky wooden dams and river dredging. There were officials, ID (P4) and ID (P11), gave respective answers as follows:

"We have seen successful cases in Europe and North America using leaky wooden dams as NFM for small upstream catchments. However, this NFM has not been tested in China. Considering the safety of flood management, we dare not promote the application of leaky wood dams in Guiyang without the support of relevant technical standards." ID (P4)

"By monitoring the river dredging project in the Nanming River, river dredging is a short-term and unsustainable measure. It only takes three to five years for the sediment to fill the silt that the dredging has removed. After that, the river water quality will deteriorate, and the water crossing section will narrow again. River dredging works is a fast solution but can not solve the root causes of the water ecology and flooding issues. The GMG has yet recommended river dredging in recent years." ID (P11)

The development of flood control facilities in China and Guiyang City described in Chapters 2.4 and 3.1 have shown China's past GIs-oriented flood control concept. Such traditional infrastructure investment has undeniably made UFM and CFM relatively advanced in Guiyang. However, SCP is still in the exploratory stage in China, and there is insufficient evidence to prove whether large-scale application of NFM and SCP can satisfy the safety of flood management. The interview results were more rational in terms of professional group perspectives. Although the professional interviewees were well aware that NFM and SCP can bring multiple co-benefits, they dare not rashly choose NFM and SCP as the primary flood management without the support of precise technical specifications. It is worth noting that non-professional and professional respondents do not like leaky wooden dams and river dredging, which may be related to the low visual attractiveness and safety concerns of leaky wooden dams and river dredging.

6.3.3 Moving beyond technical knowledge to understand stakeholders' deep values in SCMF

The primary purpose of SCMF is to reduce catchment flood risk while improving residents' living environment. Although only 30% of non-professional respondents understood the functions of NFM and SCP in flood management, it did not reduce their acceptance of green infrastructure. 85% of non-professional respondents like the green visual experience brought by NFM and SCP. At the same time, different groups of non-professionals have different primary considerations for their residential communities (environment, housing price, education, commuting convenience, etc.).

Unlike non-professionals, professionals are more concerned with the flood management safety of a programme. Even though flood events in sponge cities in recent years have caused professionals to rethink flood management strategy, 78% of professional respondents still like the certainty of GIs in flood control management. There was a common phenomenon that professionals would not risk large-scale selection of NFM and SCP as the primary means of flood management without the guidance of precise technical specifications.

The attitudes of non-professionals and professionals towards leaky wooden dams and river dredging were relatively close in the interview results. Both types of respondents do not welcome leaky wooden dams and river dredging. These results may be related to the pursuit of neatness, order, and control intention.

Because psychological value significantly correlates with people's options and attitudes towards flood management, a self-transcendence value (changing value) and a self-enhancement value (traditional value) could affect the selection of flood management (D'Souza et al., 2021). In wealthy and educated resident groups, a self-transcendence value positively correlates with a selection of NFM and SCP and negatively correlates with a choice of GIs. The co-benefits of NFM and SCP seem more significant for those residents with a self-transcendence orientation. Conversely, in professional groups, the self-enhancement value positively correlates with GIs and is negatively associated with NFM and SCP. Due to flood management safety, professionals with a self-enhancement value tend to support more conventional and well-proven measures. This finding helps explain why the general public prefers the NFM and SCP, but the professional group favourites GIs in flood management. Professor ID (P19) summarized the following reasons for this phenomenon:

"It is easier for people to choose a strategy that is easy to perceive and high in certainty. The green attributes of NFM and SCP are easy to attract the attention of non-professionals. Since NFM and SCP have not been widely used in flood control management in China, professionals cannot judge their efficiency in flood control management. In the absence of

recommendations by technical specifications, the certainty of traditional GIs in flood control management is more likely to attract the favour of professionals.” ID (P19)

In general, people like a strategy that is easy to perceive and high in certainty. The green attributes of NFM and SCP easily attract non-professionals’ attention. The interview results showed that 85% of non-professional respondents like the green visual experience of NFM and SCP. Regarding flood management, only 30% of non-professional respondents understand that SCP and NFM-related infrastructure can play a role in storing stormwater to help flood mitigation. Most respondents' acceptance of flood management positively correlates with the matching degree between the measures and the nearby natural environment. Since NFM has not been widely used in flood control management in China, professionals cannot judge their flood management efficiency. Therefore, about 78% of the professional respondents still favoured GIs due to flood management efficiency. The co-benefits of NFM and SCP seem more significant for those residents with a self-transcendence orientation. Conversely, in professional groups, the self-enhancement value positively correlates with GIs and is negatively associated with NFM and SCP. This finding helps Chapter 7 to find potential solutions and implementation pathways for SCMF pilot works in Guiyang.

Chapter 7. Potential pathways of SCMF in Guiyang

7.1 Developing a collaboration SCMF governance

7.1.1 Strengthening the supervision policy for SCMF

Based on the proposed SCMF in Chapter 1 and further discussed in Chapter 6, Chapter 7 will promote SCMF implementation in Guiyang while avoiding similar challenges and barriers in Guiyang's SCP mentioned in Chapter 5.

The *"Guiyang Flood Management and Drought Relief Plan"* is the municipal document regulating the rewards and punishment in flood control and rescue work. The document only refers to the department, organisation, or individual who has made outstanding contributions to the flood control and rescue work will be commended, and those who neglect their duties will be punished. Meanwhile, there is a lack of regulations for various departments to act together in CFM. This lack of a corresponding governance mechanism may result in the related departments not paying attention to information sharing and low efficiency of cooperation.

"Guiyang Flood Management and Drought Relief Plan" does not describe how to judge an outstanding contribution and a dereliction of duty. Meanwhile, the reward and punishment in the document only apply to the emergency process. There is a lack of reward or punishment policy on ordinary flood management. The GCG will set up an Emergency Command Centre for Flood Control And Drought Relief when facing large flood events. The Guiyang Water Resources Bureau led an emergency command centre, and other departments participated. The Emergency Command Centre is set up only in the face of devastating events as a temporary collaborative work centre. It can play a certain role in improving action efficiency and dealing with emergencies. However, the GCG will cancel the emergency command centre when the emergency ends.

Once the flood emergency work is over, there is no corresponding policy or organisation to supervise the implementation of the SCMF. The SCMF is a dynamic and norm management process. There would inevitably be emergency coordination states in an emergency. However, the lack of a normalized collaboration mechanism within departments is not conducive to the sustainable implementation of SCMF. The lack of a normalized governing structure for the SCMF planning, design, construction, and operation may impact its future implementation in Guiyang.

7.1.2 Changing the "island" to a collaboration pattern among departments

Since 1979, China's governing system has experienced eight reforms. These reforms have achieved outstanding results to some extent. However, the current governing system mentioned in Chapter 2.4.3 is still a vertically top-down and horizontally department-managing structure. This governing structure makes managing actions on public affairs inseparable from the structure itself. Different departments are responsible for independent administrative affairs before, during, or after flood events. The interview results in Chapter 5.1 described several challenges to this *"island"* governing structure.

Due to the differences in managing affairs, there is very little interaction and communication between related departments. As a result, each department rarely shares information with others, and each department is similar to an "island". However, departments with higher power and abundant resources have more authority in the governing arrangement. To some extent, they gradually form a state of the same level in form but not in substance. A relatively weak department has difficulty asking for help from others.

In the case of Guiyang, GCG is the highest authority to manage the local bureaus. However, there are overlapping responsibilities among the bureaus under the jurisdiction of GCG. This overlap of responsibilities may reduce the effectiveness and efficiency of SCMF. There are overlaps among bureaus' responsibilities in flood management, which may challenge the SCMF you proposed. For example, the Housing and Urban-Rural Development Bureau focuses more on infrastructure design and may ignore the surrounding hydrological issues. As a result, the designers may consider fewer flood issues in wetland park design.

The SCMF involves departments in charge of rural affairs, flood management, urban planning and construction, environmental management, funding, etc. Thus, the characteristics of the traditional governing structure may become the "*igniter fuse*" of the non-coordination among departments in SCMF governing. This research suggests that the GCG improves the governing system from the *"island"* governing structure to collaborative governance in the SCMF. That said, it is necessary to dim the governing boundaries among departments in the SCMF. The GCG needs to break the gaps among different bureaus.

7.1.3 Establishing an SCMF Commission Office to improve collaboration governing

Cooperation in SCMF governance can improve the effectiveness and efficiency of SCMF. To realize the unified management of SCMF, the local government must reorganize the authorities into one organization. The GCG should bring the idea of *"systematic and normalized integrated management"* for SCMF. Therefore, the government must transform the Emergency Command Centre into a normalized organisation linking different departments. This research proposed an SCMF Commission Office to integrate the management of related departments. The SCMF Commission Office leads related bureaus toward one objective in a unified work process to avoid conflicts. The SCMF Commission Office will facilitate department collaboration rather than encourage acting alone.

The specific operation mechanism of the SCMF Commission Office can be set as follows: Once the urban residents or farmers find catchment flood-related issues, they can report to the SCMF Commission Office through a telephone, an app or a website. The SCMF Commission Office initially classifies the received information according to its characteristics, then assigns tasks to specific departments for solving. For example, the blockage of drainage pipes falls within the work scope of the Guiyang Housing and Urban-Rural Development Bureau. The SCMF Commission Office assigns information to this bureau. If the problem is solved, the Guiyang Housing and Urban-Rural Development Bureau will directly give feedback to the commission office. If the bureau cannot solve the problem independently, the SCMF Commission Office will ask other departments to assist. Finally, the SCMF Commission Office will provide feedback about solutions to the public.

The SCMF Commission Office will record the issue if the problem is not solved. In the later stage, the SCMF Commission Office will organize relevant experts, social organizations and the public to discuss corresponding plans for similar problems next time. Through this discussion process, on the one hand, the SCMF Commission Office can obtain a better solution to complex issues through discussions. On the other hand, the SCMF Commission Office supervises the working process of each department. Establishing the SCMF Commission Office can increase information sharing among departments in SCMF. It will also make the interlinkage among departments to avoid buck-passing and improve the effectiveness and efficiency of SCMF implementation.

7.2 *"Multiple planning integration", s*trengthening the basic research and revising technical standards

7.2.1 Deeping integration with other planning to achieve *"multiple planning integration"*.

Planning is a relatively comprehensive and long-term guide for future development. It is a strategic direction for future actions, guiding the following programme implementation. Each special plan is an integral part of an urban master plan. A special plan means a department compiles a developing strategy to promote a programme for the industry on a certain space scale. Although there are two major legal bases in compiling SCP special plans, *"Urban and Rural Planning Law"* and *"Temporary Provisions for Compiling Sponge City Special Planning"*, it is a blank spot in SCMF. A well-compiling SCMF special plan is the basis for the scientific and orderly promotion of SCMF.

The SCMF special plan is the top-level plan from the perspective of strengthening Catchment Flood Management (CFM) to clarify the SCMF implementation systematically. It must coordinate with catchment water resources, water supply, sewage treatment and recycling, flood control and waterlogging, ecological and environmental protection, territorial space, road traffic, green space, and other special plans. Especially in the plane space, vertical space, scale, quality, quantity, indicators, and other aspects of coordination, various special plans should be the same in one catchment (i.e. *"multiple planning integration")* (Figure 50).

Meanwhile, an SCMF special planning should take managing water as the core and focus on water quality, quantity, ecology, and security. 1) For water supply, an SCMF special plan should consider water supply factors, water-saving management, utilization of unconventional water resources, and the scale and layout of relevant water projects. 2) For sewage treatment and recycling, an SCMF special plan must coordinate the aspects of sewage water conditions (quality, quantity, distribution, concentration), underground water pollution, non-point source pollution, treatment and recycling infrastructures, and pipe networks. 3) For flood and waterlogging management, an SCMF special plan should consider flood level, flood drainage abilities, flood discharge capacity, flood risks, flood areas, flood detention areas, river and lake networks, flood control projects, and emergency management. 4) For water environmental protection, an SCMF special plan must focus on the relationships with mountains, forests, fields, lakes and grasses, ecological red lines, point and nonpoint source pollutants, and water environmental quality control. 5) For territorial space, an SCMF special plan must coordinate the flood detention zones, waterlogging areas, and project land use. 6) For green space, an

SCMF special plan needs to coordinate the scale, layout, landscape, and functions of green and grey infrastructures to improve flood management.

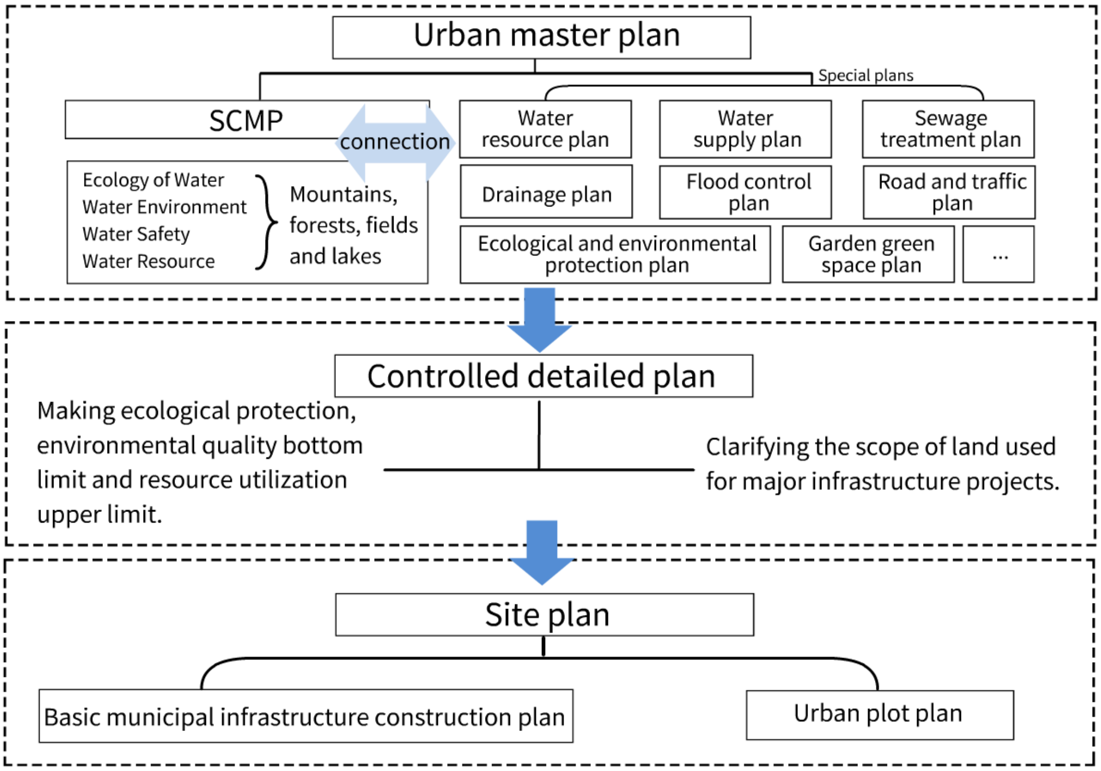


Figure 50 Relationship within SCMF special planning and relevant special planning. (Yunfei Qi)

Before the work of SCMF special planning, the CNG must publish the compiling provisions for SCMF special planning to guide local authorities in SCMF special plan. The provisions shall specify the responsible departments for compiling an SCMF special plan. The SCMF Commission Office can be a suitable organisation to lead the compilation work. The provisions also need to require planning contents, planning basis, planning terms, the data collection methods, suggested measures, and the relationship within an SCMF special plan and other plans.

Specifically, the GCG can understand the issues the Nanming River Catchment faces by investigating the current climatic, terrain, geographical, ecological, water, and socioeconomic situations. The GCG must finish an SCMF special plan to confirm the planning objectives, terms, key indexes, project review and assessment standards before conducting an SCMF project. It also needs to incorporate the key requirements of an SCMF special plan into other special plans in the catchment. Then the SCMF implementation in Guiyang can be scientific, rational, and practicable.

Generally, an SCMF special plan is the pre-layout of SCMF implementation, a meaningful way to promote a catchment's sustainable and coordinated development. As a new type of Catchment Flood Management (CFM), SCMF special planning must be well-prepared before its implementation. The CNG has to publish relevant provisions to guide and constrain local governments in compiling an SCMF special plan. Local governments should incorporate the published SCMF special planning into their urban master plan. In addition, local governments must strengthen the coordination within an SCMF special plan and other special plans. Through SCMF special plans, local governments can specify the principles, objectives, directions, and indicators of SCMF implementation.

7.2.2 Strengthening the basic research and revising technical standards

Different NFM, SCP, or GIs measures suit various climatic, terrain, hydrological, and geological conditions. Planners and designers cannot directly transfer these measures mentioned in Chapter 5.2 from one place to another. Northern China plain cities, such as Beijing, Qingdao, and Zhengzhou, face groundwater decline, pollution, and shortage (Chan et al., 2018b). Coastal cities such as Fuzhou, Guangzhou, Shenzhen, Shanghai, and Ningbo suffer from coastal storms. Inland cities in the middle sections of the Yangtze River, such as Nanchang, Nanjing, Changsha, and Wuhan, are affected by fluvial flooding in flatlands (Griffiths et al., 2020). In mountainous cities, such as Guiyang and Chongqing, the flood risks are more flash and complex, including fluvial and urban surface floods (waterlogging) due to their terrain characteristics.

However, land use shortages and high costs limit further development of SCP and GIs. The suburban and rural areas can potentially lay out additional flood management projects. The NFM in the SCMF provides an opportunity to enlarge SCP ideas to a catchment scale, which can somewhat decrease flood management's dependency on GIs. The new flood management trend is gradually changing from grey to green. However, the lack of evidence on flood reduction is a barrier to implementing NFM in Guiyang. More importantly, there are rarely ongoing basic research and published technical standards supporting the NFM in flood management.

From the structure of SCMF (Figure 1), this research found that SCMF implementation will involve many departments, such as planning, construction, landscape, environmental protection, water conservancy and finance. Among them, flood management is the critical element of SCMF. The interview results have shown that without clear technical standards, most professionals dare not risk the large-scale application of NFM and SCP for flood control management. However, the current technical standards do not explicitly propose NFM and SCP as the primary means of flood management, which has become an obstacle to the SCMF pilot. Therefore, to carry out the SCMF pilot work, revising the existing technical standards and enriching the relevant contents of NFM and SCP is necessary. According to the characteristics of different catchments, targeted guidance should be given to decision-makers, planners and designers to adopt specific NFM and SCP measures. Table 16 lists some technical standards that need to be revised. In addition, the following paragraphs continue to discuss how to manage SCMF technical standards from four different aspects.

Table 16 Current technical SCP standards and codes

Standards or Codes	Serial Number
National Technical Sponge City Guidelines - Building LID System (trial)	Trial
National Sponge City Post-Evaluation Standard	GB/T 51345-2018
Sponge City Construction Special Planning and Design Standard (Exposure Draft)	Exposure Draft

Standards or Codes	Serial Number
Sponge City Construction Monitoring Standard (Exposure Draft)	Exposure Draft
Technical standard for urban water system planning	GB 50513-2009
Standard for Planning and Design of Urban Residential Areas	GB 50180-2018
Technical Standard for Vertical Planning of Urban and Rural Construction Land	CJJ 83-2016
Technical Standard for The Design of Outdoor Drainage Engineering	GB 50014-2006
Technical Standard for Urban Sewage and Rainwater Engineering	GB 50318-2017
Technical Standards for Rainwater Management and Utilization of Buildings and Streets	GB 50400-2016

Establishment of SCMF technical standards

Well-established technical system standardization can guide and coordinate the systematic and scientific development of numerous technical standards. Thus, technical system standardization is fundamental to improving the technical level and implementation results of SCMF in China. Within the technical system standardization, many departments can modify existing departmental standards according to SCMF technical standards for providing cross-department legal and scientific support. In China, the China Association for Standardization takes charge of standardization management. The association mainly provides standardized enterprise certification services rather than managing technical standards.

Technical standards are cross-department, complex, and hard to coordinate. Technical system standardization is difficult and complex work in China. Well-established technical system standardization can help manage numerous technical standards. However, the China Association for Standardization focuses on managing enterprise certification. There is no unified organisation to manage cross-department technical standards, and various departments still independently manage their departmental technical standards. This technical system standardization process is not systematic and integrated enough. The coordination within different technical standards is challenging.

Although the *National SCP Technical Guidelines* and *National SCP Assessment Standard* have provided macro guides on SCP implementation, the NFM technical standards for managing catchment floods are lacking in China. This research suggests that the SCMF Commission Office (proposed in Chapter 7.1.3) manages SCMF-related technical standards before further improvement of China's technical system standardization. The SCMF Commission Office should collect and integrate the existing technical standards in different departments within a newly established SCMF technical standard. This SCMF technical standard must involve all SCMF project stages, including planning, design, construction, maintenance, and evaluation. Additionally, the SCMF Commission Office should fully use the exploration experience of SCMF pilot projects to develop technical standards with local characteristics to provide specific and localized expertise for SCMF standardization.

Strengthening the management of SCMF technical standards

To implement SCMF technical standardization, the government should strengthen standards management. According to the *"Administration measures of National Standards for*

Project Construction (December 30, 1992)", the national standard formulation process is divided into five-year or annual periods to improve the efficiency and quality of the standard formulation. After publishing a technical standard, the standard shall be reviewed according to the project implementation and technological development. Due to the lack of management of national standards, standards often take too long to publish, which cannot meet technology and engineering development.

Guizhou Province and Guiyang also have the problem of ageing standards. For example, the MHURD published has not updated National SCP Technical Guidelines since it was published in 2014. "*Guizhou Provincial SCP Technical Guidelines"*, published by the Guizhou Provincial Department of Housing and Urban-Rural Development in 2015, have yet to be updated. The promulgation of the standard has been close to 10 years. Relevant authorities should organize experts to sort out the problems arising in the sponge city pilot work and modify standards into new versions as soon as possible. Meanwhile, Guiyang must also compile its own technical SCP guide according to its characteristics.

Taking Guiyang SCMF as an example, Guiyang should improve the standard maintenance mechanism. The SCMF Committee Office must review the SCMF technical standard every five years after publication. After the review, the SCMF Committee Office will determine the status of the SCMF technical standard (continue, amend, or abolish). The revised standard should be based on the practical experience of the projects. The revised SCMF technical standard must meet the requirements of SCMF construction. Standard modification work must consider the actual level of science, technology, and engineering to prevent the phenomenon that *"paperwork"* does not meet development needs.

Strengthening the management of SCMF technical standards also needs to enhance the supervision of standard implementation. The SCMF Committee Office should supervise standard daily use in SCMF projects at the SCMF planning, designing, construction, and operation stages so that the SCMF standard supervision can run through all cycles of SCMF. Meanwhile, the SCMF Committee Office has to propose punishment measures for violating SCMF standards.

Encouraging scientists and engineers to participate in technical standards further

A traditional standard formulation process usually waits until the technology is mature, then considers formulating the technical standard according to the preparation, soliciting opinions, and submitting for review and approval in four stages. This standard formulation process is not adapted to the SCMF implementation because it may result in SCMF standards lagging behind the SCMF development. For instance, since 2010, the relative institute still did not modify the *"Standard for Basic Terms of Water supply and sewerage Engineering (GB/T50125-2010)"*. This far-lagging technical standard has already hindered the rapid SCP development. If the local governments and institutes do not improve this situation, it will challenge the SCMF implementation.

In SCMF construction, the government can adopt a flexible method to make unified technical standards. From foreign lessons from experience, the development of science and technology and standardization policies are unified in the standardization process. For example, in the standardization activities in the United States, the government provides financial support to researchers to participate deeply in making technical standards. The Japanese government also actively encourages experts from academic institutes to participate in standardization activities. The process and output of this academic participation are important indicators of both science and industry performance.

In SCMF standardization, the government should highlight the talent advantages of large universities, scientific research institutions, and engineering enterprises. The GCG should encourage research and engineering practical personnel to participate in the standardization activities by ‘combining production, academia, and research. This integration can enhance the scientific and technical level of technical standards. In addition, the integration can accelerate the SCMF standard compiling and modification.

As in the United States, the country only sets standards for principle issues. Other technical details and supplementary amendments are delegated to local governments or industry associations according to specific scientific, engineering, or project development situations. For fields lacking sufficient research support and practical pilots, the government can authorize engineers to formulate specific standards according to local conditions and project situations.

Meanwhile, establishing and improving technical standards are inseparable from talent. In addition to learning the flexible technical standard-making mechanism, the local government has to guarantee research payment to attract more excellent talents to contribute to SCMF.

Strengthen the publicity of SCMF technical standards

After promulgating the SCMF technical standard, it is necessary to strengthen the publicity of the standard and users’ understanding. Because SCMF involves many industries and departments, and there are a lot of technical standards in each industry. If the department does not strengthen the publicity on the SCMF technical standard, the standard users may not know how to use it or may even be unaware of its existence. This have happened in the SCP project. Some SCP designers do not deeply understand technical specifications, resulting in inefficient and low-quality design work.

The SCMF Committee office can publicize the SCMF technical standard from the following two aspects. First, the SCMF Committee office establishes a standard information network platform. This platform can provide a convenient standard inquiry channel for users to obtain effective technical standards. Thus, SCMF technical standards can be timely dissemination to users. The platform also needs to integrate advanced foreign standards, technologies, new ideas, and new processes so that standard users can timely understand the new foreign standards and technologies.

The other is professional training. Professional training is a more specific and direct way to push standard users to learn SCMF technical standards. The SCMF Committee Office regularly holds offline or online training courses, inviting well-known experts, scholars and engineers to interpret SCMF technical standards. The training courses can further deepen users’ understanding of SCMF technical standards by analysing excellent and failed project cases. In addition, the SCMF Committee Office can certify professional qualifications for qualified professionals.

The SCMF technical standard establishment and improvement must utilize advanced flood models to prepare SCMF technical standards. Considering the catchment's rainfall, climate, and economic development, technical standards must also include indicators for each land plot. The post-evaluation has to assess the SCMF projects according to the indicators strictly.

7.3 Creative maintenance and operation for SCMF projects

7.3.1 Creative SCMF project operation and maintenance

Chapter 5.3 mentioned the current SCP operation and maintenance issues. The SCMF will also encounter the same problems in the implementation. Therefore, for public (government-investing projects on public land) and non-public (facilities owned by landowners, housing developers or housing buyers) SCMF projects, it is necessary to clarify operation and management responsibilities, guarantee maintenance funds, refine the project operation evaluation and introduce corresponding incentives.

Similar to the classification of public SCP infrastructures, the construction of public SCMF projects can be divided into Build-Transfer (BT) and Public-Private Partnership (PPP) projects. For BT projects, the government, as the owner of public SCMF facilities, can authorize the municipal infrastructure management department (SCMF Committee Office) to manage SCMF projects' operation and maintenance. However, the constructor and operator companies of BT projects are usually not the same. The risks generated in the project construction may be transferred to the operation, which will affect the project's operational performance. Often, this effect is difficult to quantify and remove. Therefore, the municipal infrastructure management department (SCMF Committee Office) applying post-evaluation, performance appraisal and incentives in BT SCMF projects are relatively complicated. For the project risks outside the agreed project quality assurance, this research suggests the government continually invests an annual quota cost from the annual government budget to purchase a third-party operating company to maintain the completed SCMF projects.

For public SCMF projects in PPP construction mode, one project company implements construction and operation phases, which means the company takes all risks of these two phases. The management responsibility is relatively clear. The core point is to strictly execute performance appraisal and incentive clauses in the PPP contract between public and private investors. Meanwhile, public investors should reasonably share more franchise rights with private investors to attract longer-term private investors by promising higher investment returns.

For non-public SCMF projects, property owners (landowners, housing developers or buyers) entrust property management companies to maintain the non-public SCMF facilities. The local government has no direct contractual relationship with property management companies. Therefore, the local government lacks direct supervision of these non-public sponge facilities. Community organizations (neighbourhood or village committees) have to play a role in strengthening supervision in this aspect. According to the property management contract, community organisations implement rigid and incentive supervision. Property management companies must achieve rigid terms, such as annual rainfall volume capture ratio. Other incentive terms may include improving the landscape and providing better property management services. If a property management company achieves the incentive, the landowners, housing developers or buyers will award the company. In addition, the local government can award a "star rating" to the property management company as a high degree of market recognition.

7.3.2 Construction of an SCMF Big Data Monitoring and Information Platform

The SCMF is complex due to involving various departments and projects. An information platform can help SCMF maintain and operate more effectively and efficiently. Guiyang has highly developed big data infrastructures, which means Guiyang has a great foundation to build the SCMF Big Data Monitoring and Information Platform at once. This research suggests that the SCMF Committee Office leads the construction of the SCMF Big Data Monitoring and Information Platform to provide data support for SCMF planning, design, construction, operation and maintenance.

The platform has to reserve the planning, design, construction, operation and maintenance modules. According to the construction of SCMF projects, the platform can automatically collect various project information for further analysis. The SCMF Big Data Monitoring and Information Platform must unify (standardise) the data interface, format, and database for all related data sources. Meanwhile, the platform should support multiple devices (computers, phones, and tablets) and major systems (Windows, Android, and IOS) for interactive data exchange. Based on data monitoring and collection, the big data platform also should develop multiple-sources data fusion technology to achieve real-time data analysis. In addition, with the platform, people can integrate information from various projects and plots into a holistic catchment.

The SCMF Big Data Monitoring and Information Platform should use information means to accurately control and guide the work of SCMF projects in all stages. In terms of planning, design and construction, the SCMF Big Data Monitoring and Information Platform must effectively support SCMF planning and project decision-making. The platform should use the hydrodynamic model to simulate and identify vulnerable flooding and waterlogging areas under different rainfall intensities via automatically drawing the catchment flood risk map. According to the feedback from the platform, the planners and designers can adjust the SCMF planning and design to reduce the flood risk of the catchment.

In terms of operation and maintenance, the SCMF Big Data Monitoring and Information Platform can grasp the overall operation status of SCMF in real-time by collecting project operation data online. At the same time, the SCMF big data information platform should automatically identify the fault and excessive standard points of SCMF facilities and synchronously broadcast warnings to the government, relevant departments, and residents. The real-time monitoring and warning function can provide real-time data to help with emergency and disaster rescue work. The long-term accumulated operation information also provides sufficient data support for SCMF's continuous improvement. In addition, the platform should be able to integrate the public information disclosure function to realize real-time information release and data query services. The public information disclosure function can encourage the public to participate in SCMF and encourage public supervision and suggestion for the in-depth implementation of SCMF.

Besides collecting planning, design, construction, operation and maintenance information, the platform should be able to carry out active supervision and assessment work for SCMF projects. The platform can solve the *"pain point"* that is difficult for quantitative analysis in project post-assessments. In addition, according to the requirements of different platform users, the platform can provide unified information services for the GCG and relevant bureaus, project investors, planning, design, construction, supervision and operation companies, academic institutions, etc. Connecting with Smart Government, Smart Transportation, Smart Energy, Smart Water, and Smart Health, the SCMF Big Data Monitoring and Information Platform is an essential part of a Smart Catchment to provide critical information services for urban-rural management.

7.4 Strengthening the PPP investing model in SCMF

Chapters 5.3 and 5.4 mentioned that project maintenance and funding challenge the current SCP implementation. China's economy is declining due to the COVID-19 pandemic and the Russia-Ukraine war. The CNG's fiscal imbalance is striking. Many cities have limited financial investment. It is challenging to support SCMF construction only by relying on government subsidies and fiscal investment. The SCMF will face the same maintenance and funding challenges the SCP has been facing. In recent years, local governments and private inventors jointly funded project companies have been the consensus of PPP applications worldwide. Therefore, attracting social capital (private investors) to participate in SCMF construction and maintenance through PPP (Public Private Partnership) mode is feasible. The further strengthened PPP investing model may solve the project maintenance and funding challenges mentioned in Chapters 5.3 and 5.4.

7.4.1 The PPP structure in SCMF projects

As a popular innovative investment mode for infrastructure projects in recent decades, PPP has been widely used in public infrastructures and services. There are many practical cases. However, how to design a reasonable and feasible PPP model for SCMF based on SCMF's characteristics and actual project needs is worthy of more attention and in-depth discussion. According to SCMF projects' characteristics, the general PPP includes Build-Operation-Transfer (BOT), Reconstitution-Operation-Transfer (ROT), and Transfer-Operate-Transfer (TOT) models. New projects adopt BOT; transformation projects adopt ROT; completed projects adopt TOT.

SCMF projects are numerous and complex in a catchment, ranging from renovation to new construction. Therefore, the combinational PPP methods can be adaptable. That means one SCMF project package uses two or more PPP modes, such as BOT+ROT, BOT+TOT, ROT+TOT, etc.

In the Guiyang case, this research suggests that GCG designates the SCMF Committee Office as the implementing agency responsible for SCMF projects' identification, preparation, procurement, supervision, and transfer. The SCMF Committee Office selects private investors through an open, fair and impartial procurement procedure. The SCMF Committee Office encourages qualified, experienced, well-funded private investors to participate in a ready-to-bid SCMF project. The PPP model allows consortiums (several private inventors) to form a private investor.

The private investor who wins the bid and the subordinate state-owned company entrusted by the local government jointly contribute capital to establish an SCMF project company in the project's city. The government-entrusted state-owned company cannot hold shares over 50%. That is, the proportion from government investment shall not exceed 50%. This share distribution is to protect private investors. The SCMF Committee Office signs the PPP project contract with the SCMF project company. According to the PPP contract clauses, the SCMF project company is responsible for the project design, financing, construction, operation and maintenance during the term of the franchise right in the contract.

PPP is essentially a project financing behaviour. A locally established project company (usually a Special Purpose Vehicle (SPV) company) takes charge of the project design, financing, construction, operation and maintenance. Setting up an SCMF project company can decrease the total debt on local governments by isolating partial project debt from local governments.

In the PPP model of SCMF, the government shall authorize the SCMF Committee Office to manage all SCMF projects. Meanwhile, the GCG entrusts a governmental investing representative (a state-owned company) as a public investor to invest in a specific SCMF project but does not hold the control right of the SCMF project company. The SCMF Committee Office or governmental investing representative should not enjoy dividends and shall not interfere in the daily project operation and management during the PPP contract period. But the governmental investing representative has veto power over significant decisions of not conforming to regulation or not safeguarding the public interest (Figure 51).

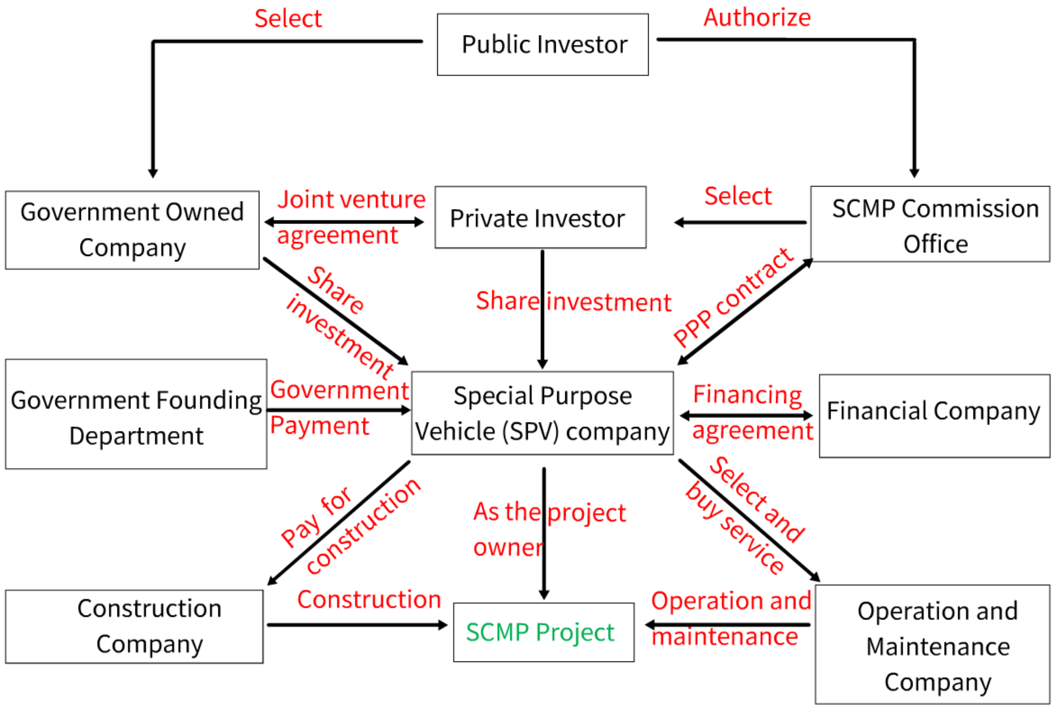


Figure 51 A PPP structure in an SCMF project. (Yunfei Qi)

After the PPP contract expires, the SCMF project company should hand over the SCMF project to the local government for free. The optimal setting of the PPP cooperation period has always been a research hotspot. Internationally, there is no definite limit on the duration of PPP cooperation, and the longest in practical cases can be up to 99 years. The profit return of a PPP project comes from the user payment or feasible gap subsidies from the government. A too-long contract will add more uncertain factors to the local government's medium and long-term financial expenditure. Therefore, the PPP period should not be too long. China's policy stipulates that the PPP cooperation period should not be longer than 30 years, and the minimum period should not be less than ten years. This research suggests following this contract period policy in China for SCMF projects.

7.4.2 Improving the SCMF project package and revenue return mechanism

CNG has proposed applying the PPP model in infrastructure construction, but it is not the only option. Foreign experience shows that in infrastructure and public services, the proportion of PPP investment in public investment is only between 3% and 15%. PPP has certain limitations and scope of application. Local governments should not set a uniform ratio for using PPP but should optimize the SCMF project package. For SCMF projects in a catchment, the local government should use PPP on more SCMF projects to avoid effectiveness fragmentation and redundant construction with other public infrastructures. The SCMF project includes more types of NFM, SCP, and GIs whenever possible. The local government can improve the overall performance by integrating all SCMF projects within a catchment.

An SCMF project should include more profitable projects generating sustainable income, such as water supply plants, sewage treatment plants, parking lots, large farms, tourist areas, new energy power plants, advertising boards, residential communities, and commercial centres. SCMF project companies can make revenue themselves and survive only by packaging potentially profitable projects into the SCMF project.

SCMF projects are mainly non-operational projects lacking direct operational income. Although some PPP contracts bundle profitable projects, the revenue is far from enough to cover the cost of SCMF projects. So the government still has to pay for SCMF projects.

The payment by the government can be divided into two parts: “availability payment” and “performance payment” according to the availability of project facilities and the usage and quality of products or services. Availability payment means that the government pays the annual cost according to whether an SCMF project company finishes building a project required by the contract. In other words, after the SCMF project company completes the project by standard, the local government shall pay the project company a fixed fee yearly. Performance payment means the government pays fees according to the project company's operating performance and maintenance quality during the PPP contract period. To improve the service quality of SCMF project companies and reduce the operating cost of SCMF infrastructures, the government should advocate performance payment in PPP contracts. Additionally, to attract more private investors to SCMF projects by formulating standardized PPP contracts clarifying the responsibilities and benefits of project company shareholders (public and private investors).

7.4.3 The choice of private investors

Based on market mechanisms, private investors should fully use technological experience and expertise in their original industries to promote the SCMF industrial chain development in synergy with other projects of related sectors. Private investors should actively research green materials and green technologies in SCMF projects. Through the construction of SCMF to promote the development of related industries. Meanwhile, private inventors should actively promote integrating SCMF projects with Shantytown Renovation, Urban Renewal, Smart City, Smart Water, and Ecological Agriculture programmes. Improving unified planning, construction, and management in related projects can increase cross-industry benefits.

Because SCMF is a new concept in China and project returns are uncertain, there are fewer suitable private investors in the PPP model. Therefore, the choice of suitable private investors is important. Selecting private investors through open, fair, and impartial competition can help reduce costs, improve efficiency, safeguard the public interest and get professional expertise from private inventors.

China's existing project procurement methods mainly include open tender, invited tender, competitive negotiation, and single-source procurement. The SCMF project implementational agency (SCMF Committee Office) should select an appropriate method to select private investors referring to the project procurement method.

Open tender means a tenderer invites non-specific companies to submit bids through a tender announcement. In other words, tenderers must publish a tender announcement on public tender platforms. All qualified bidders can participate in bidding. Because there may be many potential bidders as competitors, open tender is a relatively fair method. An open tender is one of government agencies' most common procurement methods to select suppliers. But it requires more private investors with SCMF experience and interest in PPP to participate as qualified bidders.

Invited tender means the purchaser randomly invites more than three suppliers from the qualified supplier list to participate in bidding via delivering an invitation for bid. Unlike open tender, invited tender is a non-public tender that does not need to issue a tender announcement. Because the purchaser usually does not invite too many potential suppliers, the tender cost is relatively small and highly time-saving. The invitation tender adapts to an SCMF project with a tight schedule or when fewer private investors are interested in the SCMF project.

Competitive negotiation means that a purchaser negotiates with no less than three potential suppliers meeting the qualification in negotiating the price and contract terms. It allows the negotiation suppliers to make a second-time offer for the purchaser to determine the suitable supplier. Competitive negotiation is used when fewer qualified private investors for the SCMF project.

Single-source procurement is a method without competition, meaning that the purchaser directly negotiates with the only supplier and signs a contract. Single-source procurement is adopted when only one private investor can meet the SCMF project requirement.

7.4.4 Improving Green Finance (GF) creatively to support the SCMF department further

SCMF project is a typical green infrastructure with the potential to use Green Finance (GF) profoundly. Internationally, Green Finance (GF) refers to economic activities to support improving the environment, combating climate change, and conserving and using resources efficiently. GF provides financial services for projects in environmental protection, energy conservation, clean energy, green transportation, green buildings, etc. Banking, bond, funding, and insurance companies can provide GF services to green projects. GF can promote environmental protection and sustainable development by guiding financial resources from high pollution and energy-consumption industries to greenery sectors.

In 2016, CNG defined GF in *"The Guidance on Building a Green Financial System"* as a financial service mainly covering environmental management, climate change mitigation, low-carbon transformation, and low-carbon project investment management. In 2021, China's outstanding green loans exceeded 11 trillion yuan, ranking first globally. The balance of green bonds in China is over 1 trillion yuan, ranking second globally.

At present, green credit still dominates GF in China. Although the green bond market is developing rapidly, there are drawbacks to inconsistent standards. Green insurance is still slow to develop. The development level of GF varies greatly from province to province. Some provinces lack the consciousness and enthusiasm to develop GF. China's GF development has gradually decreased from the northwest and southwest to the southeast coastal regions.

To achieve Carbon Peaking and Carbon Neutrality Goals, the CNG must adopt GF reforms to make China's economic structure, infrastructure investment, energy, and consumption greener. The support of GF is indispensable to developing green infrastructure. Although China's GF is advancing, GF has to make more significant progress in infrastructure green transformation. Improving the GF system to attract more private capital to invest in green infrastructure is urgent.

China has entered a critical economic restructuring and transformation period, and the finance demand for green infrastructures is increasingly strong. At the same time, various financial institutions in China pay great attention to GF. GF has become a new trend and trend in the development of the financial industry. Although China's financial institutions are generally optimistic about GF's development, GF faces many obstacles in specific financing practices of green infrastructure investment. For example, the relevant GF policies are imperfect; the benefits of green infrastructures are generally low and with high risks; local governments' financial conditions and credit have severely drafted; financial practitioners lack engineering experience to identify green infrastructures.

According to the *" Analysis Report of Market Outlook and Investment Strategy for China Sponge City Programme Industry "* released by the China Industrial Research Institute, the cumulative investment of SCP is expected to reach as high as 7.6 trillion Yuan by 2030. Because the SCMF includes NFM, SCP, and GIs in catchments, the SCMF's potential investment will be higher. With the rapid increase of the SCMF constructional scale, the difficulty of SCMF project financing will become a bottleneck. GF is essential to break through the SCMF financing issue.

Financial institutions should comprehensively utilize financial instruments such as green credit, green bonds, green stock indexes and derivatives, green funds, green insurance, and carbon trading to support the GF development. It is also necessary to innovate the GF mechanism to enhance the financial sustainability of SCMF projects and attract more capital to invest in the SCMF projects.

This research puts forward suggestions to promote the application of green infrastructures in the SCMF field from the following aspects. First, CNG must continuously strengthen the principle of user payment and performance payment to clarify the rights, obligations and benefits of all SCMF parties by making standardized PPP contract terms for SCMF projects. Financial institutions should innovate more GF products and services to build financial bridges within local governments, governmental investing representatives (state-owned companies), SCMF project companies, private investors, and service recipients and promote the further development of SCMF supported by PPP and GF.

Secondly, CNG must improve the profitable return of SCMF by multiple means. CNG should establish or remove government controls on the trading prices of sewage, stormwater drainage, carbon emission, and water rights. The productized SCMF-providing services can vigorously increase the profitable return of SCMF. Referring to mature oil, copper, iron and other commodities' exchange markets, the CNG should establish an SCMF exchange market with simplified trading processes to encourage SCMF project companies to participate actively in this trading. Meanwhile, governments must continuously disclose more details of SCMF project investment and SCMF-providing service prices. Then, GF institutes can use the ecological value assessment to calculate the total ecological value of SCMF projects as a major basis for following tradings. In addition, the SCMF project companies have to forecast market supplies, demands and prices of SCMF-providing services to increase SCMF's profitable return and attraction to GF institutes and private investors.

Thirdly, GF institutes adopt flexible mechanisms, such as quota auctions, to regulate the market. For example, the dynamical change of catchment environmental holding capacity can scientifically adjust the total limitational amounts of sewage, stormwater drainage, carbon emission, and water supply. These total limitational amounts will improve society's value expectation and increase the market liquidity of SCMF-providing services.

Fourthly, improving the green rating system of SCMF companies and projects is necessary. The environmental benefits of SCMF companies and projects can be incorporated into the existing GF rating system by learning from the banks' Equator Principles (EPs) in developed countries. Thus, it requires establishing a scientific, systematic and unified rating system for SCMF companies and projects to provide GF's decision-making basis and approval process.

To sum up, China's green infrastructure construction and GF have entered a stage of high-quality development. Optimizing the relevant green financial policy and system in continuous practices is necessary. The following work should be done in-depth to explore the path of GF in SCMF. 1) Strengthen GF's theoretical research and innovation, and lay a foundation for SCMF projects striving for financing. 2) Construct the GF standards in SCMF to ensure the sustainable development of SCMF. 3) Innovate GF products and services to build financial bridges between stakeholders. 4) Productizing the services that SCMF can provide and vigorously developing the trading of sewage rights, drainage rights, carbon sinks, and water rights. 5) Adopting flexible ways such as quota auctions to improve society's expectation for SCMF services and increase the market liquidity of SCMF services. 6) Strengthening international cooperation in GF and learning advanced international GF experience.

7.5 Improving public awareness and school education to encourage public participation in SCMF

7.5.1 Motivations of SCMF public participation

Public participation is a process in which motivation drives individuals to participate in project decision-making. Public participation is becoming increasingly crucial in government decision-making and planning. Planning, designing, and constructing public infrastructures must be in the public interest to gain support from the public and provide service to the public. Based on their living experiences, residents can provide feasible localized solutions to catchment issues. Public participation is playing an increasingly important role in project decision-making.

Motivation is a psychological factor that drives public actions to achieve a particular desire or belief. An individual demand usually generates an initial motivation. When the demand reaches a certain intensity, it will transform into an acting motivation. Motivation is the root of public behaviour. This personal motivation often drives public participation willingness in

SCMF. The public is more willing to participate in projects that can benefit them personally. The public is more concerned about their interests and hopes to seek additional personal interests or protect their original interests through SCMF public participation. On the other hand, the public is reluctant to participate and may even oppose projects that harm their interests.

The Perceived Positive Project Benefits are positively correlated with motivation. In certain circumstances, the motivation will amplify the effect. Similar to interview results about SCP in Chapter 4, the SCMF construction has multiple benefits to an urban ecosystem and society, such as reducing flood risk and water pollution, improving water quality, restoring the water ecological environment, improving air quality, landscape, and liveability, and increasing housing prices. The more gaining benefits from SCMF the public expects, the more they want to participate in the project decision-making and planning. The residents living along the planning subway are enthusiastic about participating in project decision-making because the build-up subway can greatly improve their commuting and increase housing prices. Similarly, residents near SCP parks are more willing to participate in the decision-making process of SCP because they feel that the park will improve their living environment.

Although the environmental SCMF benefits are relatively easy to perceive, residents' perceived negative impacts still exist in SCMF projects. The Perceived Negative Project Impacts can affect public acceptance of infrastructures. If Perceived Negative Project Impacts from a project are huge and obvious, controversies, opposition, or even conflicts may arise from the public to obstacle the project implementation. In the planning stage of a garbage power plant with the obvious negative impacts (air pollution, water pollution, landscape pollution and housing price impact), the public in Guiyang once took to the streets to protest against the project. Fierce opposition eventually failed the garbage power plant in Guiyang.

Similar to interview results about SCP in Chapter 4, the Perceived Negative Project Impacts of SCMF include the traffic jam during project construction; inadequate compensation for land occupation and housing demolition; environmental improvements that may mainly benefit wealthy communities; the shifting project costs burden from the government to residents; and the job loss and personal income decrease in the manufacturing industry caused by higher environmental requirements after SCMF implementation. The government can only mitigate Perceived Negative Project Impacts but not eliminate them. Since the public can perceive both the positive and negative effects of SCMF projects, increasing the publicity of the positive benefits as much as possible will help the public support and participate in SCMF projects.

7.5.2 Enhancing project transparency and building Catchment Flood Groups (CFGs) to encourage public participation

Besides the perceived impacts, other factors also hamper public participation. These factors include untransparent project information, poor communication platforms, and relatively low professional knowledge of residents. These additional factors lead to high time costs and low willingness for SCMF public participation. Although the government encourages the public to participate in decision-making (many government departments have set public participation modules on their official websites.), there is no law to regular this aspect. Most of the public participation is symbolic. Only a small number of well-educated residents with professional knowledge backgrounds have the initiative to browse these websites to get project information. Other ordinary residents never browse these department official websites. The official websites are not timely but selectively respond to the public's questions on the websites. Public participation is a passive rather than active process.

Increasing the transparency of project information and encouraging multiple-way communication among various stakeholders are effective paths to improve Perceived Positive Project Benefits and mitigate Perceived Negative Project Impacts mentioned in Chapter 7.5.1. Transparent project information and effective communication can improve residents' awareness of SCMF projects. Suppose residents can access real first-hand project information from the government rather than relying solely on news, rumours and anecdotes. In that case, the public will have more trust in the government and will be more likely to actively support and participate in SCMF projects.

Therefore, the government must strengthen information disclosure to ensure transparency and increase public participation's breadth and depth. The government, related departments, SCMF Committee Office, planning, design, and construction companies should timely and actively publicize information on SCMF projects through suitable platforms. It is also necessary to establish laws of information disclosure to protect the public's fundamental rights. The authorities must guarantee the public's right to know about SCMF projects. In addition, the government should encourage media supervision to strengthen the government and project credibility through media supervision.

Reliable communication platforms can promote public trust in governments and departments to increase public enthusiasm for participation. On the contrary, incomplete communication channels will hinder public participation and reduce participation willingness. Chapters 4 and 6 have shown that different types of residents have different perceptions and views on SCMF. At the same time, SCMF needs broad public support to obtain implementation opportunities. The current public participation process is mostly superficial. Relevant departments invite familiar rather than random residents to participate in project decision-making. This kind of public participation is only to cope with the process, not to understand the needs of residents. A platform without grounding can not connect decision-makers and other stakeholders.

Therefore, this study suggests building *"bottom-up"* communication platforms, CFGs, before piloting the SCMF project. Unofficial, voluntary and non-governmental organizations organize and run CFGs to avoid bureaucracy. Members of CFGs should cover the government, various departments, investors, landowners, residents, farmers, and Non-Government Organisations (NGOs). At the same time, CFGs must go deep into all stages of SCMF projects and sincerely participate in project planning, construction, investment, operation and post-evaluation. By building CFGs, SCMF can effectively break through the information and communication barriers between all relevant parties. All stakeholders can give independent opinions and suggestions on SCMF.

Because the public can easily accept unofficial information on the network, local governments must apply an open and convenient communication channel in CFGs. Examples of innovation include creating mobile applications at the catchment level, where team members can share the catchment monitoring with other team members in real-time. At the same time, these mobile applications should be able to synchronously feedback on the information collected from stakeholders directly to local authorities.

At the same time, the interview results show that the general public in China has little understanding of SCMF. Improving public awareness of SCMF is a problem to be solved during the implementation of SCMF. Due to the difference in education level, learning ability and professional background of the public, there is no need to try to make it difficult for everyone to understand the SCMF principles fully. It is enough for ordinary people to understand the basic content of SCMF. Therefore, science propaganda work in SCMF is the key to improving public awareness effectively. The CFGs' professionals can act as science propagandists to simplify the basic principles of SCMF and make it easier for the public to understand.

With the development of modern governance, Non-Government Organisations (NGOs) have gradually stepped onto the stage. NGOs have spontaneity, voluntary and independence characteristics, which government organizations lack. Therefore, NGOs in CFGs, are more persuasive than the government in promoting SCMF. Therefore, CFG can invite non-governmental organizations to participate in making a short film of the implementation of the SCMF pilot project to help the community understand the principles and benefits of SCMF. The government should actively support non-governmental organizations to promote SCMF among many stakeholders.

7.5.3 School Education

SCMF is a long and arduous task that requires several generations of joint efforts. Popularizing the concept of SCMF among students will help continuously promote SCMF in the future. The students themselves have strong learning abilities and desires for knowledge. Schools also have the advantage of teaching space and time. By giving full play to this advantage of the school, SCMF Committee Office should actively cooperate with the school, further popularize the SCMF concept and encourage students to participate in SCMF.

First, the government should actively invest in SCMF projects for schools. In addition to providing financial and technical support, the government should summarize the experience of pilot SCMF campuses for other SCMF projects. The construction of the SCMF campus can beautify the campus landscape and subtly make students and teachers improve their SCMF cognitions effectively. Secondly, this research suggests the local government give SCMF knowledge lectures by organising teachers, students and parents to participate in SCMF field trips. Specifically, the SCMF Committee Office should select professionals with SCMF professional knowledge and teaching skills to occasionally conduct field lectures on SCMF for schools. Through model display, case introduction, documentary broadcast and other forms, the selected lecturers can vividly show the principles, regulations, planning, and cases of SCMF to students, teachers and parents. These lectures should be visualized and simplified so the audience can effectively understand the SCMF. Students can also build simple SCMF models to deepen their understanding further. In addition, universities or vocational schools can award SCMF degrees. The government may also provide vocational education for SCMF practitioners.

These reserved talents for long-term SCMF construction can alleviate the shortage of SCMF professionals.

7.6 SCMF implementation steps and future suggestions in Guiyang

In recent years, the financial liabilities of the GCG have been relatively severe, and local tax revenue is difficult to maintain local financial expenditure. The primary source of fiscal income in Guiyang is still urban land sales. It is difficult for local governments to raise large amounts of investment for large SCMF infrastructures in urban centres. Therefore, this study suggests that SCMF pilot projects should be carried out in the upper reaches of rivers and villages that do not occupy the urban centre areas. This pilot project can save land for the urban centre, avoids the high demolition cost, and reduces the risk of project failure due to a lack of relevant experience. Both policymakers and investors are more likely to accept such pilot projects.

There are several suggested examples as follows (Figure 52). To push the pilot SCMF project in Guiyang, the local government needs to package cross-department projects into one SCMF pilot project creatively. For example, the local government can pilot the rural SCMF project integrated with Rural Revitalization on the upstream catchment of the Nanming River. Agricultural companies can carry out SCMF projects combined with the farm industry in rural areas. In the outer city suburbs with tourism resources, tourism companies can pilot the development of SCMF projects with caravan and camping tourism. In the suburbs with abundant light and wind resources, energy companies can carry out SCMF projects integrated with new energy. The power grid companies can pilot the SCMP projects combined with pumped storage power stations in the outer suburbs of cities with suitable terrain and power grid conditions.

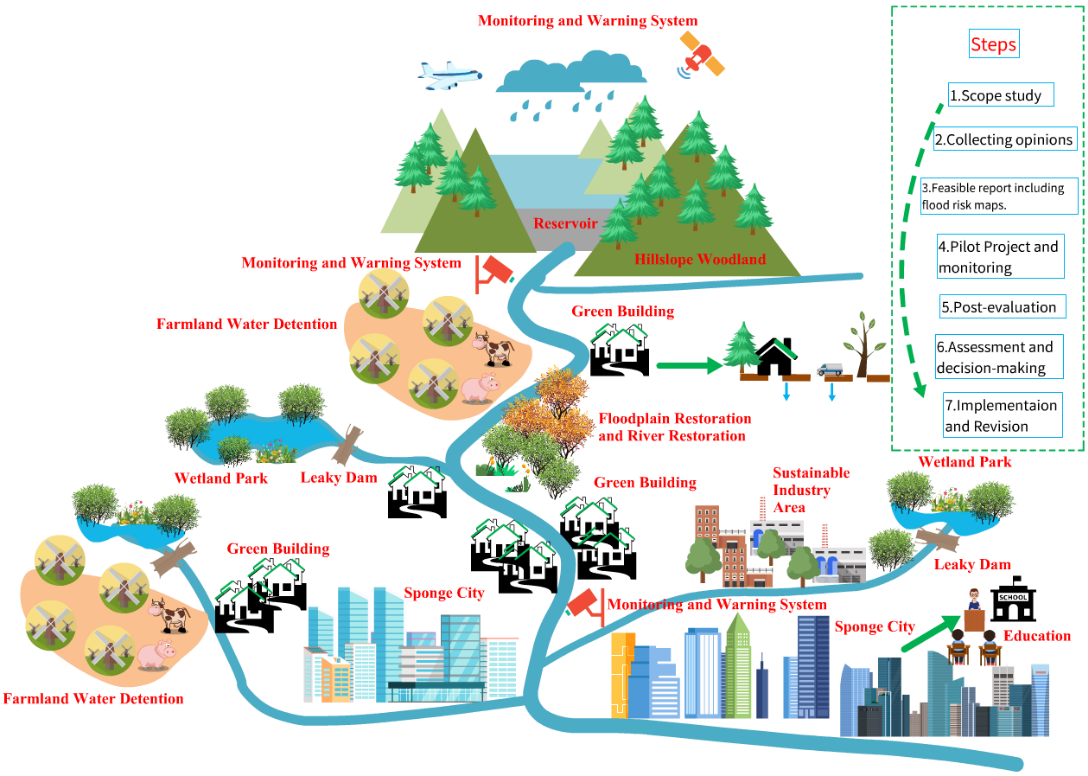


Figure 52 An SCMF diagram. (Yunfei Qi).

After finding the investors and determining the pilot project, this research suggests carrying out the SCMF pilot project according to the following steps. The first is to determine the pilot scope. The GCG must support the academic community in collecting and studying relevant plans, designs, and catchment conditions to find the deficiencies of the current CFM.

Second, the local government should fully solicit the opinions of different stakeholders in the Nanming River Catchment to identify their concerns about flood management to target the initiative SCMF pilot scope.

Third, the GCG must invite planning companies to prepare feasibility reports for SCMF. The SCMF feasibility report can help decision-makers and investors understand the SCMF pilot project's financial feasibility and the help provided to CFM and other co-benefits. Thereinto, a flood risk map is essential for determining the flood problem in pilot areas. This research recommends implementing the SCMF pilot project in the tributary catchment area to reduce the initial investment and failure risk.

Fourth, GCG must invite potential investors to investigate the pilot catchment and SCMF project. After the government and the investor reach an investment intention, the pilot catchment will officially be selected to launch the SCMF pilot project.

Fifth, the government must invite third-party institutions to conduct a post-project evaluation to evaluate the effect of the pilot SCMF project. During the operation phase of the SCMF project, the planning and design company should continue to monitor and collect the data of the SCMF pilot project to find more suitable and practical measures for the SCMF technical standards and other following SCMP projects.

Sixth, the GCG can decide whether to implement SCMF in other catchment areas according to the post-assessment. After the dynamic optimization of multiple rounds of SCMF pilot projects, SCMF will be more practical, cost-effective, sustainable and easy to maintain for the next generation.

Chapter 8. Conclusions

In human history, people have used many artificial engineering infrastructures to reduce fluvial flood risks. They include building reservoirs, dykes, flood channels, and sluices to change natural water paths or increase artificial water storage capacity in catchments. Due to the high density of infrastructures, buildings, and populations in urban areas, Urban Flood Management (UFM) has always attracted much attention worldwide. For instance, North American countries have developed Stormwater Best Management Practices (Stormwater BMPs) and Low Impact Development (LID). European countries have developed Sustainable Drainage Systems (SuDs), Nature-Based Solutions (NBS), etc. These pioneering practices have profoundly influenced Sponge City Programme (SCP) in China.

In 2013, the CNG officially initiated SCP as a new sustainable urban development strategy in urban planning, building design and flood management. The core of SCP is to restore urban hydrological characteristics that remain unchanged as far as possible after a site development, including surface runoff, flood volume, flood peak, peak occurrence time, etc. The main SCP objective is to mitigate urbanisation’s negative impacts by building fragmented artificial landscapes.

The SCP can partially enhance the UFM ability up to a one-in-30-year rain return period. However, small-separated SCP infrastructures are not specifically designed to alleviate large-scale fluvial floods. Scattered SCP infrastructures, such as green roof buildings, community rain gardens, and rainwater storage tanks, can not cope with catchment-scale flood discharges caused by intensive rainstorms. The current SCP mainly aims to manage initial rainwater in urban communities. The current SCP practices mainly help mitigate waterlogging issues at a relatively site-specific scale.

This research aims to make an original scientific contribution by proposing a Sponge Catchment Management Framework (SCMF) to further enhance Catchment Flood Management (CFM) in catchments with sponge cities. This research provides an opportunity to improve CFM on the catchment scale. This research analysed the Guiyang SCP plans and related typical SCP designs, aiming to find the issues faced by several implemented SCP projects and the future challenges and opportunities via a Case Study of the Nanming River Catchment in Guiyang, Focus Groups (FGs) and Semi-Structured Interviews (SSIs).

This research novelty proposed a Sponge Catchment Management Framework (SCMF) for Guiyang and its Nanming River. The SCMF is an umbrella frame including horizontal and vertical aspects. The SCMF has structural to non-structural elements in the flat part to achieve flood managing objectives. Vertically, the structural features (Figure 1) include NFM, GIs and SCP to manage flood in the catchment area. The SCMF arranges the structural factors from the upstream to downstream of the Nanming River. In the SCMF, NFM is a natural complement to GIs and SCP. Non-structural factors (Figure 1) have collaborative management, making consistent technical standards, and encouraging the improvement of public participation. First, many departments have participated in flood-related affairs in Guiyang. Top-down flood management is not conducive to effective SCMF implementation. Therefore, cooperation in governance is needed by breaking down barriers among various departments. Second, NFM is relatively new in Guiyang. Therefore, GCG and related departments must encourage revising technical standards to promote SCMF further. Third, public participation and stakeholders' support is the basis for successfully implementing SCMF in Guiyang.

The SCMF to be implemented in Guiyang integrates the structural and non-structural elements in the Nanming River Catchment to effectively enhance the flood resistance capacity of the catchment area and bring other co-benefits to Guiyang: 1) The SCMF can help CCG to formulate plans and projects; 2) In the emergency rescue work, it can help the local authorities understand the flood risk to improve the rescue efficiency; 3) It can assist the water company in carrying out water-related activities; 4) The SCMF can help land owners, land developers, farmers and residents to use land reasonably; 5) It can protect and beautify the catchment environment through natural measures; 6) The SCMF also can improve public awareness of flood risk and related-flood response plan. Finally, the SCMF can help Guiyang build a sponge catchment area.

There are several suggested creative examples as follows. The local government can pilot the rural SCMF project integrated with Rural Revitalization on the upstream catchment of the Nanming River. Agricultural companies can carry out SCMF projects combined with the farm industry in rural areas. In the outer city suburbs with tourism resources, tourism companies can pilot the development of SCMF projects with caravan and camping tourism. In the suburbs with abundant light and wind resources, energy companies can carry out SCMF projects integrated with new energy. The power grid companies can pilot the SCMP projects combined with pumped storage power stations in the outer suburbs of cities with suitable terrain and power grid conditions.

After finding the investors and determining the pilot project, this research suggests carrying out the SCMF pilot project according to the following steps: scope study, perspective collection, feasible report preparation, implementation and monitoring, post-evaluation, further decision, and improvement. After the dynamic optimization of multiple rounds of SCMF pilot projects, SCMF will be more practical, cost-effective, sustainable and easy to maintain for the next generation.

This research evaluated the SCMF via the Guiyang case. Although Guiyang is one mountainous city in southwest China, most research results can enlighten other sponge cities to improve flood resilience on a catchment scale. There are only a few parts of specific NFM measures that may not be suitable for plain cities, such as mountainous woodland creation and overland sediment traps.

Future research should go beyond the superficial understanding of flood dynamics to the deep values of stakeholders. The researchers should combine previous experience with the situation in Guiyang while deeply strengthening the understanding of the relationship between stakeholders' values and flood management preferences.

However, there is a certain limitation to this research. Because SCMF in China has not established a practical case, detailed monitoring data and analysis of sponge catchment is lacking. If I can carry out SCMF-related research in the future, I will continually unite colleagues and classmates to push SCMF pilot work and other related research. I will try my best to contribute to the ecological catchment transition for Guiyang. In addition, I will try to transfer the potential SCMF pilot experience and knowledge to other sponge cities and catchments.

Appendixes

Appendix 1 Abbreviations

No.	Contents	Abbreviations
1	Active, Beautiful and Clean Water Program	ABC Water Program
2	Best Management Practices	BMPs
3	Better Urban Stormwater Management	BUSM
4	Catchment Flood Management	CFM
5	Catchment Flood Management Plans	CFMPs
6	China National Government	CNG
7	the UK Environment Agency	the UK EA
8	European Commission	EC
9	Ecological Carrying Capacity	ECC
10	United States Environmental Protection Agency	the US EPA
11	Equator Principles	Eps
12	Ecosystem Services	ESs
13	Focus Groups	FGs
14	Grey-Leading Infrastructures	GIs
15	Green Finance	GF
16	Guiyang City Government	GMG
17	International Union for Nature Conservation	IUCN
18	Low Impact Development	LID
19	Low Impact Urban Design and Development	LIUDD
20	Ministry of Agriculture and Rural Affairs of the People's Republic of China	MARA
21	Ministry of Education of the People's Republic of China	ME
22	Ministry of Ecology and Environment of the People's Republic of China	MEE
23	Ministry of Emergency Management of the People's Republic of China	MEM
24	Ministry of Finance of the People's Republic of China	MF
25	Ministry of Human Resources and Social Security of the People's Republic of China	MHRSS
26	Ministry of Housing and Urban-Rural Development of the People's Republic of China	MHURD
27	Ministry of Natural Resources of the People's Republic of China	MNR

No.	Contents	Abbreviations
28	Ministry of Transport of the People's Republic of China	MT
29	Ministry of Water Resources of the People's Republic of China	MWR
30	National Sponge City Post-Evaluation Standard (GB/T 51345-2018)	National SCP Assessment Standard
31	National Technical Sponge City Guidelines - Building LID System (trial)	National SCP Technical Guidelines
32	Nature-Based Solutions	NBS
33	National Development and Reform Commission	NDRC
34	Natural Flood Management	NFM
35	Public Private Partnership	PPP
36	Sponge Catchment Management Framework	SCMF
37	Sponge City Programme	SCP
38	Structure Interview	SI
39	Semi-Structured Interviews	SSIs
40	Stormwater Best Management Practices	Stormwater BMPs
41	Sustainable Drainage Systems	SuDS
42	Urban Flood Management	UFM
43	Unstructured Interview	UI
44	Unified Nations	UN
45	Urban Water Management	UWM
46	Urban Flood Management	UFM
47	Urban Water Resources Optimisation	UWRO
48	Urban Heat Island Effect	UHIE
49	Water-Saving Cities	WSCs

Appendix 2 Ethics Approval Form

University of Nottingham Ningbo

Research Ethics Checklist for Staff and Research Students

[strongly informed by the ESRC (2012) Framework for Research Ethics]

A checklist should be completed for every research project or thesis where the research involves the participation of people, the use of secondary datasets or archives relating to people and/or access to field sites or animals. It will be used to identify whether a full application for ethics approval needs to be submitted. You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 3 and/or 4, 5, 6. **Ticking a shaded box in Sections 3, 4, 5 or 6 requires further action by the researcher**. Two things need to be stressed:

- Ticking one or more shaded boxes does not mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does not mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project – should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher: Sitong Liu; Yunfei Qi

1.2: Status: ☐ Staff

☒ Postgraduate research student

1.3: School/Division: FoSE（School of Geographic Science）

1.4: Email address: sgxls1@nottingham.edu.cn

Yunfei.Qi@nottingham.edu.cn

1.5: Names of other project members (if applicable):

1.6: Names of Supervisors (if applicable): Dr Faith Chan; Dr Dimple Thadani

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	Yes	No
1.7: I have read the University of Nottingham's Code of Research Conduct and Research Ethics (2010) and agree to abide by it: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx	☒	☐
1.8: (If applicable) I have read the University of Nottingham's e-Ethics@Nottingham: Ethical Issues in Digitally Based Research (2012) and agree to abide by it. http://www.nottingham.edu.cn/en/research/documents/e-ethics-at-the-university-of-nottingham.pdf	☒	☐
1.9: When conducting research on people (Section 5) I will prepare both a participant consent form as well as a *participant information sheet*. I am aware that the following templates are available on the Ethics webpage: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx • Participant consent form 1 • Participant Information Sheet English and Chinese	☒	☐

SECTION 2: THE RESEARCH

2.1: **Title of project:**

Please provide brief details (50-150 words) about your proposed research, as indicated in each section

Title: Understanding the socio-economic practices of Sponge City Program- the case of Guiyang, SW China

Urbanization and climate change resulted in metropolises in China are threatened by inland inundation. In this case, the proposal of *"Sponge City"* that aims at converting cities into "sponge" that has good "elasticity" in adaptation to environmental changes and response to natural disasters was raised. And more and more cities involved in the program.

This project (and the research approaches and data collection and analyses) to investigate the impacts of SCP in Guiyang by researching the relationship between housing price and SCP, gauging residents' attitudes and investigating socio-economic practices of SCP and the interfering factors and constraints under SCP in Guiyang and how to deliver good practice.

We proposed to use qualitative research approaches via using semi-structured interviews and discuss with participants (Government officials, engineers, local residents and property developers, etc,) and researchers will understand more (149 words).

2.2: **Research question(s) or aim(s)**

China is one of the countries around the world which bears the highest flood disaster frequency, the largest flood-hit population and the most serious flood disaster damage. Chinese cities are commonly facing a series of urban water issues, combining with blind and intensive urbanization after the open-door policy, the increase of impermeable land-cover conditions and frequent heavy rainwaters lead by climate change. The frequency of urban surface flooding events surged.

This project will introduce the basic principle of SCP and similar urban water management practices worldwidely (i.e. NBS from Europe; SuDs from UK, LID from USA, etc.) and analyse the revolution of real estate industry. This research focused on the case of Guiyang, the development of economy, population, urban land changes and real estate industry in Guiyang have also been investigated.

The project aims to investigate the impacts of SCP on property industry, housing prices of properties in Guan'shan lake District (the sponge area in Guiyang) will be collected and analysed, and participants' attitudes will be analysed by qualitative research approaches (via semi-structured interviews) to see if they are willing to pay a higher price for purchasing property, if yes, the real estate industry can help the government to accelerate the implementation of SCP. And these findings will be utilized in the future planning of SCP by providing current insufficiencies and contribute towards understanding the better ways for easing the pressure of waterlogging on the city and managing limited water resources, which will help practitioners and policy makers.

The specific objectives/research questions of this study are to:

- Assess current Sponge schemes broadly in China and develop a systematic framework for characterizing the benefits, opportunities, risks and weaknesses in the context of addressing urban water problems (e.g. pollution and flood risk);
- Analyse the evolution of estate industry and the policies on water resources management to figure out Whether SCP projects (e.g. green infrastructure, urban ecological parks) affect the values of proximate residential properties (house price) or improve the flood risk perception and willing to pay (WTP) in relation to SCP wider ecosystem potential (via qualitative research methods approaches (semi-structured interviews));
- Investigate What is the main factor and what are the magnitude and geographic scale of such effect? (In the process, other effects on housing price such as transportation, school and hospital should be tried to identify and exclude (via qualitative research methods approaches (semi-structured interviews));
- Understand how SCP and real estate industry to be integrated and cooperate better, the challenges, barriers and constraints, in prior to deliver the sponge city concept, and the co-ordinations of individuals, communities and stakeholders to deliver the practice (via qualitative research methods approaches (semi-structured interviews)).

These findings and the knowledge will be beneficial to deliver better sponge practices in the Guiyang and extensively to other Chinese cities that are adopted sponge infrastructures.

2.3: **Summary of method(s) of data collection**

This interview will be implemented as semi-structured interview.

It will be conducted with a fairly open framework which allow for focused, conversational, two-way communication. It also can be used both to give and receive information.

It starts with more general questions or topics (see Appendix 1 for the semi-structured interview questions set).

The set questions will be discussed during the interview, and the questions are open-ended that allowing both the interviewer and the person being interviewed the flexibility to probe for details or discuss issues.

Therefore, the semi-structured interview method is a suitable choice in this research project. We would like to provide further information that allows the ethics committees to understand the data collection and methods approach here:

(1) Sampling size and the interviewees

In order to collect date effectively and efficiently, researchers plan to choose 15 – 20 representative participants from the municipal governmental departments (e.g. Water Bureau, Local Planning authority, Municipal Housing and Construction Bureau, etc.), and the research institutes (e.g. Planning and design institutes, Building design institutes and Hydraulic design institutes, etc.), property developers, universities and local residents (that lives nearby the SCP sites) in Guiyang and scholars from universities, to join the semi-structured interviews (see Appendix 2 for the details of proposed participants).

(2) Reasons to choose these interviewees in this project

Based on stakeholders' relationships with urban water issues (e.g. urban flooding, waterlogging and pollution, etc.) and SCP projects, researchers will choose interviewees from provincial and municipal government officials, departmental officials, engineers and consultants from research institutions and consultation institutes/companies, scholars from universities, private property developers in Guiyang and local residents as noted above.

Some factors to select/identify these interviewees are here:

The master plan (that include the Sponge City projects) is initiated by the municipal government in Gui'an. Therefore, we target or focus to undertake the interviews with the government officials in this project. In fact, the SCP is a cross-departmental co-operational program that requires multi-departmental officials to be invited in the semi-structured interview process in this project.

Engineers and consultants have been involved in the SCP project design and construction processes that have been experienced some successful/unsuccessful stories which will be helpful to the researchers (myself and our research project team) to understand the good practice, barriers, constraints and barriers from the SCP projects in Guiyang.

Local residents who are living nearby and located in the SCP areas, they are persons who can directly sense the influences caused by the implementation of SCP and their views are important in this reserch.

Finally, researchers also target to interview relevant scholars. Because they have interdisciplinary knowledge, the most advanced science tools and the latest information about SCP.

In general, the researchers will carefully identify interviewees that include stakeholders as much as possible in this project.

(3) Interview length and timeline

Each interview process to be proposed and conducted within 15-30 minutes, and the whole interview process will be finished in one or two months (after the ethics application approval). Afterwards, researches will take another two to three weeks to contact with all interviewees and arrange the interviews at their agreed schedules with the participants.

Afterwards, the interview process will take about 4 to 8 weeks.

Finally, researchers need another one month to transcribe all data in texts and translate to English and proceed the data analysis by using NVivo that have been collected from the interviews.

(4) Avoiding sensitive questions

In the whole process, we should avoid all sensitive questions such as the privacy of participants. The data collected from them will only be used in the research.

All information will be anonymous and be deleted after the research project is completed.

We will compile fully and follow the University of Nottingham ethics guidance and provide the confidential forms and notice to all participants before they commit to the interviews and any methods we may conduct.

2.4: **Proposed site(s) of data collection**

The proposed site of this semi-structured interview will be in the governmental offices of the participants, or safe open-spaces with population that is not dense and allow researchers to undertake interviews smoothly in a suitable environment.

For interviewing the local residents, interviews will be arranged in safe and open-space sites with good air circulation and lower visitor flow, such as urban park, street corner, café or coffee shops that in the residential area to ensure interviewer and interviewees are undertaking the interviews in a safe and quite environment to ensure the interview quality.

If the targeted participants are on business or vacation trip, we will proceed the interview via Skype/Wechat call or by phone and recording the interview dialogue that similar to the face-to-face interview practice.

And all face-to-face interviews in this research need to consider the COVID and follow the safety rules, researchers and participants need to keep a safe social distance and wear a mask all the time.

And before the interviews, participants will be told that the interviews will be recorded and they need to sign a consent form to make sure they know the purpose and details of the interview.

2.5: **How will access to participants and/or sites be gained?**

In fact, I am a full-time UNNC MRes student and my hometown is Guiyang, I will conduct interviews when I get back to Guiyang.

Therefore, I am familiar with the targeted properties in Guiyang and it is easier for me to interview local residents. And my teammate Yunfei Qi is a part-time UNNC PhD student working for Guizhou Survey & Design Research Institute for Water Resources and Hydropower. And he has working connections professionally through the working networks on the possible targeted participants in the government institutions, consultancies, private developers, etc., which is an advantage to access with possible targeted participants by the working contacts (via phone and emails), in prior to asking their consent/permission to undertake the semi-structured interviews.

The interview sites should be only selected in public-openly accessed locations (noted in section 2.4 previously), including the local residential areas, this project will not be involved any sites are highly risk in terms of health and safety.

SECTION 3: RESEARCH INVOLVING USE OF SECONDARY DATASETS OR ARCHIVES RELATING TO PEOPLE

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If your research involves use of secondary datasets or archives relating to people all questions in Section 3 must be answered. If it does not, please tick the 'not relevant' box and go to Section 4.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
3.1: Is the risk of disclosure of the identity of individuals low or non-existent in the use of this secondary data or archive?	☐	☐
3.2: Have you complied with the data access requirements of the supplier (where relevant), including any provisions relating to presumed consent and potential risk of disclosure of sensitive information?	☐	☐

SECTION 4: RESEARCH INVOLVING ACCESS TO FIELD SITES AND ANIMALS

If your research involves access to field sites and/or animals all questions in Section 4 must be answered. If it does not, please tick the 'not relevant' box and go to Section 5.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
4.1: Has access been granted to the site?	☐	☐
4.2: Does the site have an official protective designation of any kind?	☐	☐
If yes, have the user guidelines of the body managing the site a) been accessed?	☐	☐
b) been integrated into the research methodology?	☐	☐
4.3: Will this research place the site, its associated wildlife and other people using the site at any greater physical risks than are experienced during normal site usage?	☐	☐
4.4: Will this research involve the collection of any materials from the site?	☐	☐
4.5: Will this research expose the researcher(s) to any significant risk of physical or emotional harm?	☐	☐
4.6: Will the research involve vertebrate animals (fish, birds, reptiles, amphibians, mammals) or the common octopus (Octopus vulgaris) in any capacity?	☐	☐
If yes, will the research with vertebrates or octopi involve handling or interfering with the animal in any way or involve any activity that may cause pain, suffering, distress or lasting harm to the animal?	☐	☐

SECTION 5: RESEARCH INVOLVING THE PARTICIPATION OF PEOPLE

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If your research involves the participation of people all questions in Section 4 must be answered.

Please answer each question by ticking the appropriate box.

A. General Issues

	Yes	No
5.1: Does the study involve participants age 16 or over who are unable to give informed consent? (e.g. people with cognitive impairment, learning disabilities, mental health conditions, physical or sensory impairments?	☐	☒
5.2: Does the research involve other vulnerable groups such as children (**aged under 16**) or those in unequal relationships with the researcher? (e.g. your own students)	☐	☒
5.3: Will this research require the cooperation of a gatekeeper* for initial access to the groups or individuals to be recruited?	☐	☒
5.4: Will this research involve discussion of sensitive topics (e.g. sexual activity, drug use, physical or mental health)?	☐	☒
5.5: Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	☒
5.6: Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	☒
5.7: Will this research involve people taking part in the study without their knowledge and consent at the time?	☐	☒
5.8: Does this research involve the internet or other visual/vocal methods where people may be identified?	☐	☒
5.9: Will this research involve access to personal information about identifiable individuals without their knowledge or consent?	☐	☒
5.10: Does the research involve recruiting members of the public as researchers (participant research)?	☐	☒
5.11: Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	☐	☒
5.12: Is there a possibility that the safety of **the researcher** may be in question?	☒	☐
5.13: Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	☒

**Gatekeeper- a person who controls or facilitates access to the participants*

B. Before starting data collection

	Yes	No
6.12: My full identity will be revealed to all research participants.	☒	☐

6.13: All participants will be given accurate information about the nature of the research and the purposes to which the data will be put. (*An example of a Participant Information Sheet is available for you to amend and use* at xxxxx) *http://www.nottingham.edu.cn/en/research/documents/participant-information-sheet-in-english-and-chinese.doc*	☒	☐
6.14: All participants will freely consent to take part, and, where appropriate, this will be confirmed by use of a consent form. (An example of a Consent Form is available for you to amend and use at: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx)	☒	☐
6.15: All participants will freely consent to take part, but due to the qualitative nature of the research a formal consent form is either not feasible or is undesirable and alternative means of recording consent are proposed.	☐	☒
6.16: A signed copy of the consent form or (where appropriate) an alternative record of evidence of consent will be held by the researcher.	☒	☐
6.17: It will be made clear that declining to participate will have no negative consequences for the individual.	☒	☐
6.18: Participants will be asked for permission for quotations (from data) to be used in research outputs where this is intended.	☒	☐
6.19: I will inform participants how long the data collected from them will be kept.	☒	☐
6.20: Incentives (other than basic expenses) will be offered to potential participants as an inducement to participate in the research. (Here any incentives include cash payments and non-cash items such as vouchers and book tokens.)	☐	☒
6.21: For research conducted within, or concerning, organisations (e.g. universities, schools, hospitals, care homes, etc) I will gain authorisation in advance from an appropriate committee or individual.	☒	☐

C. During the process of data collection

	Yes	No
6.25: I will provide participants with my University contact details, and those of my supervisor (*where applicable*) so that they may get in touch about any aspect of the research if they wish to do so.	☒	☐
6.26: Participants will be guaranteed anonymity only insofar as they do not disclose any illegal activities.	☒	☐
6.27: Anonymity will not be guaranteed where there is disclosure or evidence of significant harm, abuse, neglect or danger to participants or to others.	☒	☐
6.28: All participants will be free to withdraw from the study at any time, including withdrawing data following its collection.	☒	☐
6.29: Data collection will take place only in public and/or professional spaces (e.g. in a work setting	☒	☐
6.30: Research participants will be informed when observations and/or recording is taking place.	☒	☐
6.31: Participants will be treated with dignity and respect at all times.	☒	☐

D. After collection of data

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	Yes	No
6.32: Where anonymity has been agreed with the participant, data will be anonymised as soon as possible after collection.	☒	☐
6.33: All data collected will be stored in accordance with the requirements of the University's Code of Research Conduct	☒	☐
6.34: Data will only be used for the purposes outlined within the participant information sheet and the agreed terms of consent.	☒	☐
6.35: Details which could identify individual participants will not be disclosed to anyone other than the researcher, their supervisor and (if necessary) the Research Ethics Panel and external examiners without participants' explicit consent.	☒	☐

E. After completion of research

	Yes	No
6.37: Participants will be given the opportunity to know about the overall research findings.	☒	☐
6.38: All hard copies of data collection tools and data which enable the identification of individual participants will be destroyed.	☒	☐

If you have not ticked any shaded boxes, please send the completed and signed form to the School's Research Ethics Officers, with any further required documents, for approval and record-keeping.

If you have ticked *any* shaded boxes **you will need to describe more fully how you plan to deal with the ethical issues raised by your research**. Issues to consider in preparing an ethics review are given below. Please send this completed form to the Research Ethics Officer who will decide whether your project requires further review by the UNNC Research Ethics Sub-Committee and/or whether further information needs to be provided.
Please note that it is your responsibility to follow the University's Research Code of Conduct and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data. For guidance and UK regulations on the latter, please refer to the Data Protection Policy and Guidelines of the University of Nottingham:

Policy - http://www.nottingham.ac.uk/%7Ebrzdpa/local/dp-policy.doc

Guidelines -http://www.nottingham.ac.uk/~brzdpa/local/dp-guidance.doc

Any significant change in the project question(s), design or conduct over the course of the research should be notified to the School Research Ethics Officer and may require a new application for ethical approval.

Signature of Principal Investigator/Researcher: Yanfei Qi

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Signature of Supervisor (where appropriate): *faith Chen*
Date 8th Dec, 2020

Research Ethics Panel response

☑ the research can go ahead as planned

☐ further information is needed on the research protocol (see details below)

☐ amendments are requested to the research protocol (see details below)

School REO.. Date 5 Jan 2021 06/01/2021

A. LIST OF POINTS TO CONSIDER WHEN SUBMITTING AN ETHICS REVIEW (taken from ESRC (2012) Framework for Research Ethics).

Risks
1. Have you considered risks to:
    the research team?
    the participants? Eg harm, deception, impact of outcomes
    the data collected? Eg storage, considerations of privacy, quality
    the research organisations, project partners and funders involved?

Yes.
2. Might anyone else be put at risk as a consequence of this research?
None.

3. What might these risks be?
No.

4. How will you protect your data at the research site and away from the research site?
In the interview process, we will save the collected data in a special equipment with password. After the interview, we will sort the data immediately.

5. How can these risks be addressed?
We will save the collected data in special equipment with password. The data will only be used in the research. In addition, we will destroy all date after this research.

Details and recruitment of participants
6. What types of people will be recruited? Eg students, children, people with learning disabilities, elderly?
Students in university, governors in departments, engineers in institutions, managers and employees in companies.

7. How will the competence of participants to give informed consent be determined?
We will inform and ask them before the interview.

8. How, where, and by whom participants will be identified, approached, and recruited?
I myself will identify the participants via my personal working networks and connections in Guiyang, Guizhou that closely related to my current working institution. Mostly, the participants are the working colleagues from my institute and we will recruit the participants by phone, emails and communication tools (e.g. Skype, Wechat).

9. Will any unequal relationships exist between anyone involved in the recruitment and the potential participants?
No.

10. Are there any benefits to participants?
No.

11. Is there a need for participants to be de-briefed? By whom?
No.

Research information
12. What information will participants be given about the research?
Aiming to make them talk freely, we will tell participants the major purpose of this research. We will also inform them that we will protect their all privacy to remove their any fears.

13. Who will benefit from this research?
No.

14. Have you considered anonymity and confidentiality?
Yes.

15. How will you store your collected data?
We will save the collected data in a special equipment with password (e.g. USB storage etc.)

16. How will data be disposed of and after how long?
We will destroy all date after this research.

17. Are there any conflicts of interest in undertaking this research? Eg financial reward for outcomes etc.
No.

18. Will you be collecting information through a third party?
No.

Consent
19. Have you considered consent?

Yes.

20. If using secondary data, does the consent from the primary data cover further analysis?
We don't use secondary date.

21. Can participants opt out?
Yes, they can exit in the whole process.

22. Does your information sheet (or equivalent) contain all the information participants need?
Yes.

23. If your research changes, how will consent be renegotiated?
We will redesign the interview and apply for the agreement from ethic panel.

Ethical procedures
24. Have you considered ethics within your plans for dissemination/impact?
Yes.

25. Are there any additional issues that need to be considered? Eg local customs, local 'gatekeepers', political sensitivities
No.

26. Have you considered the time you need to gain ethics approval?
Yes.

27. How will the ethics aspects of the project be monitored throughout its course?
We will follow the structure of the interview. Afterwards, we will save the all process in the interview. When there is any ethic problem happen in the interview, we will stop the interview immediately, improve the process and apply the promise from the ethic panel.

28. Is there an approved research ethics protocol that would be appropriate to use?
Yes.

29. How will unforeseen or adverse events in the course of research be managed? Eg do you have procedures to deal with any disclosures from vulnerable participants?
In the research, we will hide the names of participants. Therefore, there is no potential opportunities for privacy be disclosure. The device will be set with password. Even if we lost the storage, we sill can protect participants' privacy.

We will compile fully and follow the University of Nottingham ethics guidance and provide the confidential forms and notice to all participants before they commit to the interviews and any methods we may conduct.

Appendix 3 Interview Questions

Name（姓名）:	Age（年龄）:
Gender（性别）:	Participate ID（编号）:
Occupation（职业）:	Title（职务/职称）:
Education Degree（教育程度）:	Income（收入）:
Living Place（居住地）:	Years live in Guiyang（在贵阳居住的年限）:

1. Do you know about Sponge City Programme (SCP)? Please introduce the typical SCP facilities you know. (您了解海绵城市吗？请介绍您知道的海绵城市典型设施。)

2. If you know about SCP. Which channel did you get the relevant information from? Have local decision-makers solicited your opinions on SCP? (若您了解海绵城市。您是从哪个渠道了解到相关信息的？地方决策者是否征求过您对 SCP 的意见？)

3. Did you participate in the planning and following implementation of SCP? If so, what aspect were you involved in? (海绵城市规划和执行过程中您是否参与？若有参与，参与的是什么？)

4. What do you think the sponge city construction has brought you? What do you like or dislike most about sponge city? (您觉得海绵城市建设给您带了什么？您最喜欢或不喜欢海绵城市给您的生活带来的什么？)

5. What problems and challenges does the SCP face in the implementation process? Do you think there will be greater development potential and opportunities for sponge cities in the future? (您觉得海绵城市在执行过程中遇到的问题和挑战是什么？您认为未来海绵城市还有更大发展潜力和机遇吗？)

6. Do you know the role and contribution of sponge cities to urban flood management? (您知道海绵城市对城市防洪的作用和贡献吗？)

7. Have you ever experienced major floods in Guiyang? If you have experienced it, please briefly describe the relevant flood events （您经历过贵阳市较大的洪水灾害吗? 若经历过请简单描述一下相关洪水事件。）

8. Please select your favourite three pictures as your favourite flood management measures. And explain the reasons for choosing them. (请选择您最喜欢的三幅图片，作为您最喜欢的防洪措施。并说明选择的他们的原因。)

9. Do you know the Grey-Leading flood management measures in Guiyang? Do you trust Grey-Leading flood management measures in Guiyang? (您了解贵阳市工程性防洪措施吗? 你信任贵阳的工程性

洪水管理方法吗？）

10. Do you trust green flood management measures represented by SCP? (您信任以海绵城市为代表的绿色防洪措施？）

11. What are the advantages and disadvantages of Grey-Leading flood management and SCP flood management? (您觉得工程防洪和海绵防洪各自有什么优缺点？）

12. Do you understand the concept of Natural Flood Management (NFM)? Do you support extending the sponge concept to the scope of the catchment? (您了解海绵流域概念吗？您是否支持把海绵概念延伸使用到流域的范围?)

13. Do you support the pilot Sponge Catchment Management Framework (SCMF) project? Will you participate in or help with the SCMF project? (您是否支持试点开展海绵流域项目？是否会参与或帮助海绵流域试点项目？）

14. What are your opinions and suggestions on NFM, SCP, Grey-Leading Infrastructures and SCMF? (您对自然防洪、海绵城市、传统灰色基础设施以及海绵流域试点项目有什么意见和建议？）

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Appendix 4 Supervision Meeting Records

Supervision meeting records

Num	Date	Signed Supervisors
1	September 15 2018	Faith Chan
2	Oct 30 2018	Faith Chan
3	Dec 30 2018	Faith Chan
4	Feb 9 2019	Faith Chan
5	March 3 2019	Faith Chan
6	March 24 2019	Faith Chan
7	May 30 2019	Faith Chan
8	June 15 2019	Faith Chan, Meili Feng
9	August 15 2019	Faith Chan
10	Oct 15 2019	Faith Chan
11	Dec 15 2019	Faith Chan
12	Feb 15 2020	Faith Chan
13	March 15 2020	Faith Chan
14	June 29 2020	Faith Chan, Meili Feng
15	July 15 2020	Faith Chan
16	Oct 15 2020	Faith Chan
17	Dec 20 2020	Faith Chan
18	Jan 15 2021	Faith Chan
19	Feb 17 2021	Faith Chan
20	May 19 2021	Faith Chan
21	June 20 2021	Faith Chan
22	July 23 2021	Faith Chan
23	August 15 2021	Faith Chan
24	Oct 18 2021	Faith Chan, Meili Feng
25	Dec 19 2021	Faith Chan
26	Feb 9 2022	Faith Chan
27	March 15 2022	Faith Chan
28	May 24 2022	Faith Chan
29	June 25 2022	Faith Chan
30	July 1 2022	Faith Chan, Meili Feng
31	July 20 2022	Faith Chan
32	August 1 2022	Faith Chan, Meili Feng
33	August 15 2022	Faith Chan
34	Sep 1 2022	Faith Chan, Meili Feng
35	Sep 15 2022	Faith Chan
36	Oct 1 2022	Faith Chan
37	Oct 20 2022	Faith Chan
38	Oct 30 2022	Faith Chan
39	Nov 11 2022	Faith Chan

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Appendix 5 Training Records

Training records

Num	Course title	Date
1	Planning your Research	30 June 2021
2	Understanding Supervision	7 July 2020
3	Effective Literature Searching	14 July 2020
4	Research Ethics	21 July 2020
5	Preparing for your Annual Review	28 July 2020
7	Research Methods and Practice	2 July 2020
8	Preparing for your Viva	10 September 2020
9	Bibliographic Research Data Management EndNote Basic	2 July 2020
10	Bibliographic Research Data Management EndNote Advanced	9 July 2020
11	Introduction to Nvivo-NVivo Introduction	4 August 2020
12	Build a Qualitative Database with Nvivo-NVivo Intermediate	11 August 2020
13	Textual Analysis with Nvivo-NVivo Advanced	18 August 2020
14	Introducing your University Library	6 October 2020
15	Data Analysis Course by Prof. Joe Hair	24, 25, and 26 May 2021
16	Econometrics in Social Sciences Research & NSFC Funding Applications	11 June 2021
17	Mixed Methods by Prof. Venkatesh	11, 17 and 21 June 2021
18	Theory of Experimental Design for Engineers	28 & 29 June 2021

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Appendix 6 Publications

Publications

Num	Year	Publications	Types	Sorts	Status	Connections with this thesis
1	2020	The transition of urban water resources management integrates the Nature-Based Solutions (NBS) with the Sponge City programme (SCP) to improve Natural Flood Management (NFM) in Chinese cities	SCI	First Author	Published	Chapter 2
2	2021	Exploring the ways to deliver better socio-ecological practice in the Sponge City Programme (SCP): the case of Gui'an New District, Guiyang, Southwest China	SCI	First Author	Published	Chapters 3 and 4
3	2021	Urban Flood Risk Management (UFRM) in the context of Sponge City: the case of Guiyang, Southwest China	SCI	First Author	Published	Chapters 3, 4, and 5
4	2023	Developing a "Sponge Catchment Management Plan (SCMP) "framework on catchment-scale: the case of Guiyang, SW China	SCI	First Author	Published	Chapters 3, 6 and 7

Appendix 7 Meetings and Forums

Meetings and Forums

Num	Date	Meeting	Place
1	Sep 2018	2018 (The Sixth) China Water ecology conference	Hohai University, Nanjing, China
2	Dec 2018	Efficient Utilization of Water Resources and Water-saving Technology Forum 2018	Guangzhou, Guangzhou, China
3	Nov 2019	2019 annual conference of the Chinese Hydraulic Engineering Society (CHES)	Yichang, Hubei, China
4	June 2019	Socio-Ecological Practice Research: from practice, for practice, beyond practice (SEPR) 2019 Shanghai programmes	Shanghai, China
5	Oct 2022	Modelling ecosystem restoration for multiple benefits in urban and natural environments	Oxford, UK
6	December 2022	2022 Annual Conference of Environmental Geosciences Branch of Chinese Society for Environmental Sciences	Beijing, China

Appendix 8 Certifications

Certifications

Num	Certifications
1	Class 1 Cost Engineer
2	Constructor
3	Consulting Engineer
4	Consultant Engineer
5	Economics Professional Qualification
6	Project Management Professional (PMP)
7	Hydraulic-projects trader
8	Project Manager Certificate (Safety Certificate B)
9	Senior Engineer
10	Senior Economics Professional
11	Bidding Expert

Appendix 9 Patents

Patents

Num	Patents
1	An early warning device for hydrology
2	A water monitoring device
3	The utility model relates to a solid-liquid separation device for smart city water pollution treatment equipment
4	A sponge city residential area surface runoff ecological purification equipment
5	The utility model relates to a connecting structure supported by spillway pipes for sponge cities

Appendix 10 Journal Reviewers

Journal Reviewers

Num	Patents
1	Urban Forestry & Urban Greening
2	Environmental Science and Pollution Research

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