TU Delft

LIVE WITH WATER

A sustainable water-oriented urban development pattern

Graduation Report by Jiaqi Wang

Figure 1.0.1
The Lake Chao
by Li Qian
钱黎 摄

COLOPHON

Master Thesis-P5 Report
MSc Architecture, Urbanism and Building Sciences-Track Urbanism
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Live with Water

Sub title:
A sustainable water-oriented urban development pattern,
the Lake Chao Basin as a study case

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"Water is indispensable 'stuff' for maintaining the metabolism, not only of our human bodies but also of the wider social fabric. The very sustainability of cities and the practices of everyday life that constitute 'the urban' are predicated upon and conditioned by the supply, circulation, and elimination of water. "
Swyngedouw (2004, p. 1).

Figure1.0.2
Morning Chorus in Science Island(Hefei Institutes of Physical Science)
Source: Yang Jing 科学岛晨曲 旌阳摄

Preface

The report is the outcome of my full-year graduation project in the Urban Metabolism and Climate Studio at TU Delft, which has been so far the biggest project that I have conducted in my life as an urbanist.

During my first year of Master's study in the Netherland, I am deeply impressed by the water management system here. The water system seems an inseparable and unavoidable part of urban planning in the country. This is of course partly due to the natural limitation of the territory, while it still pushes me to reflect on the current urbanisation paradigm in my motherland.

Born in the hinterland on the periphery of the Yangtze River Delta in China, not only have I witnessed the dramatic urbanisation process in my hometown but also I remembered all the environmental challenges along with this change: the water pollution in Lake Chao since 2007, the water scarcity in 2019 and the huge flooding in 2020. Thus, I feel the urgency of addressing the water issues in my hometown, especially when I read about the proposal for the 'Yangtze to Huai canal project'. All of these form my motivation for dedicating my whole graduation year to addressing the current water challenge in the Lake Chao Basin.

During this full year of study, I would like to thank my first mentor Kristel Aalbers first and foremost, who gives me in-depth guidance and encouragement all the way through. Also, I am especially grateful for all the critical comments and enthusiastic support from my second mentor Remon Rooij, and Alex Wandl, the leader of Urban Metabolism and Climate Studio. Furthermore, I want to thank my peers: Jasmijn and Jih-Ah at Urban Metabolism and Climate Studio, Bowen from the Complex City Studio and Rosemarijne from Urban Fabric Studio, for discussing each other's projects.

Last but not least, I would like to express my deep thank to my parents and grandparents. Without their love, support and influence on my growth, this thesis would never be written.

Figure 1.0.3

A Scheme of
'Water-Oriented Urban Development'
By Author

Abstract

In the past few decades, urbanisation in China has been witnessed with great speed. While this has brought a rocketing economy and improved citizens' average living standards, it does not come without any expense. Such intensive urban sprawling and industrialization in China has added up a great risk to upcoming climate challenges, especially bringing about water issues such as flooding, water pollution and drinking water scarcity that are closely linked with citizens' safety, well-being and future prosperity. Though many policies and initiatives have been proposed to mitigate these water issues, few of them can solve the issues systemically.

Hence, with the Lake Chao Basin as a backdrop, the project aims at tackling these water issues from the perspective of systemic design and thus proposes a 'water-oriented urban development'. Through the maximization method, a pattern language for 'water-oriented urban development' is constructed. This set of pattern language not only provides solutions to address the main problems regarding water quantity, water quality and water safety in the region but also is targeted at bringing about a systemic change in the area by intervening on deep leverage points.

To illustrate the implementation of the pattern language, a multi-scale framework for the Lake Chao Basin is created, with the vision for Tanchong River Basin 2030 as a strategic project. It shows how the implementation of the pattern language could reshape the landscape on different scales, engage various stakeholders and promote a sustained commitment to the water system among citizens. This will also provide transferable knowledge to other areas on how the patterns could be integrated into the future urban development process and contribute to the sustainable water system.

Keywords: Systemic Design, Urban Metabolism, Flooding, Water Pollution, Water Scarcity, the Lake Chao Basin

Reading Guides

The thesis has eight chapters:

In the first chapter, the main motivation and aim behind the research are introduced, followed by the put forward of the main research question.

Chapter 2 explain the design of the research approach and introduces the methods used.

Chapter 3 analyze the theories and set up a conceptual framework that guides the project.

Chapter 4 includes the main findings from the diagnosis of the context, which paves the way for concretizing the design in the following two chapters.

From Chapter 5 to Chapter 6, the design exploration process of the pattern language is explained in several stages.

In Chapter 7, a vision for the Lake Chao Basin with a strategic project is shown, to illustrate the implementation outcome of the pattern language designed.

Finally, in Chapter 8, the conclusion to the main research question is drawn, with a reflection on the project from different perspectives.

Glossary

Urban metabolism: "the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste."(Kennedy,2007,p.44)

Water safety: usually refers to the safety in, on, and around bodies of water, While in this project, this concept mainly is connected with the issue of protection from flooding.

Water quality: is the suitability of water for drinking, recreation, and as a habitat for aquatic organisms or wildlife(Neary,2002).

Water quantity: refers to the timing and total yield of water from a watershed. In the project, the concept is especially linked with the amount of water available for drinking and thus concerns with the drinking water supply, allocation and consumption manner.

Water system: In the thesis, the water system contains all types of water in the urban metabolism, including the natural water system of surface water, artificial water system of freshwater supply and wastewater treatment and all other water in the hydrological process, such as raining, infiltrating and evaporating. It is all of them that compose the whole dynamic water system connect between humans and nature.

Leverage Points: This concept is based on its analogy to a mechanical level, originating from a famous saying from Archimedes "Give me a place to stand and with a lever I will move the world." In the theory of systemic analysis, it refers to the place where intervention could be applied to change a system(Meadows, 1999; Metabolic,2018). Similar to its counterpart in mechanical science, the deeper the leverage point is, the bigger impact on the behaviour of the system it leads to.

Abbreviation

UN: United Nations

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

IPCC: Intergovernmental Panel on Climate Change

CMA: China Meteorological Administration

CWR: China Water Risk (non-profit organisation)

NOAA: National Oceanic and Atmospheric Administration (U.S. Department of Commerce)

NASA:The National Aeronautics and Space Administration

SDGs: Sustainable Development Goals

Mamsl: Metres above mean sea level

FAS: Future Autonomous situation

SWOT: Strengthens, Weaknesses, Opportunities and Threats

Content

Figure1.0.4
The Solar panel on the river in Lujiang
Source: ZHANG Dongdong 庐江河道光伏发电 张东栋摄

CHAPTER I. INTRODUCTION

Introduction

This chapter first gives an overview of the water challenges from both global and regional scales and points out the urgency of attaching more importance to sustainable development worldwide, which serves as a professional motivation for the thesis. Then, by introducing the current water issues in the Lake Chao Basin, a problem statement is built up to highlight why a systemic change is especially needed in the study location. This brings to the aim and the main research question of the study.

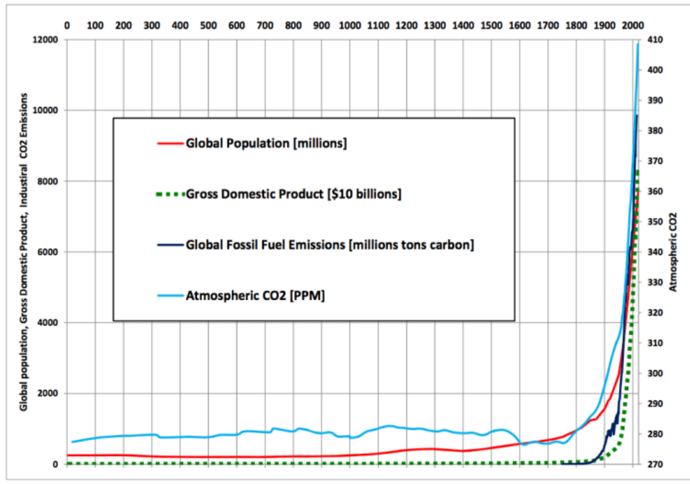
1.1 Motivation

1.1.1 On Global Climate Change

Among all the global issues in 21 century, climate change is undoubtedly the most worrying one. With the exponentially growing combustion of fossil fuels in both industrial production and vehicles, the amount of CO2 concentration in the atmosphere has been rocketing(see figure 1.1), which has caused the mounting global climate crisis(Brooke et al.,2019). According to the analyses carried out independently by NASA and NOAA, the average world temperature has increased by more than 1.0 degrees Celsius since the industrial revolution(See figure 1.2). Meanwhile, with the ever-expansion of the global market, the industrialization in developing countries and the growing world population, this trend is not about to stop in the foreseeable future(Baer,2012), which has put the whole planet at extraordinary risk.

There are many consequences of climate change that are closely related to people's daily life. One of them is the aggravation of water issues in terms of its quantity, safety and quality. To begin with, the heat waves brought by climate change are to blame for the worsening droughts, which give rise to the unstable drinking water quantity in many areas(Center for Climate and Energy Solutions, 2022). It is also likely to account for the increasing frequency and intensity of heavy precipitation over many regions. This means that floodings are not only likely to be witnessed by coastal cities by the rising sea level and high tide, but could also hit other areas (Seneviratne et al.,2012). Furthermore, the quality of drinking water is jeopardized by the salinization resulting from sea-level rise(Vineis et al.,2011) and by the degradation of the ecosystem in and along the water body(United Nations, 2014). All these interrelated processes play a role in deteriorating human's relationship with water and urging us to give enough attention to climate change(see figure 1.3).

Figure1.1
Carbon emissions, Population growth and GDP
By Brooke, J. (2019)
Data Source: Angus Maddison,U.N,World Bank,Tom Boden and Bob Andres, Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory, and Gregg Marland, Research Institute for Environment, Energy and Economics and NOAA



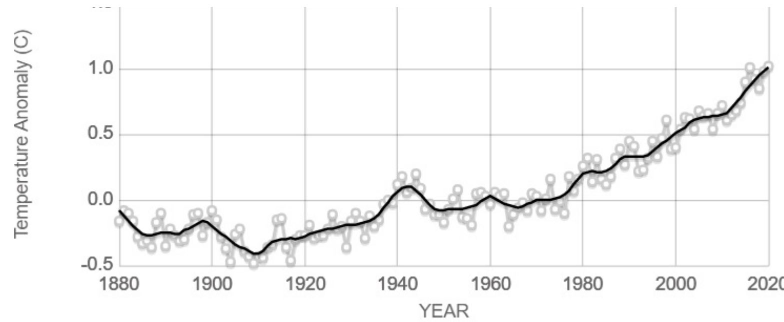


Figure1.2
Global mean temperature over time since 1880
Credit: NASA/GISS
Data:NASA's Goddard Institute for Space Studies (GISS).

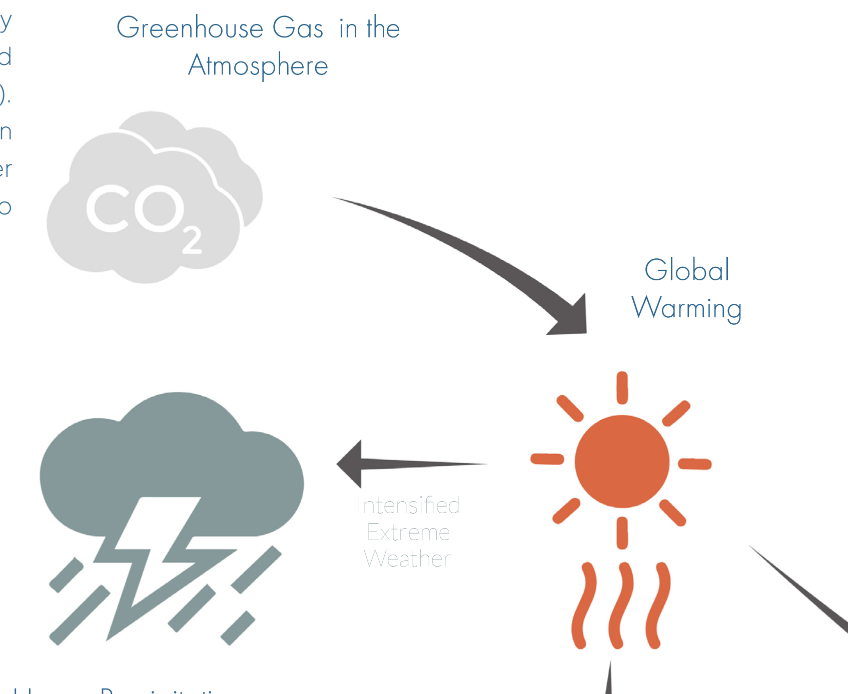
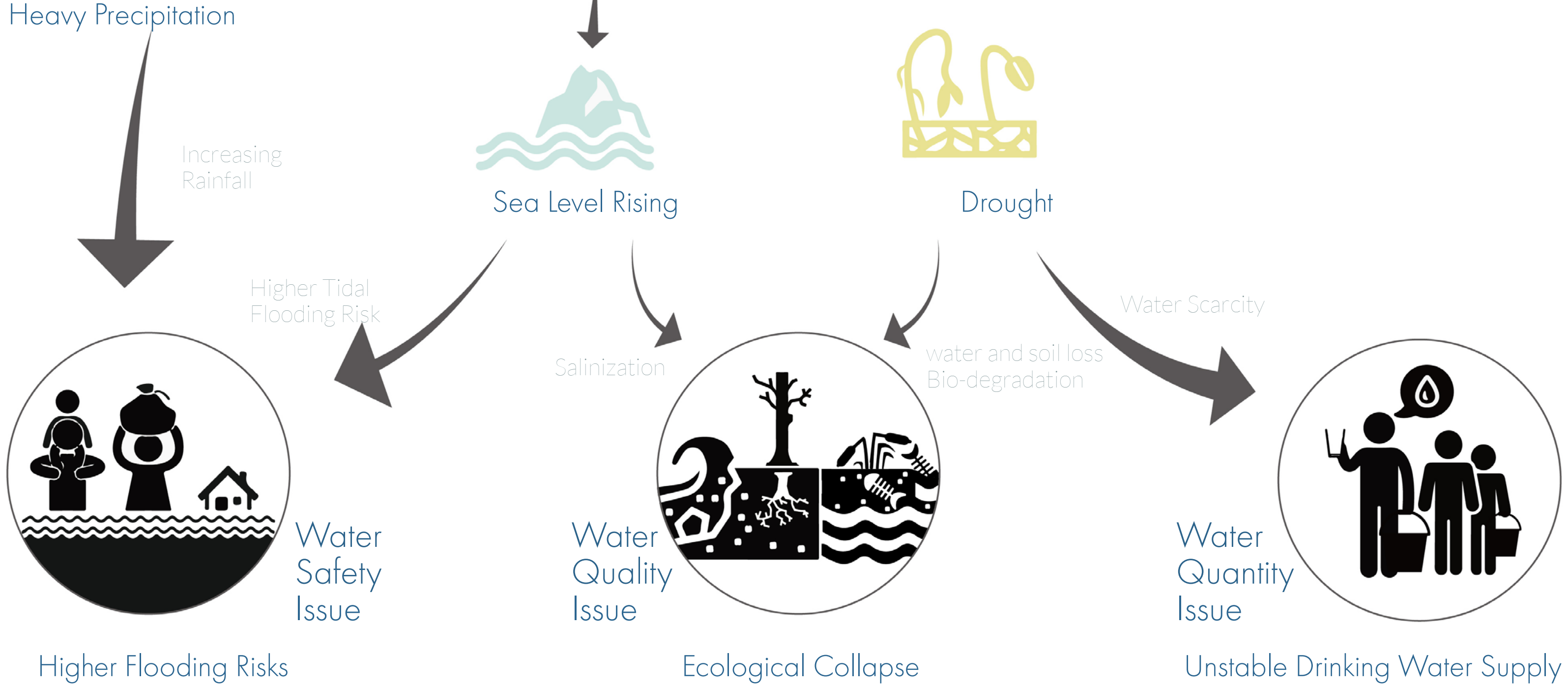



Figure1.3
Climate change and its impact on global water issues
By Author

1.1.2 On the Global Water Issues

While it is fair to say some water issues are caused by natural processes, there is no denying that the water issues in the 21st century are more serious, widespread and complicated in comparison with the past(Saeijs,1995), due to the human activities and the accompanied climate change.

Among all the water issues, flooding is the first to take into account. Historically, people in low-lying areas, especially along the river and coastline, have been vulnerable to floods. Regions, such as India and the southern part of China, are more prone to flooding due to the seasonal monsoon storm(see Figure 1.4), which are determined by meteorological conditions. Extreme weather induced by El Niño/Southern Oscillation (NOAA, 2015) also leads to uncertain floods every 3-5 years in multiple areas. This all makes flooding a prevalent issue globally. Though the fatality caused by floods has lowered thanks to the advance in infrastructure and other flooding control methods, floods and storms still account for about 67 per cent of the global natural disasters events (Padli et al., 2013). In recent decades, the increasing flooding events also caused great damage to society. From 1990 to 2019, floods all over the world have led to a direct economic loss of over $776.9 billion in total (Ritchie & Roser, 2014). Though there is not yet enough direct evidence to show how climate change will have an impact on these flooding patterns, it is already clear that humans have to prepare for the upcoming extreme rainfall and concomitant flooding(UNEP, 2020).

Turning towards the water quantity and quality problems, the matter is concerning as well. Water scarcity can be seen in every continent(UN Water, 2021). Especially in arid regions where the natural water supply is unstable, the increasing water demand can put them at high risk (see figure 1.5). In addition, the drinkability of water should also be considered simultaneously. Many areas, though not showing up in the previous water scarcity map, are running out of fresh drinking water due to pollution and salinisation. This is particularly prominent in industrialized regions, such as western Europe and North America(see figure 1.6), but it might also be confronted by countries undergoing industrialization right now.

To summarize, the water issues nowadays have already become a global challenge that is worth the attention of everyone from everywhere.

"At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (high confidence). "
(IPCC,2021,P.16)

'2.2 billion people around the world still lack safely managed drinking water, including 785 million without basic drinking water.'
(UN,2020,P.36)

Figure1.4
Distribution of Floods between 1970 and 2019 Around the World
By Shichadao. (2020)
Source: The World Bank and Columbia University

50-Year Flooding Event
20-Year Flooding Event

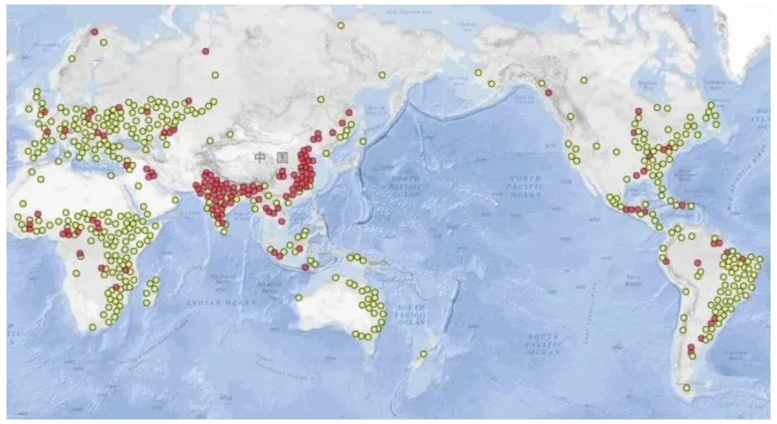


Figure1.5
Water Scarcity Around the World
Source:World Resources Institute. (2013).

Baseline Water Stress
Low(<10%)
Low to medium(10-20%)
Medium to high(20-40%)
High(40-80%)
Extremely high(>80%)
Arid & low water use
no data

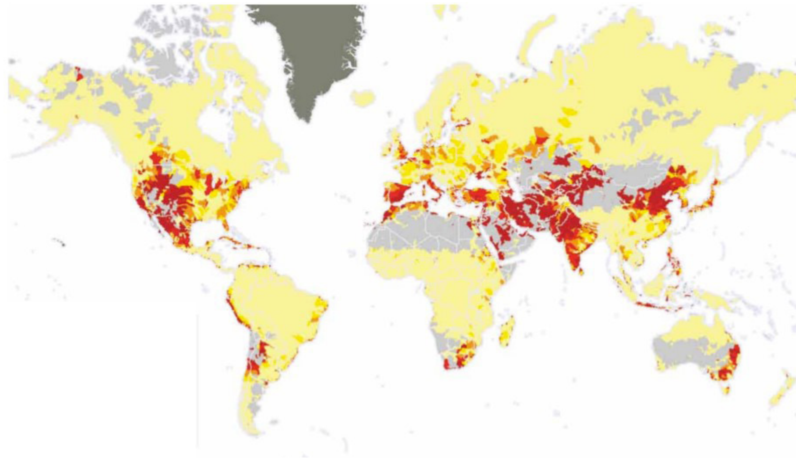
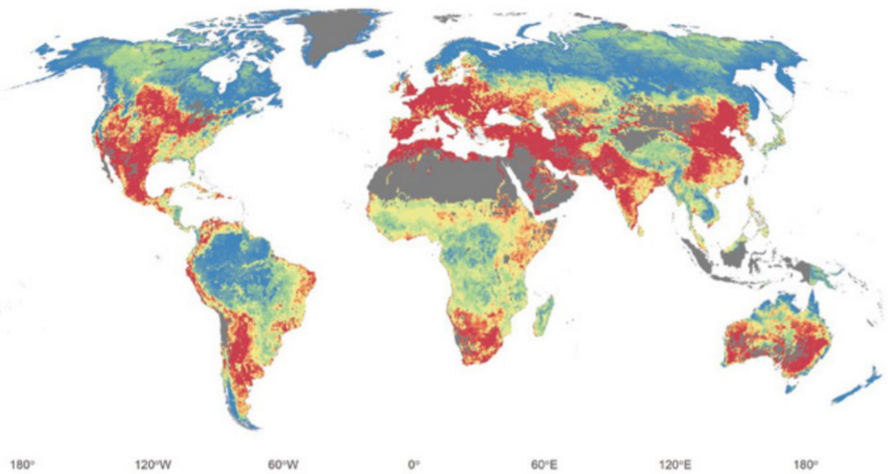


Figure1.6
Water Quality Risk
Credit and Data Source: World Bank. (2019).

High
Low



1.1.3 On Sustainable Development

Confronted with all these challenges mentioned, the concept of sustainable development was first put forward in the Brundtland Report by the United Nation officially in 1987. It not only suggests reaching a harmony between humans and nature but also emphasizes sustaining our future generations:

"Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, et al. 1987, P. 37).

To clarify the actions needed, in 2015, the United Nations has proposed 17 goals of sustainable development, which aim at protecting our planet as well as ensuring all people on the earth enjoy equal peace and prosperity by 2030(UNDP, 2022).

Though it is hard to define the priority for all these goals, Rockström and Sukhdev(2016) from Stockholm Resilience Centre argued that the sustainability of the biosphere should be seen as the foundation for society and the economy and illustrated their interpretation with a 'wedding cake' diagram(see figure 1.8). This gives us a new way of achieving sustainable development goals by prioritizing the sustainability of the environmental layer. Taking water as an example, a sustainable water system should be considered the foundation of healthy individuals, a prosperous society and an economy. Thus, finding solutions to mitigate the global water issues should be seen as an indispensable move to take on our way to reach sustainability, which was highlighted on the UN 2030 agenda.

Figure1.7
The 17 SDG Goals
Source: United Nations

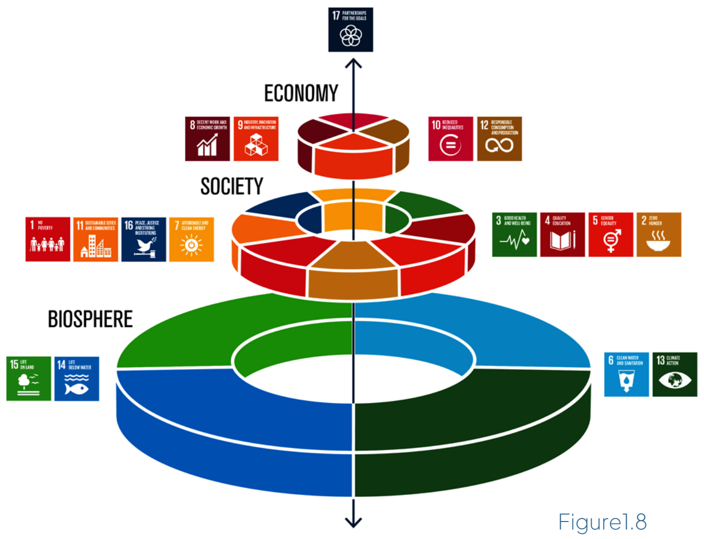


Figure1.8
The SDG 'wedding cake'.
Source: Rockström and Sukhdev(2016) from Stockholm Resilience Centre

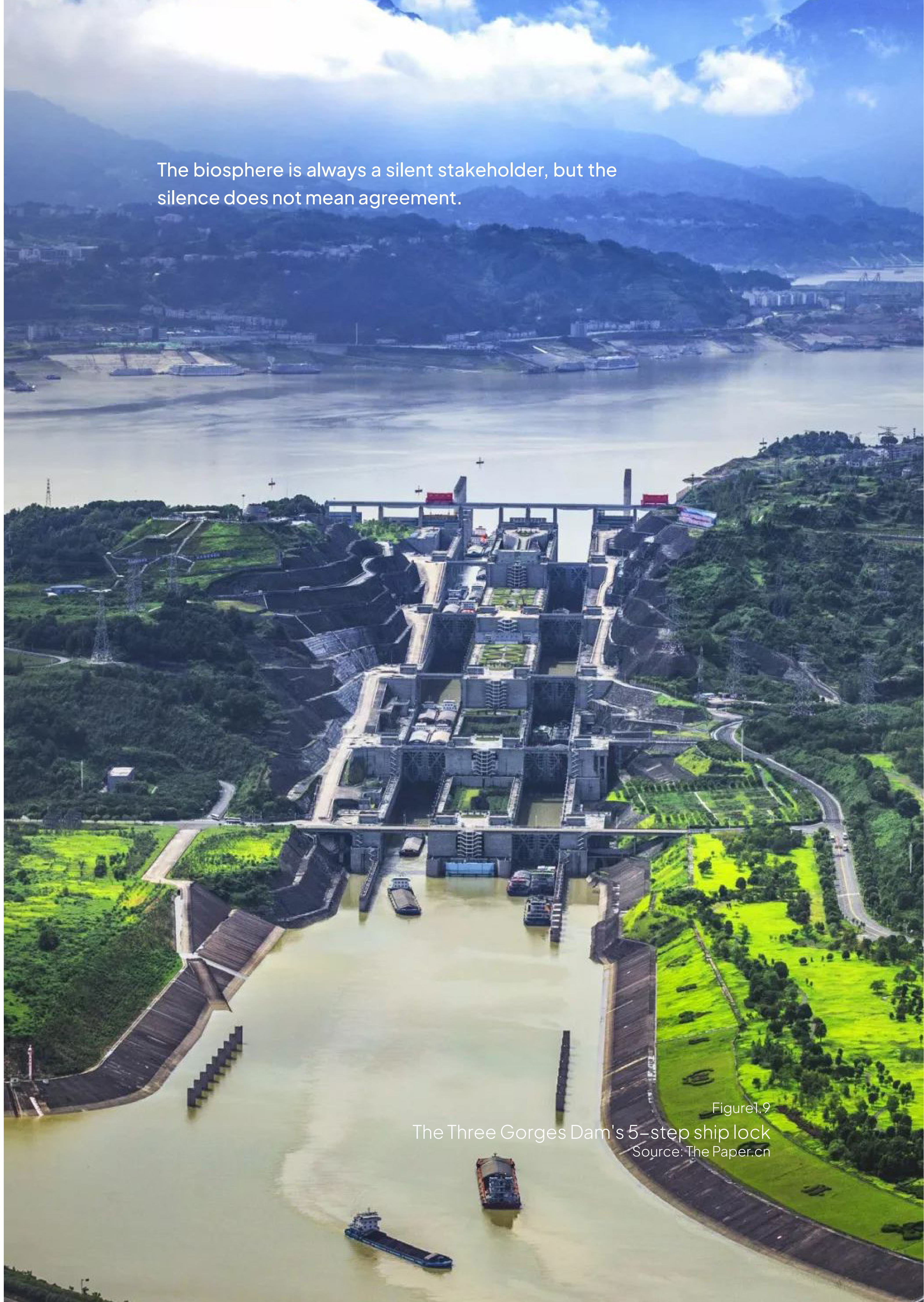


Figure1.9
The Three Gorges Dam's 5-step ship lock
Source: The Paper.cn

1.1.4 Urbanisation in Yangtze River Delta

Figure 1.9
the Functional Urban Area in Mainland China
by Ma, S., & Long, Y. (2020)

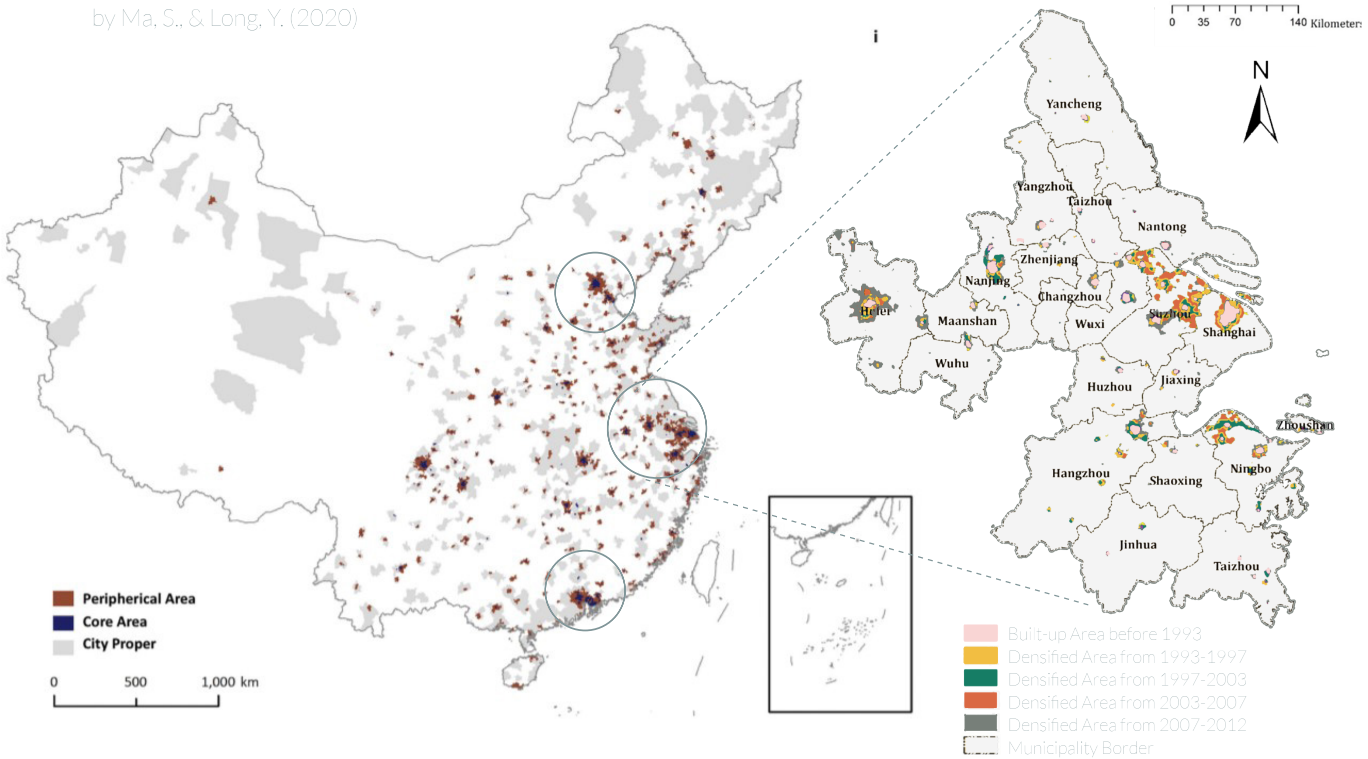
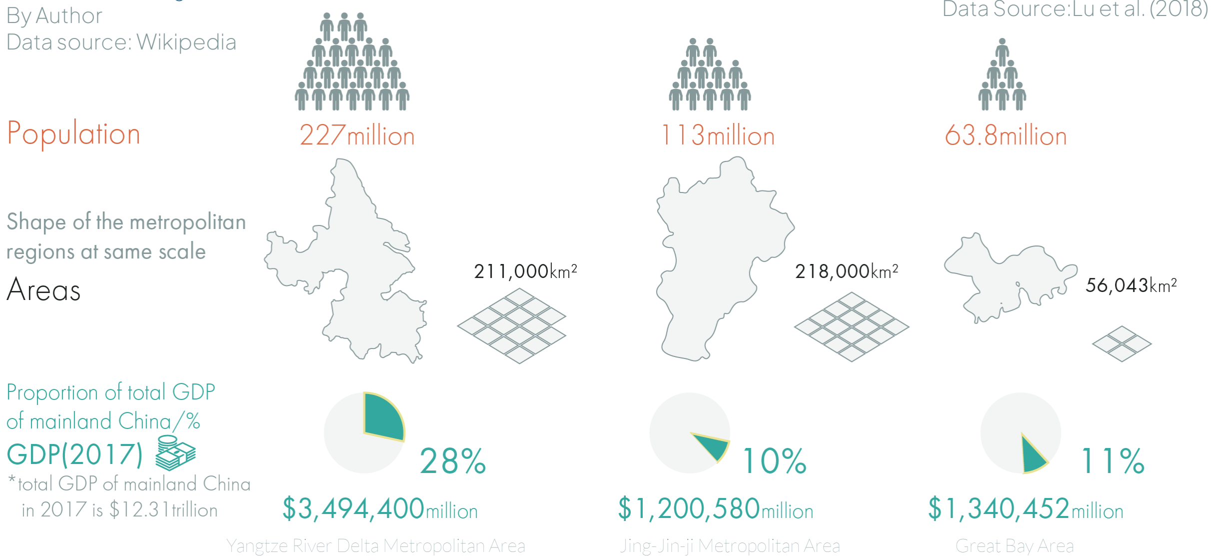


Figure 1.10
the Urbanisation of Yangtze River Delta
from 1993 to 2012
Data Source: Lu et al. (2018)

Figure 1.11
the Profile of Yangtze River Delta
By Author
Data source: Wikipedia

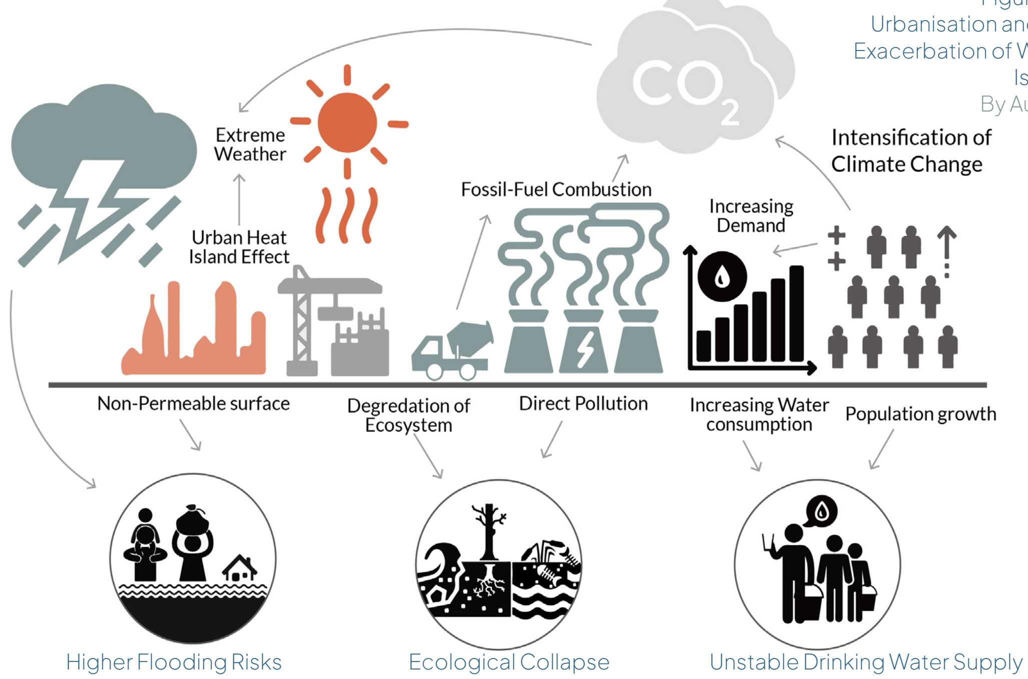


Being one of the most densely populated areas in China, the Yangtze Delta accommodates 227 million inhabitants. It is composed of 25 municipalities from three Provinces(Anhui, Zhejiang and Jiangsu) together with Shanghai, the centrally-administered municipality. As one of the most powerful economic engines of China, the Yangtze River Delta contributes nearly 30 per cent of GDP for the whole country, which is the highest one among the three major metropolitan regions in China(see figure 1.11).

However, economic prosperity does not come without any expense. Rapid urbanisation has been witnessed in the area, especially after 1993 when the eastern part of Shanghai was opened up as a special economic zone(see figure 1.10). From 1993 to 2003, the densification first took place in the outskirts of cities along the Yangtze river such as Shanghai, Suzhou, Nanjing and the coastal area in Ningbo. Since 2003, the clusters in the northwestern part of Shanghai emerged while the city of Hefei also witnessed dramatic urban sprawling. Such an exponential speed of urbanisation not only largely covers the nature space but also is accompanied by pollution and emissions from extensive industrialization. In the Yangtze River Delta, energy consumption is still largely based on coal combustion and 70% of the energy is consumed in the industrial sectors, with the majority of it going to heavy chemical industries (Dong & Dai, 2015) This ever-intensified foreign investment pattern and the unsustainable way of energy consumption have led to the increase in haze pollution problem(Ma et al., 2019). Meanwhile, the water scarcity and pollution problems are also prominent in this area (which will be detailed discussed in the next chapter 1.2.2).

Although the authorities have already realized the importance of low-carbon growth, many cities in the Yangtze River Delta have not yet found a feasible pathway to develop sustainably and probably get trapped in this 'lock-in' situation of the 'unstoppable' urban sprawling situation with the projected population growth and economic growth pressure. This will definitely lead to their further exposure to different types of environmental problems and increase the risk of water issues in the future(see figure 1.12).

Figure1.12
Urbanisation and the Exacerbation of Water Issues
By Author



1.1.5 Water issues in the Yangtze River Delta

As already mentioned previously, such a rapid urbanisation process leaves the already sensitive biophysical environment in the Yangtze river delta with even more difficulties. This is especially true when it comes to water issues.

Water Safety

The flooding issues of the Yangtze River Basin can be dated back thousands of years ago(He, 2000). Though no direct clues can be found to show the correlation between climate change and the increased flooding in the lower Yangtze plain and delta area, the risk index of heavy storms in the Yangtze River Delta has grown from 0.2 to nearly 0.8 since 2008 (Huafeng Media Group & Greenpeace, 2021). This can be particularly risky for agricultural-based districts like Anhui province, considering its low-quality infrastructure and the tremendous loss in the agriculture sector caused by flooding.

Water quantity

Yangtze river delta is also faced with extreme water quantity pressure. According to the baseline water stress map(see Figure 1.14), the Lake Tai Basin Area and Shanghai on the eastern coast are faced with extremely high baseline water stress. One prominent reason should be the high population density. But the decreased water storage capacity is also to be blamed. In fact, the surface water body has been shrinking in the Yangtze River delta in the past 50 years(Han et al., 2015), affected by the construction of grey hydrological infrastructure and urban expansion.

Water Quality

The water scarcity of the Yangtze River Delta is not purely the outcome of the water quantity issue. It is also severely affected by the water quality. The two major lake basins in the Yangtze River Delta, Lake Chao Basin and Lake Tai Basin have been confronted by severe eutrophication issues and experienced the worst water quality in the whole Yangtze River Basin(see figure 1.15). Meanwhile, the Yangtze river itself has been suffering from heavy metal pollution(See Figure 1.16). With over half of the pollutive industries located in the Yangtze River Basin, the water quality in the downstream region can be in great jeopardy(CWR, 2019).

Location of Yangtze River Basin and Yangtze River Delta

Figure1.13
Amount of Precipitation during the 2020 flooding period (June 1 to July 20)in Yangtze River Basin
Adapted from Wei Ke et al. (2019)

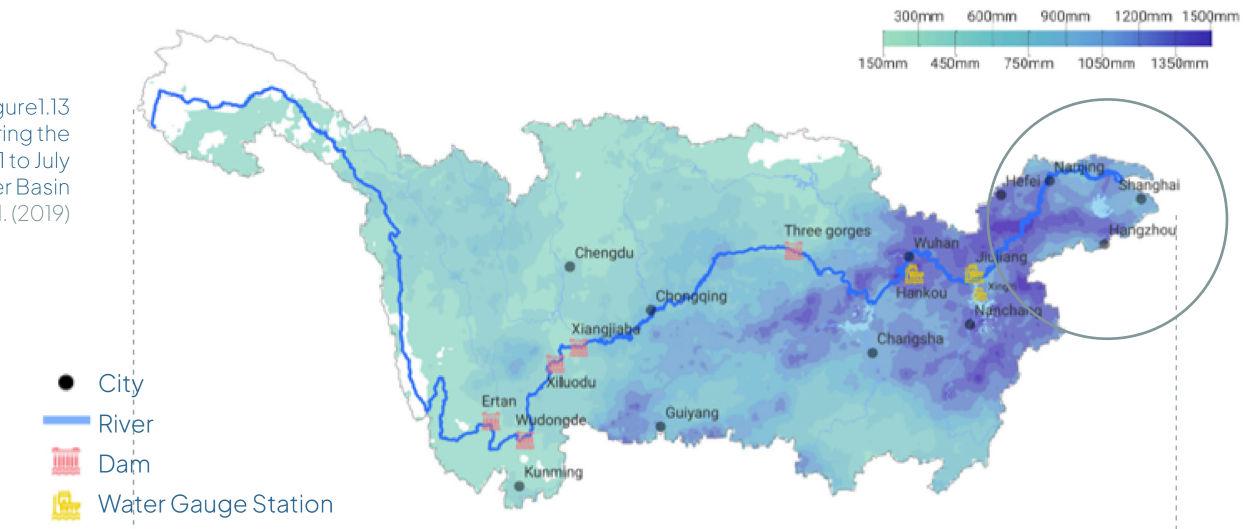


Figure1.14
Yangtze River Basin Baseline Water Stress
based on Baseline Water Stress from WRI Aqueduct Global Map

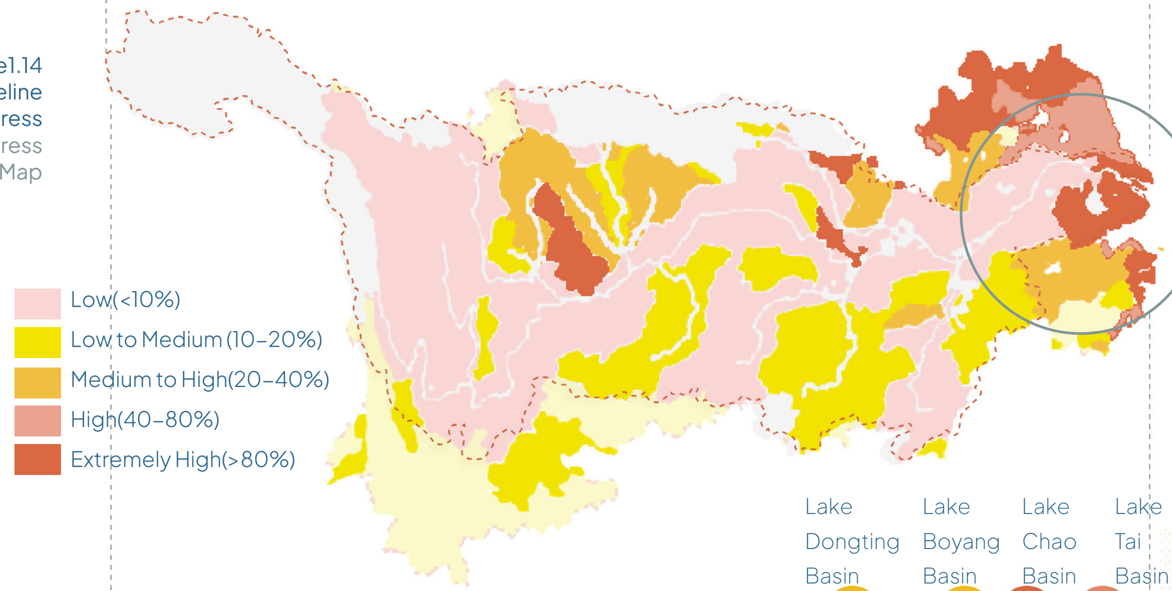
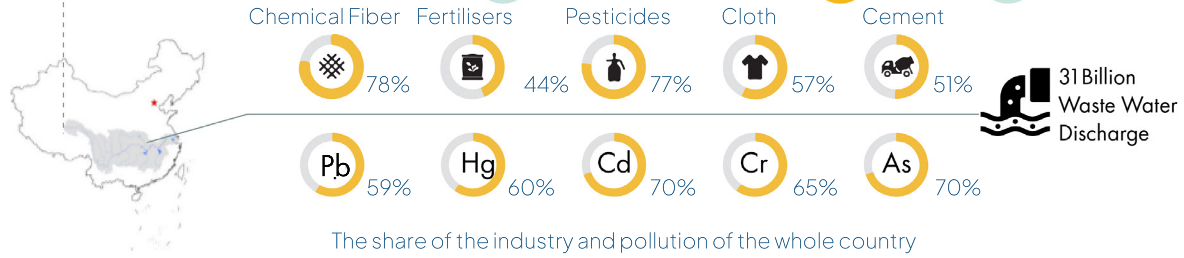


Figure1.15
Water Vitality Index of different sections in the Yangtze River Basin
Adapted from WWF(2020)

Figure1.16
Heavy metal pollution and related industries
Data Source :CWR(2019)
Adapted by the author



The share of the industry and pollution of the whole country

1.2 Problem Field

1.2.1 Getting to know the Lake Chao Basin

As a typical location to illustrate the dilemma between water issues and urbanisation, the Lake Chao Basin is chosen as the study location of this graduation thesis.

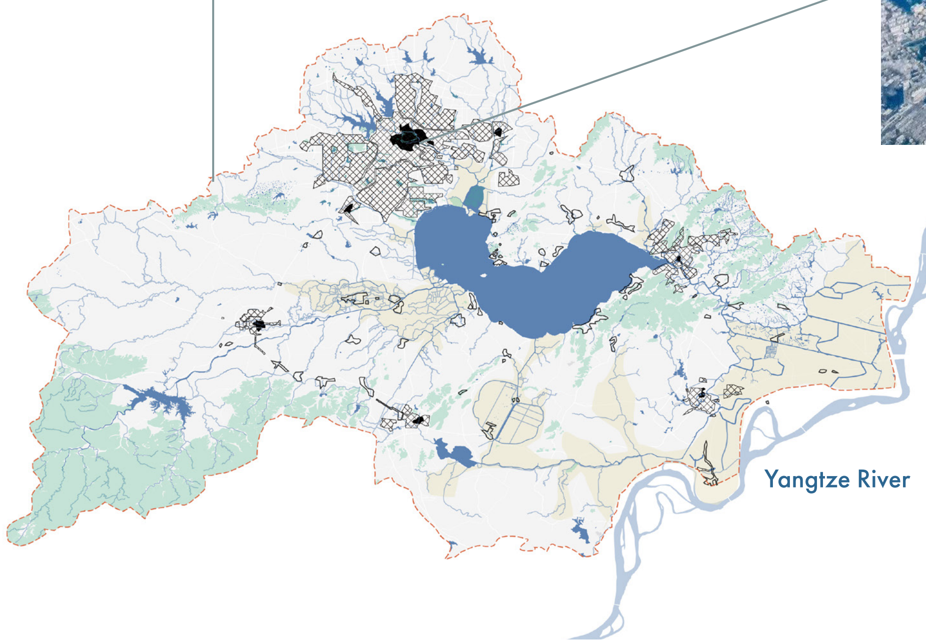
The Lake Chao Basin is part of Anhui Province and is located on the periphery of the Yangtze River Delta. It is surrounded by the mountainous Jianghuai Watershed in the north and west, and the Yangtze River in the south and east. The total area of the basin is 13,486 square kilometres, which accounts for about 9.3% of the total area of Anhui Province. It includes seven counties/cities: Hefei, Feidong, Feixi, Shucheng, Lujiang, Wuwei and Chaohu four municipalities(See 1.18). The area mainly focused on agricultural production during history and developed a traditional polder landscape around the lake and along the Yangtze (See figure 1.18 light yellow zone).

As mentioned in the previous chapter, this area has witnessed rapid urbanisation and industrialisation. Take the city of Hefei as an example(See Figure 1.18), the built-up area has grown from 5.2 square kilometres in the 1950s to 300 square kilometres in 2018(Gu, 2018). Particularly since 1986, most natural space has been substituted by the built-up area(see figure 1.18).

Such change could be vividly depicted by the transformation of the Xiaoyaojin district: Figure 1.17-1 shows the landscape of Xiaoyaojin on the outskirts of the historical town of Hefei(See figure 1.19), with an ancient-style temple surrounded by agricultural polders at the beginning of the 20th century. While within the recent two decades, this area has been surrounded by high-rise residential buildings(see figure 1.17-2).

Meanwhile, numerous factories and massive industrial zones have been built upon the southwest side of Lake Chao and along the waterway (see figure 1.17-3 and 117-4).

Figure1.18
Overview of the Lake Chao Basin
By Author



Densification

Figure1.17-1 The Portrait of Quzhuang (Current Xiaoyaojin) By Jiang Jun,1905

Figure1.17-2The comparision of Xiaoyaojin before and after densification , Source: Wikipedia

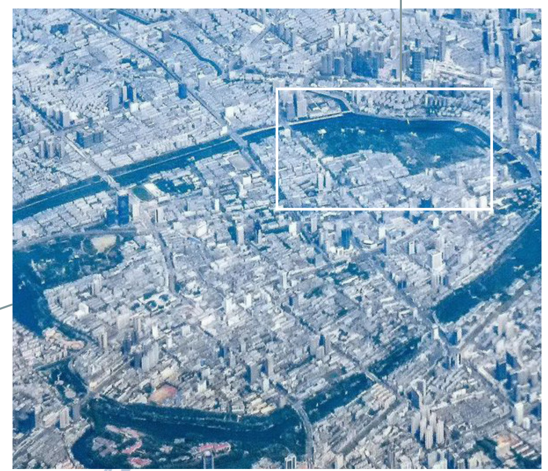


Figure1.19
Sprawling of the City of Hefei
Source: the Paper

Industrialisation

Figure1.17-3 Industrial Zone along the River Pai
Source:Tecent News

Figure1.17-4 Highway and Industrial Zone in outskirt of Hefei , Jianghuai Morning News

1.2.1 Getting to know the Lake Chao Basin

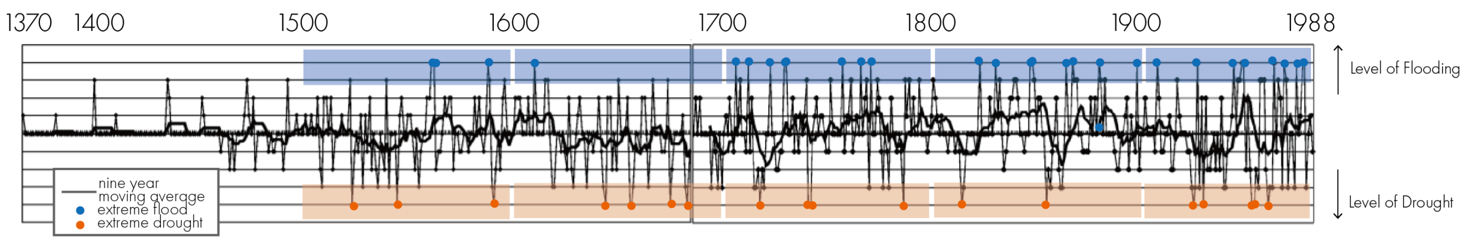


Figure1.20-a
Drought and flood events in the Lake Chao Basin during recent 600 years
Adapted By Author, from Jia et al.(2012)

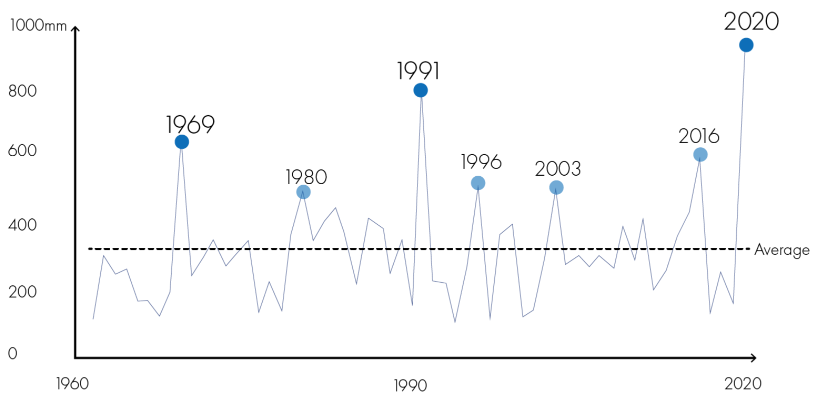


Figure1.20-b
Precipitation in rainy period(10.June-31.July) in the Lake Chao Basin during recent 60 years
Adapted By Author, Data Source:Anhui Meteorology Service

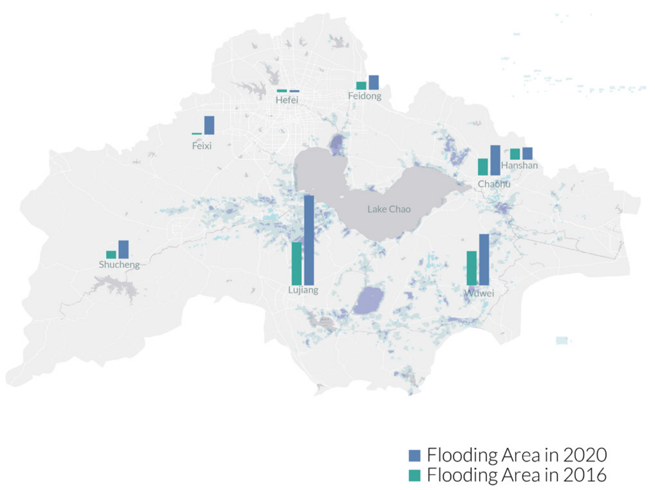


Figure1.20-c
Flooded area in 2016 and 2020
Adapted By Author, Data Source : Anhui Meteorology Service

Figure1.21
Villages around Chaohu City during the 2020 flood
Left: from Sinovision.net
Right: By Zishan Su, from Xinhua News Agency

In companion with the dramatic process of urbanisation described previously, the water issues in Lake Chao Basin have grown to be more tricky and threatening in recent years.

Water Safety

To begin with, the Lake Chao Basin is a vulnerable area compared to the other areas in the Yangtze River delta. This is due to its internal topographical limitation(the fact that all the rainwater autonomously flows towards Lake Chao and surrounding low-lying space) and the external fluvial flooding pressure from the Yangtze River. According to Jia et al.(2012), in the past 600 years, the Lake Chao basin suffered from either flood events or drought every 2 years on average. Meanwhile, this frequency has been getting higher since the 19th century(See figure 1.20-a). Especially between 1990 and 2020, not only the frequency has become higher than before, but also the intensity of the flooding(See figure 1.20-b).

In the most recent flood events in 2020, larger areas were flooded compared to those in 2016(See figure 1.20-c). While there is no concrete evidence to show whether climate change contributes to such a growing intensity of flooding events, the disappearance of water buffers and decreasing infiltration rate undoubtedly placed more risk on citizens when they are exposed to such heavy storm rain.

Water Quality

Water quality is another big challenge for the Lake Chao Basin. It is true that eutrophication is not new to Lake Chao. Actually, people in Lake Chao Basin used algae as a precious natural fertilizer for crops during the algae boom season(Xie, 2008). However, starting from the 21st century, eutrophication became more uncontrollable and ubiquitous in the basin. Nearly all the rivers' water quality within the basin has been affected by extra nitrogen and phosphorus emission(Zhang et al., 2020), especially ones going through urban districts and industrial zones which are affected by household wastewater and non-point pollution brought by urbanization(Zhao, 2020). In 2007, the Municipality of Hefei stopped taking drinking water from Lake Chao, since the water in the western part of the lake is highly polluted and not suitable for drinking anymore (Xie, 2008). In recent years, eutrophication is still serious in the western part and also has arisen in the eastern part(See figure 1.22-a). Furthermore, there is an increased risk of heavy metal pollution

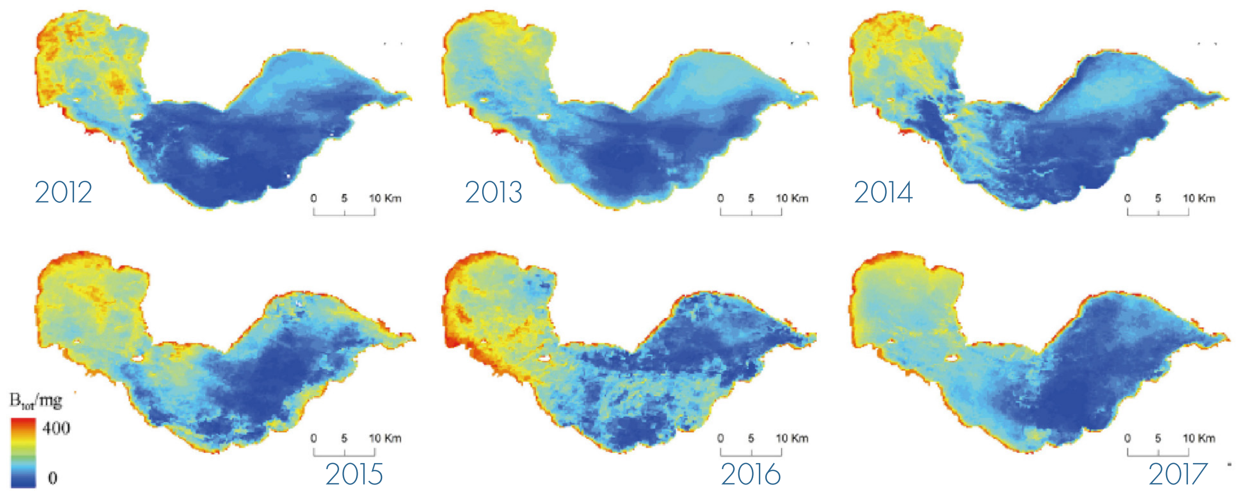
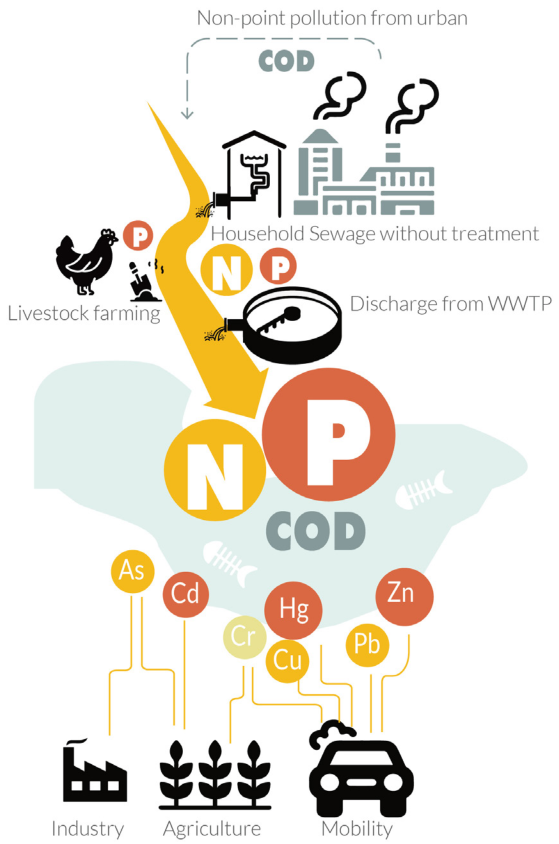


Figure1.22
Spatial distribution of Total Algal Biomass in Lake Chao from 2012 to 2017.
By Hu et al. (2021)



Source of Pollution In Lake Chao
Summary and Illustration By Author

in the lake, which is attention-worthing in the upcoming decades (Xia et al., 2020).

Drinking-Water Scarcity

One direct consequence of water pollution in the basin is the unstable drinking water quantity. Most cities in the northern part of the basin have to rely on water transferred from districts outside the basin, which places a long-term burden on their neighbouring cities.

Meanwhile, the increasing drought events also bring extra drinking water pressure. In 2019, an extreme drought hit Anhui Province, 482.4 thousand rural residents could not have access to drinking water, and even the water source of urban households is under threat(Zhang, 2020). Under such an emergency, apart from the inter-basin transferred water, the municipality of Hefei has to rely on the extra water pumping from the Yangtze River, which is an extremely energy-consuming and inefficient solution.

Looking into the future, with the growing water demand for industrial and urban use, the water quantity is projected to be not sufficient in 2030(see figure) in the biggest city inside the area (Xu et al., 2015).

Summary

The water issues in the Lake Chao Basin are probably the most representative in the Yangtze River Basin, even in China. It vividly illustrates how three typical water-related challenges have put great pressure on a developing area. Even worse, there is so far no effective and sustainable solution to solve these issues in the long run, as will be explained in the next chapter.

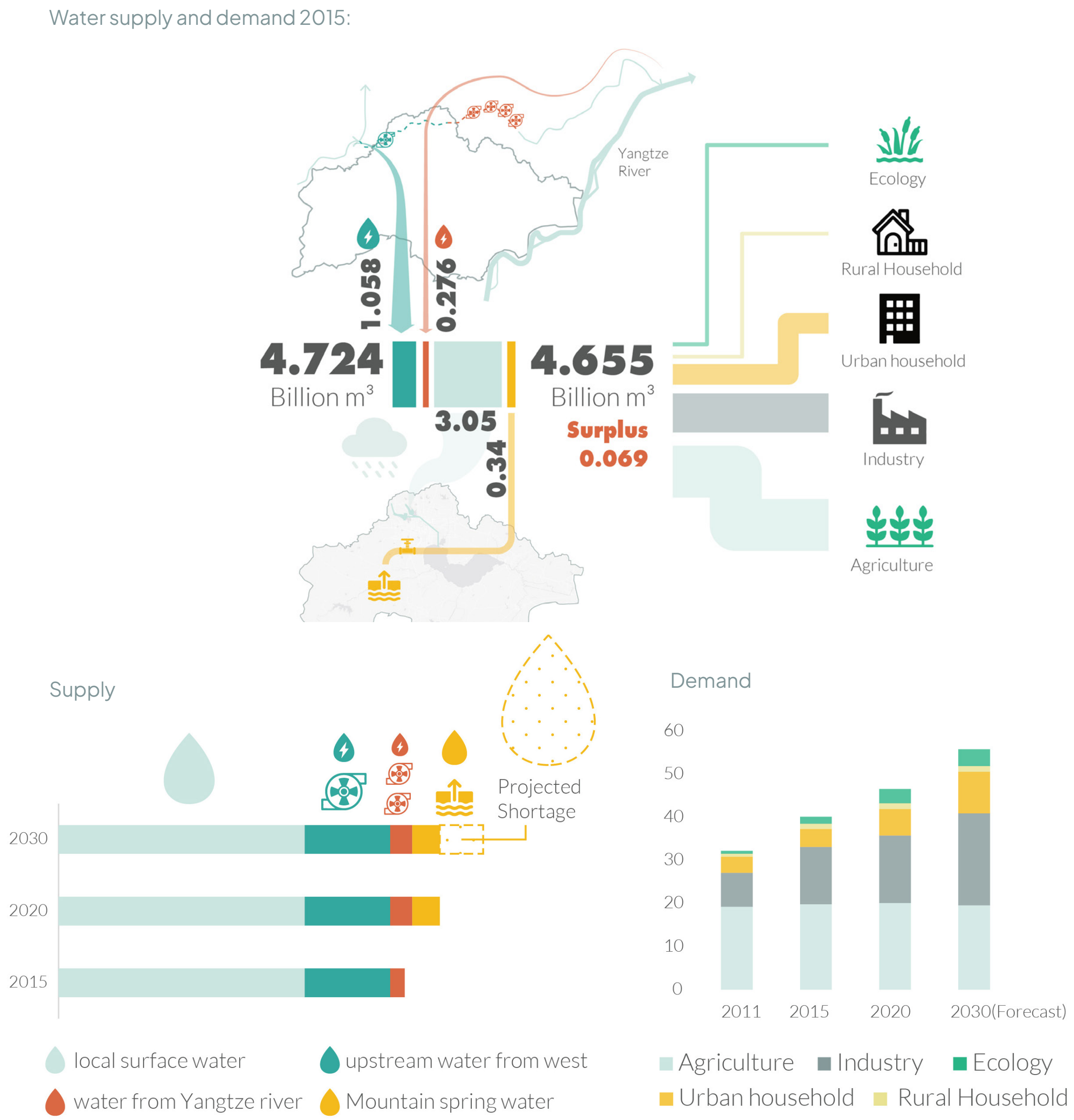


Figure1.23 Water Supply and Demand Status and Forecast in Municipality of Hefei
Data based on Xu et al(2015) Illustrated By Author

Zhegao Town in the July of 2020 Source: Liberty Times

Water pollution, Photo by :Ping Xie(2008)

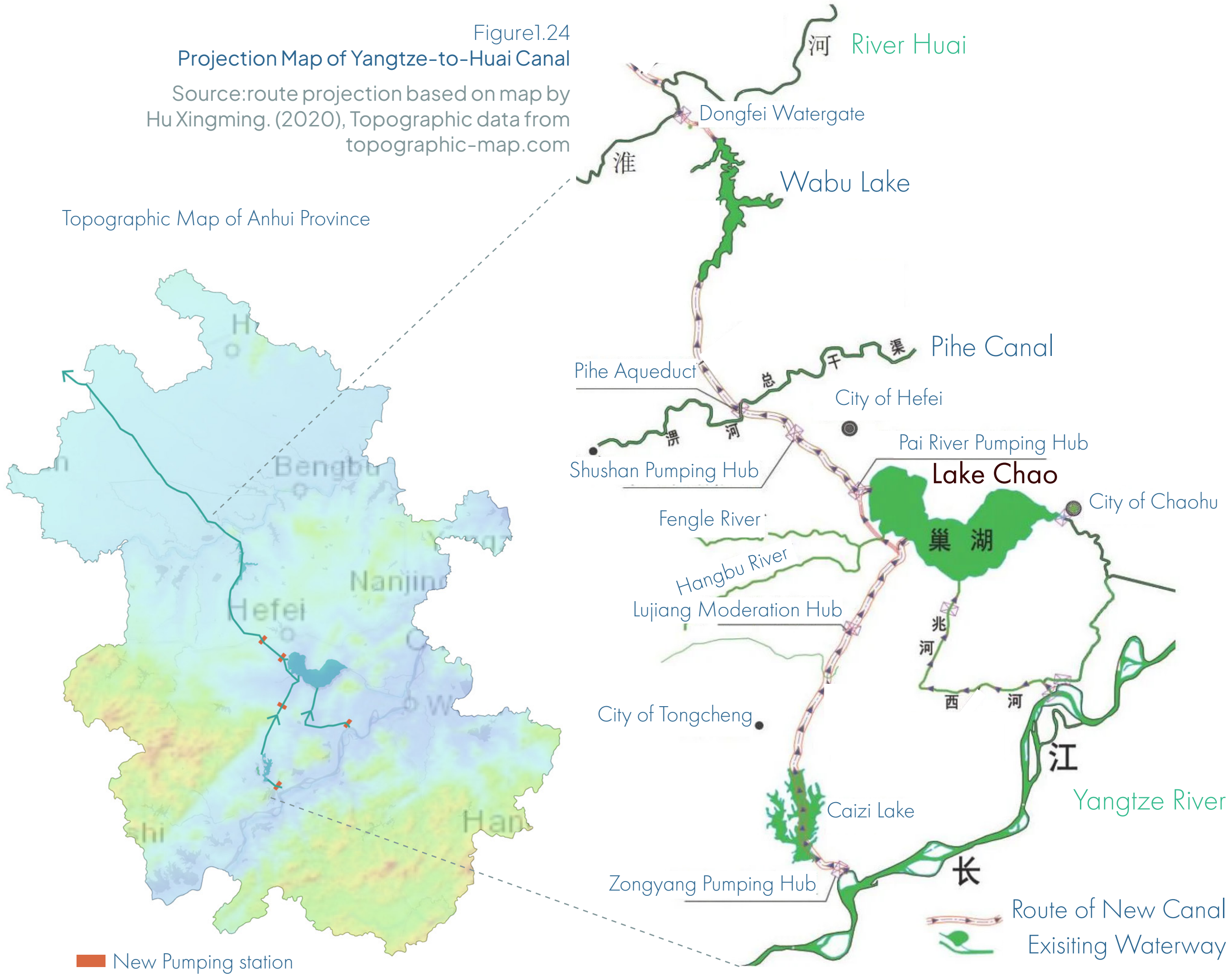
Water Scarcity, Photo by Congyu Shu(2007)

1.2.3 The Yangtze to Huai Project

Figure1.24

Projection Map of Yangtze-to-Huai Canal

Source:route projection based on map by Hu Xingming. (2020), Topographic data from topographic-map.com



The emergence of the water issues in the Lake Chao Basin certainly drew the attention of the national government. In 2014, the Ministry of Water Resources of China first drafted the proposal of connecting the Yangtze River and Huai River through Lake Chao to tackle the water issues through this large-scale water conservancy project. This was later approved by the National Development and Reform Commission(NDRC) of China in 2015.

As depicted in figure 1.24, the total length of the canal is 723 kilometres (with 587.4 km in Anhui Province), equipped with new bumping stations and moderation hubs(see Figure1.26) to manage the water level between these two rivers. According to the NDRC, the canal is projected to provide water supply to 55 districts and counties in 15 cities, covering an area of approximately 70,600km². It is estimated that by 2030, the total water transferring capacity can reach 3.303 billion m³. And the long-term project diversion volume can be expanded to 4.3 billion m³. In addition, the authorities also wish to rely on this canal to purify the polluted water in Lake Chao and gain more control over the water level during flood events.

Figure1.25
The Expanding Port of Hefei
By Chinaports (2020)

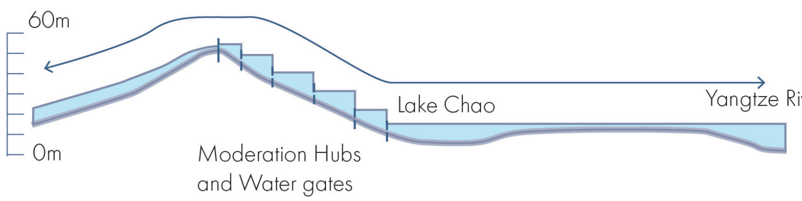


Figure1.26
Section Scheme of
Yangtze to Huai Project
By Author

However, according to the proposal approved by the NDRC, the project not only focuses on solving the water shortage, controlling water levels and improving the water quality but also aims at facilitating waterway transportation in the region to promote regional coordination and cooperation.

This can be dangerous to the already vulnerable local water ecology. For one thing, there are concerns about further pollution and emissions from the forecasted waterway transportation and its impact on the waterfront wetland ecosystem(Wu, 2018).

Meanwhile, the watergate and moderation hubs are not only energy-consuming but are also likely to generate a negative impact on fish migration. For another, it is likely that the rapid urbanisation in Lake Chao Basin Area is about to continue or even speed up after the completion of the new canal. In fact, several new ports are already being constructed by the Municipality of Hefei.

All of these doubts and concerns have shown that Project Yangtze-to-Huai is never a long-term solution to address the current water issues in the area, which leads to a problem statement on the next page.

1.3 Problem Statement

Like many human habitats around the world, the Lake Chao Basin on the periphery of the Yangtze River Delta enjoyed its flourishing thanks to the water.

However, in the past few decades, this area has experienced rapid urbanization, where the size of the cities has grown exponentially. Despite its contribution to the rise of people's overall living standard and local economy, this has led to increasing water issues in the basin. The sprawling urban territory has largely occupied the originally unpaved surface and slowed down the natural infiltration process extremely, resulting in the growing flood risk in front of the extreme storm events (Hao et al., 2019). The emissions from the expanding urban area also bring severe contaminations to the water body within the basin. This not only leads to the degradation of the local ecosystem but also makes the water of Lake Chao hardly suitable for consumption since 2007(Xie, 2008), which put extra pressure on the local drinking water supply. Additionally, with the increasing intensity and frequency of drought and flooding in this area since the 20th century (CMA, 2021; Jia,2012)., further stress on water issues is foreseeable under the threat of global climate change.

The newly-proposed water management infrastructure, the Yangtze-to-Huai project, is never a panacea to address the current water issues. Instead, it can even trigger another round of blind urbanisation and brings more water challenges. Therefore, it is high time to consider a more sustainable and systemic pathway to address the water issues and support future urban development.

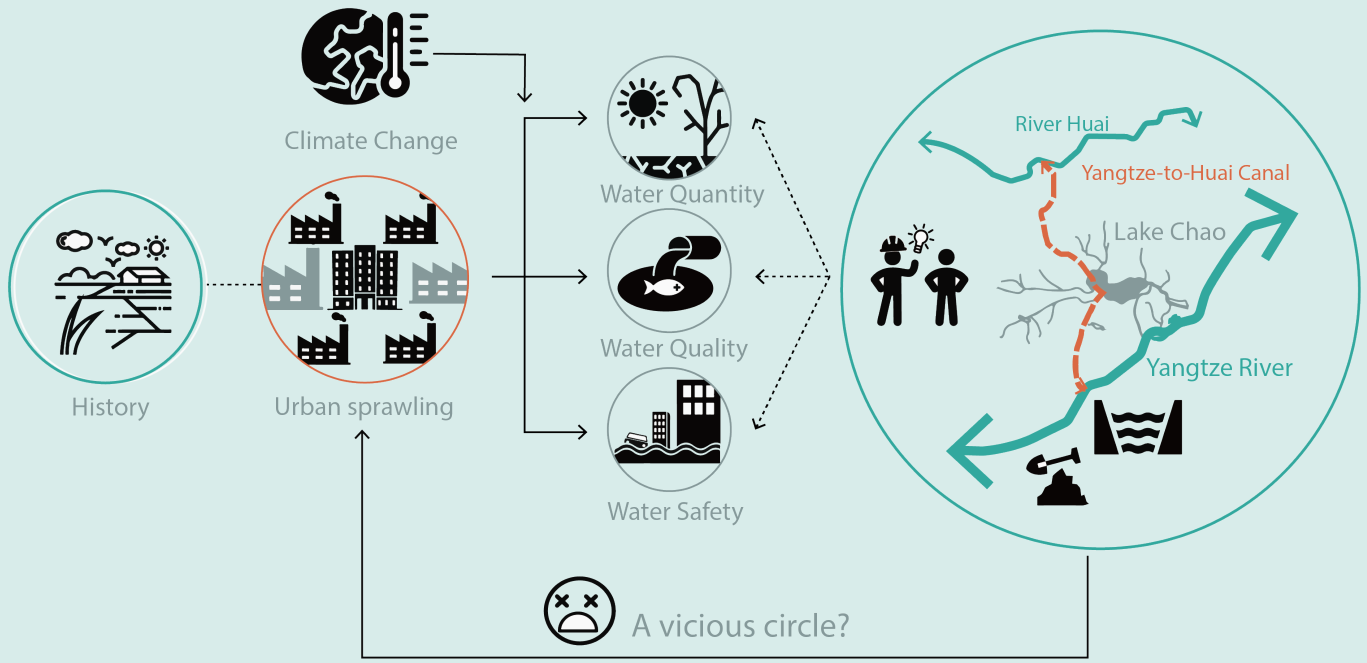


Figure1.27
Problem Statement: The vicious cycle in Lake Chao Basin
By author

1.4 Research Aim

In this graduation project, a new relationship between urban and the water circle will be explored. It aims at constructing a systemic solution from the perspective of urbanisation, which could not only address the current water issues but also support the long-run sustainability of the Lake Chao Basin. Based on this goal, the concept of 'sustainable water-oriented urban development' is proposed, which will be further defined in Chapter 3.

The desired outcome for this graduation research will be a pattern language(the concept of which will be further explained in Chapter 2.2) containing interrelated patterns that could be integrated into the future urban development and contribute to the sustainability of the water system of the study location. This pattern language will be tested and evaluated by a strategic location on a district level and provide transferable knowledge to other locations with similar water issues. All this knowledge will finally be embodied in a pattern book as an attachment to the thesis.

Such research aim and intended outcome lead to the main research question of the thesis as follows:

How can a sustainable water-oriented urban development pattern language be designed and contribute to a future-proof water system in the Lake Chao Basin?

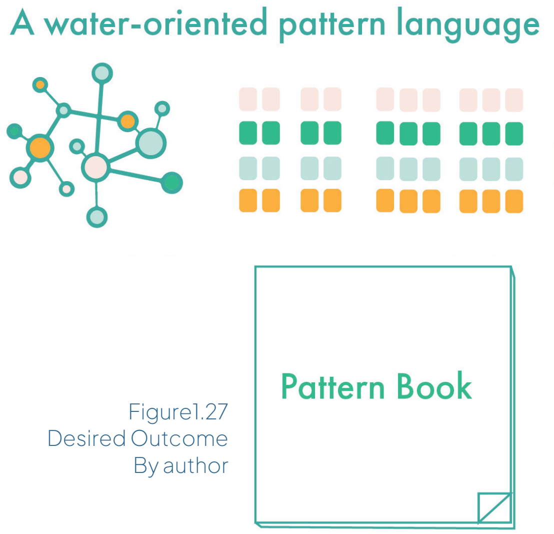


Figure1.27
Desired Outcome
By author

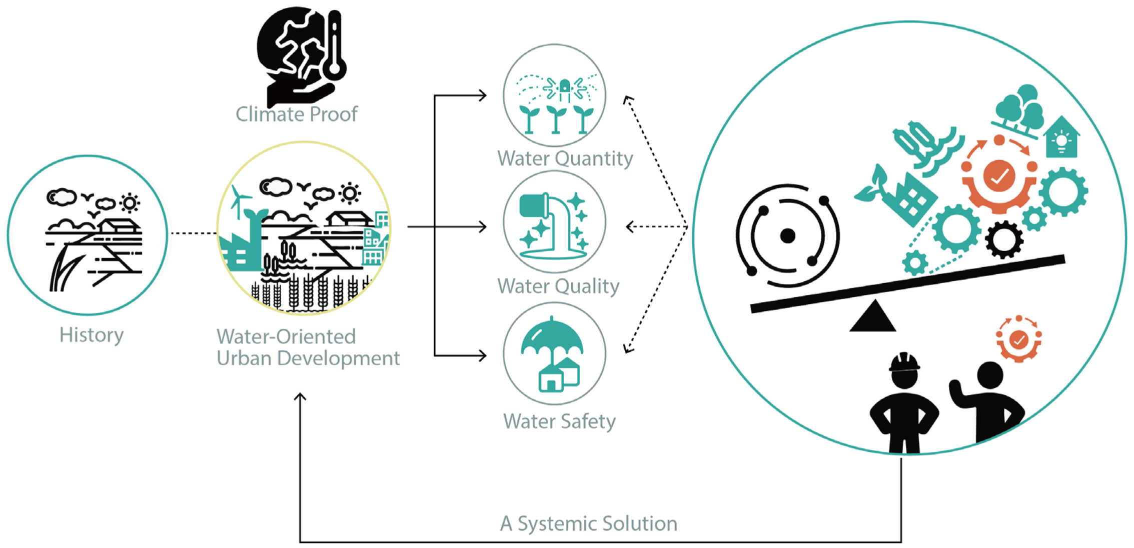


Figure1.28
A systemic solution to get out of current dilemma
By author

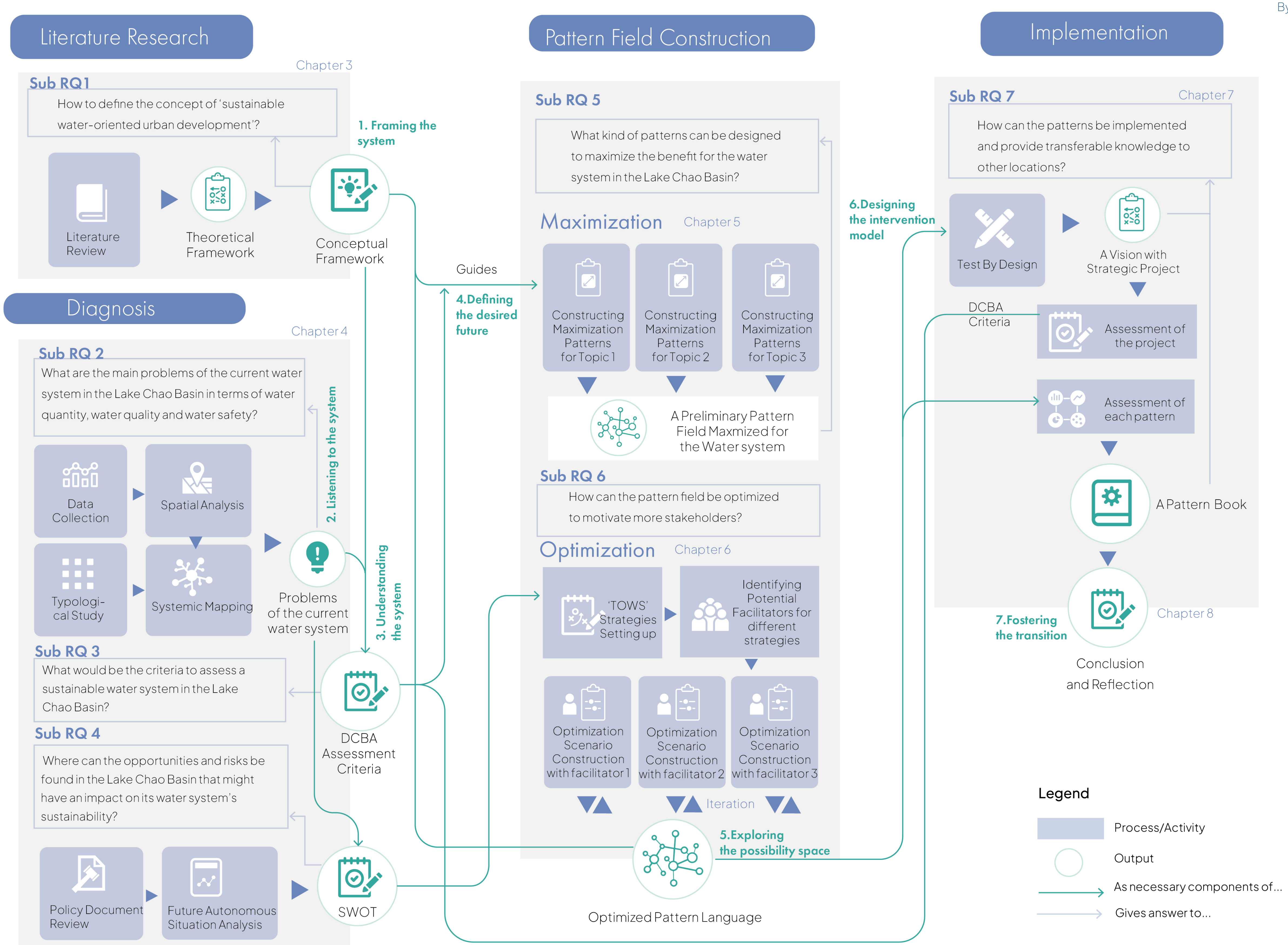
CHAPTER II. RESEARCH APPROACH

Introduction

In this Chapter, the main research approach of the thesis is decribed. At beginning of the chapter, a research framework diagram is presented to show the main research process. The diagram is explained further by the text in Chapter 2.1, where the main research questions are decomposed into seven sub research questions. An elaboration is given on how they could be answered by following certain methods and what are the intended outcomes of each stage. Chapter 2.2 provides in-depth explanations of all the main methods mentioned involved respectively to help the readers understand the research approach better.

2.1 Research Design

Figure 2.0
Research Framework
By author



2.1 Research Design

As already been put forward in Chapter 1, The main research question of the project is:

"How can a sustainable water-oriented urban development pattern language be designed and contribute to a future-proof water system in the Lake Chao Basin?"

To answer this main research question, the whole research process is structured based on the systemic design method(further explanation of the method can be seen in chapter 2.2), where a constant switch between systemic thinking and design thinking is required. Thus, the study consists of four stages, following the 7 steps sequences of systemic design (see figure 2.1). Each of these stages contains several research questions that need to be responded to.

Stage 1:
Literature review: Framing the system

Sub RQ 1:
How to define the concept of 'sustainable water-oriented urban development'?

In order to design a pattern language for a sustainable water-oriented urban development, a proper definition of this concept should be stated. In this stage, knowledge and argument related to water and built environment from different perspectives will be gathered and reviewed critically, in search of a possible synergy between them. A theoretical framework will be constructed first. This is to show how existing discourses could be interrelated in a synergetic way.

In the end, the concept of 'sustainable water-oriented urban development' is distilled from the literature in the theoretical framework, which provides the answer to SubRQ 1.

Stage 2:
Systemic Diagnosis:Listening to the system and understanding the system

Sub RQ 2:
What are the main problems of the current water system in the Lake Chao Basin in terms of water quantity, water quality and water safety?

Sub RQ 3:
What would be the criteria to assess a sustainable water system in the Lake Chao Basin?

Sub RQ 4:
Where can the opportunities and risks be found in the region that might have an impact on its water system's sustainability?

The second stage is mainly about understanding and assessing the current pressure of the water system under the process of urbanisation in the studied location. It consists of three topics of the water system: water quality(mainly about the surface water in the ecosystem), water quantity(drink water) and water safety(mainly involves precipitation). Data and geographical information related to them will be collected by mapping on different scales. With these steps, each topic is then summarized with a systemic mapping, showing the current flows of water and pointing out the main problems that need to be solved. These series of systemic mapping provide the answer to the Sub RQ2.

Following the insight from the previous steps, a hypothesis of a more desired water system is made in contrast with the current problems to answer Sub RQ3. This is formulated in the form of a 'DCBA' assessment criteria, which links the current situation and the most desired condition by the setting up of the different levels(As already explained in Chapter 2.1).

Meanwhile, considering the location is still undergoing rapid urbanisation, it is vital to consider the current trend of urban development and what kind of opportunities and risks it might bring. A future autonomous situation(FAS) is created based on the review of the existing planning policy document. The FAS is then assessed by the 'DCBA' criteria set up. With this FAS assessment, together with the previous analysis, a SWOT analysis matrix can be completed so as to answer Sub RQ4 and meanwhile pave the way for the design stage.

Limitation and Remediation

In this stage, most of the information is collected online, where biased data or outdated information might be used. In order to check and ensure reliability to the greatest extent, a fact check by google street view or other methods should be considered. In some situations, educated assumptions are also acceptable with a concrete deduction process.

Stage 3:
Pattern Field Construction: Defining the desired future and exploring the possibility space

Sub RQ 5:
What kind of patterns can be designed to maximize the benefit of the water system in the Lake Chao Basin ?

Sub RQ 6:
How can the pattern field be optimized to motivate more stakeholders?

After the diagnosis period, a pattern language can be constructed using the maximization method. As already introduced in Chapter 2.1, the maximization method is composed of two steps: maximization and optimization.

In the maximization step, Sub RQ 5 are responded to by a set of maximized patterns. For one thing, these patterns are translated from the principles under the conceptual framework proposed in Chapter 3. For another, these interventions aim at reaching the A-level criteria set up in the DCBA assessment tool.

Nextly, three optimization scenarios for a strategic location are constructed using the patterns designed. This is done by identifying potential strategies and stakeholders from the SWOT-TOWS analysis and making tailored proposals according to their specific values and interests respectively. In this process, an understanding of how different patterns might engage different stakeholders can be gained, and thus new patterns can also be thought of. This gives the answer to the Sub RQ 6.

Limitation and Remediation

The method of construction of a pattern language can be 'endless', and it is usually hard to state the completion of a pattern language. As a result, a clear line should be drawn in advance to set the maximum time budget.

Stage 4:
Implementation and Assessment:
Designing the intervention model and fostering the transition

Sub RQ 7:
How can the patterns be implemented and provide transferable knowledge to other locations?

In the fourth stage, the finished pattern field from the previous stage will be tested by creating a trans-scalar vision for the study location. The desired outcome will be a spatial framework on a macro-scale with a strategic project. The strategic project will elaborate on how the patterns could be used and illustrate the expected spatial quality on different scales as well. This strategic project will then be assessed according to the DCBA assessment tool to understand the limitations of the implementation process, which provides the materials for the final conclusion of the project. Also, each pattern will be assessed on its transferability and its contribution to either the water system or the SDG's goals, which will be later collected as a pattern book as an attached product of the project.

Finally, a response to the main research question can be made after all these research and design stages, which conclude on how the water-oriented pattern language can be designed and its value to the future water system of the study location. By clarifying the problems and limitations of the whole execution of the graduation thesis and pointing out potential further research directions, the project could shed more light on the way to sustainable development.

2.2 Research Methods

The Systemic Design Method

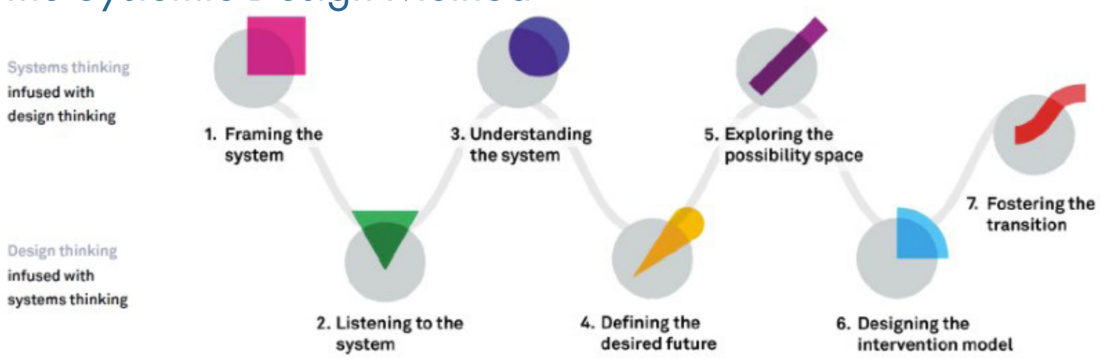


Figure 2.1
A 7-step sequence of Systemic Design
Diagram From Keynote: Hands-on with Systemic Design,
A session by Kristel van Ael and Claudia

Systemic Design is a method that integrates systems thinking with design thinking and combines the strategies from these two worlds together(Jones, P., & Kijima, K., 2018).

On the one hand, systems thinking focuses on how a system works over time and how the elements within the system interrelate with each other instead of how they function separately. It involves zooming in and out, thinking about emergencies and identifying patterns (Colab,2016). On the other hand, design thinking emphasizes producing solutions, tolerating uncertainty, and applying imagination even sometimes without complete information(Pourdehnad et al., 2018). Faced with complicated urban challenges nowadays, an integration with two worlds is necessary, especially dealing with adaptive challenges or value conflicts(Colab, 2016).

Figure 2.1 shows a seven-step sequence for a systemic design developed by Namahn's Kristel van Ael's team. By combining the design thinking strategies and systems thinking together and jumping back and force between them, this graduation thesis also follows a similar sequence when building the research approach framework(as can be seen in figure 2.0) to complete this complex systemic design assignment.

The Pattern Language

The pattern language is originally introduced to the world in A Pattern Language: Towns, Buildings, Construction(Alexander et al.,1977) and The Timeless Way of Building(Alexander, 1979) by Christopher and his colleagues. Though the content of the books received criticism(Dovey, 1990), the pattern language, as a design approach, is still a strong weapon to help designers today to understand the challenges of designing for complexity(Marshall, 2016).

A single pattern offers a way for designers to connect the recurring nature of an urban problem with a solution(Alexander, 1964,1979). In the Delft school's pattern language method, one pattern is usually presented with a hypothesis and diagrams, underpinned by theories backups and/or practical implications, all of which should be kept concise and simple(Cai, 2018).

More importantly, just like other natural languages, the pattern language has its own 'syntax'(see figure 2.2). This syntax defines the relations between each pattern. So the words(an individual pattern) could be connected by the urban designers and planners to create their own stories(Mentink et al.,2013). When the relations between the patterns are sketched out, all the patterns could be organized easily in a pattern field (Rooij & van Dorst,2020), where they could also be analyzed, discussed with others and grown and optimized further.

In this graduation thesis, the pattern language is used as a tool to not only bridge the research and design but also as a strong container of a 'solution network' to cope with the complexity of the system.

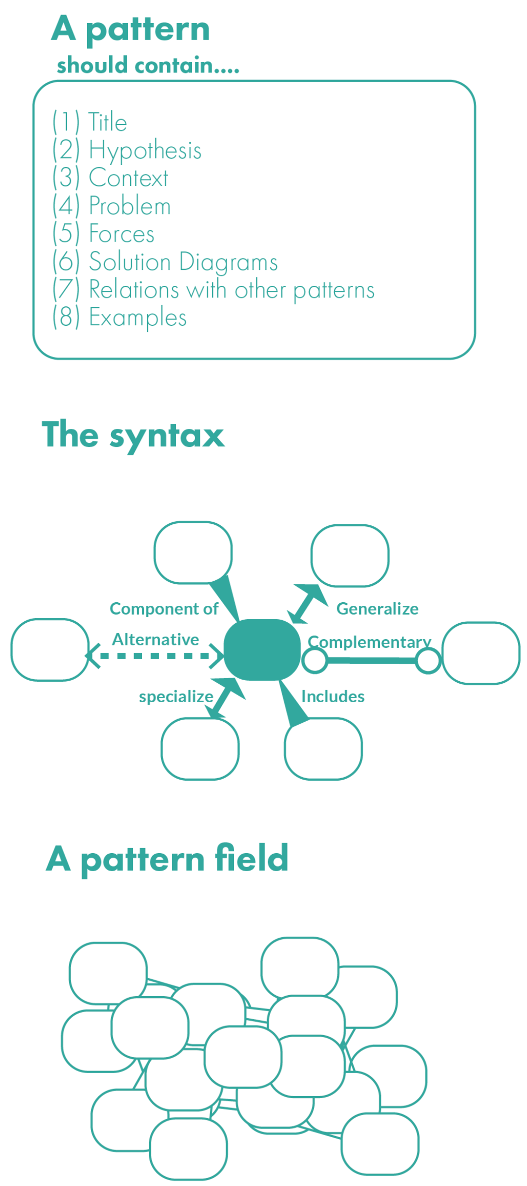


Figure 2.2
Concept of the Pattern Language
Based on Henriquez, L. , et al.(2013).
Illustrated by Author

The 'DCBA' Method

The 'DCBA' method was initially developed by BOOM (Milieukundig Onderzoek en Ontwerp Buro) for the environmental evaluation of the Ecolonia housing project in Alphen aan den Rijn in the Netherland in 1993. The system was originally borrowed from the school grade system and later on translated as gradient levels for different design criteria not only for environmental-friendly design but also as a flexible tool for the assessment of other topics(Kees Duijvestein,2015).

The four letters of 'DCBA' stand for the changing extent of ambitions:

D = normal situation or just sufficient situation;
C = correction of the normal situation, there is a consideration for the environment(or the related topic);
B = limited damage to the environment as far as possible(or related topic has been fully considered);
A = absolutely the least damage to the environment (or to the related theme).

In the graduation project, this method is used as a strong tool to sharpen and assess the project from three separate aspects of water:'water safety', 'water quality and 'water quantity'.The 'D' level criteria are formed based on the current situation of the study location, while 'A' level criteria should be set up under the guidance of a literature review. In this way, the intermediate 'B' and 'C' could be easily defined.

Note: The DCBA assessment criteria set up for this project are mainly explained in Chapter 4. It is used in Chapter 4.6, Chapter 6.2, Chapter 7.2 and 7.3. The detailed criteria list is attached in Appendix B.

The Maximization Method

The maximization method contains three stages: maximization, optimization and integration(as depicted in figure 2.3).

In the first stage, a maximization proposal is built to bring the most desirable result for certain topics. Then in the optimization phase, choices are made between different maximized solutions. This could be done by introducing a new external topic or considering the need of a specific client so long as it could justify the choice being made. And in the final phase, the optimized solution is further concretized into a real design, where local social and economic factors and other related aspects are taken into consideration.

In the thesis, the maximization method is used to build up the pattern language, and this process is mainly elaborated in chapters 5 and 6.

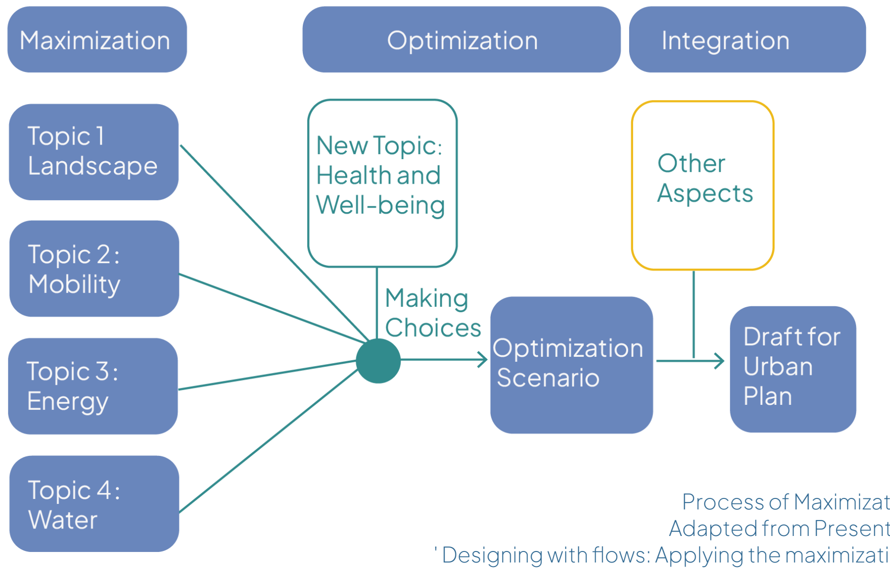


Figure 2.3
Process of Maximization Method
Adapted from Presentation slides
'Designing with flows: Applying the maximization method'
by Kristel Aalbers(2021).
Illustrated by Author

Other Methods

The Future Autonomous Situation(FAS)

The FAS analysis is a method to identify threats and weaknesses of the current system by projecting how the system might develop based on the trend and paradigm at present. The visualization of FAS(as shown in figure 2.4) helps the client to deepen the understanding of the potential and risk and explains why actions should be taken.

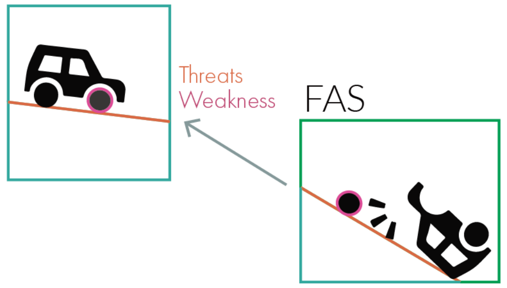


Figure 2.4
FAS Analysis
by Author

The SWOT Analysis

SWOT analysis is firstly developed at Stanford in the 1970s and it refers to 'Strengths', 'Weaknesses', 'Opportunities', and 'Threats'. Commonly, it is used as a tool for analysis, but it can also be used as a tool to explore potential strategies by filling the TOWS matrix (see figure 2.5 on the right). In a research and design project, It can provide a good summary of the analysis and link the conclusion with the strategies and design proposal.

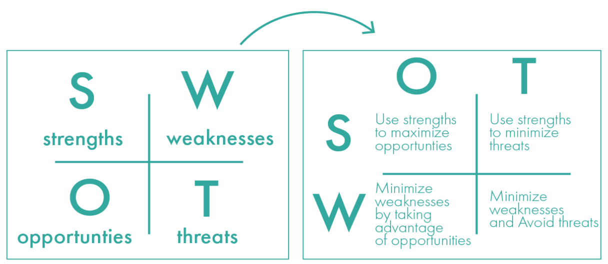


Figure 2.5
The SWOT and TOWS matrix
Adapted from Warren Lynch(2020)

The Transferability Analysis

The transferability of a solution could be analyzed based on its 'Place-specificity' (Dąbrowski,2021). This could be decided on whether it is a 'complete solution' for a specific location(or based on the need for specific groups of stakeholders), 'elements of the solutions'(or includes different choices) or a 'reasoning, approach, methodology'(or principles)
This transferable analysis is used in the final assessment of the pattern field following this method, the outcome could be found in Appendix A, as well as in the pattern book.

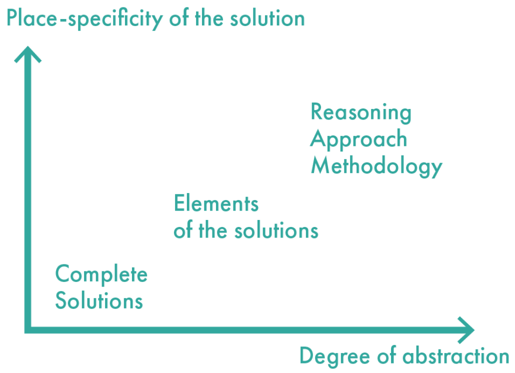


Figure 2.6
Analysis of transferability
Adapted from Marcin Dąbrowski(2021)

Figure3.0.1
Village and Agricultural Zone in the Lake Chao Basin
Source: WANG Shangyun 金色田园 王尚云摄

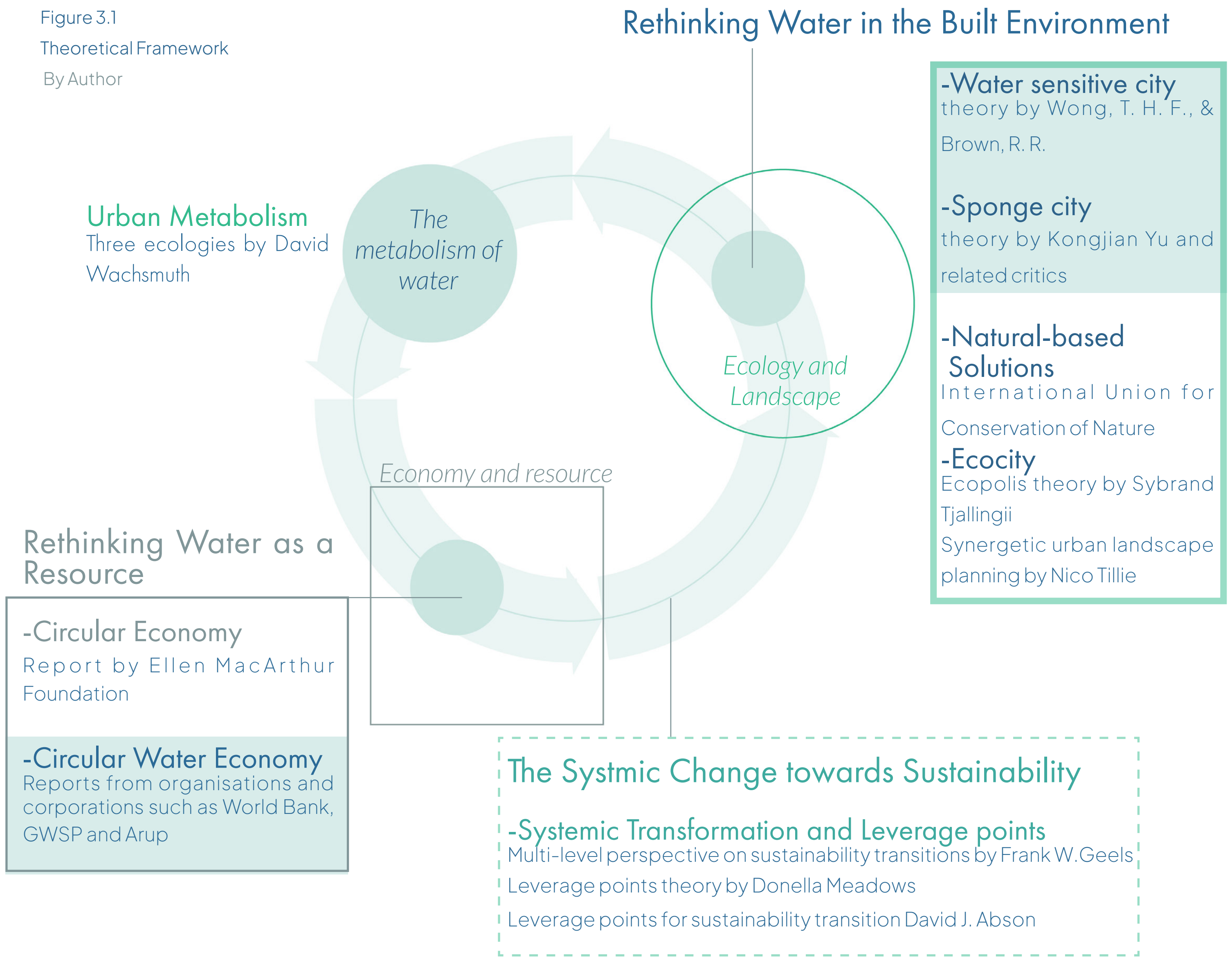
CHAPTER III. THEORETICAL FRAMEWORK

Introduction

In this chapter, the existing literature is reviewed and synthesized according to the theoretical framework. With the theories on urban metabolism and systemic design as the backbone of the project, different debates related to water are critically analyzed in Chapter 3.1 in order to find the definition of 'sustainable water-oriented urban development' intended by this graduation project. This definition is then illustrated by the conceptual framework in Chapter 3.2 as the reply to the Sub Research Question 1.

3.1 Theoretical Underpinning

Figure 3.1
Theoretical Framework
By Author



3.1.1

On Urban Metabolism

The opposition between city and nature has been largely blurred by the rapid expansion of built-up areas and also the increasingly interconnected flow of services and goods across different territories. As a matter of fact, urban metabolism should no longer be used as an analogy in the 'human ecology'(Wachsmuth, 2012), which merely compares cities as the metabolism of the human body but actually separates cities from nature. Neither should cities nowadays continue their 'industrial ecology', where nature is the source of the urban metabolism's fuel and the destination for its wastes (Wachsmuth, 2012). Instead, urban metabolism is a 'biodynamic' process which emphasizes the interweaving of social and biophysical processes that produce new forms of urban(Gandy, 2004). As a result, future spatial intervention should deal with different flows and the ever-changing natural system, instead of just focusing on the man-made aspect of the built environment. Based on this concept, in this graduation project, cities and nature are treated as an organic whole with water as one of the most important flows going through this complex system.

'The city is not merely the site of urban metabolism but rather its product.'
-(Wachsmuth, 2012, p. 519)

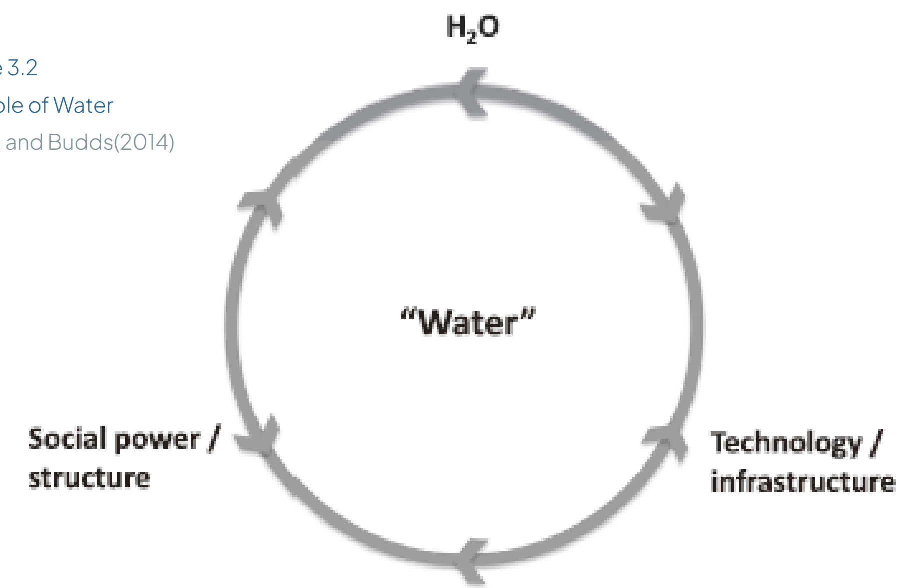
3.1.2

The Metabolism of Water

Water has always been a crucial part of society, from the supply of drinking and sanitation use to the demand in agricultural production and other economic activities. Traditionally, people perceive the relation between water and society from a hydrological perspective, seeing water as a natural element simply serving the functioning of society. However, in the recent discussion of water-society relations, scholars have attached great importance to reconsidering how water interacts with society. According to Linton and Budds(2014), the role of water in our society could be understood from three aspects(see figure 3.2).

The first one is the water's materiality (H2O).

Figure 3.2
The Role of Water
Linton and Budds(2014)



This represents the water as a basic product in our bottle or in any production chain that requires the chemical substance of H_2O.

The second one is the water in the world of technology and infrastructure, or as an object in hydrology. This could be water stored in a reservoir, flowing in a river or gathering in the clouds and waiting to become a storm.

The third one is the invisible power of water. The quantity and stability of water affect economic and cultural activities and also affect the social structure. And the ability to manipulate or utilize water also shapes the cultural identity or shows the power.

These three aspects of water unceasingly make and remake each other and reveal how water should be regarded as not only a natural resource, but also an element integrated and embedded in the dynamics of society.

This theory opens the dialogue between water, as a part of nature, and urban, as part of the man-made world, and lays the foundation of how water could be decomposed as different sections in the analysis of this graduation thesis as presented in the theoretical framework.

'Water is a brutal delineator of social power which has at various times worked to either foster greater urban cohesion or generate new forms of political conflict'.
(Gandy, 2004, p.363)

Rethinking Water in Built Environment

With the previous theory clarifying the different roles that water plays in the metabolism, this section first explores the water in the built environment from an urban planning or landscape design perspective.

Natural-based Solutions

One of the key concepts that have been proposed to tackle today's environmental challenge by seeing nature as an inseparable part is the Natural based Solutions(NbS) theory. It refers to the
'Actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.'
(Cohen-Shacham et al., 2016)

With regards to water issues, the natural-based solution can play a significant role in sustaining and improving water quality, managing water availability and mitigating water-related risks(UN-water, 2018). Meanwhile, it can also be seen as the umbrella theory of 'sponge city'(Qi, Y. et al., 2020) and 'water sensitive city'(Wong and Brown, 2009) that will be discussed next.

Sponge City

The concept of 'Sponge City' was put forward by Yu et al. (2015) to address the rising water issues in urban and rural areas of China. As opposed to the grey engineering-oriented approach, the "sponge city" is an integrated natural-based solution built upon multi-scale hydrological infrastructure. Instead of merely applying specific technology on a neighbourhood scale, Yu et.al has proposed a multi-scalar system driven by the guiding principles(p.29):

-Principle:
from"Water adapts to man" to "Man adapts to water"

-Core Strategy:
Natural based solutions, 'city as a sponge'

-Regional level:
conducting risk assessment based on data and mapping, to establish the natural protection zone or green-blue corridors on a larger scale.

- City-level:
enhancing the purification and storage capacity of the urban water system by improving and reorganizing the structure of rivers, ponds and other natural water bodies.

- Neighbourhood level:
implementing natural-based water management solutions such as constructed wetland or rainwater gardens to improve the permeability.

The sponge city theories gave us a systemic framework for dealing with water problems with a natural-based solution. However, although the strategies and principles are clear and inspiring, there is not yet a clear pathway to conduct the transition. Meanwhile, it exclusively focuses on the ecological part without acknowledging the importance of combining artificial water management strategy with natural-based solutions to handle the increasing risk of climate change(Qi et al., 2020).

Water Sensitive City

Improving the flood resilience is one of the major goals for a water sensitive city.In a recent study conducted by Cooperative Research Centre for Water Sensitive Cities, an urban flood resilience framework is developed. In this framework, three guidelines "Retreat, Accommodate and Protect" (Rogers et al., 2020, p3) are developed. This framework not only promotes giving more room for rivers('Retreat'), highlights the importance of adapting to the climate change('Accommodate') but also appreciates a hybrid mode of water infrastructure(a combination of grey and green solutions) instead of the pure natural-based solution('Protect').

More importantly, the concept of a 'water sensitive city' also concerns the social resilience of the system to absorb disturbance, and the capacity to self-organize. It emphasizes on reinforcement of water sensitive behaviour such as innovations, embracing a sustainable lifestyle and sustainable management, which can be seen as crucial leverage points to stimulate the systemic change(The concept of leverage points will be discussed further in the next section).

Ecocity

Just like urban metabolism theory describes the city as the outcome of metabolism, ecocity theory also puts the city inside the circle of 'nature'(See figure 3.3). Since the city has been regarded as the root of environmental problems, it now should search for its solutions to act and perform sustainably as an ecosystem (Tillie,2018) to face the upcoming challenges. Instead of being against nature, people in the 21st century have to adapt our cities to be more ecological-friendly and climate-proof. In fact, by shaping the living environment to satisfy the demand of the ecosystem, future urban areas should be itself function as an ecosystem.

In this sense, the waterway in the urban area should also carry out its ecological function. This not only concerns biodiversity inside the water body but also contains the ecosystem of the embankment and even the quality of groundwater that constantly flows into the surface water system.

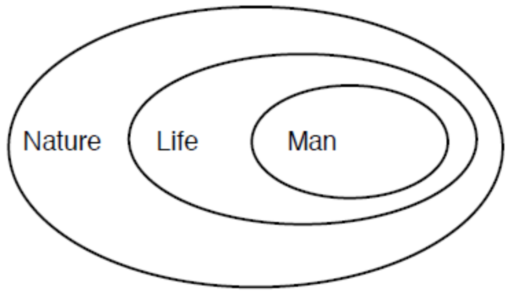


Figure 3.3
Scope of Nature
Tjallingii, S. P. (1995)

Rethinking Water as a Resource:
Circular Water Economy

Having discussed the theory focusing on the water in the built environment, another perspective of analysing the metabolism of water is considering it as a resource in the economic world.

Though many people take for granted that the water cycle is as 'circular' as it sounds, this is only true when it comes to the undisturbed natural water system. With the intensification of human intervention in the natural water loop, the cycle of 'freshwater' as a resource is not circular or sustainable anymore (Sauvé et al., 2021). This leads to the theory focusing on the circular water economy.

The concept of Circular Economy has been proposed as an alternative approach to the current linear pattern of "take-make-dispose"(MacArthur, 2013). Instead of profit-driven economic logic, It centred around closing loops and minimizing waste, turning goods in their end of service life into resources again(Stahel, 2016).

In the diagram proposed by Arup(see figure 3.4) in 2018, the circular water economy is depicted with two pathways, the nature-managed one and the human-managed one. The nature managed water involves natural-based solutions to facilitate this circular process as it originally is. On the other hand, the human-managed process requires more reuse, reduction and recycling strategies to close the water loop. Additionally, there are opinions pointing out that the environmental footprint generated by the production, transmission and treatment of water should also be part of the circular water economy(Sauvé et al., 2021).

Furthermore, maximizing the value of water also concerns the shift of people's mindset and support from governance. In fact, ignoring the value of water is the main cause of its waste and misuse (United Nations, 2021). As a result, the transition toward a circular water loop also needs a common understanding (Delgado et al., 2021) as well as proper market initiatives(Sauvé et al., 2021).

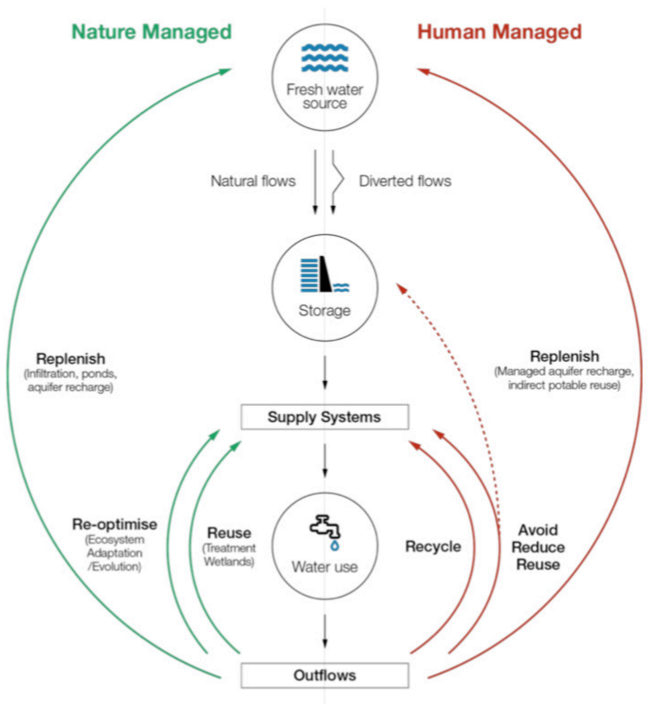


Figure 3.4
Circular Water Economy
from Arup(2018)

3.1.3
The Leverage Point Theory of Sustainability Adaptation

As can be seen from the previous paragraph, altering the metabolism of water and promoting a systemic change is never easy. First, It is a social-technological transition process that involves multiple actors(like many other transitions during history). Meanwhile, it is noteworthy that such a transition towards sustainability is actually more complicated compared to many other transitions(Geel, 2011). According to Geel, due to its aiming at a 'collective goal' without obvious user benefits, such transition requires the support of incentives and policies from the authorities to avoid free-riders and prisoners dilemmas, and also the participation of large incumbent corporations.

In order to guide such transition, Abson et al. (2016) has proposed their opinion based on the leverage points theory from Meadows(1999), where twelve leverage points(see figure) ranging from 'shallow' to 'deep' have been reinterpreted into 'parameter', 'feebacks', 'design' and 'intent'. They argued that the current sustainable intervention should shift from the shallow side (parameters such as incentives or taxes) towards the deeper side since the deeper system could sometimes constrain the types of interventions that are available at shallower leverage points(Abson et al., 2016). For instance, the spatial structure of the city can be seen as the deeper system as well as the behaviour and mindset of producers. Without changing them, the improvement of the water system can only be limited to the shallow side of the leverage and end up being superficial.

According to Abson(2016, p.33), particular attention should be given to the 'Three Realms of Deep leverage for sustainability transformation' when proposing a systemic change:

"

(i) the role of institutions and institutional decline and failure in systemic change; (ii) people's connections to nature and their influences on sustainability outcomes and (iii) knowledge production and use in transformational processes.

"

In this graduation thesis, based on the 'Three Realms' mentioned above, similar leverage points are also incorporated into the conceptual framework (see Chapter 3.2). In this way, the final proposal could be more qualified as a systemic solution that cultivates a mindset of 'water-oriented' and stimulates sustained self-organization of the system.

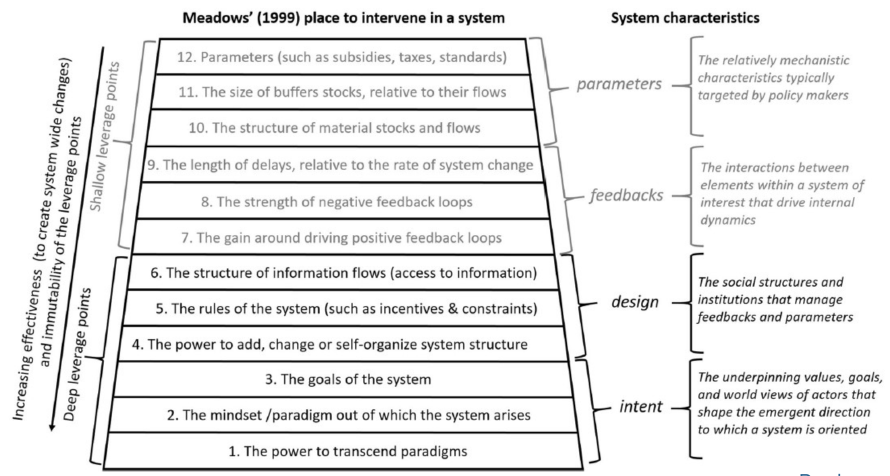


Figure 3.5
Realms of leverages
David J.Abson et al., (2016)

3.2 Conceptual Framework

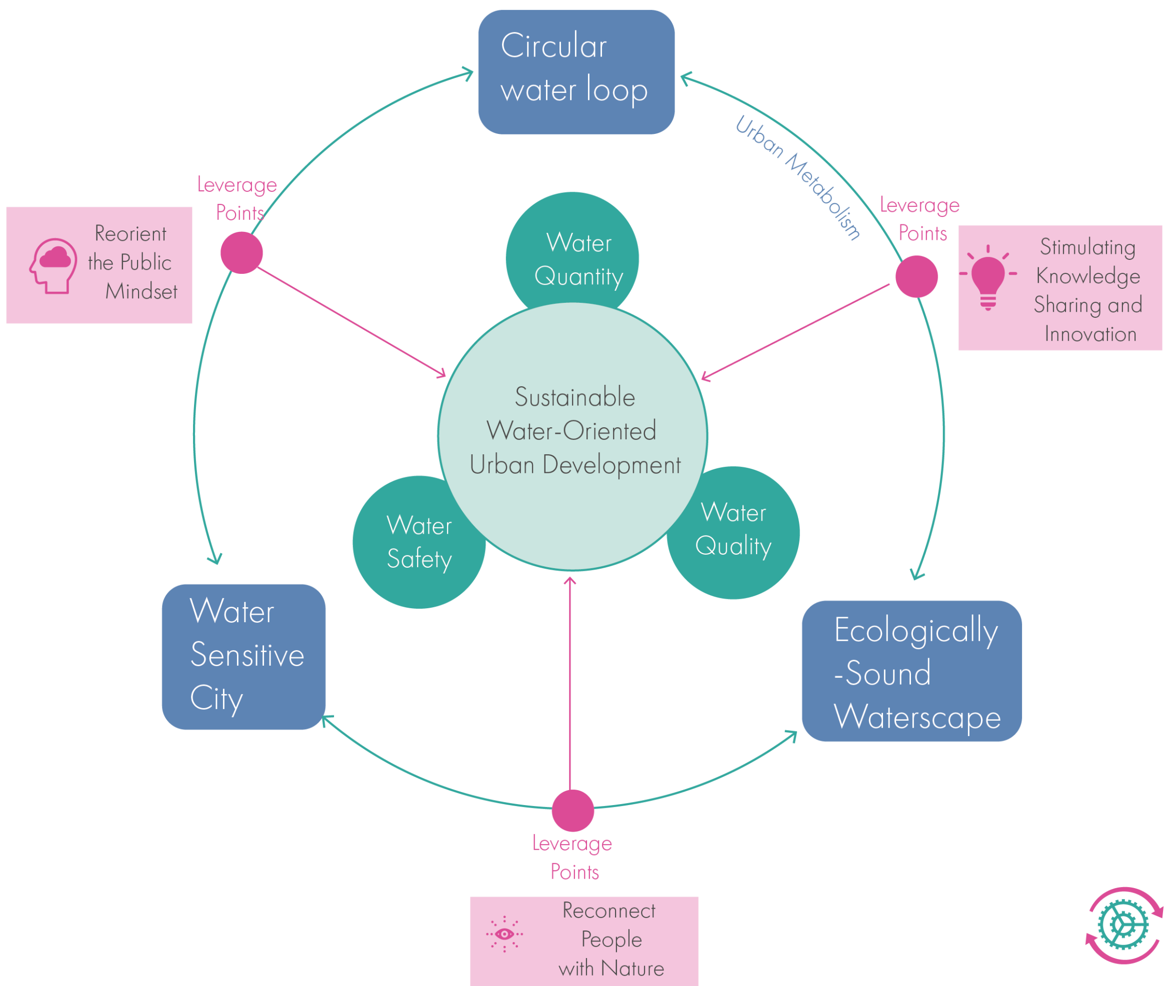


Figure 3.6
The Gear Wheel Diagram of 'Sustainable water-oriented urban development'
By Author

The scheme above shows the concept of sustainable water-oriented urban development as a systemic solution. Functioning as a 'gear wheel', the water system in the inner ring can be changed systematically by the urban metabolism and leverage points from the outside.

In the inner ring, the key aspect of the water system is depicted: Water quantity, water safety and water quality. They can be seen as the three most important indexes to measure the health and sustainability of a water system in a given location, and thus show how such urban development takes all aspects of water into full account.

On the outside circle, the water is considered in the scope of urban metabolism where three main paradigms are defined and clarified as follow:

The 'Circular water loop' deals with water as a resource, especially focusing on drinking water, wastewater and water consumption in production activities. It aims at a circular 'human managed' water loop(see figure 3.4).

The 'Ecologically-sound waterscape' is about surface water ecology. It emphasizes that the urban area functions as an ecosystem, where the health of the surface water system plays a significant role in providing habitat to related local species.

The 'Water sensitive city' here mainly focuses on improving flooding resilience(Though the original concept also touch upon water supply and ecology issues, it is narrowed down here). And it mainly involves mitigating flood risk by climate-adaptive intervention.

It should be aware that though these three topics above are depicted separately in the diagram, all of them are inter-connected in the movement of water metabolism.

Along with the three paradigms, three leverage points are identified. All of them are reinterpreted from the three realms of deeper leverage points(Abson et al., 2016) that focus on the shift of behaviour and mindset of people to participate in and sustain such development. Through 'Reorienting the public mindset', 'Reconnecting people with nature and 'Stimulating knowledge sharing and innovations', they offer the potential to integrate the three paradigms into future urban development and stimulate the change of the system.

In a nutshell, sustainable water-oriented urban development is not only about the three paradigms that redefine the relation between future water and cities, but also about how to stimulate a lasting commitment to the future water system from the citizens.

Conclusion of Chapter 3

To summarize, the concept of sustainable water-oriented urban development is constructed and presented based on the theoretical framework in this chapter. This replies to the first sub-research question and meanwhile serves as the guiding principles and leverage points as the root of the pattern language proposed in Chapter 5 and Chapter 6.

Meanwhile, based on these discussions between water and urban, the diagnosis in Chapter 4 could be carried out to examine the current water system through the lens of these theoretical underpinnings.

CHAPTER IV. DIAGNOSIS

Figure 4.0 The Construction of first highway overpass in the 1990s in the city of Hefei
From Hefei Urban Construction Archives

Introduction

This chapter dives into the diagnosis of the water system in the Lake Chao Basin.

From chapter 4.1 to chapter 4.4, an in-depth analysis of the metabolism in this area is carried out, including a comparative study of the historical and contemporary situation. Three schematic sections could be found at the end of chapter 4.2,4.3 and 4.4, which illustrates the problems of the water system from three different aspects, replying to the sub-RQ 2.

Then these problems are translated into the indicators in the DCBA criteria in 4.5, in response to sub-RQ 3. In chapter 4.6, external risks and potentials are analysed by constructing the future autonomous scenario. This is summarized by SWOT analysis and gives an answer to the sub-RQ 4.

At the end of the chapter, the problem of the current system is summarized by a conclusive diagram with three main problems highlighted. They work as a good summary to bridge this Chapter with Chapter 5.

4.1 Historical Water System

The historical water system in the Lake Chao Basin is analyzed first to grasp the traditional water system which lay the basis for the water system today. Meanwhile, by examining the water system in the past and comparing it with the water system today(discussed later in 4.2-4.4), the impact of recent urban development on the water system can be better understood.

4.1.1 The Fabric of Water and Traditional Townscape

The current polder landscape in the Lake Chao Basin can be dated back as early as the 10th century and has been continuously grown and improved by local people (Xing, 2020). This not only facilitated the local agricultural production but also led to a traditional townscape of living with water.

As can be seen in the map of Lake Chao Basin at the end of the 19th century(See figure 4.1.1), The major towns in the Lake Chao Basin at that time were distributed in the middle stream part of the major rivers in the basin, where the downstream part of these rivers are surrounded by the polder zones with dispersed rural households.

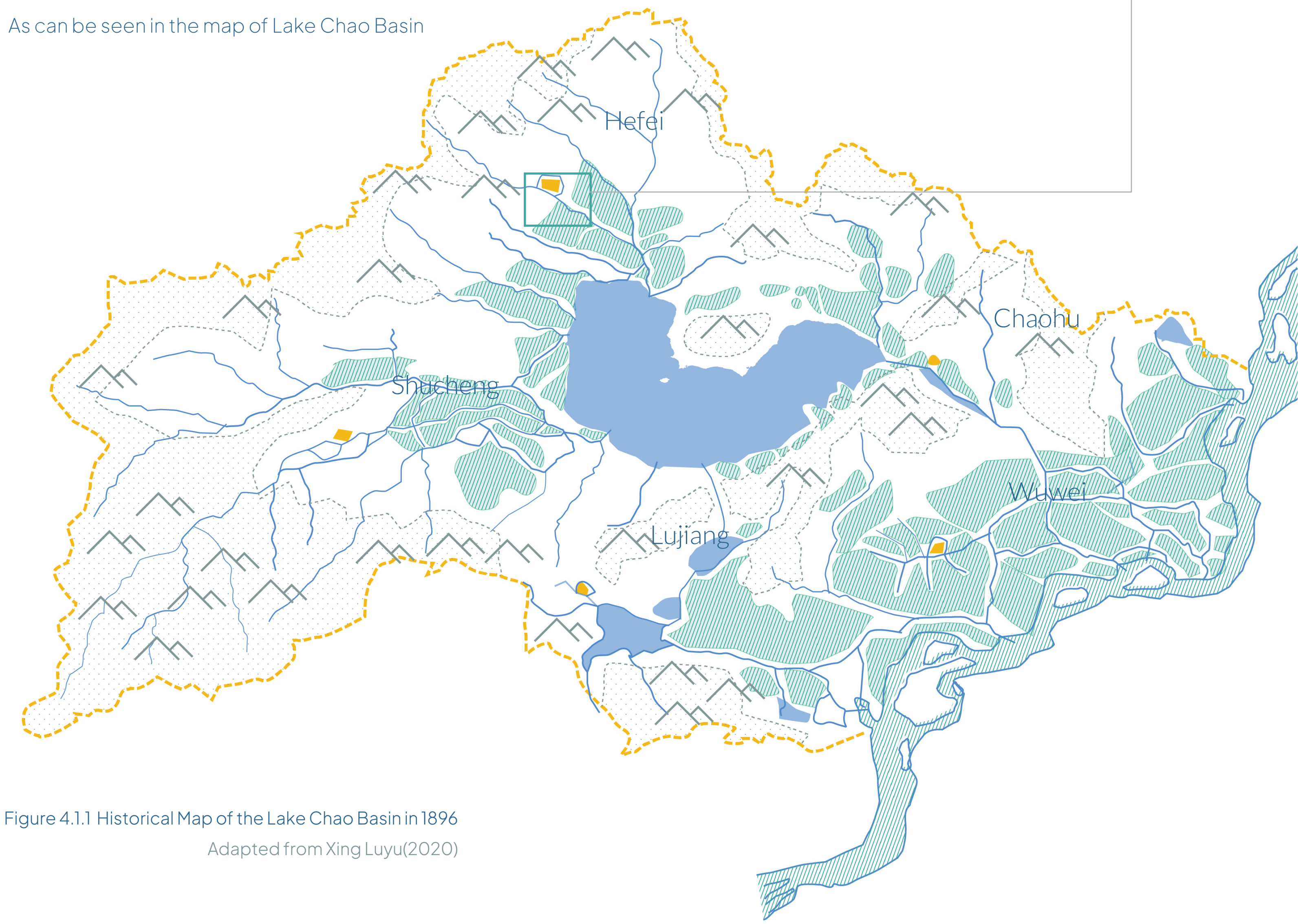


Figure 4.1.1 Historical Map of the Lake Chao Basin in 1896

Adapted from Xing Luyu(2020)

Figure 4.1.2 Drawings of Historical Hefei in 18th Century

from Hefei County Chronicle by Zuo F (2006)

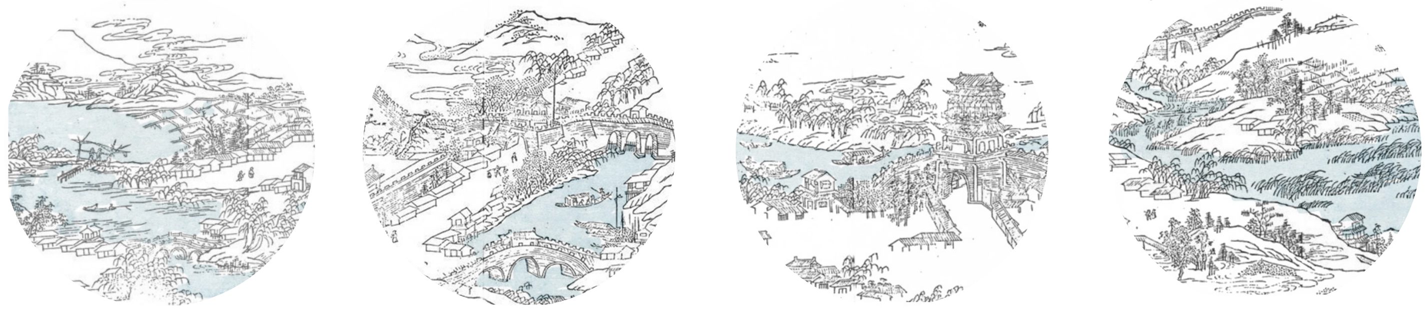


Figure 4.1.3

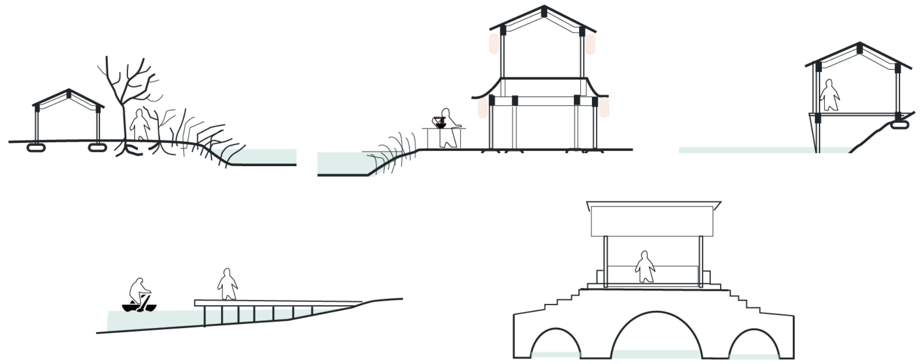
Map of Historical Hefei in the 18th Century

Adapted from Gu Dazhi(2016)

Figure 4.1.4

Building Prototypes with Water from the History

By author



Along with this water-based landscape on the large scale, historical towns in the areas are also built with water. In the historical map of Hefei(see map 4.1.3), green and blue spaces can be seen both within and around the city wall. Commercial functions were distributed along the river within the cities considering the waterway was still used as a dominant transportation mode at that time(see map 4.1.2). Also, the traditional building types tended to be integrated with the surrounding waterscape(As can be seen in figure 4.1.4). Wooden decks can be found as a small harbour where people could travel easily by boat. Bridges and waterfront areas, especially in the centre of the town, also allowed public or commercial activities. In the residential zone, stilted buildings were developed to adapt to the water levels and typological conditions.

4.1.2 Traditional 'Beitang' System

In the past, in order to balance the water supply and adjust the surface water level during both rainy and dry periods, a traditional water retention and control system was widely adopted in the Lake Chao Basin, known as the Beitang('Pond' and 'Dike') This system was actually popular also in many other parts of China and mainly consists of the basic units shown in figure 4.1.5 (Wang, 2019).

Take the city of Lujiang to illustrate how the system functions(see figure 4.1.6–4.1.8): The water source is usually the surface water or groundwater outflow from the mountain zone. This water is collected by building a pond with dikes to control the outflow and provide the drinking water supply to the citizens of the town. In the relatively low and plain area, often in the place where several rivers intersect with each other, a larger retentional lake(in this case, the Huangbei Lake in figure 4.1.6) were created, so the water could be easily stored. This water is transferred by the water canal used for agricultural cultivation in the lower polder zone. In between the lake and irrigation zone, a water gate(see figure 4.1.9) was used to control the water level better and handle the dry season.

Without having advanced modern drainage systems, the wastewater in the towns could still easily be digested by the agricultural field downstream or be purified in a natural way, due to the few toxic elements in the wastewater. As a result, the impact of such a system on the environment is rather small. Such old intelligence from the ancient Chinese fully shows how planners should work with nature instead of again it. Both its cultural value and technical value should be emphasized in today's urban development in the Lake Chao Basin.

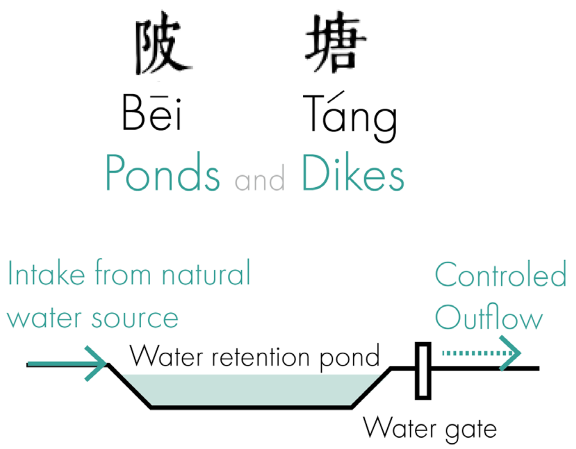


Figure 4.1.5 Diagram of the traditional 'Beitang' system
Adapted based on Wang, X.(2019)

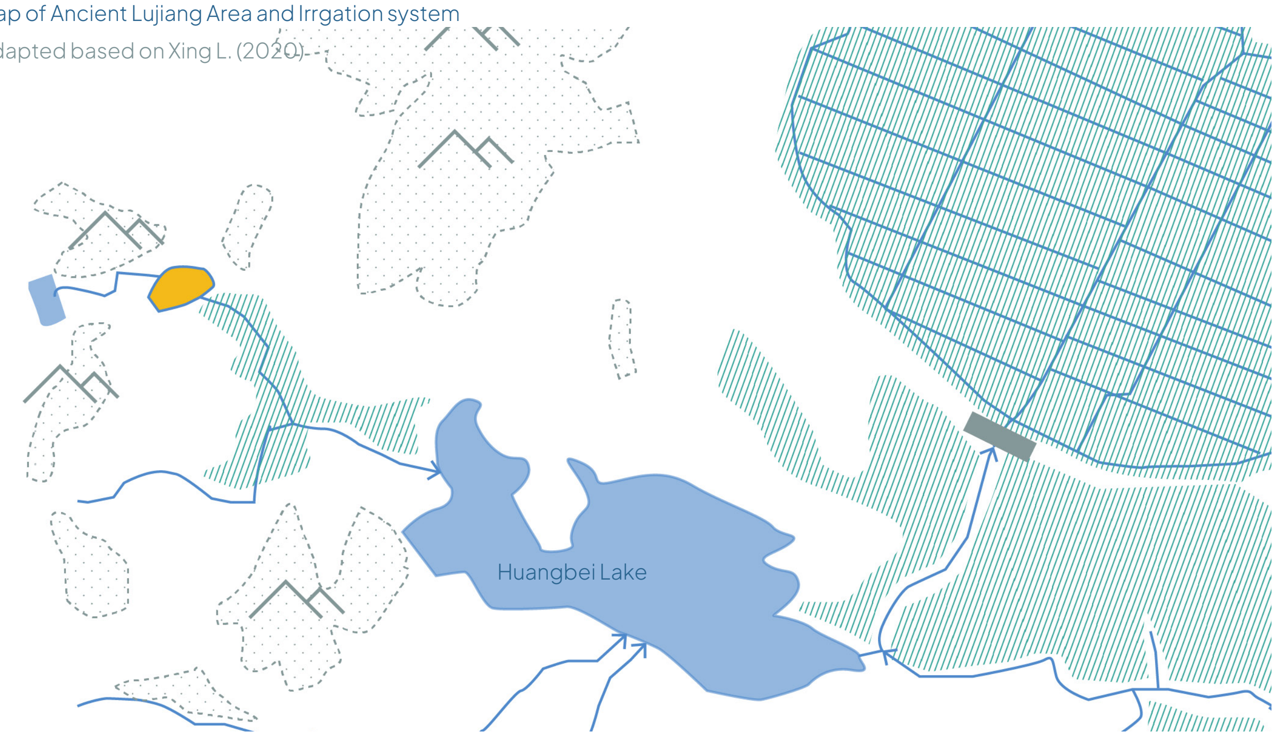


Figure 4.1.6
Map of Ancient Lujiang Area and Irrgation system
Adapted based on Xing L. (2020)

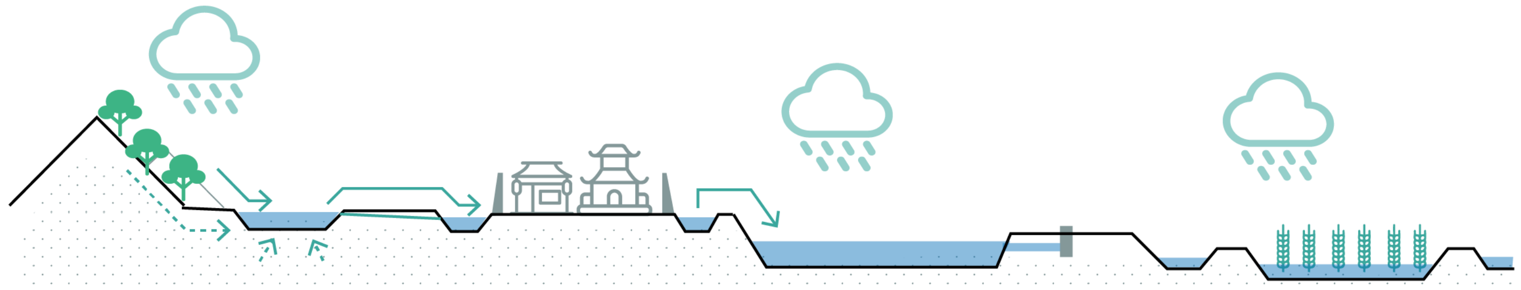


Figure 4.1.7 Traditional water flow in Lujiang Area during rainy period
Adapted based on Wang, X.(2019)

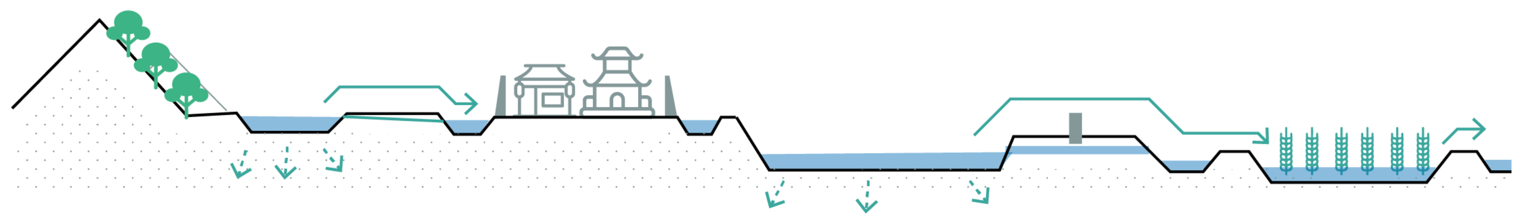


Figure 4.1.8 Traditional water flow in Lujiang Area during dry period
Adapted based on Wang, X.(2019)

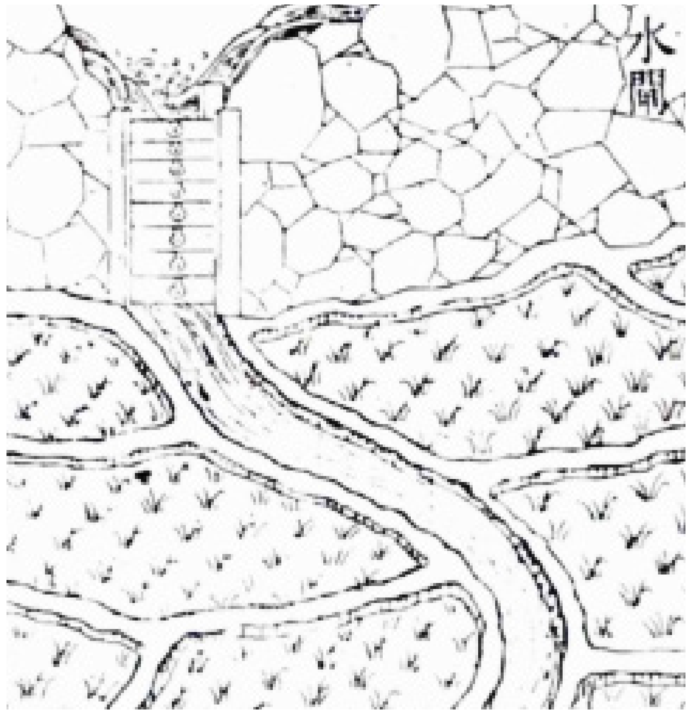
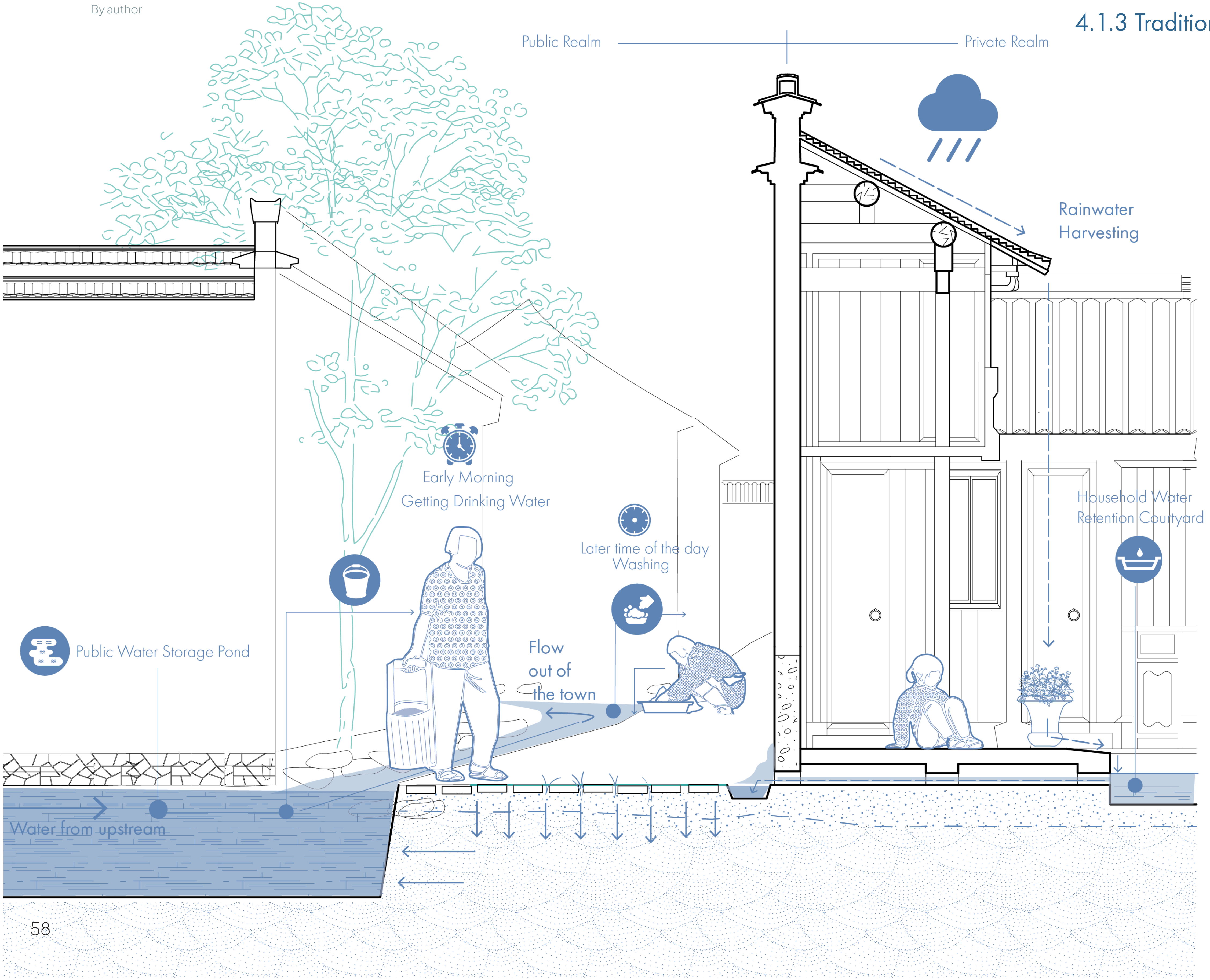


Figure 4.1.9 Diagram of Watergate and polder canals
By Wang, Z(1313)

Figure 4.1.10 Water Metabolism in the past

By author



4.1.3 Traditional Water Consumption Mode

The idea of working with nature is not only practised on a city level but also used to be embedded in people's daily life. Even inside small towns or villages, canals, as well as retentional ponds, were created for people's daily use. Certain villages in the southern part of Anhui Province even developed their own rules for using the surface water by separating the time and location of doing laundry and collecting drinking water. Additionally, in traditional residential building types, the rainwater is often guided by the rooftop into the private courtyards instead of the street, so the rainwater can be easily harvested for daily consumption(Wei and Xu,2010). Such buffers in each household also contribute to mitigating the flood risk of the whole village. More importantly, this way of living has stimulated people's attachment to water and formulated into a tradition in this area.

Takeaways for 'SWOT'

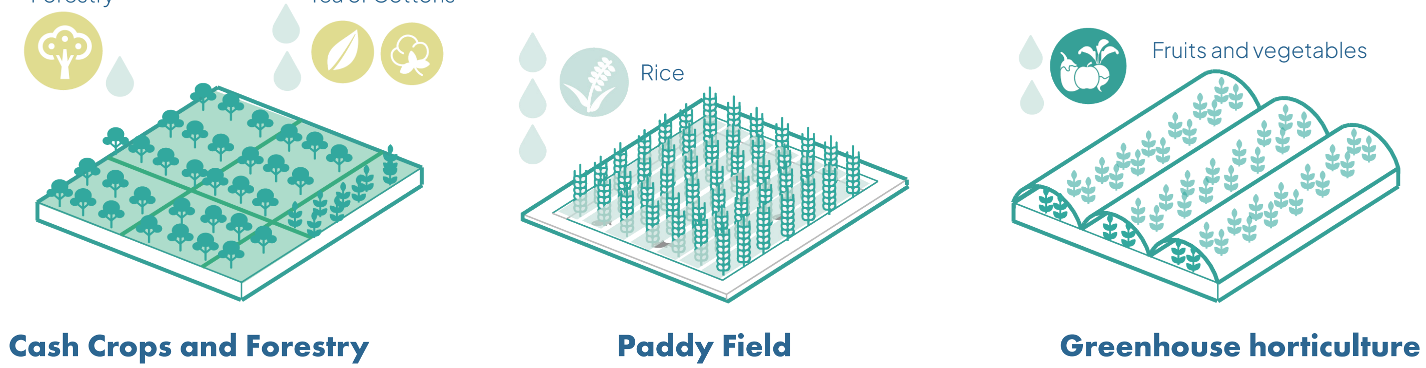
S1 The LCB has an agricultural tradition and old water supply and consumption system is sustainable.

S2 Great attachment to water can be seen from history in their daily life and old townscape.

4.2 Current Water Supply and Demand

In this chapter, the analysis focuses on the current water supply and demand system. It can be divided into two parts:
4.2.1 The irrigation system based on the historical water system mentioned in Chapter 4.1
4.2.2 The modern drinking water supply system established in the 20th century

Figure 4.2.1 Typical Agricultural Production Zone in the Lake Chao Basin
By Author



4.2.1 Irrigation system and agricultural consumption

Currently, the agricultural sector is still the biggest consumer of water in the Lake Chao Basin.

As explained in chapter 4.1, the irrigation system mainly uses surface water from nearby rivers. Especially in the low-lying zone, polder systems were formed with dense water networks(See figure 4.2.3). In this way, the nearby agricultural zone could have more stable access to water as the water can be easily transferred in and out between each polder and from Lake Chao or Yangtze river.

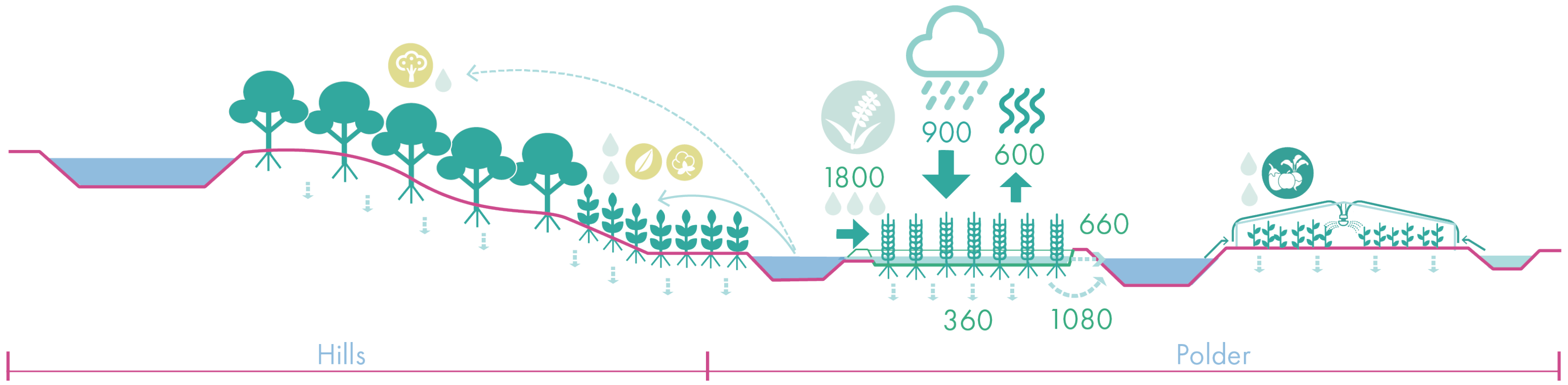
According to the accessibility to stable surface water sources, different crops with different levels of reliance on the water can be found(see map 4.2.1):

In the upper part, the lands are mainly for forestry, where deliberate irrigation is in most cases unnecessary.

In the middle part zone close to rivers, tea trees and other economical crops can be found. In some spaces next to the urban area, greenhouses are also built nowadays for vegetables and fruits cultivation. In these two types of areas, though water consumption is relatively higher than in the forestry zone, yet can be relatively water efficient.

In addition to these crops mentioned, over half of the agricultural production zone in the Lake Chao Basin is still paddy fields(see map 4.2.4). As a crop sensitive to drought and fond of wet soil, the rice needs a large amount of water to grow(Oladosu et al.,2019). At the same time, the current production still relies on the intensive paddy fields irrigation method, which can be not efficient due to the high evaporation rate and high outflow (see figure 4.2.2).

Figure 4.2.2 Systemic Section of Water Consumption in Agricultural Sector
By Author



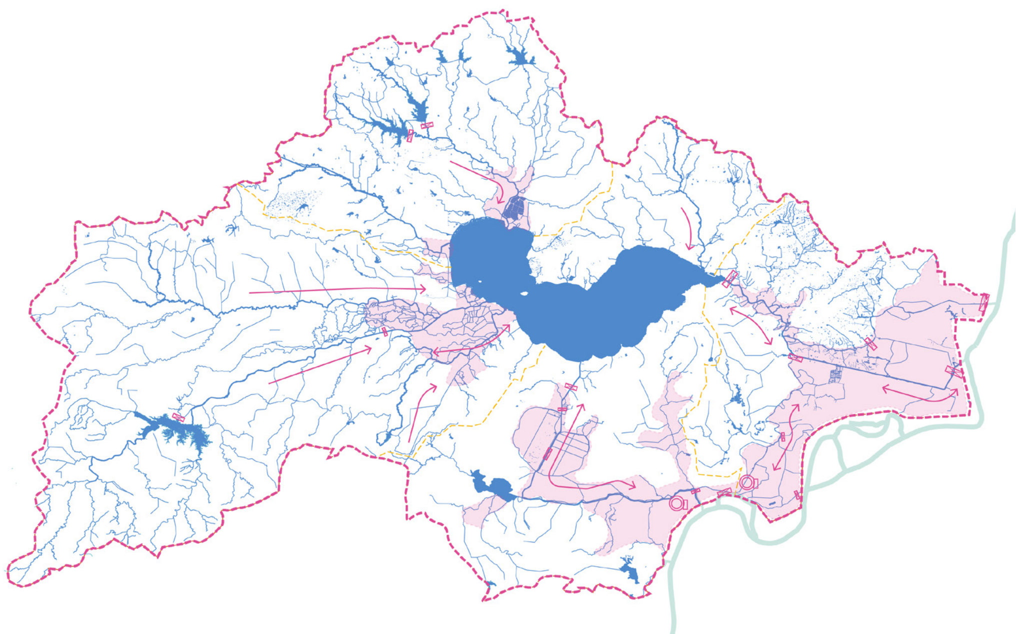


Figure 4.2.3 Polder Zone andSurface water in the Lake Chao Basin
Adapted from Xing L. (2020)

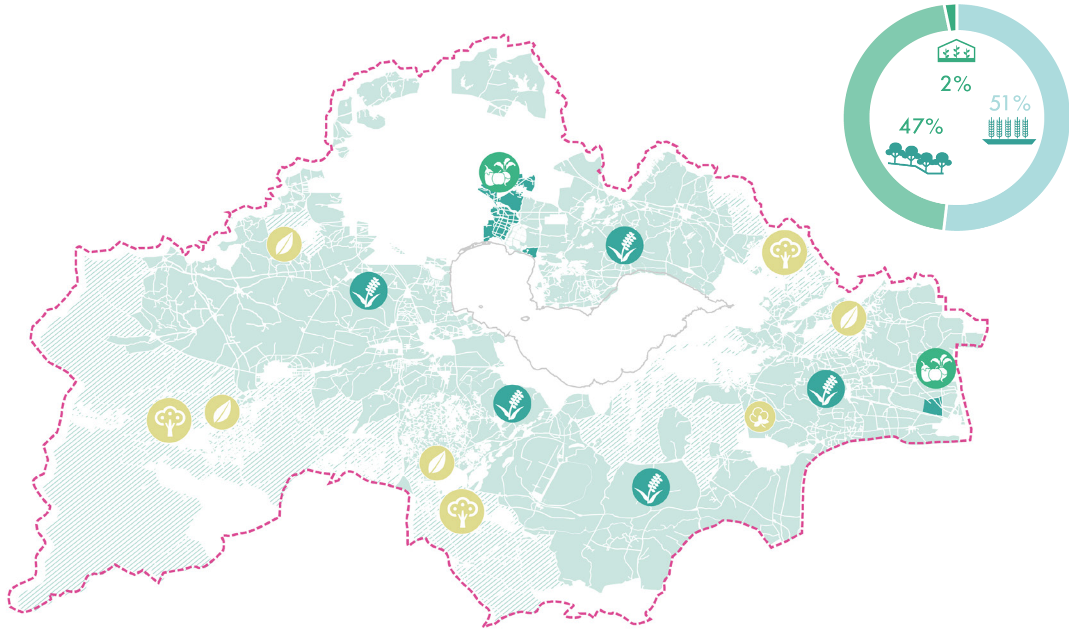
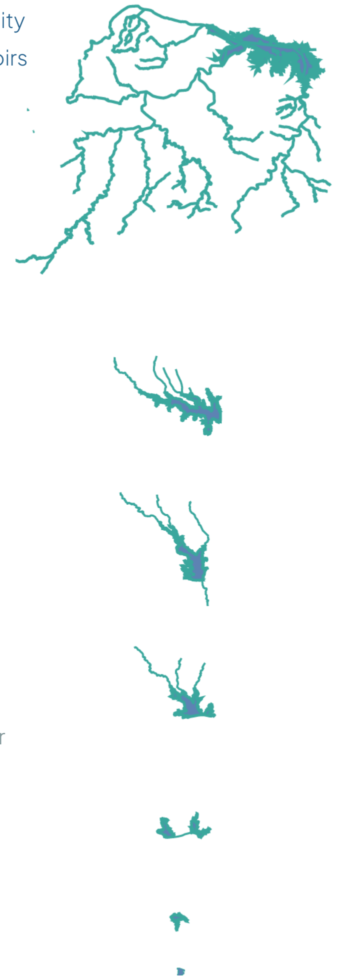


Figure 4.2.4 Map of Crop Types in the Lake Chao Basin
By Author

4.2.2 Drinking water supply and consumption

The drinking water supply system in the Lake Chao Basin is established respectively by each municipality and the main water supply relies on rainwater and surface water. Due to the contamination situation in Lake Chao and in the downstream part of most rivers in the basin, there are only several numbers of reservoirs in the higher part of the basin that can be used as drinking water sources. However, the capacity of rainwater storage in these high-lying reservoirs is rather limited and can hardly be expanded due to the topographical condition(see figure 4.2.5). This leads to high water supply pressure during the dry season which is exacerbated by the unbalanced yearly rainfall pattern(see figure 4.2.6). Hence, most municipalities have to consider relying on the water outside the basin or from the Yangtze River during the dry season when there is not enough water in the reservoir(See figure 4.2.7–4.2.8).

Figure 4.2.5
Drinking Water Storage Capacity of Main Drinking Water Reservoirs in the Lake Chao Basin



1. Longhekou Reservior
Runoff Area: 1120 Square km

2.Dongpu Reservoir
Runoff Area: 207.5 Square km

3.Dafangying Reservior
Runoff Area: 184 Square km

4.Zhongxing Reservior
Runoff Area: 114 Square km

5.Caitang-Zhangqiao Reservior
Runoff Area: 60 Square km

6.Zhangyuan Reservior
Runoff Area: 15.25 Square km

7.Guoyuanshan Reservior
Runoff Area: 7 Square km

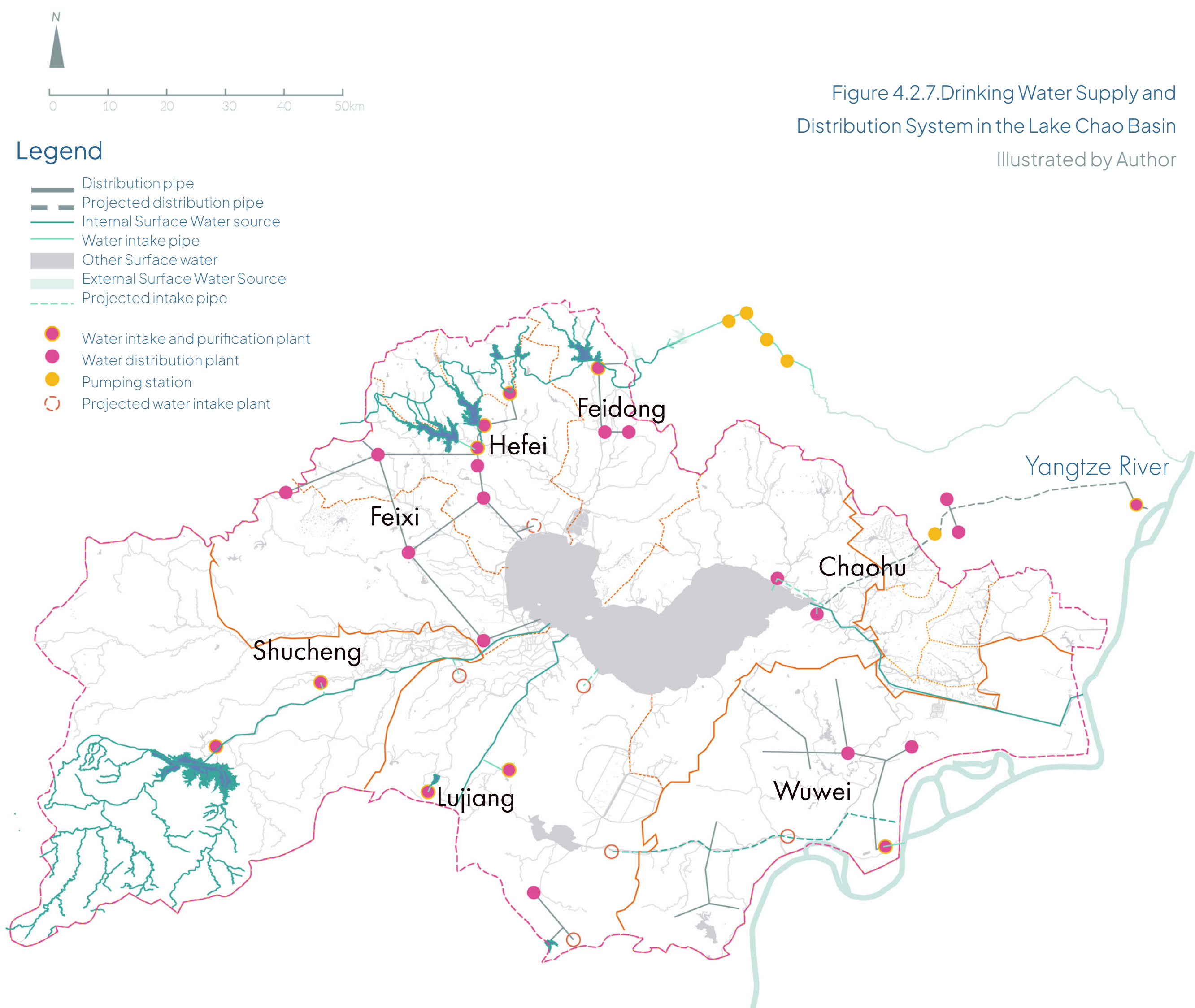


Figure 4.2.7.Drinking Water Supply and Distribution System in the Lake Chao Basin
Illustrated by Author

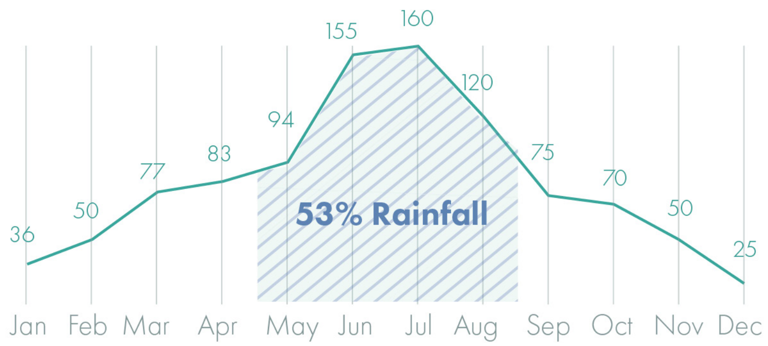


Figure 4.2.6 Average Annual Rainfall Pattern in the Lake Chao Basin
Based on data from CMA, by Author

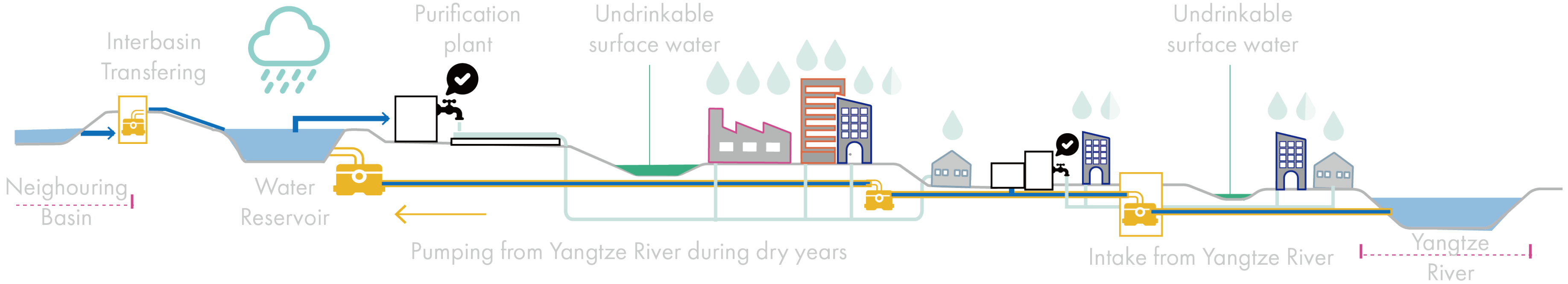


Figure 4.2.8. Systemic Section of Drinking Water System
by Author

Figure 4.2.9.Drinking Water Consumption Quantity / year

Data based on Bureau of Statistics of Anhui Province(2020)
Detailed Calculation can be found in Appendix D
Illustrated by Author

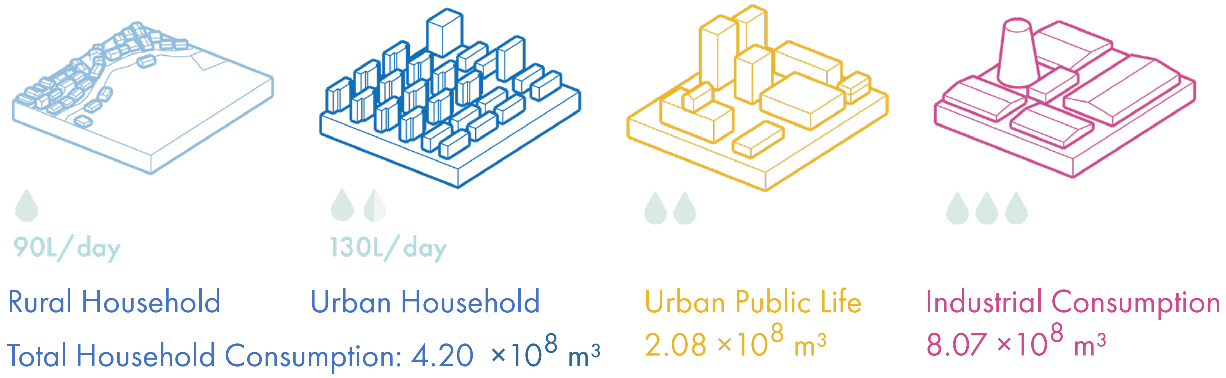
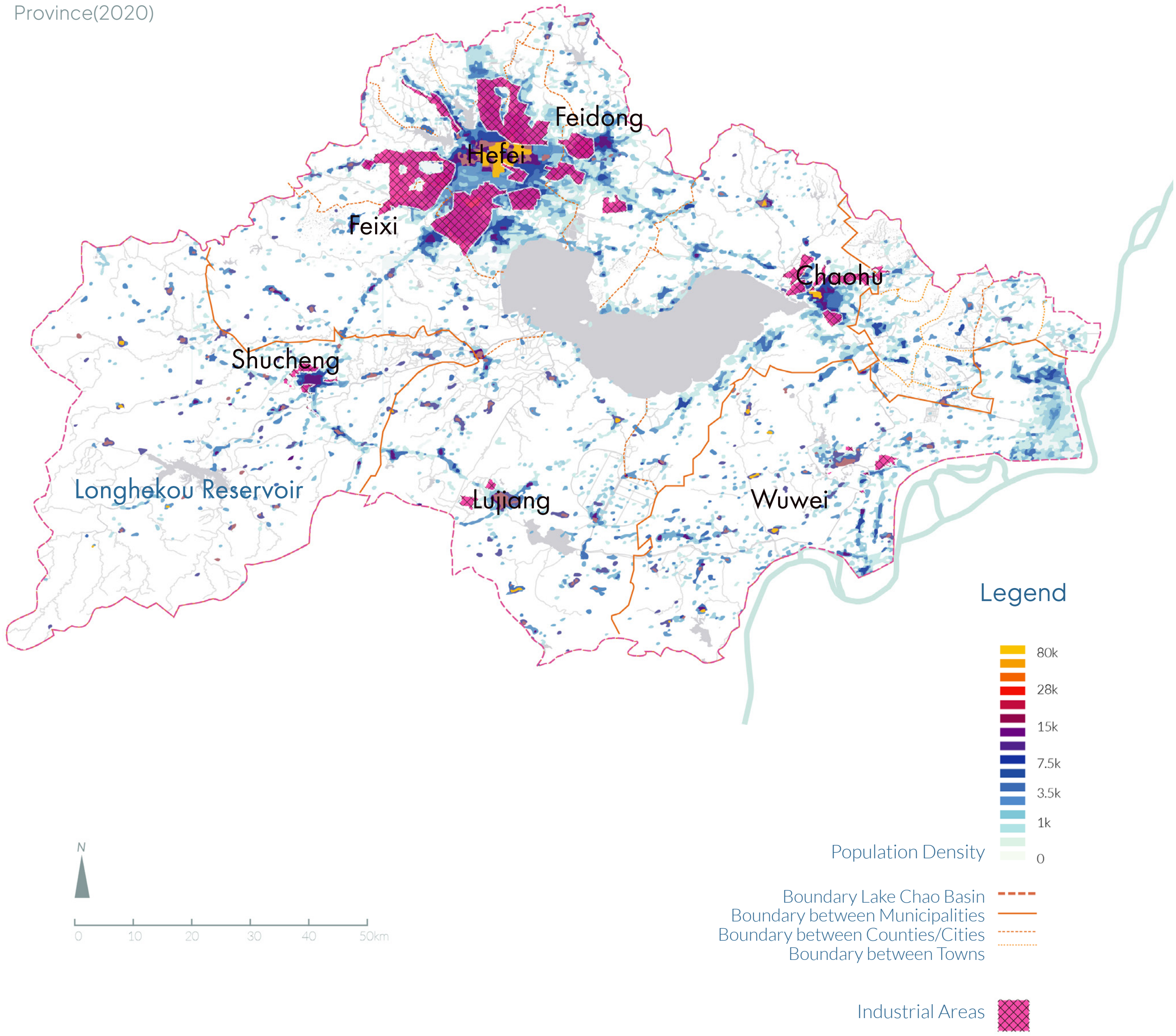


Figure 4.2.10 Major Water Consumers

Illustrated by Author
Data based on Bureau of Statistics of Anhui Province(2020)



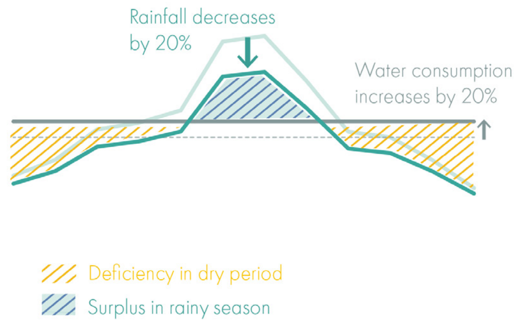


Figure 4.2.11
The future pressure between water supply and demand
by Author

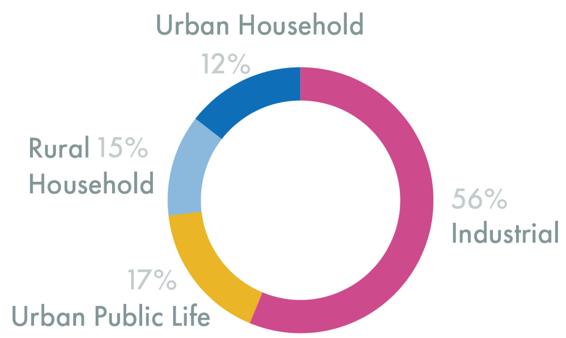


Figure 4.2.12
Consumption of drinking water
Illustrated by Author
Data based on Bureau of Statistics of Anhui Province(2020)

When looking at the water consumption part, the precious drinking water source is in fact not all consumed by citizens for daily use. Over half of the drinking water supply actually goes to industrial production(See figure 4.2.12), with considerable numbers of water-intensive manufacturing. Moreover, the amount of household water consumption might grow further, considering more rural households are likely to embrace higher living standards and increase water consumption levels. In addition, the water consumption in urban public life, including commercial and leisure activities can also rocket with the further urbanisation.

In addition, the problem of drinking water scarcity is also exacerbated by the unbalanced distribution of drinking water sources and drinking water consumers, for example, the biggest industrial zone can be seen in the municipality of Hefei while the biggest drinking water supply reservoir is the Longhekou Reservoir to the western of Shucheng(see figure 4.2.10),.

As a result, the current water storage capacity is far from being self-sufficient within the basin. Even without considering the spatial distribution of water supply, according to the line graph 4.2.11, either yearly rainfall decrease or water consumption growth can already lead to deeper water scarcity if the water storage capacity remains the same. Both of these conditions are sadly likely to happen in the future.

Summary on Water Quantity

Based on the previous analysis of the water supply and consumption in the Lake Chao Basin, the main problems and weaknesses of the current system in relation to water quantity could be identified as follow:

Main problems to solve

A1 Water Intensive Paddy Field
Though agricultural sector generally relying on sustainable water source, most of the land are water-intensive paddy field.

A2 Water Intensive Industry
The industrial sector has become the dominant consumer of drinking water supply.

A3 Inaccessibility to Sustainable Water Source
Main urban area still relying on water transfer infrastructure
There is a unblanced distribution of sustainble drinking water source and the major consumers from urban area.

Takeaways for 'SWOT'

Weaknesses

W1 Monsoon Climate
There is natural drought season of the monsoon climate and it is neccessary to store more water during rainy season.

W2 Topographical limitation
Creating more large water storage reservoirs is hard due to the topographical condition.

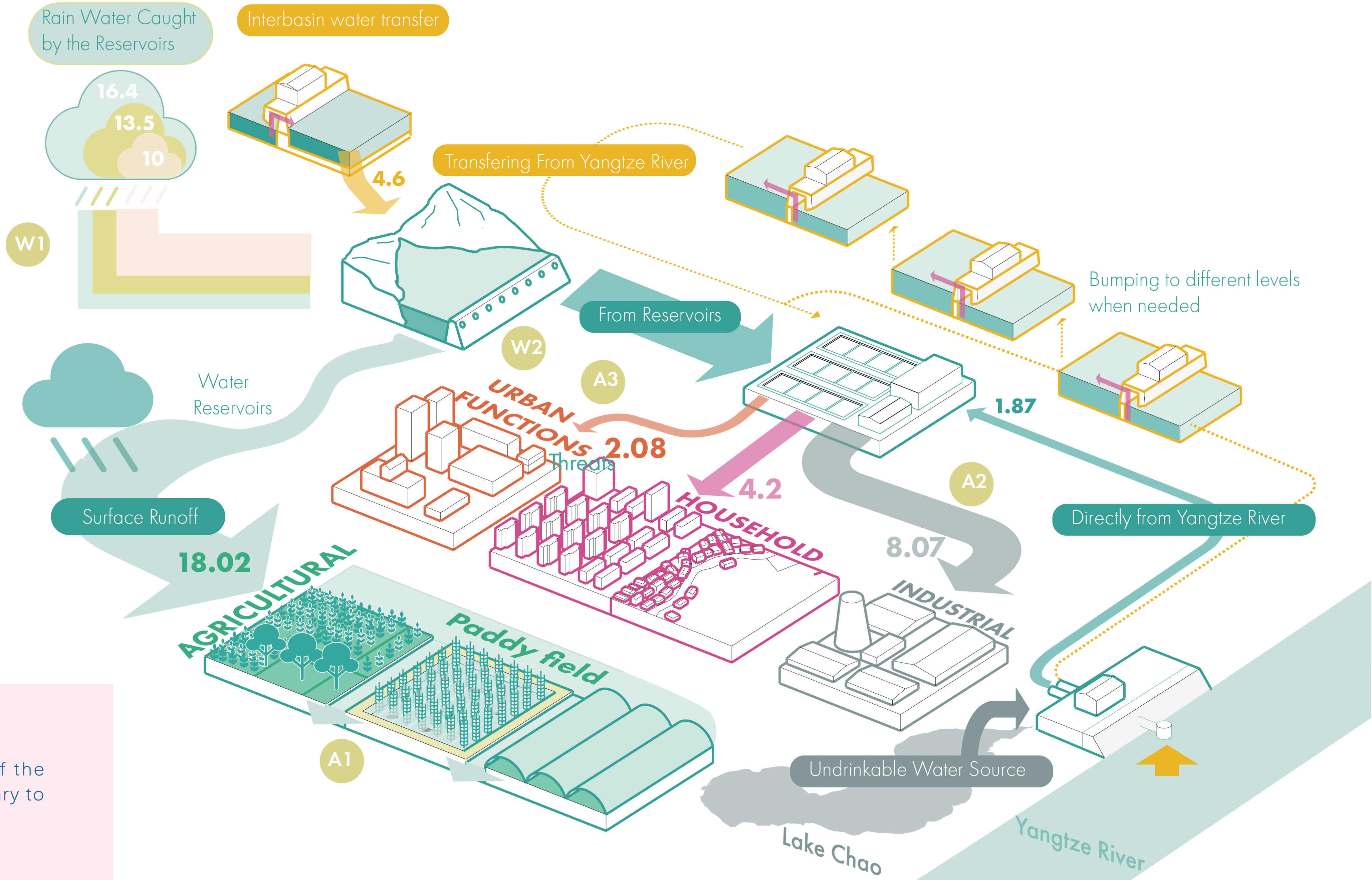


Figure 4.2.13
System Scheme of Water Quantity
Illustrated by Author

4.3 Current Challenges of Flooding

In this chapter, two major flood types are discussed. One of them is fluvial flooding which happens when heavy and continuous rainfall hit the whole region, leading to the outflow of surface water to the surrounding lands(Zurich Insurance,2020). The other is urban waterlogging when flash storm rainfall amount exceeds the grey drainage system and causes disaster to the urban area(Xue et al., 2016). These two parts of the analysis offer understanding of the current water safety problems under the existing urban morphologies of the Lake Chao Basin.

4.3.1 Fluvial Floods

The fluvial floods in the Lake Chao Basin are trick and unique because of the topographical condition. As can be seen in the map 4.3.1. Lake Chao is surrounded by relatively mountainous areas, yet the water level of the Lake Chao and Yangtze rivers is fairly close to each other. This means the river connecting the Yangtze River and the Lake Chao flows slower compared to the upstream rivers where the slope is steeper. Because of this, a large amount of stormwater is unavoidably stuck in the basin during the rainy season before they flow to the Yangtze River, which easily leads to 'fluvial floods'.

However, though the situation is decided by the nature of this area, the current urbanisation process has probably exacerbated this issue. Between 1986 and 2021, the urban area mainly expanded in the high lying part(see figure 4.3.2). This changed the hydrological condition of the area prominently. Instead of infiltrating underground, the stormwater goes directly to the urban drainage system and ends up in the lake. Consequently, when an extreme flood happens, the floodwater can reach one story high(at around 13 mamsl).

Figure 4.3.1
Urbanisation and Topographical condition
by the author

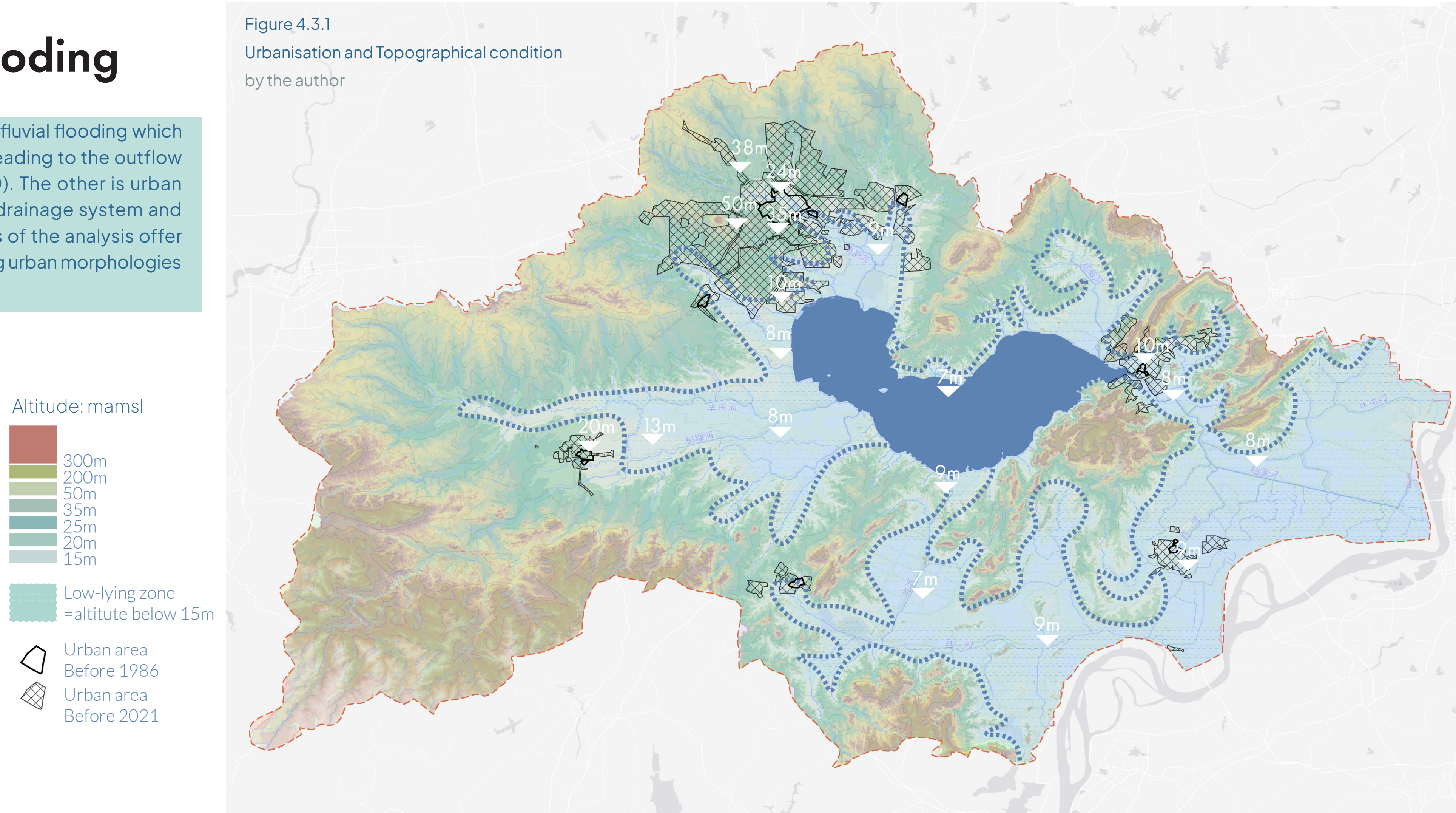
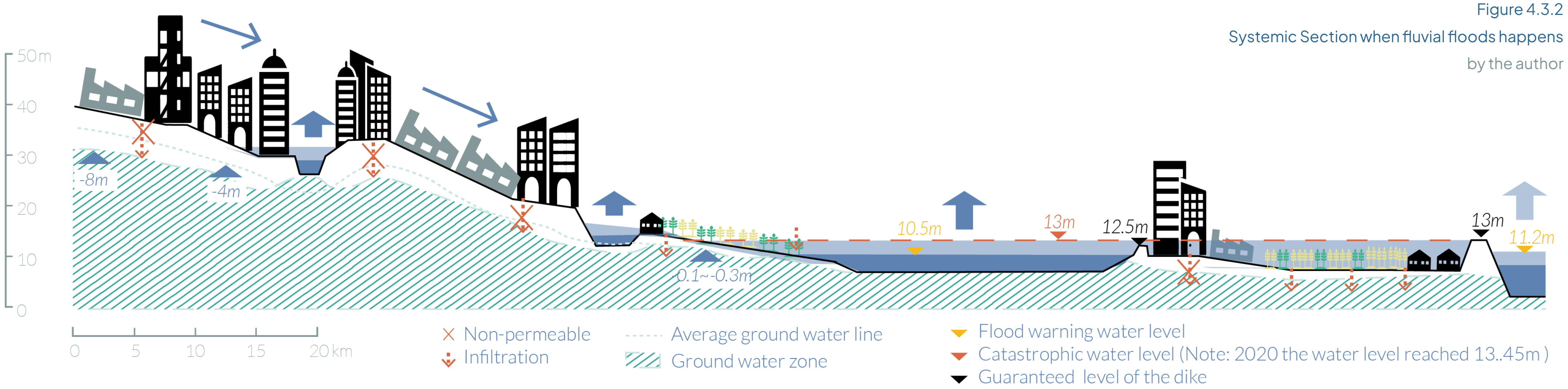


Figure 4.3.2
Systemic Section when fluvial floods happens
by the author



4.3.1 Fluvial Floods

From the geographical limitations, certain areas are obviously causing problems, while others doom to suffer more from fluvial flooding. On the right are three major types of the land use that plays different roles in front of the fluvial flooding (see figure 4.3.5):

Low-lying zone(<13 mamsl)
Industrial Zone
Residential Zone
Village
Surface Water

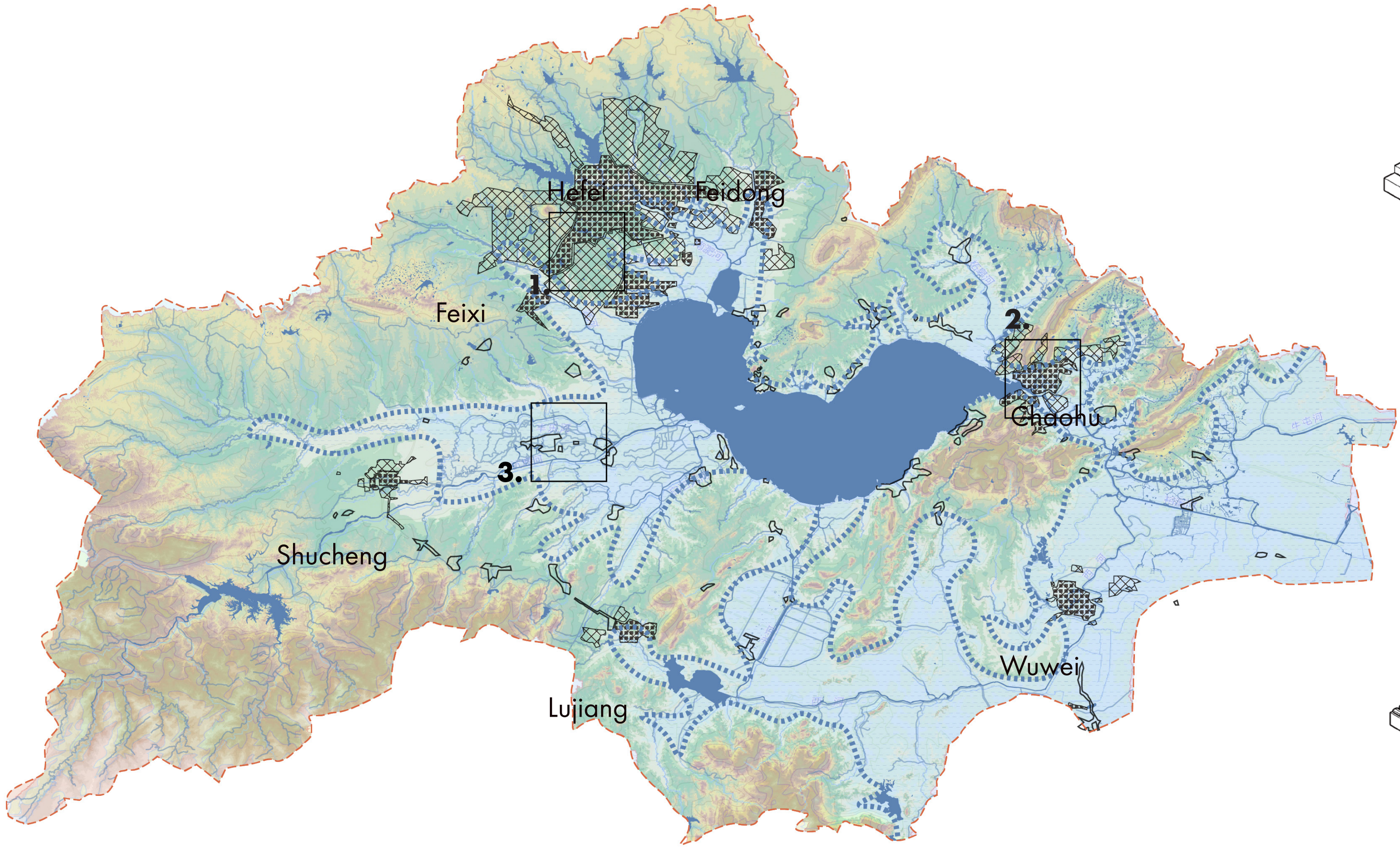
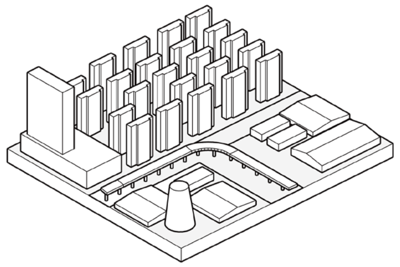
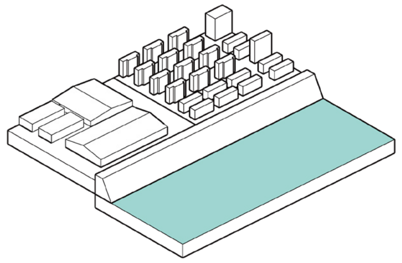


Figure 4.3.4
Flood Risk and Landuse Mapping
Photos from Sohu,CRNTT,Paper and Baidu Map
Others illustrated by the author



1. High-lying Urban and Industrial Zone

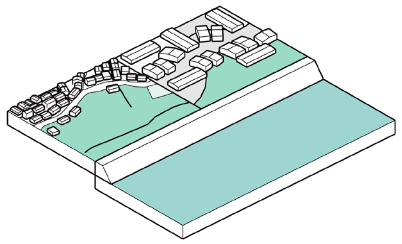
-Urban areas located at higher altitudes.
These areas are mainly built in recent decades and are typically car-oriented. Immense industrial buildings, office towers and highrise residential buildings can be seen in these areas which lead to highly sealed ground. Room for surface water or temporary water storage space can hardly be found. All this has put the natural water circle in great danger and caused problems to the downstream location. However, they also have the potential to be problem solvers.



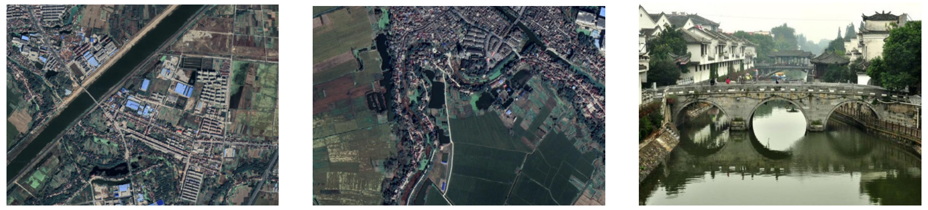
2. Low-lying Urban Area

-Urban areas located in the low-lying zone(altitude <15 mamsl).
These urban areas are usually preserved by dikes which can protect them when the water level does not exceed the major flood level. However, with the flooding in the future becoming more intense and more frequent, these cities can be also vulnerable.

3.Low-lying Old Town and Villages



Due to the low building height, low-lying geographical conditions, and not being fully equipped with water management infrastructure, this type of district is the most vulnerable. Though their infiltration rate is generally high and also keeps a lot of room for water for irrigation purposes, their groundwater level is already high and probably does not have so much capacity for infiltration. When a flood hits the region, villagers and local farmers from such districts could only rely on temporary evacuation which might still cause property damage.



4.3.2 Urban waterlogging

Another water safety challenge arises from urban waterlogging. Affected by global climate change and the urban heat island effect, extreme stormwater events have become more intense and frequent in the urban areas in the Lake Chao Basin (Hao et al., 2019). According to the record by the local meteorological institute, the depth of waterlogging in the city of Hefei can reach 800mm one hour after a 60mm rainfall.

The victims of such waterlogging are not only neighbourhoods in the absolute low-lying territory(usually next to a river, like location 2) but also located in the relatively lower zone compared to the surrounding neighbourhood(like location 3). Also, streets and even trunk roads can suffer from this water nuisance(See Zoom-in 1), leading to traffic problems and risks to both local residents and the passer-by.

Based on this mapping, these three zoom-ins showing high urban waterlogging pressure are explored further on a lower scale on the next pages.

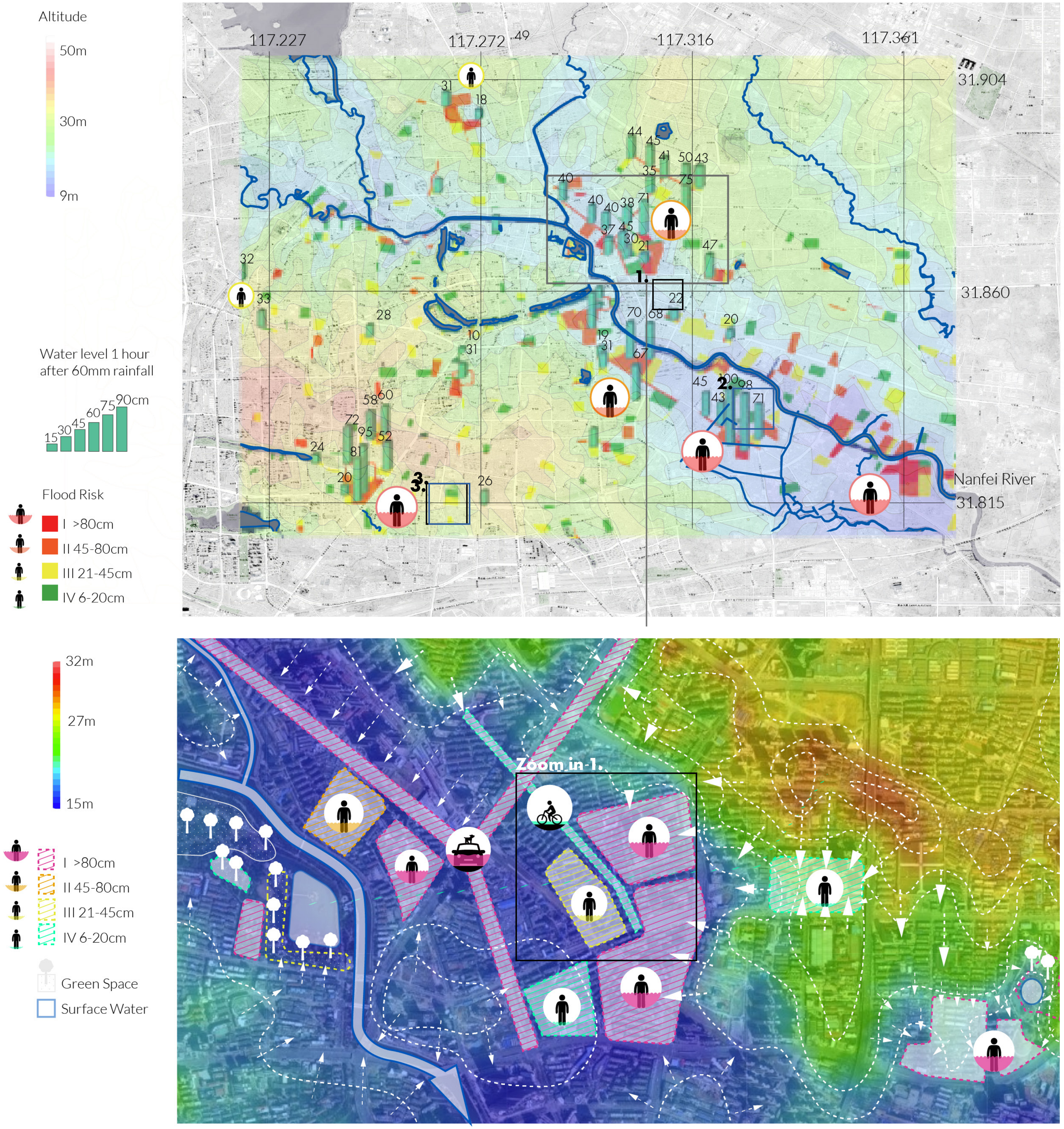


Figure 4.3.5
Mapping Waterlogging Pressure
Illustrated by Author
Data source from Hao et al. (2019)

Zoom-in 1 :

Outdated watermanagement infrastructure

Limited room for water retention

Zoom-in 2:

Informal Buildings vulnerable to flooding

Sealed by concrete

Zoom-in 3:

Car-oriented street

Green space with limited water management value

Figure 4.3.6

Neighourhoods with High Waterlogging Pressure

From Baidu Map Satellite and Street View

Zoom in 1:
Sanlijie District-New Workers' Estates

This location was built for local manufactural workers in the 20th century and their drainage system have already been outdated. They cluster around the periphery of the historical city cores and thus are usually relatively low-lying. Due to their low height and high density, buffer zones for water can hardly be found in this type of neighbourhood. So there is no buffer zone for water when storms happen.

Zoom in 2:
Wulimiao District-Manufactural urban village

This area is a suburban area with factories and residential buildings, many of which are informally built. This type of urban village can be seen in many other spaces in the region along the main waterway since the transportation is convenient. They were transformed from the previous agricultural zone by their owners autonomously to rent to migrant workers from rural areas. Because of this, they are usually of low quality and poorly planned. The subsurface is usually sealed with concrete and green space or vegetation can rarely be found. They are not only exposed to high urban waterlogging risk but also are vulnerable in front of fluvial flood risk during rainy seasons.

Zoom in 3
Anliang New Town-Enclosed neighourhood

This type of neighbourhood is built at the beginning of the 21st century and is composed of usually highrise buildings. Though green spaces can usually be seen within the neighbourhood, their impact can be limited since they are not integrated with the water management system. Besides, these neighbourhoods are typically car-oriented, usually surrounded by wide highway infrastructures. A large part of the ground surface in this neighbourhood is still paved since many of the residents rely on cars for their daily commuting. Meanwhile, the large underground parking place equipped by this type of neighbourhood might also negatively affect the infiltration process.

Summary on Water Safety

Figure 4.3.7
System Scheme of Water Safety
Illustrated by Author

Main problems to solve

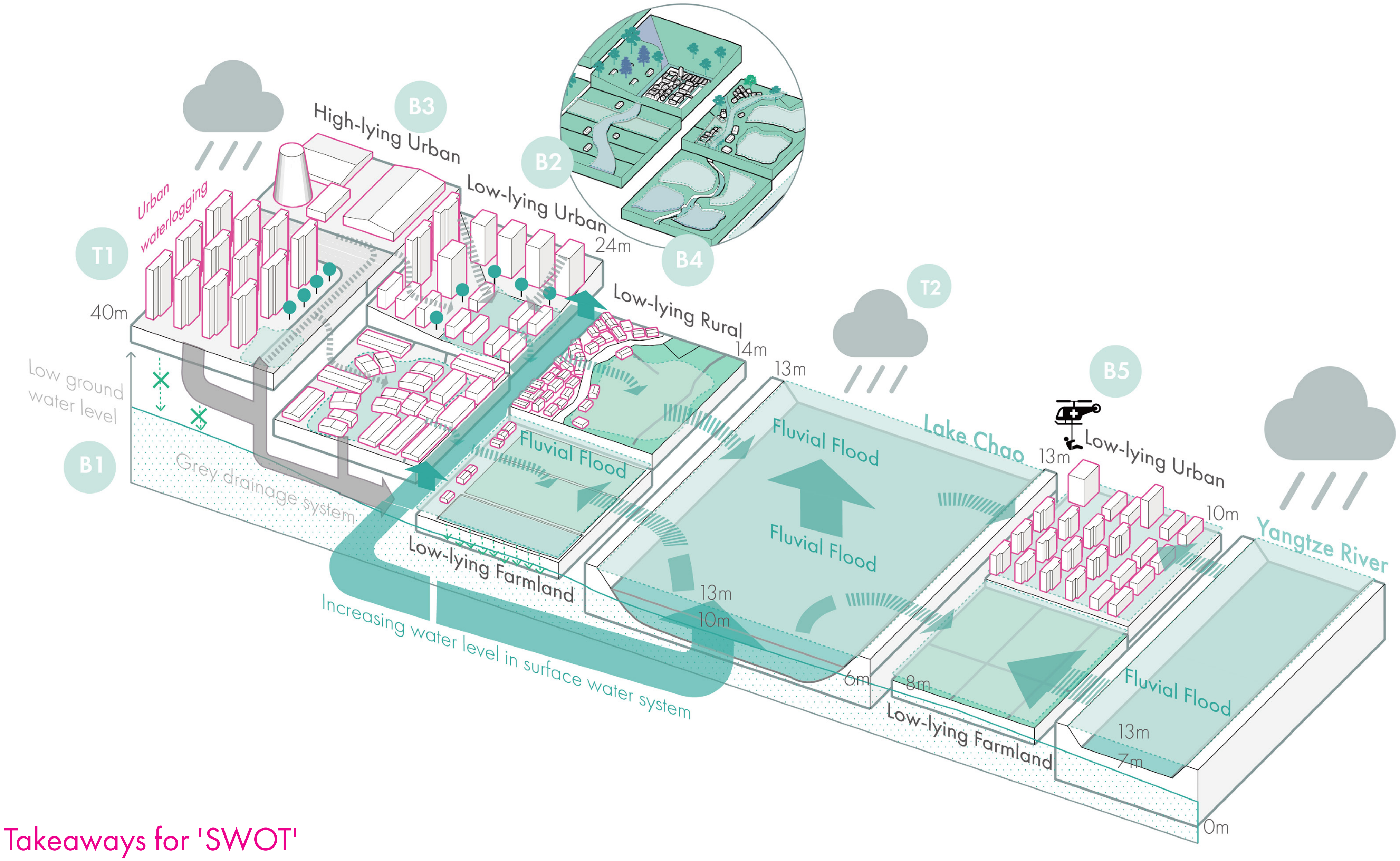
B1 Low Permeability
Not enough room for infiltration, especially in the newly built-up area

B2 Disappearing surface water
Previous ponds and streams including polder landscape are disppearing.

B3 Limited Interception
Having trees and vegetation in the urban area, yet not efficient in improving interception

B4 No Retention Buffer
Many residential zones have no buffer zone for rainwater retention. Most of them rely on a no-delayed drainage system.

B5 Relying On Temporary Evacuation
Temporary evacuation are needed for low-lying zone when flooding happens. However the economic and non-economic loss can not always be recovered



Takeaways for 'SWOT'

Weaknesses

W2 Topographical limitation
The low-lying zone around the lake and between the Yangtze River and Lake Chao is naturally more vulnerable to flooding.

Threats

T1 Paradigm of Unpermeable Densification
The contemporary mode of densification driven by cars still dominates the Lake Chao Basin.

T2 Climate Change
More intense flooding might happen in near future.

4.4 Current Water Quality

Due to the fact that the Lake Chao Basin is troubled by water pollution for a long time, the analysis of water quality begins with mapping out the water pollution in 4.4.1. And in the second part of this chapter, also explores the riparian ecosystem condition that can sustain the water quality in the long run.

4.4.1 Mapping water pollution

Pollution level and related factors

Though protected areas are established surrounding the lake Chao, the quality of water flowing into the lake Chao is already heavily polluted(see map 4.4.1). Hence, tackling the pollution of lake Chao is never only about the lake and lakefront area. To trace the source of pollution, four factors that affect surface quality are examined. This includes the level of nitrogen, the level of phosphorous, the ecological health condition of the rivers and source of heavy metal pollution of the basin.

As can be seen from the figure, emissions from the main urban areas(including their surrounding suburban areas and industrial zone) have put high pressure on the water quality. The total nitrogen and phosphorus level in rivers 1, 3,4, are all above the fourth level, all of which flow through either densely populated areas or industrial zones, which are remarkably higher than other rivers flowing in rural areas.

The pollution of the heavy metal also originates from mobility sectors and industrial sectors that are connected with the urban areas. At the same time, the water ecosystem health condition of these inner-city rivers is also diagnosed as 'sick' according to Ding (2018), meaning that they have already lost the ability to restore the polluted water themselves. As a result, understanding and controlling the emissions from urban areas should be prioritized in improving water quality.

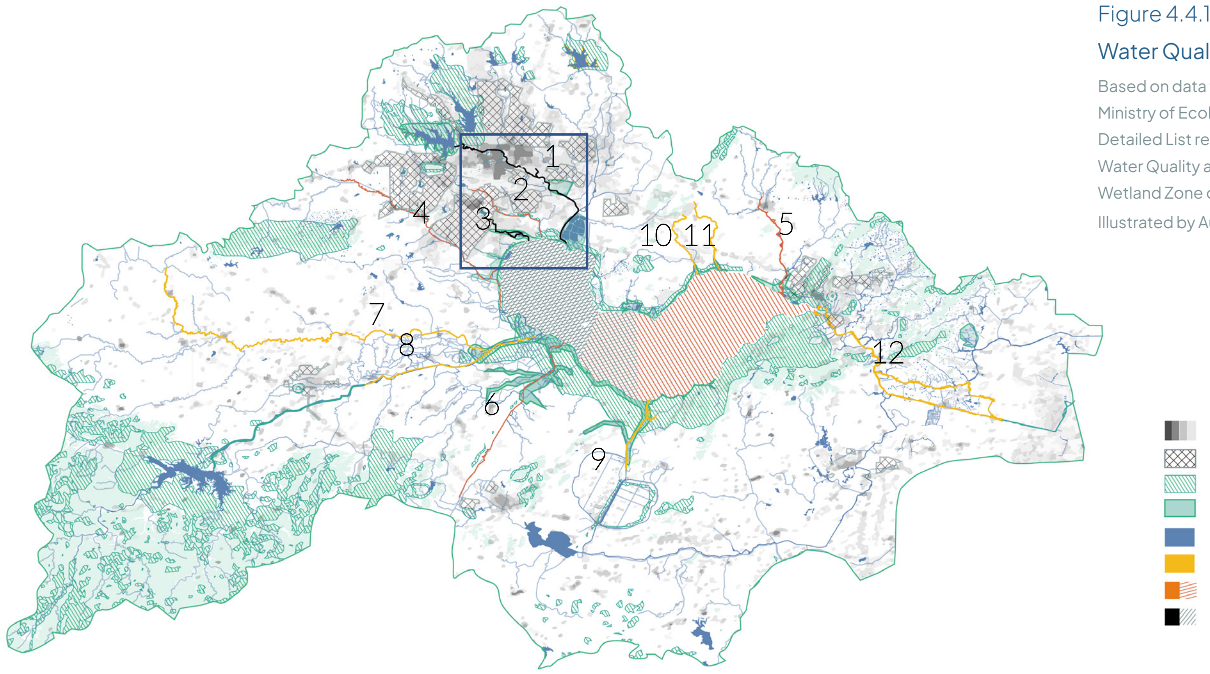


Figure 4.4.1

Water Quality and Natural Reserve

Based on data from
Ministry of Ecology and Environment, PRC
Detailed List regarding
Water Quality and
Wetland Zone can be found in Appendix D
Illustrated by Author

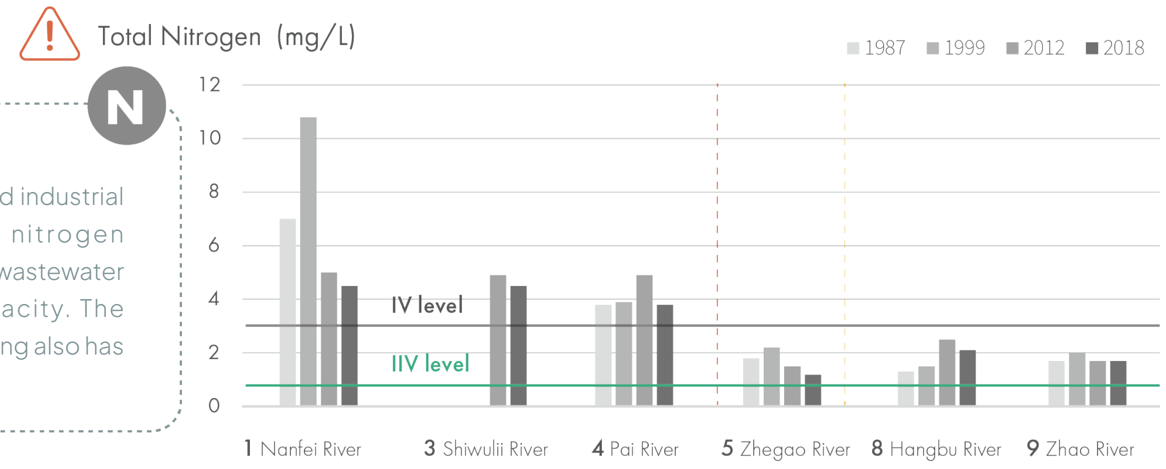
Figure 4.4.2

Nutrients Level in major rivers in the Lake Chao Basin

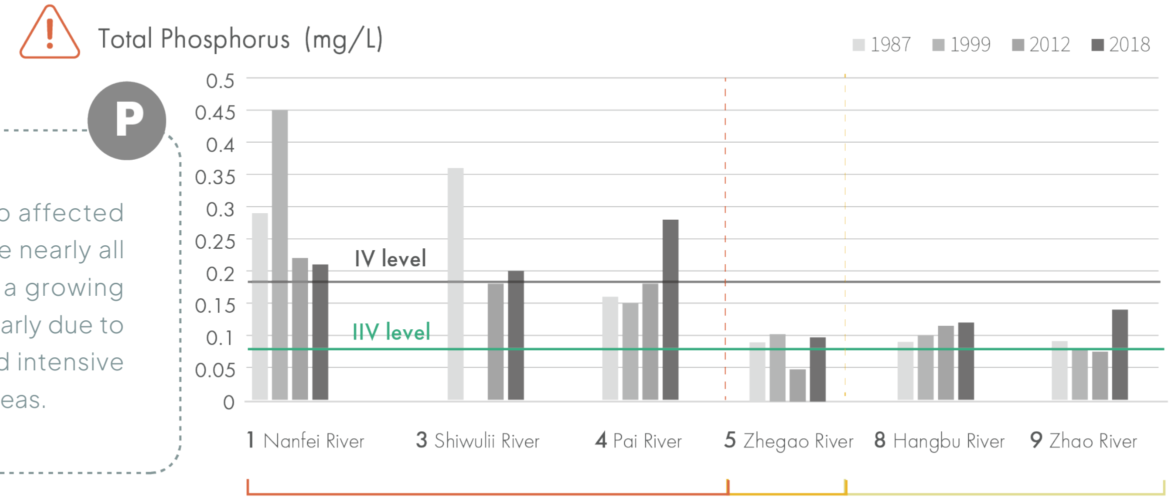
Based on data from Zhang M. et al. (2020) and Xie P.(2009)

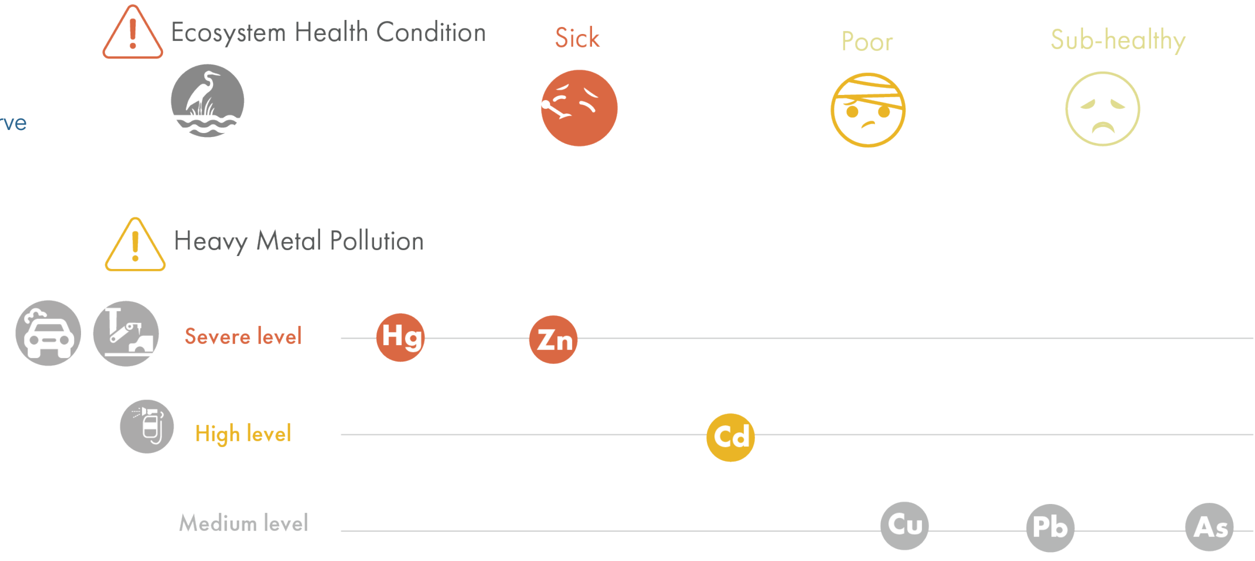
Illustrated by Author

The urban household emissions and industrial emissions play a major role in nitrogen pollution, this is due to the growing wastewater and insufficient treatment capacity. The pollution from fishery and rice farming also has an impact.



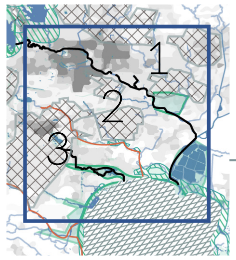
The phosphorous emission is also affected by the urbanisation process since nearly all the rivers in the chart witnessed a growing phosphorous level. This is particularly due to the expanding industrial zone and intensive livestock farming in the suburban areas.





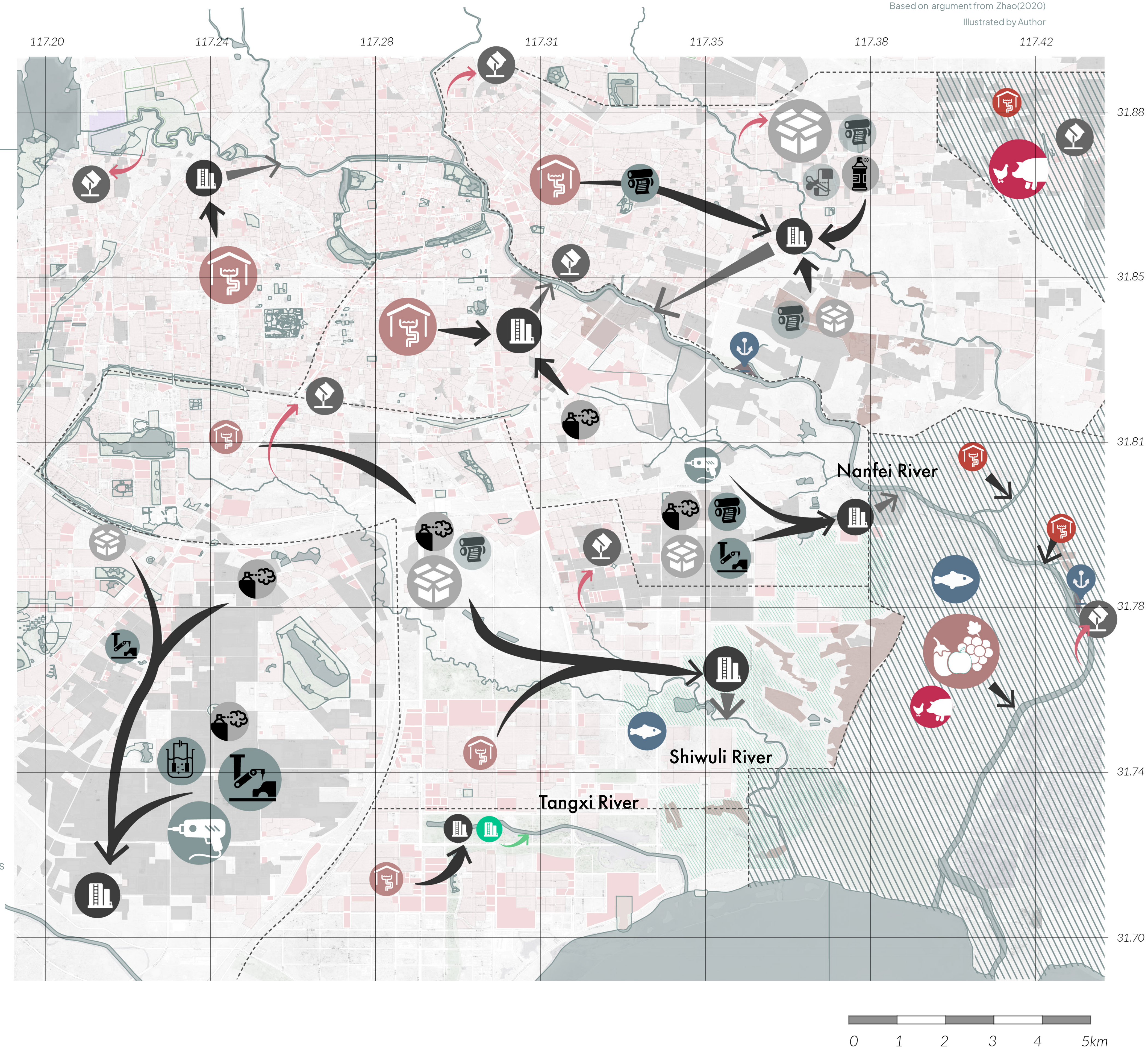
When it comes to heavy metal pollution, the mobility sector causes most of the emissions. According to Xia et al.(2020), nearly 60 per cent of mercury and over half of the zinc pollution comes from the metal wear and on-road emissions of cars. Meanwhile, the agricultural sector is to blame for nearly half of the Cadmium emissions due to the improper utilization of fertilizer and pesticides.

4.4.1 Mapping water pollution



To figure out the source of pollution of the 'inner-city' rivers and related urban activities. The potential causes of water pollution around the Nanfei river, Shiwuli River and Tangxi River are mapped out. Further elaboration regarding each of them could be found in the next pages.

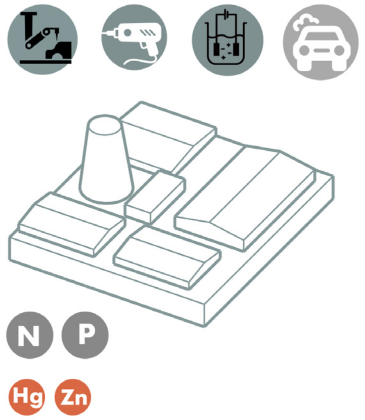
Figure 4.4.3
Mapping source of pollution on city scale
Based on argument from Zhao(2020)
Illustrated by Author



1.Water-Intensive and Pollution-intensive Industries

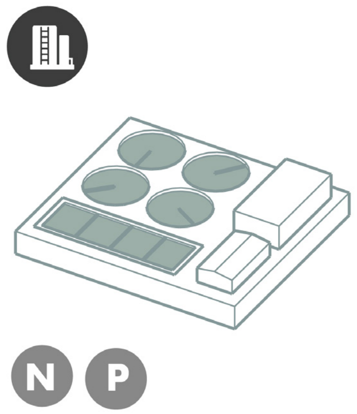
The water-Intensive and pollution-intensive industry still dominates many of the informal industrial zones. Most of the businesses is extensive in water consumption and Illegally emissions without treatment can happen to cause pollution to the water body which affects the Nitrogen, Phosphorous and COD(chemical oxygen demand) levels.

2. Car Manufacturing Cluster



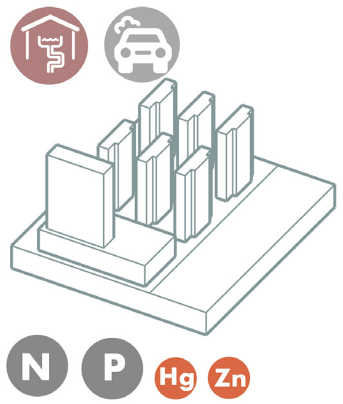
Car manufacturing is one of the pillar industries in the Lake Chao Basin and many new industrial zones are still being established to support the growing industrial chain. However, this trend can increase the risk of heavy metal pollution and cause extra pressure and difficulty in wastewater treatment.

3. Wastewater Treatment Plant



The capacity and quality of most wastewater treatment plants in the region are not sufficient in the area. At the same time, due to the lack of standards for controlling the total nitrogen and phosphorus level in wastewater treatment for a long time, many wastewater treatment plants pay no attention to the level of total nitrogen and phosphorous in their final discharge.

4. Urban Neighourhood



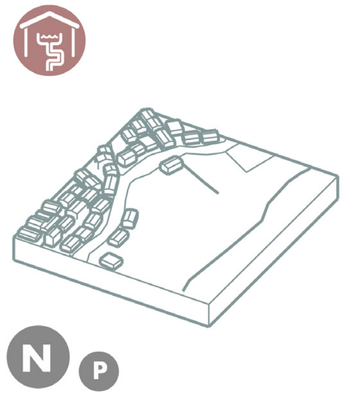
The increasing household wastewater discharge adds up pressure on the wastewater treatment plant. The wide use of cars in urban areas also plays a role in heavy metal pollution.

Figure 4.4.4

Water pollution from different landuse

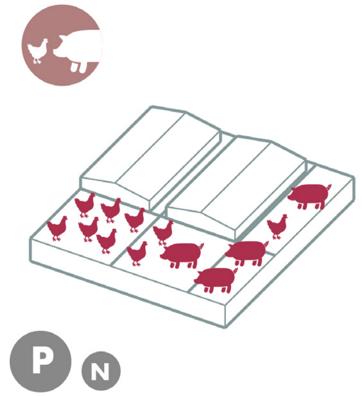
Illustrated by Author

5. Rural neighourhood



Many rural neighbourhoods are not equipped with wastewater treatment facilities, leading to direct discharge into the nearby water body.

6. Livestock farm

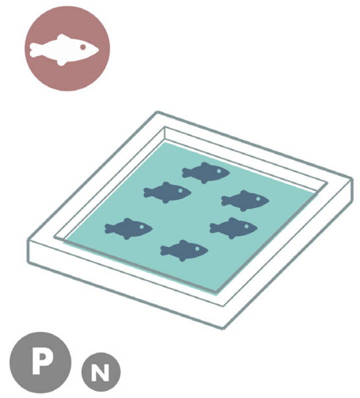


Livestock farming is intensive in many suburban areas. The manure of chickens and pigs is usually not treated properly before they cause trouble to the surface water.

7. Greenhouse

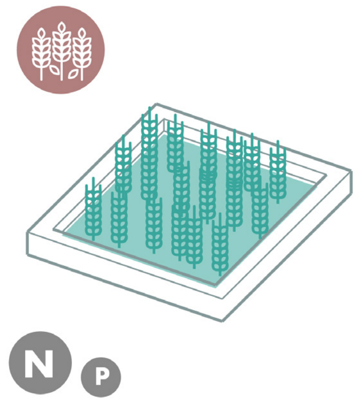
Green houses are used mainly for vegetable and fruits production, where pesticides and fertilizers are widely used compared to other types of crop farming.

8. Fish farm



Excessive fodder is often used in the fishery sector in the polder areas near lake Chao, contributing to the eutrophication of the water body.

9. Rice paddy field



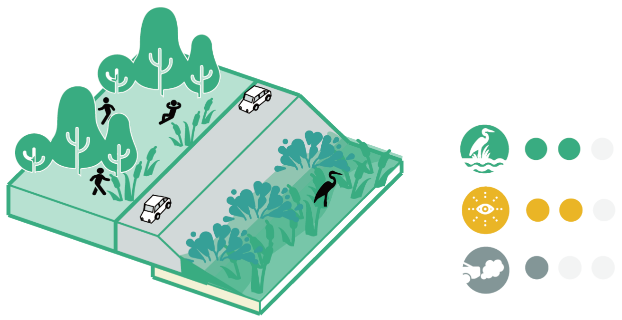
Runoff loss of nitrogen and phosphorus from a rice paddy field can be high, and they flow directly to the surface water system.

4.4.2 Riparian Ecology

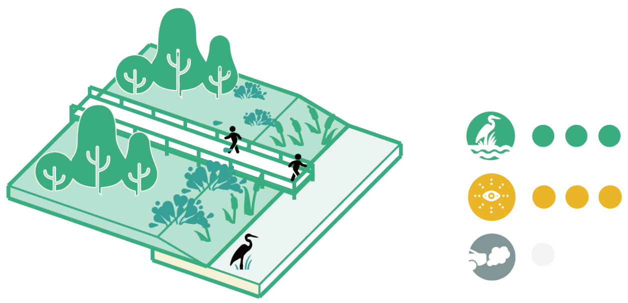
Although identifying the source of pollution is the primary step in improving water quality, sustaining a future-proof water system also needs a strong waterfront ecosystem.

In the lakefront area, as discussed before, the ecology has been emphasized as can be seen in the main three lakefront prototypes on this page. Though mobility and human activities around might cause some emissions, most land around the lake has been reserved for wetland zone. Also, the establishment of these natural reserve parks allows awareness creation among the citizens.

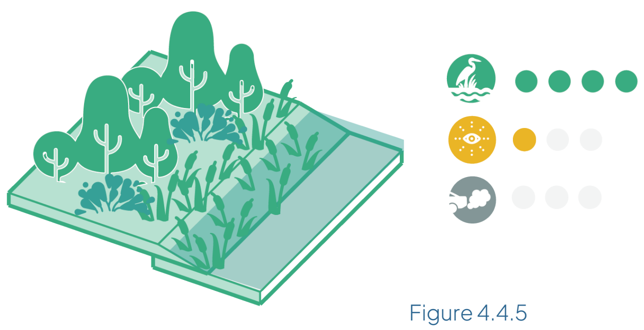
However, the riparian zone of the main rivers is rarely made for ecological use as shown in the prototypes in figure 4.4.

Natural Park

Natural Park with Floating Structure

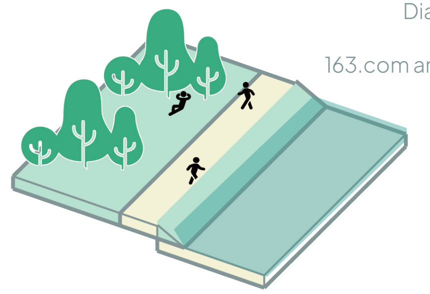



Fully Protected Area

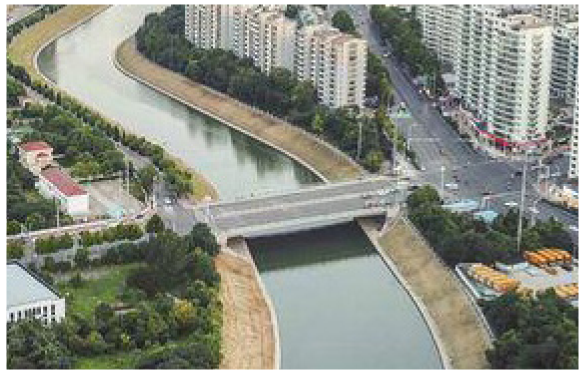
Figure 4.4.5
Main Lakefront Prototypes
Diagram by author
Photos from 163.com and Xinhua News.

Figure 4.4.6 Main Riverfront Types
Diagram by author
Photos from 163.com and Xinhua News.

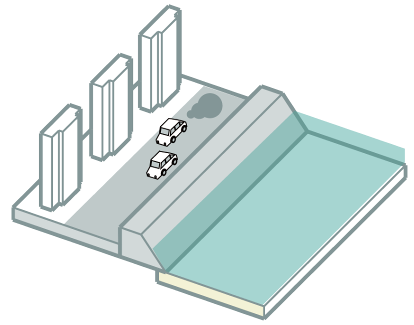
Urban Park



Though vegetation can be seen in some urban park waterfronts, the ecological value of the embankment can be rather low and is just created for leisure.

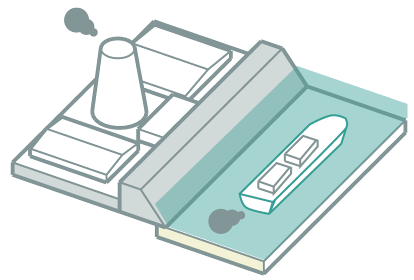


Dikes



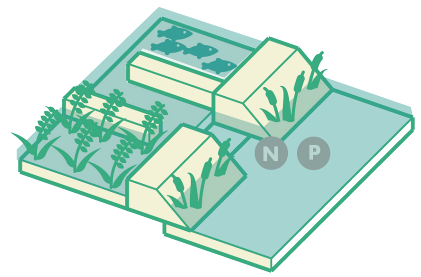
Hard dikes can usually be found along the waterfront in the inner city for the sake of water safety.

Industrial Zone and Harbour



In the major waterway for transportation, emissions from cargo transportation and waterfront industrial zone are possible, putting the ecosystem of such waterfront at high risk.

Agricultural Zone



The waterfront ecological of the agricultural zone can be monotonous and fragmented due to the potential soil and water pollution resulting from agricultural production.

Summary on Water Quality

Main problems to solve

C1 Uncontrolled Nutrients
The nitrogen and phosphorus are hardly controlled in current wastewater system

C2 Emissions from Mobility
There is increasing risk of heavy metal pollution due to the use of automobiles

C3 Waste from Livestock
Suburban livestock farming is still intensive which not only causes the surface water pollution directly but also contaminate the sub-soil and pollute groundwater.

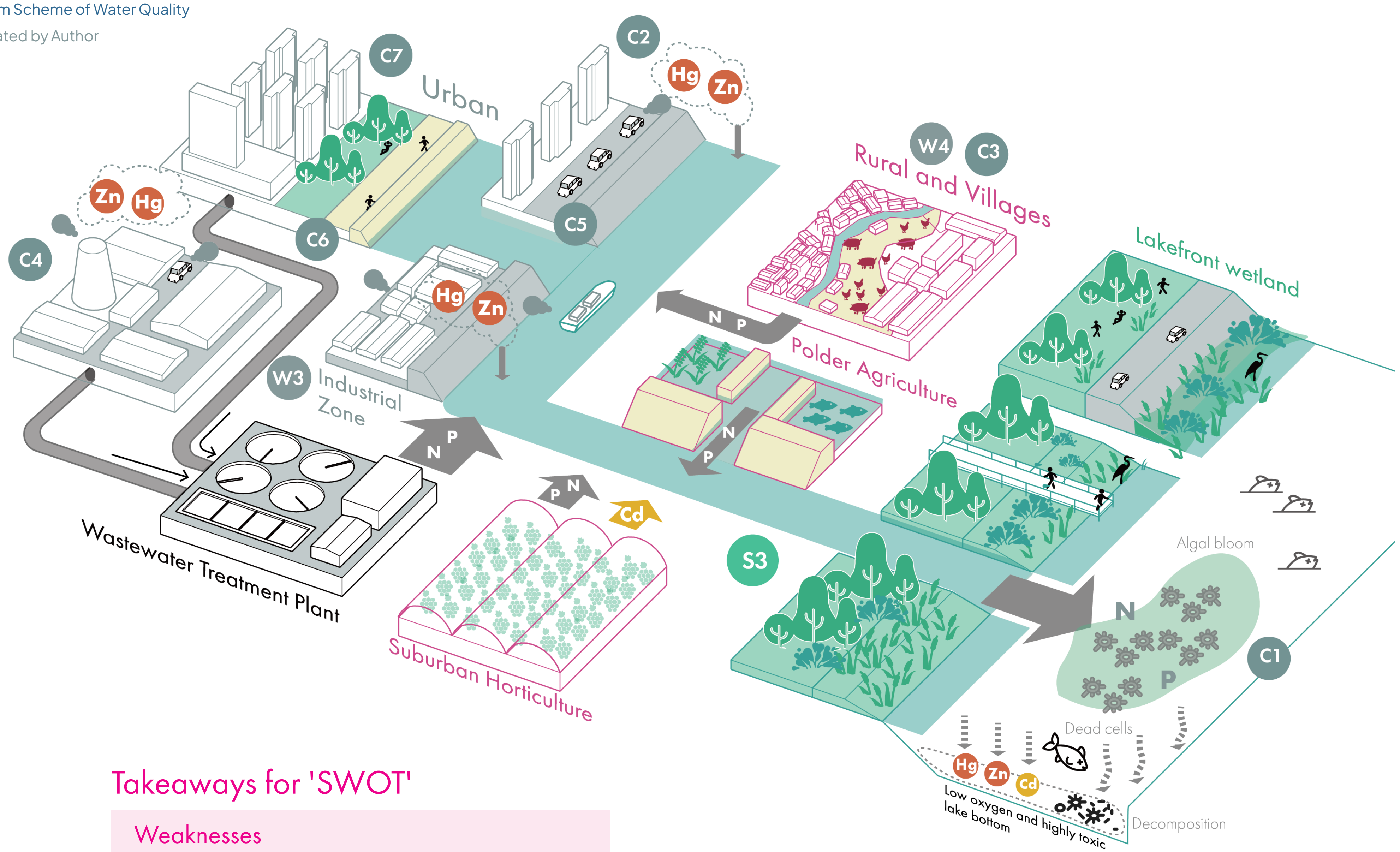
C4 Emissions from Industry
Risk of heavy metal pollution through wastewater, air and groundwater contamination is possible from industrial sector.

C5 Man-made embankment
In urban area, most of the embankment are man-made with no ecological value

C6 Fragmented Blue Ecological Network
Waterfront ecological zone can only be found around the lake.In the upstream area, not all water structure is ecologically continuous, especially through urban space.

C7 Fragile Riparian Ecosystem
Though parks can be seen in certain waterfront, most of them are not designed for local biodiversity. The local ecosystem along water network is still vulnerable.

Figure 4.4.7
System Scheme of Water Quality
Illustrated by Author



Takeaways for 'SWOT'

Weaknesses

W3 Lack of knowledge or incentives for wastewater treatment
Many small and medium-sized companies have no motivation or technology to afford their own waste water treatment or recycling facilities.

W4 Insufficient WWTP Capacity
The capacity of wastewater treatment plants are not enough to catch up with the growing wastewater quantity.

Strengths

S3 Open water and lakefront Wetland
The main water structure is open and continuous and the lakefront area is supported by park and wetland zone.

4.5 Criteria For a Desirable Future

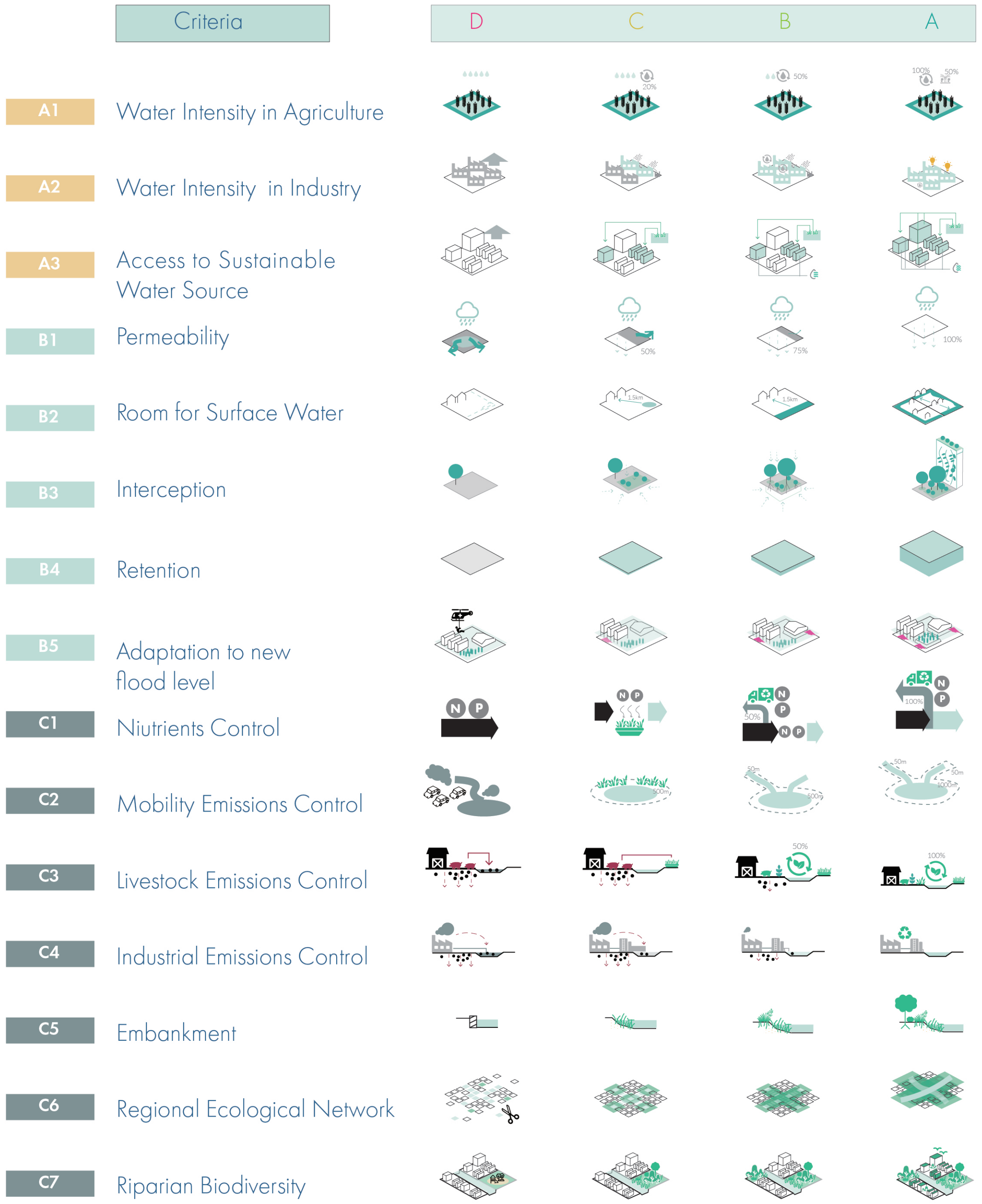
With previous analysis, 15 main problems of the current water system have been identified, which have already been explained and highlighted at the end of chapters 4.2 to 4.4 each.

These components are translated into 15 criteria for 'DCBA' assessment(see details in appendix B) to evaluate the different scenarios that will be explored afterwards.

Figure 4.5.1

DCBA Criteria Overview

Illustrated by Author



4.6 Future Autonomous Situation Assessment

To reach a desirable water system is never easy since it is also intertwined with many other factors beyond the water system.

In order to understand the external advantages, the opportunities, as well as the risks better, a future autonomous scenario of the region is created by examining the current policy and planning documents.

This scenario is then assessed by the fifteen indicators from Chapter 4.5, to project its impact on the water system. Such impact in relation to the three aspects of the water system is clarified as follows(see next page): Beginning with water safety, three of the five indicators might get worse than the current situation with the further urban sprawling trend. Local authorities are still busy establishing industrial zone and new towns as can be seen on the map. This absolutely jeopardizes the infiltration process and retention capacity, since more existing rural areas and even surface water zone might be transformed into impermeable space.

With regards to water quantity and quality, both opportunities and threats can be seen.

The agricultural sector is showing opportunities since several municipalities are encouraging technology upgrades and circularity. For example, farmers in Wuwei can get extra incentives when they upgrade to steel greenhouses or build wastewater treatment and recycling centres in the livestock and fishery sector(The Municipality of Wuwei,2022). Organic farming and agritourism are also thriving, which not only helps to cut down the emissions but also creates awareness among people. A large agritourism park can be found on the outskirt of Hefei. This movement might lead to a better score in indicators B1, C3 and C7.

Being one of the two major scientific and innovation hubs in the Yangtze River Delta, the Lake Chao Basin has multiple national-level scientific institutions and educational institutions. They are taking a more active part in collaborating with the industrial zone and paying more attention to sustainability and environmental issues. Knowledge sharing and regional investment are also possible to support innovation activities. So, there is a potential of improving the performance of B2.

However, further industrialization is still needed for the local economy. This is accompanied by the construction of new intercity infrastructure and urbanisation. More cargo ships can be expected and harbours will be created. As a result, the drinking water supply problem might get worse, as well as the eutrophication, mobility emission problems and embankment ecological condition. Though there is a policy document on emission cutting down and giving more room back to the ecosystem. They might not be prioritized before economic growth. Hence, all the other indicators might stay the same if not get worse.

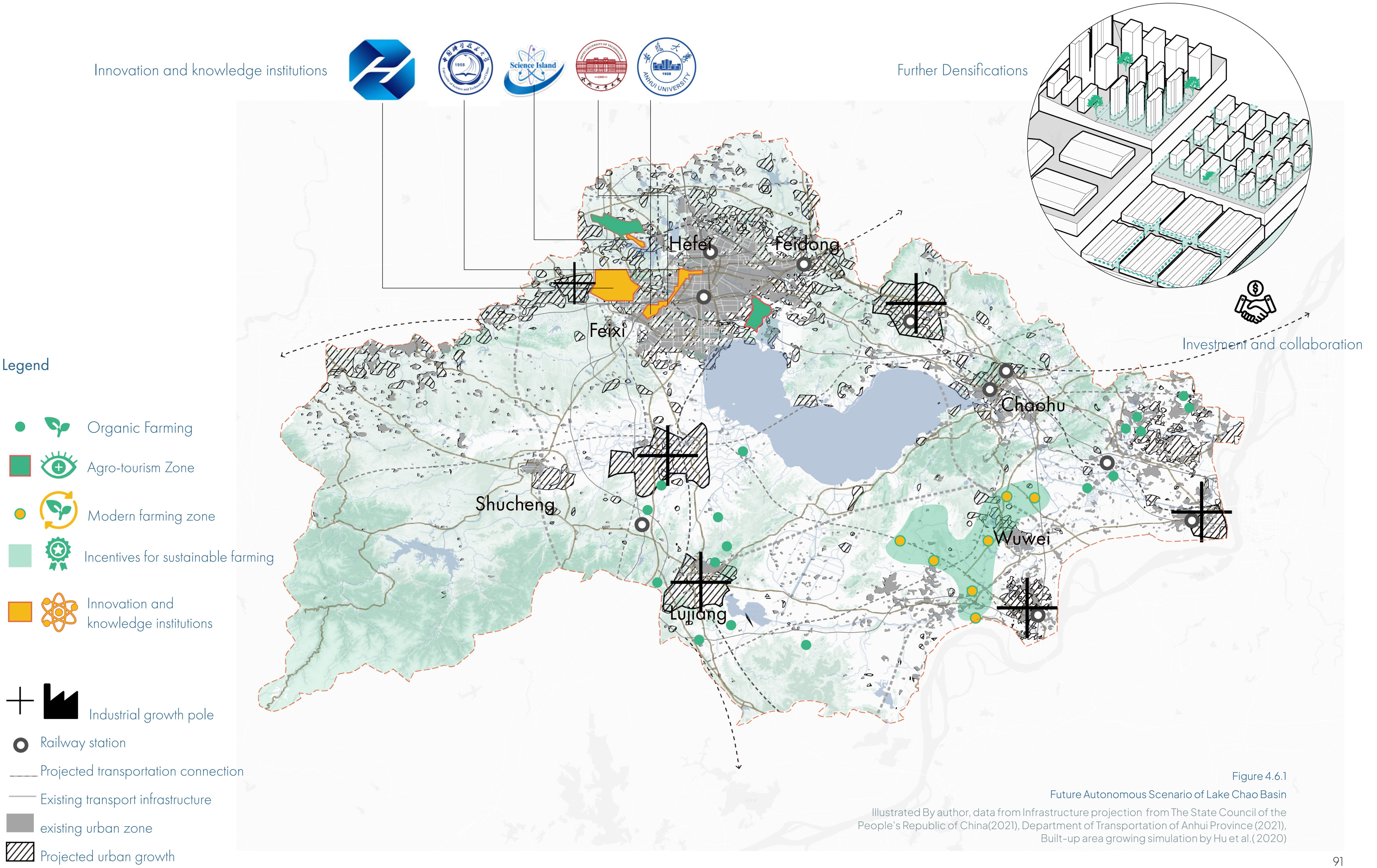


Figure 4.6.1

Future Autonomous Scenario of Lake Chao Basin

Illustrated By author, data from Infrastructure projection from The State Council of the People's Republic of China(2021), Department of Transportation of Anhui Province (2021), Built-up area growing simulation by Hu et al.(2020)

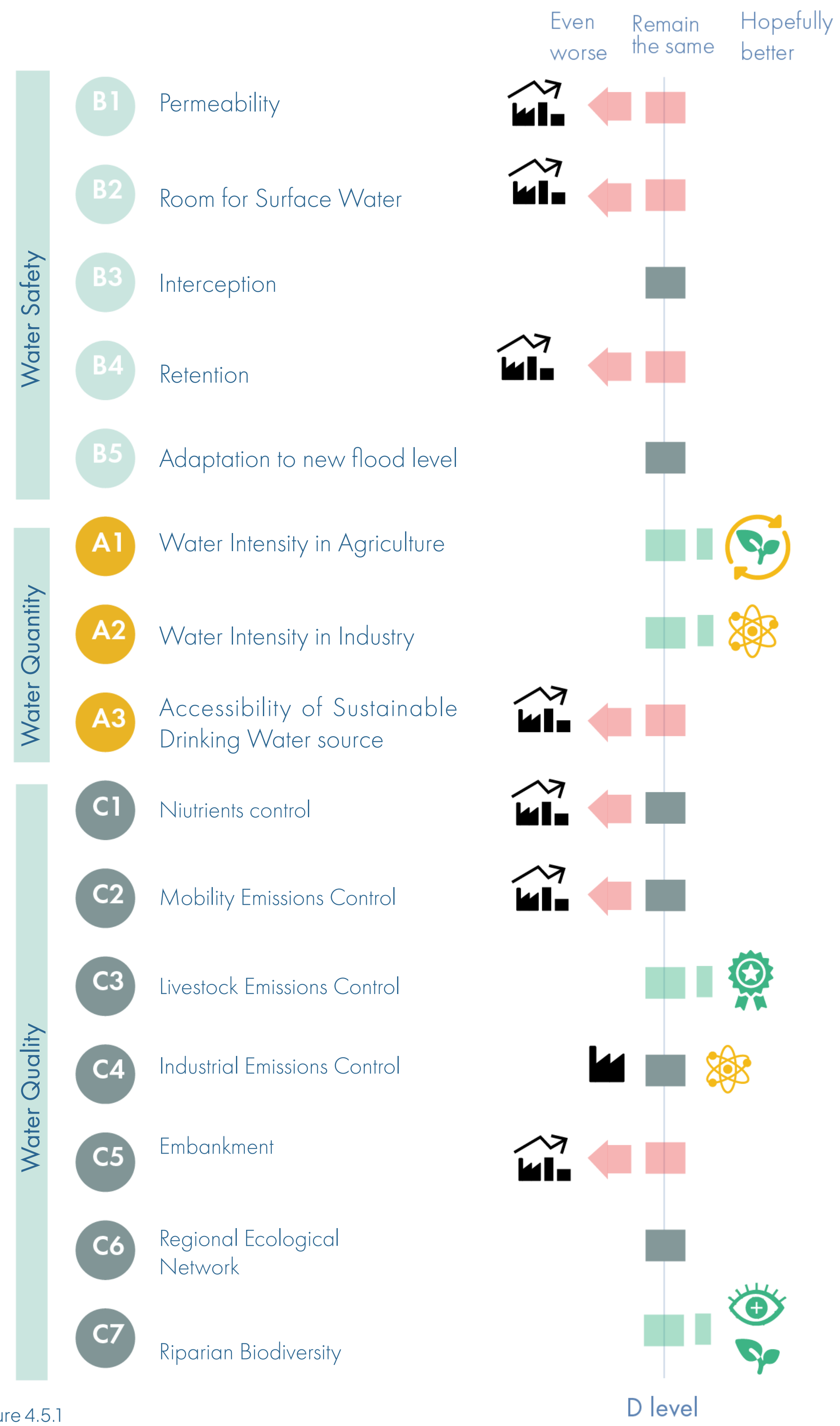


Figure 4.5.1
Impact on Water System from FAS
Illustrated by Author

To conclude, through the analysis of future autonomous scenarios, several unique conditions for the Lake Chao Basin that might have an impact of water system are identified as follow:

- **S4** National scientific and innovation hub
- **O1** Thriving organic farming zone
- **O2** Policy support on climate action
- **O3** Innovations and investments are avalible and possible
- **O4** Attention from sustainability and envionmental from knowledge institutions
- **T3** Further industrialization is needed for the local economy

So far, all the strengths, weaknesses, opportunites and threats from the previous diagnosis have been summarized as follows. They will be further referred to and translated into 'TOWS strategy' in Chapter 6.

SWOT

Strengths

- **S1** Having an agricultural and sustainable farming tradition
- **S2** People have attachment to water
- **S3** Open water system supported by existing park and wetland zone.
- **S4** National Scientific Hub in this location

Weaknesses

- **W1** Unbalanced precipitation during the year and limited water storage space
- **W2** Hard to create new large-scale drinking water source within the basin due to topo-graphical condition.
- **W3** Small and medium-size factories Lack of knowledge and motivation
- **W4** Lack of wastewater treatment facility

Opportunities

- **O1** Thriving organic farming zone
- **O2** Policy support on climate actions
- **O3** Innovation and investment are available and possible
- **O4** Attention to environment from scien-tific and education institutions

Threats

- **T1** Paradigm of Unpermeable Densification
- **T2** Climate Change and increasing flooding events
- **T3** Further industrialization and urbanisa-tion might have to happen

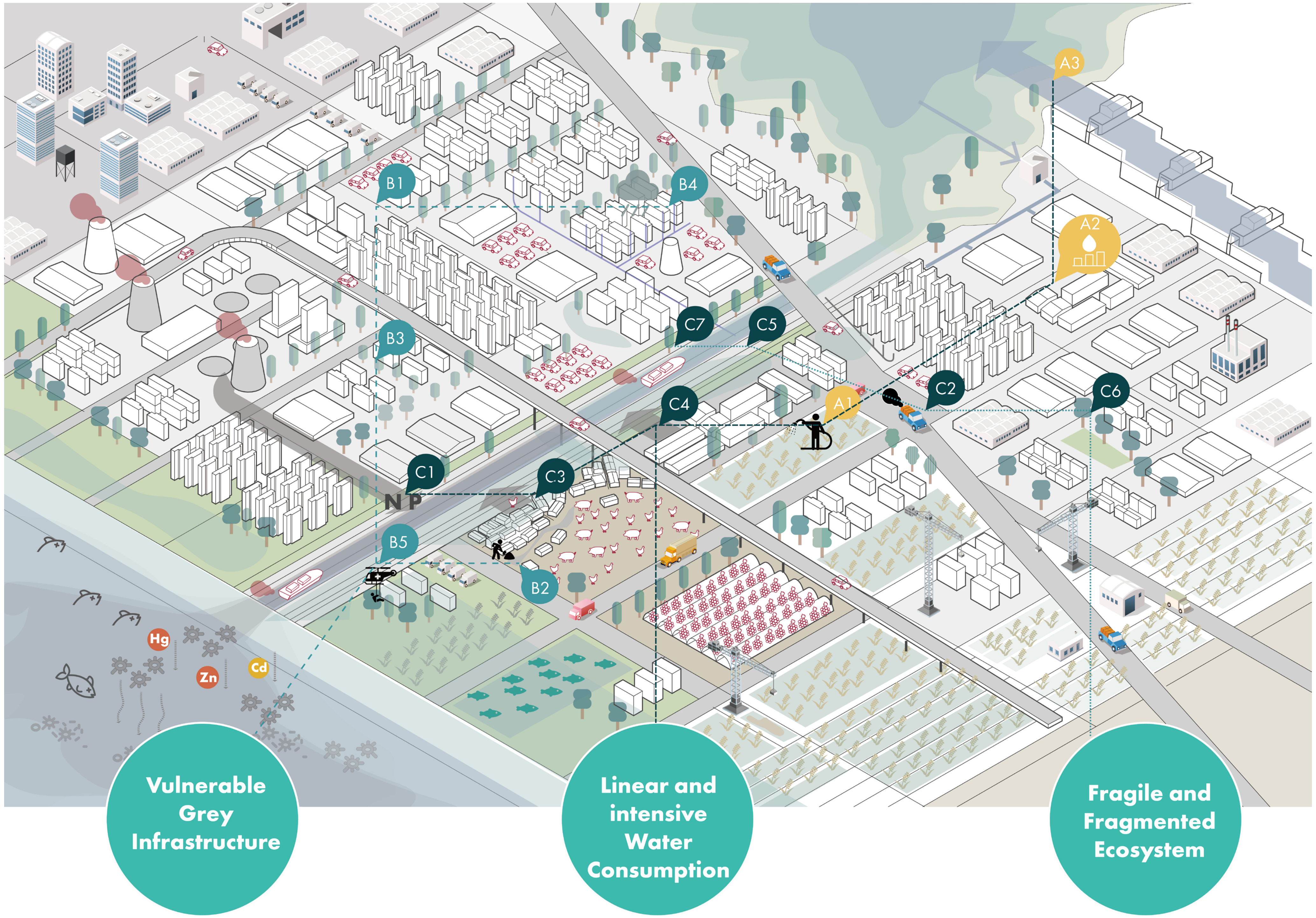


Figure 4.6
Problems of Current Water
Metabolism of Lake Chao Basin
Illustrated by Author

Conclusion of Chapter 4

To summarize, this chapter has identified 15 factors that affect the current water metabolism in the Lake Chao Basin, which can be categorized into three main groups(as can be seen in the diagram on the left) :

Vulnerable grey infrastructure,
Linear and intensive water consumption
Fragile and fragmented ecosystem.

These three main issues are tackled respectively by three maximization topics, as will be seen in Chapter 5.

B1 Low Permeability
B2 Disappearing surface water
B3 Limited Interception
B4 No Retention Buffer
B5 Relying On Temporary Evacuation

A1 Water Intensive Paddy Field
A2 Water Intensive Industry
A3 Inaccessibility to Sustainable Water Source
C1 Uncontrolled Nutrients
C3 Waste from Livestock
C4 Emissions from Industry

C2 Emissions from Mobility
C5 Man-made embankment
C6 Fragmented Blue Ecological Network
C7 Fragile Riparian Ecosystem

CHAPTER V. MAXIMIZE FOR WATER

Introduction

Starting from chapter 5 towards the end of chapter 6, the pattern language is constructed based on the previous analysis, following the two stages of the maximization method: maximization and optimization(as explained in Chapter 2.1), with these two chapters focusing on one of them respectively.

In chapter 5, three maximization scenarios are built based on the input from both the diagnosis chapter and theoretical underpinnings(as shown in diagram 5.1). From these three maximization scenarios, different patterns can be extracted, all of which aim at reaching the maximized benefits from the three different aspects of water respectively.

This preliminary list of patterns(shown in Chapter 5.4) serves as the answer to the Sub RQ5 and will be further enriched and concretized in the optimization stage in chapter 6.

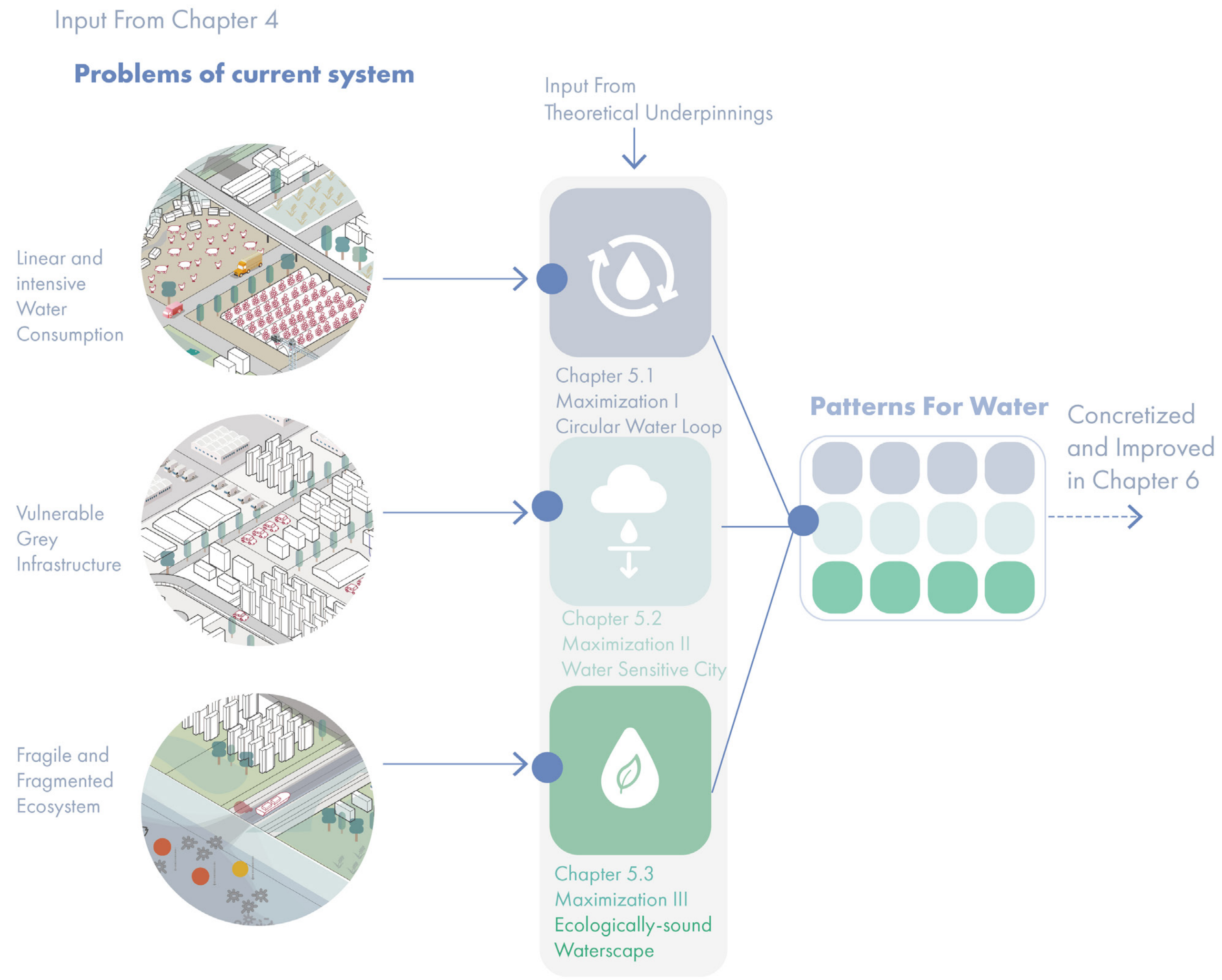


Figure 5.1
Structure of Chapter 5
and its relation with other chapters
By author

5.1 Maximization I: Circular Water Loop

The first maximization topic is closing the water loop, which not only tackles the water quantity issues in the Lake Chao Basin but also focuses on reducing the water pollution caused by different sectors.

The foremost principle under this topic is having access to sustainable water supplies, as many of the cities in this region still rely on water transferred from other areas. Apart from the existing water reservoir available, more space should be created for rainwater harvesting to provide decentralized backup water resources in parrel with the centralized water supply. Greywater recycling is another action needed to be taken, particularly for the growing urban areas.

Meanwhile, the concept of circularity in water consumption should be embraced especially by the agricultural and industrial sectors in the area since they are the dominant water consumers. This could be done by minimizing their water consumption by upgrading their technology or recycling wastewater. Also, by recycling and reusing the elements from the wastewater, the potential discharge to the surface water can be cut down and thus mitigates the environmental impact of production.

The section below shows an ideal situation maximized under this topic.

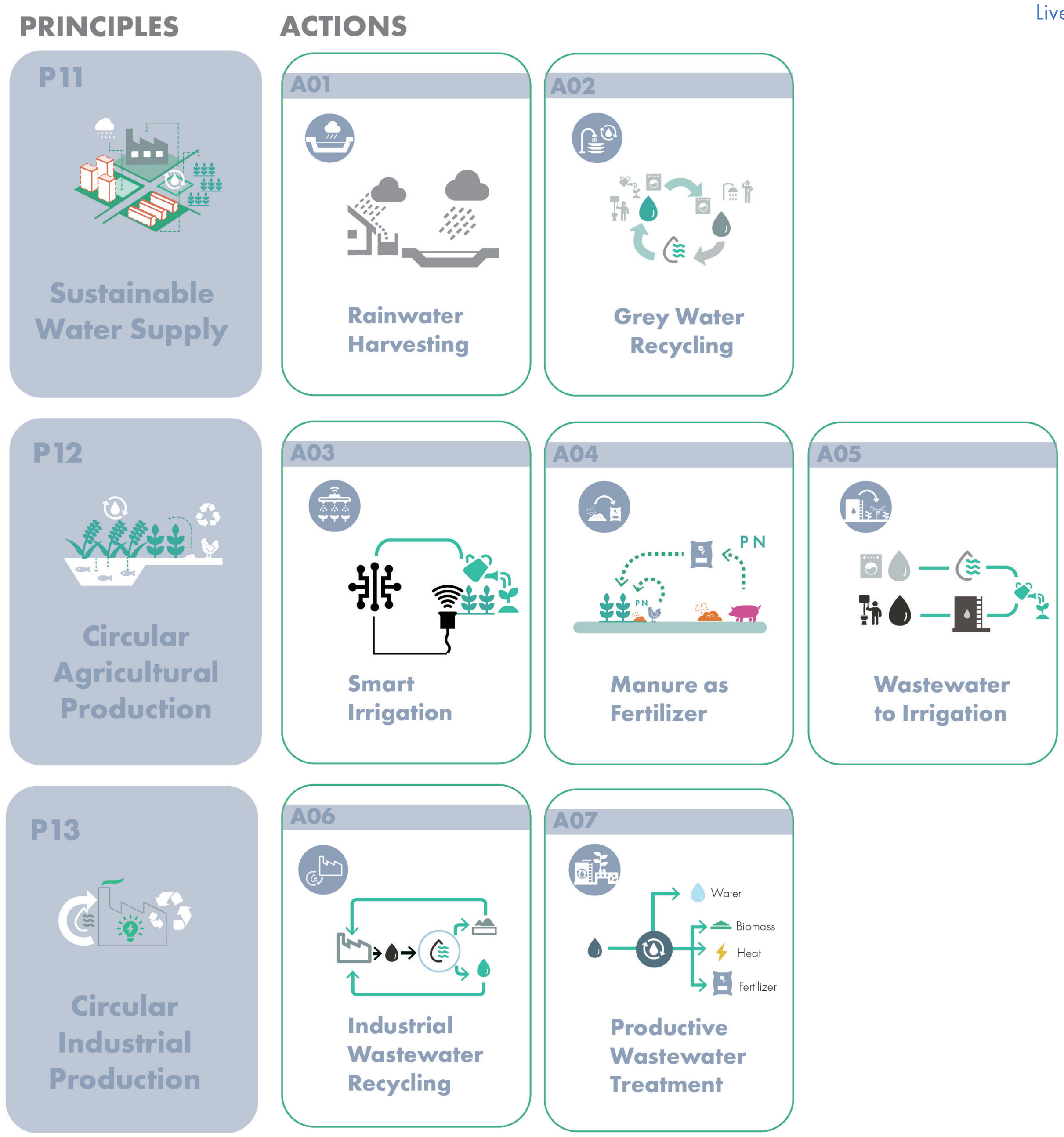
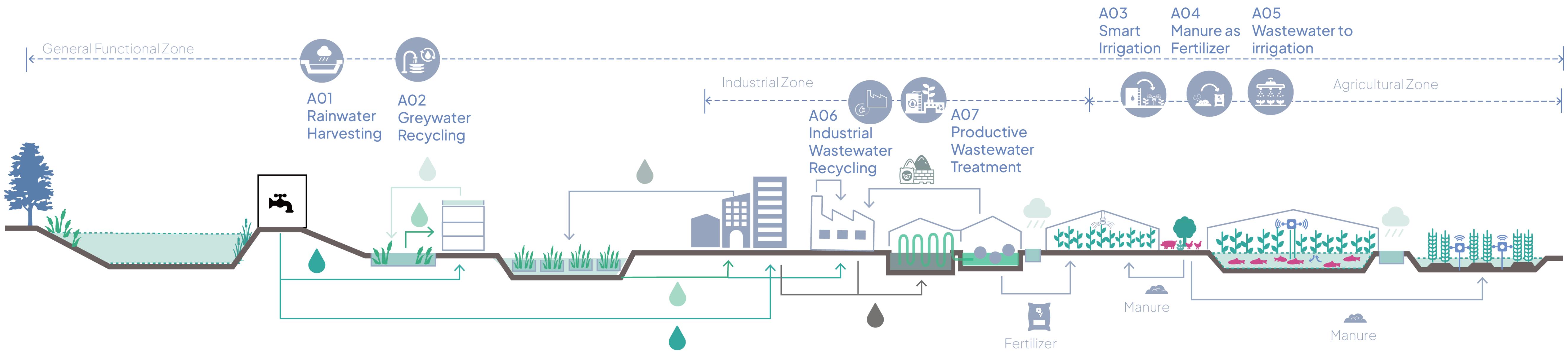


Figure 5.2
Scheme of Maximization Scenario I: Circular Water Loop
by Author



5.2 Maximization II: Water Sensitive City

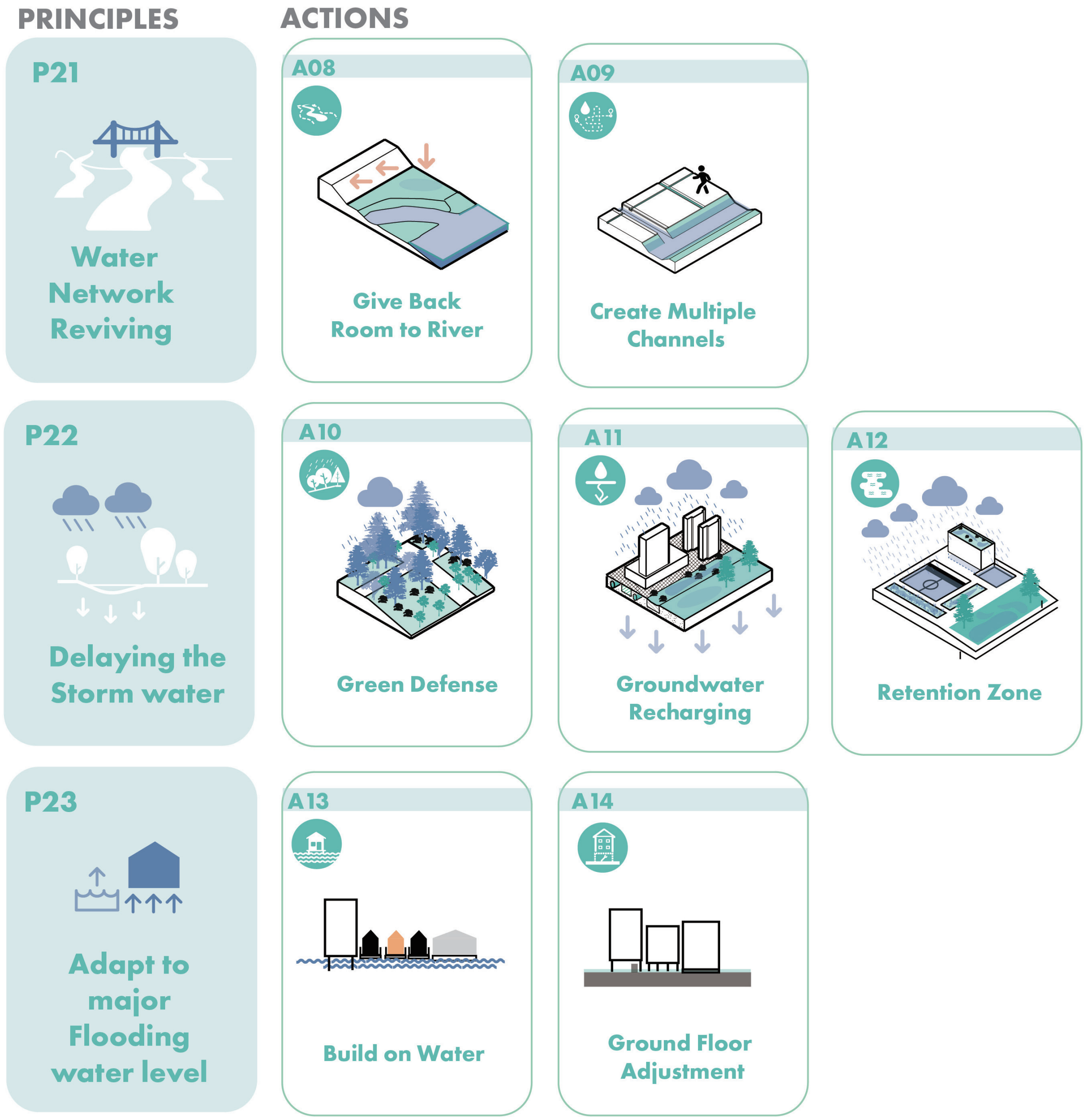
The second maximization scenario is created based on the 'water sensitive city' theory, which mainly focuses on addressing the water safety issues.

The first principle in this scenario is reviving the water network, (exclusively referring to the surface water network). It includes making more room for rivers and revitalizing the surface water network in the cities. The latter can serve as a delayed pathway for water in parallel with the underground drainage system and has the potential to be further combined with other types of natural-based solutions such as helophyte filters or bioswale.

The second principle is delaying the stormwater, including using the vegetation, improving infiltration and creating more retentional zone. As can be seen in the section, this principle should especially be considered by the high-lying urban district in the region, in order to reduce their own chance of urban waterlogging as well as to mitigate the risk of fluvial flooding in the low-lying.

The third principle is adapting to the major flood level, which should be mainly considered by the low-lying areas. As these areas are more likely to suffer from fluvial flooding, simply relying on natural-based solutions might not help them a lot. Instead, new building types or necessary relocation should be considered to provide them with long-term safeguards in front of climate change.

The following section illustrates how different actions should be taken according to their altitude.



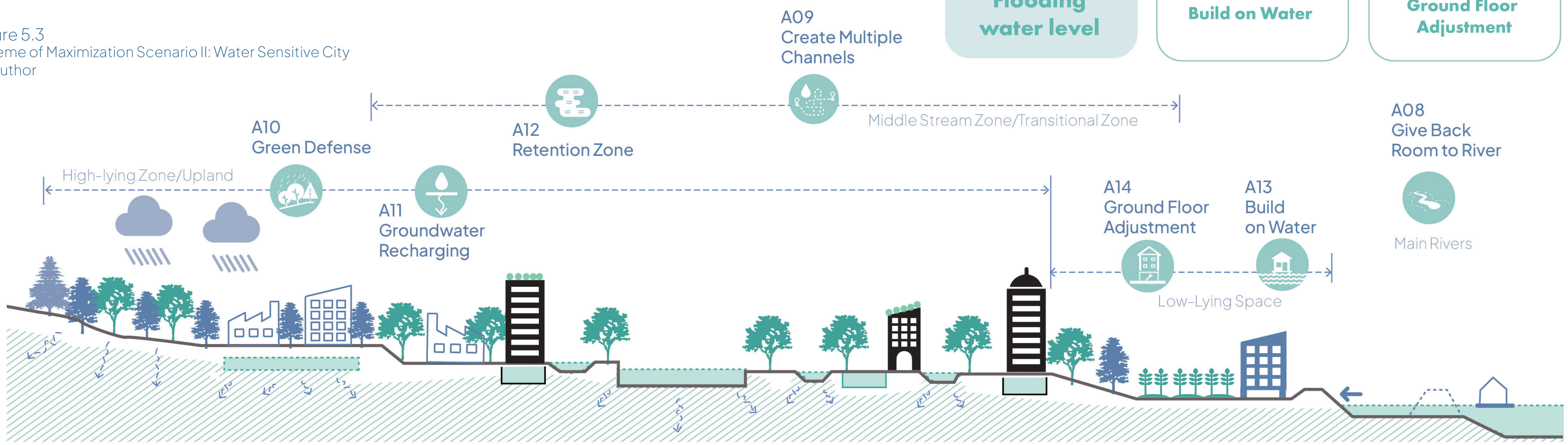


Figure 5.3
Scheme of Maximization Scenario II: Water Sensitive City
by Author

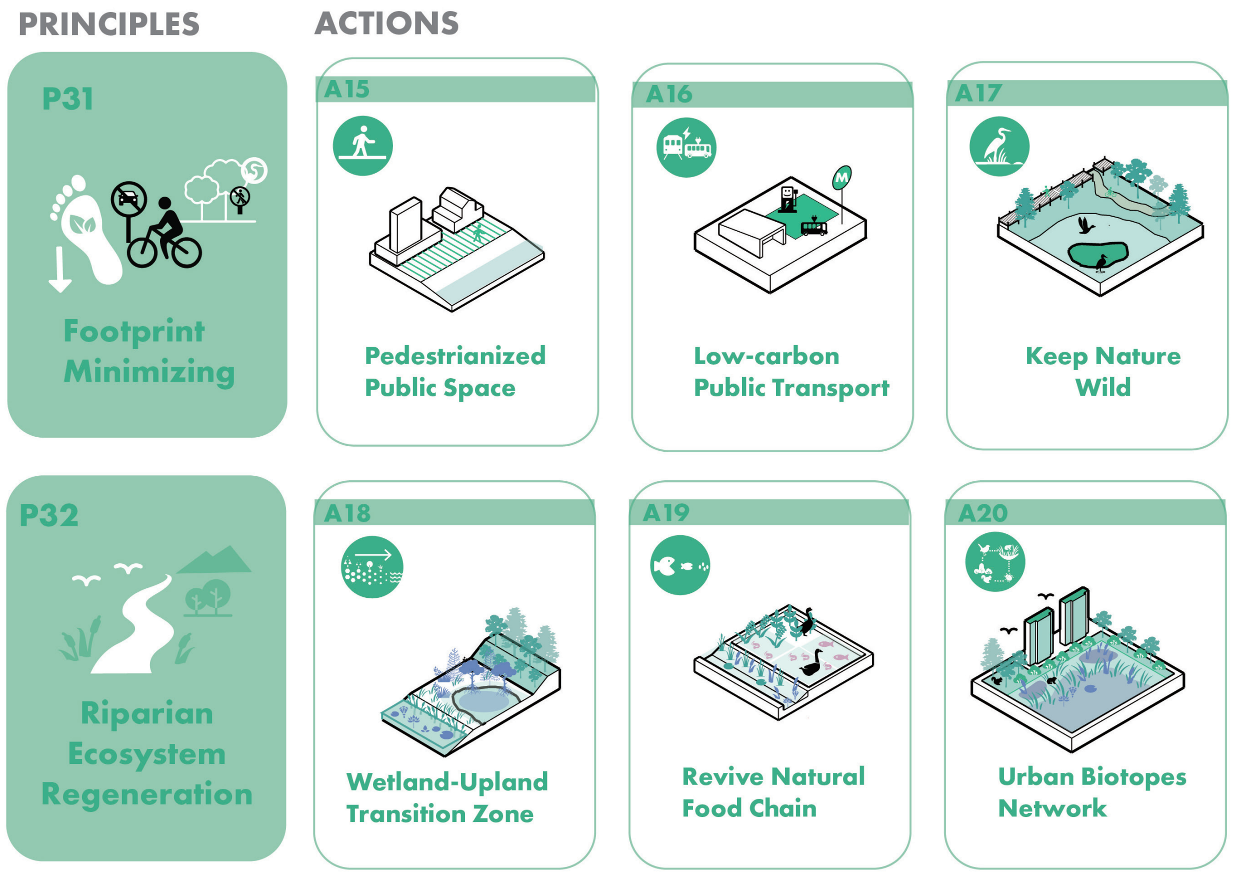
5.3 Maximization III: Ecologically-sound Waterscape

The third maximization scenario centres around the flourishment of the ecosystem that ensure the soundness of the water quality in the region.

For one thing, it is about minimising people's interference with nature. This can be done by creating more natural reserves where human activities are prohibited or limited. Meanwhile, by pedestrianising more urban spaces and promoting green transportation, further emissions into the surface water, air(which indirect cause water pollution in the form of acid rain), and soil (which affects the groundwater quality)could be inhibited.

For another, the riparian ecosystem has its own transitional natural characteristics(Nicola, C. et al., 2011) and concerns the survival and health of all types of animals that either nest next to the water, hunt for food in the water or breed in the shallow riparian zone. So, regenerating the ecosystem from upland to wetland needs to choose suitable types of local vegetation instead of purely planting monotonous vegetation along the river. In the rural riparian areas, agricultural production should also learn to obey the natural food chain and contribute to local biodiversity. In the urban area, a connecting biotope network within the city should be established to boost the ecosystem within the urban area, and the health of the water system.

The following section depicts the ideal performance of different zone under the topic of 'ecologically-sound waterscape'.



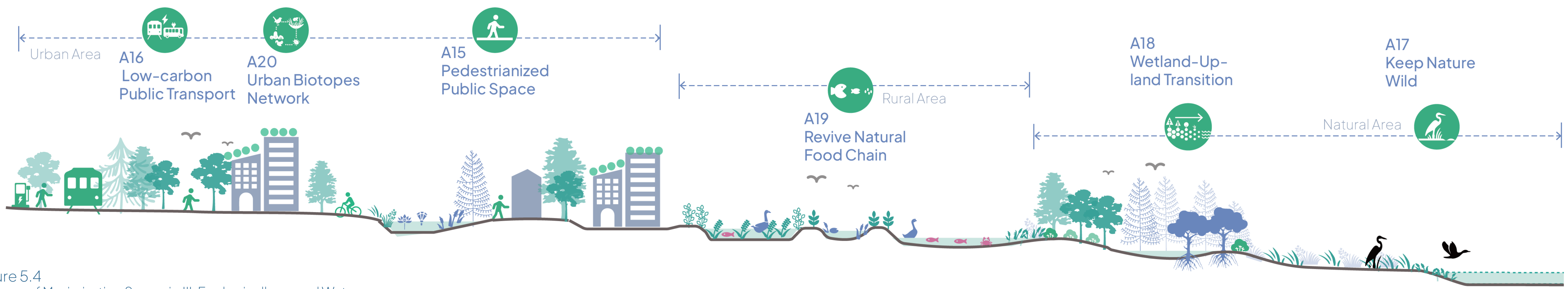
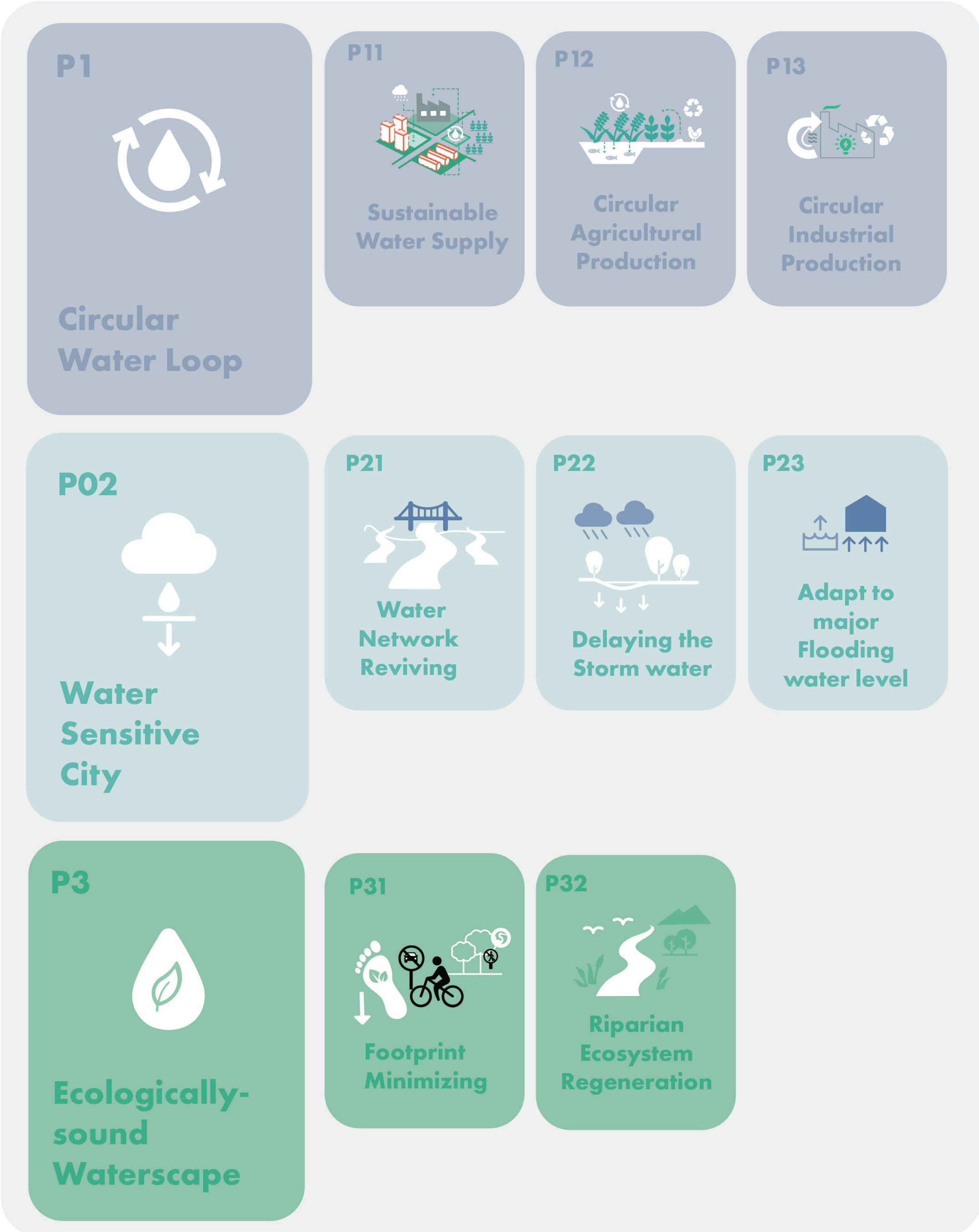


Figure 5.4
Scheme of Maximization Scenario III: Ecologically-sound Waterscape
by Author

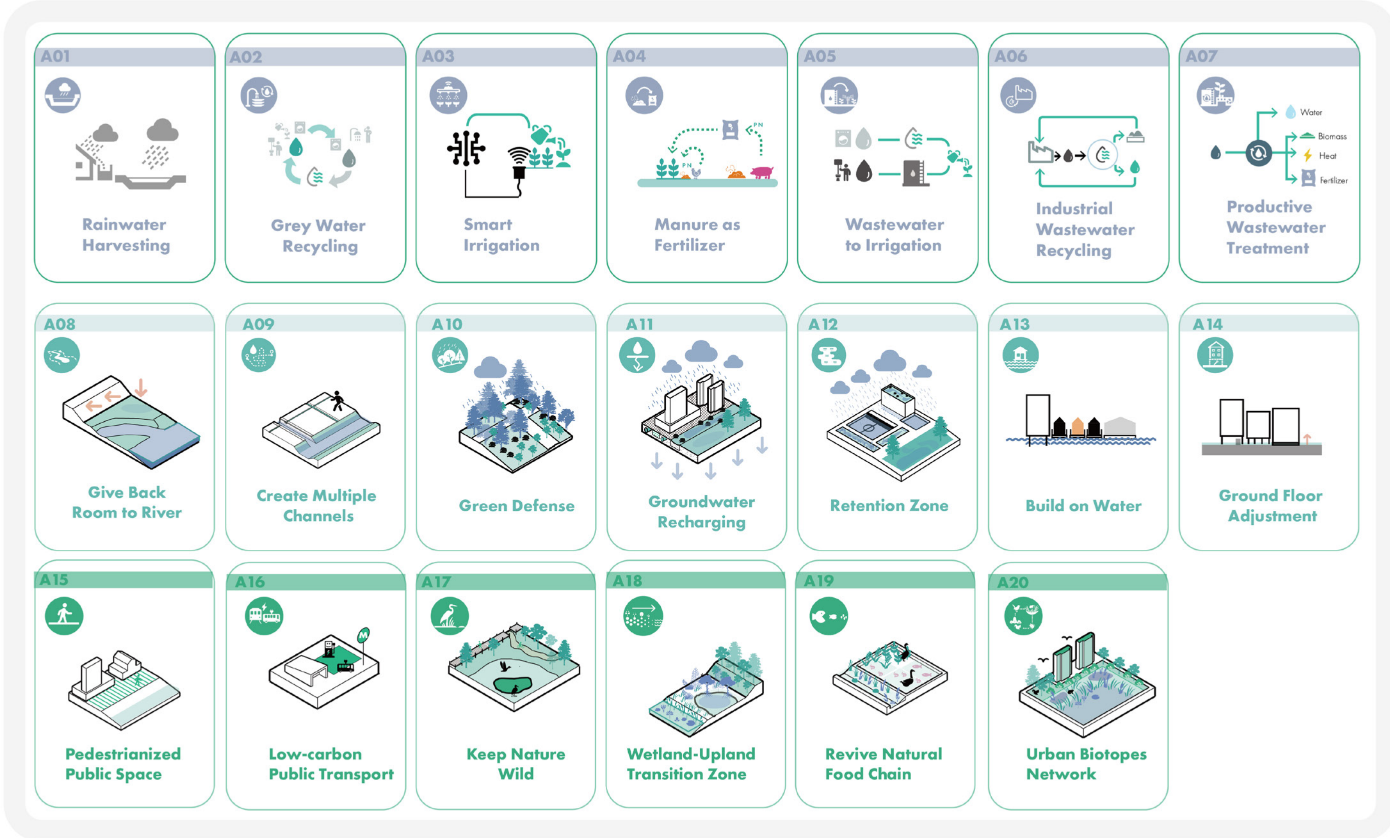
5.4 Patterns for Water:

Figure 5.5
Patterns from Maximization Stage
by Author

PRINCIPLES



ACTIONS



Conclusion of Chapter 5

From the three maximization scenarios constructed in this chapter, a set of patterns could be harvested, as shown on these two pages. The three topics make sure that all these patterns are designed for the benefit of the water system and thus reply to the Sub RQ 5.

However, it should be aware that, all these patterns presented in this Chapter are still abstract, which are principles and actions that could be spatialized in multiple ways in practice. As a result, how to concretise these patterns into practical spatial interventions is further explored in Chapter 6 to make sure these 'water-oriented' principles and actions could be integrated into the process of 'urban development'.

Figure 6.1.0
"Test the Pattern Language!"
By author

CHAPTER VI. OPTIMIZE WITH FACILITATORS

Introduction

Developing a systemic solution involves engaging related stakeholders and interventions upon deep leverage points. Though the previous patterns developed in Chapter 5 create desirable schemes for the sake of water, they can be too broad or even too ideal to be adopted by real stakeholders in the region.

Hence, in chapter 6, in order to answer sub-RQ 6, three optimization scenarios are created for a strategic location under three themes to iterate the pattern language. These three themes are identified from the previous SWOT analysis, with each of them having the potential to engage certain groups of stakeholders.

Through this process, the previous pattern language is enriched by new 'programme' and 'measure' patterns. These two types of patterns are more concrete and practical for the stakeholders to consider during the process of urban development. At the end of this chapter, the whole pattern language network is presented to show the interrelation between different patterns.

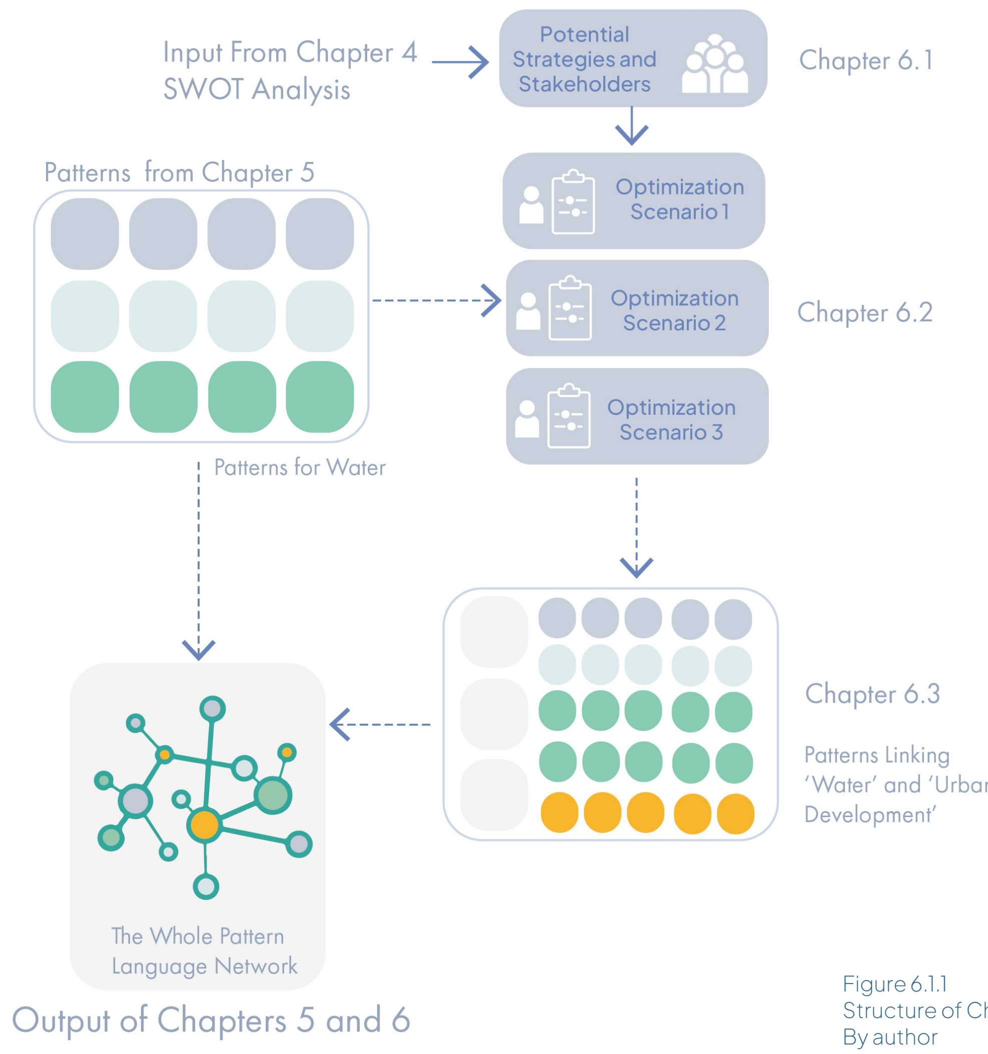


Figure 6.1.1
Structure of Chapter 6
By author

6.1 The Themes for Optimization

By translating the 'SWOT' into 'TOWS', several strategies could be found as shown in figure 6.1.1. With these pathways, three themes for the optimization stage are identified. All three themes have the potential to engage stakeholders that might become the facilitators of the 'water-oriented urban development' process.

Optimization Theme I: Scientific Park

This theme focuses on combining 'strengths' and 'opportunities'. By engaging the education and knowledge institutions in this region, there are possibilities to integrate scientific research activities into the landscape and promote more research on sustainability.

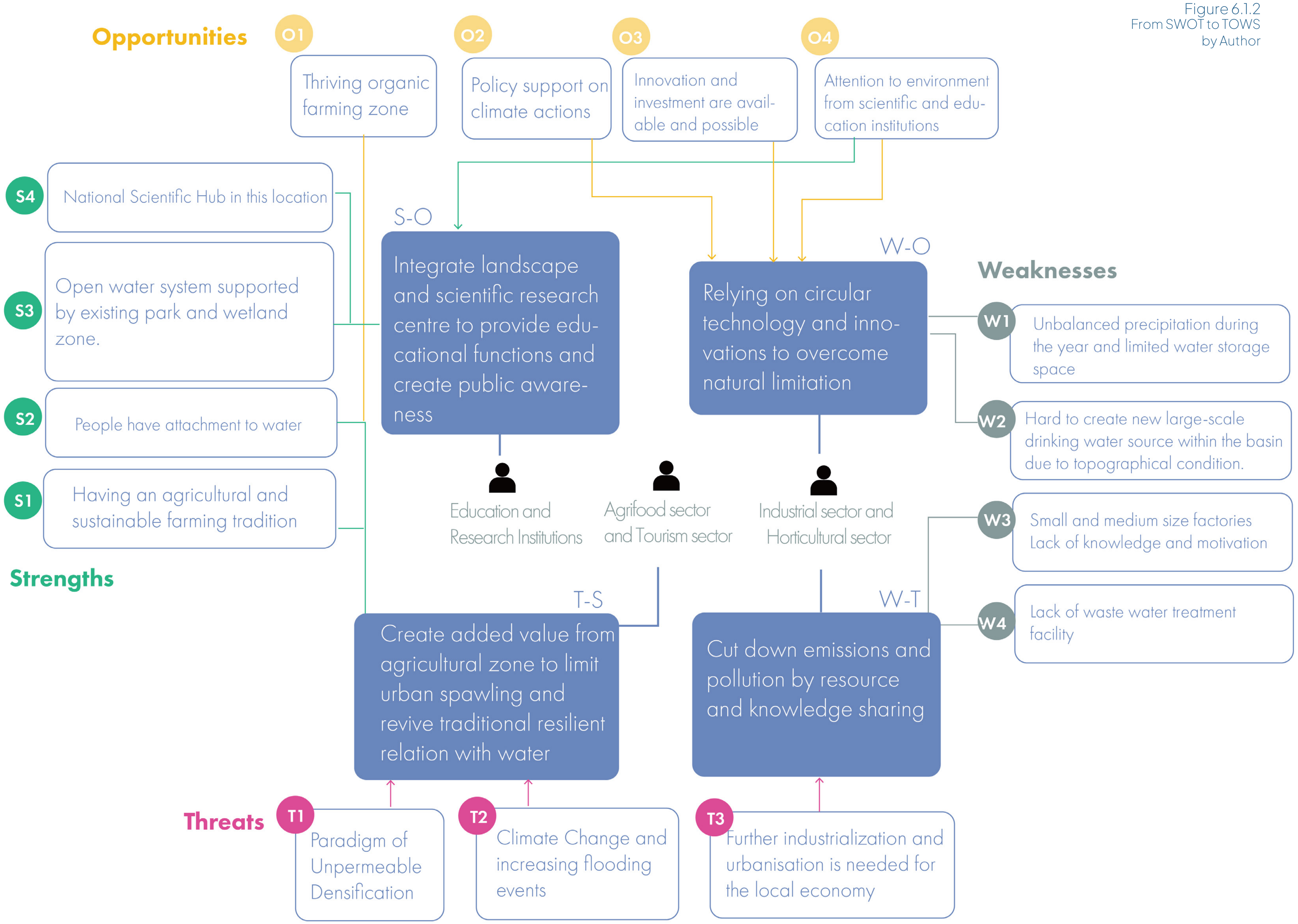
Optimization Theme II: Resilient Polder

This theme uses the 'strengths' to avoid and minimize the threats from the changing climate, which focus on reviving the polder agricultural zone and the traditional resilient lifestyle with water. The agri-food and tourism sector might be interested in investing in such a proposal since it brings added value and extra income to food production.

Optimization Theme III: Circular Harbour

Another pathway is about overcoming the internal weakness of the water system by promoting circular technology and innovations. This proposal might cater to the benefits of both the manufacturing and horticulture sectors since they are still searching for ways of upgrading their technology and production to sustain the local economy.

Figure 6.1.2
From SWOT to TOWS
by Author



6.2 Optimization Process

In order to iterate the pattern language based on real context, a strategic location,' Tanchong River Basin', is chosen. It is a hybrid zone undergoing rapid urban development next to the River Pai(Important Segment of the Yangtze-to-Huai Project). As shown in figure 6.2.1, it is surrounded by urban, industrial and polder agricultural zone. Hence, it can serve as a strategic location to test all the three themes mentioned in Chapter 6.1 and is capable of being further developed into a strategic project in Chapter 7. Meanwhile, as a basic hydrological unit, it covers different geographical conditions(the altitude is ranging from 10mamsl. to 40mamsl.) and thus provides the possibility of implementing the full patterns within this individual area.

Through the optimization process, three scenarios are constructed through a series of imagined conversations as depicted in 6.2.2 and 6.2.3. By shifting between the role of the urban planner and the potential facilitators constantly, new patterns can be generated(see 6.2.3).

Especially, bearing the leverage point theory in mind, new programmes that can have an impact on deeper leverage points are intentionally introduced during this process, to make sure the systemic change could be stimulated.

At the end of every round of iteration, the DCBA criteria are used to give immediate feedback on the scenarios to understand where the compromise from the water system is given(See figure 6.2.4). Detailed maps of these three scenarios and other intermediate products of the process can be found in Appendix C.

Figure 6.2.1 Optimization Location
Illustrated by Author

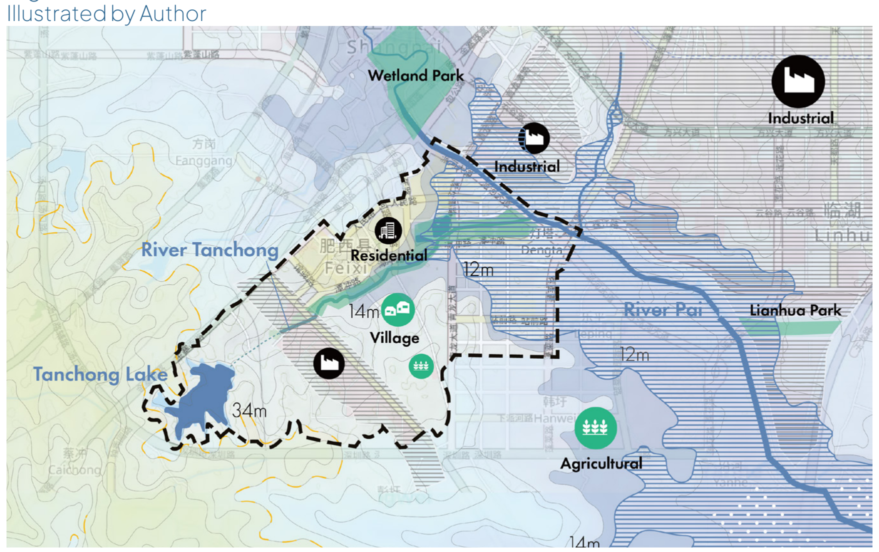


Figure 6.2.2 Draft Proposal in Constructing Optimization Scenarios
by Author

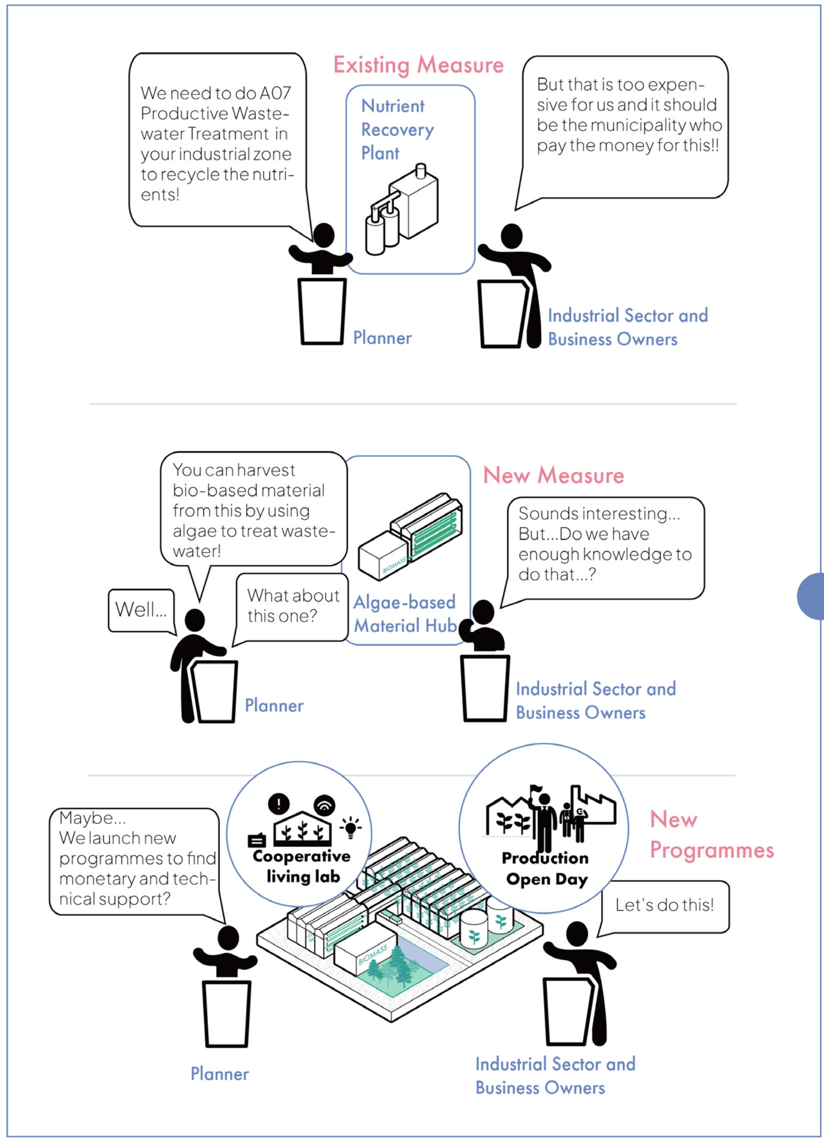


Figure 6.2.3
Imagined Dialogue in the Optimization Process
by Author

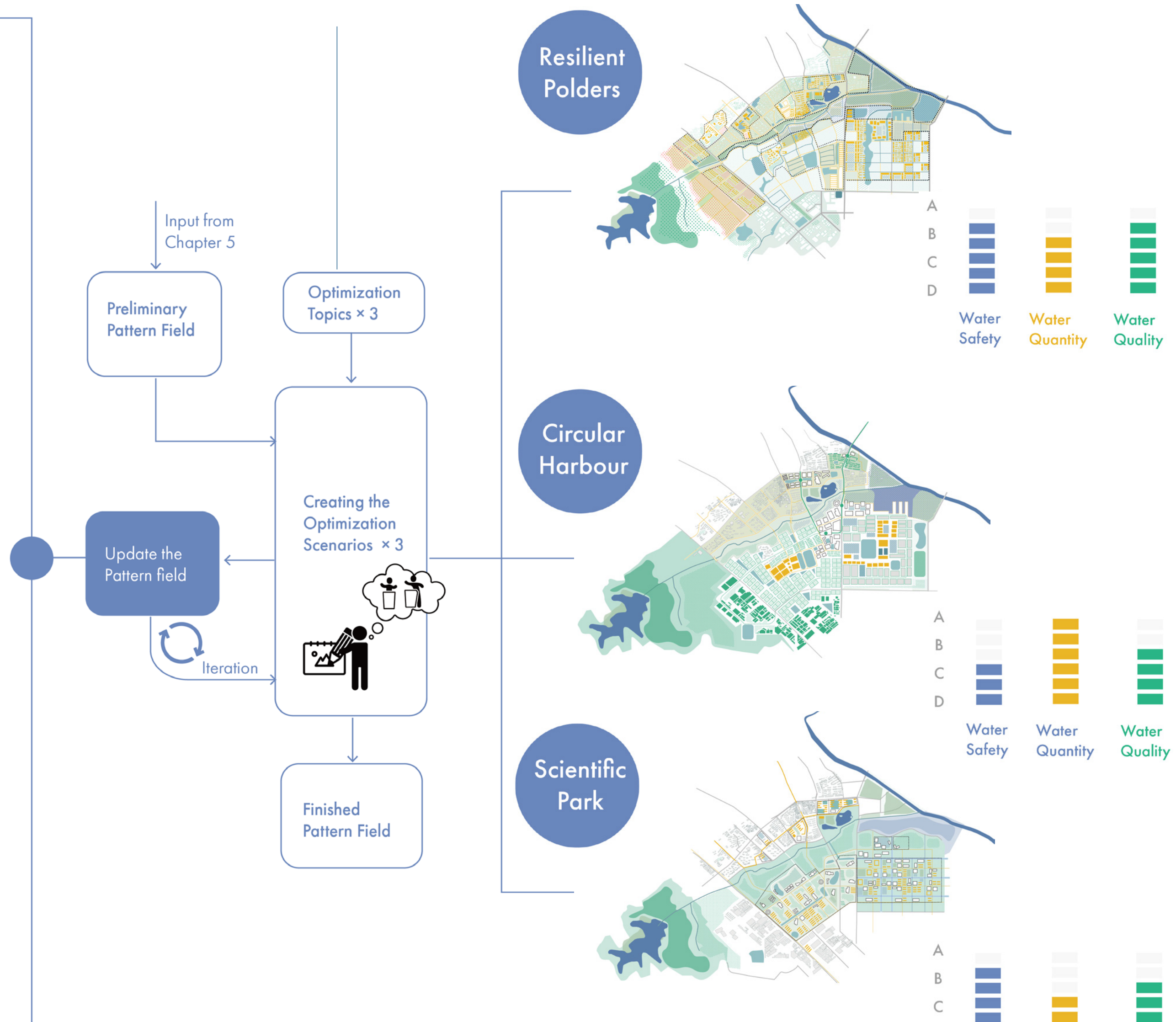


Figure 6.2.4
Optimization Scenarios
and Their Water System Performance
by Author

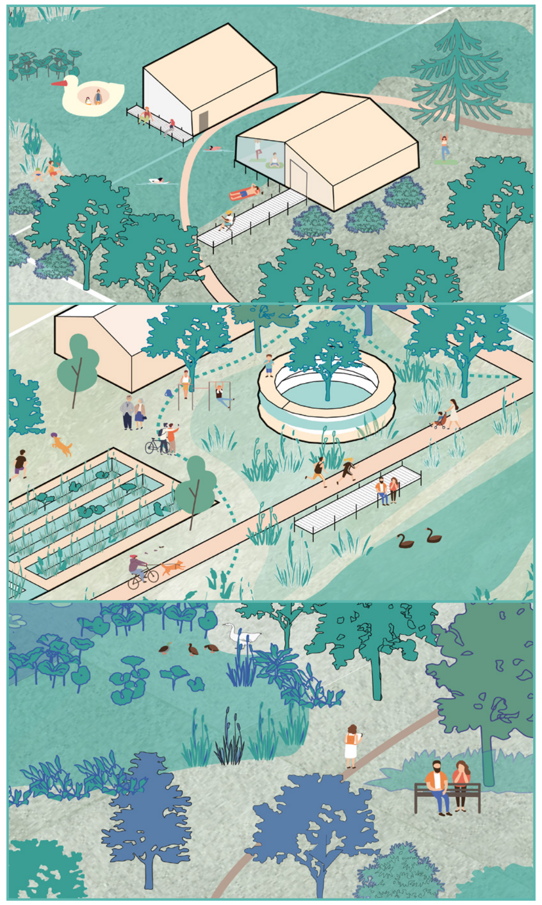
6.3 The Patterns linking 'Water' and 'Urban Development'

Figure 6.3.1
Patterns Linking Water and Urban development: Leverages and Programmes
by Author

From the optimization process, ten 'Programme' patterns are harvested, all of which could be linked back to three deeper leverage points from the conceptual framework(see Chapter 3.2). They open doors for the implementation of many other patterns and promote lasting behavioural change in the system.

Leverage Points(L) and Programmes(PG)

L1
Reconnect People with Nature

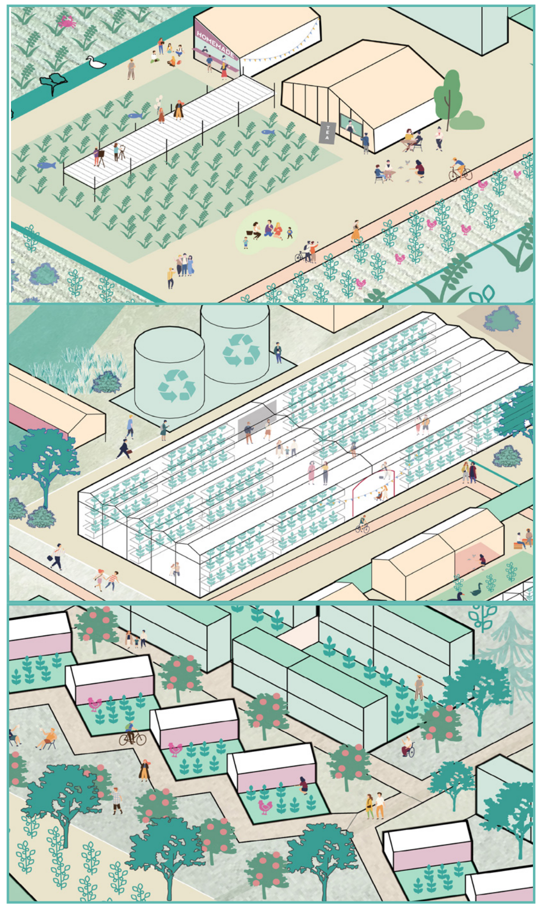


PG01
Interaction with Water

PG02
Public Park for All Ages

PG03
Nature Exploration Route

L2
Reorient the Public Mindset

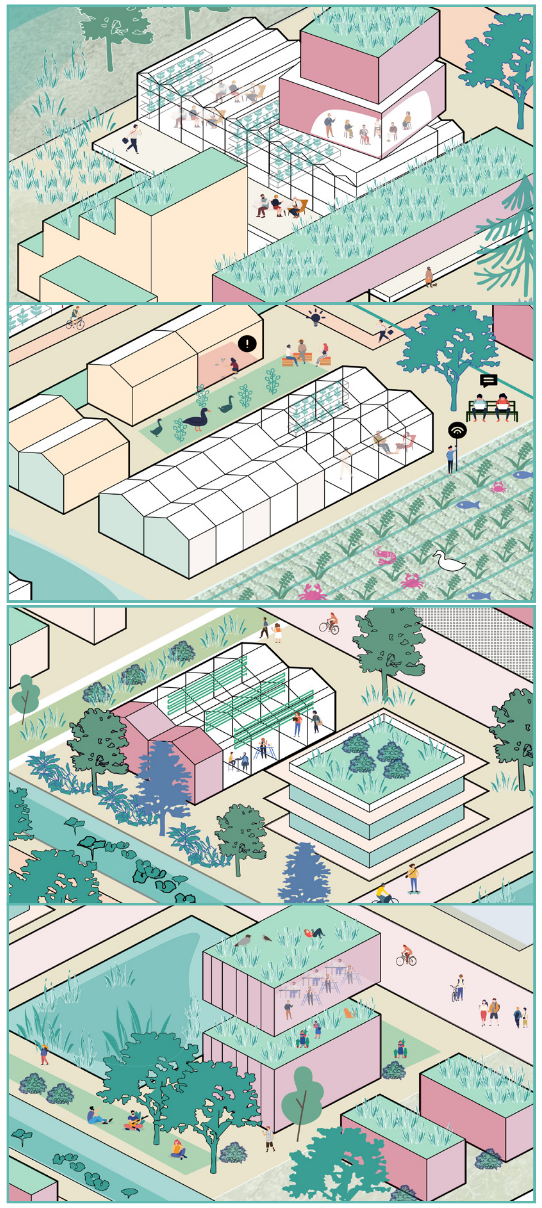


PG04
Agro-tourism

PG05
Production Open Day

PG06
Urban Farming

L3
Stimulating Knowledge Sharing and Innovation



PG07
Knowledge Forum

PG08
Cooperative living lab

PG09
Circular Internship Programme

PG10
Vocational Education

Next to the 'Programmes', 64 'Measures' patterns have also been produced through the optimization phase. All these 64 measures can be associated with the 'Actions' and 'Principles' in Chapter 5, as they can be seen as the concrete form of the 'Actions' and 'Principles'. In this way, the planners and stakeholders could choose the suitable measures to realize the actions according to their own needs and based on different contexts.

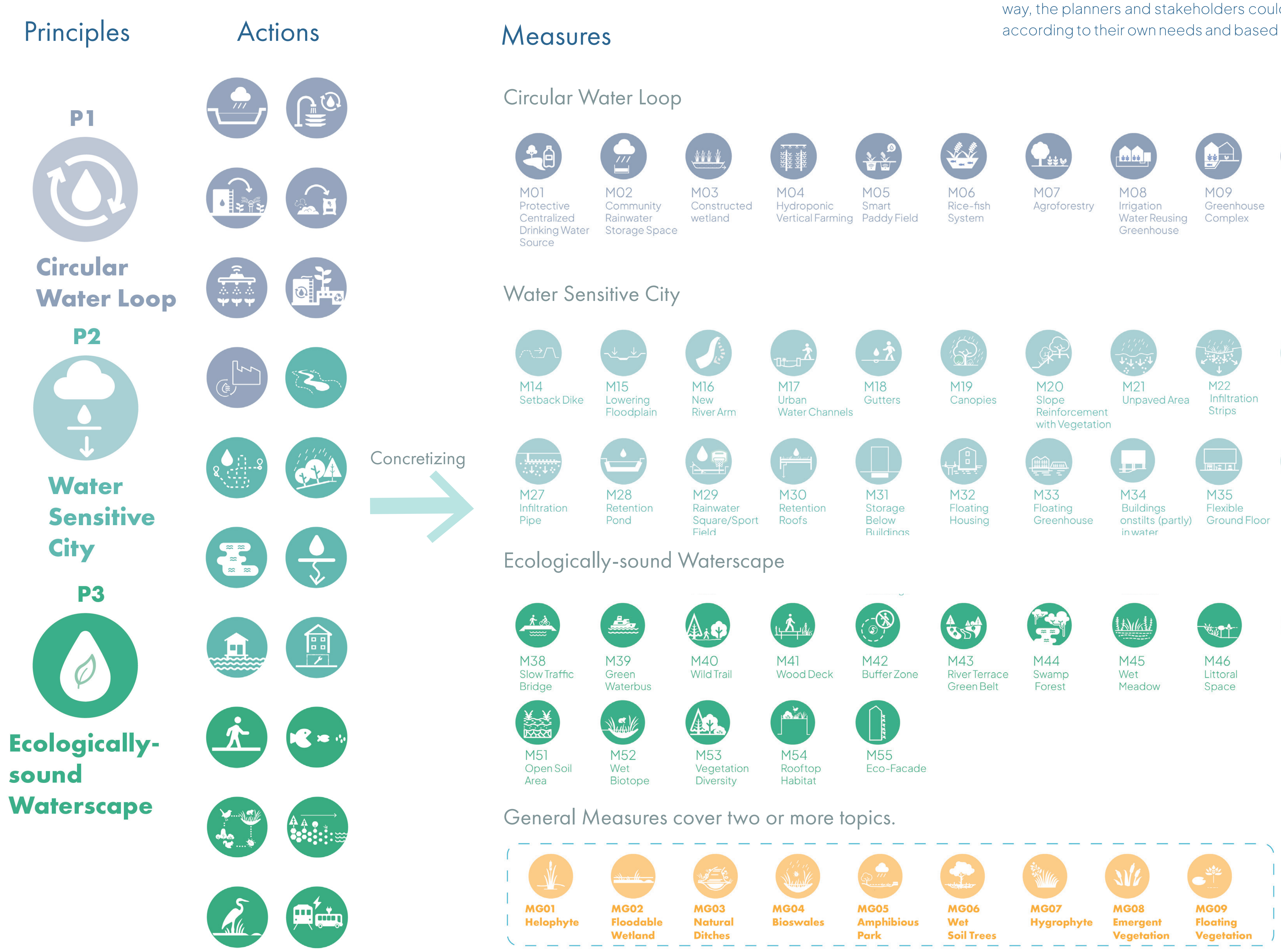
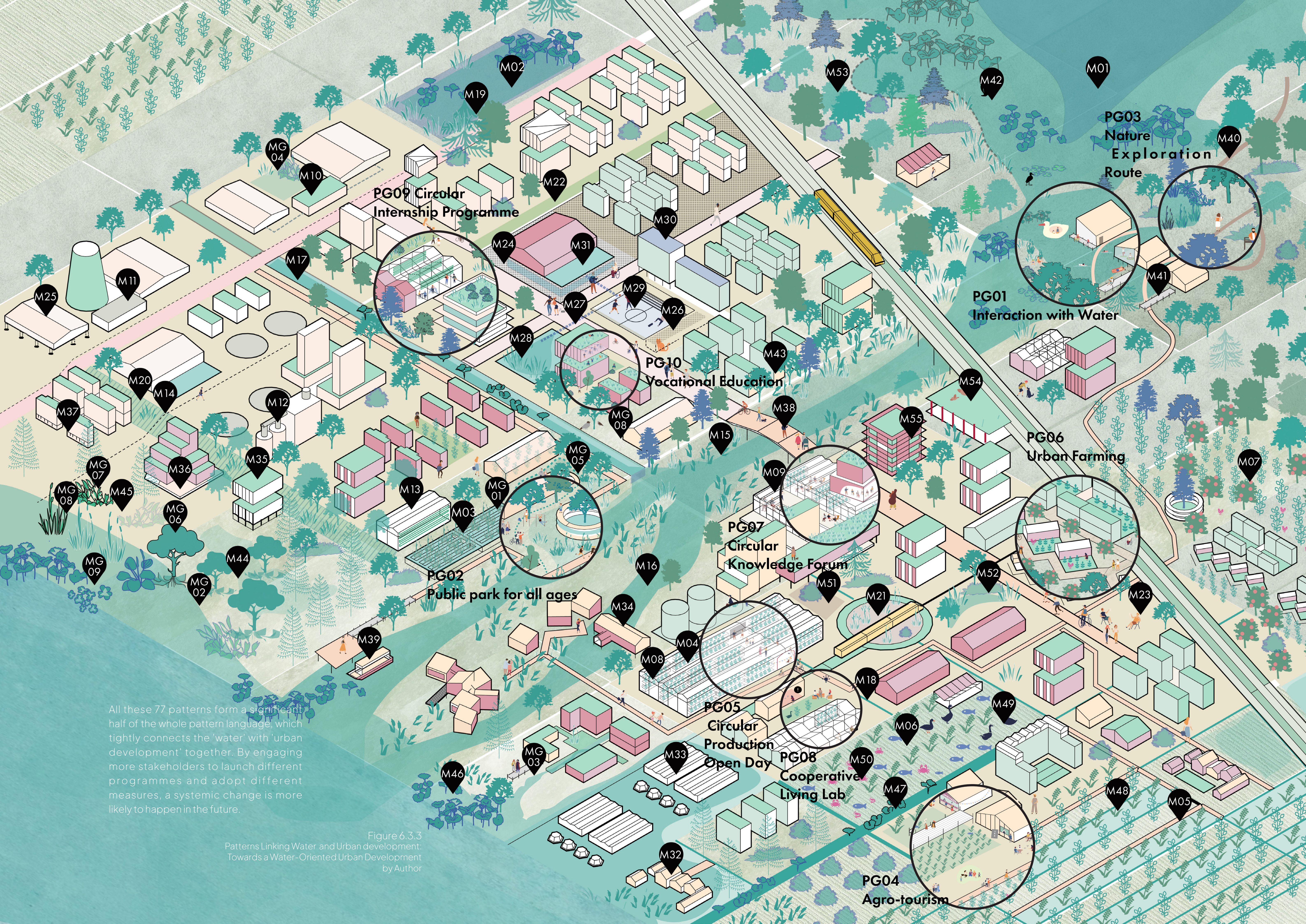


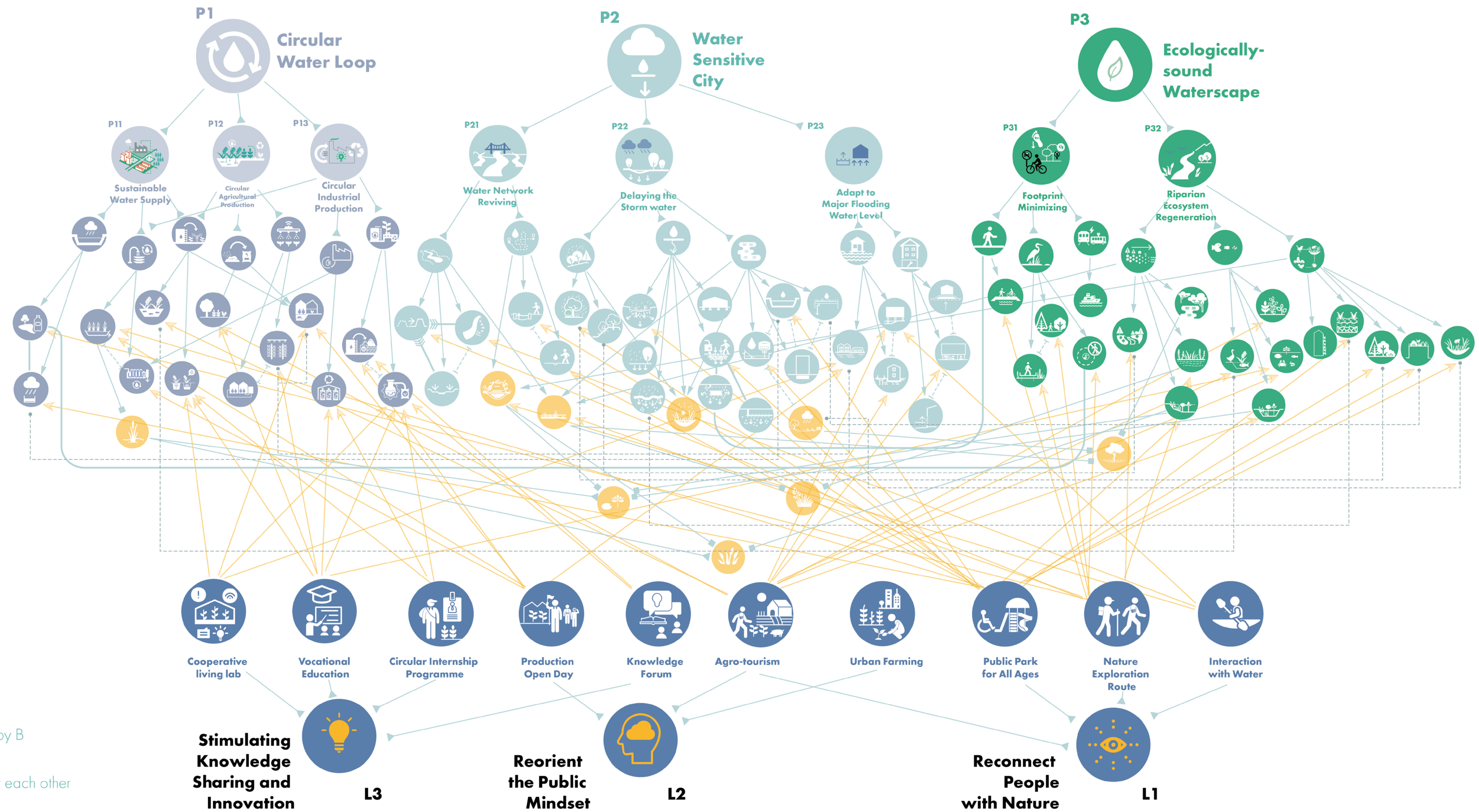
Figure 6.3.2
Patterns Linking Water and Urban development: From Actions to Measures
by Author



All these 77 patterns form a significant half of the whole pattern language, which tightly connects the 'water' with 'urban development' together. By engaging more stakeholders to launch different programmes and adopt different measures, a systemic change is more likely to happen in the future.

Figure 6.3.3
Patterns Linking Water and Urban development:
Towards a Water-Oriented Urban Development
by Author

Figure 6.4
The Pattern Language Nework for Water-Oriented Urban Development by Author



A — B need A to complete
A — B A includes B
A — B A can be concretized by B
A — B A B need each other
A — B A B is an alternative for each other
A B A B co-exist
A — B A is a component of B
A — B A facilitates the implementation of B

Conclusion of Chapter 6

Via the construction of three optimization scenarios, different spatial translations of the 'patterns for water' according to the interest of the stakeholders are found, with the introduction of new programmes linking to deeper leverage points. In this way, the pattern field can motivate more facilitators and participants into the water-oriented urban development, which replies to the sub-RQ 6.

Conclusion of Chapter 5 and Chapter 6

So far, the pattern language for a water-oriented urban development has been completed as shown above. The 77 patterns 'linking water with urban development' in Chapter 6, together with the 31 patterns 'for water' (presented at the end of chapter 5) make a complete pattern network as can be seen in figure 6.4. The 108 patterns in total interconnect with each other and form a systemic solution to address the water challenges in the Lake Chao Basin. It contains principles and actions that centre around the water system, as well as concrete measures and programmes that aim at engaging local stakeholders. All the patterns work jointly to realize sustainable water-oriented urban development. (Detailed explanation of individual pattern and their relations could be found in Appendix A.)

In the next chapter, an integrated vision is developed with this finished pattern language, to test and illustrate how it can be used in a real spatial planning project to realize a 'water-oriented urban development'

CHAPTER VII. IMPLEMENTATION: The Vision of a New Educative Waterscape

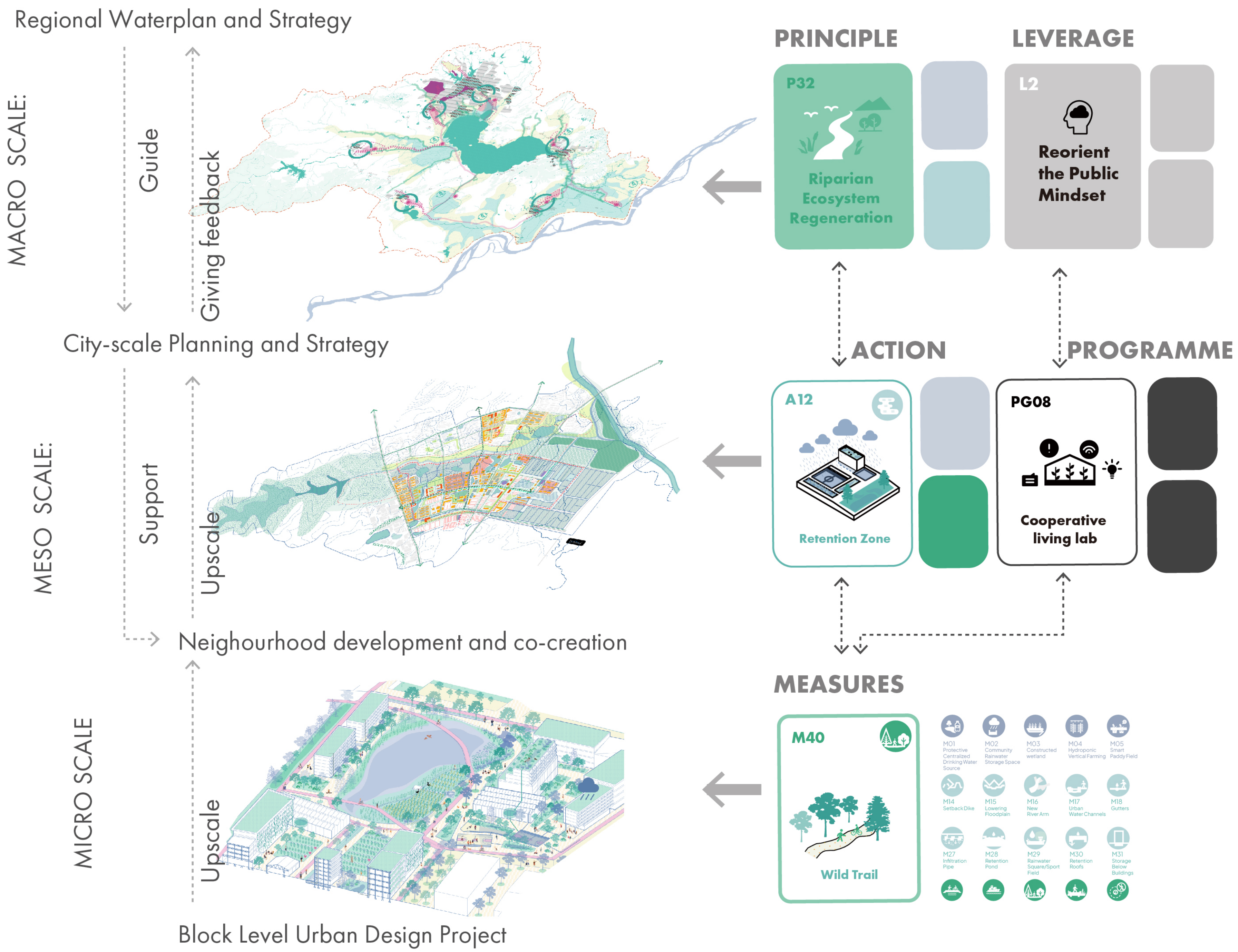
Figure7.1
Vision Impression
By Author

Introduction

In this chapter, a vision for Tanchong River Basin is developed to visualize how the pattern language can be ideally integrated into the future development of the Lake Chao Basin. This vision is presented on different scales, with a zoom-in urban design project to show the desired spatial quality as well as the possible implementation strategies of the pattern language. The vision is then evaluated by the DCBA criteria developed in chapter 4, to show its contribution to the water system in the area. With the exploration in this chapter, the answer to the sub RQ7 could be found.

7.1 A Multi-level Implementation Framework

Figure7.1.1
A Cross-scale Framework for implemetation
By Author



The implementation of the pattern languages involves practices on different scales, which aims at creating a positive feedback loop between these scales and thus stimulating the systemic change of the whole region.

On the macro-scale, the policymakers, the regional planners and experts from the waterboard can set up a spatial framework to show the related areas to implement certain 'Principles' and 'Leverages'.

On the meso-scale, the city planner could use the pattern language to engage the main facilitators(just like the optimization process in chapter 6), to create an integrated vision that supports the water-related 'Actions' with different 'Programmes'(see chapter 7.2).

On the micro-scale, the community planners could use these patterns to organize co-creation activities to concretize the 'Action' patterns in different ways based on the intentions of the stakeholders involved.

Meanwhile, it is important to note that, the implementation of this whole set of pattern language is not necessarily a bottom-up or a top-down process(as can be seen in figure 7.1.1). On one hand, the local stakeholders could launch a possible pattern combination according to their own interest to contribute to the water system in a 'grass-roots' way. This movement can be scaled up with the support of upper-level administrators. On the other hand, the decision-makers could also formulate policy documents and reach out to related stakeholders to stimulate a top-down transition.

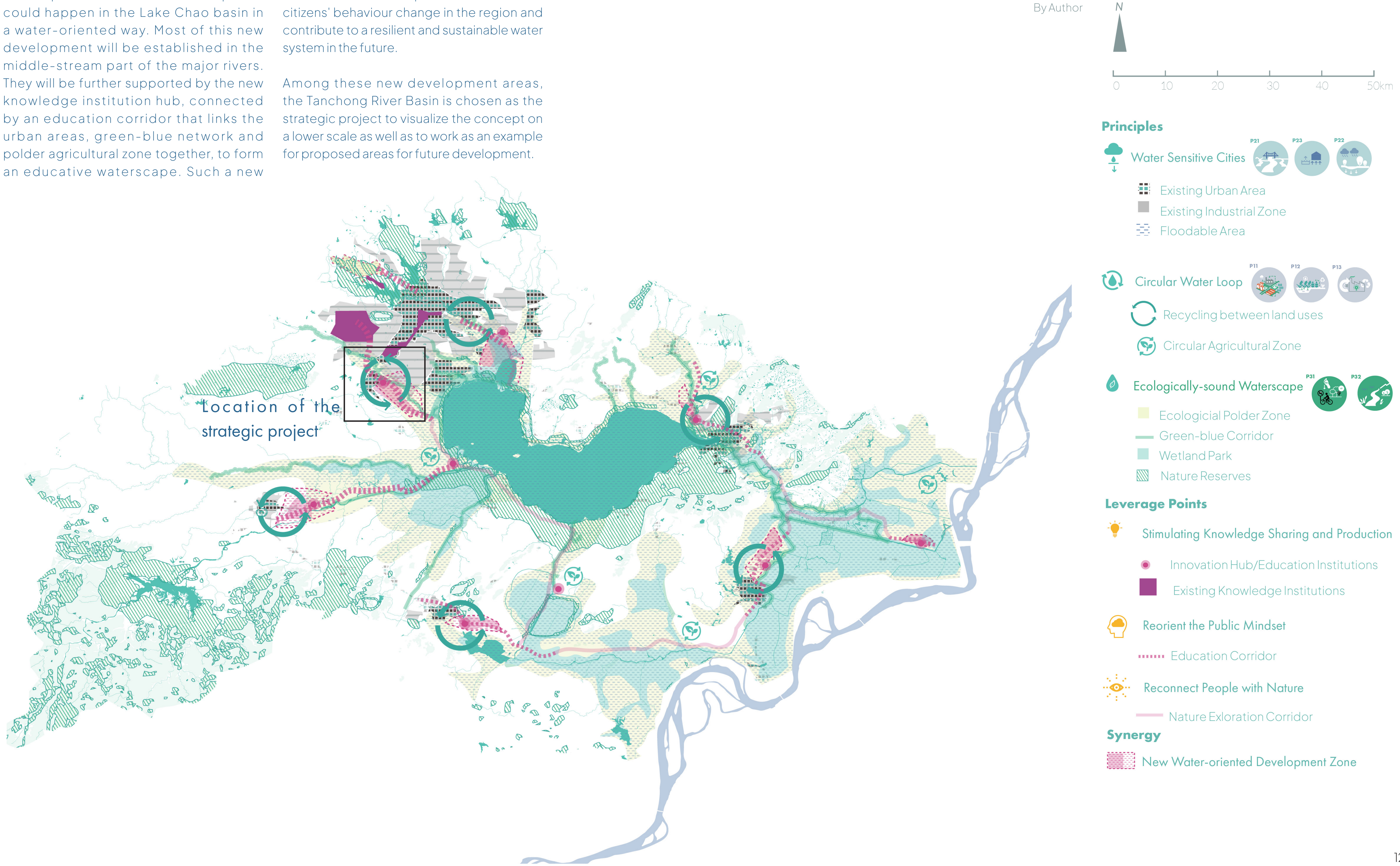
To show how this could happen and what kind of vision it might lead to, the following part of this chapter depicts the trans-scalar implementation process and design outcome of the patterns language.

Macro scale

This map shows how urban development could happen in the Lake Chao basin in a water-oriented way. Most of this new development will be established in the middle-stream part of the major rivers. They will be further supported by the new knowledge institution hub, connected by an education corridor that links the urban areas, green-blue network and polder agricultural zone together, to form an educative waterscape. Such a new educative waterscape aims to lead the citizens' behaviour change in the region and contribute to a resilient and sustainable water system in the future.

Among these new development areas, the Tanchong River Basin is chosen as the strategic project to visualize the concept on a lower scale as well as to work as an example for proposed areas for future development.

Figure7.1.2
Spatial Framework for A Water-oriented Lake Chao Basin 2050
By Author



7.2 Strategic Project: Tanchong River Basin 2030

Vision Statement:

With the implementation of the water-oriented pattern language, the citizens in Tanchong River Basin can live with water in a sustainable way. The boundary between agricultural production, industrial zone and residential zone are blurred, so the water loop can be fully circular to minimize the freshwater consumption. The urban space is designed with the natural rainwater circle taken into full account, which makes sure that the citizens are fully protected from further flooding events. The ecosystem is also regenerated for the flourishment of the waterscape, with the polder agricultural zone, wetland zone and urban space interconnecting to form a dynamic ecological network. More importantly, the whole area will function as an educative park. By integrating all types of programmes into people s daily life and daily production, the mindset of people can be reoriented to appreciate a more sustainable relationship with water in the future.

The 3D illustrates how the patterns are used to outline the skeleton of this vision: On one hand, the 'action patterns' are first decided according to the land use and geographical condition of the location(See the vision decomposition 1 on next pages). On the other hand, the 'programme patterns' are suggested in combination with them, based on the needs of potential stakeholders(See Programme detail in vision decomposition 2). Such a combination could intervene in the system on deeper leverage points and clarify the most important 'actions' needed for different zones.

In order to further clarify how these pattern combinations could function, an urban design project at 'Zone 6' is chosen to visualize the implementation process and outcome on a lower scale in 7.2.

Figure7.2
Spatial Framework 3D
for Tanchong River Basin
By Author

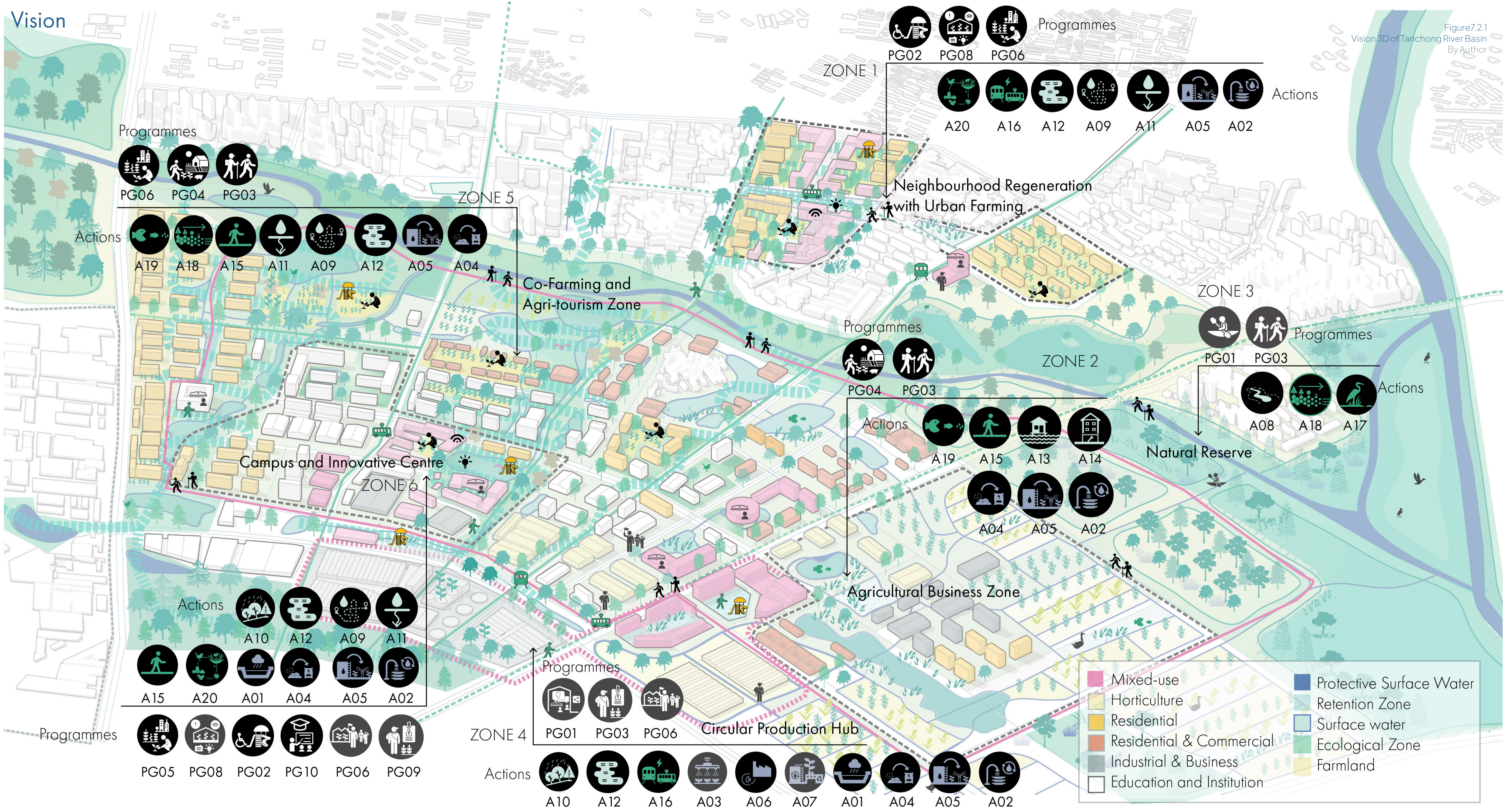


Figure7.2.1
Vision 3D of Tanchong River Basin
By Author

Vision Decomposition: Layer for water

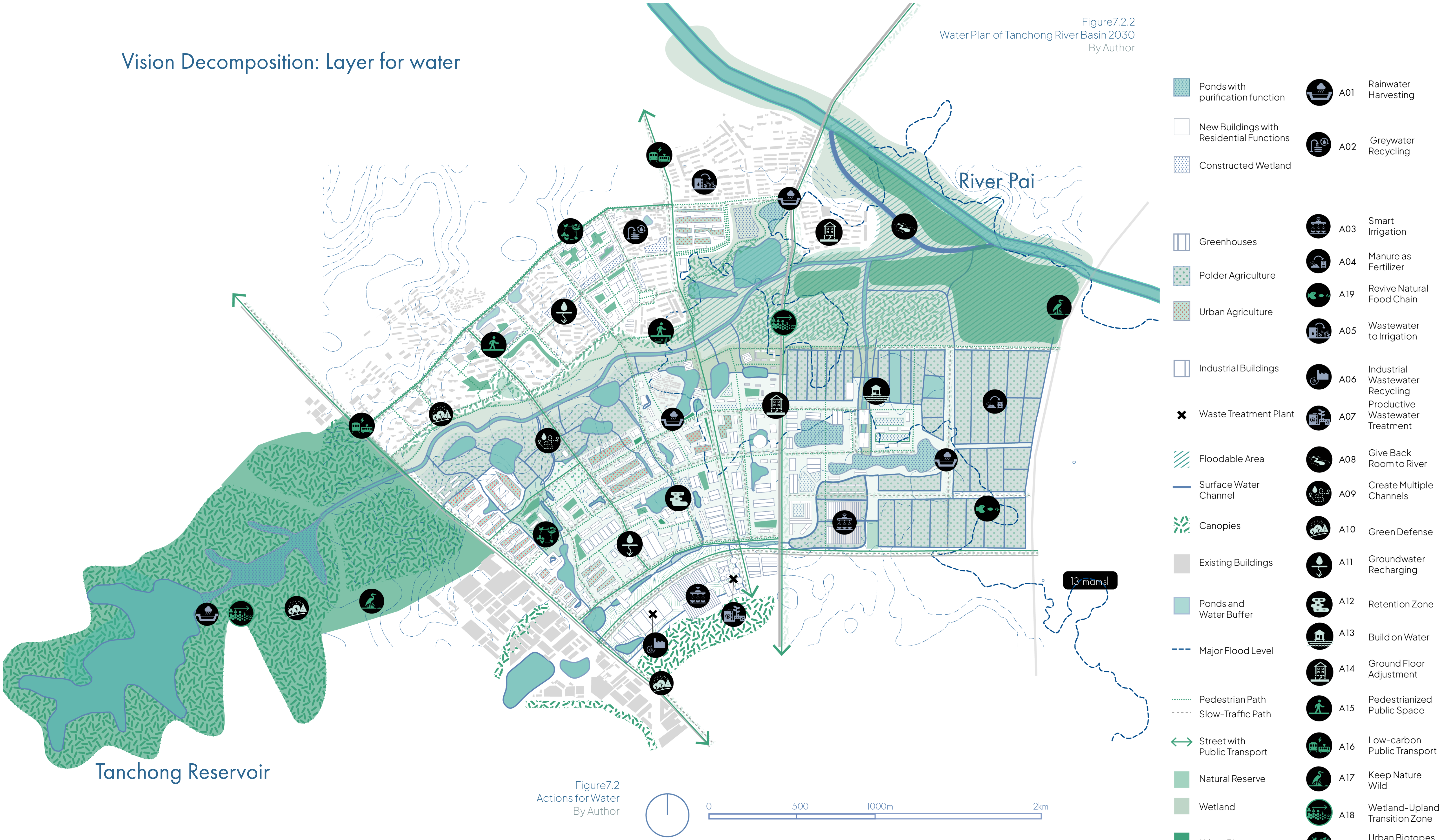
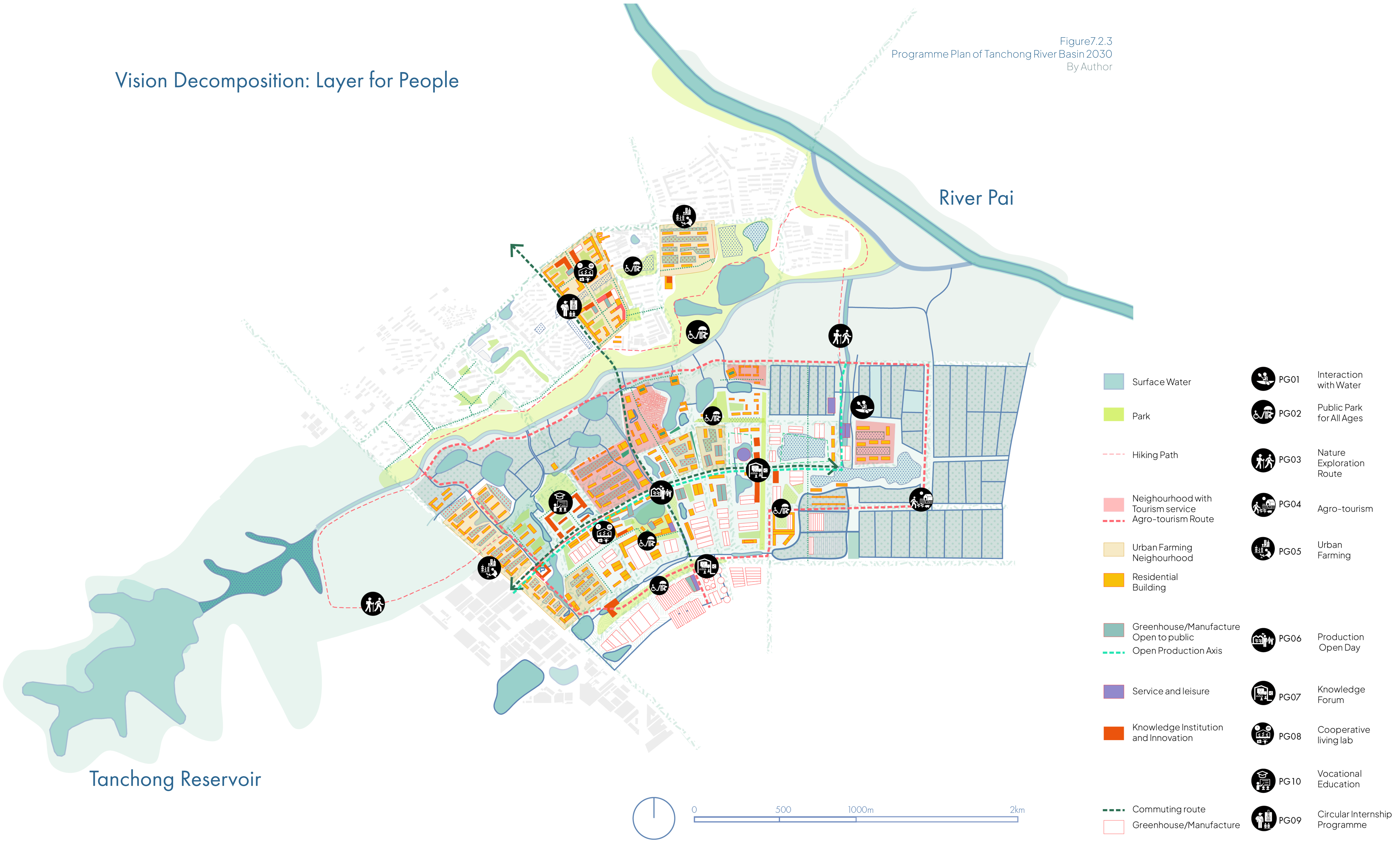


Figure7.2.2
Water Plan of Tanchong River Basin 2030
By Author

Figure7.2
Actions for Water
By Author

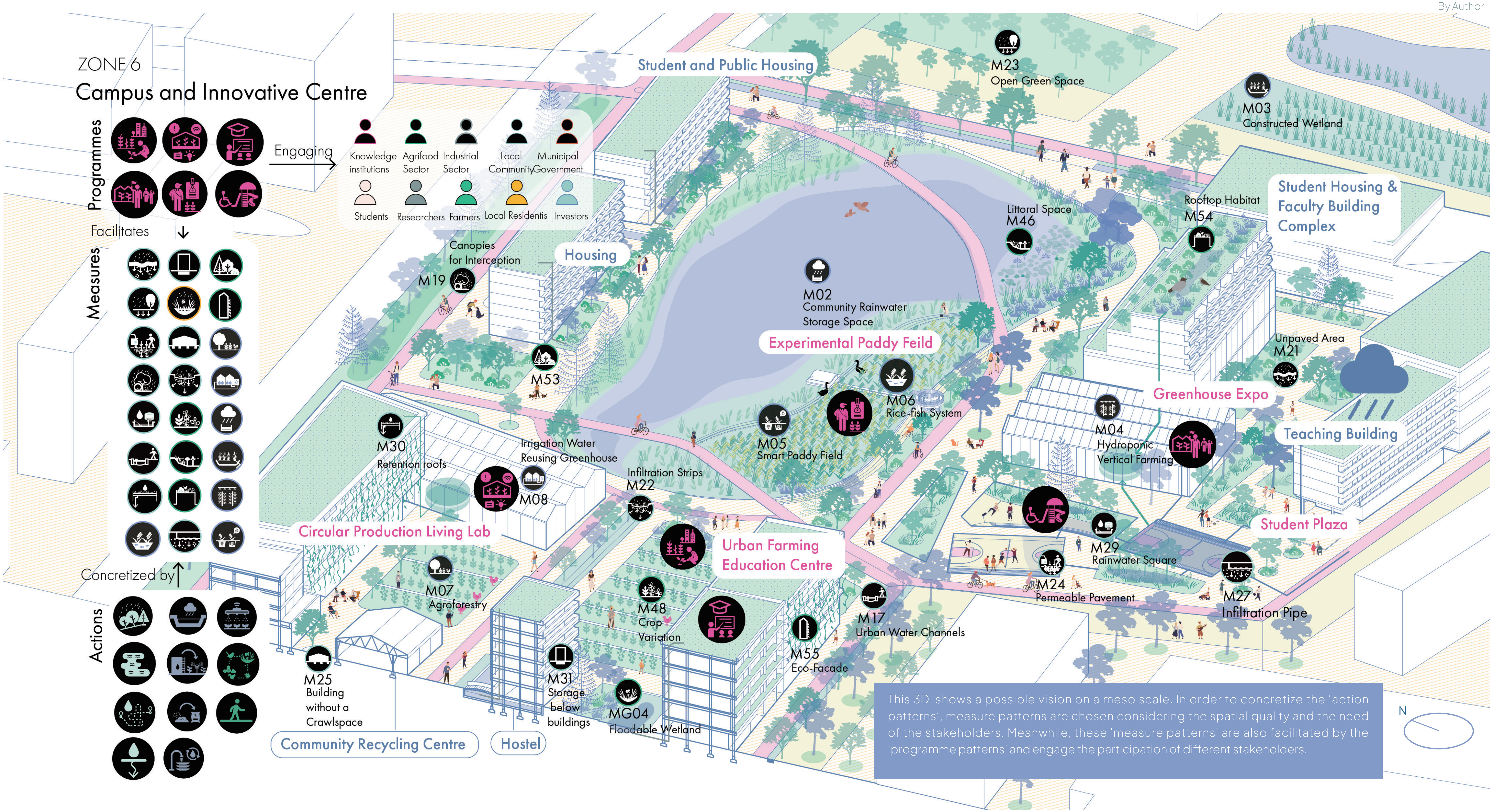
Vision Decomposition: Layer for People

Figure7.2.3
Programme Plan of Tanchong River Basin 2030
By Author



Micro scale

Figure7.2.4
Campus and Innovation Centre in
Tanchong River Basin 3D
By Author



This 3D shows a possible vision on a meso scale. In order to concretize the 'action patterns', measure patterns are chosen considering the spatial quality and the need of the stakeholders. Meanwhile, these 'measure patterns' are also facilitated by the 'programme patterns' and engage the participation of different stakeholders.

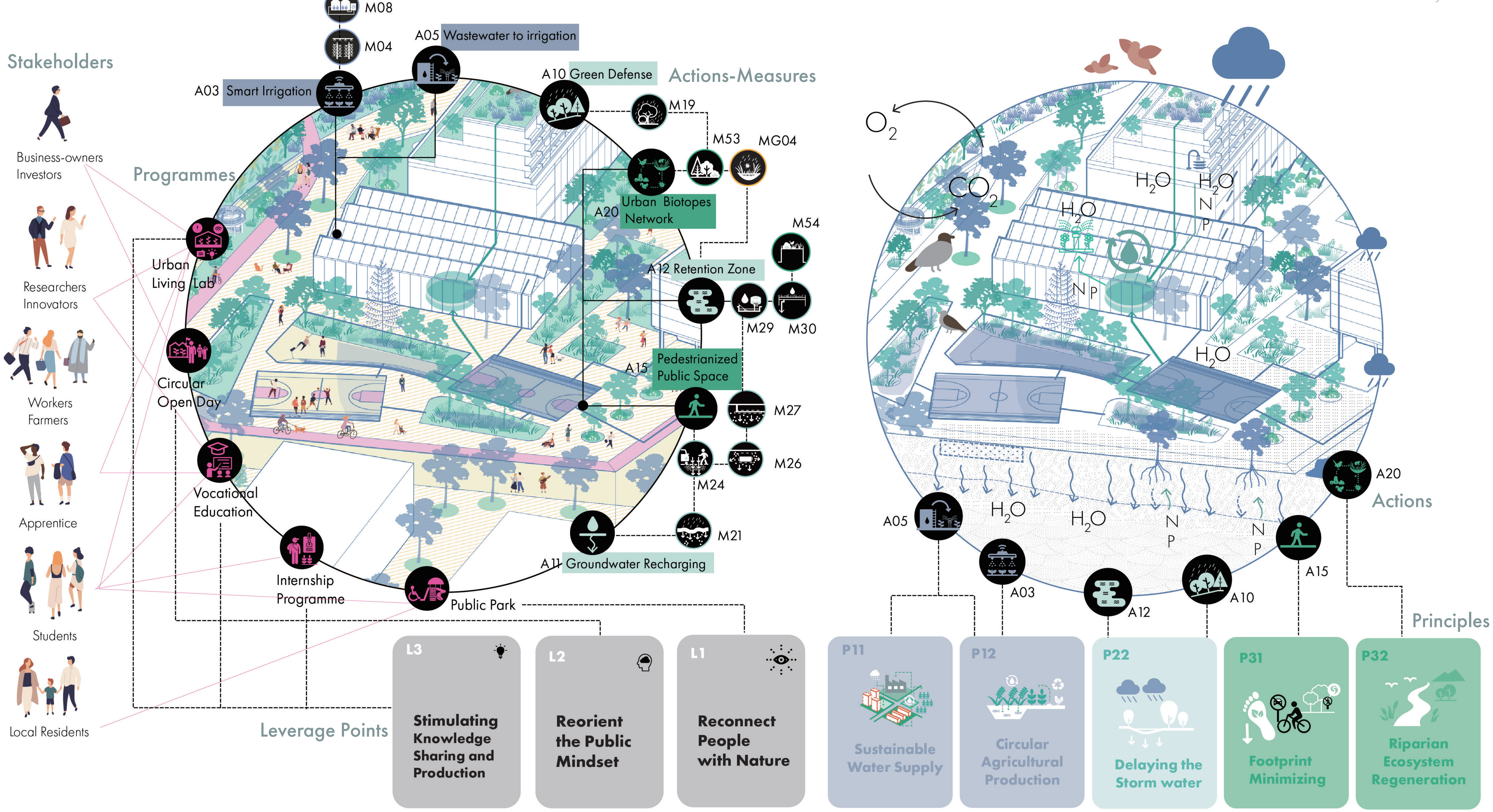
Micro scale

Take the student plaza area as an example to illustrate the implementation process.

In this area, five programme patterns are suggested, which are likely to attract multiple stakeholders to participate in the development process. These programmes also contribute to the three deeper leverage point patterns, so systemic change could be expected in the future.

Based on these programme choices, this area is designed to provide students and local residents with more public space to do sports and hold other events, such as open production day. Thus, instead of a rainwater pond, a rainwater plaza works as an alternative to it. And since pavement is unavoidable in this case, permeable materials, infiltration boxes and infiltration pipes are selected. In the end, all these measures still contribute to the 'actions', which could further be connected with the guiding principles of a water-oriented urban development, as can be seen below.

Figure7.2.5
Implementation of Patterns
By Author



Micro scale

As can be seen, people can participate in different activities in this place, where they are also surrounded by all types of water flows.

On sunny days, students, researchers and local residents can easily spend their break time here and children might be attracted by the irrigation machines inside the greenhouse. The whole plaza becomes a dynamic public space.

On rainy days, the sunken plaza holds the rainwater from blocks nearby and this rainwater could be transferred to the greenhouse and used for irrigation later afterwards. People who go passing by the square can notice this process and probably become aware of the flooding issue better.

Using the DCBA criteria, this student plaza area is evaluated. It can be noticed that the water quality makes the most compromise since more attention is given to people instead of the ecosystem here. Meanwhile, it is also important to note that though there are multiple patterns contributing to the delay of the rainwater, they are still not the best solution to address the water safety problem. But the added value from this micro-scale vision is still high considering its contribution to the social aspect.

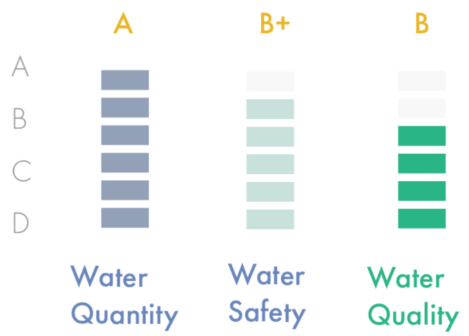
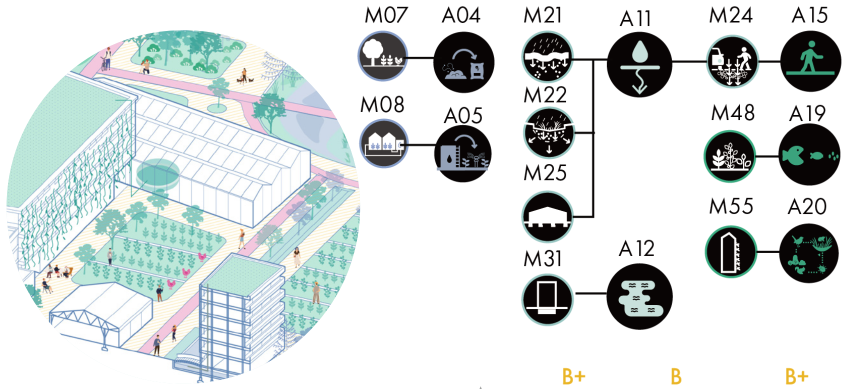


Figure7.2.6
Performance of the patterns on micro scale:
Rainwater Plaza
By Author

Micro scale

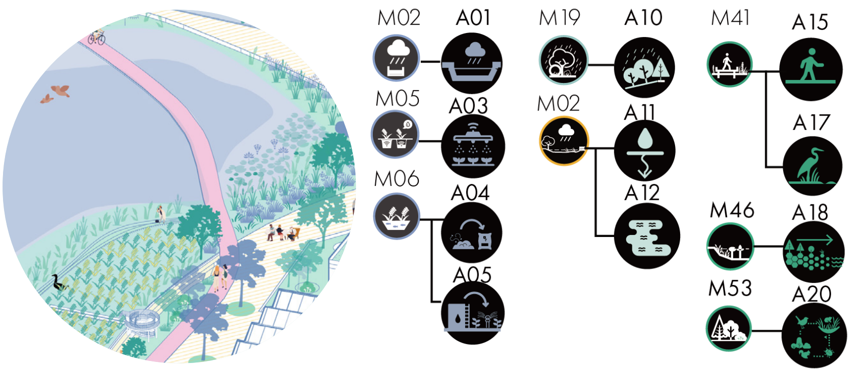
Following a similar process, other design outcomes are also possible and make their own contributions to the water system (as shown in the other two zoom-ins on micro scale below).

Urban Farming Education Centre



An urban farming education centre is established on campus to link local residents, researchers and students, where awareness of circular production could be promoted.

Experimental Paddy Field Park



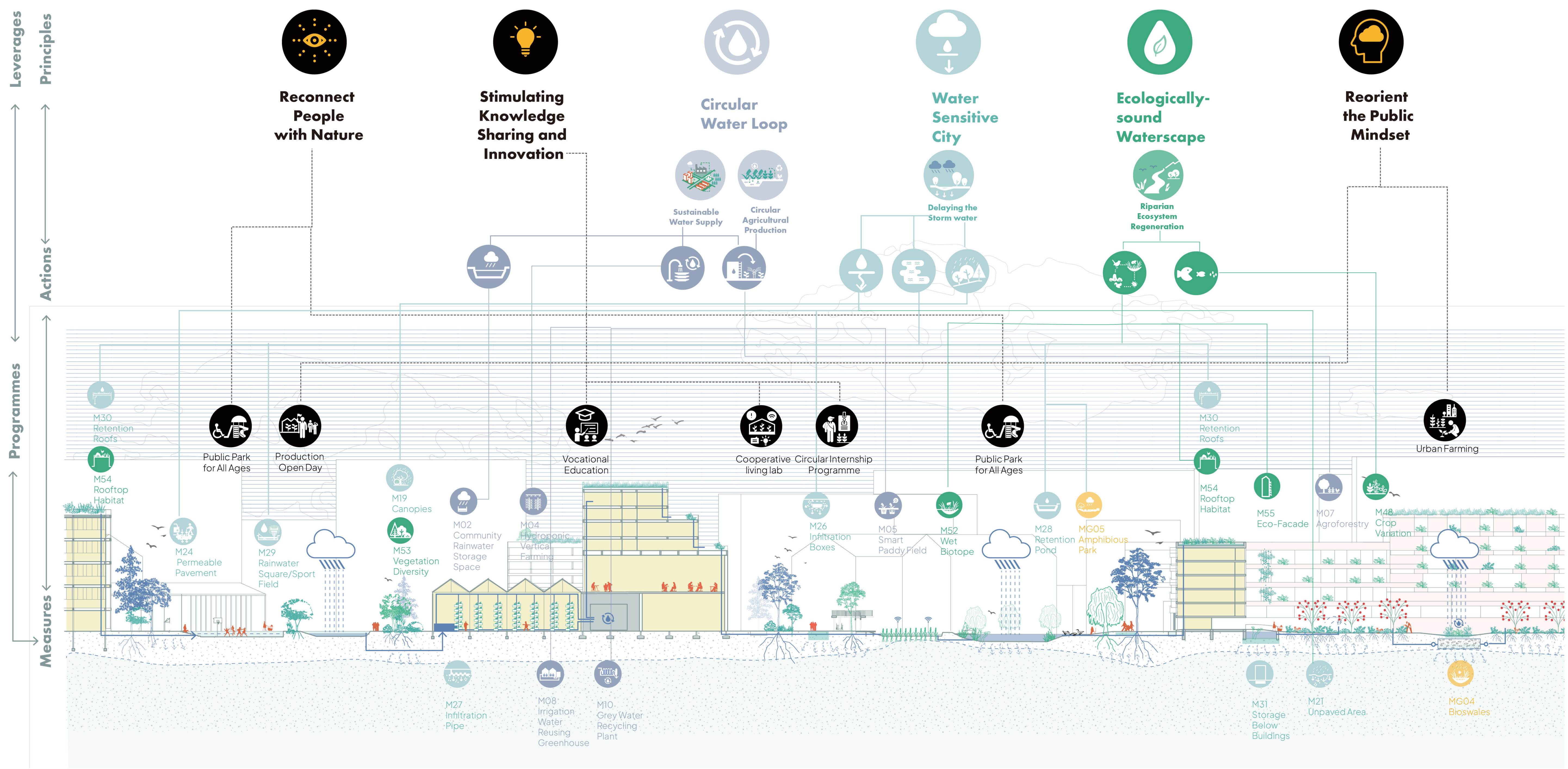
The experimental paddy field is integrated into an amphibious park in this area. It not only provides green space for residents but also bridges students with local rice farmers better.

Figure7.2.7
Performance of the patterns on micro scale: Urban Farming Education Centre
By Author

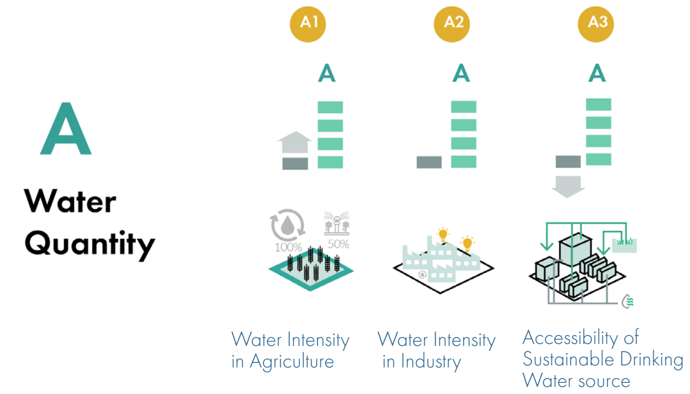
Figure7.2.8
Performance of the patterns on micro scale: Experimental Paddy Field Park
By Author

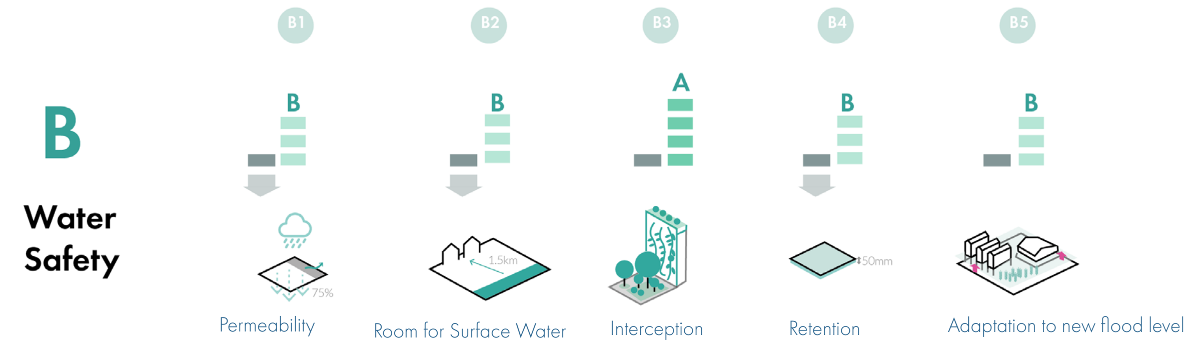
Micro scale

As can be seen in this section, the same action pattern can have different translations on the micro-scale according to the needs of stakeholders and the launched programmes. As a result, there is no definite design outcome on a micro-scale, as long as the 'action' could be taken. All of these possibilities are able to contribute to the implementation of 'leverage' and 'principles' of the water-oriented urban development.



7.3 Evaluation of the Vision





FAS Score(from Chapter 4.6)

Vision Score

Figure7.3.1
Decomposition of the vision and evaluation
By Author

Based on the spatial structure of the strategic project and on the spatial quality achieved by the micro-scale design in Chapter 7.2, the vision is evaluated from the fifteen DCBA indicators from Chapter 4.

As seen in figure 7.3.1 the vision scores at A level in water quantity, with all the three indicators achieving A level respectively. However, it should be noted that this vision does not take the population growth in the area into account, which means limiting the population growth is needed if aiming at reaching the A level.

In terms of water safety, this vision achieves at the B level in general, with the bio-interception at the A level. Yet, if comparing this score with that of the future autonomous scenario, the achievement is still impressive, because nearly all the indicators tend to get worse in FAS.

As for water quality, most of the indicators can achieve the A level. The main barrier comes from the existing highway and the consumption of fossil fuels from the industrial sector, which still takes a long time to make the transition.

The outcome of this evaluation means that if the suggested urban development areas could take a similar strategy as Tanchong River Basin, the spatial framework on macro scale(in figure 7.1.1) could bring an obvious improvement in all three aspects of water and contribute to a future-proof water-system.

Conclusion of Chapter 7

This chapter outlines the multi-scale implementation framework of the pattern language. By using the Tanchong river basin as a strategic project that bridges between macro and micro scales, it explains how the pattern language could be adopted and facilitate a systemic change in the water system of the Lake Chao Basin.

This implementation framework as well as the pilot project also provides transferable implementation processes for other areas(no matter within or outside the study area), and thus replies to the sub RQ 7: 'How can the patterns be implemented and provide transferable knowledge to other locations?'

CHAPTER VIII. CONCLUSIONS AND REFLECTIONS

In the final chapter, the research outcome of the thesis is concluded by replying to the main research question. Both contributions and limitations are discussed in a reflective way to shed light on future research in related fields.

8.1 Conclusions

Many of the water issues faced by today's cities are actually not independent and simple problems within either the discipline of water management or water ecology. Instead, it is a systemic problem that should be examined on a wider scope, through the lens of urbanism. That explains why the concept of 'sustainable water-oriented urban development' is put forward by this project.

To respond to the main research question of the thesis 'How can a sustainable water-oriented urban development pattern language be designed and contribute to a future-proof water system in the Lake Chao Basin?', it is divided into two parts and discussed based on the combination of the findings from each sub research question.

1. How can a sustainable water-oriented urban development pattern language be designed?

On the one hand, the pattern language of the water-oriented urban development is a natural-oriented solution that concentrates on the metabolism of water involving all types of water flow that occur in the built environment. Through the exploration of the three dominant paradigms: 'water-sensitive city', 'circular water loop', and 'ecologically-sound waterscape', it turns out to be promising to synergise these paradigms under the view of urban metabolism. In fact, since water quantity, water quality and water safety are instinctively interrelated with each other under natural conditions, many overlapping and reinforcement situations between the interventions under these topics could be identified from such a big picture of metabolism.

As listed shown in figure 8.1, many natural-based patterns contribute to all three aspects of the water system and should be attached with greater importance in future development.

On the other hand, this pattern language emphasizes its role as a systemic solution by introducing deeper leverage points to have an impact on people's behaviour and way of thinking. This includes 'Reorienting the public mindset', 'Stimulating knowledge sharing and innovation', 'Reconnecting people and nature' and a series of programmes under each topic. By introducing programmes under these deeper leverage points, other related measures are more likely to be implemented into the urban development process and bring about a lasting behavioural change in the system. For example, as shown in figure 8.2, twenty-five other patterns can be considered easily attached to (or facilitated by)the programmes of a public park. The completion of such a park is likely to create awareness among the citizens thus encouraging them to give a sustained commitment to the water system.

In a nutshell, instead of being purely 'water-oriented' and focusing on the water system itself narrowly, the pattern language of a 'sustainable water-oriented urban development' focuses on the changing of the larger urban network connecting water and

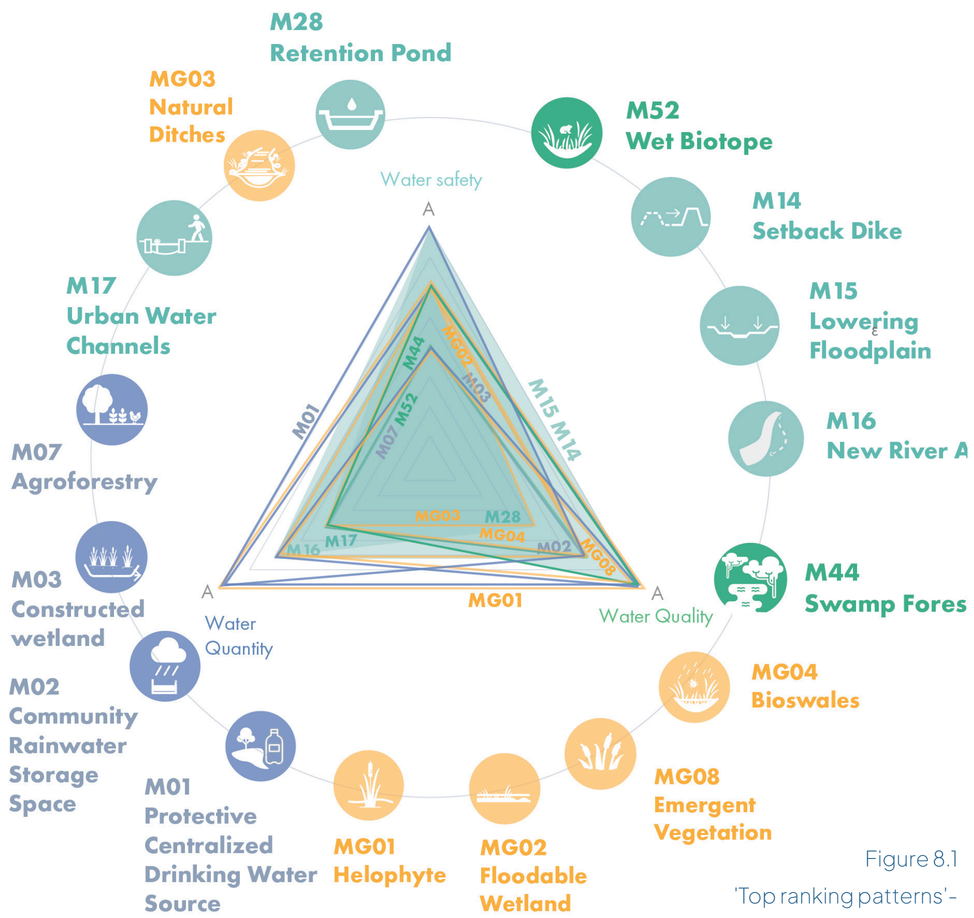


Figure 8.1
'Top ranking patterns'-
considering their contribution to
all three topics
By author

people and in order to achieve a sustainable future.

2. How can a sustainable water-oriented urban development pattern language contribute to a future-proof water system in the Lake Chao Basin?

In the project, the pattern language is targeted at solving the water issues specifically in the Lake Chao Basin and thus is designed based on the analysis of the current problems of this location. At the end of the analysis part, fifteen indicators with DCBA criteria are set up regarding water safety, water quantity and water safety. And in the final assessment of the strategic project, increases in all of the indexes could be noted with several of them reaching A-level. This means the implementation of such a pattern language has the potential of addressing the water issues in the area and bringing all-around improvement to the water system.

Furthermore, as many of the programmes in this pattern language are proposed based on the opportunities in the location and from the interest of stakeholders in the Lake Chao Basin (in the optimization stage), many stakeholders(such as paddy field farmers, agricultural knowledge institutions) within the regions might be better engaged by this set of patterns. So, the implementation of these patterns is promising to bring about a systemic change, especially in this region.

Though being an 'urban development pattern, this pattern language also has the potential to be improved and used as a design toolkit for future urban regeneration processes in this

Figure 8.2
PG02 and the
related patterns
by author

region. The improvement could be done by following a similar process in the optimization stage(as in chapter 6) where more patterns for regeneration could be thought of. It can be expected that, though more social considerations need to be made when carrying out an urban regeneration project, this pattern language can still work as a good starting point to organize a co-creation tool to communicate with existing stakeholders or introduce new stakeholders. And this can further contribute to the sustainability of the water system in the Lake Chao Basin.

The ultimate ambition of this pattern language goes that:

If all the citizens in this region try to integrate this pattern language during their daily practice, multiple small efforts could make a huge difference to the water system.

And if the decision-makers could not only embrace a 'water-orient' vision but a water-oriented planning process to engage citizens and gradually make a value change in the society, the water system, as well as the other aspects of the region, could become more resilient and sustainable.

Apart from answering the main research question, the design outcome together with the research approach of the project also provides other transferable knowledge, which will be discussed further in the next chapter. Moreover, considering the ethical aspect and the methods used, the limitation of this project will also be acknowledged in chapter 8.2.

8.2 Reflections

Scientific Relevance

Centring around water, the project explores the possibility of realigning the metabolism of water for a sustainable future. Since the flow of water not only plays a fundamental role in the natural ecosystem but also is interrelated to many social challenges (such as drought and flooding issues), it is a crucial and urgent topic that young urbanism should dedicate to and make an impact on.

Though there are already abundant theories and discussions on different water issues, the knowledge gap still exists on how to systemically address water problems from an urbanist's view. For one thing, the research into 'water ecology', 'circular economy' and 'urban flooding' are usually not from the same disciplines. There are limited numbers of integrated solutions available to tackle the water issues by spatial intervention through the lens of the built environment and design aspect, which the effort of the urbanists is well needed. Meanwhile, many of the current theories on the topic of water developed from the view of urban design, such as 'sponge city '(Yu et al., 2015) and 'water sensitive city'(Wong and Brown, 2009), fail to provide a systemic solution to guide the urban development and address the water challenges systemically. For instance, the practice of sponge city is mainly from landscape architects' view, which emphasizes the natural-based concept without realising how the flow of water is actually interconnected with different urban functions and social activities (including agricultural, industrial production and household use). While the water sensitive city theory highlights from a social aspect by proposing reinforcing water-sensitive values and behaviours the theory, most of the current interpretations of the concept in the urban design practice still need to be scaled up and engage with wider city-shaping processes, where a systemic view is needed(Wong et al., 2020).

By combining the theory of urban metabolism and the method of systemic design, this project contributes to filling the knowledge gap by providing a more systemic and synergetic pathway that not only covers different aspects of water flows but also provides a design solution that can have an impact on the deeper leverage points which leads to a more systemic change in the built environment. With the conceptual framework of 'sustainable water-oriented urban development' and the pattern field as the outcome, the thesis enriches the current discourse on the topic of water and cities and hopefully would provide new perspectives for both urbanists, architects and landscape architects to deal with water in their design practice.

On Design and Research

As a project for an urbanism graduation thesis, it is executed by intertwining design and research together. In this process, knowledge is constantly harvested from either 'research for design' or 'research via design' in search of the answer to the main research question.

For the first half of the project, the research is done to prepare for design, where previous knowledge and the context are studied. Through literature review on the water in the built environment and urban metabolism theory, a theoretical underpinning is framed and a conceptual framework is formed accordingly. The latter guides the project and serves as the cornerstone of the design. Then, mapping and visualizing the current water flow through different territories contribute to an in-depth understanding of the performance of the current water system which is shaped by current urban morphology and consumption manner. It helps to figure out both the natural and social conditions of the territory, the factors that bring about the current water problems, as well as the potential offered by the location. These points are concluded by SWOT analysis and translated into design strategies by using the TOWS method and hence ensuring the coherence of the project.

For the second half of the thesis, the research is carried out through design. The core of this part is the use of the maximization method. In the maximization stage, design solutions are come up with by spatializing the principles from previous literature studies. These solutions are then tested and constantly improved in optimization stages by constructing different scenarios for the potential stakeholders. In this way, spatial impacts from these stakeholders' interests could be evaluated and reflected upon. A deeper understanding of what added value could be brought by proposed design interventions could also be gained. Additionally, according to Stappers and Giaccardi (2017), when constructing all the scenarios as well as the strategic project, the whole process can be seen as a research activity. Because in this process, new 'prototypes' are generated based on the real challenges and context and it certainly provides new knowledge in the form of the design outcome.

Last but not least, the project also uses two key methods to bridge these two aforementioned parts of the thesis. One is the DCBA method and the other is the pattern language by Christopher Alexander (1977). By setting up different levels in the DCBA criteria, it links the current situation (that concluded from the context analysis part) with the more desired situation (set up according to the principles of the theories), it offers orientation and direct feedback for different design solutions. Constructing the pattern language also ensures that the conclusion from the analysis is properly translated into design principles while various pieces of design ideas can be filtered, improved and interconnected with each other properly so as to respond to the research questions.

On Systemic Engineering and Pattern Language

Water issues in today's world are not a simple problem that could be easily addressed by a simple concrete solution. Instead, it is a wicked problem that needs a holistic view and approach to understand and tackle. In this graduation project, a pattern language is constructed with the aim of realizing a systemic engineering process, where the following pieces of experience have been gained.

Firstly, the construction of the pattern language helps to decompose the system into different small elements and offers a trans-scalar perspective of the whole system. To understand how a pattern network should be established, knowledge of how different elements could have an impact on related scales is required and thus it pushes the designers to think of the connections between different elements. For example, the permeability in the high-lying zone could impact the flood risk in the low-lying zone, though these two factors do not usually appear on the same scale. In this process, the performance of the whole system under the impacts of different elements became clearer.

Next to it, the construction of a pattern language allows the planners to think about how to establish a desired positive feedback loop within the system to reach an intended behaviour change rather than purely creating a standard and precise master plan. Though illustrating a vision is an important part of planning, the pattern language encourages the planner to focus more on the 'Why', 'How' and 'What' behind the solution to guide a

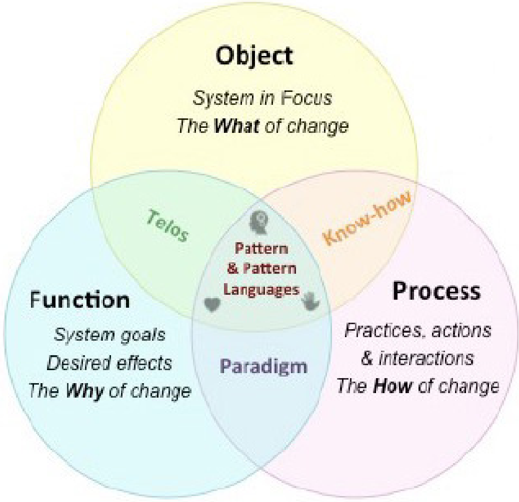


Figure 8.3
Pattern Languages and the what, why and how of change
by Finidori et al ,(2015)

self-organization process(see figure 8.3). In this project, by constructing 'Principles', 'Leverage',' Actions', 'Measures', and 'Programmes', this pattern language is able to offer not only a vision, and a set of strategies but also the logic and reasoning behind it. So it is open to change and growth in the future according to the feedback from the system.

The pattern language also allows the planning process to become more open to the public and transparent. Just like its original intention of Alexander to undermine architects' control over construction processes(Finidori et al.,2015), the use of pattern language in urban planning strategy provides a solution network that is accessible to more citizens. This not only allows multiple stakeholders to join the future urban development but also provides a communication tool between them to facilitate a mutual understanding and a win-win scenario. As already put forward in the implementation framework in Chapter 7, further trans-scalar and inter-disciplinary connections between different stakeholders become possible, and a feedback loop between the top-down and bottom-up planning processes could be expected.

On Methodology

Pattern Language × Maximization Method

As mentioned previously, the thesis has experimented with coupling the pattern language and maximization methods to frame the main research approach, which provides insight into the implementation of both methods.

For one thing, using the pattern language to build the maximization scenario allows a certain level of 'softness' in the maximization proposal. This is actually desired by the maximization method since the maximization scenario actually serves as a communication tool in the optimization stage which is used to highlight the most important objectives and principles instead of making a concrete master plan. Constructing a set of patterns in the maximization stage can achieve a similar even better effect because in this way different actors in the optimization phase are able to clarify their intentions better via a simple pattern. As a result, this project shows the potential of introducing pattern language as an effective 'bridge' when developing the maximization scenarios. This also indicates the pattern language as a strong tool of communication in the planning process. Although due to the time limit the optimization scenarios in this graduation project are developed without consulting real stakeholders, it is highly possible that these optimization scenarios could be done in a form of co-creation with pattern language as a tool.

Nextly, the maximization method also serves as an engine for creating more patterns, as well as testing and iterating the pattern field constantly, which deepens the understanding of the patterns made. To illustrate, in the optimization stage, new perspectives and real context are introduced which actually brings in a new lens of seeing the existing patterns(Such as from the perspective of the agri-food sector, from the transportation sectors etc.). Meanwhile, constricting these optimization scenarios and the integration scenarios in a real-world location helps to understand how these patterns perform and interrelate with each other. All the compromisation and choosing process involved contributes to the practical implications of the pattern field.

To conclude, using the pattern language and maximization methods as a whole in a project brings mutual benefits to each other and further explorations and improvements on such integration are warmly welcomed.

DCBA Method

Another key method used in the thesis is the DCBA method. It plays a significant role and can be seen as a clue linking different components of the project.

The DCBA firstly connect the outcome of research to the design(already mentioned previously). Particularly, the indicators of the DCBA method can be reinterpreted to different patterns without so much effort. For instance, one of the indicators focuses on eutrophication prevention. To reach the A-level criterion that 'all the nitrogen in the wastewater from all sectors is recycled', the pattern 'productive wastewater treatment plant' is introduced. At the same time, the B and C level criteria of the same indicator focus more on the control of the nutrients level in the wastewater without fully recycling them, which leads to the ideas such as purification through vegetation.

Secondly, the DCBA method serves as a dashboard of the project in nearly all stages. In the diagnosis part, using it to assess the future autonomous situation helps to discover threats and potentials of the region(in Chapter 4.6). In the optimization stage, the direct feedback from DCBA methods visualizes the performance of the design outcome and at the same time encourages the iteration of the patterns to reach higher scores. Also at the end of the project, assessing the final vision and comparing it with the score of future autonomous situations can highlight the achievement of the project in an intuitive way.

Conclusion

It is interesting to note that while all the three methods mentioned above are all methods born in the last century, they still show endless possibilities and attract numerous practitioners nowadays. So hopefully, the exploration made in this project might bring some experience for the future practice of all these three methods and contribute to their further evolution.

Societal Relevance and Transferability

From a societal perspective, this project also provides a new angle to address environmental challenges related to water that is faced by contemporary cities, not only for the authorities from the Lake Chao Basin but also for other Chinese cities and cities around the world with similar problems.

Since 2015, the Chinese Central Government has launched the 'Sponge City' initiative to deal with urban flooding problems(State Council of the People's Republic of China, 2015). Under this trend, the municipality of Hefei also takes action and the 'Sponge City Plan of Hefei'(Hefei Municipal City Planning Administration et al.,2016) has been carried out since 2016. However, the flooding in the lower Yangtze River plain in 2020 still caused tremendous loss to the inhabitants in the Lake Chao Basin region and also put a huge economic burden on the local authorities(see figure 8.6). Meanwhile, the government

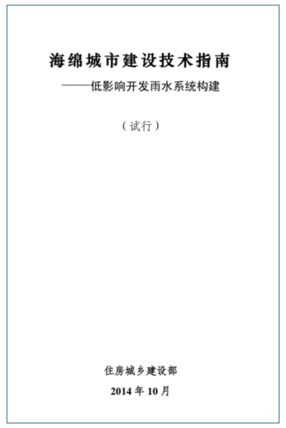


Figure 8.4

Sponge City Construction Manual
Ministry of Housing and Urban-Rural Development(2014)

Figure 8.5

The Framework of the Integrated development of Yangtze River Delta metropolitan region
Council of the People's Republic of China(2021)

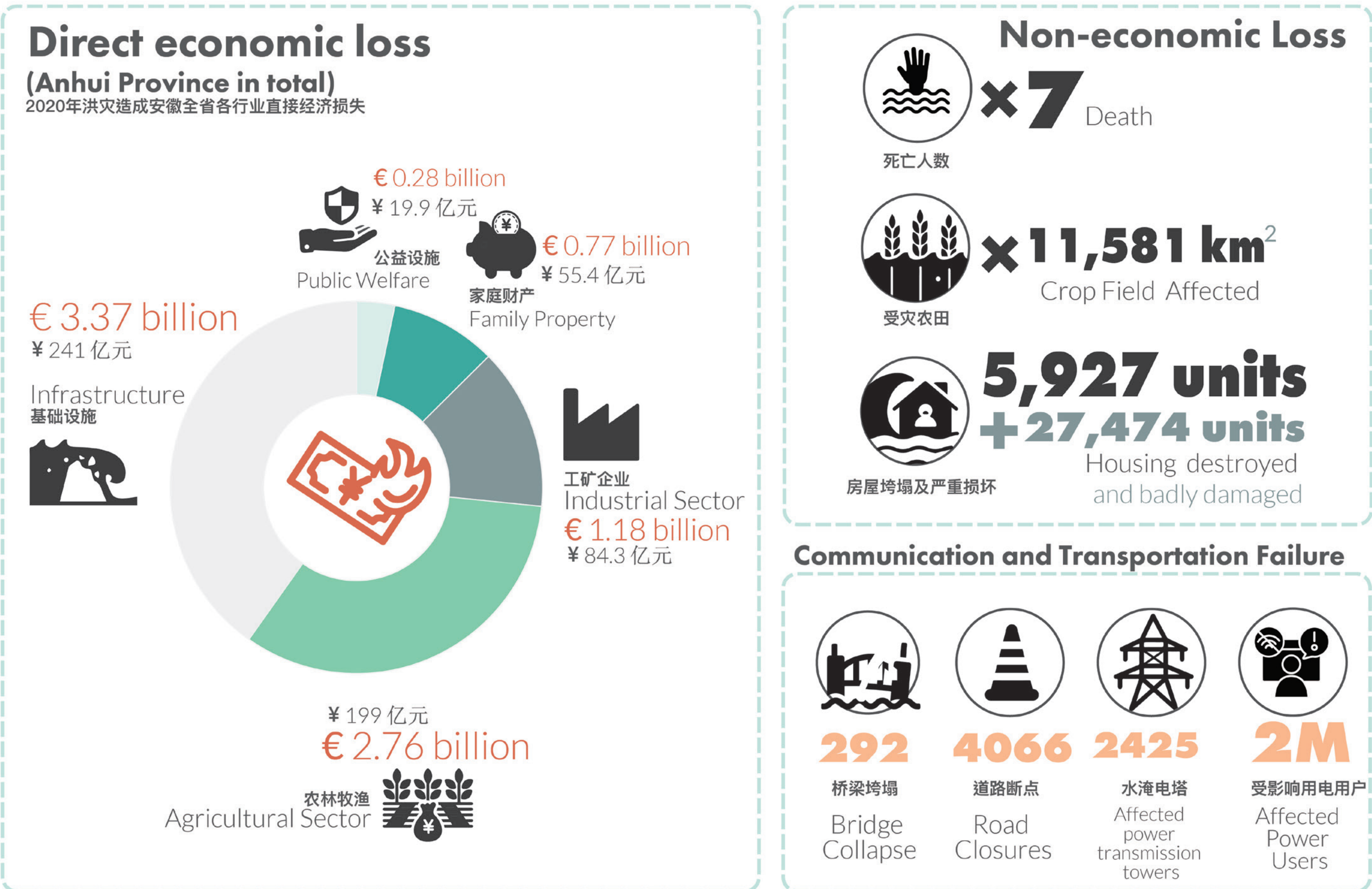


Figure 8.6 The Loss from 2020 Flooding in Anhui Province

Source:Floods in Anhui Province in 2020 Investigation Evaluation Report by Anhui Provincial Government(2021)

Figure 8.7

Numbers of Patterns that have contribution to different SDG's

by Author

of Anhui Province has been devoted to fighting against the water quality of Lake Chao since 2012. Billions of RMB have been spent(L. Wu, 2021) yet only brought about slight improvement. So the thesis would hopefully offer a new pathway to tackle these challenges systematically and serve as an inspiration for the local government.

On a regional scale, this graduation study as well offers insights for other cities within the Yangtze River Delta when executing the current planning framework of YRD. The current planning document (See figure 8.5) emphasised both economic further industrialisation and the water quality of Lake Chao, Lake Tai and other main water bodies in the region, but failed to mention how the synergy could happen between them with a concrete urban development strategy. Sharing similar dilemmas between water issues and urbanisation while enjoying comparable natural conditions, the cities within the YRD, especially the second-tier cities focusing on agricultural and industrial production functions, can also benefit from using the same pattern language. Following the way of constructing the strategic project of the 'Tanchong River Basin', these cities can consider the implementation of the same pattern language (slight adaptation to the measures are suggested according to real context, but the main structure and principles can remain the same) to construct their own framework. The DCBA criteria in this thesis may also be used to assess to performance of the outcome, with the adjustment of the standard according to their current condition.

Moreover, under the impact of climate change, many other regions in China and all over the world are also struggling with water issues such as drought, pollution and flooding. Many measures and principles in the pattern language are considered transferable to these locations. To illustrate, in the Pearl River Delta in the south part of China, heavy rainfall during the Typhoon season arrives every year(Wikipedia contributor,2020), the principles of 'water sensitive city' and related patterns could be considered and reinterpreted according to their needs. Similarly, for the area in the northern part of China, such as the Jingjinji Metropolitan Region, water scarcity has been an issue for years(Huang et al., 2020), and the patterns under the principle of 'circular water loop' might be transferable. And for many other cities around the world with surface water and caring about its ecological value, patterns from 'Ecological Sound Waterscape' can be implemented.

Additionally, the pattern language not only solves the water issues but also includes interventions that could contribute to the overall sustainable development of the society. As can be seen in figure 8.7, the whole pattern language touches upon nine of the SDG's goals set by the UN. Thus, this pattern language has the potential to offer reference to any cities searching for solutions to achieve these SDG's goals.

Limitations and Ethical Considerations

Though the project already tried to find a 'realistic' and 'practical' pathway based on the research, there are still many limitations of the project that could not address or failed to take into consideration.

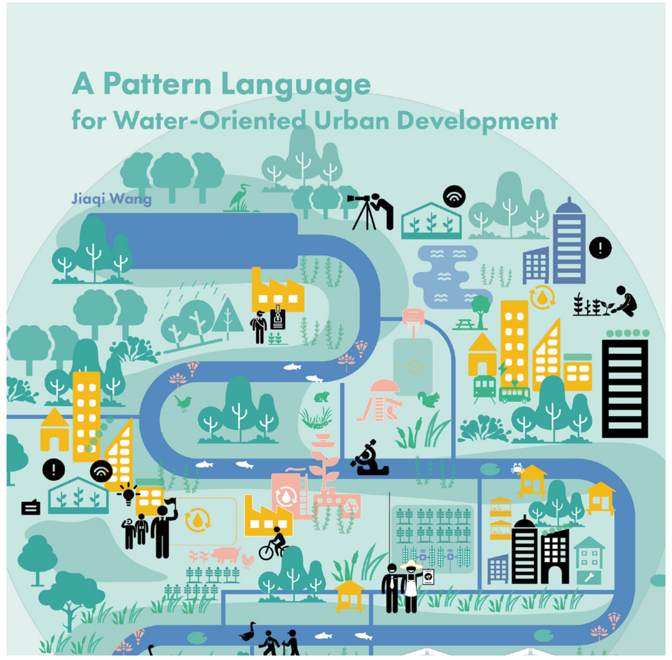
First, due to the project's preconceived setting of being 'water-oriented', it tends to prioritize climate issues in front of other types of economic and social challenges. This argument might be true from the point of the whole society since the natural layer serves as the foundation of any kind of social and economic prosperity. However, it is hard for an individual to choose between joblessness and pollution, especially considering that climate adaptation strategies are often associated with gentrification and technology upgrading. Meanwhile, as put forward at the end of Chapter 7 already. The final vision does not take population growth into consideration intentionally if the basin aims for water quantity self-sufficiency. From a water-oriented perspective, it seems wise to acknowledge that nature has its carrying capacity. However, it is still open to discussion on whether it is just to limit population growth and whether this might intensify the ageing society crisis and other types of social problems. Aware of the timespan of the graduation year, this project chooses to focus on the technical and spatial design aspects more on purpose, but it does not mean the governance aspect and social impact assessment are minor. In fact, it is important to consider whether such kind of development can truly be financially feasible without damaging the interests of the most vulnerable groups of people when implementing the pattern language. Thus, further exploration on these topics is still needed to fully ensure the justice of concretizing such water-oriented urban development where joint effort from many disciplines is warmly welcomed.

Another issue of the project is that it focuses much on constructing a generalizing solution and thus sometimes omits some unique and complicated cases in the study location. For example, it does not provide unique solutions to informal industrial zones, several historical towns, a deserted airport and other interesting and unique locations, but chooses to drop them under the 'industrial zone', 'village' and 'brown field' labels when making the pattern language. Though such generalising process can make the conclusions more transferable to other locations, this might oversimplify some important issues connecting with these locations, such as how to intervene in a historical village while still keeping its cultural value and how regeneration happens in an informal industrial zone without hurting the collective memory and its social value.

In fact, every location has its own limitations and potentials that should by no means be simplified by patterns or represented by several quantitative indicators(as used in the DCBA method). Over relying on the patterns, typologies and quantifiable indicators to construct and assess a spatial framework can sometimes backfire with the loss of diversity or a sense of place. So, when implementing the patterns, practitioners should still highlight the research process in every unique context to interpret the patterns according to each case.

To conclude, as a master thesis, the project is unable to weigh everything at the same. The pattern language of water-oriented urban development' has its own focal points in the sustainability of water systems and promoting systemic change centring around water, but the further effort on its governance, its social impacts and context-specific implementation of it are still required.

The water-oriented development can be seen as one voice.
And a just, resilient and sustainable city still needs more voices.



SCAN ME

Attached to this academic report, the final outcome of this graduation project also contains a pattern book for the public, which contains a more detailed explanation of every single pattern. If there is any further interest in this design outcome, please scan the QR code above.

References

Aalbers K. (2021, September 21). *presentation: AR3U110 Q5 Integrative intensive week 1.7-1.8 Designing with flows: Applying the maximization method* [Course presentation]. Faculty of Architecture & the Built Environment, Technical University of Delft.

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., ... & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*(1), 30-39.

Alexander, C. (1977). *A pattern language: towns, buildings, construction*. Oxford university press.

Alexander, C. (1977). *A pattern language: towns, buildings, construction*. Oxford university press.

Alexander, C. (1979). *The timeless way of building* (Vol. 1). New York: Oxford university press.

Arup. (2018). *Water and Circular Economy: A white paper.* https://www.arup.com/-/media/arup/files/publications/w/water_and_circular_economy_whitepaper.pdf

Brundtland, G. H. (1987). Our Common Future. Report of the World Commission on Environment and Development: Our Common Future.

Cai, J. (2018). Design with forms as well as patterns. *A+BE | Architecture and the Built Environment*. https://doi.org/10.7480/abe.2018.30

China Water Risk. (2019). *Yangtze Water Risks, Hotspots & Growth*. https://www.chinawaterrisk.org/wp-content/uploads/2019/09/CWR-Yangtze-Water-Risks-Hotspots-Growth.pdf

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. *IUCN: Gland, Switzerland*, *97*, 2016-036.

CoLab. (2016). *Follow the Rabbit:A Field Guide to System Design*. https://www.ryerson.ca/content/dam/cpipe/documents/How/Follow%20the%20Rabbit_%20A%20Field%20Guide%20to%20System%20Design.pdf

Dąbrowski, M.(2021, March). *presentation: AR2U088 Research and Design Methodology for Urbanism* [Course presentation].Faculty of Architecture & the Built Environment, Technical University of Delft.

Delgado, A., Rodriguez, D. J., Amadei, C. A., & Makino, M. (2021). Water in Circular Economy and Resilience.

Ding Y. (2018). *Ecosystem Health diagnosis of Rivers(Nanfei River, Zhegao River, Fengle River, Hangbu River) into the Chaohu Lake*. [Master dissertation, Anhui University]. China Master's Theses Full-text Database.www.cnki.net

Dong, X. & Dai, X. (2015).Chang san jiao qu yu huan jing wu ran gen yuan pou xi ji xie tong zhi li dui ce 长三角区域环境污染根源剖析及协同治理对策 [The Root of Pollution in Yangtze River Delta and the Collaboration of Regional Environmental Governance]. Chinese Journal of Environmental Management(*中国环境管理*), *7*(3), 81-85.

Dovey, K. (1990). The pattern language and its enemies. *Design Studies*, *11*(1), 3-9.

Duijvestein, K. (2015). Methods for the design of a sustainable built environment. In *The theory of Chris van Leeuwen* (pp. 85–90). the Faculty of Architecture and the Built Environement.

Gandy, M. (2004). Rethinking urban metabolism: water, space and the modern city. *City*, *8*(3), 363-379.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*, *1*(1), 24-40.

Gu, D. (2018). *A Research on Urban Development and Morphological Transition of Hefei [Doctoral dissertation,Southeast Univeristy]*.China Doctoral Dissertations Full-text Database.www.cnki.net

Finidori, H., Sayfan G. Borhini & Thomas Henfrey (2015). Towards a fourth generation pattern language: Patterns as epistemic threads for systemic orientation. *Proceedings of the Purplsoc (Pursuit of Pattern Languages for Societal Change)Conference 2015*. Krems, Austria: Danube University.

Han, L., Xu ,Y., Yang, L., Deng, X., Hu, C., & Xu, G.(2015). Jin 50 nian chang san jiao di qu shui xi shi kong bian hua ji qi qu dong ji zhi 近 50 年长三角地区水系时空变化及其驱动机制[Spatial and temporal changes of the water system in the Yangtze River Delta in the past 50 years and its driving mechanism]. *Acta Geographica Sinica 地理学报*, 70(5).

Hao Y., Chen J., Wang Y., Wang H., Qiu X., Wang,D., Zhai, Z.(2018).Research on urban waterlogging risk early warning based on high spatial-temporal resolution precipitation forecast product. *Torrential Rain and Disasters*, 38(3): 229-237.

Hefei Municipal City Planning Administration, Hefei Urban-Rural Construction Committee, Urban Planning & Design Institute of Shenzhen, & Urban Planning & Design Institute of Hefei. (2017, December). He fei shi hai mian cheng shi zhuan xiang gui hua shuo ming shu 合肥市海绵城市专项规划说明书 [Sponge City Planning Manual of Hefei (2016–2030)]. http://www.hefei.gov.cn/xxgk/gmjjfzgh/zxgh/201801/t20180123_2467890.html

Huafeng Media Group & Greenpeace. (2021). *Coexisting with Floods - Climate Change Risk Assessment and Future Scenario Prediction in China's Major Cities*. http://download.caixin.com/upload/city-climate-risk-report-2021.pdf

Huang, Z., Liu, J., Mei, C., Wang, H., Shao, W., & Li, Z. (2020). Analysis of driving forces of water demand in Jing-Jin-Ji district in recent years based on water demand field theory. *Science China Technological Sciences*, *63*(12), 2593-2605.

IPCC (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

Jia, T. F., Shi, W. Y., Zheng, X. Y., Zhang, W. G., & Yu, L. Z. (2012). The flood and drought disasters of the Chaohu Lake Basin in the past 600 years. *Sci. Geograph. Sinica*, 32, 66-73.

Jones, P., & Kijima, K. (2018). Systemic Design. *Theory, Methods, and Practice*.

Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of industrial ecology*, 11(2), 43-59.

Linton, J., & Budds, J. (2014). The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water. *Geoforum*, *57*, 170-180.

Ma, R., Wang, C., Jin, Y., & Zhou, X. (2019). Estimating the effects of economic agglomeration on haze pollution in Yangtze River Delta China using an econometric analysis. Sustainability, 11(7), 1893.

MacArthur, E. (2013). Towards the circular economy. *Journal of Industrial Ecology*, 2(1), 23-44.

Meadows, D. H. (1999). Leverage points: Places to intervene in a system.

Mentink, B., Henriquez, L., Van Niekerk, L., & Verheul, R. (2013). The IPG BAR project.http://resolver.tudelft.nl/uuid:819eded6-4e65-42c4-9f44-ab725976fe20

National Oceanic and Atmospheric Administration. (2015). The El Niño Southern Oscillation (ENSO) is one of the most important climatic phenomena on Earth. NOAA | National Oceanic and Atmospheric Administration. Retrieved May 2, 2022, from https://www.noaa.gov/education/resource-collections/weather-atmosphere/el-nino

Neary DG. (2002). Hydrologic values. In: Richardson J, Bjorheden R, Hakkila P, Lowe AT, Smith CT, eds. *Bioenergy from sustainable forestry: guiding principles and practice*. Dordrecht: Springer Netherlands.

tilliela, C. L. E. R. I. C. I. (2011). Riparian zones: where green and blue networks meet.

Oladosu, Y., Rafii, M. Y., Samuel, C., Fatai, A., Magaji, U., Kareem, I., ... & Kolapo, K. (2019). Drought resistance in rice from conventional to molecular breeding: a review. *International journal of molecular sciences*, *20*(14), 3519.

Padli, J., Habibullah, M. S., & Baharom, A. H. (2013). Determinants of flood fatalities: Evidence from a panel data of 79 countries. *Soc Sci Humanit*, *21*, 81-98.

Pourdehnad, J., Wexler, E. R., & Wilson, D. V. (2017, November 5). *Integrating Systems Thinking and Design Thinking*. The Systems Thinker. https://thesystemsthinker.com/integrating-systems-thinking-and-design-thinking/

Qi, Y., Chan, F. K. S., Thorne, C., O'Donnell, E., Quagliolo, C., Comino, E., ... & Feng, M. (2020). Addressing challenges of urban water management in Chinese sponge cities via nature-based solutions. *Water*, 12(10), 2788.

Ritchie, H. and Roser, M. (2014) - "Natural Disasters". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/natural-disasters' [Online Resource]

Rogers, B. C., Bertram, N., Gersonius, B., Gunn, A., Löwe, R., Murphy, C., ... & Arnbjerg-Nielsen, K. (2020). An interdisciplinary and catchment approach to enhancing urban flood resilience: a Melbourne case. *Philosophical Transactions of the Royal Society A*, *378*(2168), 20190201.

Rooij, R. and M. van Dorst (2020). A Pattern Language Approach to Learning in Planning, in Urban Planning (ISSN: 2183-7635),

Sauvé, S., Lamontagne, S., Dupras, J., & Stahel, W. (2021). Circular economy of water: Tackling quantity, quality and footprint of water. *Environmental Development*, *39*, 100651.

Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., ... & Zwiers, F. W. (2012). Changes in climate extremes and their impacts on the natural physical environment.

Stahel, W. R. (2016). The circular economy. *Nature*, *531*(7595), 435-438.

Stappers, P. J., & Giaccardi, E. (2017). Research through design. In *The encyclopedia of human-computer interaction* (pp. 1-94). The Interaction Design Foundation.

State Council of the People's Republic of China. (2015, October 11).Guo wu yuan ban gong ting guan yu tui jin hai mian cheng shi de zhi dao yi jian 国务院办公厅关于推进海绵城市的指导意见 [Guiding Opinions of the General Office of the State Council on Promoting the Construction of Sponge Cities]. THE STATE COUNCIL THE PEOPLE'S REPUBLIC OF CHINA. http://www.gov.cn/zhengce/content/2015-10/16/content_10228.htm

Swyngedouw, E. (2004). *Social power and the urbanization of water: flows of power*. OUP Oxford.

The Municipality of Wuwei.(2022).Wu wei shi tui jin xian dai nong ye fa zhan de ruo gan fu zhi zheng ce 无为市推进现代农业发展的若干扶持政策[Several supporting policies for Wuwei City to promote the development of modern agriculture]. https://www.wuhu.gov.cn/group1/M00/1E/CD/rBgXC2HhEmOAJ2AqAAQGY4TELSw213.pdf

The State Council of the People's Republic of China. (2021).Chang jiang san jiao zhou qu yu yi ti hua fa zhan gui hua gang yao 长江三角洲区域一体化发展规划纲要[The Framework of the Integrated development of Yangtze River Delta metropolitan region].THE STATE COUNCIL THE PEOPLE'S REPUBLIC OF CHINA. http://www.gov.cn/zhengce/2019-12/01/content_5457442.htm

References

Tillie, N. (2018). Synergetic urban landscape planning in Rotterdam: Liveable low-carbon cities. *A+ BE| Architecture and the Built Environment*, (24), 1-284.

Tjallingii, S. P. (1995). Strategies for ecologically sound urban development. *Ecopolis. Leiden: Backhuys.*

UNDP. (2022). Sustainable Development Goals. United Nations Development Programme. https://www.undp.org/sustainable-development-goals

United Nations. (2020). The Sustainable Development Goals Report 2020. United Nations Publications.

United Nations. (2021, March 24). *Recognize 'true value' of water, UN urges, marking World Day*. UN News. https://news.un.org/en/story/2021/03/1087922

vol 5, 1. http://resolver.tudelft.nl/uuid:633c25c3-73ee-44c6-8ae1-61349713b8a0

Wachsmuth, D. (2012). Three ecologies: Urban metabolism and the society-nature opposition. *The Sociological Quarterly*, *53*(4), 506-523.

Wang Xiyue.(2019).*The Impounding Lake System of China and its Relationship with Ancient Cities[Doctoral dissertation*,Beijing Forestry University].China Doctoral Dissertations Full-text Database.www.cnki.net

Water, U. N. (2018). 2018 UN World Water Development Report, Nature-based Solutions for Water.

Wei, B. Xu, W. (2010).Wan nan gu cun luo ji pai shui she ji tan xi 皖南古村落给排水设计探析[Analysis on Water Supply and Drainage Design of Ancient Villages in Southern Anhui]. *甘肃科技纵横*, (2), 80-81.

Wikipedia contributors. (2020, December 18). *Flooding of the Pearl River*. Wikipedia. https://en.wikipedia.org/wiki/Flooding_of_the_Pearl_River

Wong, T. H., & Brown, R. R. (2009). The water sensitive city: principles for practice. *Water science and technology*, *60*(3), 673-682.

Wong, T. H., Rogers, B. C., & Brown, R. R. (2020). Transforming cities through water-sensitive principles and practices. *One Earth*, *3*(4), 436-447.

Wu, S. (2018), Countermeasures for possible secondary ecological and environmental problems in the construction of the project of diverting the Yangtze River to Huaihe River(引江济淮工程建设可能次生的生态环境问题应对措施). China Flood & Drought Management, 28(12),33-35, DOI:10.16867/j.issn.1673-9264.2018261.

Wu, L. (2021, September 3). *A total of 36 billion yuan has been invested in the comprehensive management of Chaohu Lake, one of the five major freshwater lakes in China*. China News.Com. https://www.chinanews.com.cn/sh/2021/09-03/9558003.shtml

Xia, J., Long, J., Gao, Y., Chen, Y., Meng, J., Zhou, Y., & Chen ,S. (2020). Chao hu chen ji zhong jin shui wu ran sheng tai feng xian ping jia ji lai yuan jie xi 巢湖沉积物重金属污染生态风险评价及来源解析[Ecological Risk Assessment and Source Analysis of Heavy Metal Pollution in Chaohu Lake Sediments]. Earth and Environment, 48(2), 220-227.

Xie P. (2009). *Looking through the history of Chaohu Lake: cyanobacteria, eutrophication and geological evolution*(翻阅巢湖的历史: 蓝藻、富营养化及地质演化). Science Press(科学出版社).

Xing, L. (2020). *The Research of the Polder Landscape of Chao Lake Plain——Take Ecological Network Planning in Wuwei New District and Design of Makou River Park as a Case* [Master dissertation, Beijing Forestry University].China Master's Theses Full-text Database.www.cnki.net

Xu, J., Wang, P., Wang, Z., Li, Y., & Ji, H. (2015).Study On Supply-demand analysis and sustainable development plan of waterresourcesinHefei(合肥市水资源供需分析及可持续利用规划研究).*Journal of Water Resources Water Engineering(水资源与水工程学报)*, (1), 96-101.

Zhang Min, Shi Xiaoli, Yang Zhen & Chen Kaining. (2020).The variation of water quality from 2012 to 2018 in Lake Chaohu and the mitigating strategy on cyanobacterial blooms.*Journal of Lake Sciences*, 2020,32(1):11-20.DOI 10.18307/2020.0102

Zhang, X. (2020). An Hui Shui Li Nian Jian 安徽水利年鉴[*Anhui Water Conservancy Yearbook]*. Anhui Water Conservancy Yearbook Editorial Board.

Zhao, D.(2020).Thoughts and Examples of Urban Non-point Source Pollution Control in Nanfei River, Hefei City(合肥市南淝河城市面源污染治理思路及实例).*China Construction(中华建设)*,12,182-183

Zuo, F. (2006). Hefei County Chronicle. Huangshan Press (黄山书社).

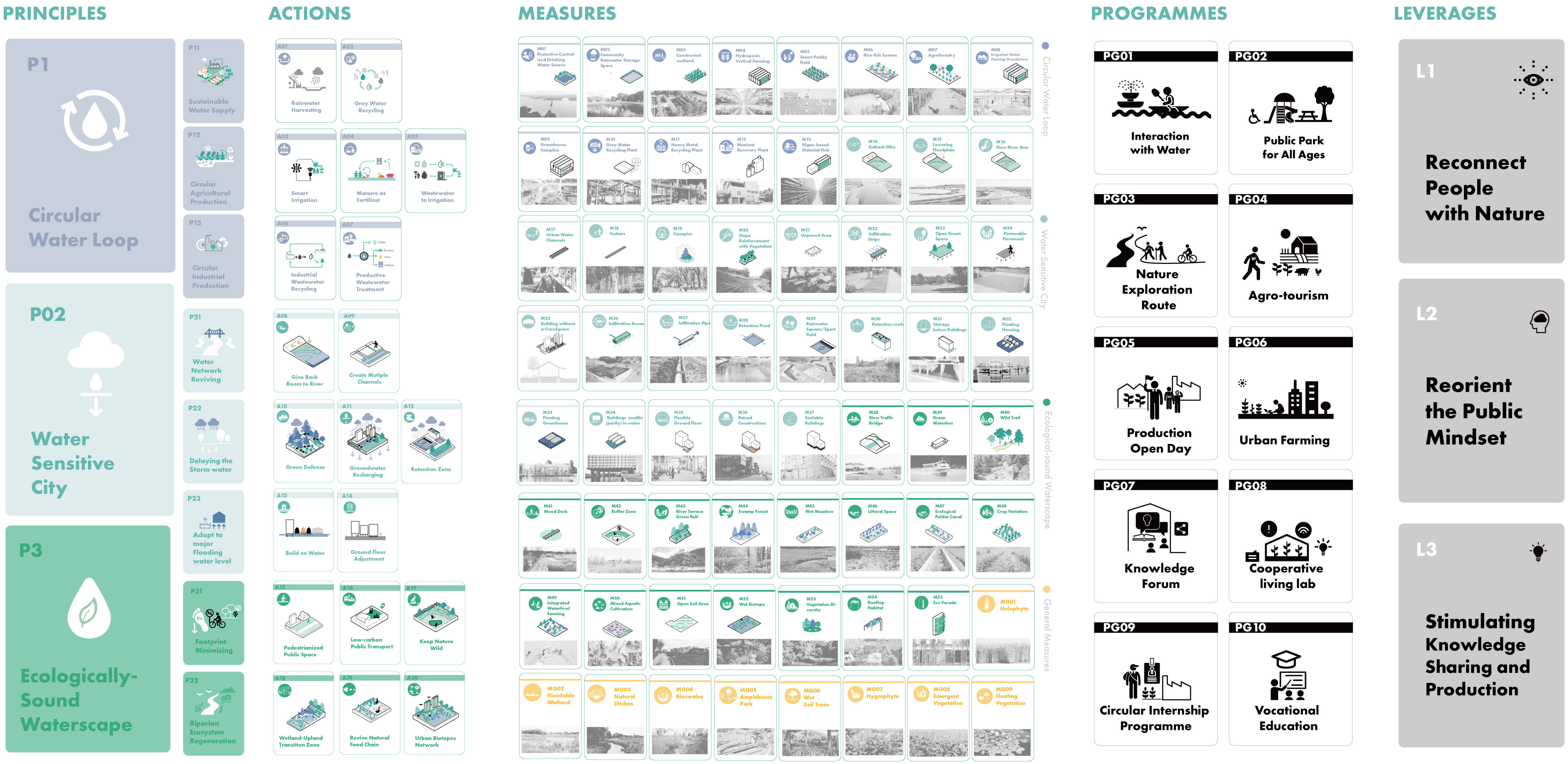
Zurich Insurance. (2020, July 22). *Three common types of flood explained*. Https://Www.Zurich.Com/En. https://www.zurich.com/en/knowledge/topics/flood-and-water-damage/three-common-types-of-flood

APPENDICES

Appendix A: Pattern List

Patterns at a glance: (See the zoom-in of 'Measures' in the next pages)

A Pattern Language for Water-Oriented Urban Development



Appendix A: Pattern List

Zoom-in of the Measure Patterns

Appendix A: Pattern List

Zoom-in of the Measure Patterns

Pattern Network in details

INDEX		Contains	Specialized:	Complementary:	Alternative:	Contribute to	Components of:	Co-exist well with/facilitating	Facilitated by
P01	**Circular Water Loop**	P11, P12, P13							
P11	**Sustainable Water Supply**	A01,A02,A05					P01		
A01	**Rainwater Harvesting**		M01,M02			P11	P11	A12	
M01	Protective Centralized Drinking Water Source	MG01,MG08		A17,M42		P11	A01		PG02,PG03
M02	Community Rainwater Storage Space	MG01,MG08				P11	A01	M28	PG02,PG01
A02	**Grey Water Recycling**		M03,M10			P11	P11		
M03	Constructed Wetland			MG01	M10		A02		PG02,PG08
P12	**Circular Agricultural Production**	A03,A04,A05					P01		
A03	**Smart Irrigation**		M04,M05			P12			
M04	Hydroponic Vertical Farming					P12	A03		PG05,PG07,PG09,PG10
M05	Smart Paddy Field			M47	M06,M49	P12	A03.A05		PG05,PG07,PG08,PG09,PG10
A04	**Manure as Fertilizer**		M06,M07,M09			P12			PG06
M06	Rice-fish System			M47	M05	P12	A04,A19		PG04,PG09,PG10
M07	Agroforestry			M48		P12	A04,A19		PG04,PG09,PG10
A05	**Wastewater to irrigation**		M08,M09,M06			P11,P12			PG06
M08	Irrigation Water Reusing Greenhouse			M04		P12	A05		PG07,PG09,PG10
M09	Greenhouse Complex			M04		P12	A04.A05		PG05,PG06
P13	**Circular Industrial Production**	A06,A07					P01		
A06	**Industrial Wastewater Recycling**		M10,M11			P13			
M10	Grey Water Recycling Plant				M03	P13,P11	A02,A06		PG10
M11	Heavy Metal Recycling Plant					P13	A06		PG09,PG10,PG05
A07	**Productive Wastewater Treatment**		M12,M13			P13			
M12	Nutrient Recovery Plant					P13	A07		PG09,PG10,PG05
M13	Algae-based Material Hub					P13	A07		PG05,PG07,PG08,PG09,PG10
P02	**Water Sensitive City**	P21,P22,P23							
P21	**Water Network Reviving**	A08,A09				P02			
A08	**Give Back Room to River**		M14,M15,M16,MG02			P21			
M14	Setback Dike					P21	A08	Complementary for:MG02.M15.M16	PG03
M15	Lowering Floodplain			M14		P21	A08		PG03
M16	New River Arm			M14		P21	A08		PG03
A09	**Create Mutiple Channels**		M17,M18,MG03			P21			
M17	Urban Water Channels	MG09			MG03,M18	P21	A09		A15,PG01,PG02
M18	Gutters				M17,MG03	P21	A09		A15,PG02
P22	**Delaying the Storm Water**	A10,A11,A12				P02			
A10	**Green Defense**		M19,M20			P22		M16,M43	
M19	Canopies			M53		P22	A10	MG06	PG02
M20	Slope Reinforcement with Vegetation					P22	A10	M43	
A11	**Groundwater Recharging**		M21,M22,M23,M24,M25,M26,M27,MG03,MG04			P22			
M21	Unpaved Area		M22,M23,MG04,MG05,M52			P22	A11	M51	PG02,PG06
M22	Infiltration Strips	MG07			MG03,MG04	P22	A11		PG02
M23	Open Green Space			M19,M53		P22	A11		PG02
M24	Permeable Pavement					P22,A11	A15		PG02

INDEX		Contains	Specialized:	Complementary:	Alternative:	Contribute to	Components of:	Co-exist well with/facilitating	Facilitated by
M25	Building without a Crawlspace			M24,M26		P22	A11	M27	
M26	Infiltration Boxes				M27	P22	A11		
M27	Infiltration Pipe				M26	P22	A11	Complementary for M28, M29; Co-exist well with M25, M24	
A12	**Retention Zone**		M28,M29,M30,M31,MG04,MG05			P22		M02	
M28	Retention Pond	MG01			M29	P22	A12	M02,MG05	PG01,PG02
M29	Rainwater Square/Sports field				M28, MG05	P22	A12		PG02, A15
M30	Retention roofs		M54		M31	P22	A12		PG06
M31	Storage below buildings				M30	P22	A12		
P23	**Adapt to Major Flood Level**	A13,A14							
A13	**Build on Water**		M32,M33,M34			P23			
M32	Floating Housing				M34	P23	A13		PG04
M33	Floating Greenhouse					P23	A13		PG06,PG08
M34	Buildings on stilts/(partly) in water			A12	M32,M35	P23	A13		PG04,PG03,PG01
A14	**Ground Floor Adjustment**		M35,M36,M37			P23			
M35	Flexible Ground Floor			M25	M36,M34	P23	A14		
M36	Raised Constructions				M35,M37	P23	A14		
M37	Sealable Buildings				M35,M36	P23	A14		
P03	**Ecological Sound Waterscape**	P31,P32							
P31	**Footprint Minimizing**	A15,A16,A17							
A15	**Pedestrianized Public Space**	M38		M24		P31		M04,M05,M29,M52	PG02
M38	Slow Traffic Bridge					A15	A15		PG03
A16	**Low-carbon Public Transport**		M39			P31			
M39	Green Waterbus					P31	A16		PG01,PG03,PG04
A17	**Keep Nature Wild**	M40,M41,M42		M42		P31			
M40	Wild Trail				M41		A17		PG03
M41	Wood Deck				M40		A17		PG03
M42	Buffer Zone					A17			PG03
P32	**Riparian Ecosystem Regeneration**	A18,A19,A20							
A18	**Wetland-Upland Transition**	M43,M44,M45,M46,MG02							
M43	River Terrace Green Belt		M19	M53		A18			PG02
M44	Swamp Forest	MG06				A18	MG02		PG03
M45	Wet Meadow	MG07				A18	MG02		PG02
M46	Littoral Space	MG01,MG08,MG09				A18			PG01
A19	**Revive Natural Food Chain**	M47	M48,M49,M50,M06,M07						
M47	Ecological Polder Canal	MG01,MG08,MG09				A19			PG04
M48	Crop Variation						A19	M07	PG04
M49	Integrated Waterfowl Farming			M47			A04,A19		PG04,PG08,PG10
M50	Mixed Aquatic Cultivation			M46,M47			A19		PG04,PG08,PG10
A20	**Urban Biotopes Network**	M51,M53	M52,M54,M55						
M51	Open Soil Area					A20	M21		PG02
M52	Wet Biotope	MG06,MG07,MG08,MG09	MG03,MG05		MG04	A20,A11,M21		MG04	PG01,PG02
M53	Vegetation Diversity					M19,A20		Complementary for:M19,M23,M43,M54	PG02
M54	Rooftop Habitat			M53		A20		M30	
M55	Eco-Facade						A20		
MG01	Helophyte					M01,M02,M03,M46,M47, M52,M28	A01,A02,A12,A18,A19,A20		PG02,PG04,PG01
MG02	Floodable Wetland		M44,M45	MG08.MG09			A08,A17,A18		PG01,PG02,PG03
MG03	Natural Ditches			M46	M17,M18,M22	M52	A11,A09,A20		PG01,PG02,PG04

INDEX		Contains	Specialized:	Complementary:	Alternative:	Contribute to	Components of:	Co-exist well with/facilitating	Facilitated by
MG04	Bioswales			M46	M22	M52	A11,A12,A20		PG02
MG05	Amphibious Park			M45,M46	M28,M29		A10,A11,A12		PG02
MG06	Wet Soil Trees					M44,M52	A10,A18,A20		PG02,PG03
MG07	Hygrophyte					M20,M22	A10,A11,A18,A20		PG02,PG03
MG08	Emergent Vegetation					M01,M02,M46,M47,M52	A01,A18,A19,A20		PG01,PG02,PG03
MG09	Floating Vegetation					M17,M46,M47,M52	A09,A18,A19,A20		PG01,PG02,PG03
L01	**Reconnect People with Nature**	PG01,PG02,PG03,PG04							
PG01	**Interaction with water**						L1	M02,M17.M28,M34,M39,M46,M52	
PG02	**Public Park for all ages**						L1	A15,M01,M02,M03,M17,M18,M19,M21,M22,M23,M24,M28,M29,M43,M51,M52,M53, MG01,MG03,MG04,MG05,MG06,MG07,MG08,MG09	
PG03	**Nature exploration route**						L1	M01,M14,M15,M16,M34,M38,M39,M40,M41,M42,M44,MG02,MG06,MG07,MG08,MG09	
L02	**Reorient the Public Mindset**	PG04,PG05,PG06							
PG04	**Agro-tourism**						L1, L2	M06,M07,M32,M34,M47,M48,M49,M50	
PG05	**Circular Production Open Day**						L2	M09,M11,M12,M13,M31	
PG06	**Urban Farming**						L2	A04,A05,M09,M21,M33,M30	
L03	**Stimulating Knowledge Sharing**	PG07,PG08,PG09,PG10							
PG07	**Circular Knowledge Forum**						L3	M04,M05,M08,M13	
PG08	**Cooperative Living Lab**						L3	M13,M33	

Patterns Evaluation

INDEX		Transfer-ability	Water safety	Water quantity	Water quality	3	6	11	12	13	15	Other SDGs
P01	**Circular Water Loop**	5										
P11	**Sustainable Water Supply**	5										
A01	**Rainwater Harvesting**	5										
M01	Protective Centralized Drinking Water Source	5	3	4	4		6			13	15	
M02	Community Rainwater Storage Space	5	4	4	3		6			13		
A02	**Grey Water Recycling**	5										
M03	Constructed Wetland	5	2	3	4	3	6					
P12	**Circular Agricultural Production**	5										
A03	**Smart Irrigation**	4										
M04	Hydroponic Vertical Farming	3	1	4	1				12			2
M05	Smart Paddy Field	3	2	3	1				12			2
A04	**Manure as Fertilizer**	5										

INDEX		Transfer-ability	Water safety	Water quantity	Water quality	3	6	11	12	13	15	Other SDGs
M06	Rice-fish System	2	2	2	2				12		15	2
M07	Agroforestry	3	2	2	3				12		15	2
A05	**Wastewater to irrigation**	4										
M08	Irrigation Water Reusing Greenhouse	3	1	3	1				12			
M09	Greenhouse Complex	3	1	3	2				12			
P13	**Circular Industrial Production**	5										
A06	**Industrial Wastewater Recycling**	5										
M10	Grey Water Recycling Plant	4	0	3	2		6					
M11	Heavy Metal Recycling Plant	3	0	3	3				12			
A07	**Productive Wastewater Treatment**	5										
M12	Nutrient Recovery Plant	4	0	2	3		6		12			
M13	Algae-based Material Hub	3	0	2	3		6		12	13		
P02	**Water Sensitive City**	5										
P21	**Water Network Reviving**	3										
A08	**Give Back Room to River**	4										
M14	Setback Dike	4	4	2	4					13	15	
M15	Lowering Floodplain	4	4	2	4					13	15	
M16	New River Arm	4	4	3	3					13	15	
A09	**Create Mutiple Channels**	3										
M17	Urban Water Channels	5	3	3	2	3				13		
M18	Gutters	5	2	2	0					13		
P22	**Delaying the Storm Water**	5										
A10	**Green Defense**	5										
M19	Canopies	5	2	1	2	3				13	15	
M20	Slope Reinforcement with Vegetation	5	2	1	2	3				13		
A11	**Groundwater Recharging**	5										
M21	Unpaved Area	5	2	0	1					13		
M22	Infiltration Strips	5	2	1	1					13		
M23	Open Green Space	5	2	0	2	3				13		
M24	Permeable Pavement	5	2	0	0			11		13		
M25	Building without a Crawlspace	4	2	0	0					13		
M26	Infiltration Boxes	5	2	0	0							
M27	Infiltration Pipe	5	1	1	0		6			13		
A12	**Retention Zone**	5										
M28	Retention Pond	5	3	2	2	3	6			13		
M29	Rainwater Square/Sports field	5	3	0	0	3		11		13		

INDEX		Transfer-ability	Water safety	Water quantity	Water quality	3	6	11	12	13	15	Other SDGs
M30	Retention roofs	4	2	1	1	3		11		13		
M31	Storage below buildings	4	2	1	0					13		
P23	**Adapt to Major Flood Level**	4										
A13	**Build on Water**	3										
M32	Floating Housing	2	2	0	0					13		
M33	Floating Greenhouse	2	2	2	0				12	13		2
M34	Buildings on stilts/(partly) in water	5	2	1	0			11		13		
A14	**Ground Floor Adjustment**	5										
M35	Flexible Ground Floor	4	2	0	0	3		11				
M36	Raised Constructions	5	1	0	0	3		11				
M37	Sealable Buildings	5	1	0	0	3		11				
P03	**Ecological Sound Waterscape**	5										
P31	**Footprint Minimizing**	5										
A15	**Pedestrianized Public Space**	5										
M38	Slow Traffic Bridge	5	1	0	2	3		11		13		
A16	**Low-carbon Public Transport**	5										
M39	Green Waterbus	3	1	0	1	3		11		13		
A17	**Keep Nature Wild**	5										
M40	Wild Trail	5	1	0	2	3					15	
M41	Wood Deck	5	1	1	3	3	6				15	
M42	Buffer Zone	5	1	1	2		6				15	
P32	**Riparian Ecosystem Regeneration**	5										
A18	**Wetland-Upland Transition**	3										
M43	River Terrace Green Belt	3	2	0	2		6			13	15	
M44	Swamp Forest	2	3	2	4		6			13	15	
M45	Wet Meadow	4	2	1	3		6			13	15	
M46	Littoral Space	5	1	2	4	3	6				15	
A19	**Revive Natural Food Chain**											
M47	Ecological Polder Canal	2	1	2	3				12			
M48	Crop Variation	4	1	1	2				12		15	2
M49	Integrated Waterfowl Farming	2	1	2	2		6				15	2

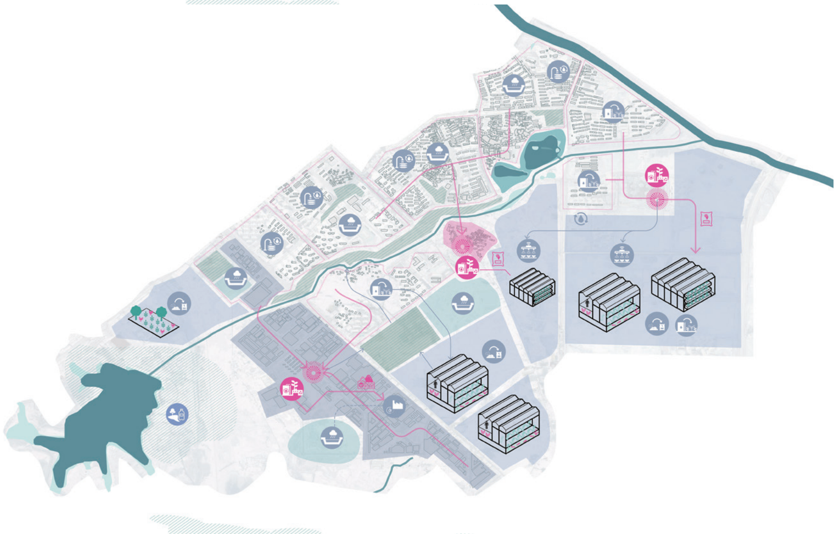
Appendix B:
DCBA Assessment Indicators and Criteria

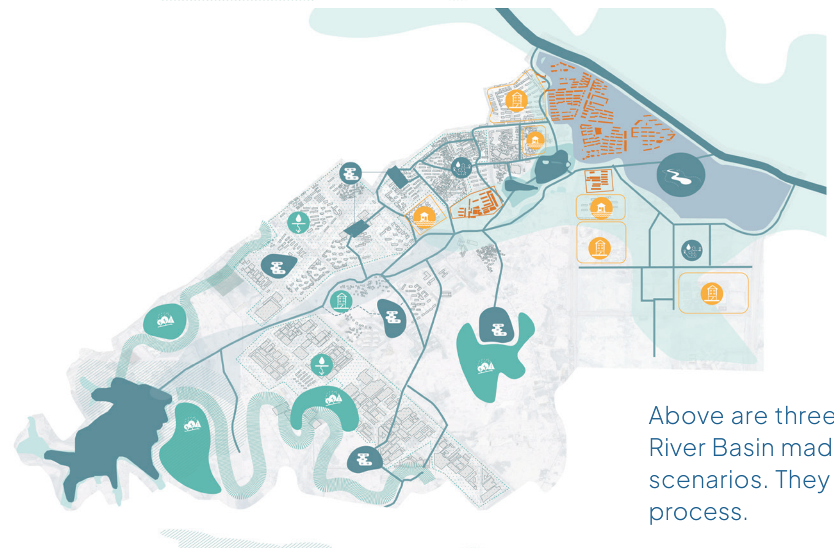
Title	Criteria of different Levels: D	C	B	A	Applicable to Different Scales: Block	District
A1 Water Intensity in Agriculture	Current situation (generally relying on sustainable water source, while most of the land are water-intensive paddy field.)	Over 20% of the paddy fields have access to recycled wastewater in paddy fields production.	Over half of the paddy field have access to recycled wastewater in paddy fields production.	All of the paddy fields have access to recycled water, with over half of the paddy fields upgrading with water-saving technology.	√	√
A2 Water Intensity in Industry	Current situation (growing water demand from industrial sector)	Over half of the industrial zone have access to sustainable water source(including rainwater).	All industrial zone have access to sustainable water source(including rainwater), with over half of the industrial zone have access to recycled wastewater.	All of the industrial zones have access to recycled water, with half of them upgrade into water-efficient production mode。	Not	√
A3 Accessibility of Sustainable Drinking Water Source	Current situation(growing water consumption from urban life, sometimes have to rely on unsustain-able drinking water source)	Half of the urban residential and commercial zone have access to decentralized water source.	Half of the urban residential and commercial zone have access to decentralized water source with sharing greywater treatment facilities	All of the urban residential and commercial areas have access to a decentralized water source, with all households equipped with grey water recycled facilities.	Not	√
B1 Permeability	Current situation (Not enough room for infiltration, especially in the newly built-up area)	Over 50% of the rainwater could go into the subsoil.	Over 75% of the rainwater could go into the subsoil.	All of the rainwater could go into the subsoil.	√	√
B2 Room for Surface Water	Current situation(many previous water buffers have disappeared)	Every residential zone having access to water buffer zone within 1.5km	Every residential zone having access to main open water structure within 1.5km	Reviving continuous open water grid of roughly 2.5kmx2.5km in the region	Not	√

Title	Criteria of different Levels: D	C	B	A	Applicable to Different Scales: Block	District
B3 Interception	Current situation (Having trees and vegetation in the urban area, yet not efficient in improving interception)	Having grass and bushes to improve interception.	Having both arbours and bushes with enough room for the root.	Green roof/ facade; Multilevel vegetation for interception.	√	Not
B4 Retention	Current situation (not enough room for retention)	Increasing the room for retention for 20mm rainfall	Increasing the room for retention for 50mm rainfall.	Increasing the room for retention for 200mm rainfall	√	Not
B5 Adaptation to new flood level *14mamsl. for the Lake ChaoBasin	Current situation (Temporary evacuation are needed when floods happen)	The flood risk of residential zone below 14m is mitigated.	The flood risk of residential zone and industrial zone below 14m is mitigated.	The flood risk of all zone below 14m is mitigated.	Not	√
C1 Niutrients Control	Current situation (The nitrogen and phosphorus are hardly controlled in current wastewater system)	All the urban wastewater will be treated thoroughly in the treatment plant with Nitrogen and phosphorus level controlled before being discharged.	All of the wastewater in the rural household will be treated, with the nitrogen and phosphorus recycled.	All the phosphorus and nitrogen in the wastewater (including rural and urban) from all sectors are recycled.	Not	√
C2 Mobility Emissions Control	Current situation (there is increasing risk of heavy metal pollution due to the use of automobiles)	Car-free zones are established within 1km around the wetland zone.	Car-free zones are not only established around the main wetland structure(within 1km), but also around the urban water structure within 50 metres.	Cars are totally prohibited within 50 metres of the main urban water structure; 1000 metre within the main wetland zone.	√	√

Title	Criteria of different Levels: D	C	B	A	Applicable to Different Scales: Block	District
C3 Livestock Emissions Control	Current situation (Open field farming are still intensive which not only causes the surface water pollution directly but also contaminate the subsoil and groundwater)	Wastewater from farmland is purified before going to the surface water.	Organic farming methods are adopted in at least half of the agricultural production zone to prevent the contamination of both water sub-soil.	All agricultural zone will adopt organic farming methods to reduce their environmental impact in terms of contamination towards both water and subsoil.	√	√
C4 Industrial Emissions Control	Current situation (Risk of heavy metal pollution through wastewater, air and groundwater contamination)	All the wastewater from industrial sectors are properly treated with heavy metal controlled.	All the industrial zone reduce their wastewater production and emission by recycling.	All the industrial zone relies on the clean energy and become fully circular in terms of all types of waste management.	√	√
C5 Embankment	Current situation (In urban area, most of the embankment are man-made with no ecological value)	The embankment is made for nature with 250mm-width ecological zone.	The embankment is made for nature with a 500mm-width ecological zone.	The embankment is made for nature and has a 10m width gradient zone for different species.	√	Not
C6 Regional Ecological Network	Current situation The raparian zone is not continuous enough to support water ecology	The main open water structure should have natural raparian node at least every 1km.	Main open water structure is supported by continuous natural raparian at least 10-metre wide (breakpoints should no longer than 50 metres)	Main open water structure is supported by continuous natural raparian at least 50-metre wide with no break points.	Not	√
C7 Riparian Biodiversity	Current situation (Though parks can be seen in waterfront, most of them are not designed for local biodiversity)	Existing waterfront park space should be improved for biodiversity.	Nodal Spaces for biodiversity are created in waterfront area every 500m.	All urban blocks next to open water are renovated with space created for ecology to form a network.	√	Not

Appendix C: Products from the Optimization Stage





Above are three maximization scenarios for Tanchong River Basin made at the beginning of the Optimization scenarios. They lay the foundation of the optimization process.

Optimization Theme I: Scientific Park

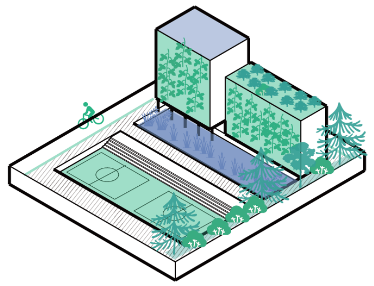
Key Facilitators:
Education institutions and Research Institutions

Goal:
Establishing a new ecological-friendly campus and research hub and support more research on nature and sustainability.

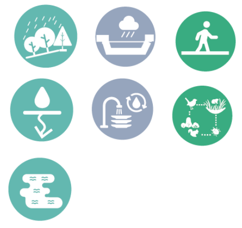
Interest from education institutions:
New campus area and faculty buildings;
Students accommodation and facilities;

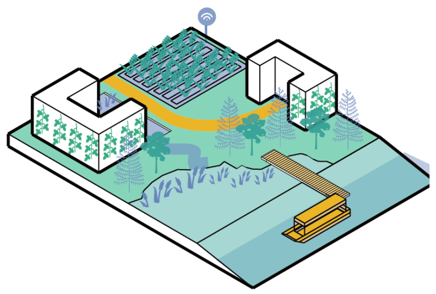
Interest from research sectors
New Labs and experimental space;
Accommodation for researchers;

Contribution to water system

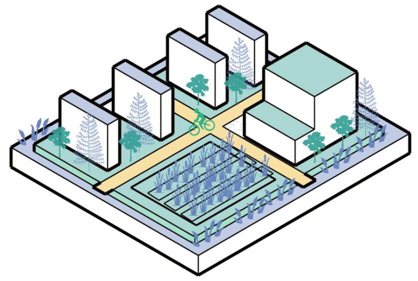


Climate-proof Student Accomodation

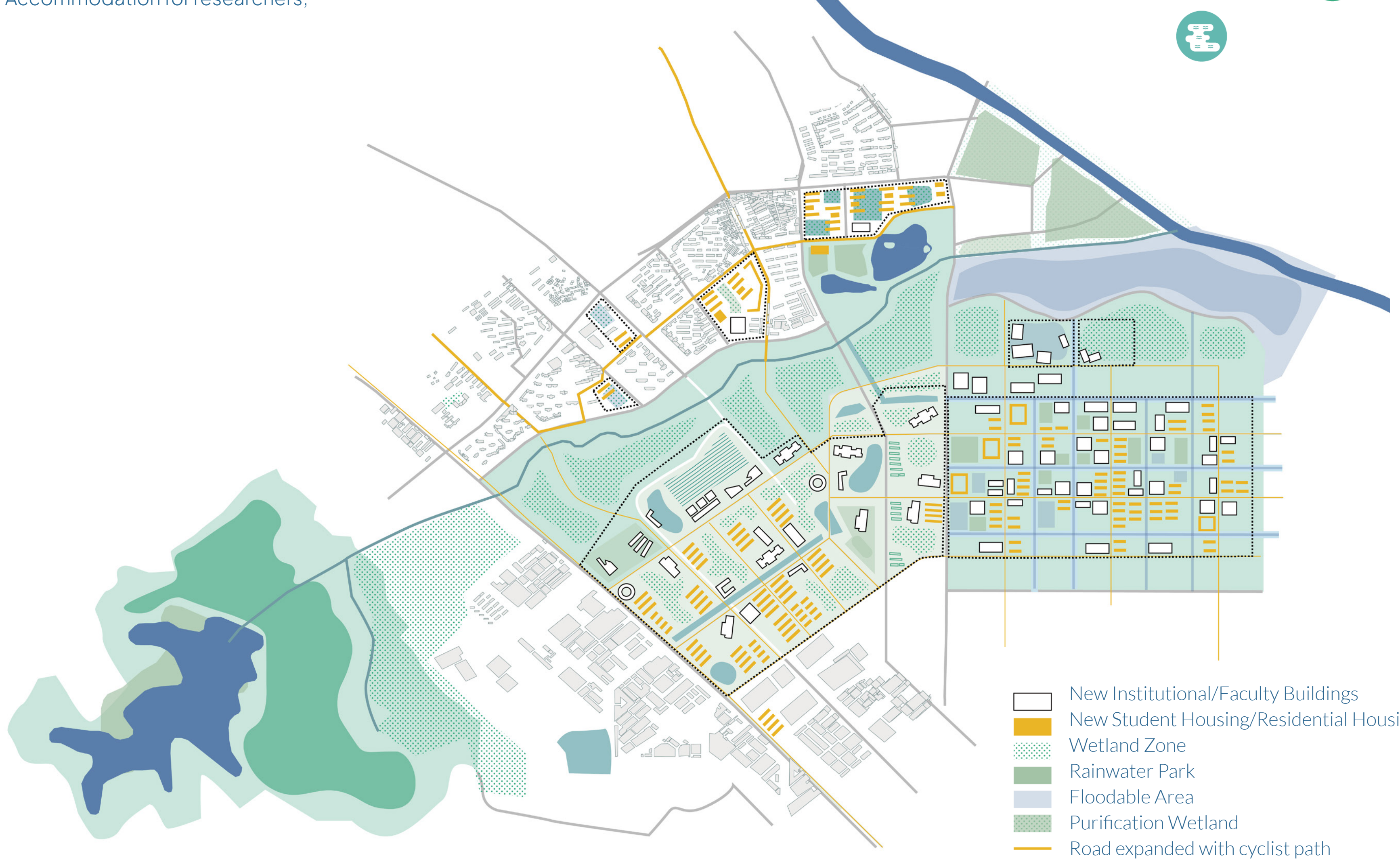


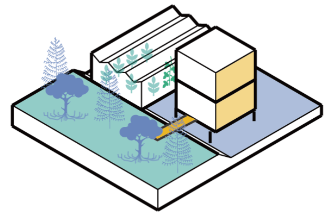


Garden-like Campus

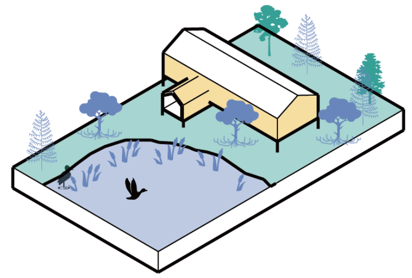


Researcher's Islands

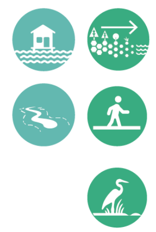




Floating Labs



Wildlife Observation Centre



New Institutional/Faculty Buildings
New Student Housing/Residential Housing
Wetland Zone
Rainwater Park
Floodable Area
Purification Wetland
Road expanded with cyclist path
Pedestrian/Cyclist-only

Optimization Theme II: Resilient Polder

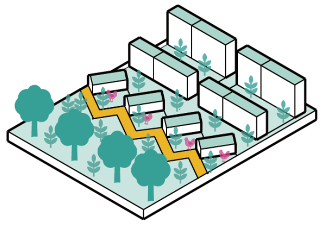
Key Facilitators:
Agrifood sector and Tourism sector

Goal:
Creating added value from agriculture and reviving traditional polder identity

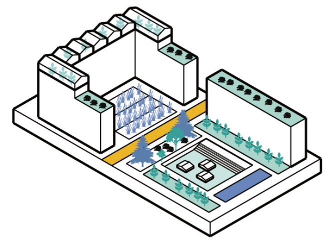
Interest from the tourist sector:
Renovating existing neighbourhood;
Creating tourism zone with facilities;
New attractive accomodations and programmes for visitors

Interest from the agrifood sector:
Introducing urban farming functions;
Bringing extra income for farmers with tourism facilities;

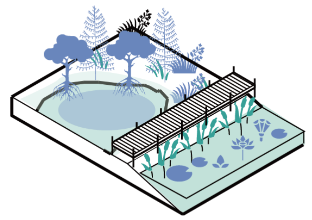
Contribution to water system



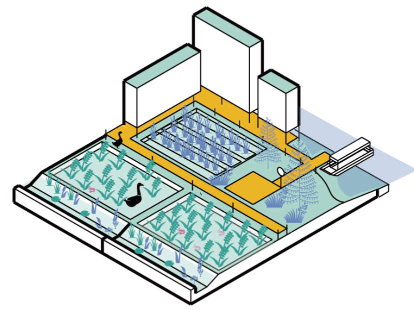
Agriforestry Neighbourhood



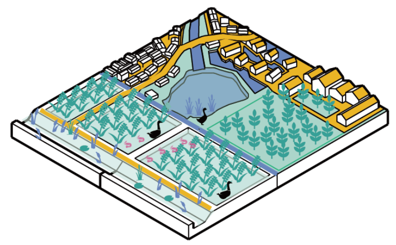
Urban farming neighbourhood



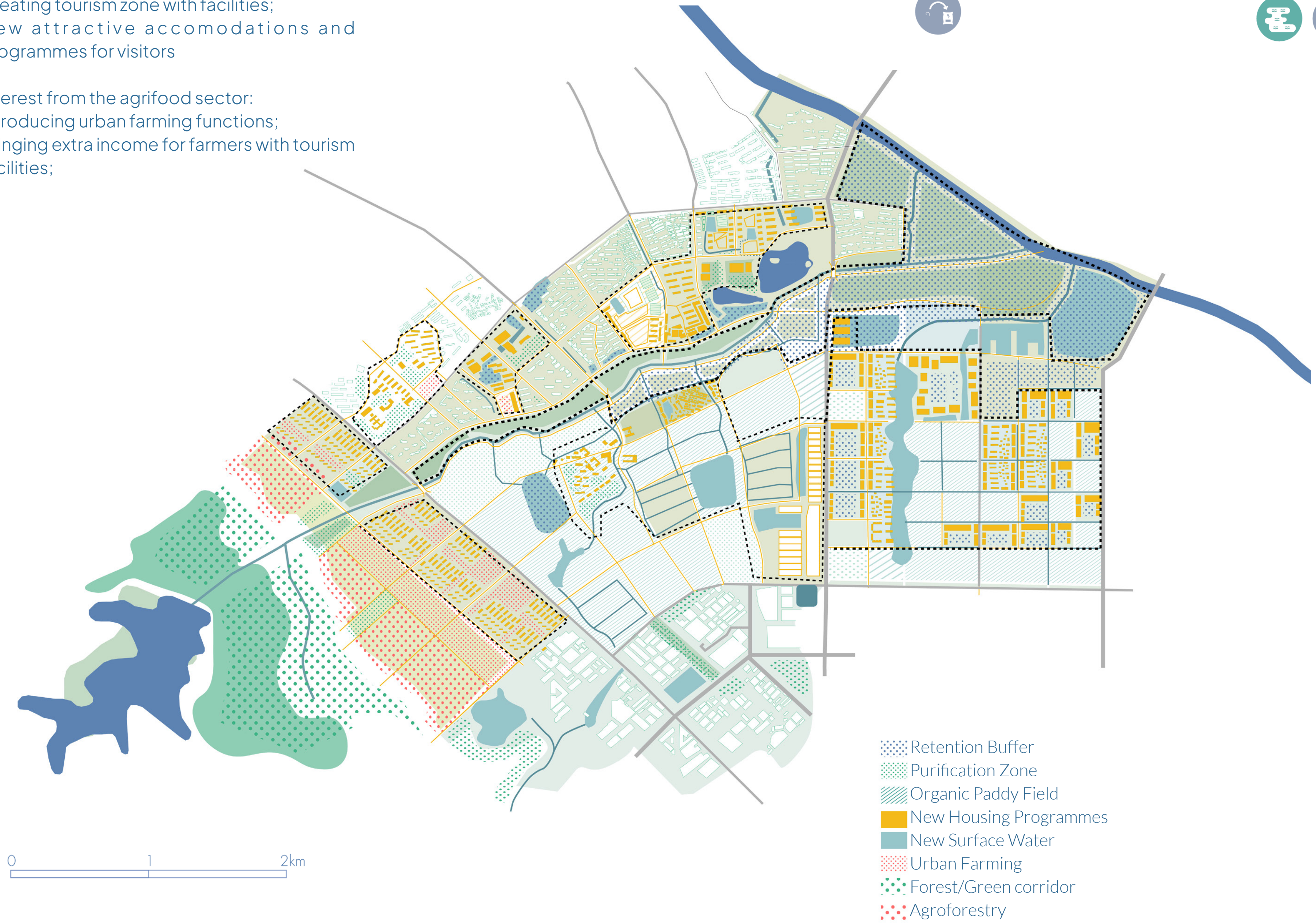
Wetland Tourism Park



Floating tourism facility and apartment



Co-farming accommodation for holiday



Optimization Theme III: Circular Harbour

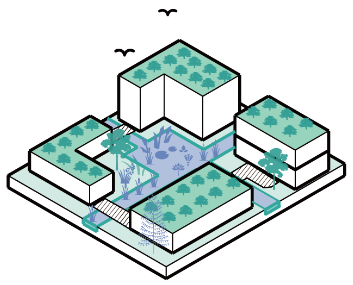
Key Facilitators:
Industrial sector and Horticultural sector

Goal:
Relying on circular technology and innovations to establish a zero-emission harbour

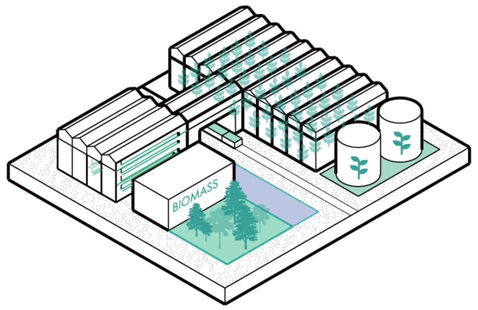
Interest from both sectors:
New port to facilitate logistics;
Innovation hubs and exhibition centre to attract talents and investment;

Interest from horticultural sectors
Existing agricultural zone be upgraded into greenhouse horticulture;
Having deeper collaboration with industrial sectors.

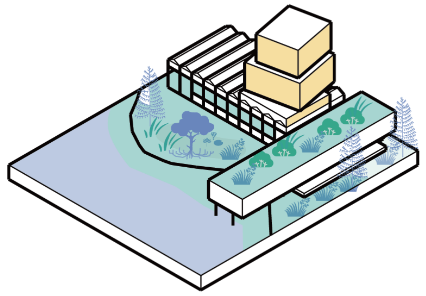
Contribution to water system



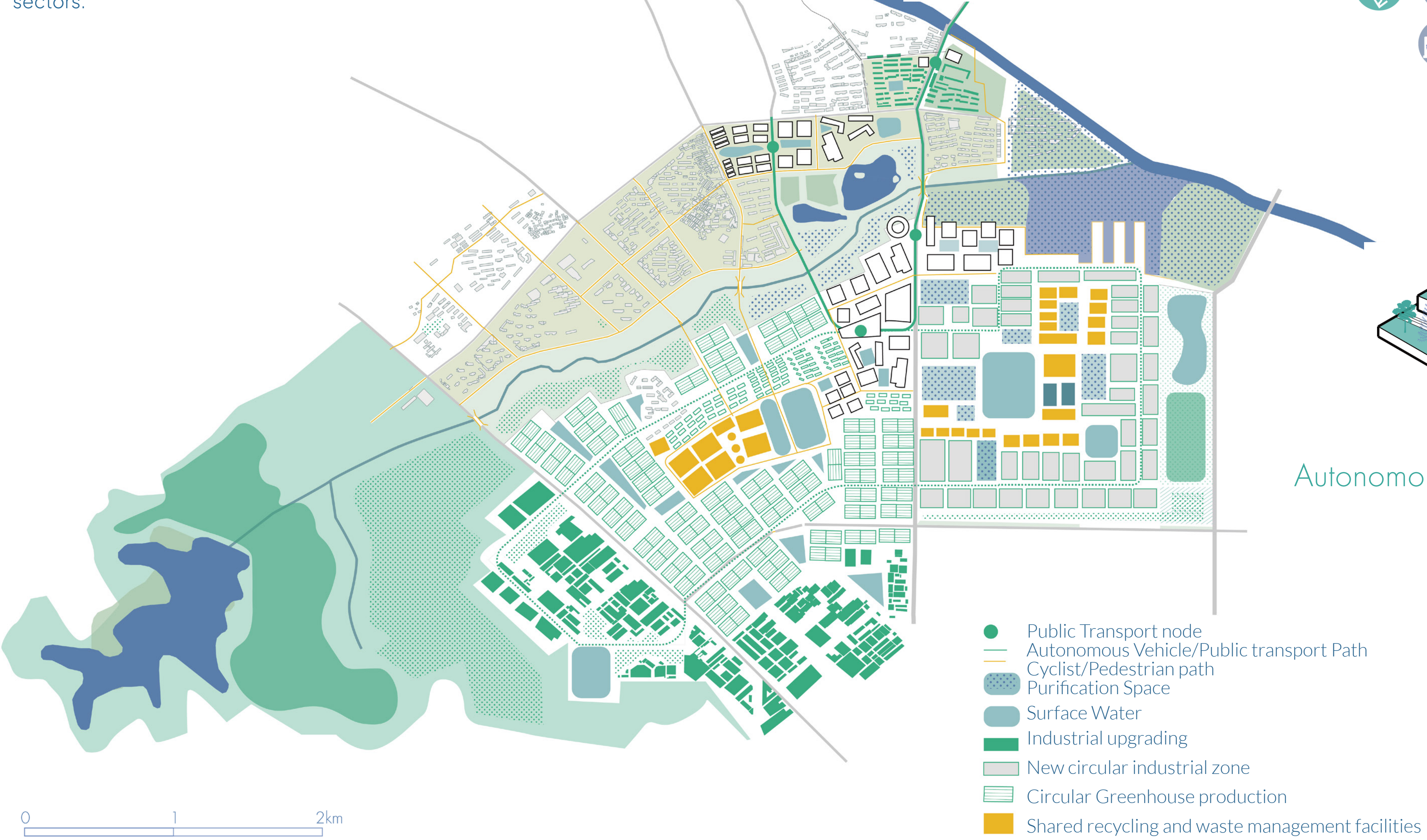
Research & Development Hub

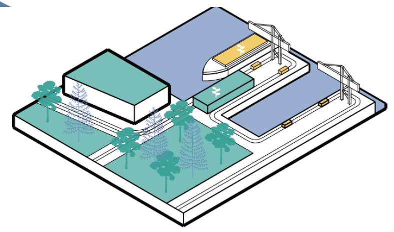


Circular Horticulture Centre

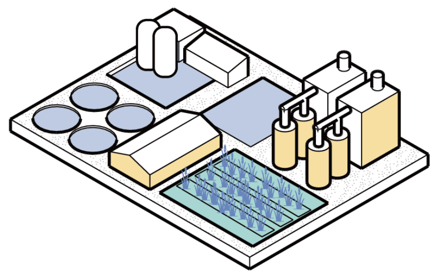


Exhibition and Visiting Centre



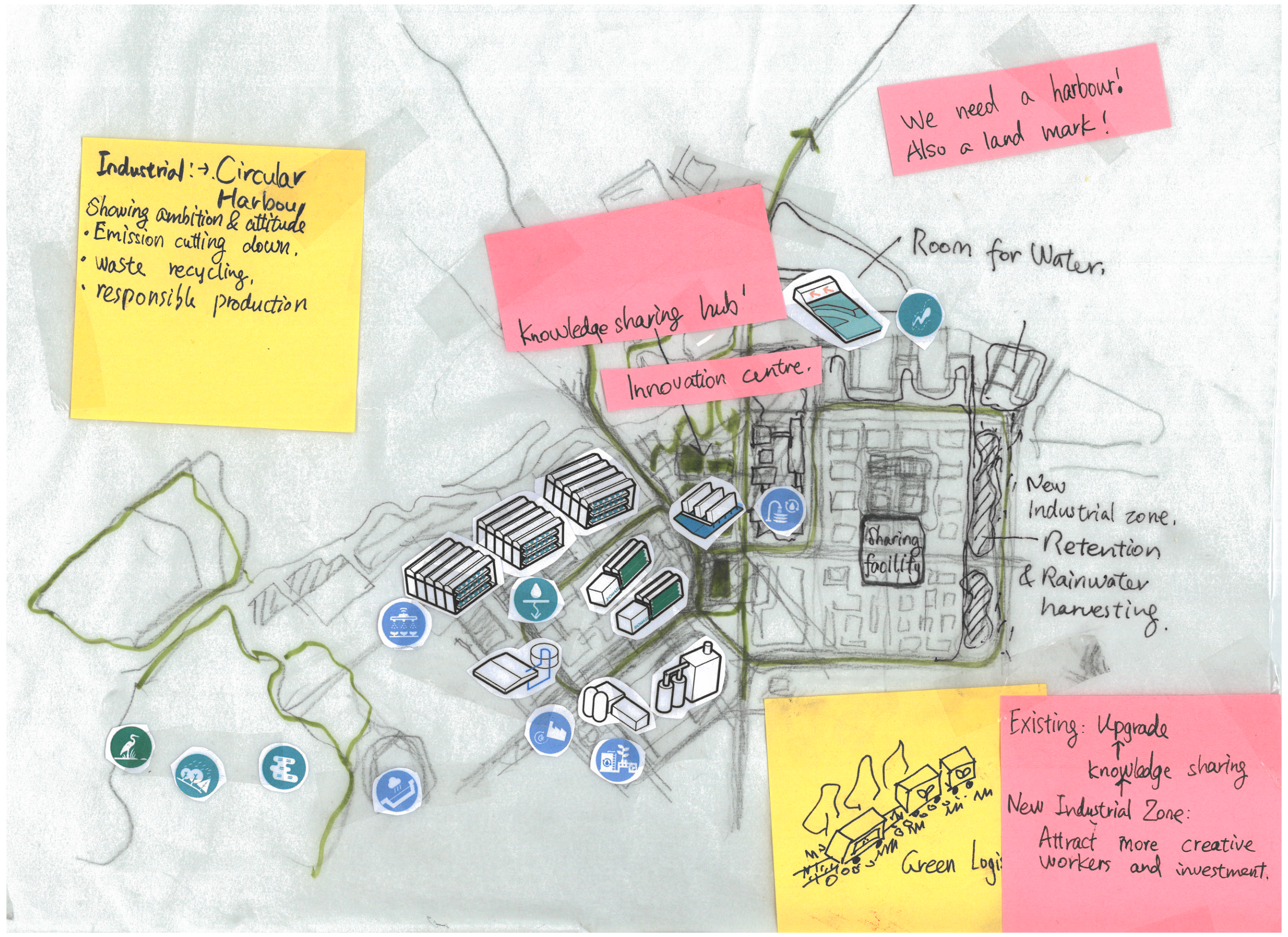


Autonomous Logistic Harbour



Sharing Recycling Centre

Draft Scenarios



Appendix D: Data List

List 1: Householde water consumption per county/city is calculated according to their population based on the data from the province by National Bureau of Statistics. The urban public use quantity uses the data of the Municipality of Hefei, since the urban core of other municipality is not inside the basin.

Municipality Name	Num	城市区划	County/City name	Population (2020)	Average daily Water Consumption Per personnel/L	Household Water Consumption/cubic metre	Urban Public Use(*10^8 cubic metre)
合肥Hefei	1	合肥市区	Hefei City	5,118,199	130	**242,358,542.6**	2.08
	2	肥东	Feidong County	884,792	90	29,065,417.2	
	3	肥西	Feixi County	967,508	90	31,782,637.8	
	4	巢湖	Chaohu City	727,162	90	23,887,271.7	
	5	庐江	Lujiang County	888,238	90	29,178,618.3	
	6	长丰县双墩	Shuangdun Town	76,098	90	2,499,819.3	
	7	长丰县岗集	Gangji Town	50,960	90	1,674,036.0	
六安 Lu'an	8	舒城	Shucheng County	749,273	90	24,613,618.1	
芜湖 Wuhu	9	无为	Wuwei City	817,997	90	26,871,201.5	
马鞍山 Ma'anshan	10	含山县清溪镇	Qingxi Town	42,279	90	1,388,865.2	
	11	含山县林头镇	Lintou Town	66,951	90	2,199,340.4	
	12	含山县陶厂镇	Taochang Town	32,387	90	1,063,913.0	
	13	含山县铜闸镇	Tongzha Town	25,880	90	850,158.0	
	14	含山县运槽镇	Yuncao Town	23,891	90	784,819.4	
	15	和县功桥镇	Gongqiao Town	32,601	90	1,070,942.9	
	16	和县白桥镇	Baiqiao Town	31,059	90	1,020,288.2	
	Total					420,809,489.2	
				10535275		4.208	2.08

List 2: Industrial water consumption data is calculated according to the GDP based on water consumption/GDP of the Municipality of Hefei. This number could be even slightly lower than the real situation, considering the water consumption efficiency in the clustered industrial zone in Hefei might be higher than factories in other areas.

Municipality Name	Num	城市区划	County/City name	GDP from Industrial sector(万元/10k Yuan)	Industrial Water Consumption calculated based on GDP/cubic metre)	GDP from Agriculture(万元/10k Yuan)	Agriculture Water Consumption calculated based on GDP/cubic metre)
合肥Hefei	1	合肥市区	Hefei City	2255.56		11.93	61,374,627.0
	2	肥东	Feidong County	229.39		65.94	339,232,431.3
	3	肥西	Feixi County	341.96	505,000,000.0	55	282,950,920.9
	4	巢湖	Chaohu City	184.7		38.51	198,117,090.2
	5	庐江	Lujiang County	159.09		56.31	289,690,297.4
	6	长丰县双墩	Shuangdun Town	*Take 30% of Changfeng County's GPD	43,061,566.4	19.251	99,037,966.9
	7	长丰县岗集	Gangji Town	73.386			
六安 Lu'an	8	舒城	Shucheng County	135.61	79,573,474.9	33.24	171,005,247.5
芜湖 Wuhu	9	无为	Wuwei City	240.43	141,079,939.2	51.21	263,453,030.1
马鞍山 Ma'anshan	10	含山县清溪镇	Qingxi Town	*Take 50% of Hanshan County's GPD			
	11	含山县林头镇	Lintou Town				
	12	含山县陶厂镇	Taochang Town		22,576,428.3	10.93	56,230,064.8
	13	含山县铜闸镇	Tongzha Town				
	14	含山县运槽镇	Yuncao Town	38.475			
	15	和县功桥镇	Gongqiao Town	*Take 30% of He County's GPD	16,533,162.9	8.031	41,315,979.0
	16	和县白桥镇	Baiqiao Town	28.176			
	Total				807,824,571.8	350.352	1,802,407,655.1
					8.08		18.02

湿地名录	面积/公顷	面积/sqm	市镇	级别
肥西三河国家湿地公园	1887.22	18872200	肥西县	国家
庐阳董铺国家湿地公园	4667.43	46674300	合肥市区	国家
巢湖半岛国家湿地公园	998.36	9983600	巢湖市	国家
安徽合肥巢湖湖滨国家湿地公园	1535.31	15353100	包河区	国家
安徽省庐江马尾河国家湿地公园				国家
含山大渔滩省级湿地公园	466.3	4663000	含山县	省级
肥东龙栖地省级湿地公园	573.71	5737100	肥东县	省级
巢湖柘皋河省级湿地公园	446.65	4466500	巢湖市	省级
安徽巢湖槐林省级湿地公园	193.96	1939600	巢湖市	省级
庐江栖凤洲省级湿地公园			庐江	省级
肥东长临河省级湿地公园			肥东县	省级
派河市级湿地公园			肥西县	市
玉带河市级湿地公园			肥东县	市

List 3:
Main protective wetland around Lake Chao

List 4:
Major polluters types from industrial sectors
(Source: Anhui Provincial Department of Ecology and Environment)
Grouped by administration zone
The map in 4.4.1 is partly based on the industrial types involved.

包河区	**11**
Car Manufacture	5
wastewater treatment	6
巢湖市	**11**
Fibre and material	1
Food Processing	6
pharmaceutical industry	1
Steel processing	1
wastewater treatment	2
巢经开	**2**
Plastic	1
wastewater treatment	1
肥东县	**12**
Fertilizer producing	3
Food Processing	1
Paper	1
Pesticides Producing	2
Plastic	1
Steel processing	1
wastewater treatment	3
肥西县	**7**
Car Manufacture	1
Plastic	2
wastewater treatment	4
高新区	**20**
Car Manufacture	1
Coating	1
Electronic equipment	3
Electronic etching	2
Food Processing	2
pharmaceutical industry	7
Plastic	1
solar cell production	3
经开区	**20**
Car Manufacture	4
Chemical	1
Coating	1
Electronic equipment	1
Electronic etching	3
Fibre and material	1
Food Processing	2
Metal processing	2
pharmaceutical industry	2
Plastic	1
wastewater treatment	2

庐江县	**15**
Car Manufacture	1
Chemical	1
Coating	1
Electronic etching	1
Fodder processing	1
Food Processing	2
magnet materials	4
Metal processing	1
wastewater treatment	3
庐阳区	**4**
Coating	1
Food Processing	1
Thermal Plant	1
wastewater treatment	1
舒城县	**2**
Coating	2
蜀山区	**7**
Electronic etching	2
Food Processing	1
Livestock	1
pharmaceutical industry	1
wastewater treatment	2
无为县	**8**
Ceramic Manufacturing	1
Clothing and textile	1
pharmaceutical industry	1
Rubber industry	1
wastewater treatment	4
新站区	**15**
Coating	4
Electronic equipment	1
Electronic etching	5
Metal processing	1
solar cell production	1
Steel processing	1
wastewater treatment	2
瑶海区	**3**
Clothing and textile	2
wastewater treatment	1
长丰县	**4**
Battery	1
Coating	1
Livestock	1
wastewater treatment	1
总计	**141**

List5:
Everage Water Quality Of Major Rivers in the Lake Chao Basin

水体	2014	2020	2021	Average
南淝河	V-	V	V	V
双桥河	-	IV	-	IV
白石天河	V	IV	IV	IV
派河	V-	IV	IV	IV
柘皋河	III	IV	-	IV
裕溪河	III-II	III	II	III
杭埠河	III	II	IV	III
丰乐河	III	IV	III	III
十五里河	V-	IV	-	IV
兆河	III	IV	-	III
东半湖		V-	IV	V
西半湖		III	IV	IV

资料来源: 安徽省环境保护厅 《2014年12月全国地表水质月报》,《 2020 1-6月全国地表水质月报》, 《2021年6月全国地表水质月报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