Water Safety: Fragile Urban Riverfront

Applying more resilience to the urban river corridor of Chongqing

P5 Report

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CONTENTS

Dedicated to Lu N.

Abstract

This research took the Chongqing main town as an example to study the impact of seasonal floods in the upper reaches of the Yangtze River on the city, and strategies to improve flood resilience in the river corridor area in mountainous cities. The study first analyzed the water safety, water conflict, and water opportunities in the upper reaches of the Yangtze River and in the urban area of Chongqing to understand the risk of floods with different triggers (transit flood, local storm flood) and how to reduce the risks. Then, analyze and select the severity of flood influence in the river corridor area in the Chongqing main town, and find out the areas which most vulnerable to flood. Thus to carry out the design to improve flood resilience in these areas.

Through the analysis and comparison of two more extreme flood control scenarios, the study puts forward a road map for the implementation of river corridor flood resilience and the principles of flood resilience urban design for the cities in the upper stream of Yangtze River. In the design experiment, the road map and the design principles are used to implement flood resilience design for the two most severe hazard areas selected in the previous analysis. The results show that this method can not only enhance the flood resilience of those areas, but could also bring ecological, social and economic benefits. From the design results, in the current urban environment, the hybrid infrastructure approach is suitable for flood resilience design in all kinds of situations. And the percentage of green and blue facilities in hybrid infrastructure depends on the amount of space that can be used as flood treatment zone. In the future regional flood control design, the methodology used in this study can be used to evaluate the severity of flood hazards in the river corridor area of other upstream Yangtze River cities. And it could also serve as a reference for flood resilience river corridor design.

Key words:

Yangtze River, mountainous city, flood, flood resilience design, hybrid infrastructure

01. Motivation

Introduction

The Yangtze River, as the largest river in China, there are a large number of people living in its basin and made this area the most densely populated area in mainland China. This river also brings rich nature resources and transport advances which contribute to the boost of industrialization, urbanization and economy development of this area. However, the densest and developed areas in mainland China are facing the most serious flood issues. The seasonal flood damage farmland, infrastructures, and even buildings, which cost a large number of economic loss every year, sometimes it even cause the loss of lives. The mechanism of the flood is believed to be the synergy of nature issues such as climate change and monsoon and artificial issues such as the massive built of infrastructure expansion of urban areas. In order to analyze this issue and find a possible solution for the city along the Yangtze River to dealing with the seasonal flood and mitigate the influence, the research will focus on how to make the urban riverfront to be a flood resilient area by the synergy of nature system and constructed environment.

As a research which based on the existing phenomena and including different contexts (nature, artificial), the research approach will base on the pragmatic worldview, in order to learn the potential connection between different contexts and find a way to solve, at least mitigate, this issue. The whole research will be an inductive research, which starts at one crucial area along the Yangtze River and trying to come out a general flood defense approach for the whole cities located Yangtze River basin. In this case, the area selected should be representative and have some common issues with other cities. The mixed method design, which including both quantitative and qualitative methods, will be used in this research. As complex research which including different systems and stakeholders, which may require the different methods, the mixed method gives the potential to using pre-determined methods, and also to using the emerging methods which could come out during the processing of research. The data collected will include statistical and text analysis of flood issues in the Yangtze river basin, mapping of basic geo-information, surface runoff, land use, and etc. The statistic and text could help to describe and analyze the characteristics and mechanism of the Yangtze River flooding, which could be the solid foundation of potential flood defense approach, and the mapping of geo-information, surface runoff, land use, and etc. could show the conflict areas between natural systems and artificial systems.

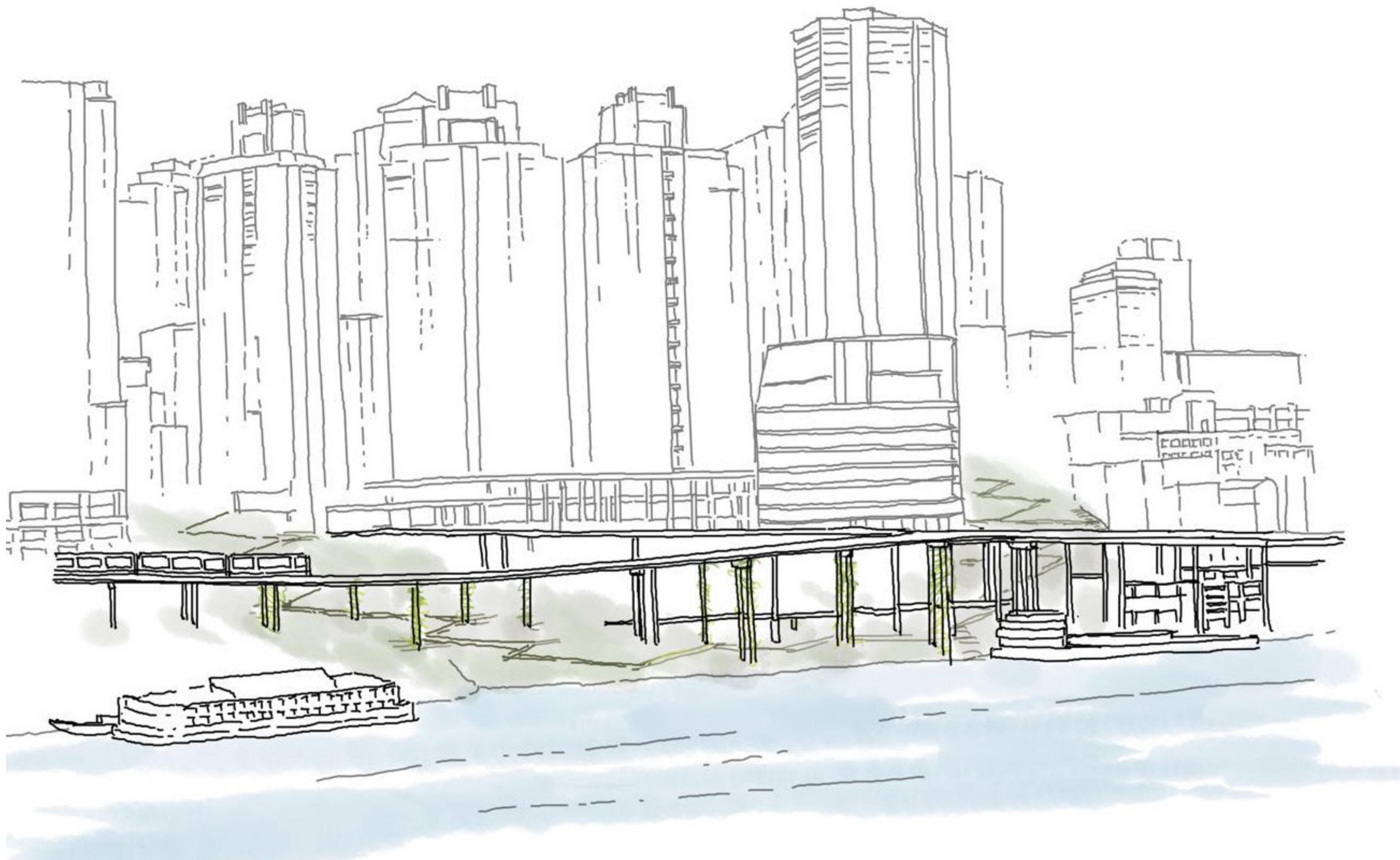


Fig.1. The image of resilient Chongqing riverfront. edited by author

Personal motivation

Human settlements are closely related to water. In human history, large-scale civilizations and cities have often been accompanied by strong water systems. At the same time, the relationship between humans and water is very delicate. The river can bring prosperity and development to a city, but it can also bring disasters and destruction. In 1998, a series of huge floods hit southern China, causing huge loss of life and economy. It also left a deep impression on me when I was a child. In the two decades from 2000 to 2020, due to massive infrastructure construction and rapid urban expansion in China, cities seized a large amount of natural land, making the conflict between cities and nature, especially the nature water system, more intense. Therefore, at the boundary between the city and the water, a large amount of water retaining infrastructure was constructed, And this further splits the relationship between the city and the water. And in ancient China, there is a story of the Great Flood of Gun-Yu (大禹治水), The leader of ancient ages, Gun-Yu, managed water by dredging waterways instead of building dams, which may bring us some new thinking.

As studied in Chongqing, which is a city along the Yangtze River for 5 years, the seasonal flood influences the city a lot. Also by the construction of the hard infrastructures(most of them are not flood defense infrastructure) the natural connection between the eco and water system of the city and the river are cut, and it is also hard for people to reach the waterfront areas. The territory between the river and urban is vulnerable, which not just cause the fragile for flood defense, but also cause the urban waterlogging.

In the whole Yangtze River basin, Chongqing is not a single example, so in my project, I want take Chongqing as an example, to investigate a multi-scale water management strategy which could be used as a paradigm for the cities along the Yangtze river to manage the seasonal flood issue and to create a resilience living environment.

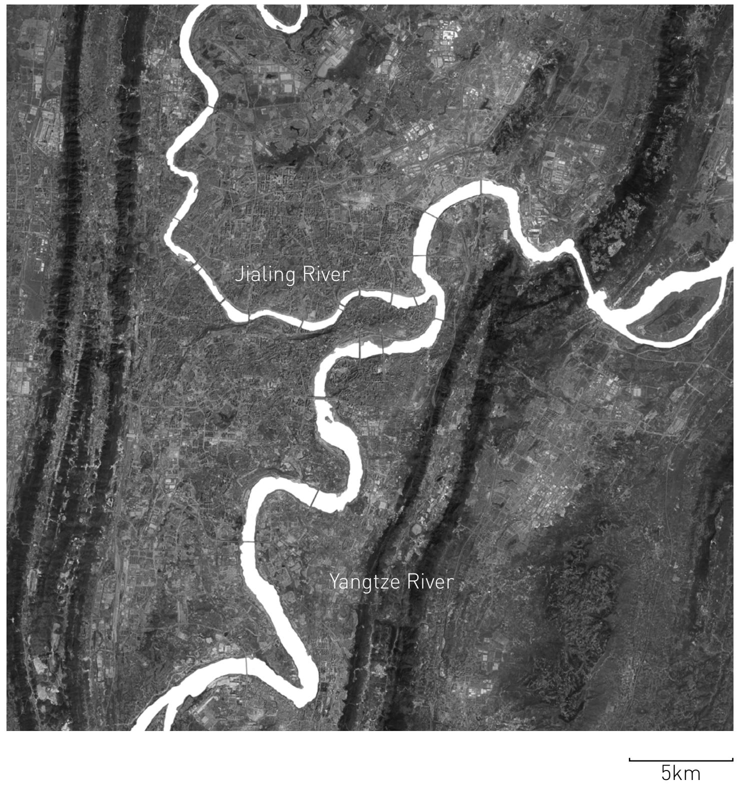


Fig.2. A map of Chongqing main city, edited by author

Context

Chongqing, as the biggest city located in the upper Yangtze River basin, is highly influenced by the annual flood, which causes a large number of loss properties. The types of floods in Chongqing are considered variously, the transit flood and local storm flood, and the reason caused those floods is different. The first kind is due to the rainstorm in larger area of the upstream of Yangtze River and Jialing River, and the second on is originated from rainstorm in some areas inland or regional concentration rainstorm (Dai, Zeng and Li, 2013). In that case, doing a flood defense research in Chongqing, could not only explore the mechanism of different types of floods, but could also analysis the inner relationship between them.

Now, most of the researches and studies in floods resilient cities are based on plain cities. Chongqing, as a mountainous city that is also the representative geography type for most upstream Yangtze River cities, urgently needs related researches. Special geographical conditions have brought more complex terrain and water catchment for the city, which could bring more opportunities and potentials while implementing floods resilience to the city.

Chongqing has a really long river corridor which should lead lots if potentials to the city itself and to residents, however, most of the river corridors now are considered to be the hazard area, not only because of the flood, but also because of the massive constructions of infrastructures (tubes, train tracks, urban expressway parking lots, and etc.). While implementing natural resilience, the social resilience should also be considered, the riverfront area should be more accessible for residents. And this area could be great opportunities for high-quality public spaces and even places for urban farming and primary education.

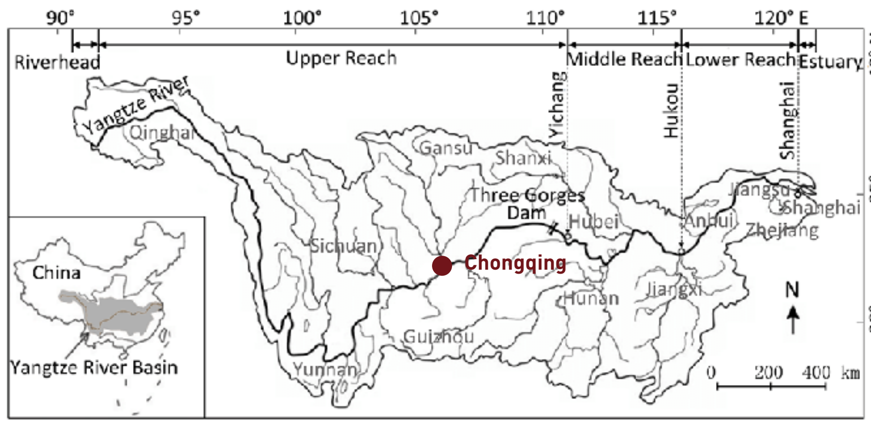


Fig.3. Geographic location and sketch map of the Yangtze River Basin and Chongqing

Chongqing's urban development process - urbanized and natural

Before 1949,

The history of Chongqing's construction can be traced back to the pre-Qin (before 207 BC) period and has a long history. During the Qing Dynasty, Chongqing had already become an important town in southwest China. Zhang Yunxuan's Chongqing Fuzhi map describes the characteristics of Chongqing in the late Qing Dynasty. It can be seen from the map that the main city of Chongqing at this time relies on the Yuzhong Peninsula and echoes the Jiangbei city on the north side, forming the urban structure of Chongqing city at that time, while the rest of the area is mostly mountainous and forested.

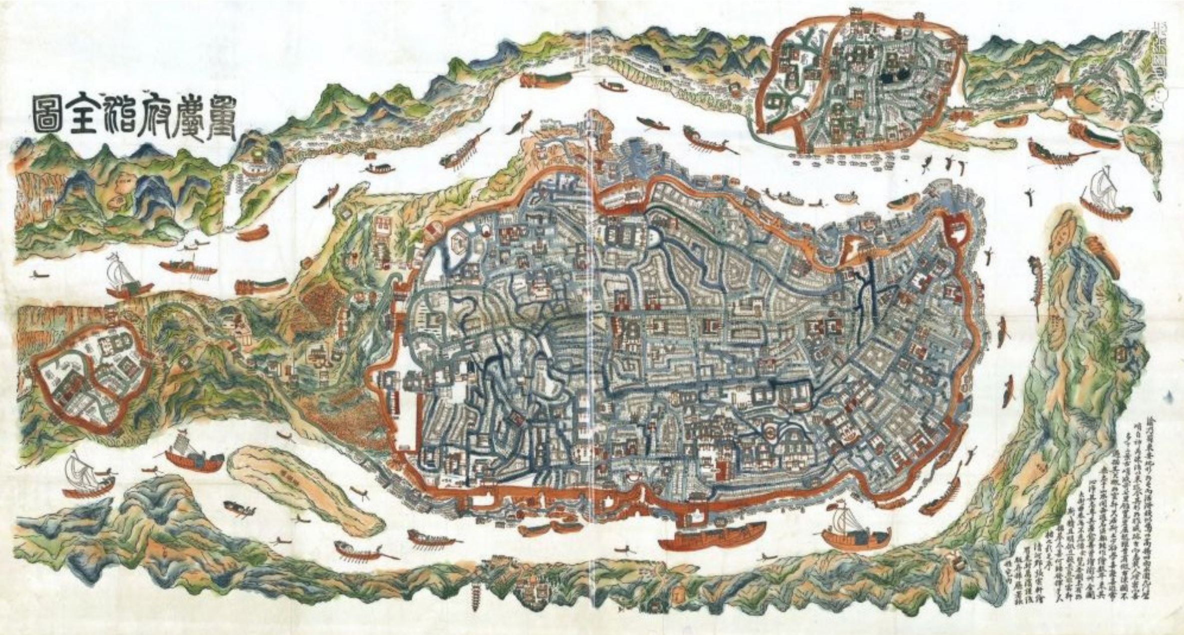


Fig.4. Chongqing Fuzhi Map, Zhang. Yunxuan, 1886-1890

The "Chongqing Concession Commercial Port Map" drawn in 1907 also describes the corresponding situation.

Fig.5. Chongqing Concession Commercial Port Map, 1907

After the beginning of the Second Sino-Japanese War, the Kuomintang government moved the Chinese capital to Chongqing. As can be seen from Fig. 5, during the temporary capital era Chongqing basically maintained the structure of the late Qing Dynasty. The urbanized areas mainly consisted with Yuzhong, Jiangbei and Shapingba, in the entire city area, the urbanized area is much smaller than the natural area.

In the he draft of the ten-year development plan for the temporary capital after the Second Sino-Japanese War, the idea of evacuation of urban population, reduction of population density, and development of satellite towns was proposed. Such a vision laid the foundation for the development of Chongqing's urban spatial structure in the next few decades.

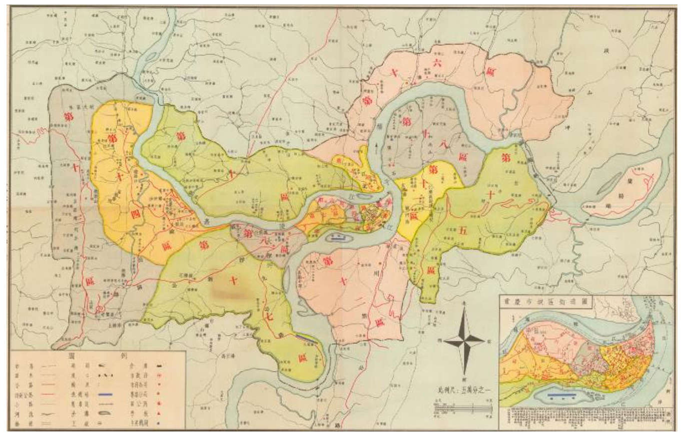


Fig.6. Chongqing Boundary Map, 1940

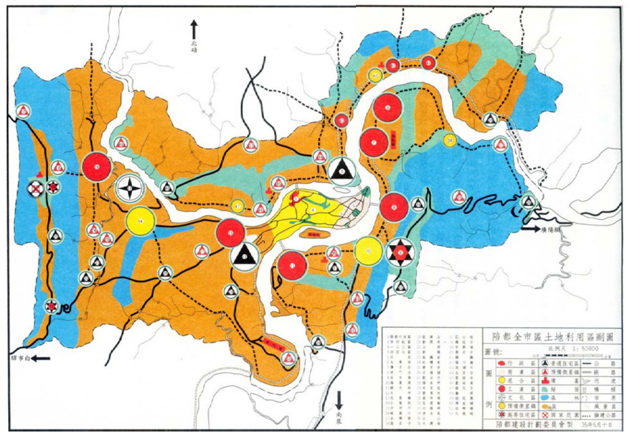


Fig.7. Land use planning map of the temporary capital, "The draft of the ten-year development plan for the temporary capital", 1946

After 1949,

After the Chinese Civil War, Chongqing as the key city of the Third Front Movement, a large number of industrial clusters are growing rapidly. Industries are scattered along the Yangtze River and external transportation lines, forming a number of industrial zones and satellite towns. Due to the emphasis on the productivity of the city, residential areas are only constructed nearby the factories and function as supporting facilities for industrial area, thus forming relatively independent production and living areas, once again strengthening the cluster-like urban structure.

In "Preliminary Urban Planning of Chongqing", the cluster-like urban structure has been further strengthened. The plan formally put forward the city layout principle of "large scale dispersion, small scale concentration", emphasizing the dispersion of industries on a larger scale. 9 districts including Shizhong District, Dayang District, Dadukou District, Jiangbei Industrial District, and Lijiatuo-Daojiao Industrial District are planned. 4 satellite cities of Beibei, Xiema, Xipeng, and Nantong are planned in the periphery. This version of urban plan largely inherited the urban planning thoughts in the "Temporary capital Plan" and further established the urban spatial pattern of Chongqing's leap-forward cluster development.

In the following 2 decades, this spatial patten of leap-forward cluster development forms patchy urbanized areas. And a large amount of natural areas still remains between those urbanized patches.

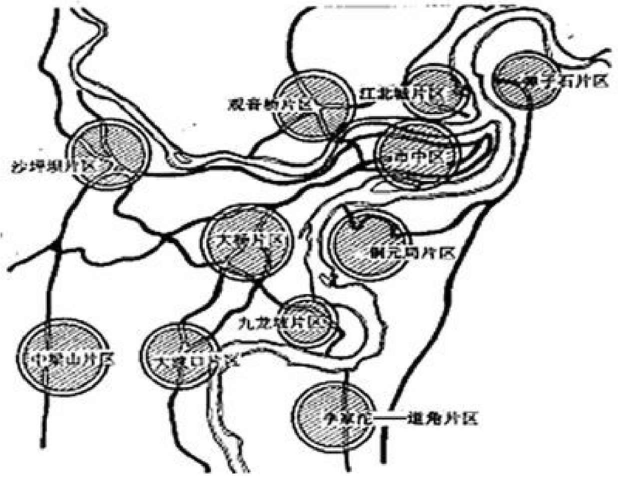


Fig.8. Preliminary Urban Planning of Chongqing, 1960

In 1983, the “Chongqing City Master Plan (1981-2000)” was approved by the State Council, in the plan formally proposed a “multi-center, cluster-style” urban spatial structure from the planning, and strictly controlled the city’s scale. The evolution of Chongqing’s overall urban spatial form has also been further strengthened to a cluster structure under the guidance of this planning idea. It is easy to notice from Fig. 9 that in this version of master plan, there are still a large number of undeveloped green spaces that exist between different urban clusters.

Before 2000, the development of Chongqing city was relatively rational, the city scale did not expand excessively, and there were always rivers, green areas, natural slop, and farmland that function as the buffer zone located between the city clusters. Bring green space into the city to disperse the heat island and improve the environment. Moreover, when facing extreme weather like rainstorms, these natural areas play an important role in mitigating the disaster.

In 1997, Chongqing became the fourth direct-administered municipality in the country, and the urbanization process of Chongqing entered a period of rapid development. Over the past ten years or so, the increasing of Chongqing’s urban structure has undergone both a leap and a gradual expansion. The original urban boundary has been breached on a large scale, and the original city clusters have gradually expanded and merged. Due to the rapid urban expansion during this period, the green belt between the clusters was gradually eroded, and the clusters in the central city gradually merged together.

In the “Chongqing City Master Plan (2007-2020)”, it is proposed to strictly define the boundaries of the functional areas, control the development scale of the urbanized areas, not erode the surrounding remained buffer green belt, and avoid the adhesion between different urban clusters. However, due to the rapid population development and urban expansion, the buffer zone between clusters has been eroded a lot, and its scale is much smaller than before 2000. The main town has gradually lost its original cluster-like spatial characteristics. At the same time, in this version of the master plan, the key development direction of the city is north, and the construction of the new north zone has been vigorously promoted. Two urban sub-centers have been built on the north and south sides of the original main town, which has led to the further expansion of Chongqing’s urbanized area. The outer natural space is further eroded.

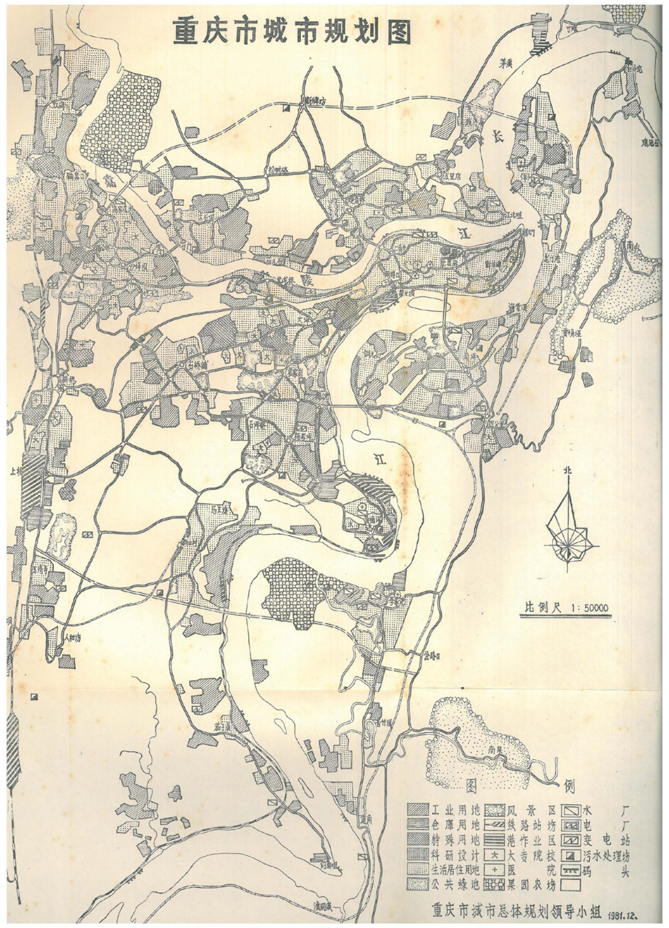


Fig.9. Chongqing City Master Plan (1981-2000), 1981

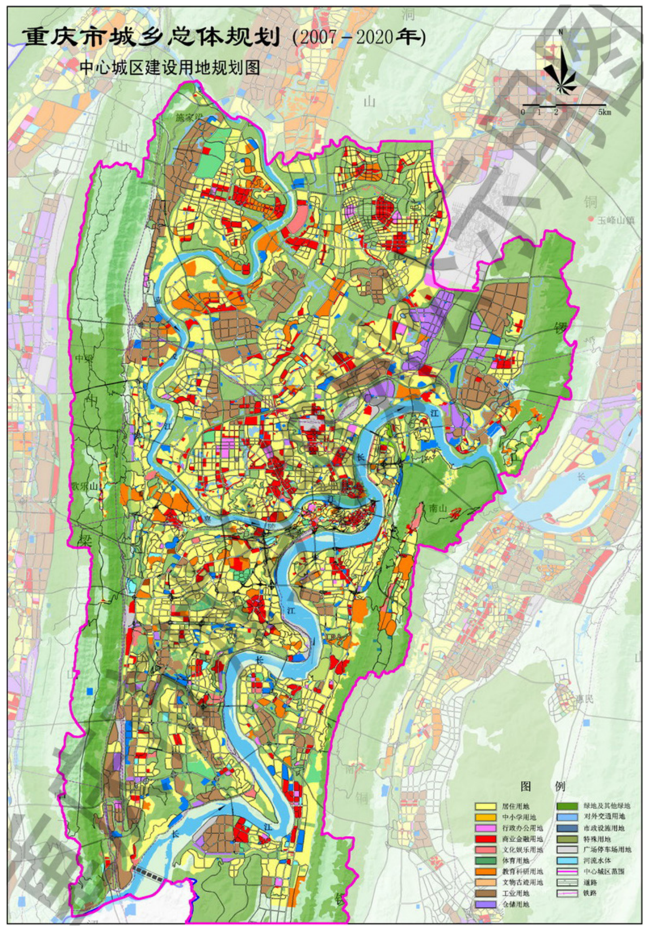


Fig.10. Chongqing City Master Plan (2007-2020), Revised in 2011

In the recent 100 years of Chongqing’s urban development, natural areas have been largely replaced by urbanized areas. Especially after 1997, a large number of natural areas have been lost in the city. Although corresponding control strategies have been proposed in the master plan, they have not reached the effect that they are expected. The rapid increase of impermeable areas has also brought great pressure on Chongqing’s nature and ecology in the end.

Fig.11. The impact of the flood on the surrounding communities,Ciqikou, Chongqing shoot by Gou, Y. edited by author

02. Problem Field

Climate change

The climate change, especially global warming, highly influences the global environment and ecosystem, it brings phenomena like sea level rising, El Niño, and etc., which not only disturbed the eco system balance but also cause the serious threats to the human living environment. The climate change also shows the relevance with flood issues around the world. A series of researches (e.g. Bell et al. 2007; Prudhomme et al. 2003; Milly et al. 2002; Lehneretal. 2006; Hirabayashi et al. 2008; Dankers and Feyen 2009; Dankers et al. 2013) shows that the predict influence of climate change on the flood hazard may be very substantial, however, those influences depend on the climate scenarios in different areas. The projection shows that in south and east Asia, the precipitation in flood-prone areas will increase due to the climate change (Arnell and Gosling, 2016).

Researches in China show the same result. The projected consistently increasing average temperature in China will caused the precipitation to significantly increase in southern China and southwestern China, and in the late years of the 21th century, the annual precipitation will increasing in the source and middle and lower reaches of the Yangtze River basin (Cao, Zhang and Shi, 2011). It could predict that climate change will influence the precipitation in the Yangtze River basin and affect the increase of flood hazards in this area.

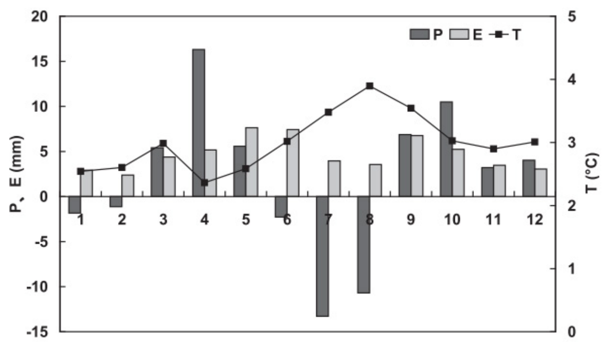


Fig.12. Effects of climate change on monthly mean temperature (T), precipitation (P) and evapotranspiration (E) in the Yangtze River basin.

Monsoon

A large part of the Yangtze river basin lies at the subtropical monsoon region. The mean annual precipitation in the basin varies from 270-500mm in the western region to 1600-1900mm in the southeastern region (Gemmer et al., 2008). Annually, this region experiences a cold-dry winter and a warm-wet summer, and 70%-80% precipitation occurs in the summer season (Yu et al., 2009). This kind of distinct spatial-temporal variation of rainfall often leads to drought/flood hazard in different places at the same time or at the same place in different seasons (Gemmer et al., 2008). By analyzing the history data of East Asian summer monsoon and drought/flood distribution patterns of eastern China, a close relationship could be seen. When the East Asian summer monsoon was stronger (weaker), regions north of the Yangtze River was prone to drought (flood), and the Yangtze River Valley and regions south of it were prone to flood (drought) (LI, WEI and LI, 2011).

Combing with climate change, monsoon could bring more flood threats to the Yangtze River basin in summer. During the years of El Niño, the enhanced subtropical high at the western North Pacific strengthens the summer East Asian, and brings larger amounts of precipitation to the Yangtze River catchment than the normal years, which may cause the larger magnitude of floods in the Yangtze River basin (Yu et al., 2009).

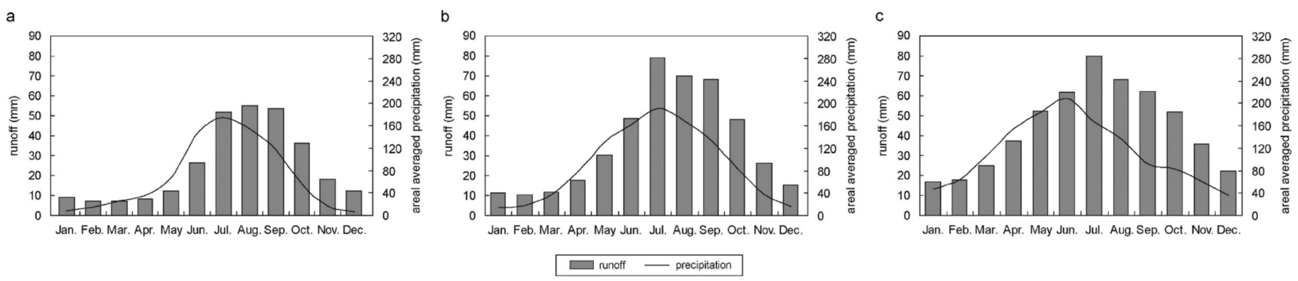


Fig.13. Monthly area-averaged precipitation and corresponding discharge of the River Yangtze at (a) Pingshan, (b)Yichang, and (c) Datong (1960–2004)

Reservoir system

During the construction of flood defense infrastructures for decades, the Yangtze River basin has basically formed a comprehensive flood control system, based on dikes and reservoir system. The core of the reservoir system is the Three Gorges Reservoir, combining with other main and tributary reservoirs, flood storage and detention areas, significantly increasing the flood defending capacity of this region (Hu et al., 2020). However, research (He, Zhang and Liu, 2017) shows that the current flood control operation of the Three Gorges and upstream reservoirs are underutilized their storage capacities. As for downstream of the Three Gorges, millions of people live there with many large, important cities like Wuhan, Nanjing, and shanghai, in that case, the maximum releases of the Three Gorges reservoir are limited by the maximum allowable non-damaging channel capacity at the downstream (Zhou et al., 2018). Therefore, when the heavy monsoon rain fall brings heavy flood in summer, the cities located in the upstream of the Three Gorges reservoir have to sacrifice themselves to keep the downstream major cities, important industrial areas, and plenty of farm land safe. Those are the facts considered to be the main reasons that caused the flood issues in the up and middle stream of the Yangtze River basin.

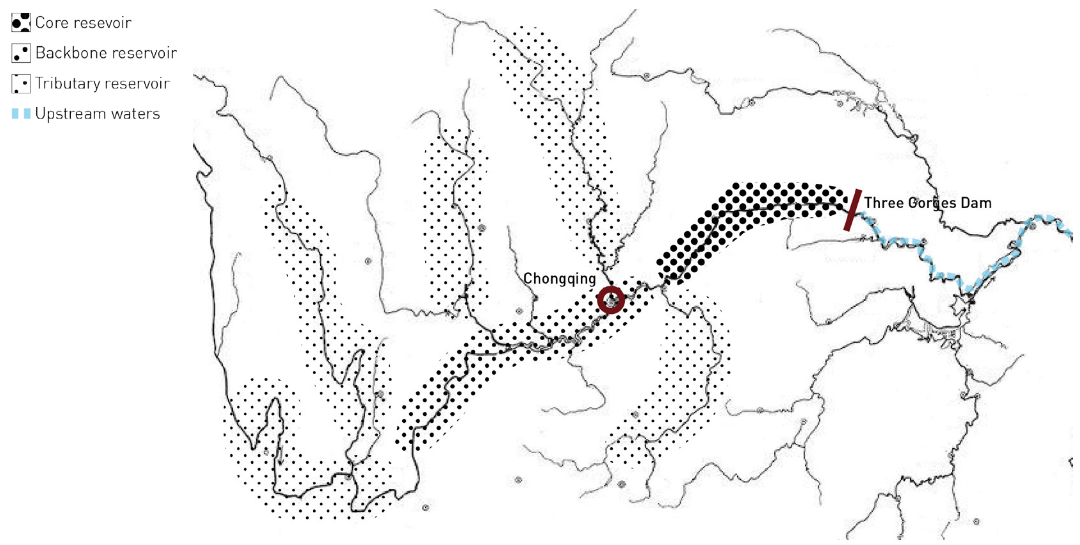


Fig.14. Reservoir system located in the Yangtze River basin, edited by author

Runoff coefficient

The Yangtze River basin, as the home for more than 400 million inhabitants, is one of the densest and most urbanized area in China. Due to human activities, the nature surface changed significantly in recent decades. The population pressure caused deforestation, agricultural land expansion, urbanization, construction of roads and infrastructures, reclamation of wetlands and lakes, and strengthening of embankments. Those activities lead to the reduction of the capacity of natural water storage in the area, and increasing runoff coefficient value (Gemmer et al., 2008).

The climate change could also influence runoff coefficient value. A trend show that in the past 40 years, the evapotranspiration over the Yangtze Reiver reduced significantly (Xu et al., 2006). The upward trend in summer rainfall and the decrease of surface evaporation will leads to an increased surface runoff (Gemmer et al., 2008).

With the increased runoff coefficient, the threat of flood hazards will also increase. The increase of the runoff coefficient reduces the infiltration capacity of surface water and significantly decreases the natural regulation and storage capacity of city to flood, thus results in the rapidly rise of storm water runoff. Therefore, the storm runoff condition of urban area is changed, which leads to the increase of total runoff volume and peak discharged, consequently, the time of pick flood moves up, thus the threat and risk of flood is increased (Dai, Zeng and Li, 2013).

Soil erosion

Human activities and destruction of vegetation has led to heavy soil erosion in the upper reaches in the Yangtze River. From 1949 to 1998, due to the rapid growth of the population, the rate of vegetation coverage in this area decreased by half, from 23.9% to 11.7%. And slope farmland, which is the majority type of farmland in the upstream of the Yangtze River basin, is the major type of erosion land. Most of these slope farmlands is steeply sloped land with an annual erosion modulus of more than 10,000 tons/km^2 (He and Jiao, 2000). The reducing of forest will also made the soil more susceptible to erosion, as forest plays an important role in reducing rainfall erosivity and protecting soil from detaching (Yin and Li, 2001).

Soil erosion and loss reduced the soil profile's thickness and the soil's water storage capacity, leads to the increasing of the amount of runoff in the upstream of the Yangtze River basin, and consequently, increasing the threat and risk of flood in these area. For the downstream areas, the lost soil will deposit in the riverbed, which raises the level of the riverbed eventually causing the river to become a suspended river. These phenomena will threaten safety of life and properties for the inhabitants living along the downstream of the river. The silt deposition also reduces the area of natural lakes, and reduction the water storage capacity. Thus, the originally natural flood resilient area might become fragile. The Dongting Lake for example, has decreased from 6000 km2 in 1925 to 2600 km2 in 1998, with a loss of water storage capacity of 11,000 million m3(He and Jiao, 2000).

Erosion types	Annual erosion amount (million tons)
Erosion from slope farmland	9.45
Gravity erosion	1.00
New added erosion[a]	2.34

[a] Erosion by infrastructure construction or mining.

Table.1. Characteristics of erosion in the upper and middle reaches of the Yangtze River

Infrastructure

The growing population and urbanization boost urban area expansion in the Yangtze River basin. The rapid expansion of the urbanized areas and impermeable pavement requires strong capacities for urban infrastructures. However, some of the sewer drainage facilities in most cities are built in the 1960s and 1970s, some facilities in the low-lying areas were constructed at a low design standard (Dai, Zeng and Li, 2013). As a result, when facing the strong rainfall bring by the summer monsoon, cities do not have enough drainage capacities to deal with the rainstorm and flood and suffer the local waterlogging easily.

Zoom into the research area the river corridor in Chongqing, the massive hard infrastructures (urban expressway, train tracks, tubes) occupied the spaces in the riverfront, which reduced the accessibility for people to the natural water areas. As a traditional port city, Chongqing and its residents have tent relationship with water in many aspects, however, in recent years, the expansion of urban areas and construction of infrastructures has gradually changed the original relationships

Fig.15. Riverfront of Yuzhong district, Chongqing, shoot by Guo, Y.

Social segregation

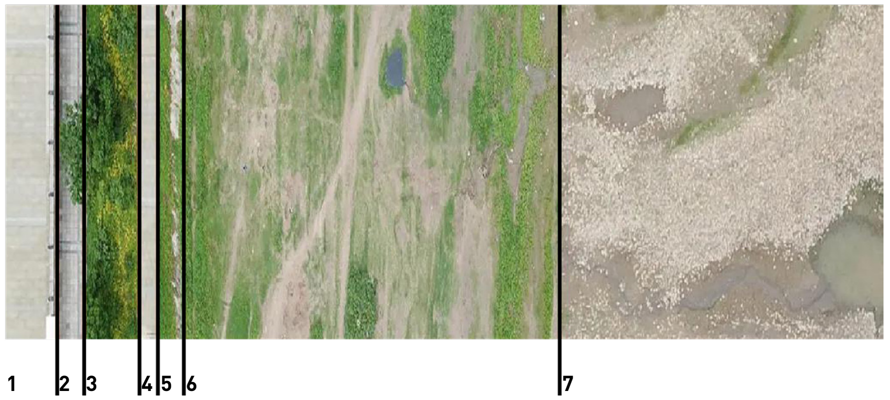
As a regional central city, Chongqing is also facing the same social segregation problem as many Chinese cities do. The opportunities in major city obviously higher than the small city and small and it attracts a large number of migrant workers poured into the city. However, it is hard for the migrant workers to integrate into the city. Due to the economic disadvantage, some migrant workers (mostly manual workers) have to live in the accommodations with a poor living environment and with barely public space. The gap between them and locals is huge (Doulet, 2008). They have their own community and rarely communicate with the outside world except for work. Other migrant workers, who work in the office, have higher income, however, most of them move often. It makes them segregate with local residences and leads to a decline in community cohesion.

On the other hand, with the development of capital, there are a trend that growing numbers of public spaces are provided in large-scale shopping malls and commercial complexes. So did Chongqing, the number of shopping malls and commercial complexes growing rapidly in recent 20 years. However, some believe that this kind of public space just looks like public space, but with the private interests' management and control, they are not public essentially (Langstraat and van Melik, 2013). And this kind of public spaces are called pseudo-public spaces. The pseudo-public spaces are public in certain extent, but due to the capital demand, they are not really welcome all classes of people. The study (Wang and Chen, 2018) in Shanghai and Chongqing show same result, the levels of publicness of pseudo-public spaces are noticeably lower than traditional public spaces in contemporary China. The massive number of pseudo-public spaces are not really for everyone, which also caused social segregation.

Biodiversity

Within the scope of Chongqing, the overall ecological resources are rich and have various biomes. However, in Chongqing main town, the ecosystem is very fragile. The rapid development of cities in recent years has led to the disappearance of the natural green space between the original urban clusters, which has severely damaged the biodiversity of the city. The biodiversity survey of Chongqing main town shows that the large and medium size mammal are rarely seen in the main town area and are replaced by species that are associated with humans, such as mice and weasel (Peng and Peng, 2018). This study shows that within the Chongqing main town, large and medium-sized mammals with high requirements for habitat area and environmental quality have already withdrawn due to the pollution and the loss of habitat caused by the expansion of the urban area.

The same phenomenon can be observed in Chongqing's water-level fluctuation zone. In the Chongqing main town, a large number of hard infrastructures such as viaduct road and hard embankment have been built on both sides of the river corridor. Such a large amount of construction has a negative impact on the biodiversity of the water-level fluctuation zone. The plant communities in the water-level-fluctuating zone themselves are fragile and are in the initial stage of succession (Chen et al., 2019). Under the influence of frequent flooding and human disturbance, the ecosystem becomes more fragile. The existing protection has not improved the situation. Existing protection only with single plant species and monotonous planting in the water-level fluctuation zone, which results in monotonous vegetation structure, poor species, and low ecological functions on the riverbank (Yuan et al., 2020).



1. Square
2. Secondary sidewalk
3. Concrete grid revetment
4. First sidewalk
5. Concrete revetment
6. Mudflat
7. Pebble riverbank

Fig.16. Chongqing riverside ecology current situation

Problem statement

The changing of nature and implementation of technology leads to the increase of flood hazard threats for the cities located in the Yangtze River basin. Chongqing, as the largest city in the upstream area, is more threatened by flood hazards. The conflicts between the expansion of urbanized areas and frequent natural disasters are more serious, especially in the riverfront area. To tackle this issue, a lot of manpower, material resources, and money are invested in annual flood control, however, the current solutions are the emergency measures like emergency evacuation, building temporary flood defenses by sandbags, and etc. It could help when the flood is coming but it does not help to solve the core of this issue. By the implementation of the emergency measures, the urban riverfront, as the first line of flood defense, is treated as the urban hazard area, costing the loss of potential ecology and society values.

Therefore, the current flood control measures urgently need to be changed. By understanding the mechanism of the flood, based on the ecology aspect and technical aspect, a more sustainable way of flood control should be investigated, not only to protect the safety of inhabitants' life and property but also to help the riverfront area generate maximum potential value for the ecology and society.

Fig.17. Flood defense slogan "*The flood is ruthless, people are compassionate, and one side is in trouble and all parties support*", Ciqikou, Chongqing shoot by Gou, Y. edited by author

03. Research aim

The aim of the research is to develop a multi-scale flood defense strategy for the cities located in the upstream of the Yangtze River basin. To gradually translate the original emergency flood defense measures to a long-term sustainable flood defense strategy.

- Regional flood management

For the regional scale, the research will explore the mechanism of flood in the upstream of Yangtze River and a dynamic reservoir system management strategy to make use of the flood adjustment capacity for the existing reservoirs in the upper Yangtze River basin.

- Resilient riverfront

For the local scale, the aim is to explore what role the urban riverfront could play in flood defense for Chongqing, and how to transit the existing danger urban riverfront to a resilient area for the environment and society.

- Toolbox

Also, it is an attempt to generalize the design of management and space and to explore how the natural system and technical aspect could synergy for the flood defense, and obtain a flood defense toolbox for the upstream Yangtze river city.

Fig.18. An inflatable boat was left on the street after the flood, Shapingba district, Chongqing, shoot by Gou, Y. edited by author

04. Research questions

Research question:

Base on the goal and relevant aim of this project, research questions are formulated as bellow, the main research question is directed towards the goal of implementing a flood resilience riverfront for Chongqing in the near future.

" *How to shift the* ***fragile urban riverfront,*** *which caused by changes (climate change, monsoon, increasing infrastructure) and actual quality (spatial, infrastructural, nature), into a flood resilient area by the synergy of* ***nature system*** *and* ***constructed environment*** *in Chongqing?*"

Sub questions:

The sub-questions are developed based on both the aims and the way they could contribute to the main research questions.

1. "What are the artificial and natural reasons which caused the flood in the Yangtze River basin seasonal flood in Chongqing?"

The first sub-question helps to understand the reason and mechanism of the seasonal flood n the Yangtze River basin.

2. "How does the seasonal Yangtze river flood influence basic urban flows (energy, water, traffic) and related (potentials for) spatial quality of Chongqing, and what measures are used to defense/mitigate flood?"

The second sub-question helps to analysis the flood influence from the urban perspectives.

3. "How can solutions to address urbanization (development of buildings and infrastructure) and natural processes (water runoff, infiltration, biodiversity, and eco-systems services) be synergetic to increase urban flood resilience?"

The third sub-question helps to find the potential opportunities to implement flood resilience in mountainous cities by the nature-based solutions.

4. "What co-benefits could flood resilient urban riverfront brings to society and economy?"

The final sub-question helps to explore the potential positive influences and co-benefits that this research could bring.

Fig.19. Commercial street after the flood, shoot by Gou, Y. edited by author

05. Methodology

Introduction:

The methodology chapter built as the backbone of the research of seasonal flood issues in Chongqing. As a research which based on the existing phenomena and including different contexts (nature, artificial), the research approach will base on the pragmatic worldview. In order to learn the potential connections between different contexts and to find a way to solve, at least mitigate, this issue the whole research will be an inductive research. It starts at serval crucial areas along the Yangtze River and trying to come out a general flood defense approach for the whole cities located Yangtze River basin. In this case, the area selected should be representative and have some common issues with other cities.

The mixed method design, which including both quantitative and qualitative methods, will be used in this research. As complex research which including different systems and stakeholders, which may require the different methods, the mixed method gives the potential to using pre-determined methods, and to using the emerging methods which could come out during the processing of research.

Methodology roadmap

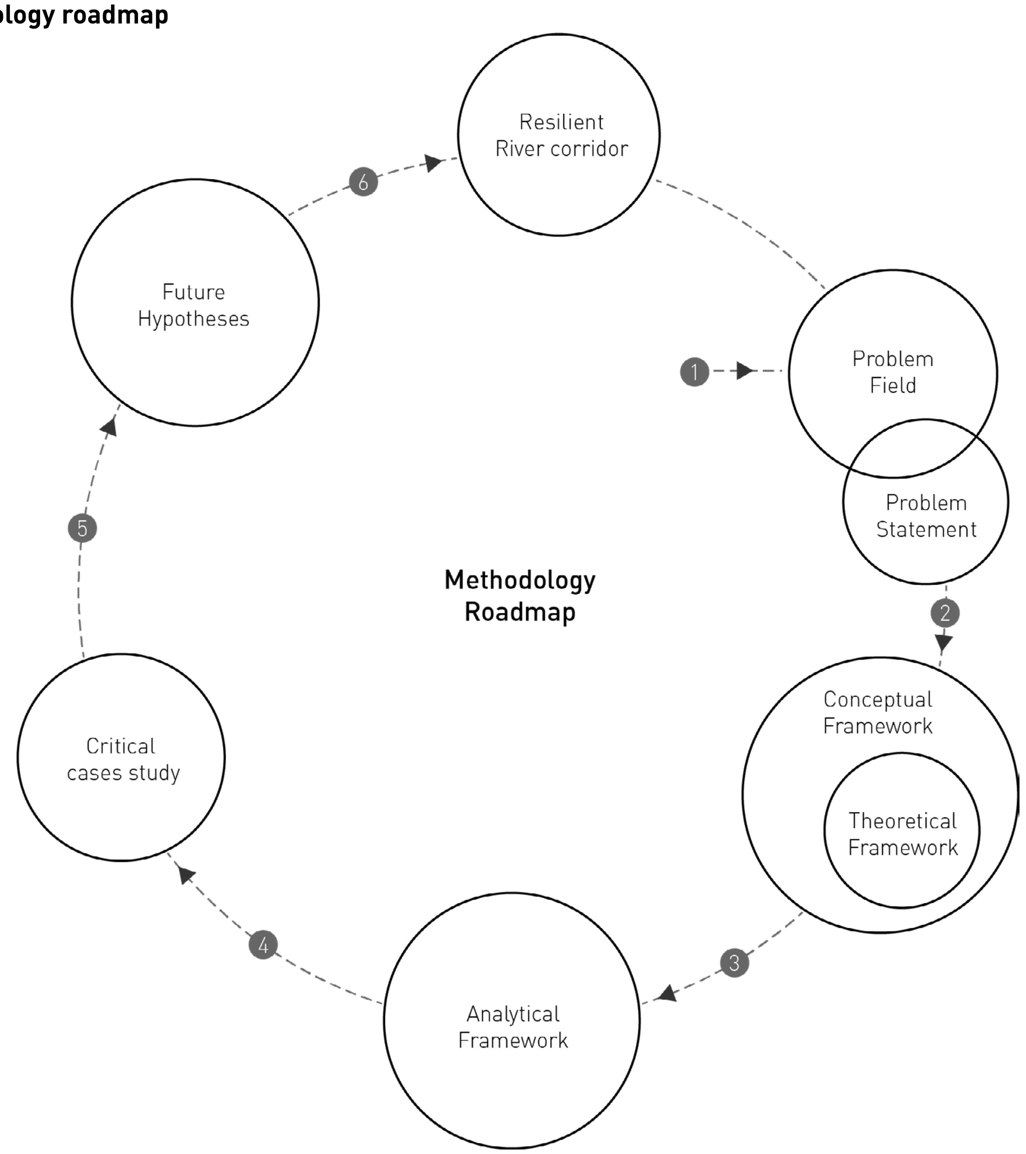
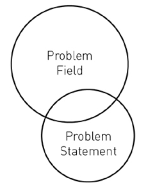
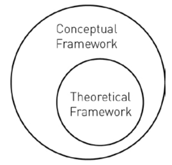


Fig.20. Methodology roadmap, edited by author



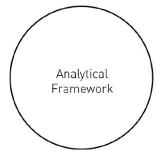
1. Problem field and problem statement

After having delved into the problem of the seasonal flood issue and its influence, the thesis focuses on the lack of flood resilience when it comes to establishing strategies that counteract the flood hazard in river corridor areas of Chongqing.



2. Conceptual and theoretical framework

The technical system and natural system are expected to work simultaneously to increase the flood resilience and bring co-benefits to society, economy, and ecosystem. And those strategies are supported under various theories.

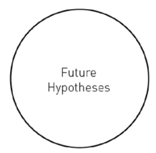


3. Analytical framework

By implementing the mixed methods, water safety, water conflict, and water opportunities are analyzed in order to filter out the most typical and crucial areas that were highly influenced by the flood.

4. Critical cases study

The critical cases are chosen in order to test the proposed framework and analyze the vulnerability in a certain context.



5. Future hypotheses

The hypothesis of the future flood control scenarios set the boundaries for research, allowing research to position itself at any point in the boundary according to local conditions of the critical cases.

6. Final outcome

The final outcome is the design of flood resilience river corridors for critical cases and a generalized flood control toolbox for upstream Yangtze river mountainous cities. And the final outcome will be reflected to see if it has countered the problem mentioned in the problem statement.

Conceptual framework

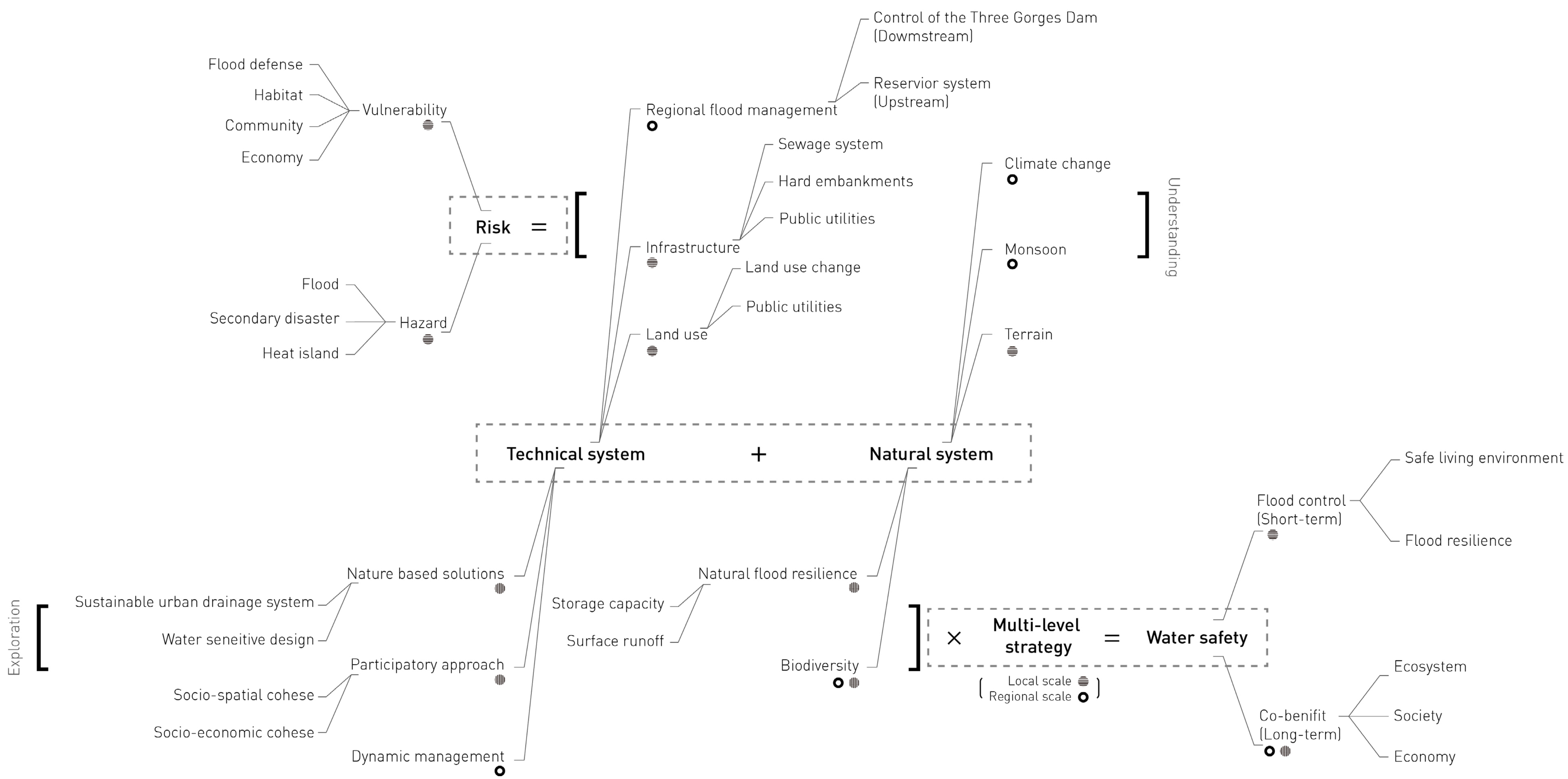


Fig.21. Conceptual framework, edited by author

The conceptual framework depicts the project's approach to using technical and natural systems to shape resilience environments. Therefore, an understanding of these systems is required and to find the connect with current issues and the potential to improve.

The project will implement multi-scale strategies to reach the goal of water safety and increase flood resilience. Therefore, the potential connections between these two systems will be categorized by scales.

When implementing flood resilience, it is very important to consider the social integration of the ecological system in the city with the built environment, as it could bring long-term benefits to society, economy, and ecosystem.

Theoretical framework

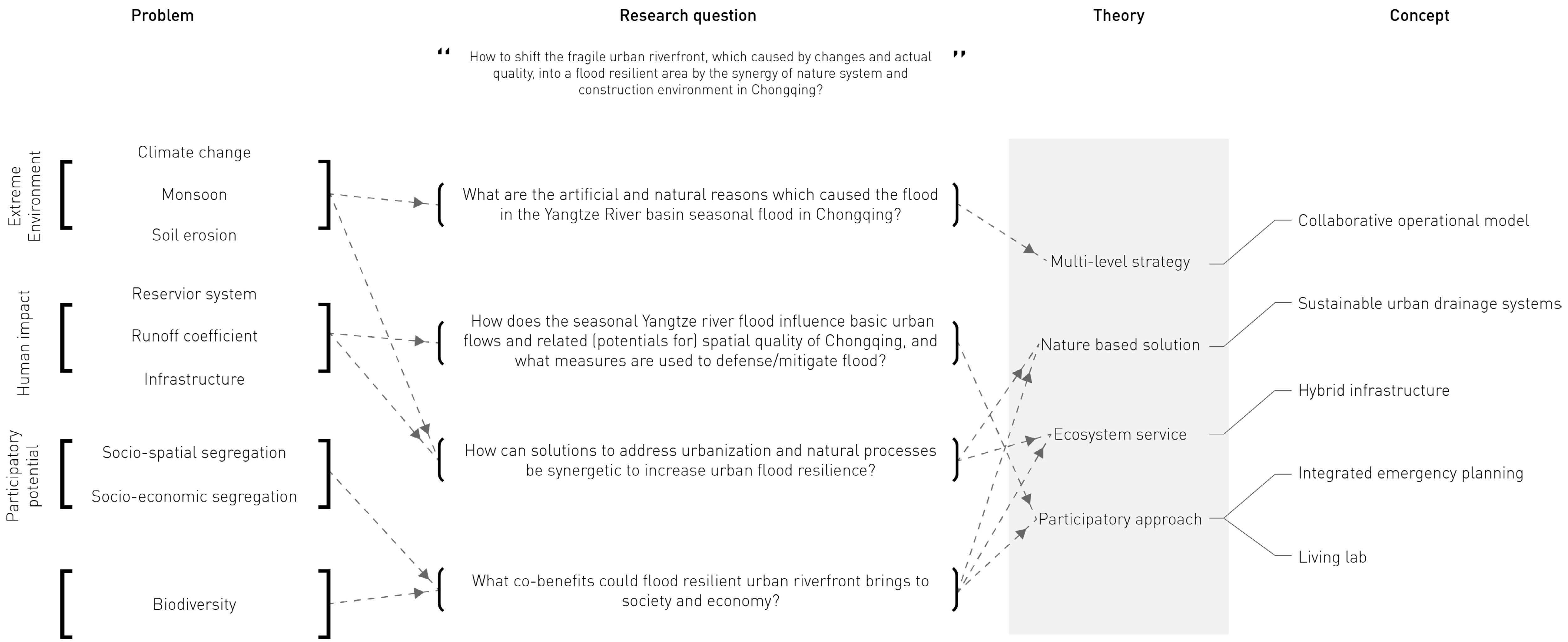


Fig. 22. Theoretical framework, edited by author

Multi-scale strategy

The multi-scale strategy in urban planning and urban design is a basic strategy to study and tackle the cross-scale factors. The Multi-scale strategy for hydro system is based on the monitoring of nested spatial scales: (1) the hills- lope scale, where processes influencing the runoff generation and its concentration can be tackled; (2) the small to medium catchment scale (1–100km2), where the impact of the net- work structure and of the spatial variability of rainfall, land- scape and initial soil moisture can be quantified; (3) the larger scale (100–1000km2), where the river routing and flooding processes become important (Braud et al., 2014). It could help to understanding the mechanism of the hydro system and the reason of flood.

In the regional scale, to reaching the goal of flood resilience, the collaborative operational model of reservoir system could make use of the potential flood capacity of the reservoir system, by the operation of reservoirs and reservoir system in different scales (Hu et al., 2020). In the local scale, the result of the multi-scale hydrometeorological observation could help the research to build the hydrological modelling for vulnerability, and to find the critical areas and opportunities for the implementation of flood resilience. With the multi-scale strategy, the research could provide the water safety in different scales for the flood hazard area in Chongqing, also in the upstream Yangtze river cities.

Nature-based solutions

The nature-based solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience (European Commission, 2019). The nature-based solutions could mitigate flood issues efficiently. Simultaneously it has a high potential for multi-functionality for secondary disasters, climate changes, adaptation, recreation, and biodiversity conservation (Kalantari et al., 2018). Thus, compare with the current emergency flood defense measures, the flood defense measures based on the nature-based solutions could not only mitigate the flood hazard but also brings long-term benefits.

A concept under this theory is sustainable urban drainage systems. Different from the "gray" infrastructure solutions, this approach sustainable urban drainage systems aim to slow down and reduce the quantity of surface water runoff in an area in order to minimize downstream flood risk (Davis and Naumann, 2017). It includes the following elements: (1) Rainwater harvesting systems; (2) Green roofs; (3) Permeable pavements; (4) Bioretention systems; (5) Trees; (6) Swales, detention basins, retention ponds, and wetlands; (7) Soakaways and infiltration basins (Woods Ballard et al. 2015). This kind of solution is diverse in nature, and the drainage method used depends on local characteristics (State of Green, 2015). In Chongqing, the complex topography creates more possibilities for the system, which is different from plain cities. For example, the slope creates more possibilities for the bioretention system.

Ecosystem services

The ecosystem services are the benefits that humans could obtain from ecosystems, and one of those benefits is flood control. By transforming the hard infrastructure and introduce more green spaces to the highly urbanized area, the ecosystem services will provide more benefits in urban environments. In Chongqing, due to the complex terrain and natural hydro system, the ecosystem services have more potential for the goal of flood resilience and co-benefits.

This theory is including the concept of hybrid infrastructure. The hybrid infrastructure, which is a combination of 'gray' infrastructure (hard embankments, water gates, bulkheads, etc.) and 'green' infrastructure (vegetations, floodplain, etc.), capitalizes on the best characteristics of these two types. It could minimize the risk of flooding effectively and greatly enhance the city's adaptability (Sutton-Grier, Wowk and Bamford, 2015). Comparing with the hard river embankments, which are wieldy constructed now, the hybrid embankments could increase the water storage capacity in the basin and slow down the conversion of rainwater runoff into floodwater.

Participatory approach

In order to enhance local flood disaster mitigation, participatory approaches for flood disaster management are proposed. The idea is to involve all stakeholders, including the government, local communities, non-governmental organizations (NGOs), media, the private sector, and academia (Khan & Rahman 2007). Furthermore, as local people are those immediately affected when disasters occur, they become the first responders to the event (Gaillard & Mercer 2013). Thus, in the case study of Chongqing, the participatory approach should be implemented as there are large number of communities are highly affected by the flood.

The integrated emergency planning is the combination of top-down and bottom-up strategies, which needs the participate of local stakeholders. To protect the property and life, it assesses the future risk and resilience capacity of local communities, and to contribute a more cohesive community. And the concept of the living lab could be the critical testing point which is a place for research and design experiments. It also needs the participation of the local communities and stakeholders, to see the potential impacts (both positive and negative) and potential co- benefits that the design test brings.

Theory essay

Runoff as a Key Element for Flood Defense in the Mountainous City

- Taking Chongqing as an example

AR3U023 Theories of Urbanism
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Abstract:

In the process of urban expansion, the impermeable urban pavement was taken the place of green-belt, wetland, and lakes, which caused the reduction of flood control and retention capacity of the original ecosystem and the increasing frequency and destruction of the flood. This phenomenon leads to the rapid increase of stormwater runoff; thus, the total runoff volume and peak discharge are also increased, resulting in an increase in flood threat and risk. In the Yangtze River basin, almost every city has faced this issue. The rising amount of urban runoff also put huge pressure on the Yangtze River and caused transit flood to downstream cities. In this case, runoff could play an important role in flood defense, which could reduce local flood and reduce the transit flood for downstream areas.

Chongqing, as the largest city located upstream of the Yangtze River, also has the most typical geographical condition, which is mountainous, in the upper Yangtze River region. The geographical condition contributes to a more complex runoff system and more opportunities to transfer the runoff to natural swales, creeks, and wetlands. It helps to increase the flood storage capacity of the city. Moreover, Chongqing's learning and experience could also be implemented in the flood defense of other cities located upstream of the Yangtze River.

Keywords:

Runoff, Flood resilience, mountainous city, nature-based solution, Chongqing, Yangtze River basin

1. Introduction

The Yangtze River floodplain is one of the most important ecosystems and human habitats in China and the world (Wang and Wang, 2016). The Yangtze River basin has the highest biodiversity in China. There are 459 million inhabitants living along the river, which is 1.8 times dense than the average population density coefficient in China. The urbanization rate is around 49%. The Yangtze River basin also plays an important role in the Chinese economy and agriculture. This area creates 40.3 trillion yuan (around 6.15 trillion USD) gross domestic product annually, and there are more than 200 km2 of agricultural land along the river. However, this area suffered from the annual floods a lot and caused a serious loss of property and life. The recording of floods in this area could be seen since Han Dynasty (around 185 BC), and the recent research (Yu et al., 2009) shows that after 1950, there is an increasing trend of flood occurrence in the Yangtze River basin. The reason for flood occurrence could be seen in nature and human effects. In nature sections, climate change, especially global warming, shows high relevance with flood occurrence. It is predicted that due to global warming in the late years of the 21st century, the annual precipitation will increase in the Yangtze River basin and affect the increase of flood hazards in this area (Cao, Zhang and Shi, 2011). As for human effects, the expansion of urbanized area increases the impermeable pavement leading to an increasing of surface runoff, and the increasing of the agricultural land increases the soil erosion and causing the decrease of natural water capacity, which both contribute to the more serious flood hazard and more fluent occurrence of flood issues (Gemmer et al., 2008).

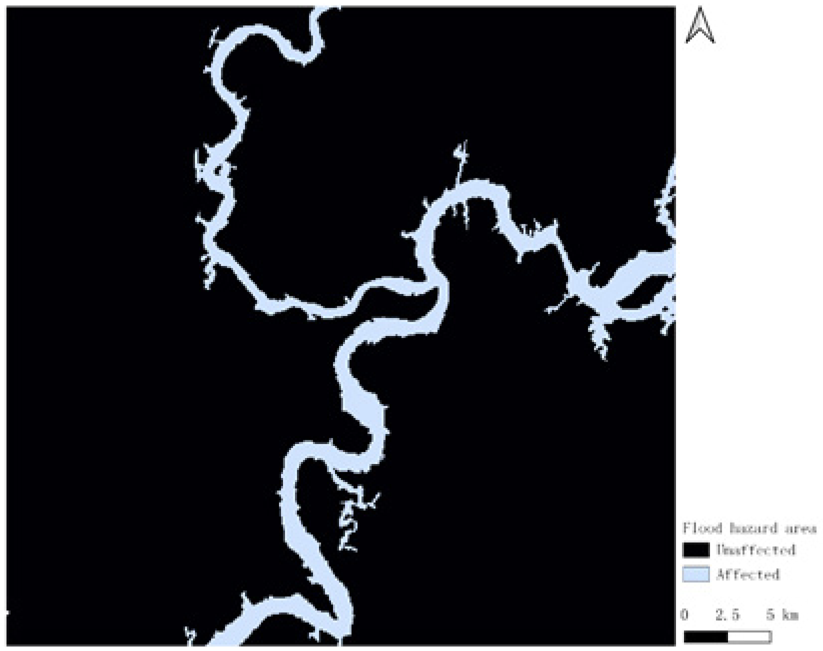

Fig. 1. Areas affected by floods in Chongqing, edited by the author.

Due to the density, the Yangtze River flood highly threatens the safety of inhabitants' property and life. During the summer of 2020, the Yangtze River basin suffered from catastrophic flooding, the most serious flood since 1998. As of July 22, 2020, 45.5 million inhabitants had been affected by the floods, with 142 people had died or been missing, and the flood caused around 116 billion RMB (around 16.5 billion USD) direct economic loss (Wei et al., 2020). Chongqing, as the biggest city in the upper reach of the Yangtze River, also suffered a lot from the flood. In total, 263,200 people were affected, 251,000 people were emergency evacuated, and the direct economic loss was around 2.45 billion RMB (around 373 million USD). This essay will focus on the flood issues in Chongqing. By analyzing the surface runoff system in Chongqing, combined with the development and evolution of the city, the article will explore the importance of surface runoff for flood control. Since this system is based on geographical conditions, land use, and topography, it has great potential to become a tool to guide urban resilience in the future. Simultaneously, since Chongqing has typical characteristics of cities in the upper reaches of the Yangtze River, the adaptability and universality of this research in other upper reaches cities will be discussed.

2. Flood features in Chongqing

Due to the monsoon, Chongqing is prone to flooding during the rainy season, during the rainy season, the main town in Chongqing will be affected by heavy rain and rainstorm. The flood not only threatens local safety but also puts pressure on downstream cities. Understanding the causes of Chongqing floods, the types of floods could be summarized, which could help understand the flooding mechanism and formulate corresponding flood control measures for each type of flood.

2.1. Local storm flood

Chongqing is located upstream of the Yangtze River, and in East Asia subtropical monsoon zone, the precipitation is highly relevant to the monsoon. The mean annual rainfall in Chongqing is about 1100mm for the recent 10 years. The rainy season is focused from May to October, which 70-80% of the precipitation accounting for the whole year, and this concentrated precipitation will cause flooding. The reason caused local storm flood is the rainstorm in some areas inland or regional concentration rainstorms. This type of flood mostly occurs on small and medium-sized rivers, as the rainwater will first flow to those hydro systems. In the rainy season, it frequently happens, with the intensive attack, precipitous fluctuation, and strong destructive power. As it always starts at small upstream rivers, it will suddenly influence the main downstream hydro system, and combined with secondary disasters such as mountain flood disasters, submerging all infrastructure and farmland along riversides, and causing a large amount of soil erosion, thus forming a torrential flood disaster (Dai, Zeng and Li, 2013).

2.2. Transit flood

The transit flood in Chongqing is originated from the rainstorm in the larger area upstream of the Yangtze River or Jialing River. As the last reach of the Yangtze River before the Three Gorges Dam, when the flood comes, this reach of the river will be a part of the flood control system to protect the downstream river basin. This type of flood always happens in the main hydro systems, for Chongqing is the Yangtze River and Jialing River, and it always comes with high peak, large volume with precipitous fluctuation. The duration for this type of flood is long, mainly in a period of 6 to 10 days. During the flood period, the water level varies greatly, usually from 20m to 30m (Dai, Zeng and Li, 2013). This flood's features make urban areas, factories, mines, docks, and agricultural lands located along the riverside easily be inundated, thus forming a flood disaster. However, as this type of flood is originated from upstream, it is easy to predict. At present, the emergency evacuation measures are used to mitigate the influence of this flood. The flood that occurred in Chongqing this summer 2020 belongs to this type.

2.3. Flood combined of various occasions

This type of flood occurred when the local storm flood and the transit from upstream happening simultaneously. Its characters are abrupt rising of small rivers, streams, and springs, but prevented by the Yangtze River and Jialing River (Dai, Zeng and Li, 2013). As it is composed of the 2 previous types of floods, this flood leads to more serious long duration damage and loss. The flood will not only cause secondary disasters such as mountain flood disasters and soil erosion, but it will also inundated the building and infrastructure along the river, resulting in geologic disaster and huge losses.

3. The human impact on surface runoff and flood issue

With the expansion of urban areas and agricultural land, human activities are highly changing the nature geography conditions and natural terrain, which always leading to the increasing of surface runoff and decreasing of nature water storage capacity. In the past 30 years, the urbanized area in Chongqing extended almost 3 times, resulting in a massive expansion of impermeable pavement and infrastructure construction, which significantly increased the runoff coefficient in Chongqing. As shown by the flood features above, if the city's water storage capacity can be improved and the surface runoff coefficient can be reduced, more precipitation can be stored locally instead of flowing directly into the river, thereby reducing flood disasters. Therefore, understanding how human activities affect surface runoff and floods could help explore how to build a more resilient hydro system for the living environment.

3.1. Urban expansion

In the process of urbanization, more and more people moving from the countryside to cities, which caused a rapid increase in urban population and urban areas. The population of Chongqing main town increased from 4.92 million to 6.63 million between 1989 and 2016 (Chongqing Statistical Yearbook, 1990; 2017), and the rapid expansion could also be seen in the area of the urbanized surface. The urban expansion and land-use changes are highly correlated with watershed hydrology (Todd et al., 2007). The research (Gumindoga et al., 2014) shows that a 10% increase in imperviousness

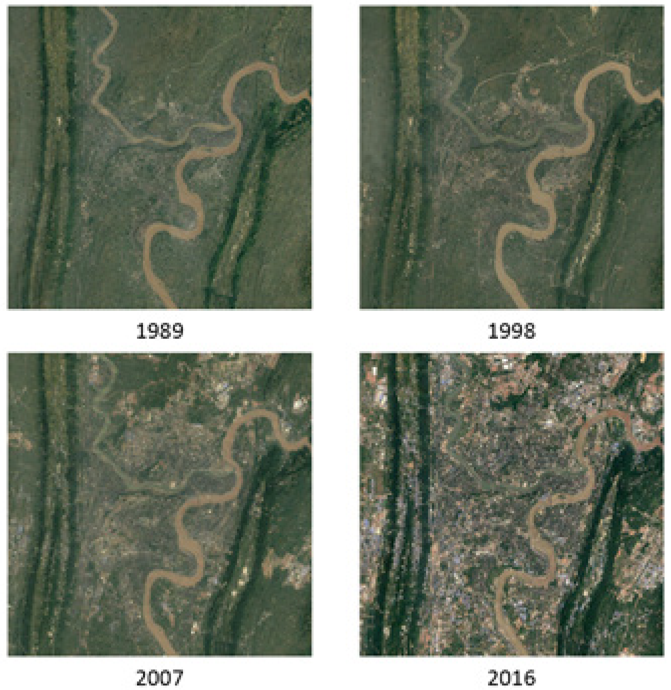

Fig. 2. The extension of Chongqing main town area between 1989 and 2016, edited by the author.

results in an increase in the range of 9.8% to 10.2% in annual mean surface runoff. The increasing of urbanized sufferance will increase cc, which caused the decreasing of precipitation infiltration and the water volumes stored in the soil. Therefore, compare with the vegetation surface, the urbanized surface tends to generate more runoff. With the deduction of precipitation infiltration caused by the increasing of paved and roofed surfaces, the hydrological response of a basin to rainstorm events tends to be faster (Arnone et al., 2018).

As a result, when the monsoon brings heavy rainstorms in summer, the urban expansion and the changes in land use will lead to an increase in total runoff volume and peak discharged. Consequently, the time of pick flood moves up, thus the threat and risk of the flood are increased (Dai, Zeng and Li, 2013).

3.2. Agricultural activities

The agricultural activities in Chongqing could be categorized into two types. The first one is rural agriculture and the second is urban agriculture. Both of them could play an important role in flood control. The major type of farmland in upstream of the Yangtze River is slope farmland. Most of these slope farmlands are steeply sloped land with an annual erosion modulus of more than 10,000 tons/km2 (He and Jiao, 2000). However, there is no evidence shows that compared with natural forests, this type of farmland will increase the amount of surface runoff. The analysis of the Yangtze drainage basin indicates that, on average, When the rainstorm is 90 mm, the runoff depth in the forest area is about 60 mm, and the runoff depth in the non-forest area and farmland is only 35 mm. This is because the flood storage capacity of the forest area has a certain limit. After the flood storage capacity reaches saturation, the effect on reducing the flood peak and runoff coefficient will be reduced (Cheng et al., 1998). The flood storage capacity of non-forest areas and farmland is similar to that of forest areas. The difference is that floods in forest areas occur more slowly, while non-forest areas and farmland are relatively faster. Therefore, although the peculiar agriculture of the mountain region can cause soil loss, compared with the impervious surface of the city, the farmland can still regulate the water system and increase the resilience of the flood. Therefore, if the soil erosion caused by mountain agriculture can be reduced, then the farmland will have the potential becomes an important part of flood control.

Therefore, in the construction of urban-rural integration, urban flood control is not only limited to cities, but the farmland around cities should also take on a certain flood control role, as it enhances the water storage capacity of the soil in the basin and reduces the rate of flooding, thereby reducing the flood peaks and the duration of floods in the main river system. As for the urban agriculture within the city, as a bottom-up, massive patchy land distributed in urban slopes, also brings a certain flood resilience to urban land that uses the impervious ground to a certain extent. It reduces the city's surface runoff coefficient and slows down the rate and peak of the flooding.

3.3. Infrastructure construction

The drainage system and urban hydraulic infrastructures are built to tackle the issue of seasonal flood and waterlogging. The built infrastructure that Chongqing is wildly using now could help to control the flood as soon as they are constructed. However, when facing changes from nature and humanity, they may have the opposite effects (Sutton-Grier, Wowk and Bamford, 2015).

In the main town of Chongqing, some of the drainage facilities are built in the 1960s and 1970s, and some facilities in the low-lying areas were constructed in a low design standard. Due to the development of the city and the increase in rainfall brought by the summer monsoon in the past two decades, such drainage facilities have been unable to meet the existing urban needs (Dai, Zeng and Li, 2013). As a result, when the rainstorm arrives, the drainage facilities cannot quickly discharge the rainwater, which causes the surface runoff to increase rapidly. The rainwater flows into the main river channel rapidly, causing the river's water level to increase rapidly, forming a local storm flood in a short time, and the rainwater will also collect in some low-lying areas, causing urban waterlogging.

To resist transit floods and reduce soil erosion, a large number of hard embankments have been used in Chongqing's main and secondary rivers. Such embankments can protect the lives and property of residents when they resist transit floods. However, its effectiveness declines over time, and it does not have the capacity to adapt to changing environments (Sutton-Grier, Wowk and Bamford, 2015). In the past two decades, the precipitation in the upper reaches of the Yangtze River tends to increase. The more severe transit floods caused by the more frequent rainstorms in the upper reaches have limited the protection of hard embankments. When facing the local storm floods, it often produces counterproductive effects. Hard river embankments are often constructed of materials with poor water permeability. Therefore, they block the exchange of river water and groundwater, reduce the flood storage capacity and resilience of the area, and accelerate the formation of local storm floods.

4. Surface runoff as an ecology flood control tool

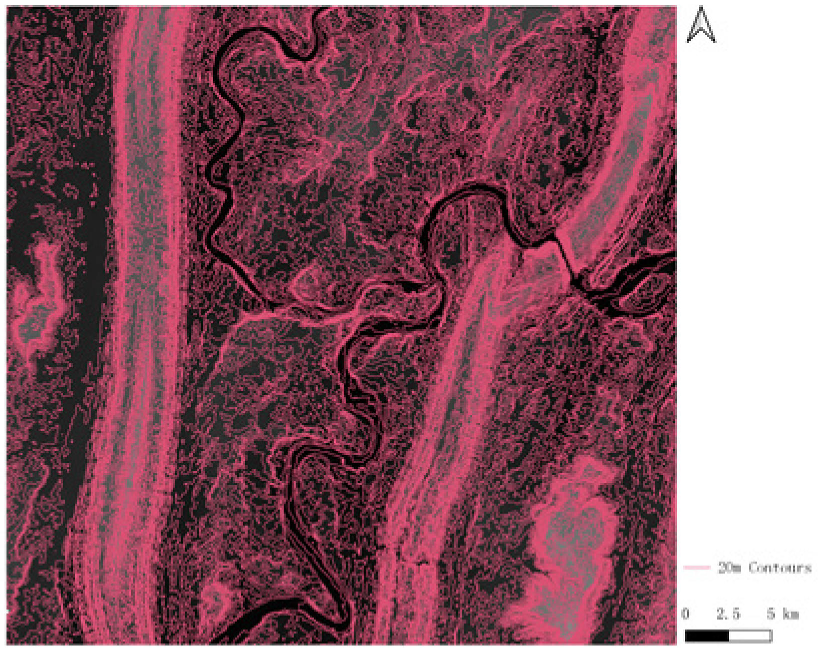

Fig. 3. The topography of Chongqing, edited by the author.

It can be seen from the above chapters that with the development and expansion of cities, the increase in surface runoff has significantly increased the threat of floods to cities. In the process of flood control, the control of surface runoff is particularly important. As a mountainous city, Chongqing has a complex topography, large undulations, and large slopes. In the mountain rainstorm runoff, the hydrological process of the watershed takes place rapidly and subsides in a short time. Rainfall produces fast runoff and high flow velocity, which has a higher impact on the urban ecosystem and has a prominent impact on the basin's water environment. Affected by the slope of the terrain, the rainfall catchment area is relatively narrow, and the drop is large. The erosion effect of rainwater runoff on the ground is more obvious than that of plain areas (Hu, Z. 2016). Therefore, surface runoff on the ground is more obvious than that of plain areas (Hu, Z. 2016). Therefore, surface runoff in mountainous cities is particularly important in urban flood control. Surface runoff can be used as the basis for the construction of flood control facilities in mountainous cities. At the same time, in this process, theories such as Water Sensitive Urban Design, Nature-based Solution, and Ecosystem Participation can be used as well, thus not only increasing urban flood control capacity but also increasing urban resilience to floods.

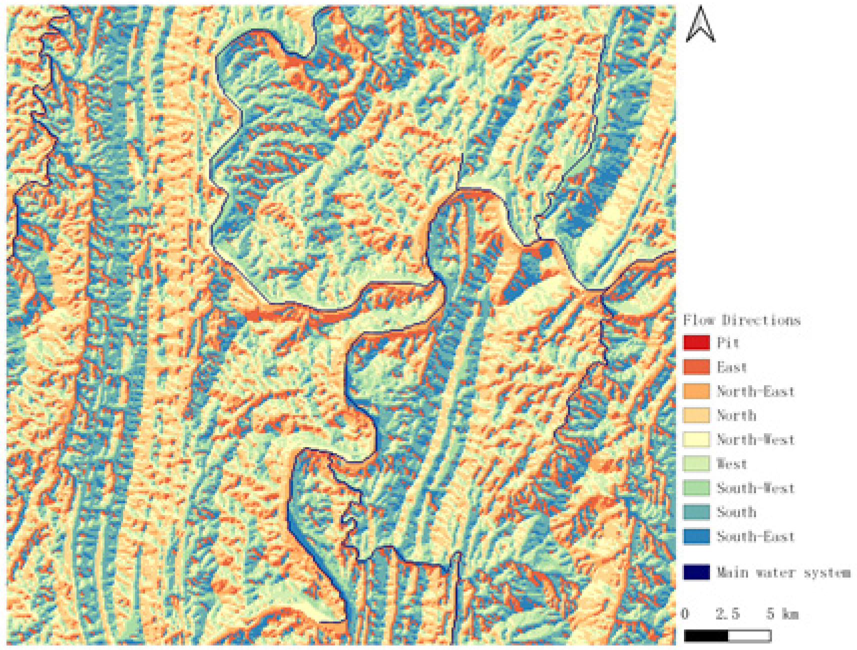

Fig. 4. The topography of Chongqing, edited by the author.

Instead of focusing on control floods with 'gray' infrastructure solutions, the nature-based solution provides a more adaptive way to control the flood. The hybrid embankments and sustainable urban drainage systems aim to slow down and reduce the quantity of surface runoff in the urban area in order to minimize the downstream flood risk. As the nature-based solution, the hybrid embankments and sustainable urban drainage systems using the natural process and combing the grey/green infrastructure to slow, store, infiltrate and treat the runoff (Davis and Naumann, 2017). This approach will control and minimize the flood hazard and increase the flood resilience and climate adaptation of the city. In the meantime, it will also contribute to the ecosystem.

The hybrid embankments, which is a combination of 'gray' infrastructure (hard embankments, water gates, bulkheads, etc.) and 'green' infrastructure (vegetations, floodplain, etc.), capitalizes on the best characteristics of these two types. It could minimize the risk of flooding effectively and greatly enhance the city's adaptability (Sutton-Grier, Wowk and Bamford, 2015). Comparing with the hard river embankments, which are wieldy constructed now, the hybrid embankments could increase the water storage capacity in the basin and slow down the conversion of rainwater runoff into floodwater. Moreover, the hybrid embankments could also provide co-benefits for society and the economy besides the flood defense.

The sustainable urban drainage systems include the following elements: (1) Rainwater harvesting systems; (2) Green roofs; (3) Permeable pavements; (4) Bioretention systems; (5) Trees; (6) Swales, detention basins, retention ponds, and wetlands; (7) Soakaways and infiltration basins (Woods Ballard et al. 2015). This system will reduce surface runoff and increase water storage capacity in highly urbanized areas through the facilities above or below ground, thereby achieving the purpose of enhancing urban stormwater resilience. This kind of solution is diverse in nature, and the drainage method used depends on local characteristics (State of Green, 2015). In Chongqing, the complex topography creates more possibilities for the system, which is different from plain cities. For example, the slope creates more possibilities for the bioretention system. By collecting runoff from the hillside into a temporary surface pond, the velocity of surface runoff is reduced, thereby enhancing the flood resilience of the mountainous city and reducing soil erosion. And part of the depressions can be used as ecological swamps, thereby enhancing the city's water regulation capacity.

Elements of sustainable urban drainage systems	Functions
Rainwater harvesting systems	Collect and store rainwater from roofs and other paved surfaces (such as car parks) for re-use
Green roofs	Involve constructing a soil layer on a roof to create a living surface that reduces surface runoff
Permeable pavements	Act as a hard surface for walking or driving, while enabling rainwater to infiltrate to the soil or underground storage
Bioretention systems eg. rain gardens	Collect runoff in a temporary sur- face pond before it filters through vegetation and underlying soils
Trees	Capture rainwater while also providing evapotranspiration, biodiversity and shade
Swales, detention basins, retention ponds and wetlands	Slow the flow of water, store and treat runoff while draining it through the site and encouraging biodiversity
Soakaways and infiltration basins	Promote infiltration as an effective means of controlling runoff and supporting groundwater recharge

Fig. 5. Functions of sustainable urban drainage system elements (Woods Ballard et al. 2015).

Under the context of the nature-based solution, urban agriculture could also play an important role in the flood. As the large natural patch in the city, while reducing soil erosion through 'green' or 'gray' infrastructure, urban agricultural areas could also be used as a part of a sustainable urban drainage system to enhance urban flood resilience.

5. The potential co-benefits

Using theories such as Water Sensitive Urban Design, Nature-based Solution, and Ecosystem Participation to implement the flood resilience to the mountainous city, the flood control measures also bring the potential co-benefits to the ecosystem, social and economic.

5.1. The co-benefits with ecosystem

The flood defense strategy could help to increase biodiversity. In the main town of Chongqing, due to the massive construction of impermeable surface, the species of plants for greening are single, and the species of animals are also limited. By implementing the hybrid embankments and sustainable urban drainage systems, and better flood resilience, the local ecosystem will also be improved. In the construction of the infrastructure such as the hybrid embankment and rain garden, to achieve better environmental resilience, the selection of species will be more extensive. Therefore, a variety of plants will be selected instead of a single type, and different types of plants will attract and provide habitat for different species of insects and animals. Thus the formation of a more complex and resilient ecosystem has increased the biodiversity of the city. Additional facilities such as roof greening and bioswales have transformed the originally hard impermeable surface into a natural permeable surface, thereby creating areas of habitats for local insects and animals and brings nature back to the city.

Another co-benefit that the flood defense strategy could bring is better water and air quality and reducing urban heat island. When harvesting rainwater, sustainable urban drainage systems could filter and purify the rainwater (Liu et al., 2016). Comparing with the runoff on the impermeable surface, the water discharge to the natural hydro system by the sustainable urban drainage systems could effectively reduce water pollution. When implementing the flood control strategy base on the nature-based solution, plants will be used in a large area and replace the original hard surface. The vegetations will help to increase pollutants deposition and improve air quality. Moreover, vegetation, especially trees, can reduce local temperatures through evapotranspiration and shading, which could help mitigate the urban heat island effect, especially for the microclimate (Baró and Gómez-Baggethun, 2017).

5.2. The co-benefits with social & economy

The enhancement of urban flood resilience also helps strengthen social resilience. The flood resilience urban environment could protect the local inhabitants' lives and property better, especially for communities in the vulnerable areas. A safer living environment can contribute to a more resilient society. By extending the natural permeable areas in the city, the flood resilience strategy also provides high-quality public spaces for local communities. Those public spaces create opportunities for leisure and recreation and thereby promote health and well-being. Those areas give people opportunities to release mental stress, doing physical exercises, and contribute to a healthier lifestyle. Those public spaces also help create a sense of place, cultural identity, and social cohesion, which are important factors for societies to adapt to change (Cabral et al., 2017). As an important part of the flood control facilities, urban agriculture could also function as a driver for community building and social cohesion and increase socio-ecological resilience. Due to its important ecological value, flood control facilities and the surrounding public space could also be used as popular science spots for kids, providing environmental education, understanding natural processes, cycles, and climate change processes for the next generations.

In terms of economy, from the urban and regional scale, improving urban flood resilience means that the economic losses caused by annual flooding disasters will be greatly reduced and compare with gray infrastructure, the green infrastructure could bring more economic benefits (van Ham and Klimmek, 2017). The economic benefits could be found in tourism, business opportunities, and property values. At the same time, the sustainable urban drainage system contributes to a better and safer urban environment, which will promote property values around the facilities. The quality of public spaces will also attract tourists and promote local tourism. And it will also promote the development of surrounding businesses and create employment related to sustainable development.

6. Conclusion

The runoff in the urbanized area has increased due to the expansion of impervious areas, land use changing, and low capacity of the drainage system. The high runoff coefficient will accelerate the formation of local storm floods during heavy rains and cause more severe transit floods for downstream areas. In Chongqing, because of the more complex topography of the mountainous city, rainstorm produces more surface runoff and has a more serious impact on floods hazard. Therefore, the reduction of runoff would effectively alleviate the threat of flooding to the city. To reach that goal, theories such as nature-based solutions, ecosystem participation, etc. could be implemented to increase the flood resilience of the city. Meanwhile, those theories will also bring co-benefits to the local ecosystem, society, and economy. It contributes to a more resilient urban, not only in flood defense but also in the ecosystem and society.

This essay only discussed the situation and solution of flood issues in Chongqing. As Chongqing has the typical topography and hydro features in the upper reaches of the Yangtze River, in the future, the theories and methods in this essay could also be implemented in other upper reach cities to mitigate the flood hazard and to control the flood in regional scale.

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Research framework

The starting point of this research is personal motivation, by combing it with the scientific relevance, social relevance, and theoretical researches, the problem statement is built. Constantly, defining the research questions and aims. The research will implement the mixed method which combines quantitative research for the terrain, water catchment, runoff and qualitative research for the stakeholders, residents. By understanding what made the flood, how flood influence people, and why it is urgent to improve the current flooding situation, the flood control scenarios, and design & management component will be the experiment to twisting the current issue. After comparing the design results and current situations, it will prove whether the research is effective and whether the research could reach the aims.

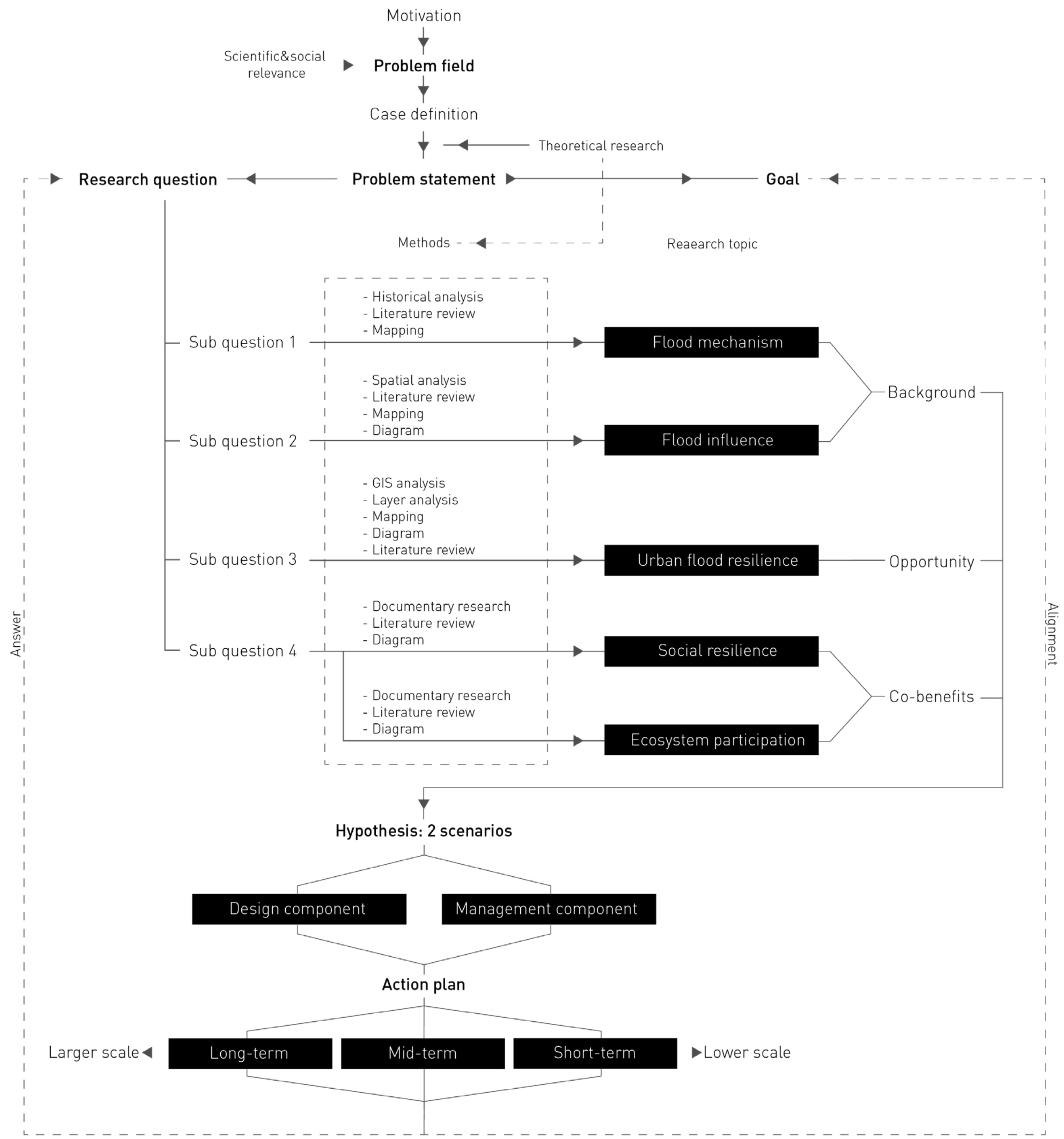


Fig. 23. Research framework, edited by author

Methods

For the development of the research project, finding answers for the research questions, the following methods are used in the project.

(1) Theory review

The theory review includes the literature view and historical revies, the aim of it is to explore theories and understand the context of the research. It provides the foundation of the research approach, conceptual framework, and theoretical framework. The first and the second sub- research questions requires the literatures and theories describing the flood mechanism and influences. The third and the forth sub-research questions require the theories relevant to flood defense strategy and its co-benefit.

(2) Document analysis

The aim of this method is to collect relevant data and understanding the government's strategies. To understanding regional Yangtze river hydrological information, the documents from the Yangtze River Water Resources Commission are needed. It also helps to understanding the first sub-research question. The analysis of the Chongqing 2020 Master Plan and other previous master plans of Chongqing helps to understanding the development and the land-use change of the case area. And it helps to answer the second and third sub-research questions. The statistical repots of Chongqing help to collect the data and describe the characteristic of the city, answering the third sub-research question.

(3) Mapping and spatial analysis

This theory also includes the layer analysis and GIS analysis. The aim of this series of methods is to understand the spatial relations between build environment, constructed and non-constructed landscapes, and social-spatial relevance. It also helps to find the flood hazard area and to select the case study areas. The visualization of data collection could bring a general answer to the second and third sub-research questions.

(4) Scenario making

The aim of this method is to explore the boundaries of the research and to help the following design test to position itself in between the boundaries. It could also help to discuss the relationship between human and hazard. The exploration of the extreme situations could help to answer the main and the third sub-research questions.

(5) Research by design

The aim of this method is developing the regional and local flood control strategy and later for the design interventions, showing the possible guidelines. It will also provide the possibilities of emerging methods found during the research. This method is used as the answer for the main research question, as well as the first and second sub-research questions

(6) Design test

The aim of this method is to check the research relevance and practicality, also reflect on the main research question, to test if the outcomes could answer the question. This method is not only about the reflection of the flood resilience, it will also include the stakeholders, social-spatial sector, and social-ecological sector. The design test would allow for the reflection on defined theories, and revision of the developed strategy.

Analytical framework

The analytical framework describes the aim, purpose, and data resources of the analysis. In order to get the flood resilience vision in the regional and local scale, the framework is set and to analyze present water issues in its safety, conflict, and opportunity. As the water issues include different elements, both quantitative and qualitative methods will be used in the analysis. The quantitative analysis will be implemented mainly in the natural system, and the qualitative analysis will mainly be implemented in the social-spatial aspects.

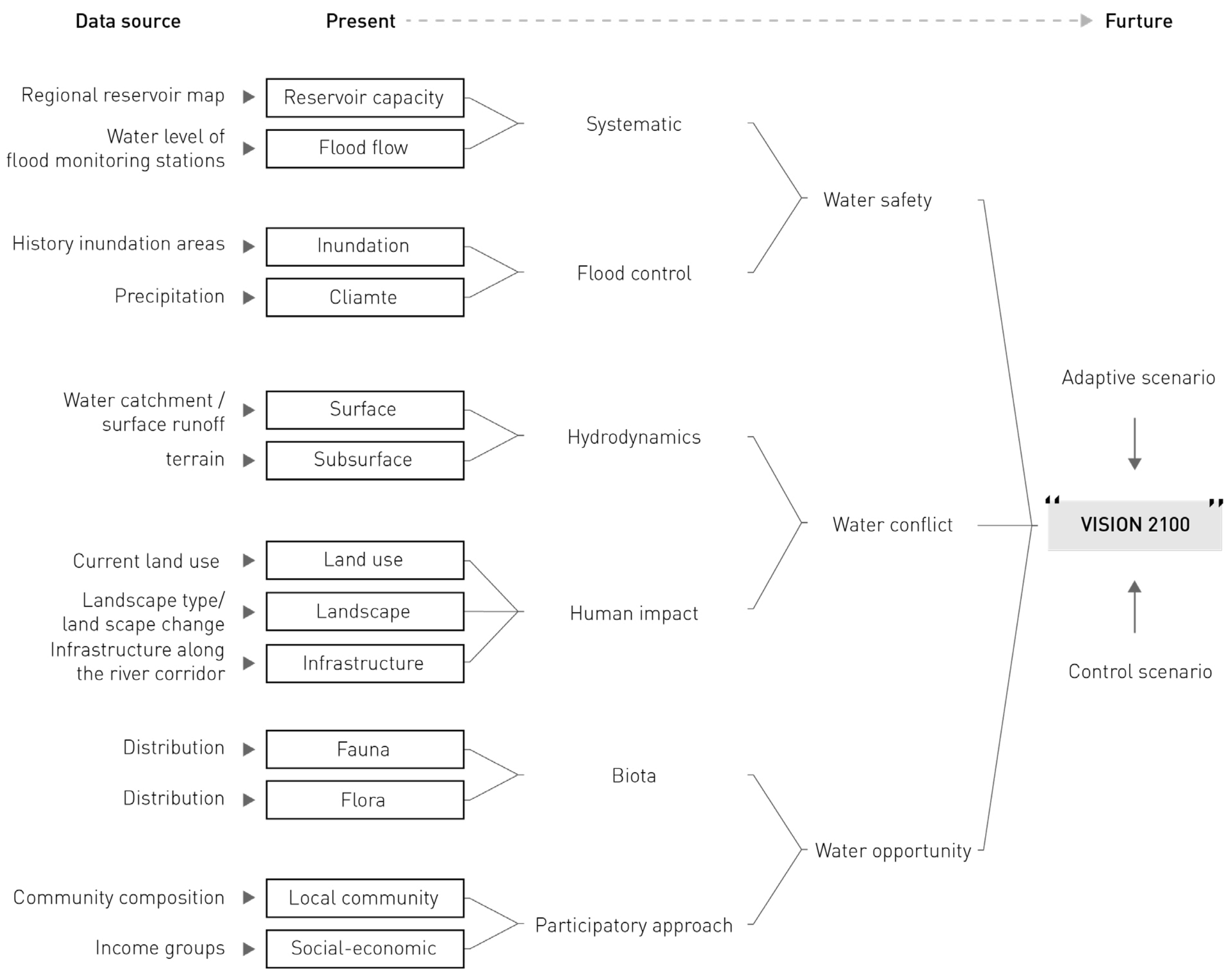


Fig. 24. Analytical framework, edited by author

Fig.27. After the flood, a man and a dog, Ciqikou, Chongqing, shoot by Gou, Y. edited by author

06. Analysis

After exploring the research statement and research question, the analysis part helps to answer the first and second sub research question, explore the characters and the conflicts of the study area, and select the sites for the design test. The water safety analyzes the reason and impact of flood issues on regional and urban scales. The water conflict analyzes how natural systems conflict with man-made environments. The water opportunities analyze the ecology and social status quo and issues which could be improved simultaneously with flood resilience.

Charpter structure

a. Water safety

- Systematic
- Flood control

b. Water conflict

- Hydrodynamics
- Human impact

c. Water opportunity

- Biota
- Participatory approach

d.Location selection

Water safety

The section of water safety discusses the systematic reason of flooding and how floods will influence the urban environment. The section consists of two parts, systematic and flood control. The first part starts from regional scale in order to understanding the mechanism of flood and the flood capacity, which provided by built infrastructure, of upstream Yangtze River. Furthermore, discuss the current limitations and pressures of regional flood control. The second part is on the urban scale, in order to find out the vulnerable urban areas that easily influenced by the annual flood hazard.

Chapter structure

a. Systematic

- Reservoir capacity
- Flood flow

b. Influence

- Climate
- Inundation areas

Systematic

Reservoir capacity

- Status quo of upstream Yangtze River water system & hydro infrastructure

The Yangtze River Basin is a wide area, and has heavy rainfall and frequent heavy rains. Most of the floods of the mainstream have a large peak height and a long duration. The Yangtze River flood is formed by heavy rain, and the time of flood occurrence corresponds to the time of heavy rain. At the same time, the Yangtze River Basin has many water systems, complex water regimes, different locations of rainstorms in each year, large differences in flood sources and composition, and wide distribution of flood disasters.

The upstream of the Yangtze River Basin also hasa complex water system, and there are many water systems that merge into the Yangtze River. Among them, the main tributaries are the Yalong River, Minjiang, Jialing River, and Wujiang. In order to control the frequent floods in summer, many reservoirs have been built in the upper reaches of the Yangtze River and its tributaries, and the upstream reservoir system has gradually formed, which has improved the flood control capacity of the upper reaches of the Yangtze River. At the same time, important nodes on the Yangtze River (such as the junction of the two rivers, important cities) are also equipped with flood control stations to detect water levels and cross-section runoff.

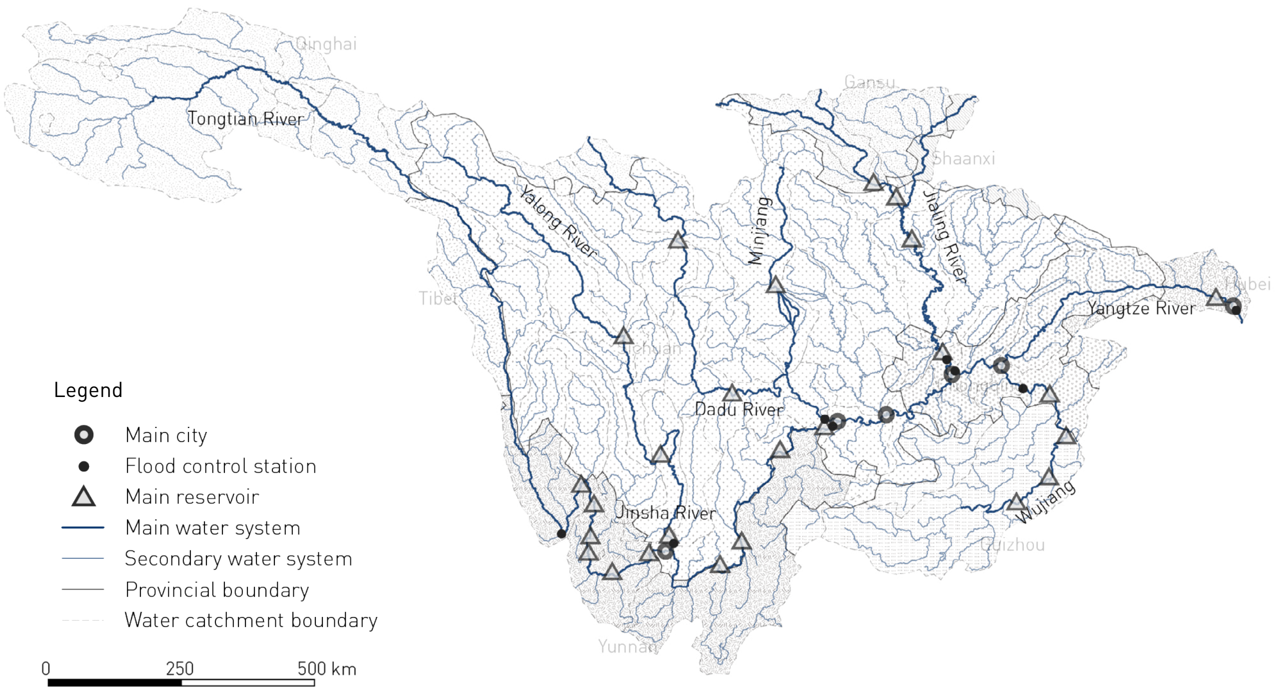


Fig.28. Map of the upper Yangtze River water system, edited by author

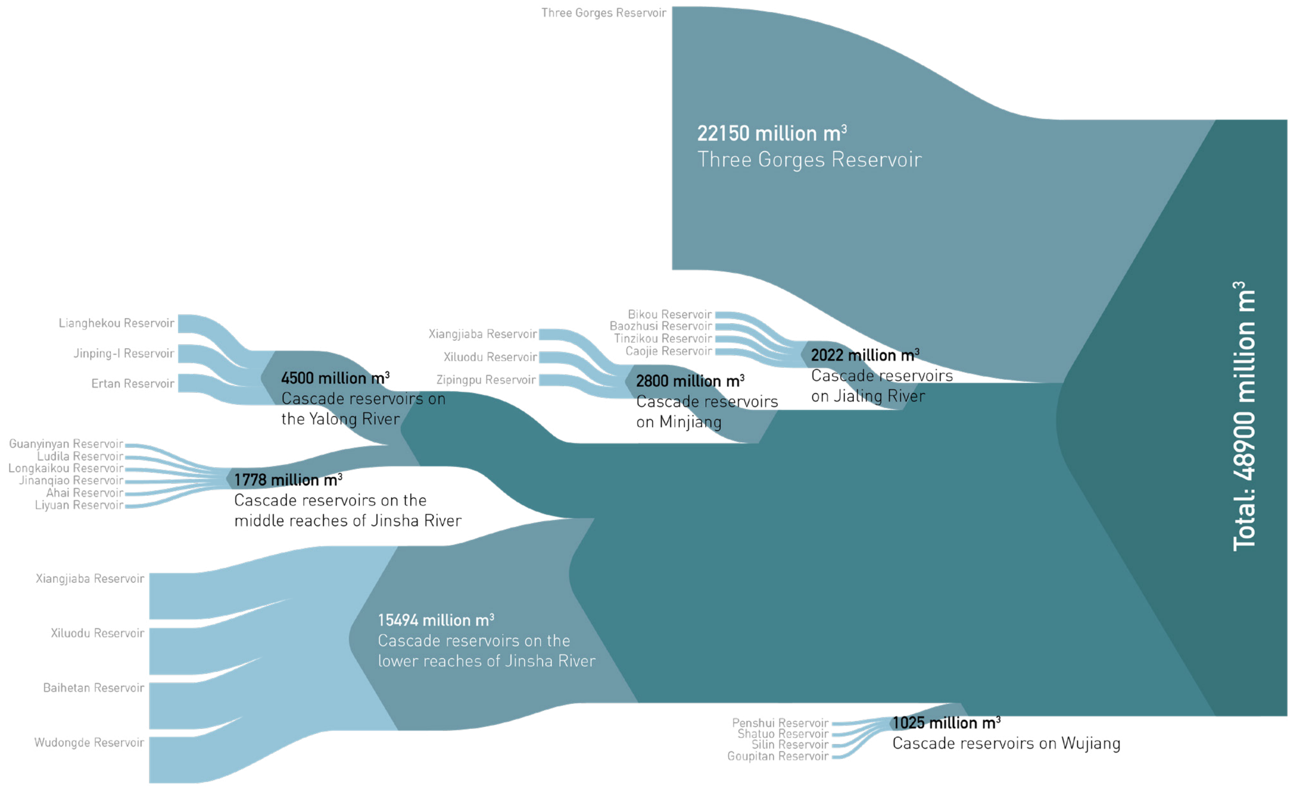


Fig.29. Reservoir capacity of the upper Yangtze River, edited by author

- Reservoir capacity

The reservoir groups on the upper reaches of the Yangtze River are an important part of the Yangtze River flood control system. According to the overall arrangements for flood control of the Yangtze River, most of the reservoirs in the upper reaches of the Yangtze River are responsible for dual flood control tasks. In addition to meeting the flood control requirements of the river section, they also cooperate with the Three Gorges Reservoir to play a flood control role in the middle and lower reaches of the Yangtze River. The reservoir groups are follows:

Group(1) Cascade reservoirs in the middle reaches of the Jinsha River

Group(2) Cascade reservoirs in the lower reaches of the Jinsha River

Group(3) Cascade reservoirs in the Yalong River

Group(4) Cascade reservoirs in the Minjiang

Group(5) Cascade reservoirs in the Jialing River

Group(6) Cascade reservoirs in the Wujiang

Group (1): Raising flood control capacity in Panzhihua City. Cooperate with the Three Gorges Reservoir to undertake flood control tasks in the middle and lower reaches of the Yangtze River. When necessary, cooperate with the cascade reservoirs in the lower reaches of the Jinsha River to reduce the flood control pressure of the Sichuan-Chongqing river sections.

Group (2): Raising the flood control capacities in the main urban areas of Yibin and Luzhou in the Sichuan-Chongqing river section. Mitigating flood pressure in the Chongqing main town; cooperate with the Three Gorges Reservoir to undertake flood control tasks in the middle and lower reaches of the Yangtze River.

Group (3): Cooperate with the Three Gorges Reservoir to undertake flood control tasks in the middle and lower reaches of the Yangtze River. When necessary mitigate flood pressure of the Sichuan-Chongqing river section, downstream of Yalong river and Jinsha river

Group (4): Raising the flood control capacities in the lower reaches of the river, when necessary mitigate flood pressure of Leshan.

Group (5): Raising the flood control capacities in cities along the river such as Cangxi, Langzhong, Nanchong, Hechuan, Sinan and, etc. Mitigating the flood pressure in the Chongqing main town.

Group (6): Raising the flood control capacities in cities along the river such as Yanhe, Pengshui, Wulong and, etc. Cooperate with the Three Gorges Reservoir to undertake flood control tasks in the middle and lower reaches of the Yangtze River.

Fig.30. Schematic diagram of 25 reservoirs in the upper reaches of the Yangtze River, edited by author

Flood flow

The diagram below shows the relationship between the different water systems of the upstream Yangtze river, and comparison of the annual flow of mainstream and different tributaries of the upstream Yangtze river. Also, the diagram could represent the quantity of flood occurs of mainstream and different tributaries of the up stream Yangtze river.

The total reservoir capacity of upstream Yangtze river is around 48900 m^3, however the quantity of total annual runoff is around 438938 m^3, which means the storage capacity of all reservoirs in the upper reaches of the Yangtze River accounts for only one tenth of its annual flow.

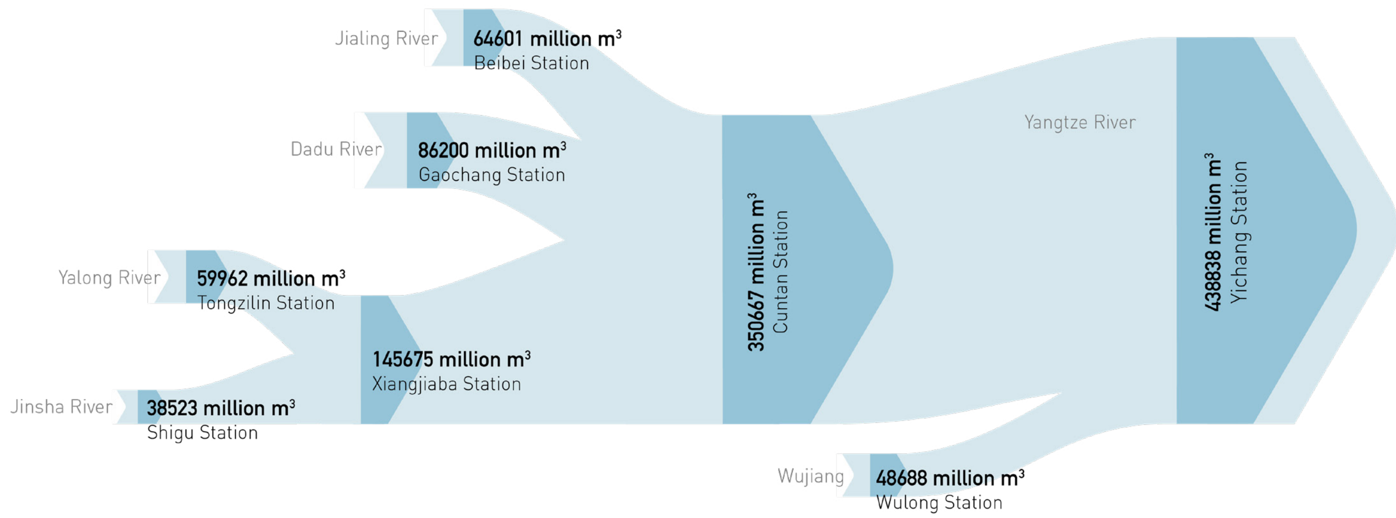


Fig.31. Annual flow of the upper reaches of the Yangtze River, edited by author

The current storage capacity has improved the flood control capacity of the upper reaches of the Yangtze River to a certain extent, but it is still difficult to cope with more sustained catastrophic floods. Therefore, in order to raise the regional flood control capacity to the utmost extent, the reservoirs on the upper reaches of the Yangtze River need to cooperate in a dynamic way, rather than the current linear way.

Flood Control

Climate

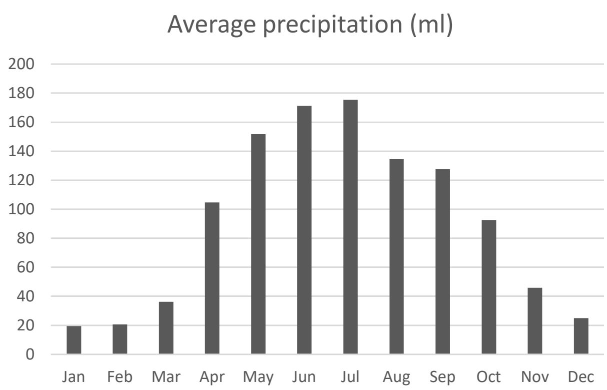
- Regional climate

Regional climatic characteristics are one of the causes of summer floods in Chongqing. Due to the affection of summer monsoon, the upper reaches of the Yangtze river often occurs long-lasting and heavy precipitation, which leads to flooding in the upstream areas. If the flood exceeds the flood storage capacity of the upstream reservoirs, in order to control the flood, the upstream reservoir group needs to coordinate with the Three Gorges Reservoir. Ensuring the safety of the upstream cities. At the same time, in order to ensure the safety of the downstream cities of the Three Gorges, the Three Gorges cannot discharge the flood at the maximum amount except for the catastrophic flood in the upstream. Therefore, if floods occur in multiple upstream tributaries at the same time, it is easy to cause the flood discharge of the Three Gorges to be less than that of the upstream reservoir group. This phenomenon will bring a long peak flood period to the Chongqing section of the Yangtze River which located in the upper reaches of the Three Gorges, resulting in Chongqing's transit flood.

This kind of transit flood usually floods fields, facilities, and buildings along the river corridors, causing a large number of economic losses.

- Urban climate

Chongqing's climate condition is one of the main causes of Chongqing floods. The local storm floods that occur frequently in summer are caused by the climate characteristics of Chongqing. It can be seen from historical data that the average monthly rainfall days in Chongqing urban area throughout the year are high, especially the monthly rainfall days from April to June reached more than 15 days. From the perspective of rainfall, due to the influence of the monsoon, the rainfall from April to October is relatively large, especially in June and July, the monthly average rainfall has reached more than 160ml. Because of the concentrated and heavy rainfall in Chongqing, it is also very easy to cause local storm flood in summer.



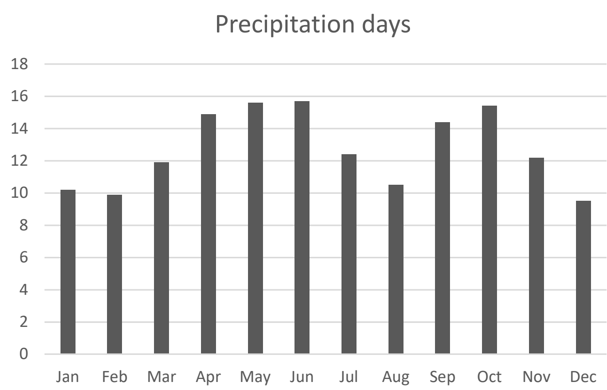


Fig.32. Average monthly rainfall in Chongqing, edited by author **Fig.33.** Average monthly rainfall in Chongqing, edited by author

Local storm floods will rapidly increase the surface runoff in a short period of time, which raising the water level of the main water system rapidly, threatening the facilities and houses along the banks of the water system, and increasing the pressure of flood control downstream cities. In addition, the rapidly increasing surface runoff will also bring many secondary disasters, such as landslides and mudslides, which threaten the human living environments. Because a large amount of soil is washed away, the plant group on the riverbank becomes fragile and single, and at the same time reduces the habitat of other animals, thereby reducing the biodiversity of the environment.

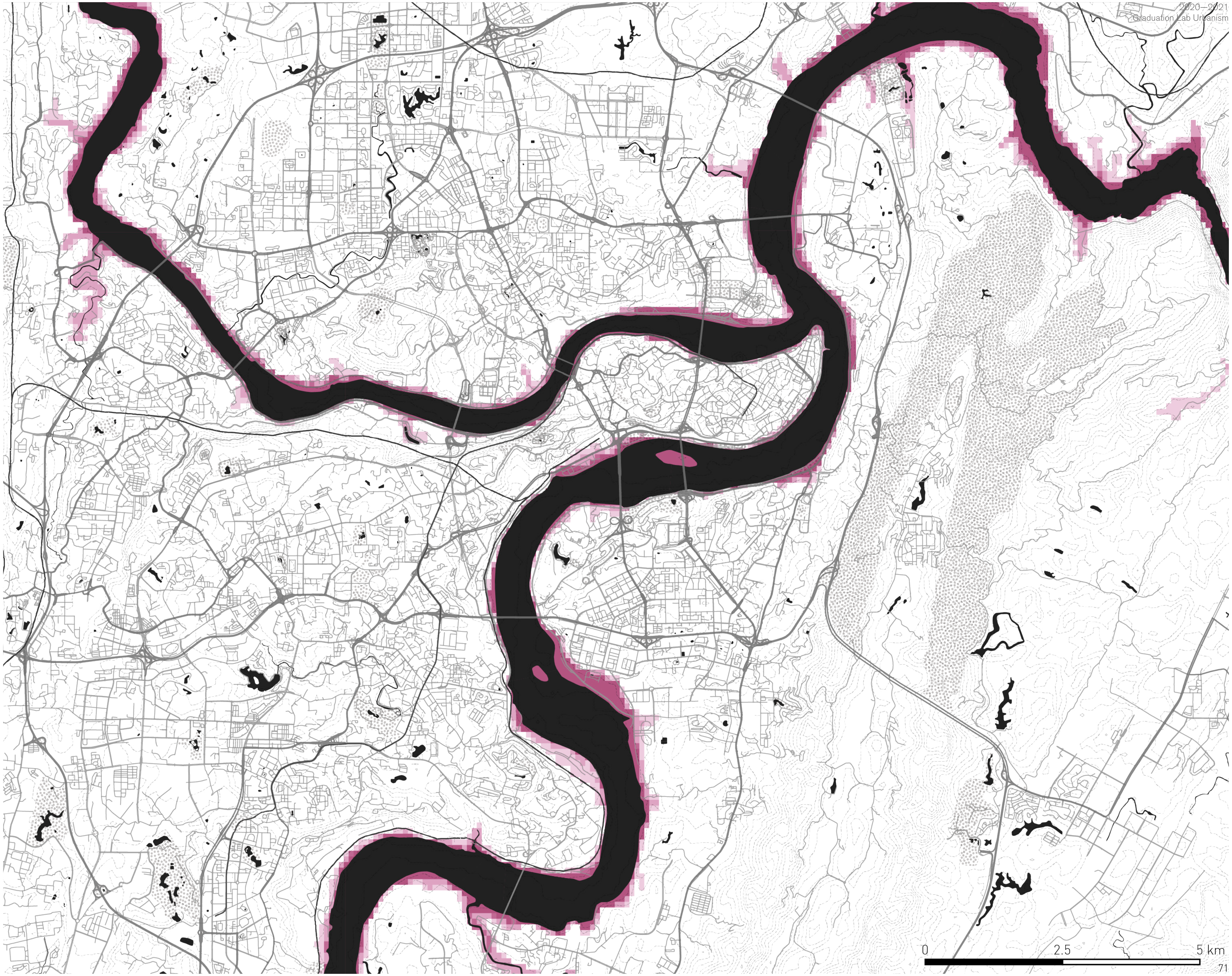
- Influence

The regional scale and urban scale climate conditions greatly affect Chongqing's water safety. The annual floods in Chongqing are basically composed of climatic factors under these two spatial scales. Seasonal floods seriously threaten the safety of urban environments and properties. As a mountainous city, Chongqing has limited land suitable for urban construction. Under the strong demand for urban expansion, some urban areas are constructed in lands that easily to be affected by the flood, without considering the safety issues. This also makes the impact of the flood on the city more severe.

Inundation

The Chongqing main town is highly affected by the annual flood. The Inundation map is based on the data of the highest flood level from 2010 to 2020, reflecting the intensity of flooding inundation in the Chongqing main town.

The map will help to find the critical area which highly affected by the flood.



N

Legend

Affected by the flood

Low

High

Water Conflict

The water conflict refers to the conflict between the natural hydro system and built environment. It is mentioned in the theoretical chapter that as a mountain city surface runoff has a key role in improving urban flood control resilience, therefore, this section intends to discuss the conflict between natural hydrological environment and artificial construction caused by surface runoff in the Chongqing main town. In the hydrodynamic part, the location of the main runoff and its flow direction are analyzed. In the human impact part, it analyzes how landscape changes, the distribution of urban functional areas, and infrastructure. With this series of analyses, the conflict between natural hydro system and built environment could be mapped out, and the most serious water conflict areas in the Chongqing main town could be found.

Chapter structure

a. Hydrodynamics

- Surface

- Subsurface

b. Human impact

- Landscape

- Land use

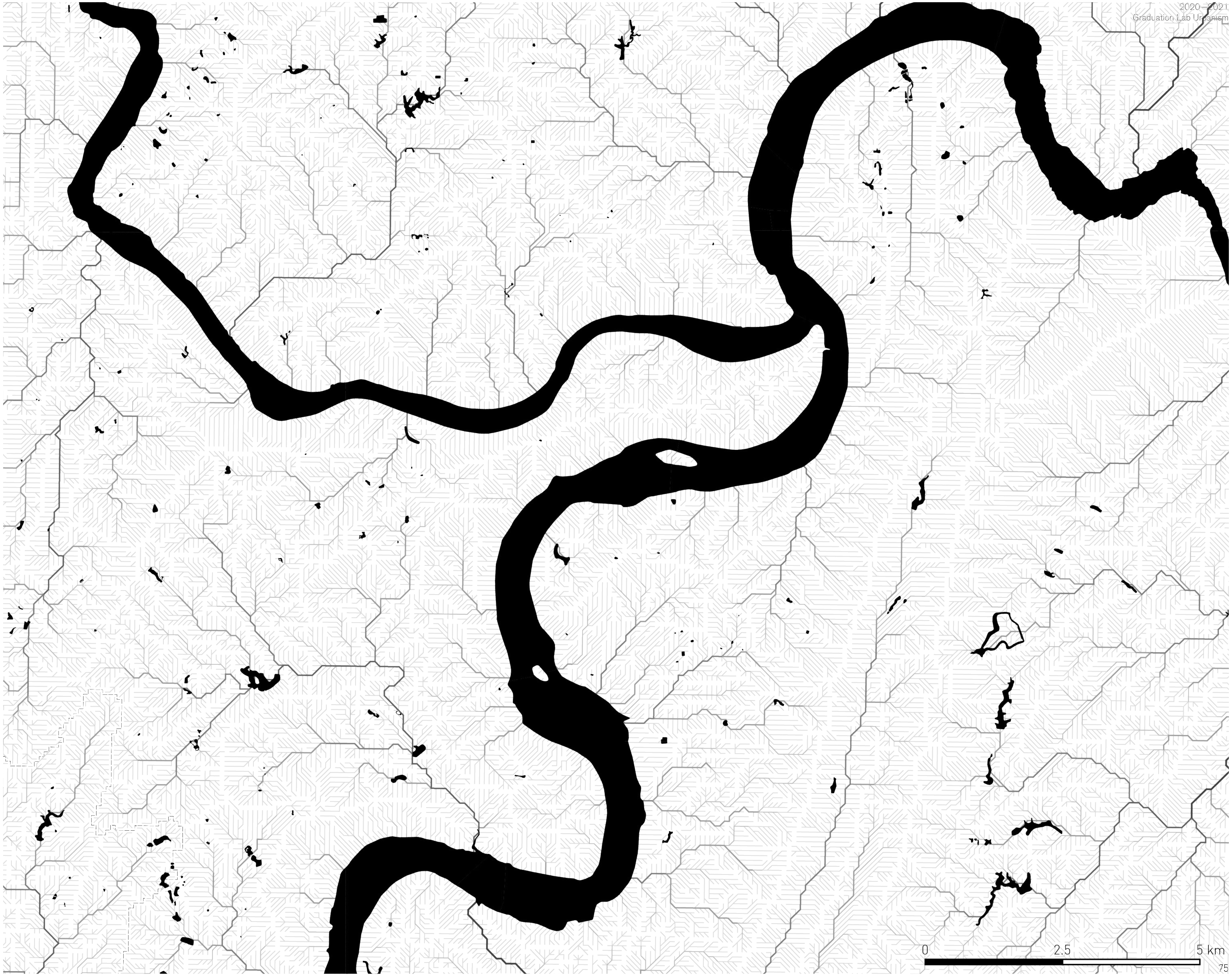
- Infrastructure

Hydrodynamics

Surface

- Runoff

Surface runoff is an important stage between the conversion of rainwater into flood, and runoff hierarchy can be obtained through runoff analysis. Increasing the water capacity and resilience on the high hierarchy runoff will more effectively slow down the speed of rainwater gathering, thereby reducing or at least mitigate the occurrence of local storm floods.



N

Legend

Runoff hierarchy

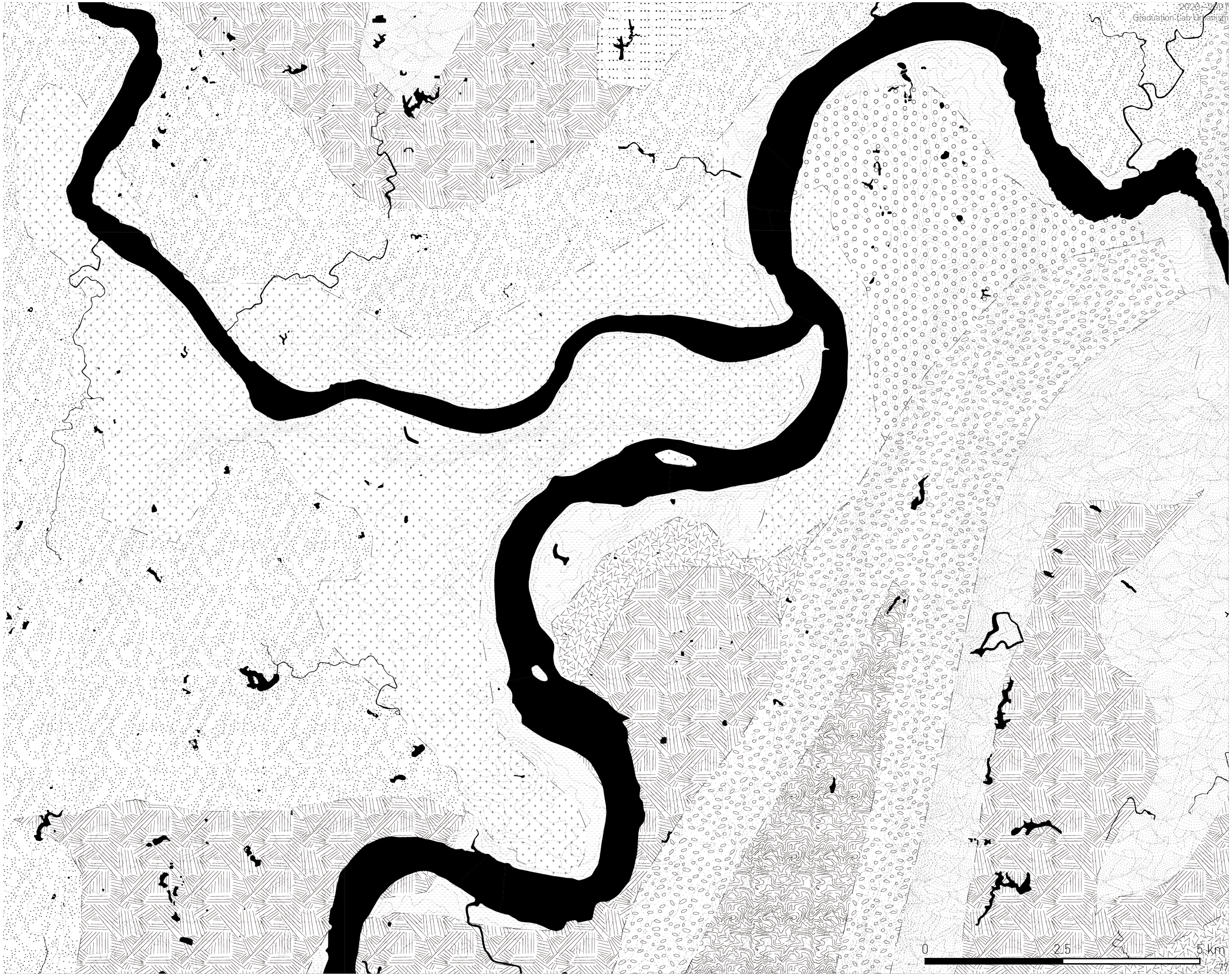
1 Low
2
3
4
5
6
7 High

Basin boundary
Nature water system

Subsurface

- Soil type

In addition to topography, soil type can also significantly affect surface runoff. When runoff flows through, the soil with good infiltability will seep more rainwater, thus significantly weakening the intensity of surface runoff. Therefore, when studying surface hydrology, subsurface soil conditions also need to be considered.



N

Legend

- Dark yellow brown soil
- Urbanized area
- Yellow soil
- Riverbed
- Lime (rock) soil
- Calcareous purple soil
- Paddy soil
- Neutral purple soil
- Waterloggogenic paddy soil
- Brown soil

Subsurface

- Soil type&soil infiltration

The rate that water infiltrates into the soil and moves through the soil affects the amount and rate of runoff leaving the site. As a result of low infiltration and transmission rates, fine textured soils, such as clay, produce a higher runoff volume than do coarse textured soils, such as sand. Sites having clay soils may require the construction of more elaborate drainage systems than sites having sandy soils.

Soil scientists have assigned all soils to one of four hydrologic groups based on infiltration and transmission rates. The four hydrologic soil groups based on infiltration and transmission rates are:

Group A (low runoff potential): These soils exhibit high infiltration and transmission rates and low runoff volume. They are chiefly deep, well drained sands or gravel.

Group B (medium low runoff potential): When thoroughly wet, but not saturated, these soils display moderate infiltration and transmission rates and runoff volume. They are moderately to well drained soils, generally moderate in depth, moderately fine to moderately coarse in texture, including sandy loam, loam, silt loam, and silt.

Group C (medium high runoff potential): These soils have slow infiltration and transmission rates and high runoff volume when wet. They are distinguished by a layer that impedes downward movement of water and are moderately fine to finely textured. This group includes clay loam.

Group D (high runoff potential): These soils have the slowest infiltration and transmission rates and the highest runoff volume. They are chiefly clay soils with a high swelling potential or have a permanent high water table. Other characteristics may include a claypan at or near the surface and shallow soils over nearly impervious material.

Based on this classification and the characteristic of different soil types in Chongqing, the relationship between soil type and soil infiltration is built, and the information of soil type could be translated to soil infiltration.

Group A

Riverbed

Characteristic:

Rock and loamy sand

Group B

Dark yellow brown soil

Characteristic:

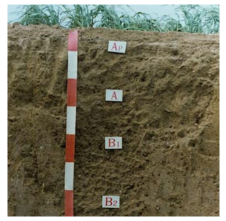
Loam, sandy loam

Calcareous purple soil

Characteristic:

Gravel soil, loam

Brown soil



Characteristic:

Sandy soil, sandy loam

Group C

Yellow soil

Characteristic:

Silt loam

Lime (rock) soil

Characteristic:

Clay loam

Neutral purple soil

Characteristic:

Clay loam

Group D

Urbanized area

Characteristic:

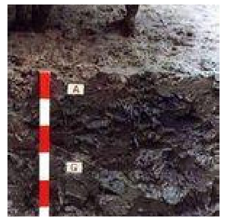
Impervious material

Paddy soil

Characteristic:

Clay with high water table

Waterloggogenic paddy soil



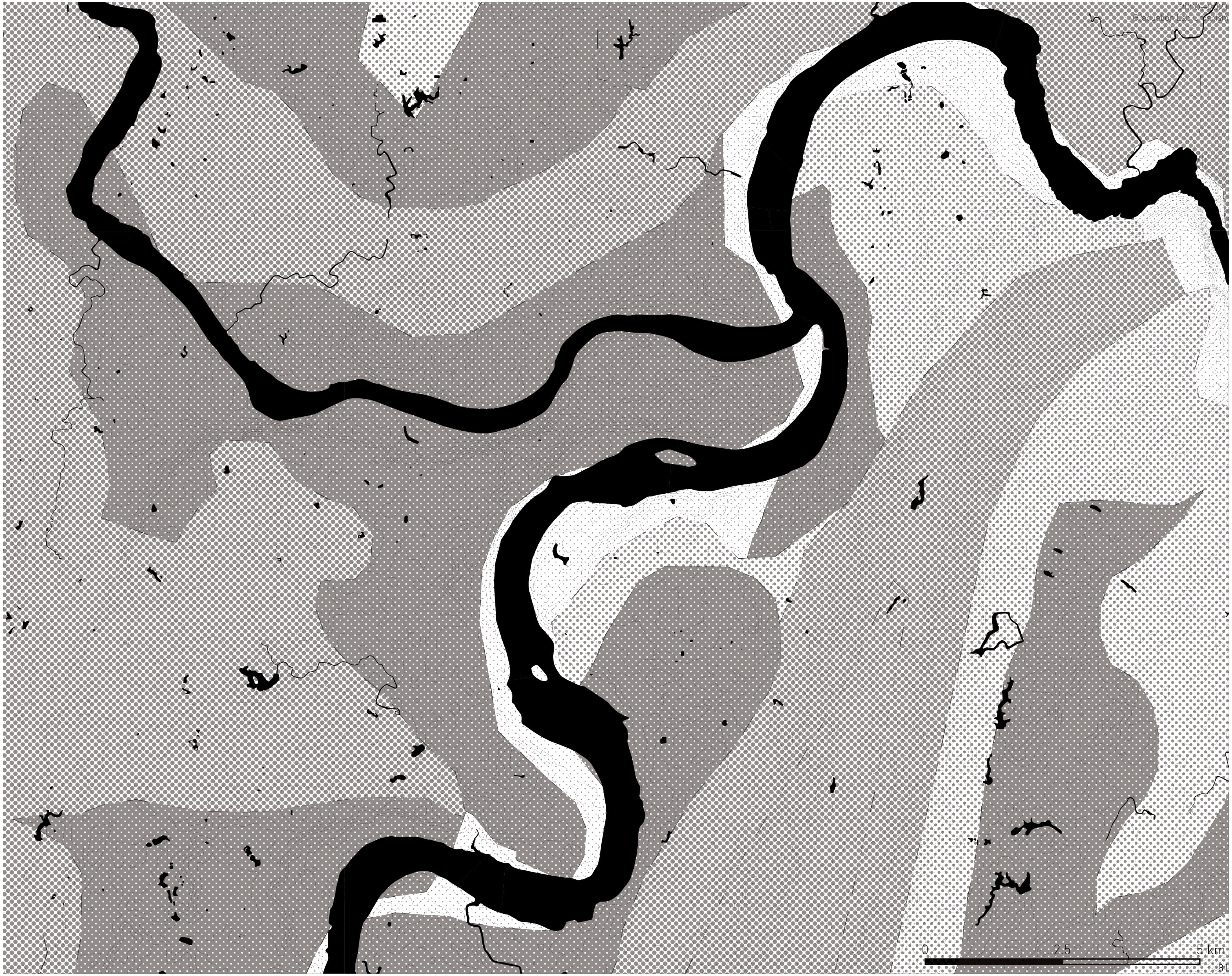
Characteristic:

Clay with high water table

Subsurface

- Soil infiltration

Through soil infiltration and surface runoff, the natural surface hydrological environment can be obtained. And could help better understand the hydrological characteristics of the city.



N

Legend

- Group A
- Group B
- Group C
- Group D

Human impact

Landscape

The current landscape shows that the urbanized land is the major type of landscape in Chongqing. This means a large amount of area in Chongqing is covered by the impermeable pavement. That fact leads a fierce conflict between the urban environment and nature.

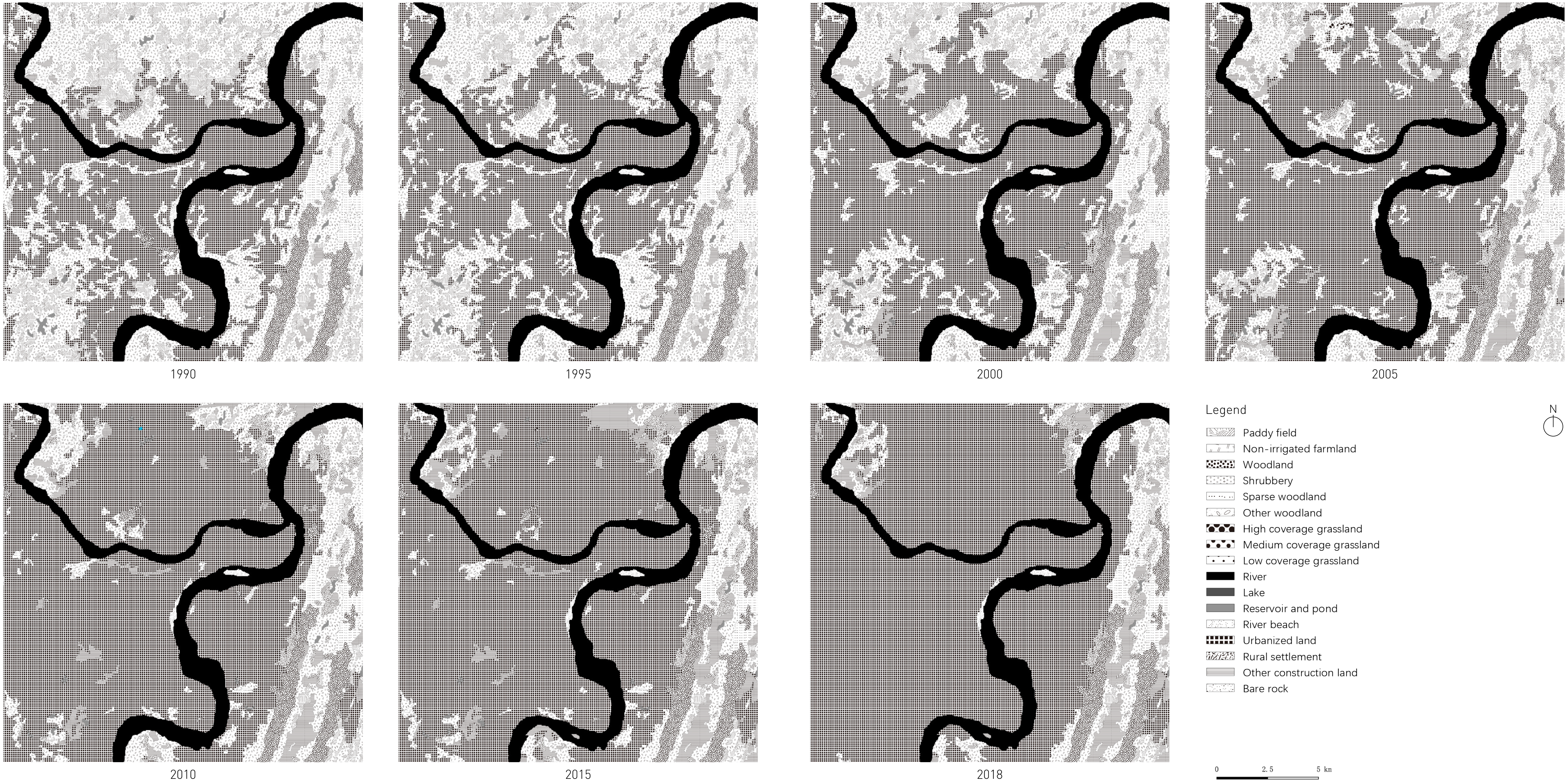
N

Legend

- Paddy field
- Non-irrigated farmland
- Woodland
- Shrubbery
- Sparse woodland
- Other woodland
- High coverage grassland
- Medium coverage grassland
- Low coverage grassland
- River
- Lake
- Reservoir and pond
- River beach
- Urbanized land
- Rural settlement
- Other construction land
- Bare rock

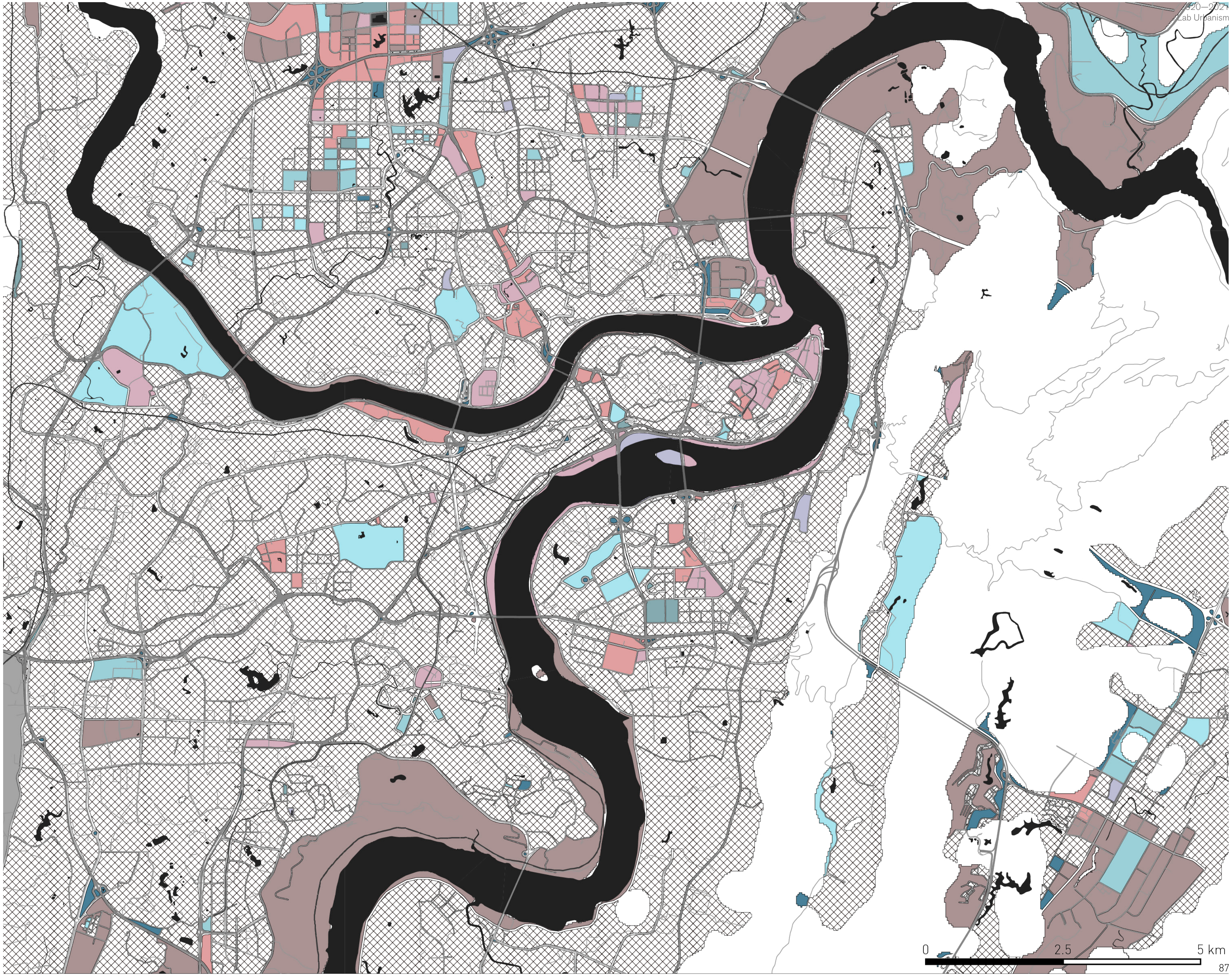
Landscape change

With the rapid development of urban area in the past 30 years, urbanized land has continuously eroded other landscape types, resulting in a huge reduction in the area of landscapes such as woodland and grassland. This process not only greatly reduces the complexity of Chongqing's landscape, but also reduces the water resilience and animal habitat in this area. And with the natural environment replaced by impermeable areas, the conflict between human impact and natural hydro system is continuously rising.



Land use

There are many important urban functions on both sides of the river corridor in Chongqing, and different urban functions bring different urban characteristics. In the analysis of the built environment, these functions and characteristics should also be considered. In the later design test, these elements could also be used as an important basis.



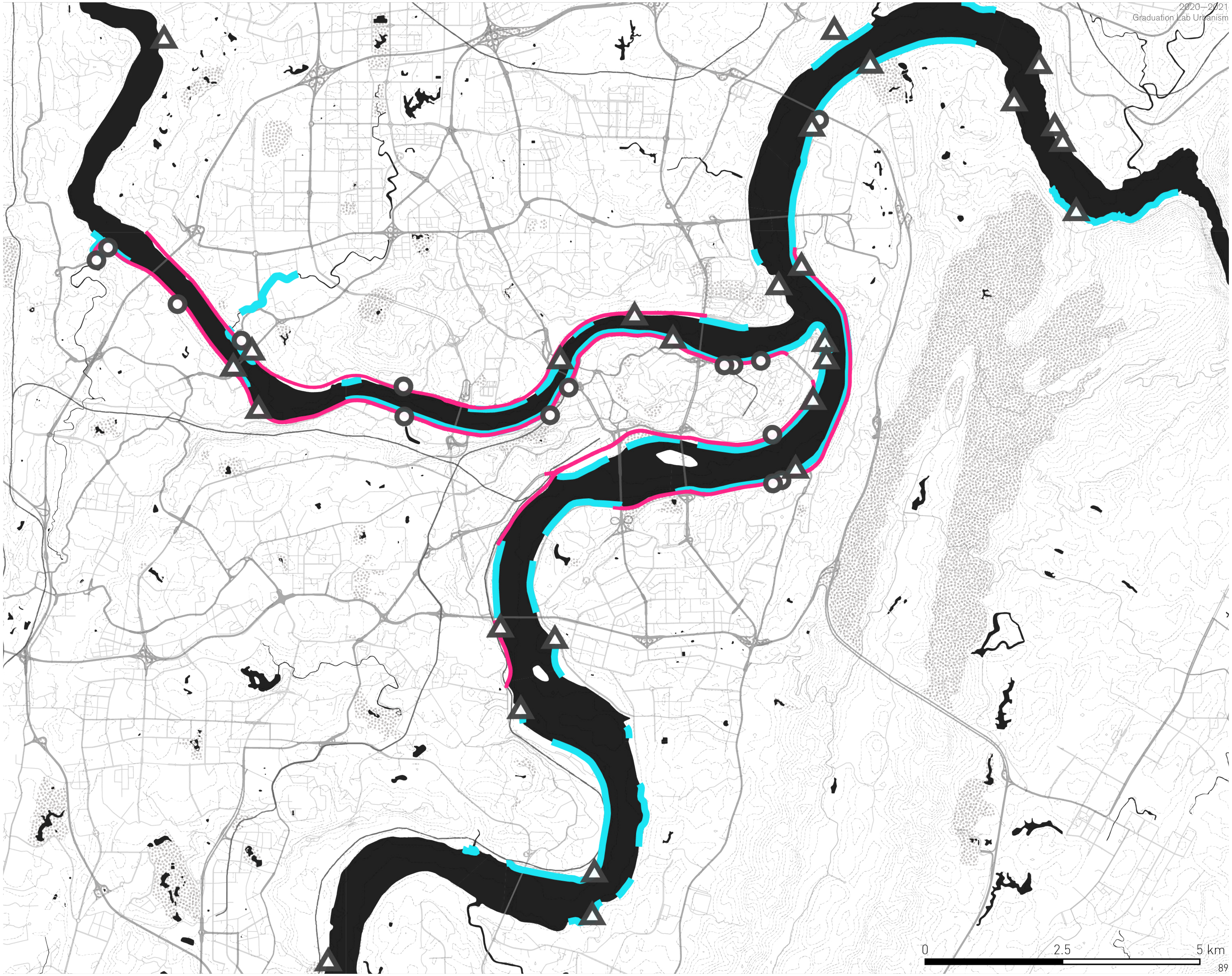
N

Legend

- Residential
- Business office
- Business services
- Industry
- Transport station
- Airport facilities
- Administration
- Education
- Medical
- Sports and culture
- Parks and green spaces

Infrastructure

There are massive hard infrastructures on both sides of Chongqing's river corridor. Some infrastructures such as hard embankments are influence the flood resilience and ecosystem in a negative way. And others such as the viaduct road split the riverfront area and urban environments, decrease the accessibility of the river corridor area, and reduce the potential of the riverfront area to be leisure space for the city.



N

Legend

- Dock
- Parking lot
- Hard embankment
- Viaduct road

Conflict

Through the overlay analysis of the natural water system and the built environment, the potential water conflict area along the river corridor of Chongqing is obtained.

N

Legend

Water conflict area

Runoff intensity

Low

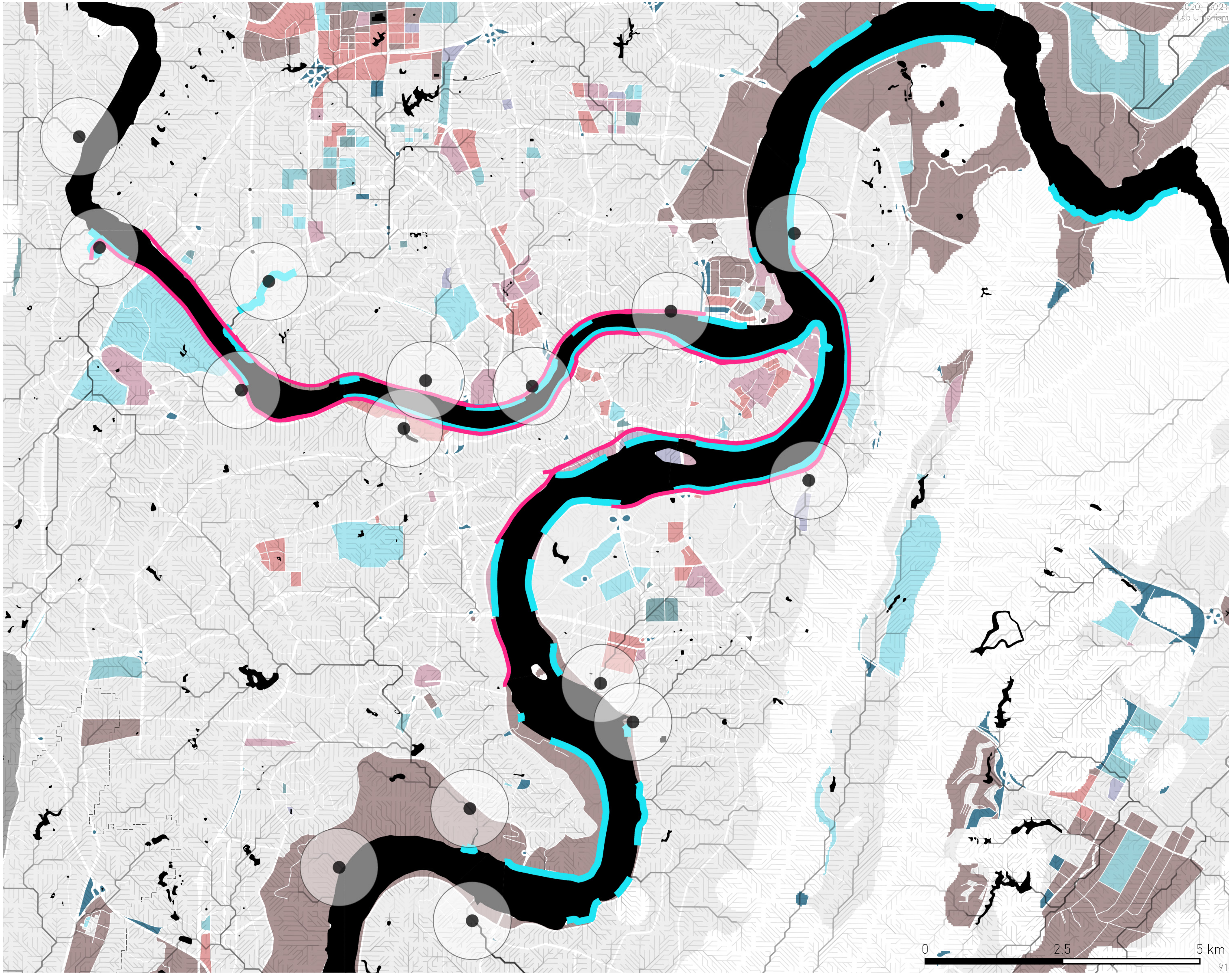
High

Urbanized area-land use

- Residential
- Business office
- Business services
- Industry
- Transport station
- Airport facilities
- Administration
- Education
- Medical
- Sports and culture
- Parks and green spaces

Infrastructure

- Hard embankment
- Viaduct road



Water Opportunity

The opportunity means the positive effects that the research could bring apart from flood control. While increasing urban flood resilience, other problems in the city also have the opportunity to be solved simultaneously. In Chongqing's river corridor area, biodiversity is generally low and there is a lack of animal habitats, and urban expansion will make this problem even worse. As a major city upstream of the Yangtze river, Chongqing is also facing many social problems such as social segregation and an aging population. With the implementation of flood resilience in the city and the improvement of living environments, the research also has the potential to bring the co-benefit from social and ecological aspects.

Chapter structure

a. Biota

- Flora

- Fauna

b. Participatory approach

- Social-economy

- Community composition

Biota
Flora

Urban forest
Coniferous and broad-leaved forests

Pinus massoniana

Useage:
A common tree used in plantation forestry

Camphor tree

Useage:
Windbreak and producing camphor

Gum trees

Useage:
Windbreak and soil fixation forest

Schima argentea

Useage:
Windproof, fireproof, medicinal use

Paper mulberry

Useage:
Alleviate air pollution

Koelreuteria bipinnata

Useage:
Alleviate air pollution, construction material

Symplocos setchuensis

Useage:
Medicinal use

Black locust

Useage:
Soil fixation forest

Cinnamomum pedunculatum

Useage:
Construction material

Glossy privet

Useage:
Garden tree, medical use

Trema tomentosa

Useage:
Medicinal

Chinese firo

Useage:
Mountain greening, construction material, medical use

Litsea

Useage:
Medical

Ficus virens

Useage:
Windproof, medicinal use

Paulownia

Useage:
Construction material

Chinaberry

Useage:
Greening tree species in cities

Camptotheca acuminata

Useage:
Medicinal use

Water Fluctuating Zone Plant
Shrub

Distylium chinense

Useage:
Alleviate air pollution

Salix variegata

Useage:
Water fluctuating zone greening, good soil and water conservation capacity

Campylotropis macrocarpa

Useage:
Build shelter forest and improve soil quality

Lycium chinense

Useage:
Water fluctuating zone greening

Swida paucinervis

Useage:
Soil-preserving plant for consolidating river cliffs

Tall grass

Saccharum spontaneum

Useage:
Water fluctuating zone greening, good soil and water conservation capacity

Phragmites australis

Useage:
Conserve water, provide habitat for birds

Miscanthus sinensis

Useage:
Improve soil quality

Phragmites karka

Useage:
Provide habitat for birds, good soil and water conservation capacity

Grass

Carex thomsonii

Useage:
Consolidating river embankments

Pogonatherum paniceum

Useage:
Consolidating river embankments

Cynodon dactylon

Useage:
Reduce soil erosion, consolidating river embankments

Hemarthria compressa

Useage:
Food for wildlife

Polygonum lapathifolium


Agricultural plant

Corn

Useage:
Food

Sweet potato

Useage:
Food

Fauna

Mammal

Anourosorex squamipes

Habitat:

Indoor, farmland, shrub

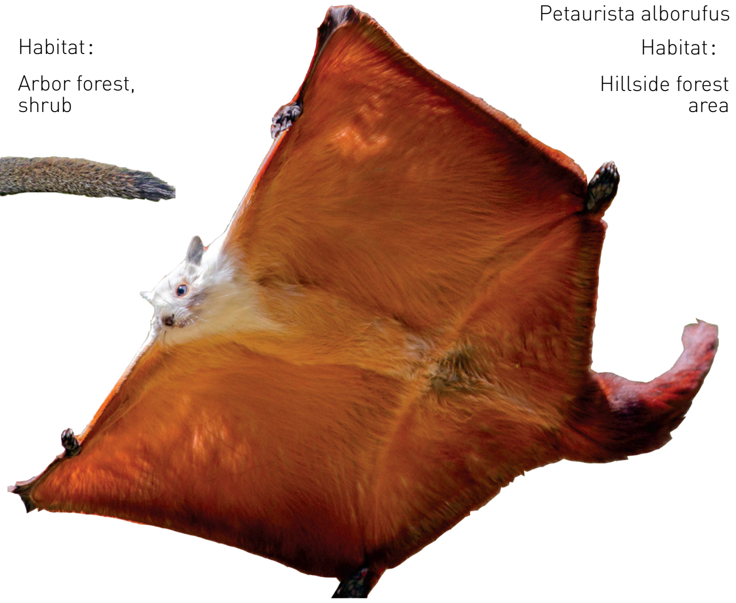
10cm

Callosciurus erythraeus

Habitat:

Arbor forest, shrub

Petaurista alborufus



Habitat:

Hillside forest area

Apodemus draco

Habitat:

Reed land, sandy land, rural oasis, etc.

Micromys minutus

Habitat:

Reed land, sandy land, rural oasis, etc.

Rattus nitidus

Habitat:

Mountain and hilly areas, piedmont crops and piedmont bushes, gardens, fields

Rattus flavipectus

Habitat:

Fields, countryside, and urban areas

Rattus norvegicus

Habitat:

Grasslands by the river, shrubs, fields, and houses

Mus musculus

Habitat:

Fields, countryside, and urban areas

Leopoldamys edwardsi

Habitat:

Forest margin, shrubs, fields

Atherurus macrourus

Habitat:

Mountain forest

Mustela sibirica

Habitat:

Forest margins, river valleys, shrubs and grass hills

Lepus capensis

Habitat:

Fields, woods, grasses, shrubs and forest margins

Bird

Little grebe

Habitat:

Lakes, ponds, canals

Bambusicola thoracica

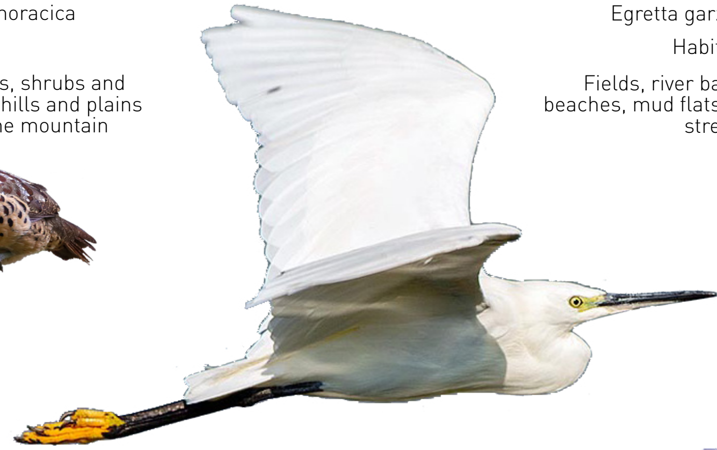
Habitat:

Bamboo forests, shrubs and grasses in low hills and plains at the foot of the mountain

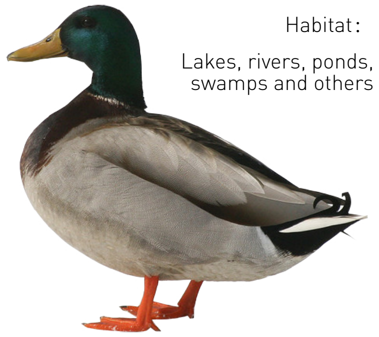
Egretta garzetta

Habitat:

Fields, river banks, beaches, mud flats and streams



Mallard



Habitat:

Lakes, rivers, ponds, swamps and others

Pica pica

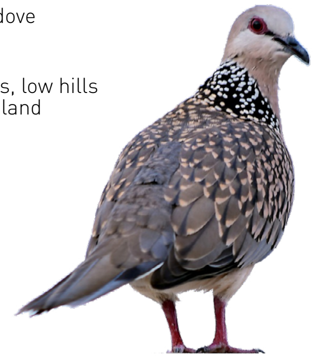
Habitat:

Forest, field

Spotted dove

Habitat:

City parks, low hills and farmland



Sparrow

Habitat:

Urban area, field

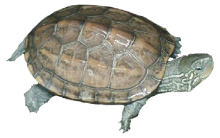
Amphibian

Fejervarya multistriata

Habitat:

Fields

Mauremys reevesii



Habitat:

Marshes, shallow ponds, streams, and canals with muddy or sandy bottoms.

Pelodiscus sinensis

Habitat:

rivers, lakes, ponds, canals and creeks with slow currents

Bufo gargarizans

Habitat:

Grass, under rocks on hillsides, or earth caves, etc.

Cyclophiops major

Habitat:

Mountain broad-leaved forest

Gekko subpalmatus

Habitat:

Stone cracks and wall cracks

Fish

Habitat:

Creeks with slow currents

Leiocassis longirostris

Habitat:

River bay, underwater

Ctenopharyngodon idella

Habitat:

Ponds, reservoirs

Silver carp

Habitat:

Rivers, lakes, reservoirs

Bighead carp

Habitat:

The surface layer of the water

Asian carp

Habitat:

Rivers, lakes, reservoirs

Carassius auratus

Habitat:

Shallow waters, streams or static water areas

Distribution

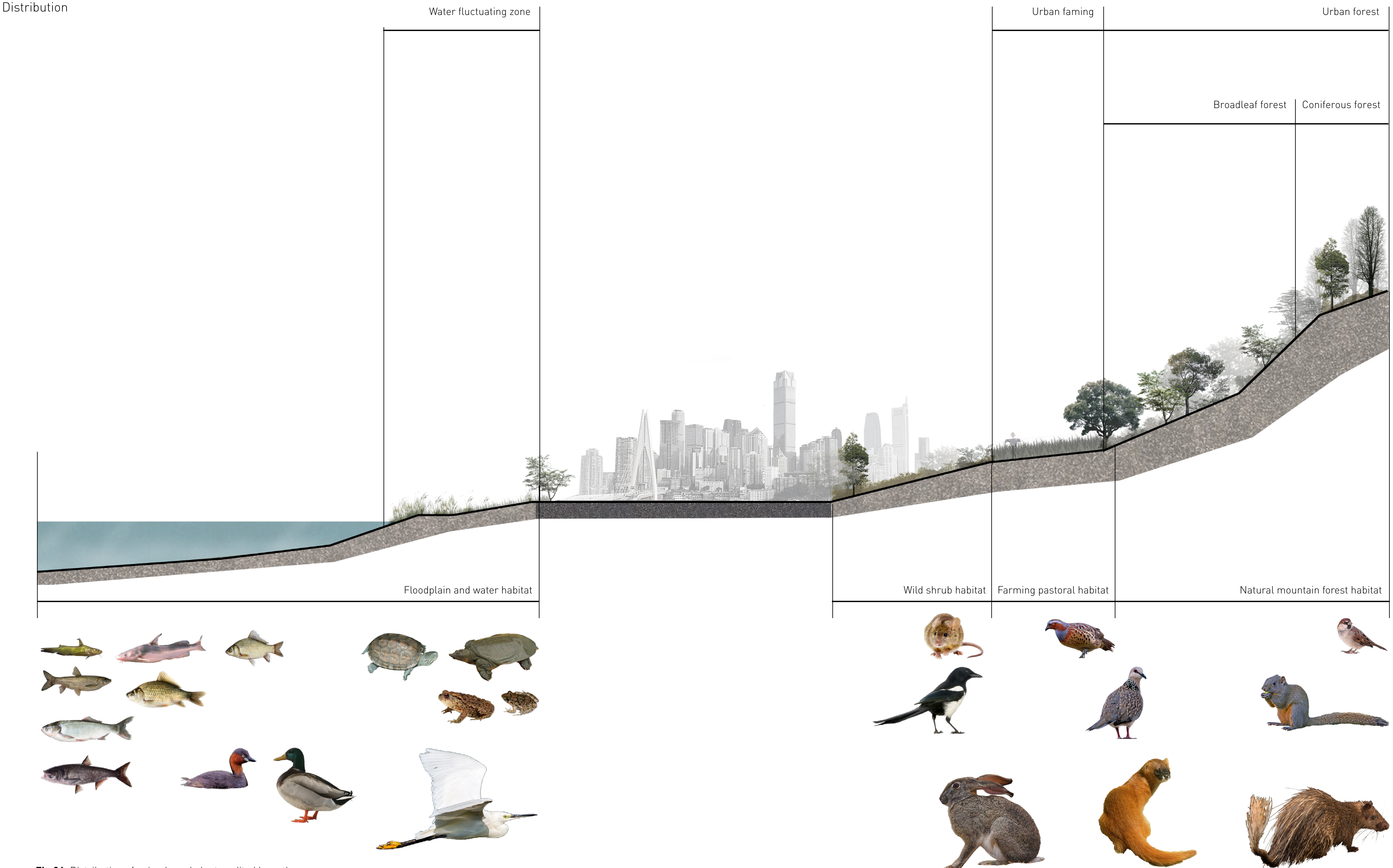


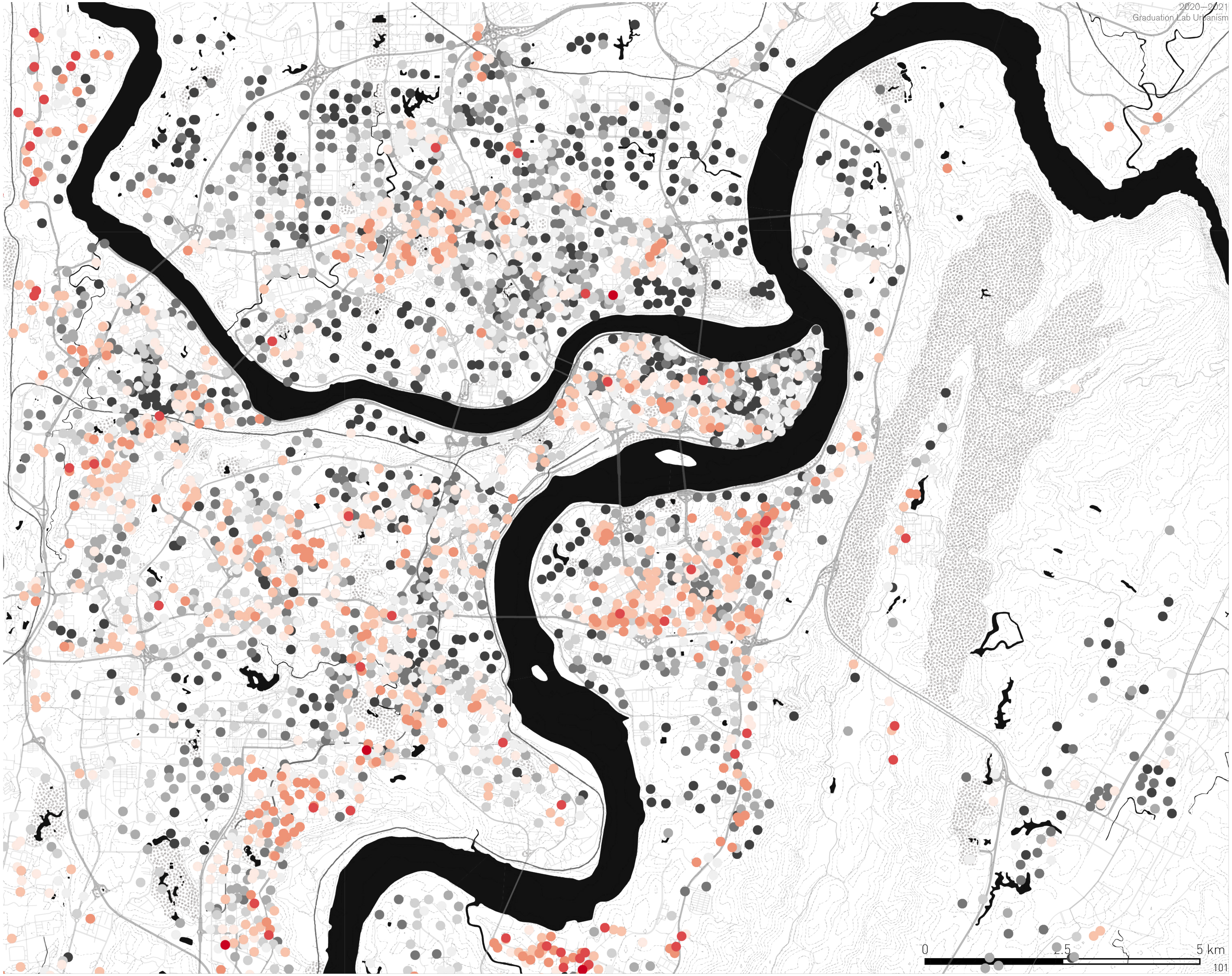
Fig.34. Distribution of animals and plants, edited by author

Participatory approach

Social-economy

- Housing price

To a certain extent, the distribution of housing prices can reflect the quality of houses and the distribution of different income groups. And low-income groups represent socially disadvantaged groups to a certain extent.



N

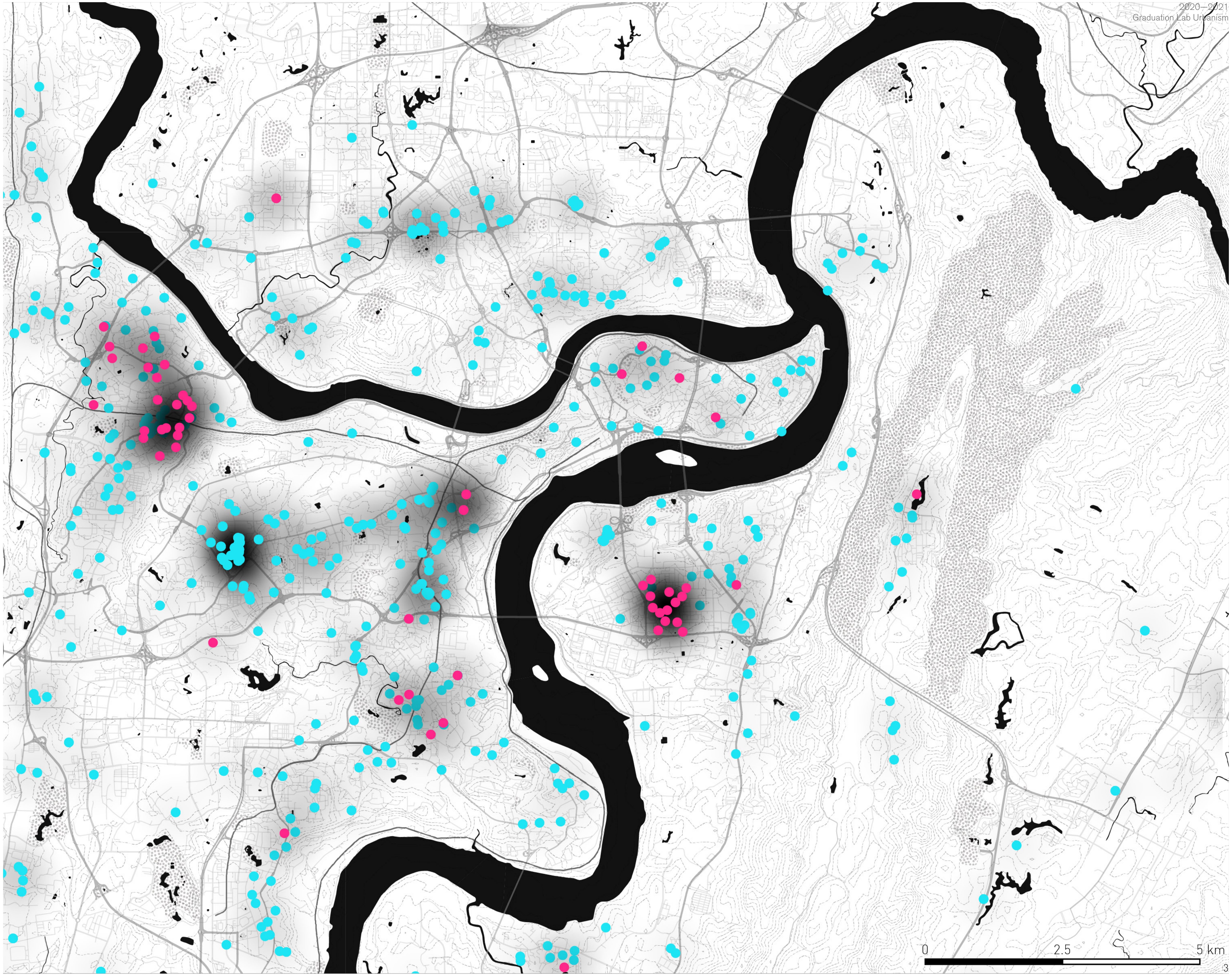
Legend

- 3649-5247
- 5247-6776
- 6776-7958
- 7958-8995
- 8995-9998
- 9998-10957
- 10957-11982
- 11982-13350
- 13350-15376
- 15376-62957

Social-economy

- Housing quality

By selecting houses with low structural standards and existing over 40 years, an area with a poor living environment is obtained, and this area has a certain correlation with the distribution of houses with lower prices. Therefore, while increasing flood resilience, the project should also consider improving the living environment quality of these areas if it is possible.



N

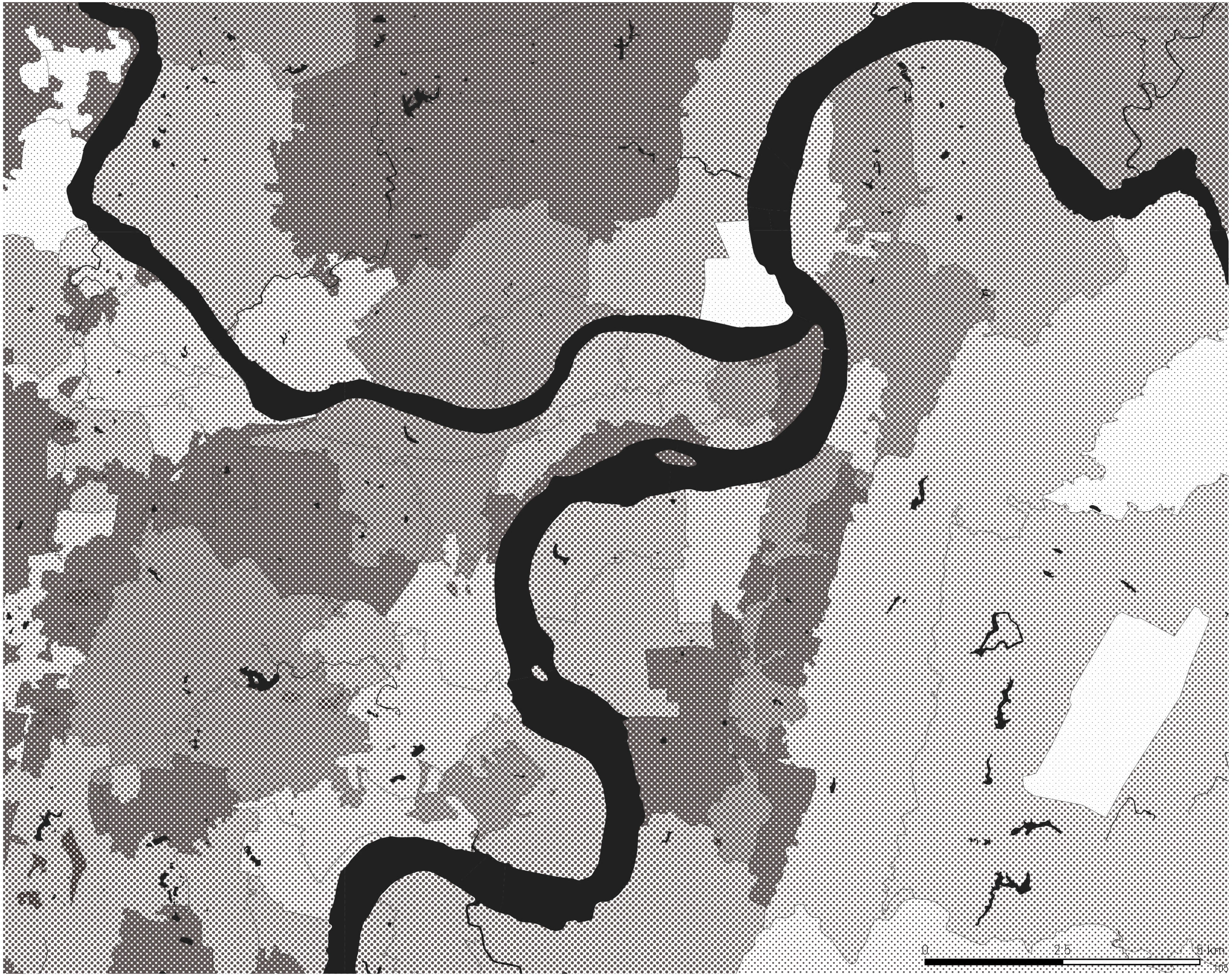
Legend

- Housing built before 1980
- Housing with poor structure

Community composition

- Migrant population

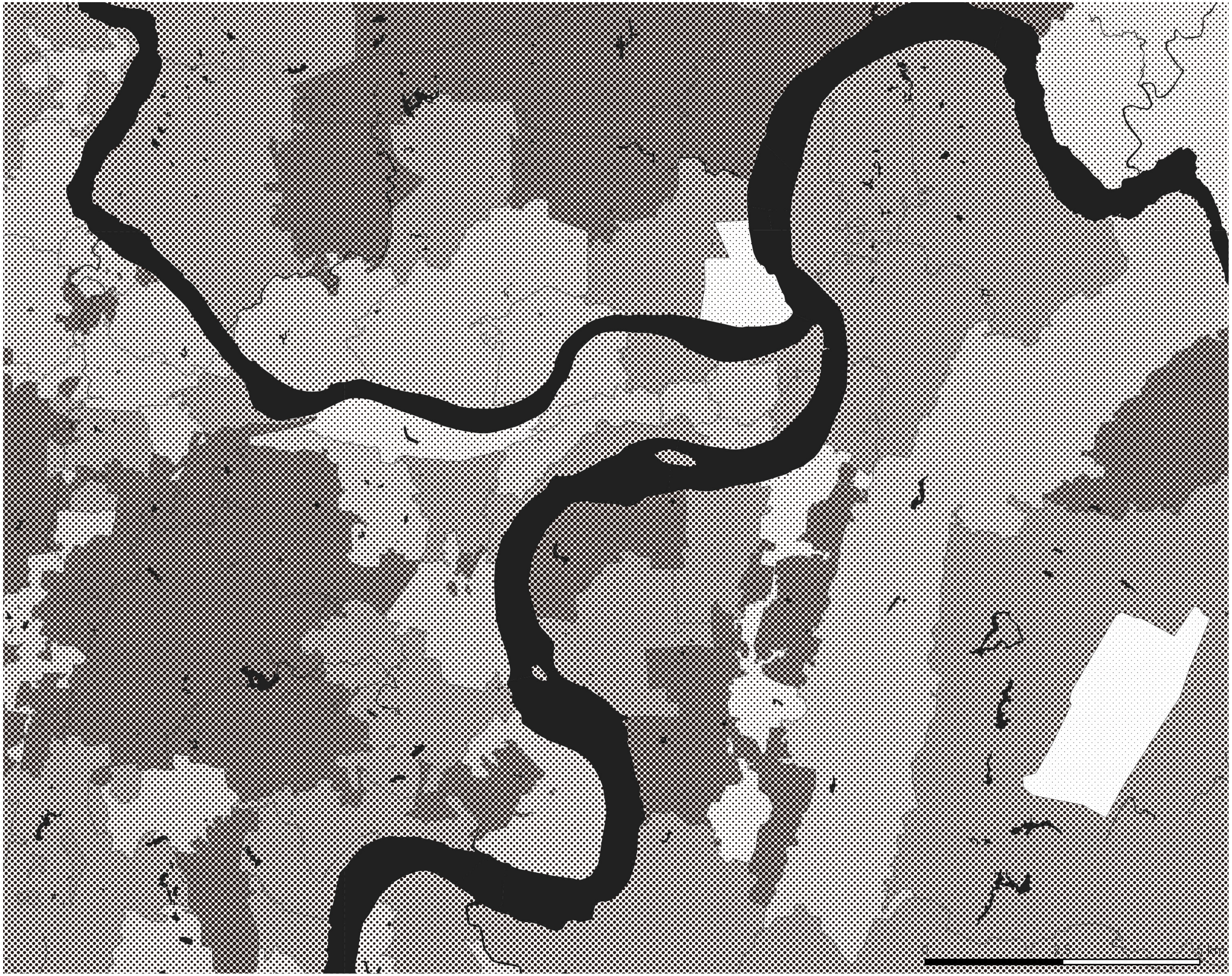
In the composition of the community, a high proportion of migrants often leads to a decline in community cohesion. In Chongqing main town, many communities have such problems. And these communities are often distributed in highly urbanized areas.



Community composition

- Children (under 14 years old)

In Chongqing main town, the proportion of teenagers and kids in many communities is high. This type of community often brings a high demand for public spaces such as playgrounds.



N

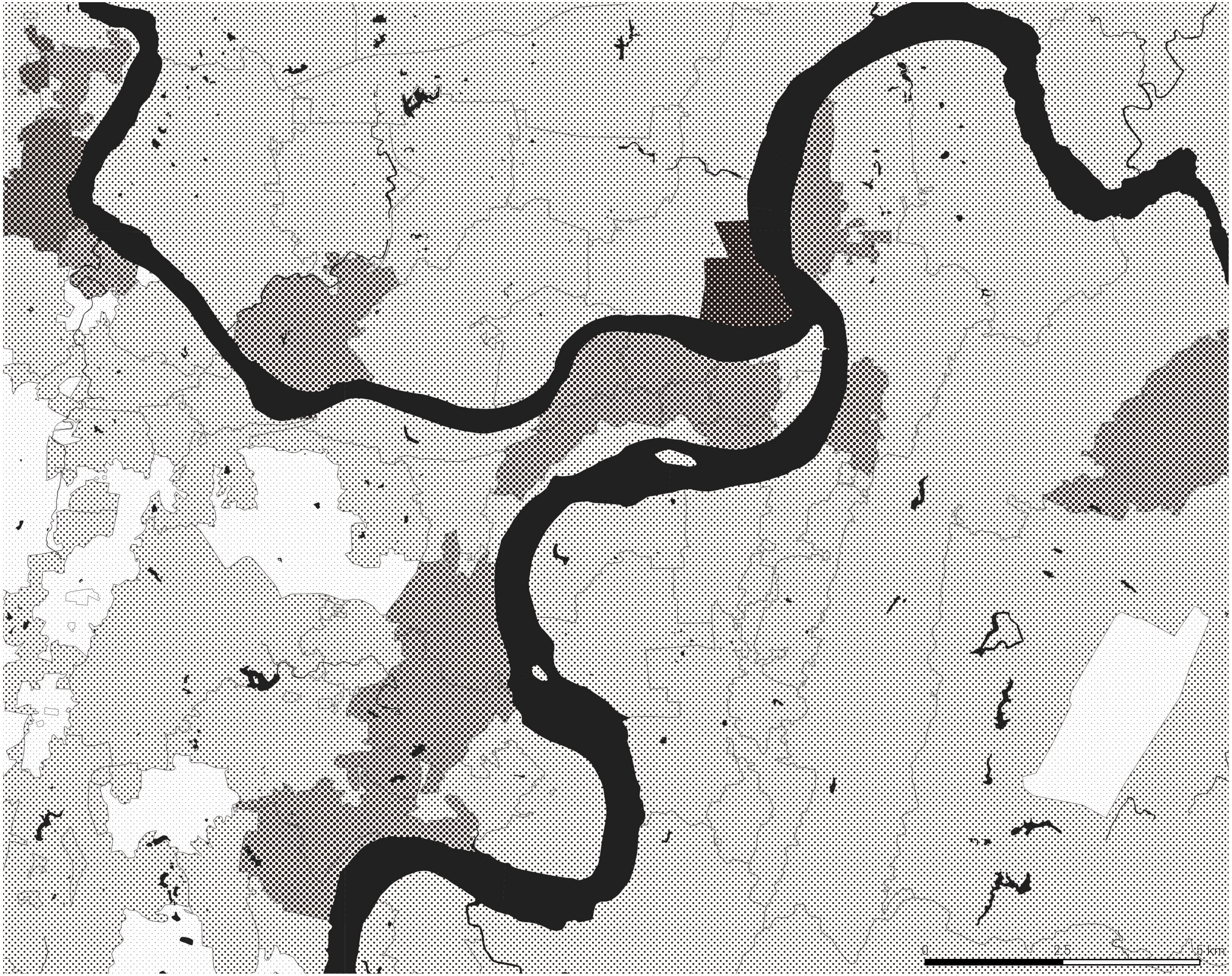
Legend

0.0-2.5%
2.5-5.0%
5.0-7.5%
7.5-10%
10-12.5%
12.5-15%

Community composition

- Elderly people (over 65 years old)

In the Chongqing main town, Yuzhong District and Jiulongpo District have the highest degree of aging in communities. Such communities often need to provide safe leisure spaces and exercise facilities for the elderly.



N

Legend

- 0-5%
- 5-10%
- 10-15%
- 15-20%
- 20-25%

Community composition

- Vulnerable people

Vulnerable people refers to the elderly over 65 years old and children under 14 years old, which is a key indicator of population vulnerability. When flooding or waterlogging occurs, both the elderly and children belong to the high-risk groups, and their ability to withstand disasters is worse than those between 14-65 years old. Therefore, the greater the proportion of the vulnerable people, the weaker the carrying capacity of the city and the more severely affected by disasters (Peng, 2020).

Location selection

Purpose:

In the next step, the design test will be implemented on some typical locations to testing the effectiveness of the potential future flood control measurement. And the location selection is to find the river corridor sections which have the highest hierarchy of flood risk and water conflict, and the locations should also include as much landscape type as possible in order to bring diversity to subsequent exploration.

In order to understand the hierarchy of the flood risk of Chongqing's water corridor sections, a flood influence assessment is proposed. The assessment is to evaluate the extent of flood hazard impact and the hydro conflict between nature and human activities in different river corridor sections. And the assessment is based on the research did by Merz and Annegret H. Thieken (2004), Mancusi et al. (2015), Peng (2020), Huang et al. (2020), and Liu et al. (2020).

Flood influence assessment:

- Rough location selection:

Base on the result of the analysis of water safety and water conflict, the river corridor sections which are under risk of seasonal flood and have the most serious conflict between nature and human activities are selected as the potential location for further assessment.

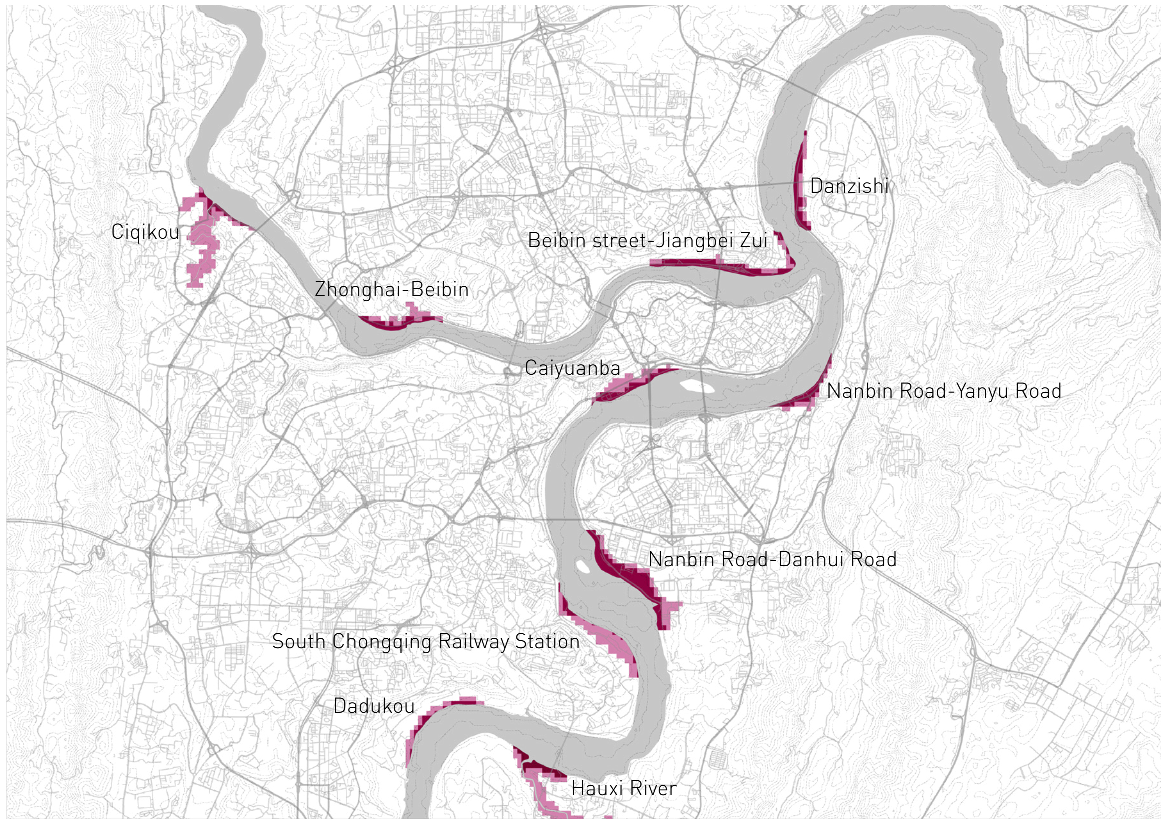


Fig.35. Rough location selection, edited by author

There are 10 locations selected in the rough selection, which are:

(1) Ciqikou: Mixed area combing with residential, commercial, historical heritage, and farmland;

(2) Zhonghai-Beibin: Highly urbanized area mainly covered by residential;

(3) Beibin street-Jiangbei Zui: One of Chongqing's CBD, highly urbanized area mainly covered by offices, financial and business functions;

(4) Danzishi: The future CBD for Chongqing, highly urbanized area mainly covered by offices and residential areas;

(5)Caiyuanba: The highly urbanized area mainly covered by facilities such as railway station, warehouses, and highway;

(6) Nanbin road-Yanyu road: Highly urbanized area mainly covered by commercial and residential mixed area;

(7) Nanbin road-Danhui road: Highly urbanized area mainly covered by commercial and residential mixed area;

(8) South Chongqing railway station: Covered by facilities, including station, railway, warehouses, and dock;

(9) Huaxi River: Mainly covered by urban greening and city park;

(10) Dadukou: Mostly covered by nature, but also industrial areas.

- Scoring the locations:

In order to understand the flood risk on different river corridor sections and find the riskiest location. The result of rough selection is evaluated by the assessment of flood risk. The flood is considered combining by two aspects, hazard and vulnerability. The flood hazard does not directly lead to a harmful outcome, but the definition of hazard does mean that there is a possibility of damaging occurring (Mancusi et al., 2015). Besides the flood hazard, the flood risk is also about vulnerability. Vulnerability is defined as the damage potential and loss susceptibility of the affected elements at risk. In terms of the "elements at risk", it includes all elements of the human system, the built environment, and the natural environments (Bruno Merz & Annegret H. Thieken, 2004). In practice, the flood risk can be simply represented as " probability times damage", to describes the expected damage that can occur or will be exceeded with a certain probability in a certain period (B. Merz et al., 2010).

As for the calculation of the flood damage, a common way is using the potential damage index (vulnerable index) times the area of the area affected by the flood hazard (Liu et al., 2020). This method can straightforward quantify the damage caused by the flood, so as to compare the flooding severity of each river corridor section.

In this research, the flood risk will be represent as:

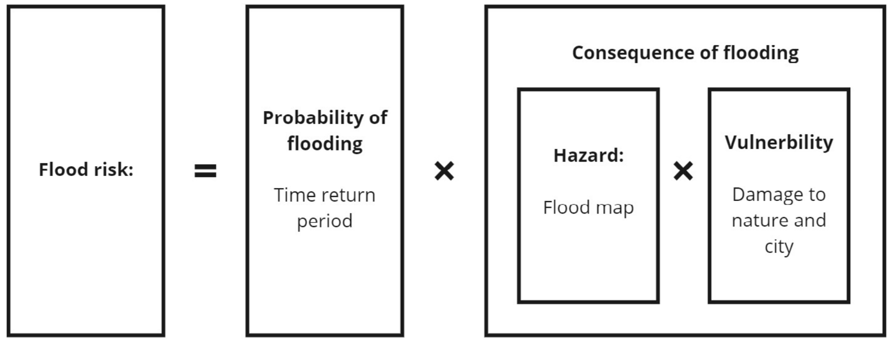


Fig.36. Framework for flood risk assessment, edited by author

Flood risk = Flood time return period × Inundation area × Vulnerable index (1)

$$\text{Flood risk}_{10} = \text{Flooding probability}_{10} \times \text{Inundation area}_{10} \times (\text{Index}_1 + \text{Index}_2 + \dots \text{Index}_n) \quad (2)$$

$$\text{Flood risk}_{100} = \text{Flooding probability}_{100} \times \text{Inundation area}_{100} \times (\text{Index}_1 + \text{Index}_2 + \dots \text{Index}_n) \quad (3)$$

$$\text{Flood risk}_{total} = \text{Flood risk}_{10} + \text{Flood risk}_{100} \quad (4)$$

1. Flooding probability:

According to the floods data in Chongqing for the last 20 years, the flood could catalogize into 2 groups, the 10-year flood, and the 100-year flood, and the probabilities of these two types of floods are about 0.85 and about 0.1, respectively.

2. Inundation area:

The inundation area is the area that will be affected when the flood occurs, which could represent the flood hazard area. By the analysis of flood data from previous years, the average water level of the 10-year flood is about

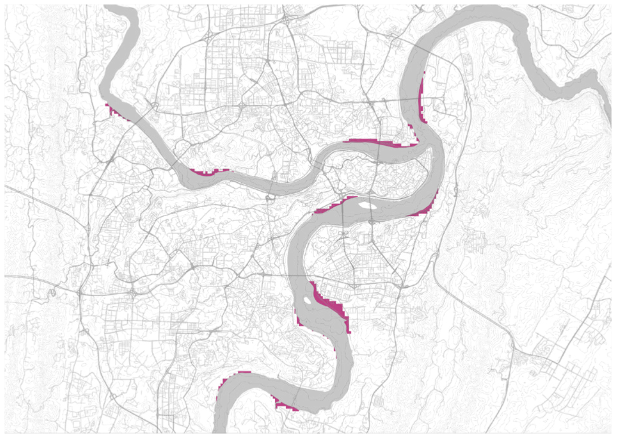


Fig.37. Inundation map 10-yaer flood, edited by author

Fig.38. Inundation map 100-yaer flood, edited by author

185m, and of the 100-year flood is about 195m. By the simulation of GIS, the inundation area of each river corridor section could be calculated.

	100-year flood(ha)	10-year flood(ha)
Ciqikou	94.3826	9.2452
Zhonghai-Beibin	40.7872	20.4747
Beibin street-Jiangbei Zui	63.7872	47.9942
Danzishi	39.3490	25.1676
Caiyuanba	47.8266	21.3614
Nanbin road-Yanyu road	31.3635	20.2422
Nanbin road-Danhui road	95.0800	64.3058
South Chongqing railway station	60.4617	7.5097
Huaxi River	65.2400	15.5331
Dadukou	31.6155	9.7751

Table.2. Inundation area of different river corridor sections, edited by author

3. Vulnerable index:

The vulnerable index could include elements from human system, built environment, and natural environment. In this research due to the result of the analysis, the accessibility of the data, and relevant research (Feng et al., 2001; Pan, 2020), the elements are defined as runoff intensity, vegetation coverage (natural environment), infrastructure coverage, tertiary industry (built environment), and vulnerable population (human system). The construction of the evaluation index adopts a combination of qualitative and quantitative analysis methods. The evaluation index system is constructed by referring to relevant research and literature, and each specific evaluation index is quantified and graded, so as to carry out the following evaluation.

(1) Runoff intensity:

The runoff is one of the most important part in the hydro system. Under the influence of different topography and soil infiltration, the runoff intensity of an area determines the speed and intensity of flooding in this area and its downstream areas. If the runoff intensity is higher in a location, the speed and intensity of flood formation in the area and its downstream areas will be higher, otherwise, the flood formation will be relatively mild. In the study, runoff intensity is defined as the level of runoff and the amount of high-grade runoff (main runoff) in the area. The higher the level of runoff in the area and the greater the amount, it means that the area is more threatened by flooding.

Runoff intensity					
Classification	Class I	Class II	Class III	Class IV	Class V
Runoff intensity	Extremely low	Low	Mediun	High	Extremely high
Quantitative assignment	1	2	3	4	5

Table.3. Classification table of runoff intensity, edited by author

(2) Vegetation coverage:

The degree of vegetation coverage also greatly affects the risk of flooding in the city. The higher the vegetation coverage rate, the easier the rainwater will be infiltrated, so that the runoff and the accumulation of water in the city will be reduced, thereby reducing the city's flood disaster risk.

Vegetation coverage rate					
Classification	Class I	Class II	Class III	Class IV	Class V
Vegetation coverage	Extremely low 0 < (V. C.) ≤ 20%	Low 20 < (V. C.) ≤ 40%	Mediun 40 < (V. C.) ≤ 60%	High 60 < (V. C.) ≤ 80%	Extremely high 80 < (V. C.) ≤ 100%
Quantitative assignment	5	4	3	2	1

Table.4. Classification table of vegetation coverage rate, edited by author

(3) Infrastructure coverage:

The infrastructure here is to analysis the infrastructure laying along the river corridor such as the hard embankment and the viaduct road. Those infrastructures highly influenced the natural hydro system and the social well beings by decrease the natural capacity of water infiltration and storage, and the accessibility of locals to reach the riverfront area. Thus, a location with high infrastructure coverage could lead to a serious flood hazard and social issues. Due to most of the river shorelines are covered by both hard embankment and viaduct road, the maximum rate of riverside infrastructure coverage is up to 200% (fully covered by both hard embankment and viaduct road).

Riverside infrastructure coverage rate					
Classification	Class I	Class II	Class III	Class IV	Class V
Vegetation coverage	Extremely low 0 < (I. C.) ≤ 40%	Low 40 < (I. C.) ≤ 80%	Mediun 80 < (I. C.) ≤ 120%	High 120 < (I. C.) ≤ 160%	Extremely high 160 < (I. C.) ≤ 200%
Quantitative assignment	5	4	3	2	1

Table.5. Classification table of riverside infrastructure coverage rate, edited by author

(4) Tertiary industry:

The proportion of tertiary industry can directly reflect the level of regional economic development. The greater the proportion of the tertiary industry in a location, the higher the economic loss it will suffer during a disaster, and the higher its corresponding vulnerability. Based on the research did by Pan (2020), the evaluation index divides the tertiary industry into 5 levels.

Tertiary industry rate					
Classification	Class I	Class II	Class III	Class IV	Class V
Tertiary industry	0 ≥ (T. I.) > 40%	0 ≥ (T. I.) > 40%	0 ≥ (T. I.) > 40%	0 ≥ (T. I.) > 40%	0 ≥ (T. I.) > 40%
Quantitative assignment	1	2	3	4	5

Table.6. Classification table of tertiary industry rate, edited by author

(5) Vulnerable population:

The proportion of vulnerable population is a key index to measure the vulnerability of the population. When floods occur, both children (under 14 years old) and the elderly (over 65 years old) belong to high-risk groups, and they are fragile to disasters. Therefore, the greater the proportion of the vulnerable population, the more fragile the region's society is, and the more severely affected by the disaster. Based on the research did by Pan (2020), the evaluation index divides the vulnerable population into 5 levels.

Vulnerable population rate					
Classification	Class I	Class II	Class III	Class IV	Class V
Vulnerable population	(V. P.) > 40%	40 ≥ (V. P.) > 30%	30 ≥ (V. P.) > 20%	20 ≥ (V. P.) > 10%	10 ≥ (V. P.) > 0%
Quantitative assignment	5	4	3	2	1

Table.7. Classification table of vulnerable population rate, edited by author

Based on the evaluation index system, the river corridor sections selected by the rough selection are assessed as follows. The resulting assessment indexes of each location will be used as the vulnerable index and to calculate the extent of flood damage.

	Runoff intensity	Vegetation coverage	Riverside infrastructure	Tertiary industry	Vulnerable population
Ciqikou	5	5	1	2	4
Zhonghai-Beibin	3	4	3	1	3
Beibin street-Jiangbei Zui	2	5	2	1	4
Danzishi	2	5	3	1	3
Caiyuanba	0	5	5	3	3
Nanbin road-Yanyu road	4	5	5	1	5
Nanbin road-Danhui road	4	5	1	1	3
South Chongqing railway station	0	5	2	2	3
Huaxi River	4	4	1	1	3
Dadukou	3	3	1	1	3

Table.8. River corridor sections evaluation, edited by author

And the score of locations will be based on the result of the evaluation and selected the most vulnerable locations in 10-year flood, 100-year flood, and overall. According to the score and the characteristics of different sites, 3-4 locations will be finally selected as sites for the implementation of flood resilience design.

	100-year flood	10-year flood	Overall
Ciqikou	**160.4504**	133.5931	294.0436
Zhonghai-Beibin	57.1021	243.6489	300.7510
Beibin street-Jiangbei Zui	89.3021	571.1310	660.4331
Danzishi	55.0886	299.4944	354.5830
Caiyuanba	76.5226	290.5150	367.0376
Nanbin road-Yanyu road	53.3180	292.4998	345.8177
Nanbin road-Danhui road	133.1120	**765.2390**	**898.3510**
South Chongqing railway station	72.5540	76.5989	149.1530
Huaxi River	84.8134	171.6408	256.4542
Dadukou	34.7771	91.3971	126.1742

Table. 9. Flood vulnerability score of different locations, edited by author

The flood vulnerability score of rough selected locations shows that Ciqikou is the most vulnerable place when facing the 100-year flood, and Nanbin road-Danhui road is the most vulnerable place for 10-year flood and overall. Therefore, these two locations will be selected as the locations to explore the flood resilience design in severe floods and ordinary floods. Besides, for the diversity of the location selection locations which have other representative characteristics will also be selected. To better understanding the relationship between water and infrastructures (especially infrastructure of industry), Caiyuanba is selected due to there are a railway station located and have lots of relevant infrastructures. Dadukou is also selected because it is almost a natural area.

Also, the selected locations could represent three typical landscapes, which is highly urbanized area (Nanbin road-Danhui road, Caiyuanba), peri-urban area (Ciqikou) and natural area (Dadukou).

Design locaiton:

- Nanbin road-Danhui road

Runoff intensity: High

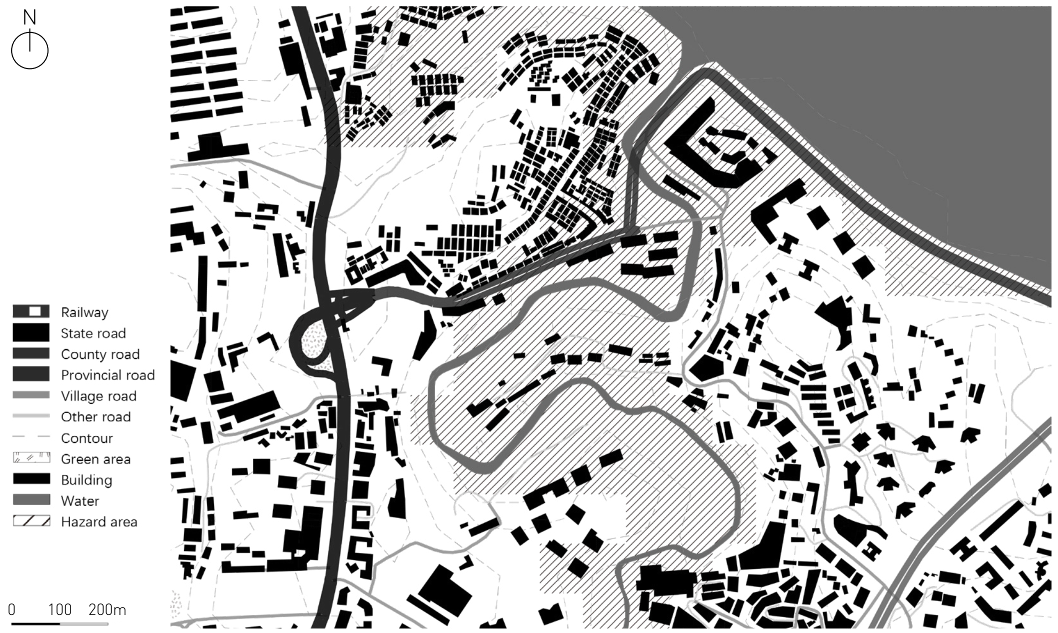
Vegetation coverage: 0.145

Vulnerable population: 0.199

Infrastructure coverage: 0.317

Tertiary industry: 0.61

- Ciqikou



Runoff intensity: Extremely high

Vegetation coverage: 0.181

Vulnerable population: 0.207

Infrastructure coverage: 0.334

Tertiary industry: 0.917

- Caiyuanba

Runoff intensity: Low

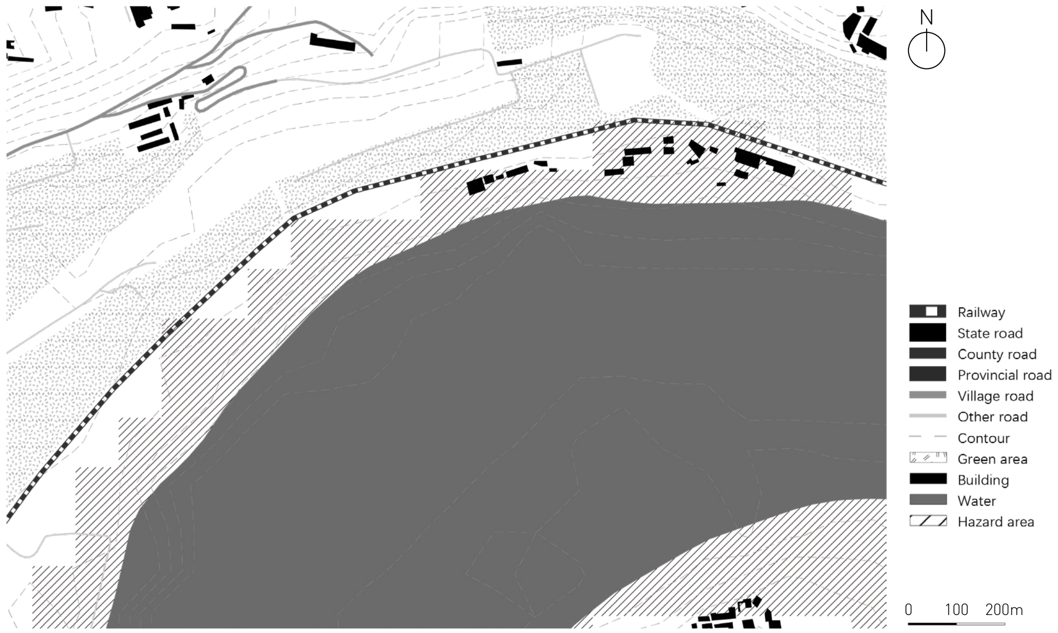
Infrastructure coverage: 1.8

Vegetation coverage: 0.105

Tertiary industry: 0.822

Vulnerable population: 0.175

- Dadukou



Runoff intensity: Low

Infrastructure coverage: 0.05

Vegetation coverage: 0.457

Tertiary industry: 0.307

Vulnerable population: 0.221

Fig.39. An example of the scenario collage, edited by author

07. Projections

In this chapter, based on the status quo and the analysis, the variety possibility of Chongqing's future flood control implementation on different spatial and temporal scales will be discussed. Then, by comparing the advantages and the disadvantages of different futures, trying to explore a future plan that can maximize the benefits of Chongqing's flood resilience implementation under the different stakeholders' needs. Based on the plan, generate a series of strategy and design principles on different spatial and temporal scales for the following design test.

Charpter structure

a. Priorities' conflict

- Regional

- Urban

- Local/community

b. Scenarios

- Adaptive Flood

- Defense Flood

c. Design principle

- Region/city

- Local

Priorities' conflict

The summer floods caused by the monsoons are a very serious problem for the management department throughout Chongqing and the Yangtze River Basin. However, when managers at different scales face the same problem, due to the different goals and management methods they consider, they often have different or even opposite approaches in solving the same problem.

- Macro-regional scale

At the national and macro-regional scales, the Yangtze River Basin is an important ecological corridor in China, as well as a habitat for many species. However, in the first 40 years of development (1978-2018), the rapid expansion of cities and the construction of some major water conservancy facilities have caused pollution and habitat decrease which serious threats to the Yangtze River ecosystem. And the number of some species has declined sharply. Therefore, the state government now regards ecology as the top priority for the future development of the Yangtze River. Among the five basic principles for the development of the Yangtze River Economic Belt proposed in the "Outline of the Yangtze River Economic Belt Development Plan" promulgated in 2016, the first is the ecological protection and restoration of the Yangtze River.

The outline of the plan pointed out that "establish and improve the most stringent ecological environment protection and water resources management system, strengthen ecological restoration of the entire Yangtze River, respect the laws of nature and river evolution, and coordinate and handle the relationships among rivers and lakes, upper, middle and lower reaches, mainstream tributaries, etc., to protect and improve the ecological service functions of the river basin". Therefore, at the level of national and macro-regional strategies, the solution to the flooding problem in the Yangtze River Basin should start from the ecological direction, based on natural river channels and runoffs, and proceed with the lowest disturbance to the natural water system.

- City scale

At the city scale, the municipal government usually considers the economy, development, and safety of the city as the highest priority, and ecology has always been the second or third consideration option for a long time. At the level of flood control, ecology is often not a priority factor considered by the municipal government. However, due to the increase of people's awareness of the importance of ecology, and the recognition of the green economic benefits that ecology can bring to cities in recent years, the priority of ecology is also advancing. In the "Chongqing master plan (2001-2020)" which promulgated in 2007, a special plan for the cluster isolation green buffer zone and a special plan for the urban green space system were also added to strengthen the importance of ecology in the master plan. Moreover, the boundary of the city area strictly defined to protects the green belt from erosion in the master plan. It is certain that the city scope of Chongqing and most Chinese cities will be further expanded in the future. However, due to the city's need for green and the improving benefits brought by the green economy in the future, the priority of ecological factors on the city scale will be further improved. What is certain is that although urban economy, development, and safety are still the main priorities considered by the municipal government, ecology will become an important and indispensable factor in the development of the future city.

- District and community scale

At the district and community scale, the priorities considered by local officers are mostly factors closely related to basic human needs such as safety and hygiene. Ecological considerations are often limited to the extremely small scale like street trees and community gardens, without systematic long-term consideration. When dealing with sudden disasters such as floods, a more effective hard infrastructure approach or faster emergency escape approach is more likely to be favored by managers at this level. Ecological solutions that take a long time to be effective will not be considered.

At the same time, the existing ecological mitigation approach often requires the creation of a large amount of permeable ground, such as grassland or directly exposed soil. However, when selecting indicators such as "sanitary cities", too much exposed soil and leaves that have not been cleaned (even if the fallen leaves are on the grass) are regarded as unclean. These indicators are quite important indicators of local grassroots officials' achievements, and are the prizes that different urban districts and communities need to fight for every year, which also prevents priority applications of ecological approach at the community and urban district scale.

From the priority conflicts at various scales, it is not difficult to see that although at the macro-regional level ecology is the priority and regarded as one of the most important indicators in the future, at the community scale is the opposite. The effectiveness and the long time period implementation of the ecology flood defense approach is the main reason that grassroots officials refuse this approach. Overall, as the scale goes from macro to micro, the consideration of ecological priority also changes from high to low. This inconsistency in priorities also brings difficulties to proposing an overall multi-scale flood control approach to the city.

Scenario generation

As described in the previous chapter, priority at each scale has its own reasonable reasons and advantages. Base on that, the scenario analysis is used to explore the possibility of flood control future in Chongqing, and to explore measures to improve flood resilience that can be beneficial to the city in the long-term and at each scale. According to different priorities at different scales, the scenarios are set as adaptive scenarios conforming to the macro-regional scale's priority and defense scenarios conforming to the district scale's priority. Compare and analyze the impact of different scenarios on different elements through the scenario generation.

For the research area, Chongqing, the object of this study, it is clear that these two scenarios will not be fully adopted. But through the analysis and comparison of these two more extreme scenarios, a set of flood defense design principle roadmaps, which could fit different site's characteristics and needs in different scales, can be generated. This allows sites with different characteristics to adopt different flood defense designs according to their characteristics, and at the same time, the benefits can be maximized in different scales.

- Flood adaptive scenario:

In the flood defense of the city, the urban environment will adapt the flood, and leaving the space for water. City will go backwards and there is a certain distance between the city and the water. The residents who originally lived in this area need to leave.

Scenario position

Only nature systems ▼ Only constructed systems

- Flood retaining scenario:

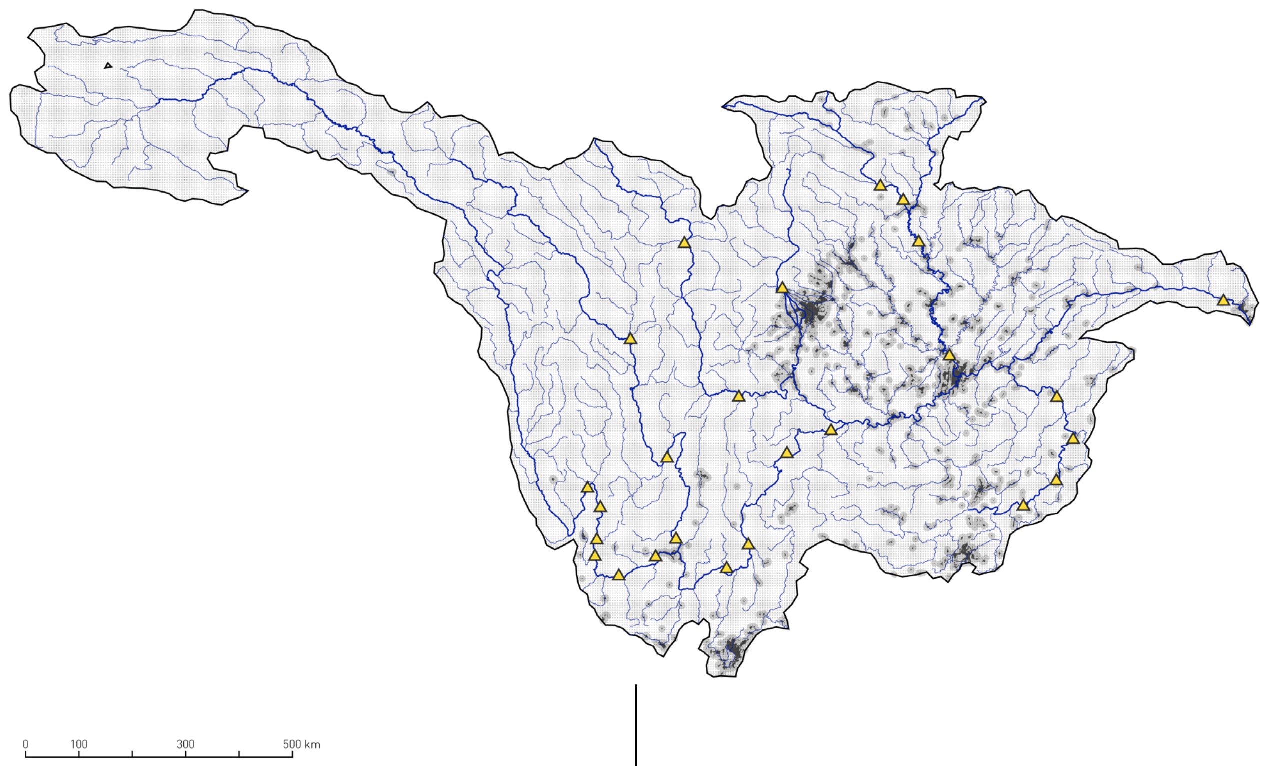
In the flood defense of the city, the hard infrastructure and centralized water management methods are wildly used. Then flood issue will be solved mainly by the heavy engineering-based solutions.

Scenario position

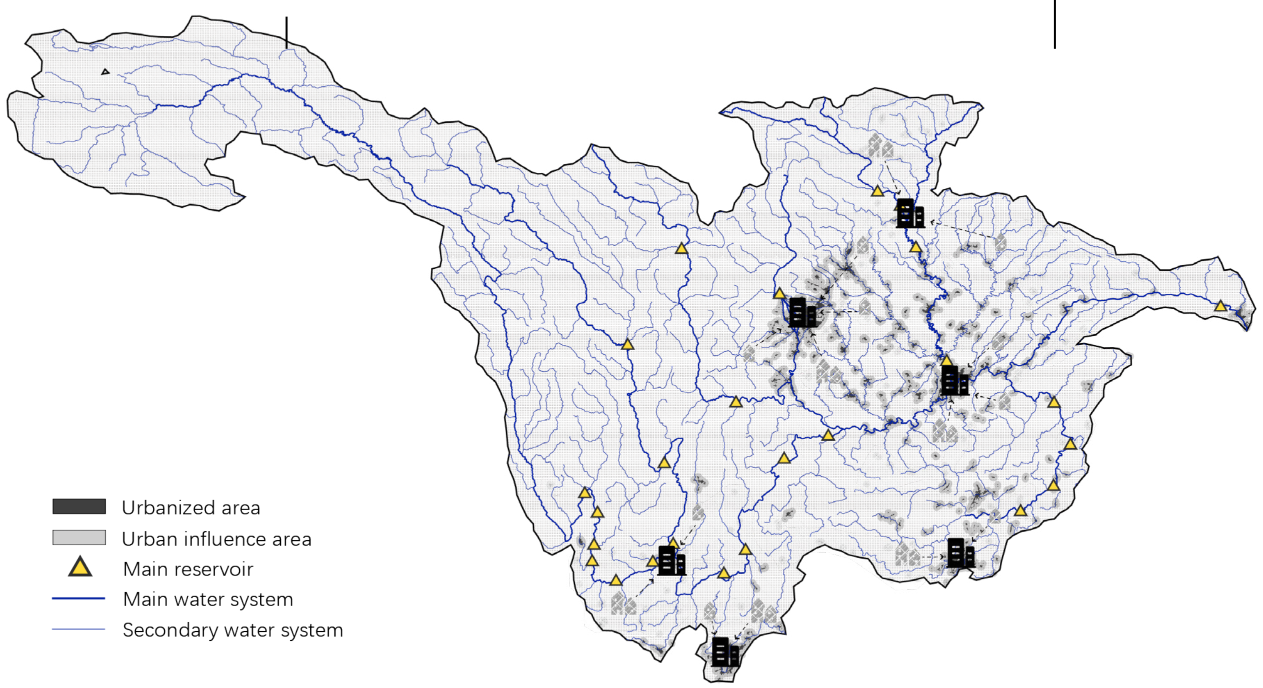
Only nature systems ▼ Only constructed systems

Regional

2020

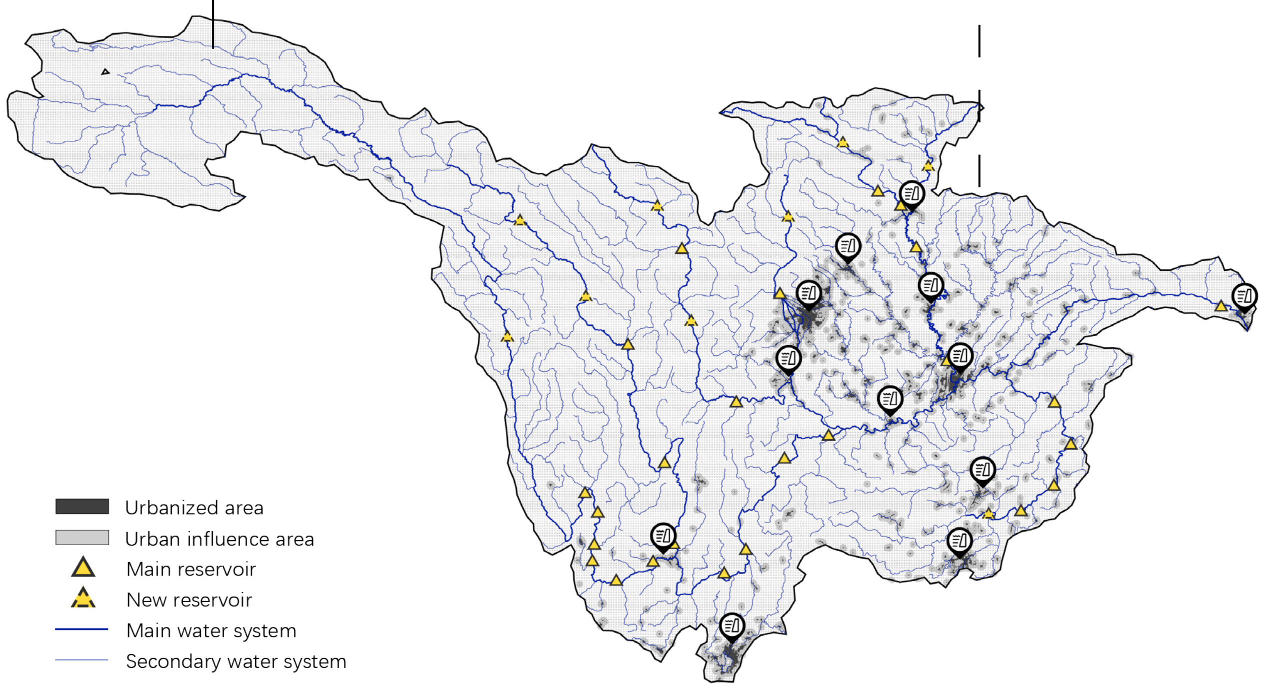


Flood adaptive 2100



Small settlements will be re-organized to the large settlements, leaving the space to natural, reducing human impact on nature, and increasing the natural water storage capacity.

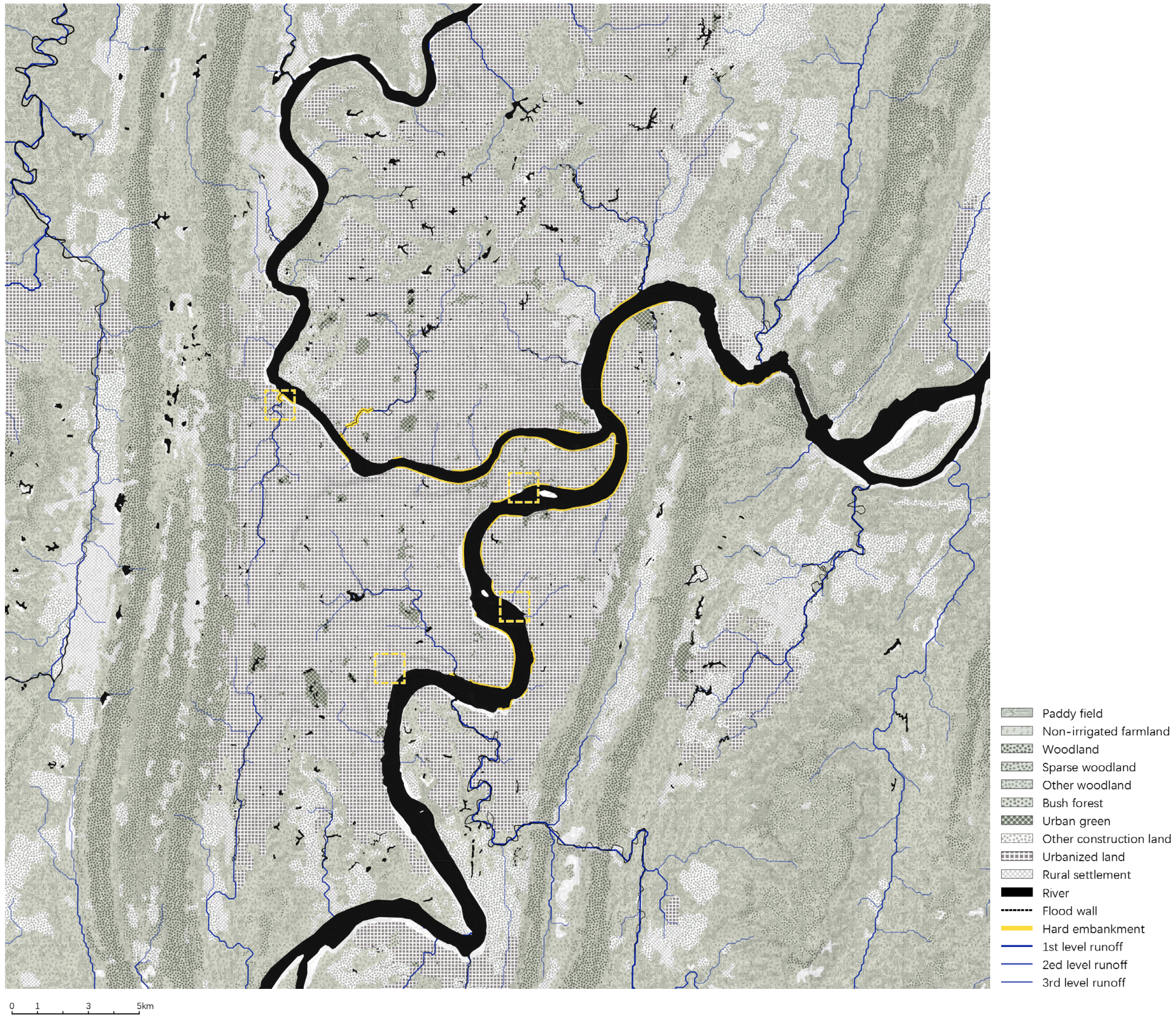
2100 Flood retaining



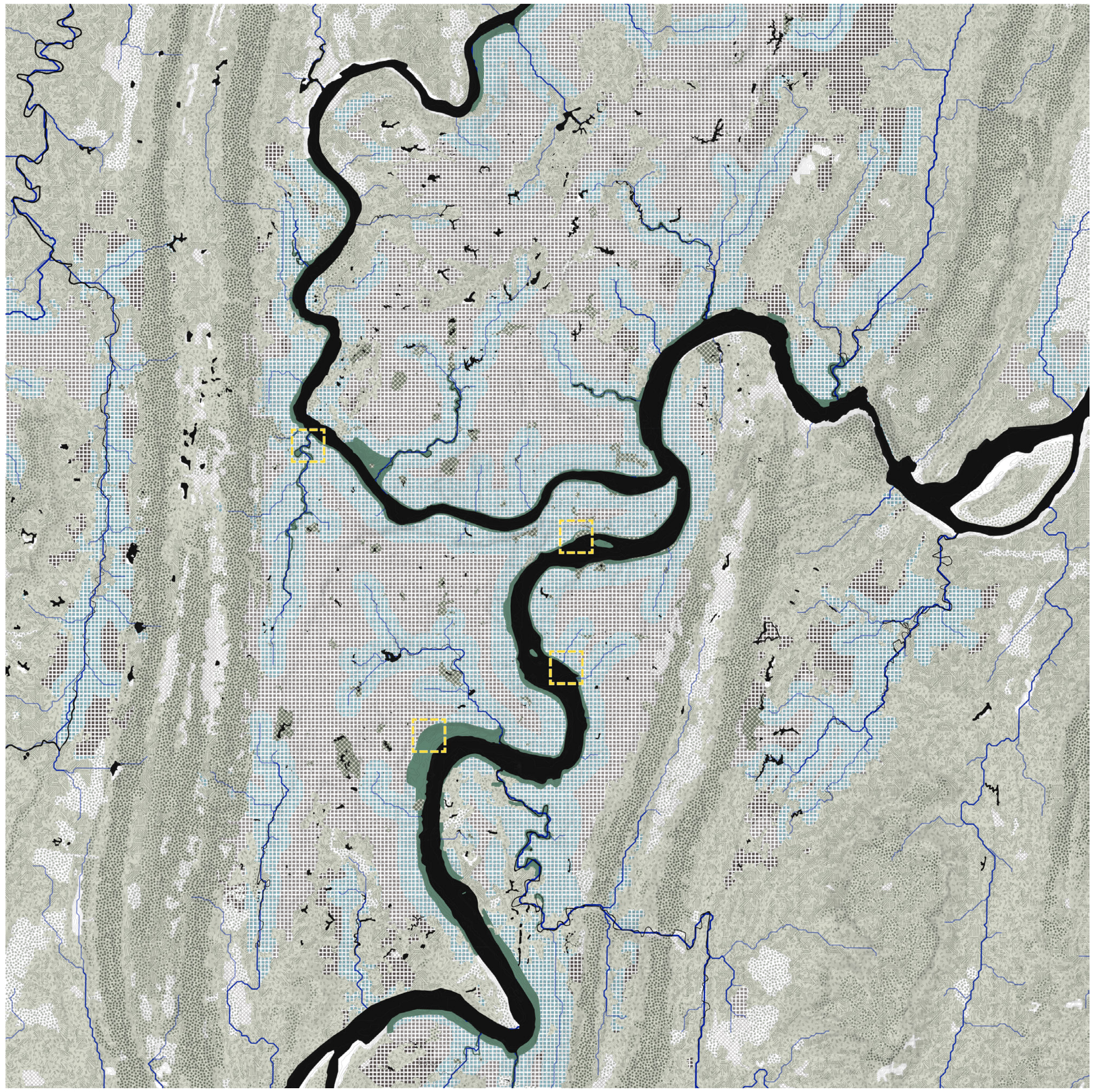
IThe location of settlements will remain unchanged. Infrastructures like dykes and floodwalls will be widely used along the river corridors through settlements. More reservoirs will be built.

Urban

2020

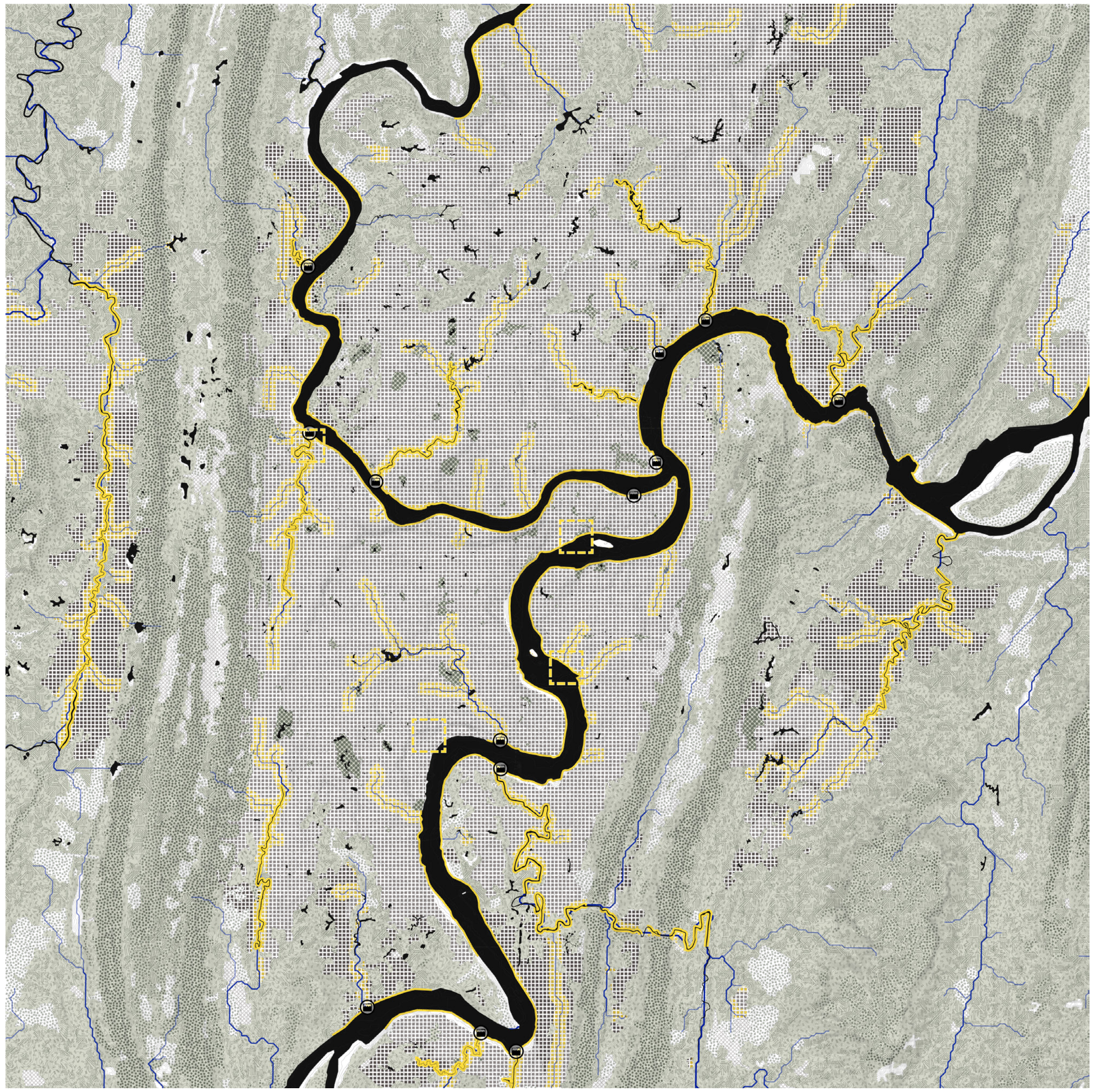

Paddy field
Non-irrigated farmland
Woodland
Sparse woodland
Other woodland
Bush forest
Urban green
Other construction land
Urbanized land
Rural settlement
River
Flood wall
Hard embankment
1st level runoff
2ed level runoff
3rd level runoff
0 1 3 5km

Flood adaptive 2040



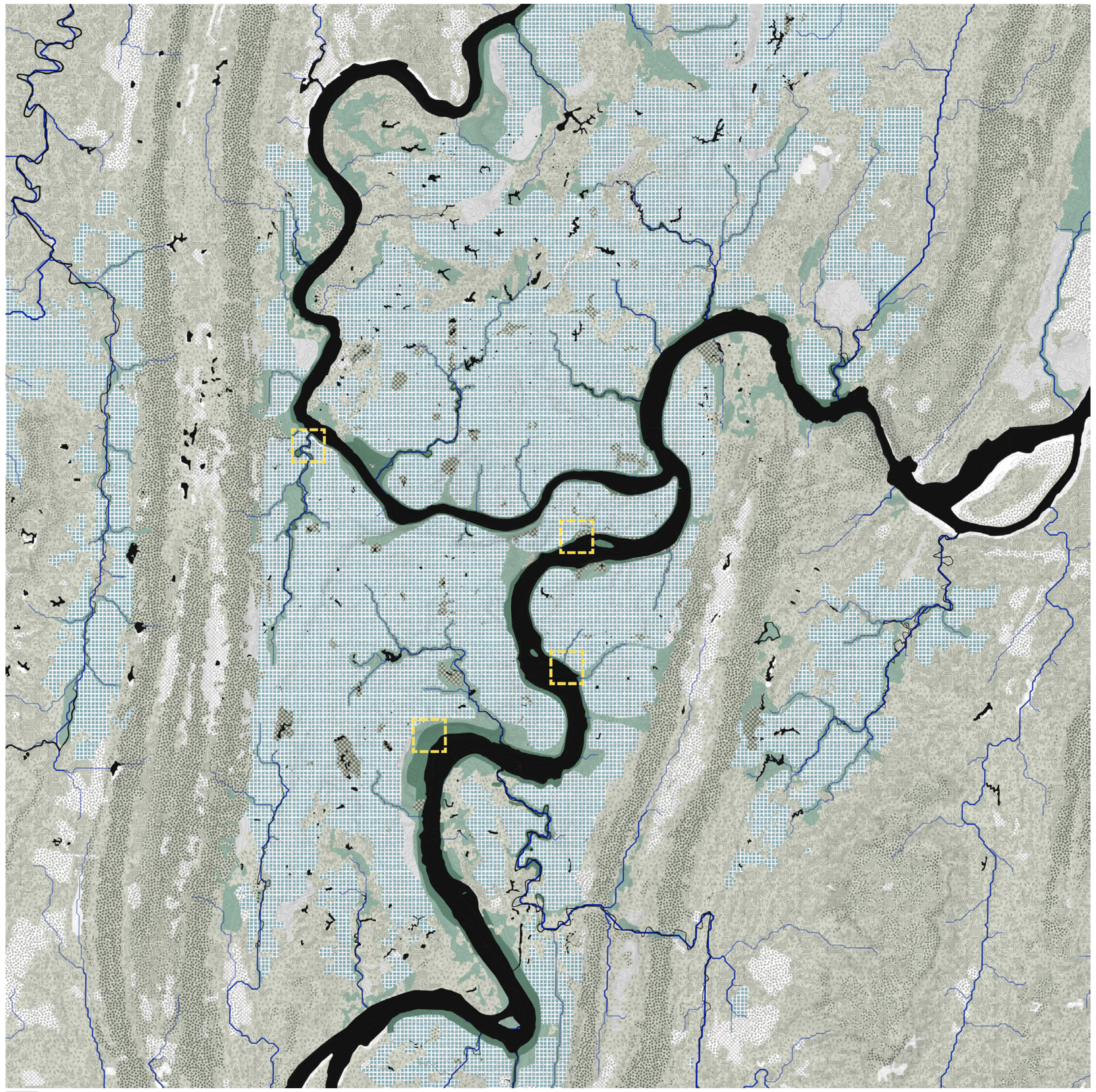
Making the green buffer along the existing rivers and creeks, leaving space for the flood.

2040 Flood retaining



The highly urbanized areas will be protected by hard infrastructure. Add flood water containers at the main runoff outlets.

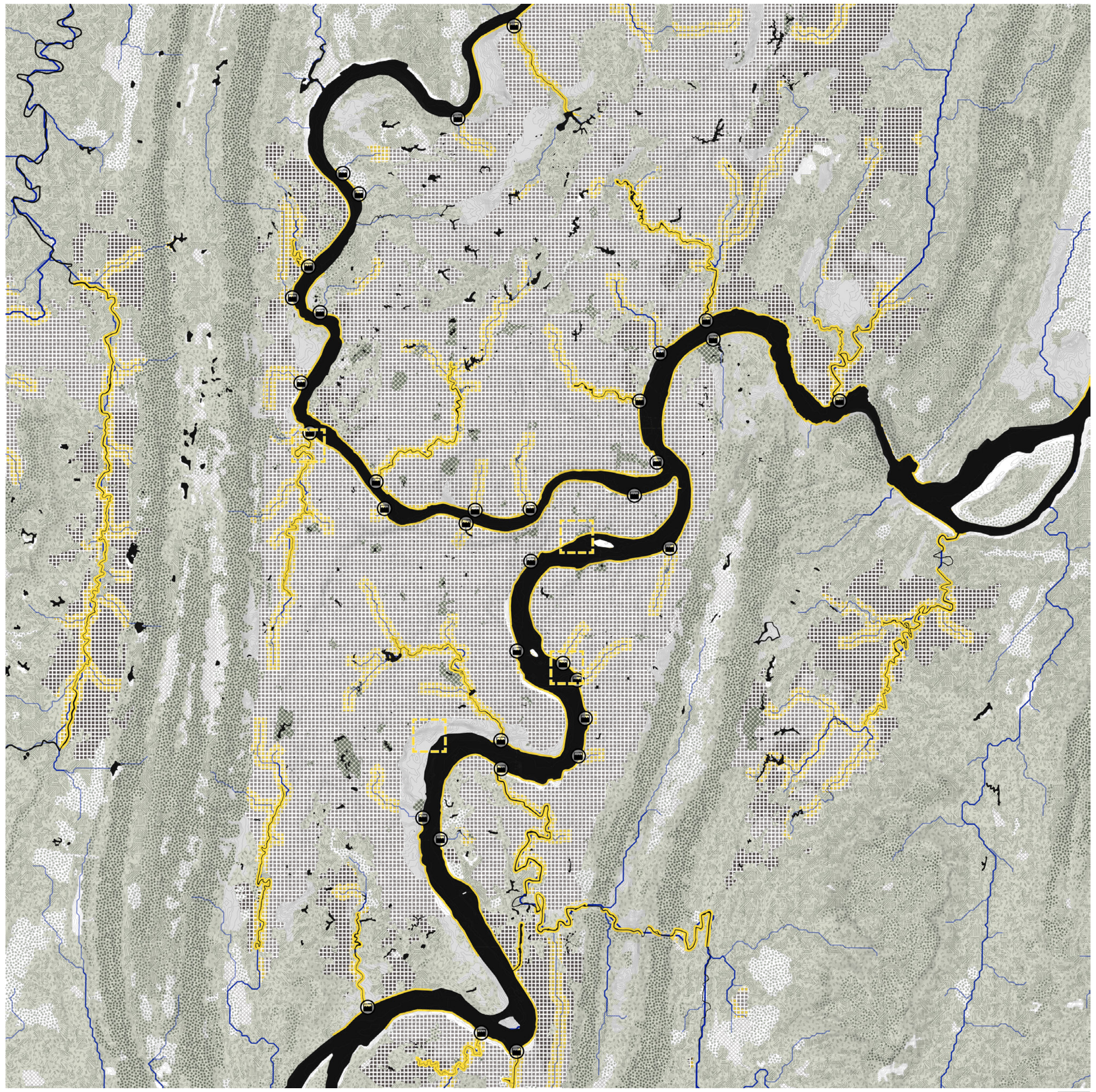
Flood adaptive 2100



Paddy field
Non-irrigated farmland
Woodland
Sparse woodland
Other woodland
Bush forest
Urban green
Other construction land
Urbanized land
Urbanized expansion 2040
Flood reslience urbanized area
Reduce urban area 2100
Rural settlement
River
Natural expansion 2040
Natural expansion 2100
1st level runoff
2ed level runoff
3rd level runoff

Making the green buffer along the main runoff, and connecting the existing green space. Formed the cluster-like urban structure again.

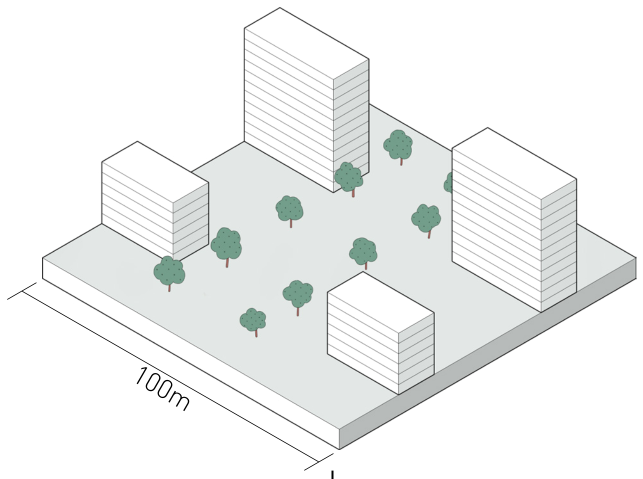
2100 Flood retaining



Paddy field
Non-irrigated farmland
Woodland
Sparse woodland
Other woodland
Bush forest
Urban green
Other construction land
Urbanized land
Urbanized expansion 2040
Permeable pavement area
Reduce urban area 2100
Rural settlement
River
Flood wall
Hard embankment
1st level runoff
2ed level runoff
3rd level runoff
Flood water container

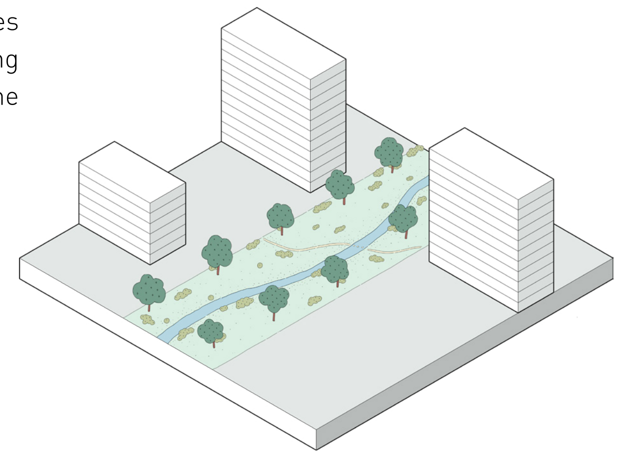
Maintenance the hard infrastructures and strengthened them when necessary. Adding more containers to increasing the flood storage capacity.

Micro
Invisible runoff 2020



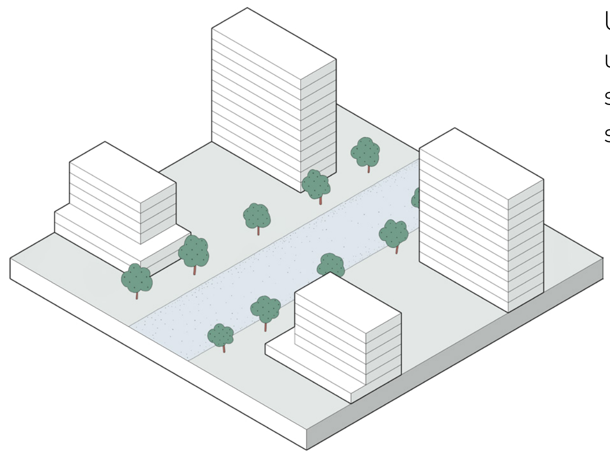
Flood adaptive 2040

Making the ecological flood facilities such as rainwater garden along the main runoff, and increasing the natural permeable areas.



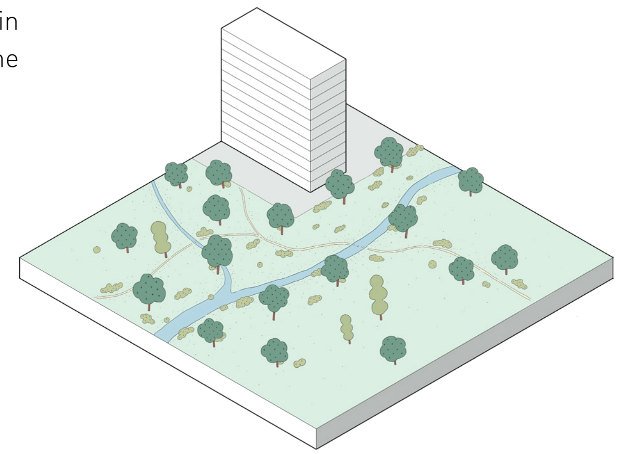
2040 Flood retaining

Using permeable pavement and underground rainwater collection system along the areas which have serious runoff issues.



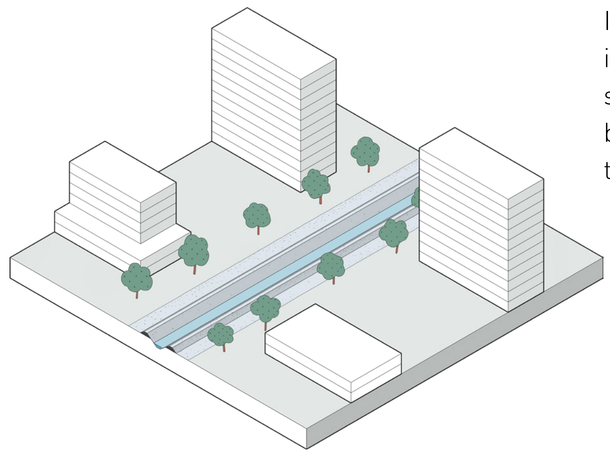
Flood adaptive 2100

Demolish the vulnerable building in the hazard area and extending the green space and rainwater garden.

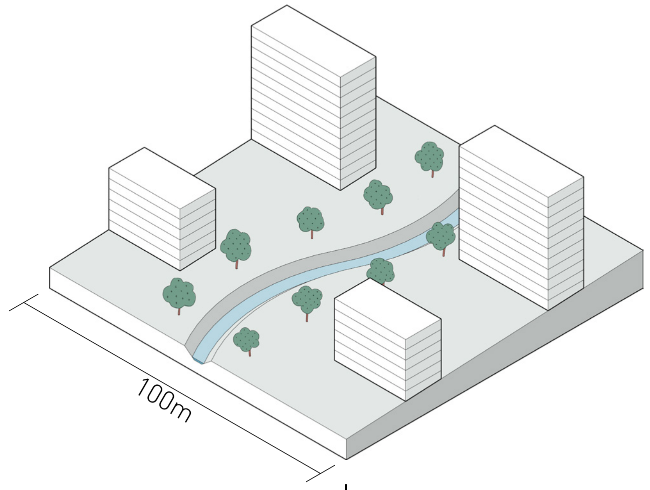


2100 Flood retaining

If the runoff issues getting worse in the future, the flood retaining structure (dyke, floodwall, etc.) could be used at the hazard area to protect the urbanized environments.

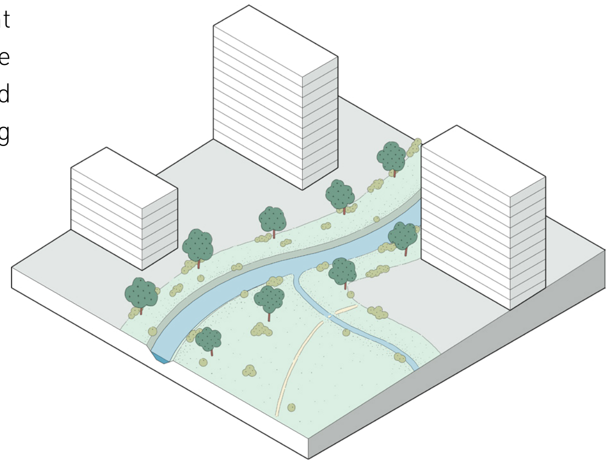


Creek 2020



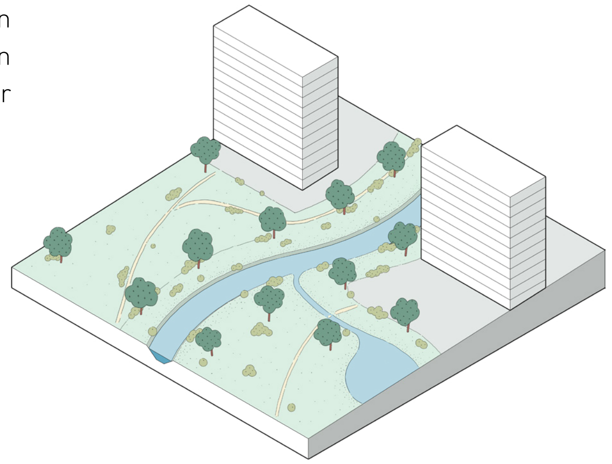
Flood adaptive 2040

Switch the existing hard embankment to the ecology solution, extend the green space and natural habitat, and connect the rainwater garden along main runoff to creek.



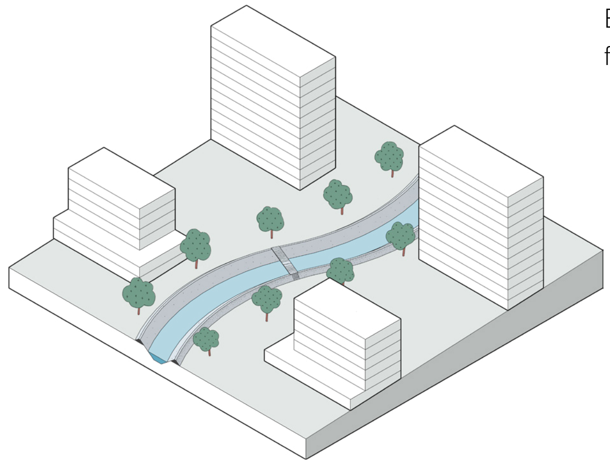
Flood adaptive 2100

Demolish the vulnerable building in the hazard area and extend the green space, increase the nature water capacity.



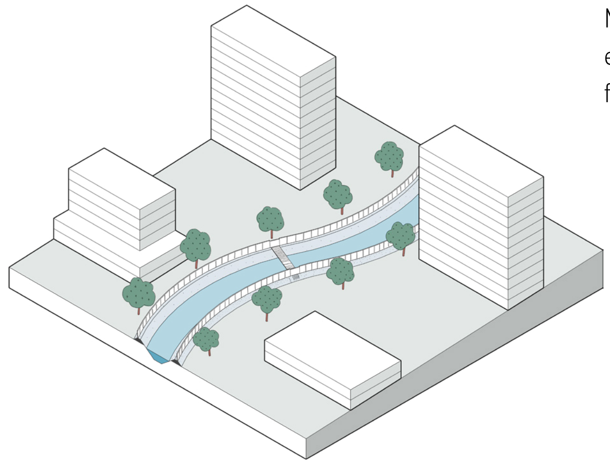
2040 Flood retaining

Build dyke along the creek to retain floodwater in an emergency.

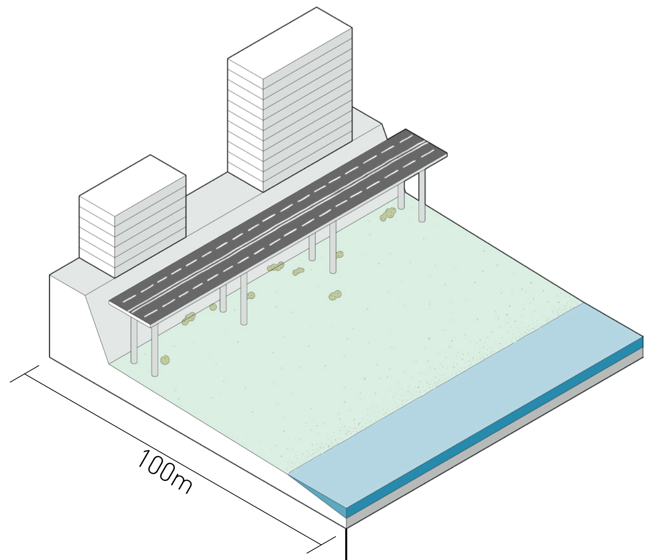


2100 Flood retaining

Maintenance and strengthen the existing hard infrastructures, built floodwall when necessary.

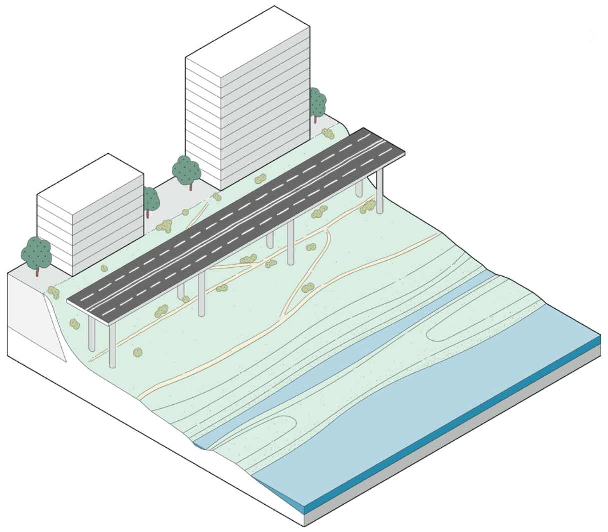


Main river 2020



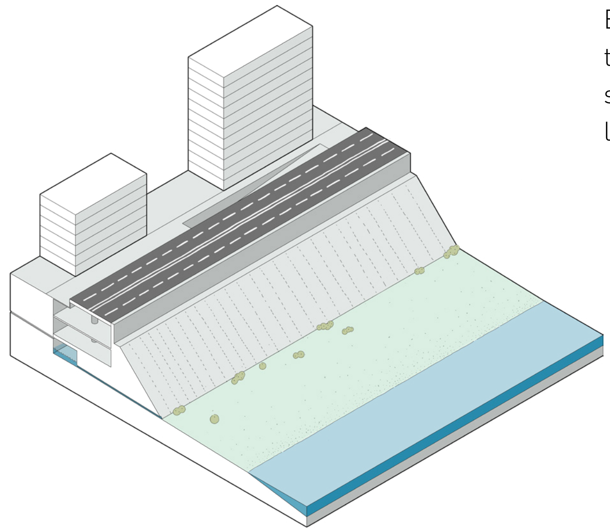
Flood adaptive 2040

Switch the existing hard embankment to the ecology solution, extend green space and natural habitat, and increase biodiversity. Build pathways along the river corridor, increasing the area's walkability, and provide high-quality public spaces to local residents.



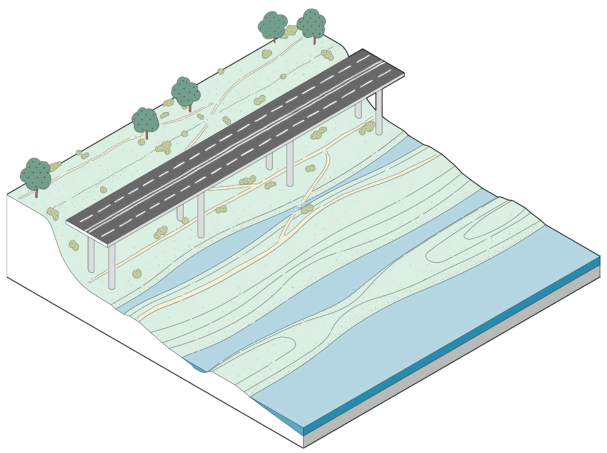
2040 Flood retaining

Base the viaduct road to strengthening the hard embankment, and use the space under the viaduct as parking lots and floodwater containers.



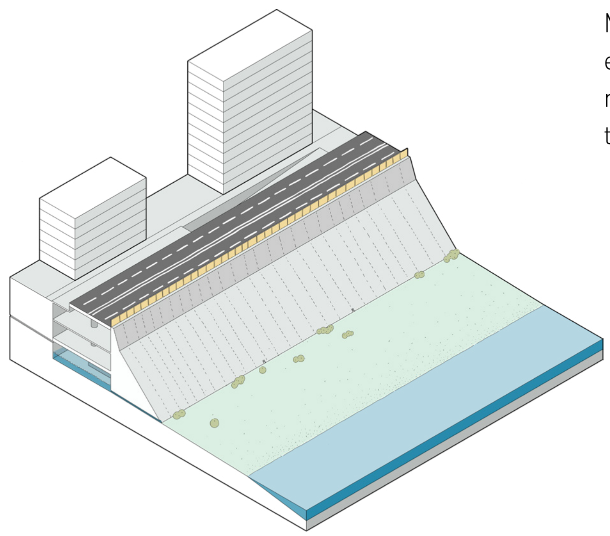
Flood adaptive 2100

Make the area more natural, and give more space to the river.



2100 Flood retaining

Maintenance the existing hard embankment and built the floodwall if necessary. Increase the capacity and the number of floodwater containers.



Intervention

- Intervention principles

After discussed and explored the priorities and the future scenarios, the goal of the intervention is to generate a flood resilience future. The intervention is not only to mitigate the flood issues but also to provide ecology values and social wellbeing.

To make the intervention more specific and clear, and could be used as a reference to other upstream Yangtze river cities, an intervention road map is generated. The road map is based on the state policy document and scenario making, combine with the priorities of different stakeholders. The road map takes the proportion of blue and green area as the standard, and divides the site into settlements and natural areas. Then subdivide these two types of sites. Set up different flood resilience implement methods for sites with different characteristics. It is a tool to guide the planners to find the most suitable flood control intervention for different sites.

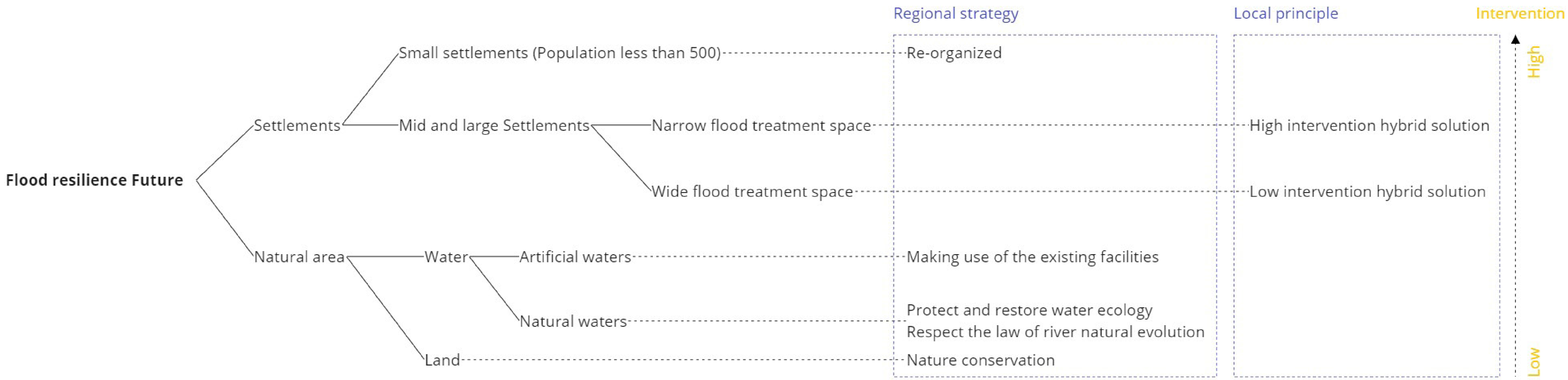
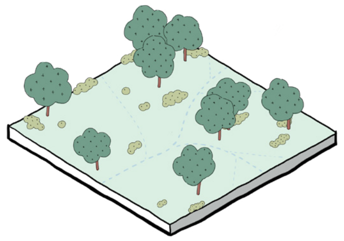


Fig.40. Intervention principle road map, edited by author

- Regional strategy

Regional-scale strategies mainly target natural areas and small settlements. In this type of site, blue and green areas often occupy most of the area. According to the "Outline of Yangtze River economic belt development", this type of site will take the role of ecological protection and restoration. From the perspective of implement flood resilience, this kind of site will be more responsible for the protection and restoration of natural water systems and the enhancement of water storage capacity. Systematically enhancing the flood resilience of this type of site can greatly alleviate the flood pressure in downstream urban areas.

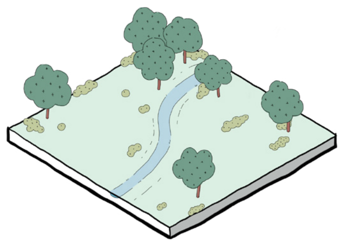
Natural land



Nature conservation:

Natural lands are forests, grasslands and all natural areas without artificial construction. Although this type of area is not part of the natural water system, it is an important carrier of the natural water system. Natural land is the upper reaches of creeks and rivers. When it rains, the runoff generated in natural land will flow into downstream rivers. It also takes the role of natural water storage, and the higher the abundance of its plant population, the higher the natural water content. Therefore, this type of sites must be strictly protected. Strictly limit the development scope of cities and farmland so that human activities do not affect those sites, thereby protecting their biodiversity and natural water storage capacity. And enhancing flood resilience on the regional scale.

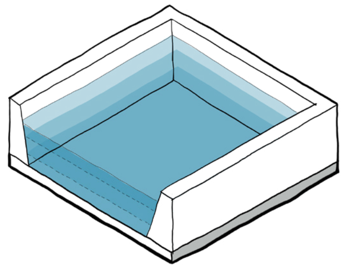
Natural waters



Protect and restore natural water system:

Natural water is the existing surface water system and is the core of the natural water system. Flood disasters are often reflected in the instability of natural water system. In the "Outline of Yangtze River economic belt development", for natural water, it is mentioned that the laws of nature and the evolution of rivers should be respected. And the relationship between rivers and lakes, between upper, middle, lower reaches, and between mainstream and tributaries should be coordinated. These measures reduce the intervention of human activities in natural waters and the conflict between human activities and natural water systems. Thus, reduces the probability of floods caused by human influence and enhances flood resilience on a regional scale.

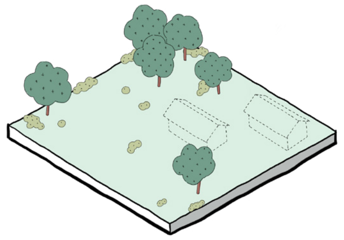
Artificial waters



Making use of the existing facilities:

Artificial water is the man-made water areas, such as reservoirs. The upper reaches of the Yangtze River have now formed a large-scale reservoir group, which has a certain regulating effect on the water level and floods of the Yangtze River. However, as mentioned in the problem field, the existing reservoir operation method is too fragmented and does not maximize the water storage capacity of the entire system. In order to maximize the use of existing infrastructure resources, integrate existing reservoirs and categorize them into three levels: core reservoir, backbone reservoir, and tributary reservoir. The tributary reservoir is mainly responsible for the flood control and regulation of its own river. The backbone reservoir, with the cooperation of the tributary reservoir, guarantees the flood control safety of important cities along the Yangtze River mainstream, And the core reservoir, which is, the Three Gorges Reservoir controls the amount of flood flowing into the middle and lower reaches of the Yangtze River (Hu et al., 2020).

Small settlements



Re-design:

Small settlements are the small villages scattered in natural areas. When suffering the floods, these small settlements are the most vulnerable areas. Human activities around it will also often affect the natural water system, and these effects will often cause itself and downstream to be threatened by floods. In order to protect small settlements and reduce their negative impact on natural water systems, it is necessary to reorganize the relationship between the small settlements and natural water systems in areas threatened by floods. For example, de-pavement hard river embankment, restoration of wetland occupied by fields, etc. And enhance the flood resilience of the region through the reorganization.

- Local principle

The Local principle focuses on large and medium-sized settlements, which is the flood defense principle in cities and towns.

In the process of flood control, green and blue infrastructure can not only effectively control floods, but also bring a lot of ecological and social value to the urban environments. In urban, due to the high frequency of human activities, it is difficult to achieve a 100% ecology solution. Therefore, in the urban and town cases, the hybrid flood defense solution will be implemented. According to the proportion of the areas that can be transferred into green and blue, the hybrid solutions can be divided into high intervention hybrid solutions and low intervention hybrid solutions. The difference between high intervention hybrid solution and low intervention hybrid solution is the proportion of green and blue infrastructure, and the biggest factor affecting the proportion of green and blue infrastructure is the amount of urban area that can be transferred. In highly urbanized areas with complex functions and high density, the area that can be transformed is relatively limited. On the contrary, In the urban fringe, or in the functional transformation area where the city is undergoing regeneration, the area that can be transformed is relatively large.

In the local flood defense principle, in order to improve water quality and bring more add-values, the area of the green and blue areas should be increased as much as possible. The feasibility of different sites is determined by the size of the area that can be transformed, so as to determine the use of the high intervention hybrid solution or the low intervention hybrid solution. In the case area, transforming more urbanized areas into green and blue areas during the implementation of flood resilience design and urban regeneration, which could also help Chongqing restore the original cluster-like urban structure during the long-term period.

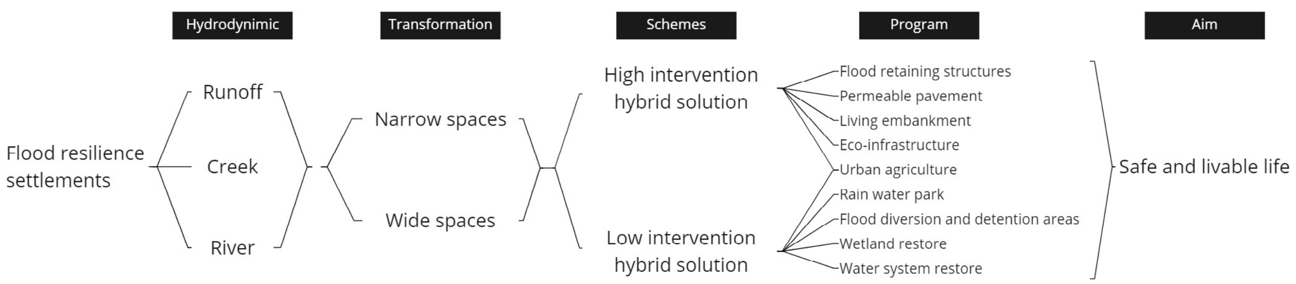
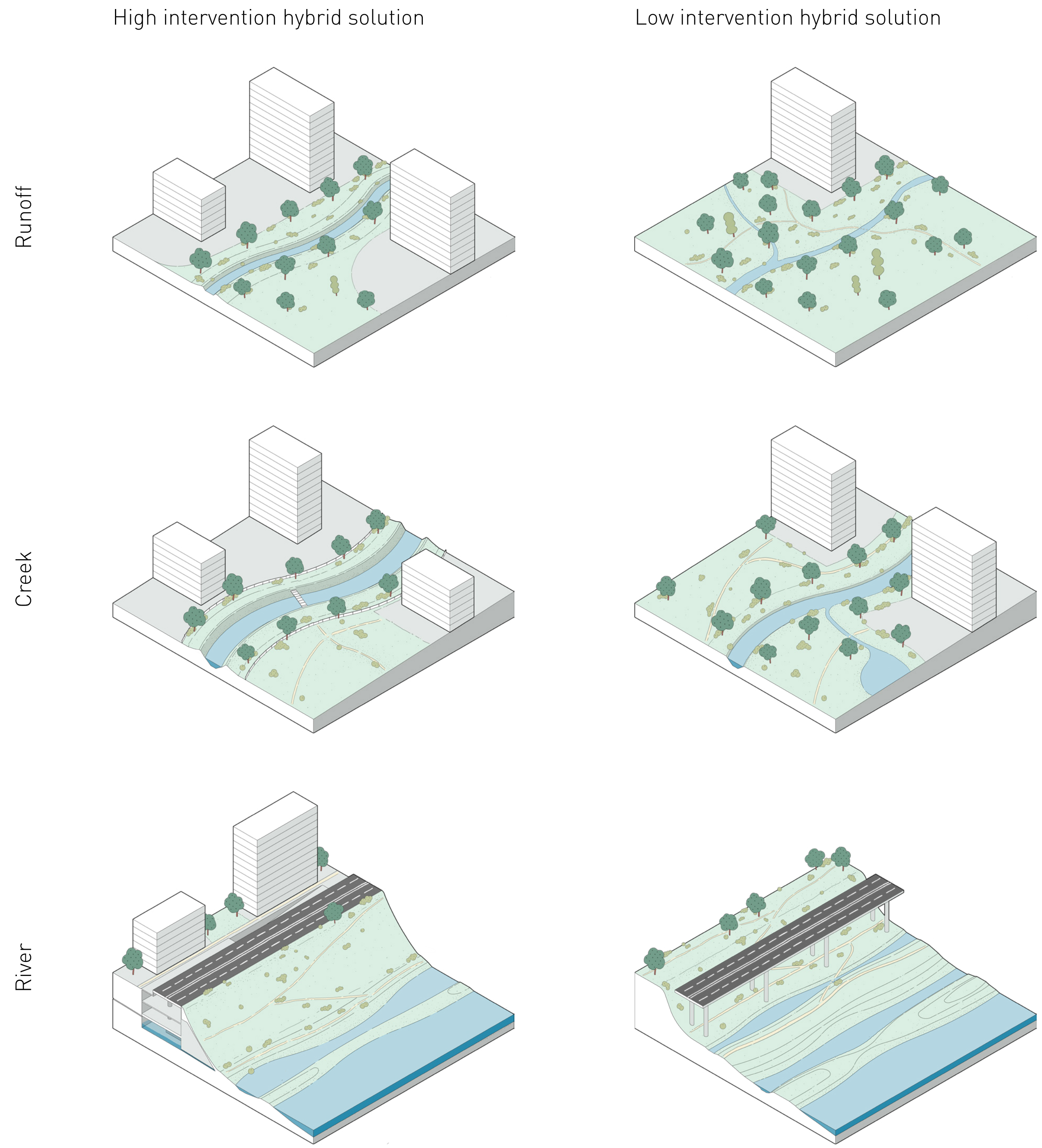


Fig.41. Local principle road map, edited by author



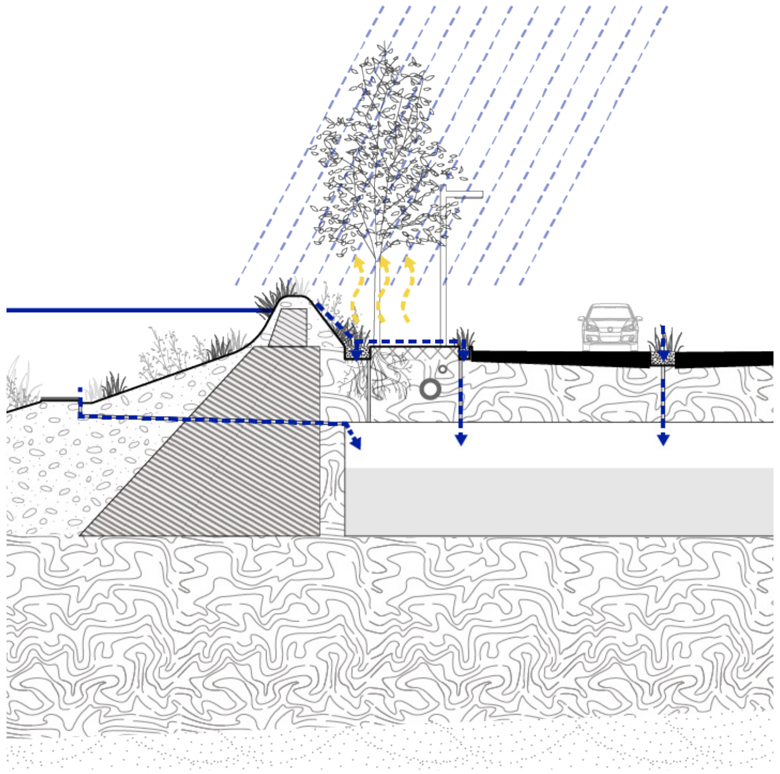


Fig. 42. Flood resilience design, edited by author

08. Design experiment

The design experiment is based on the intervention principle. And the selection of the experiment site is based on the flood influence assessment results in the previous section, selecting the areas that are highly affected by the flood hazard. Since the case sites in the study are all in the urban environment, the local principle was used as the guideline during the design experiment. The goal of the design experiment is to provide a safe environment for areas under flood hazards by using hybrid flood control infrastructures. Then to protect the lives and property of local residents, and to reduce the impact of floods on the urban environment. When applying the hybrid infrastructure, increase the area of green and blue in the urban environment as much as possible, and deal with Chongqing's flood problem in a more natural and ecological way. While bringing a safe urban living environment, it also brings co-benefits to the local community and the ecology of the city.

The purpose of the design experiment in this study is to serve as the beginning of urban flood resilience design for Chongqing and even the upper reach Yangtze River Basin cities. Flood resilience design for one or several sites can be achieved in a short period of time, but the flood resilience future of the entire city and even the region will take a long time and be completed step by step. Therefore, the design experiment is a practical application of the research and the theory. In the future, it could be used as a reference for more flood resilience designs.

Charpter structure

a. Case 1: Nanbin road-Danhui road

b. Case 2: Ciqikou

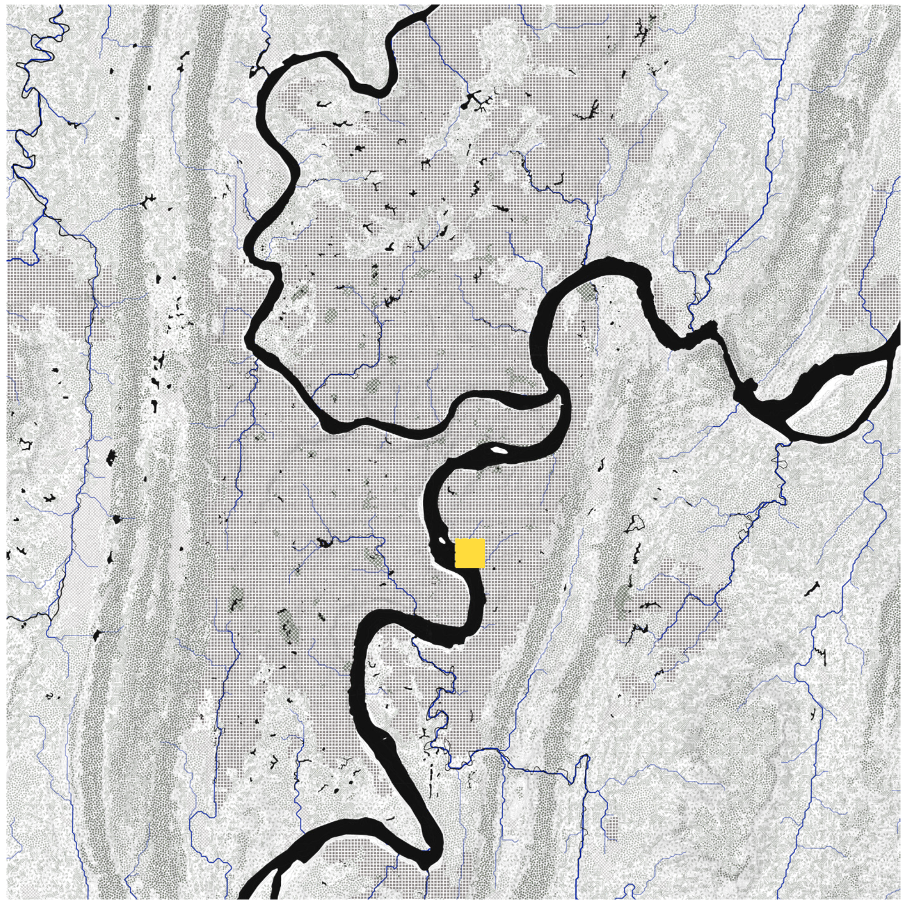


Fig.43. Location of Nanbin road-Danhui road area, edited by author

Case 1: Nanbin road-Danhui road area

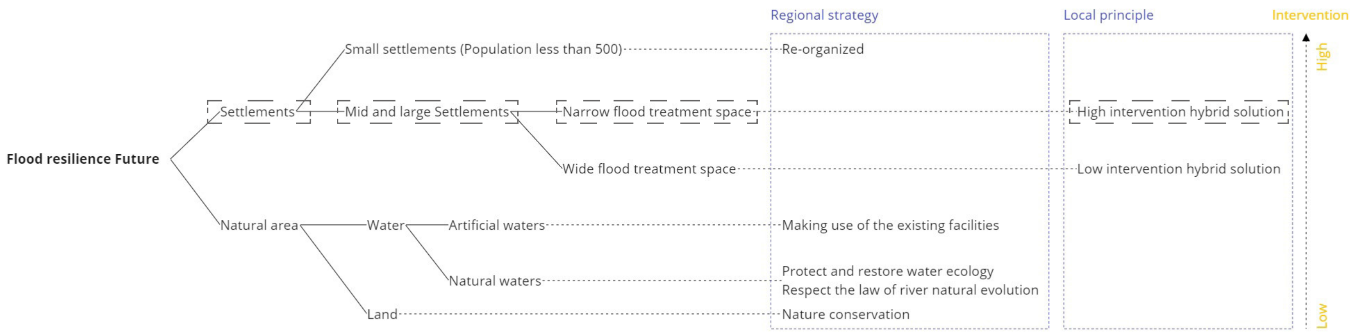
- Basic information:

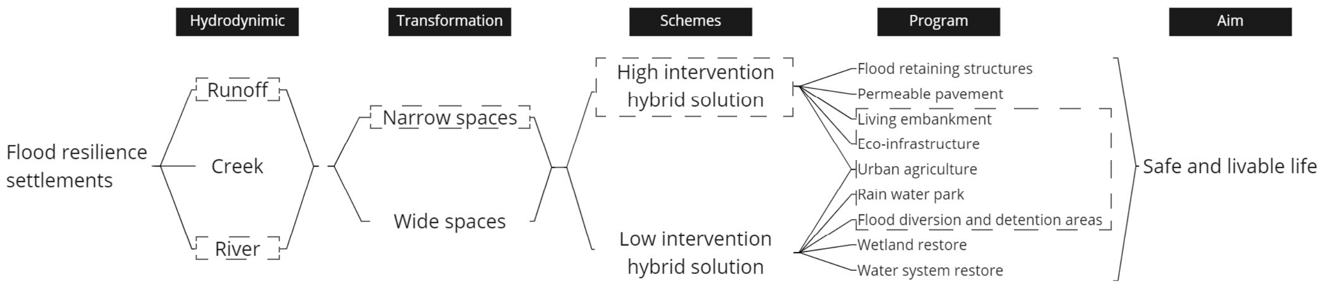
This area is located along the Yangtze River in the Nan'an District of Chongqing, and located in the upstream direction of Yangtze River. In the flood influence assessment, this site has a large area under the flood hazard, and has the highest score in the final Flood vulnerability score. It is the most severe flood-affected area in the main town of Chongqing. Therefore this site is chosen as one of the design experiment case study areas.

This area is a highly urbanized area, with high density and a large population. The site is mainly covered by the high-rise residential communities built in 20 years. Around the communities, there are some small commercial buildings such as retails and restaurants. The urbanized area and Yangtze River's riverside are separated by the Nanbin road, and the Nanbin road is the riverside express road in Nan'an District, which plays a very important role in the city's mobility.

- Guideline

Nanbin road-Danhui road area is a dense area and has a large population, and most of the high-rise residential communities on the site are constructed in recent years. At the same time, Nanbin road is the main road of the city. Therefore, in this area, there is limited space that can be used to deal with floods and be transformed into green and blue areas. Because of that, according to the intervention principle, a high intervention hybrid solution will be used in this venue. By transforming the existing hard embankment, implement the flood diversion channel and the rain garden, the flood resilience of the area will be increased.

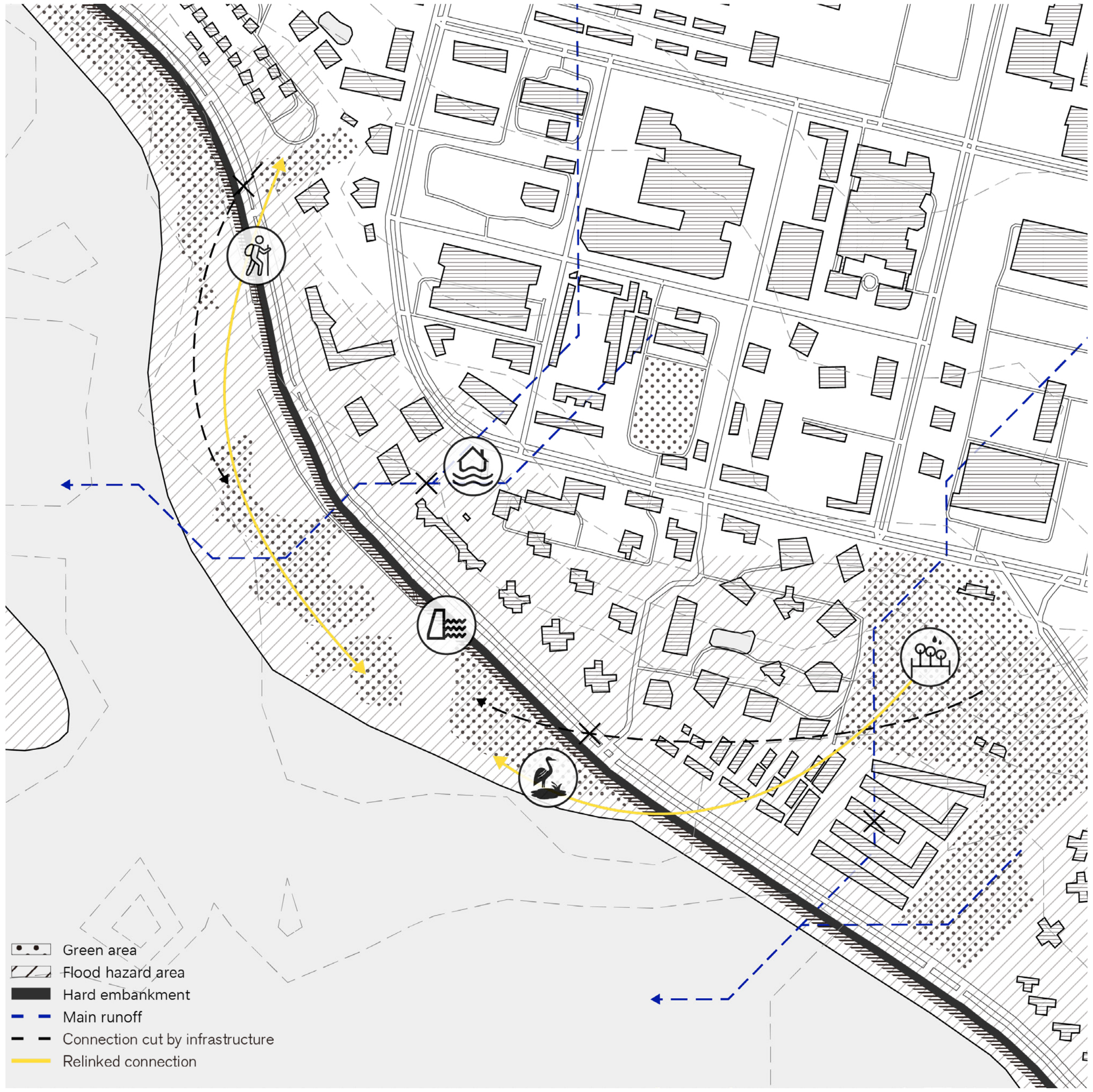




- Intervention

Inside the site, most of the green spaces are those within the residential community, which are scattered and do not undertake ecological functions. And the large green area in the southeast corner of the site is unused and surrounded by walls, blocking the connection with the outside environment. The current riverfront area is occupied by express road and hard embankment, which separates the urban environment from the riverfront area in terms of ecology, water system, and walkability. There are two main runoffs flowing through the site from the northeast to the southwest, but currently, there is a lack of consideration related to them.

There are three main aspects to intervene in the site. First, in order to cope with the flooding of the Yangtze River, a flood diversion channel was added to the existing riverfront area to increase the water storage capacity during the disaster. And transfer the existing hard embankment to bio-



embankment, plant different plants in the vertical direction base on the different environment. Thus, enhancing the natural water storage capacity. Second, in order to deal with the runoff, use the large green space in the southeast direction, implement eco-infrastructure such as rainwater park and bioswales. Finally, co- benefits. Ecologically, in order to break the separation, build bio-bridges, connect the green space in the urban environment with the riverfront area, and form an overall ecosystem. In society, provide local residents with high-quality public spaces, such as trail systems and urban farms, to enhance community cohesion.

- Land ownership change& stakeholders

In the process of flood resilience intervention, as it involves changes in the functions of riverside land, it will definitely involve the change of land ownership and the participation of stakeholders. In "Outline of Yangtze River economic belt development", the outline emphasizes the importance of river corridor ecological protection. Therefore, in the Nanbin road-Danhui road area, the government will take over the river corridor area from resource-consuming and polluting enterprises, cooperate with green investment and development companies, and jointly develop and manage the river corridor area. While enhancing the resilience of floods in this area, it also brings more added value to its ecology and social welfare.

While cooperating with enterprises, residents as important participants and stakeholders in and around the site, their wishes and suggestions should be fully considered in the process of flood resilience intervention. And their needs should also be given priority consideration.

Tramsformation	Land-ownership
Riverfront area	Owned by states, rented by Yabadong dock company, and partly sublet to leisure company.
↓ Flood bypass channel	Owned by states, rented by eco-tourism company
Abandoned greening	Owned by states.
↓ Rainwater park	Owned by states, rented by sustainable leisure company and real-estate developer.
Fragment green space	The green space outside the residential community owned by states, and inside owned by local residence.
↓ Bio-swale system	The green space outside the residential community owned by states, and inside owned by local residence.

Fig.44. The transformation of land ownership, edited by author

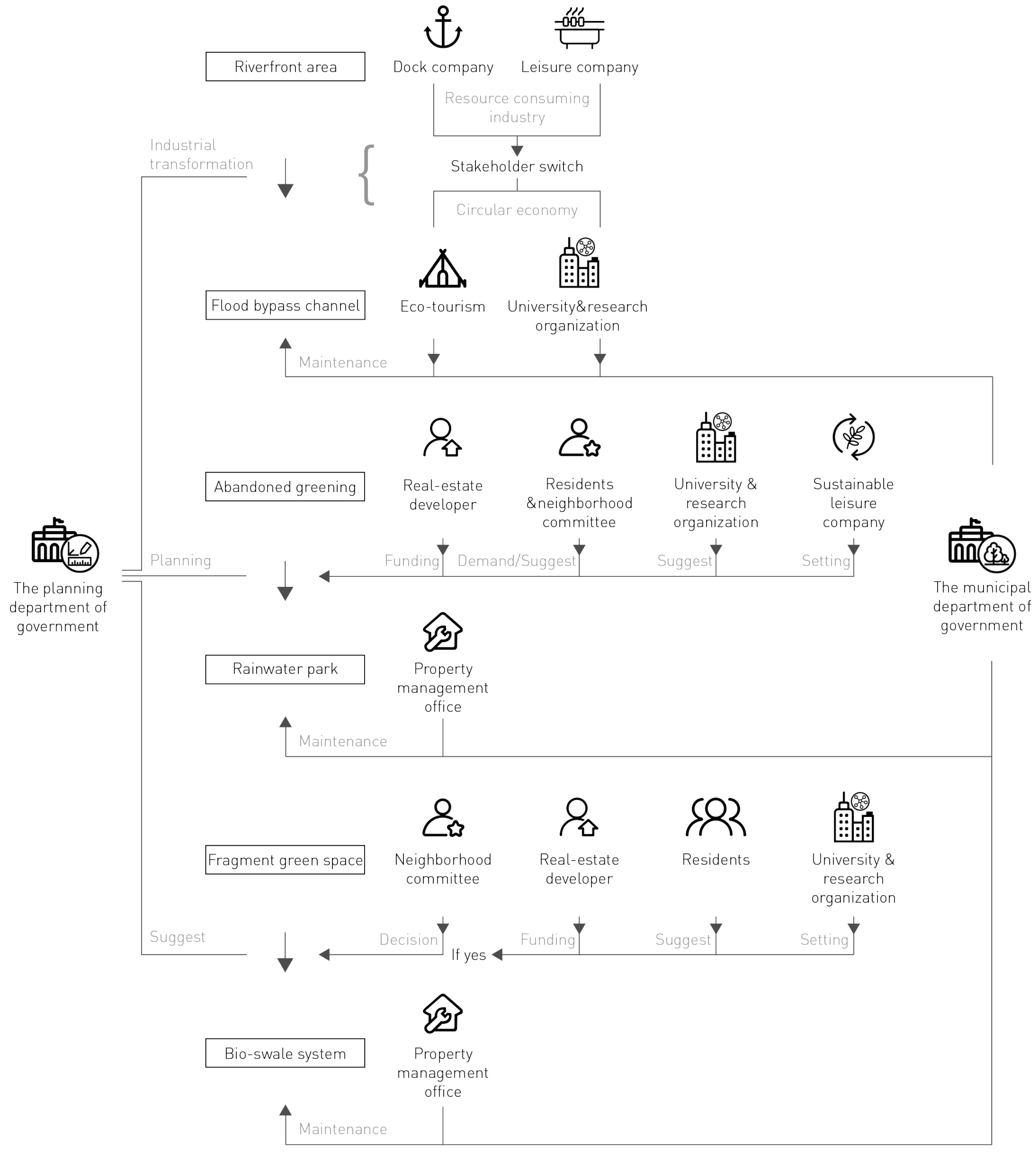
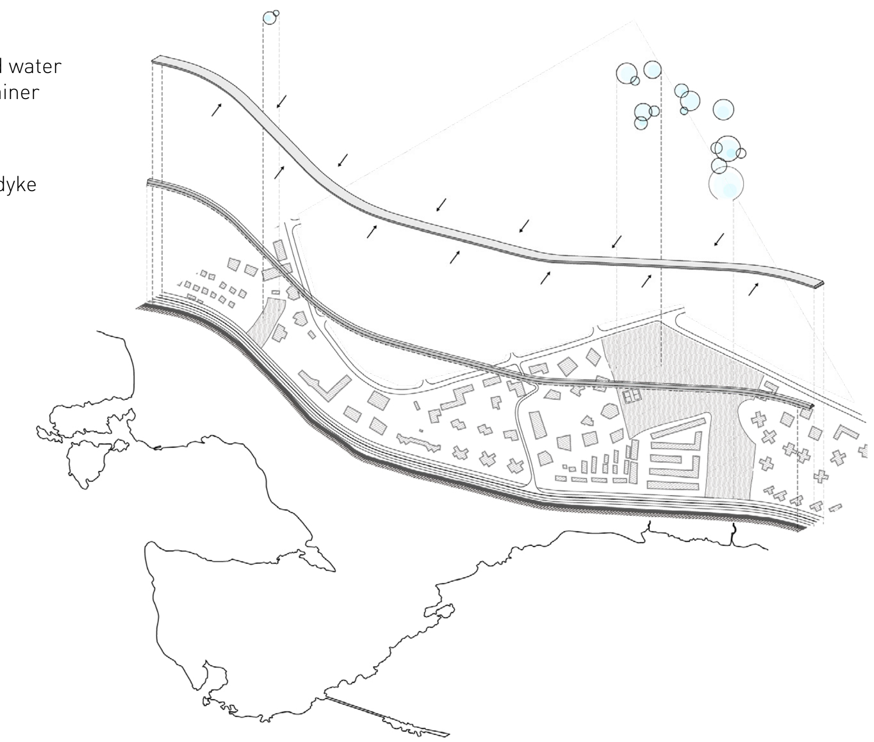
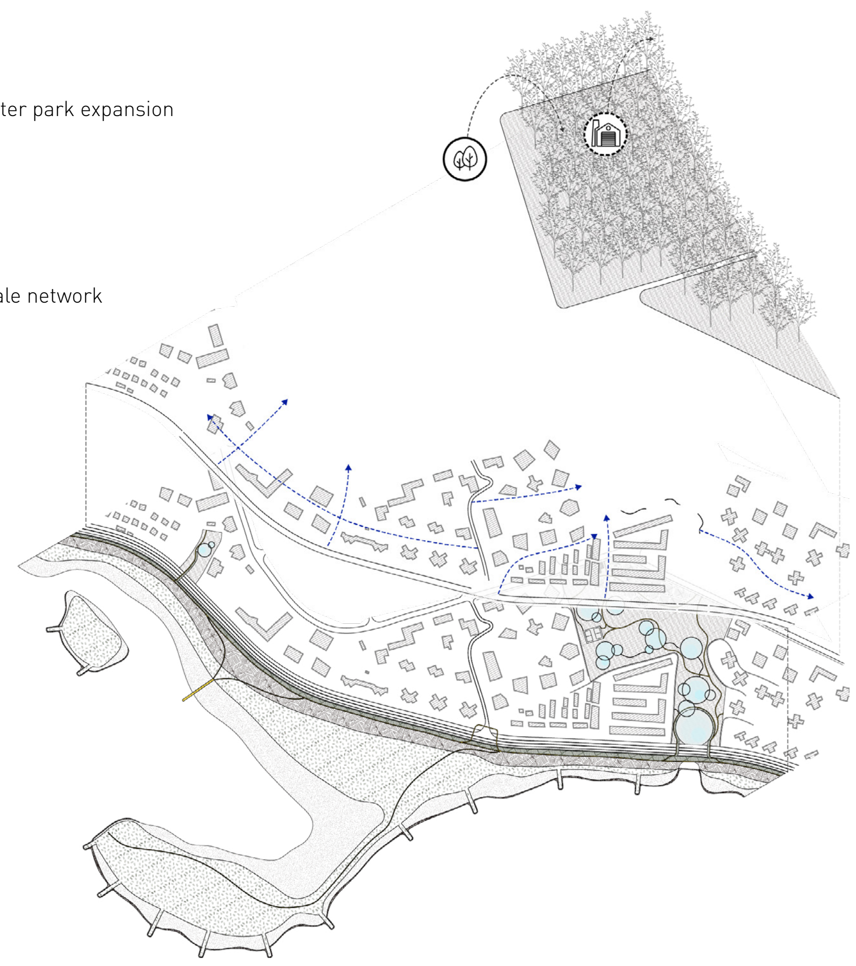


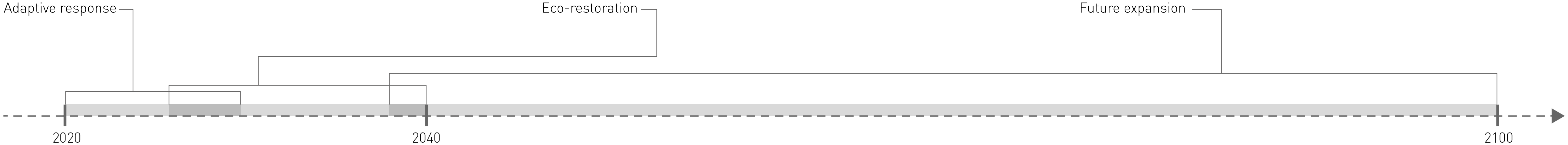
Fig.45. Stakeholders engagement, edited by author

- Progressive development

Since the flood resilience intervention in the riverfront area is a long-term development process, the progressive development is to describe the urgency and certainty of different actions in this process. Thus, the progressive development shows which is the most essential actions that currently urgent, and which is the long-term actions that need to be implemented gradually in the future.







Plan

Legend

- Rock revetment
- Sandy embankment
- Low grass zone
- High grass zone
- Ecodyke&bridge
- Urban farming
- Rainwater park
- Bioswale
- Rainwater pond
- Court
- Pathway

0 100 200

- Vertical

The intervention is manifested in the vertical direction of the site as changes in topography and plant populations.

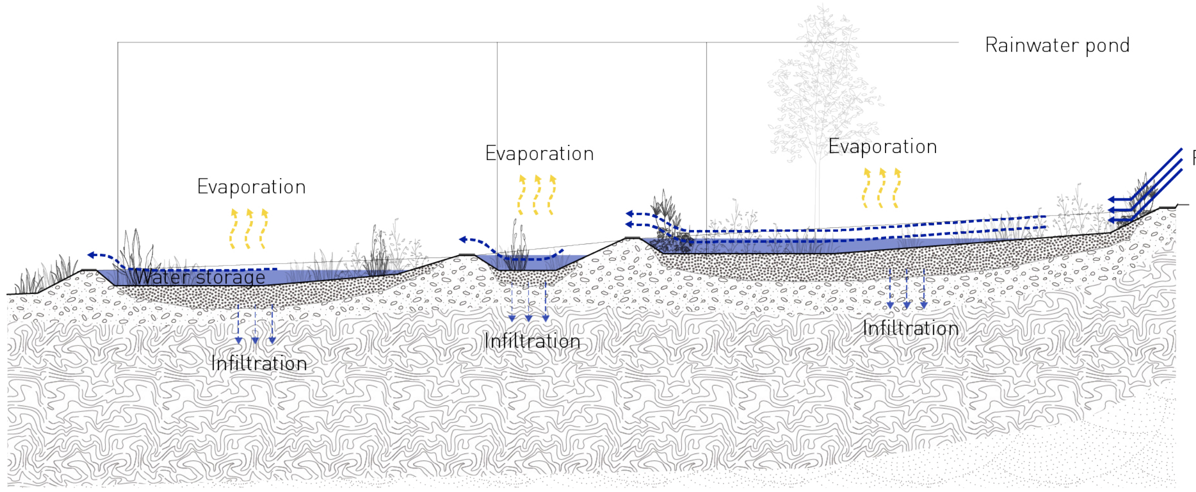
In section 1-1 open the green area which was currently isolated by the wall, and use the height difference, implement a series of rainwater parks. The rainwater parks were connected by the bio-swales, and form an overall rainwater collection system. This system can help reduce surface runoff during heavy rains and reduce or slow down the occurrence of local storm floods. At the same time, the open green space also provides high-quality leisure and landscape functions for the surrounding residents, and also provides a habitat for the wild animals in the city.

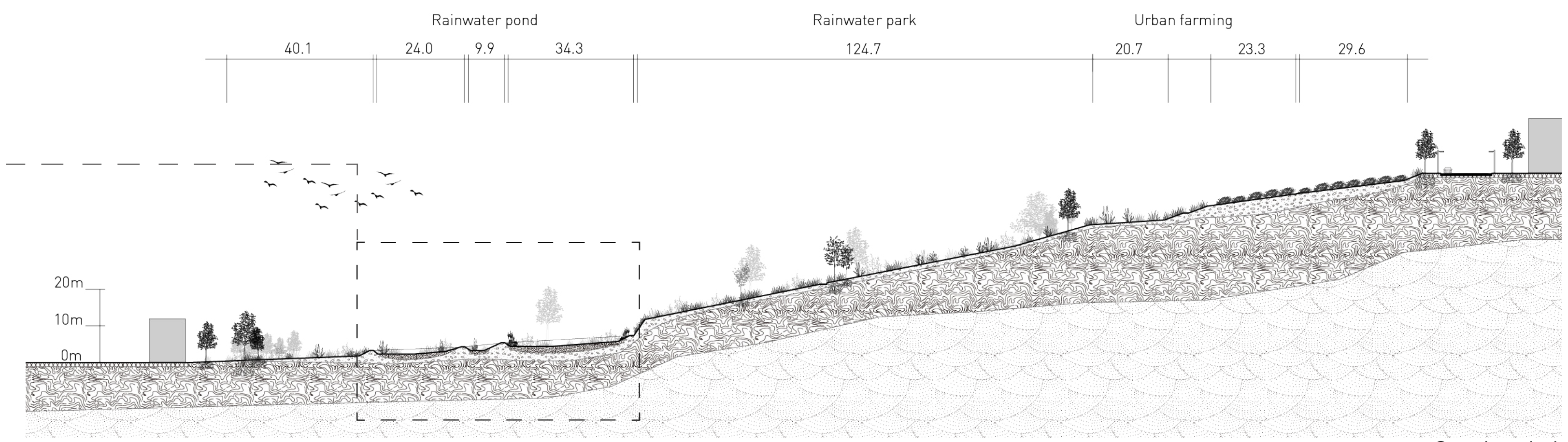
Biome

	Rainwater pond	Rainwater park	Urban farming
Fauna	Mallard	Apodemus draco	Callosciurus erythraeus
	Egretta garzetta	Mustela sibirica	Micromys minutus
	Pelteobagrus fulvidraco	Lepus capensis	Apodemus draco
	Gekko subpalmatus	Callosciurus erythraeus	Rattus norvegicus
	Bufo gargarizans	Pica pica	Leopoldamys edwardsi
	Fejervarya multistriata	Spotted dove	Pica pica
	Mauremys reevesii	Gekko subpalmatus	Sparrow
	Pelodiscus sinensis	Bufo gargarizans	
		Fejervarya multistriata	
		Anourosorex squamipes	
Flora	Carex thomsonii	Carex thomsonii	Corn
	Cynodon dactylon	Cynodon dactylon	Sweet potato
	Hemarthria compressa	Hemarthria compressa	
		Phragmites australis	
		Swida paucinervis	
		Lycium chinense	
		Ficus virens	
		Litsea	

Legend

- Riverbed
- Sandy
- Lime soil
- Rock
- Pavement
- Brown soil



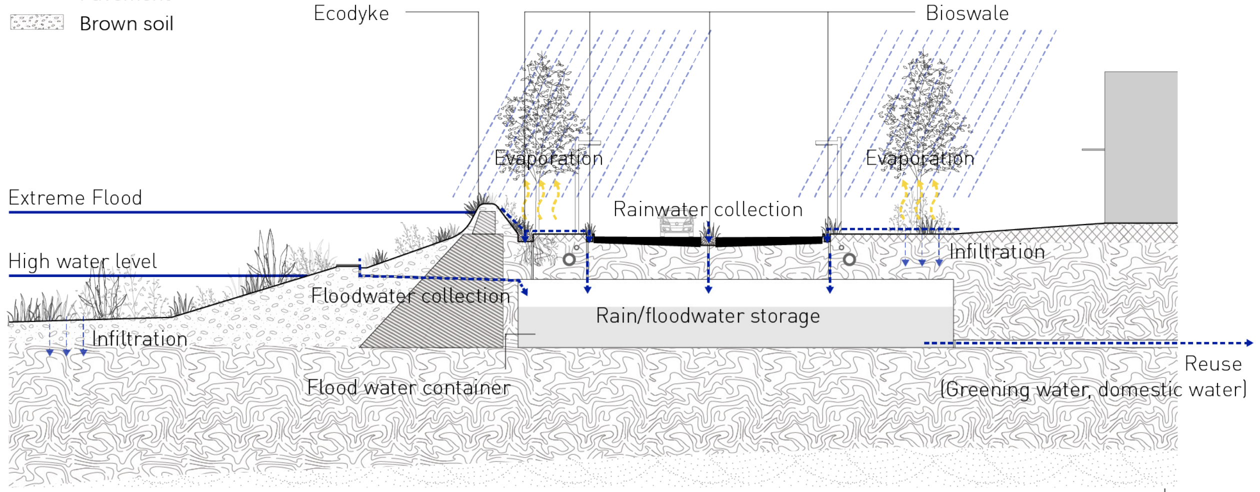


Section 1-1

In section 2-2, covering the original hard embankment with soil, and planting different vegetation on it according to the frequency and the influence of flooding. So as to transform it into eco-embankment, protect the river embankment and increase the nature water storage capacity of the area. Set up a flood diversion channel in the riverfront area to reduce the pressure caused by transit flood. Cultivate vegetations that can conserve the soil and increase the natural water storage capacity in the riverfront area. Transform the bare riverfront into a green area, enhance the resilience of the riverbank ecosystem and reduce soil erosion.

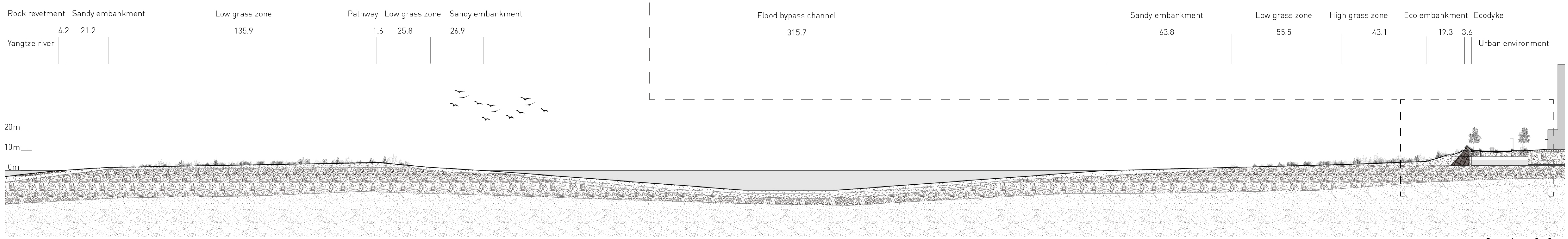
Legend

- Rock revetment
- Sandy embankment
- Lime soil
- Rock
- Pavement
- Brown soil



Biome

	Low grass zone	High grass zone	Eco embankment
Fauna	Egretta garzetta	Egretta garzetta	Spotted dove
	Pelodiscus sinensis	Pica pica	Pica pica
	Pica pica	Sparrow	Gekko subpalmatus
	Spotted dove	Bambusicola thoracica	Sparrow
	Little grebe	Spotted dove	
		Little grebe	
Flora	Hemarthria compressa	Miscanthus sinensis	Cynodon dactylon
	Carex thomsonii	Saccharum spontaneum	Carex thomsonii
	Pogonatherum paniceum	Phragmites australis	Miscanthus sinensis
	Cynodon dactylon	Phragmites karka	
	Polygonum lapathifolium		



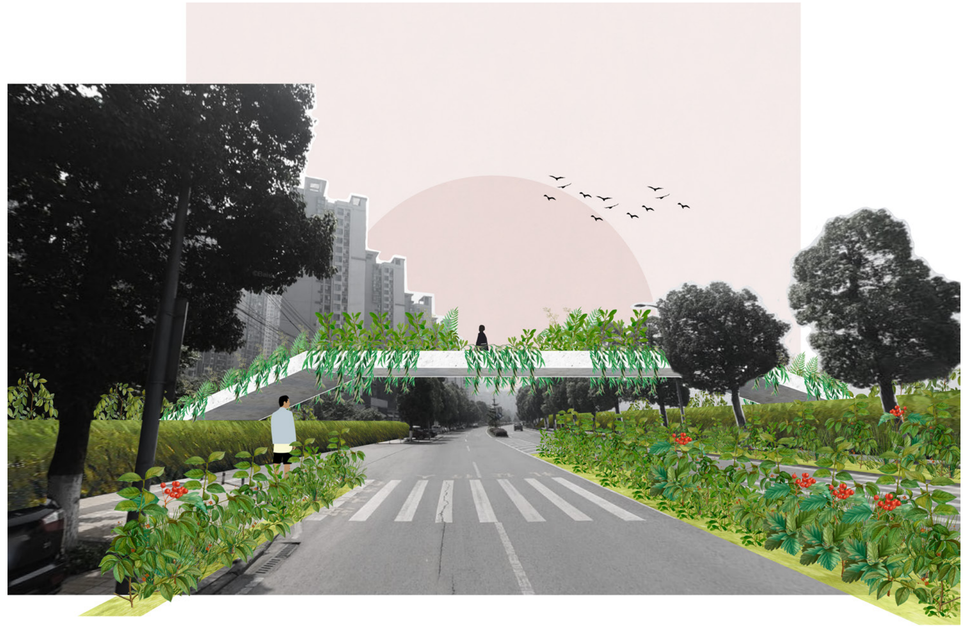
Section 2-2

- Flood resilience performance

Under extreme conditions, such interventions can effectively provide a safe urban environment and protect the lives and properties of local residents. As shown in the sections and plan, when the flood occurs and the water level of the Yangtze River rises, the transit flood enters the flood diversion channel. The local storm flood is stored in the rainwater collection system for the next step of infiltration or evaporation, instead of directly flowing into the river, reducing the pressure of flood peak. Therefore, the flood will only have a limited impact on the urban environment and public infrastructure.

At the same time, due to the Implement of green infrastructure, when the water level changes, the landscape of the riverfront area and rainwater park will also change, forming a dynamic landscape system. The application of different plant populations and the construction of riparian ecosystems have also reduced the erosion effect of floods on the river banks, providing a more stable ecological environment for the riverfront areas.

A view of Nanbin Road



N

Low water level (170m above sea level)

Medium water level (175m above sea level)

Extreme flood (195m above sea level)

Fig.46. Situations under different water levels, edited by author

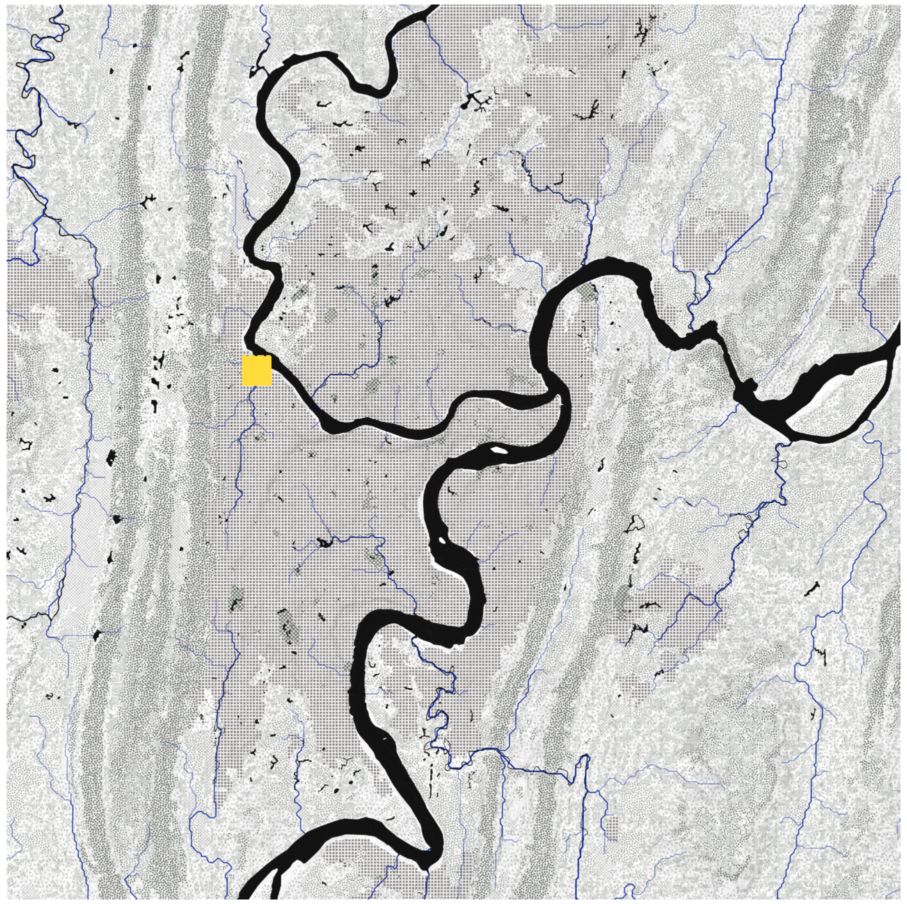


Fig.47. Location of Ciqikou area, edited by author

Case 2: Ciqikou area

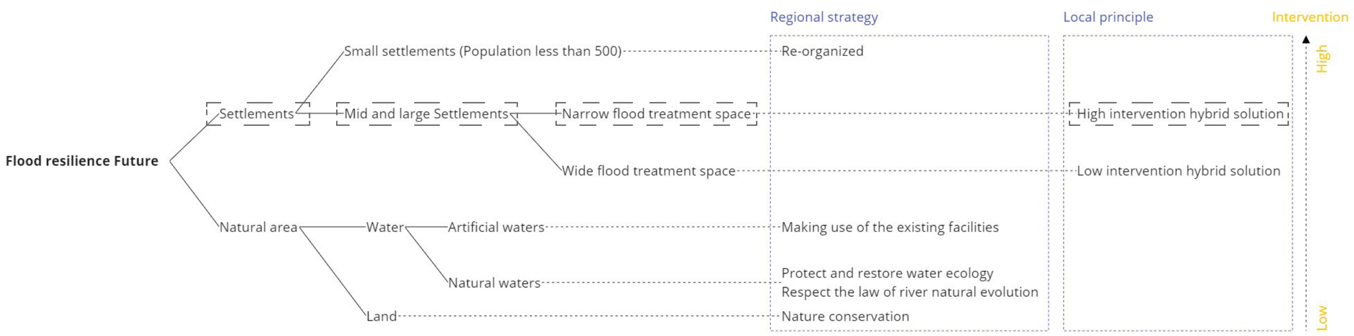
- Basic information:

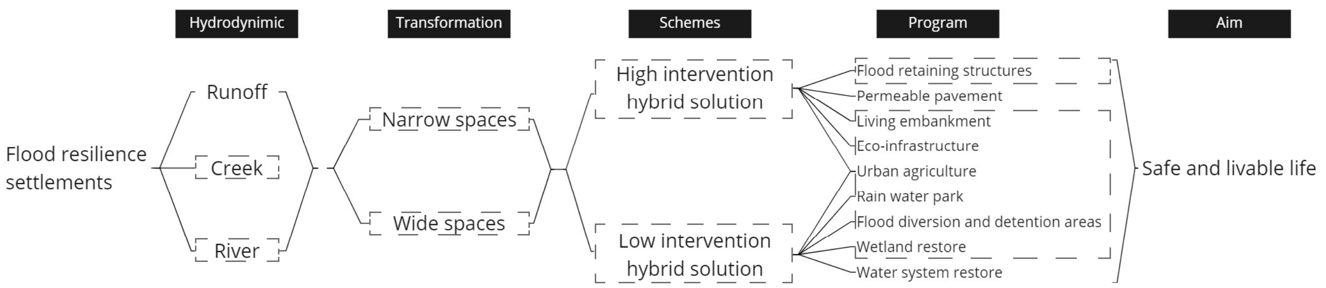
The site is located at the intersection area of Qingshui Creek and Jialing River in Shapingba District, Chongqing City. In flood influence assessment, this area is the most vulnerable place when facing 100-year floods. Moreover, it scored high in the final Flood vulnerability score, which means it is one of the areas severely affected by floods in Chongqing main town. Therefore, it is chosen as one of the case study areas of the design experiment.

The site is located at the boundary of different urban function areas and has complex land use. Apart from natural areas, there are schools and old residential areas inside the site. The north side of the site is the historic town of Ciqikou, which is an important historical and cultural attraction in Chongqing. And it is a key protection area for the urban landscape. Along the Jialing River on the east side of the site is a newly built commercial complex and high-density residential communities. The riverfront area is occupied by a large number of hard infrastructure. The south side of the site is mainly occupied by old factories and residential communities. Generally speaking, the north side of the site and the area along the Jialing River both assume important urban functions, while the urban environment inside the site and on the south side of the site needs to be updated. Most of the factories are now vacant and abandoned, lost their original production functions. The residents in the residential communities around the factory were mostly original factory workers. But now residential buildings are mostly vacant and lack maintenance, becoming the edge space in the city.

- Guideline

The urban function of the Ciqikou area is complex, so the site is mainly divided into two areas. The first one is the highly urbanized area along the Jialing River, which is mainly covered by commercial complex and high-rise residential community. The second is the urban edge area along the Qingshui Creek, which is mainly occupied by natural area, old communities and abandoned factories. Therefore, in the first type of area, the space that can be used to deal with floods is limited, while in the second type of area, there is a lot of space that can be transferred. According to the intervention principle, in the first type of area, the existing infrastructure will be transformed with a high intervention hybrid solution. In the second type, the low intervention hybrid solution will be used to create more green and blue areas for flood diversion.

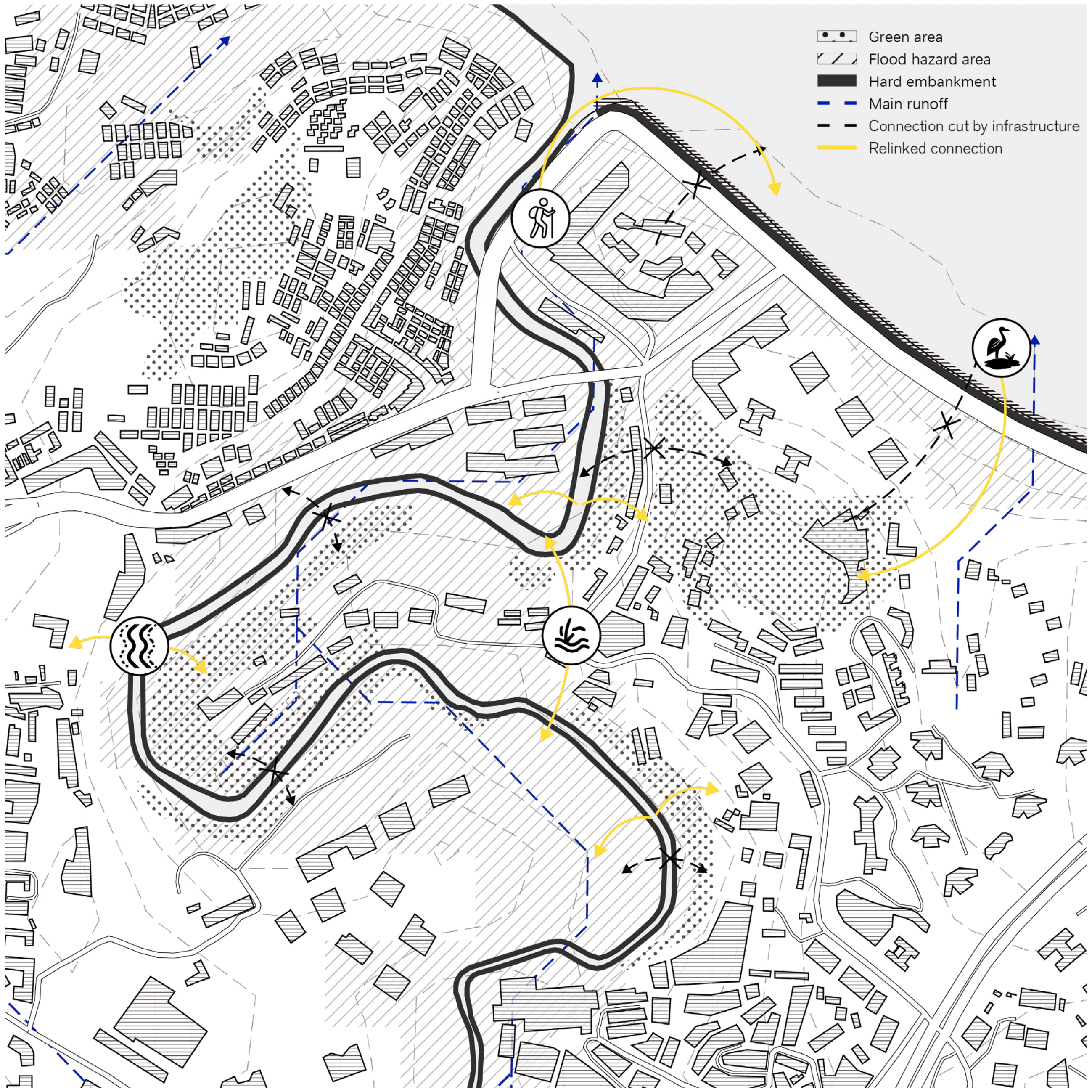




- Intervention

On the site, the bank of Qingshui Creek is now covered by the hard embankment, which separates Qingshui Creek from the surrounding natural environment. And this flood retaining method has not achieved a good flood control effect. When there is a sudden heavy rain, it will aggravate the occurrence of local storm floods. The riverfront area of Jialing River is occupied by a large number of infrastructures such as viaducts and three-dimensional parking lots under the viaducts. A large amount of infrastructure separates this riverfront area from the urban environment in terms of ecology and walkability.

There are three main aspects to intervene in the site. First, restore the natural river course of Qingshui Creek. De-pave the hard embankment along the



creek, restoring the ecology of the riverbank. And use more ecological flood control measures. Implement flood diversion areas such as flood channels and flood detention areas on both sides of Qingshui Creek. Second, the infrastructure on the banks of the Jialing River will be transformed. Transfer the hard embankment along the river into eco-embankment. And use existing infrastructure's structure to build a floodwater container to enhance water storage capacity. Third, co-benefit. On the social level, provide residents with high-quality public spaces, such as urban farming and the walkway system that runs through the site. Thereby enhancing community cohesion and activating old communities.

- Land ownership change& stakeholders

In the Ciqikou area, the conversion of land ownership change mainly consists of two parts. The first part is along the Jialing River, where it was developed by real estate developers and investment groups, and has now been built into a commercial complex and high-rise residential area. Therefore, in the process of implementing flood resilience, cooperation with existing stakeholders should be strengthened, so that real estate developers and investment groups can take more environmental responsibilities.

The second part is along the Qingshui River, here are mostly old communities and abandoned factories. The land ownership change in this area is mainly transformed from the original factory area into a circular and ecologically oriented industry, thereby converting the original brownfield into an area with greater ecological value. Since there are still a large number of residential areas in this area, in the process of implementing flood resilience, residents' ideas and demands should be respected to the utmost.

Tramsformation	Land-ownership
Qingshui creek riverside	Owned by states.
Flood channel	Owned by states, rented by eco-tourism company and investment group.
Jialing riverfront area	Owned by states, rented by real estate company and tourism investment company.
Eco flood retaining facility	Owned by states, rented by real estate company and tourism investment company.
Abandoned industrial area	Owned by states, rented by the industrial company.
Ecological restoration area	Owned by states, rented by the tourism investment company.

Fig.48. The transformation of land ownership, edited by author

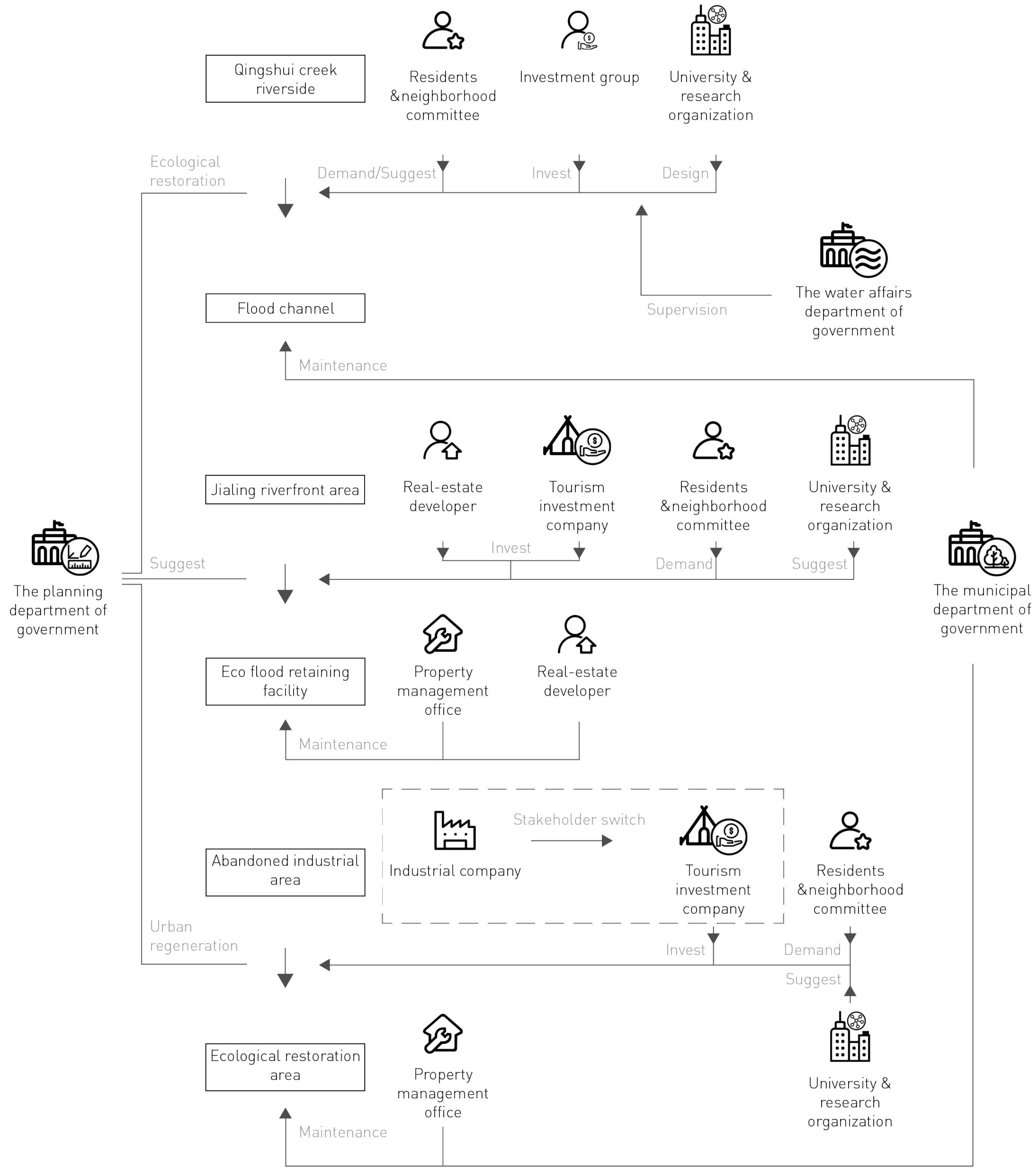
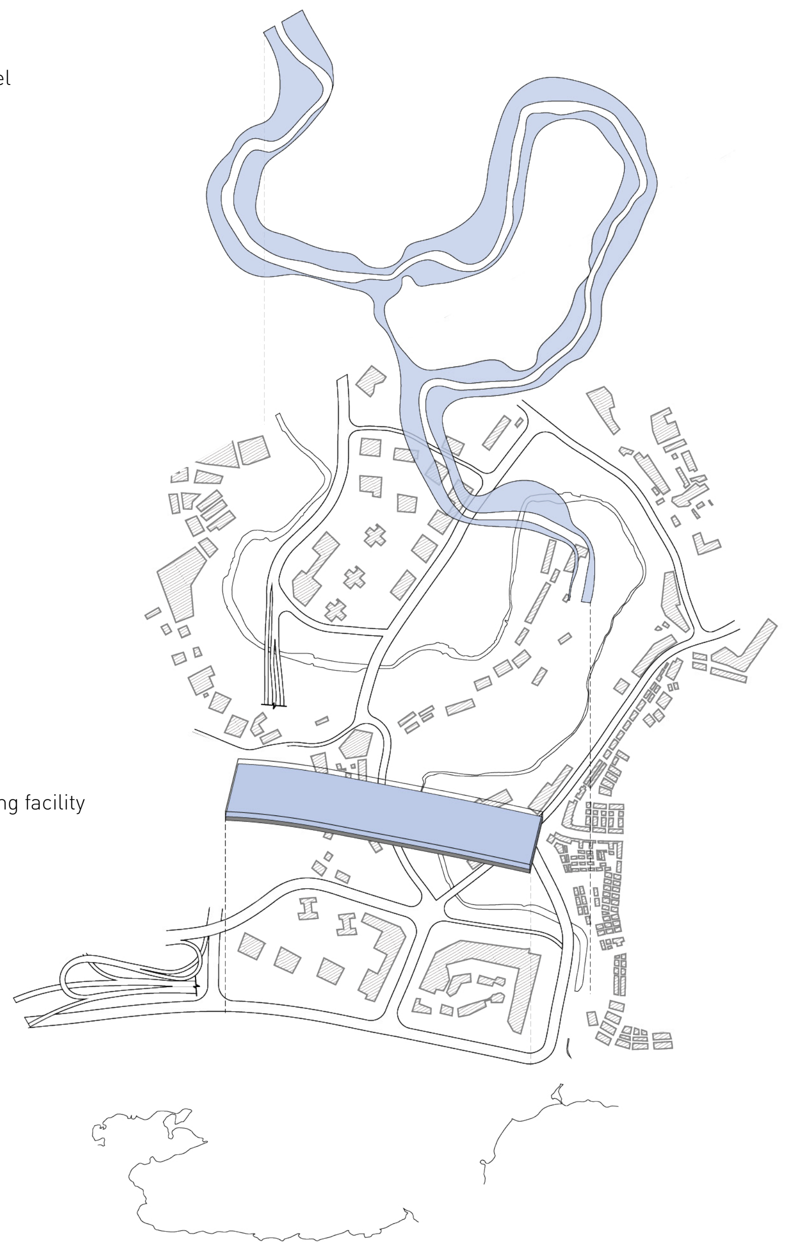


Fig.49. Stakeholders engagement, edited by author

- Progressive development

Flood channel

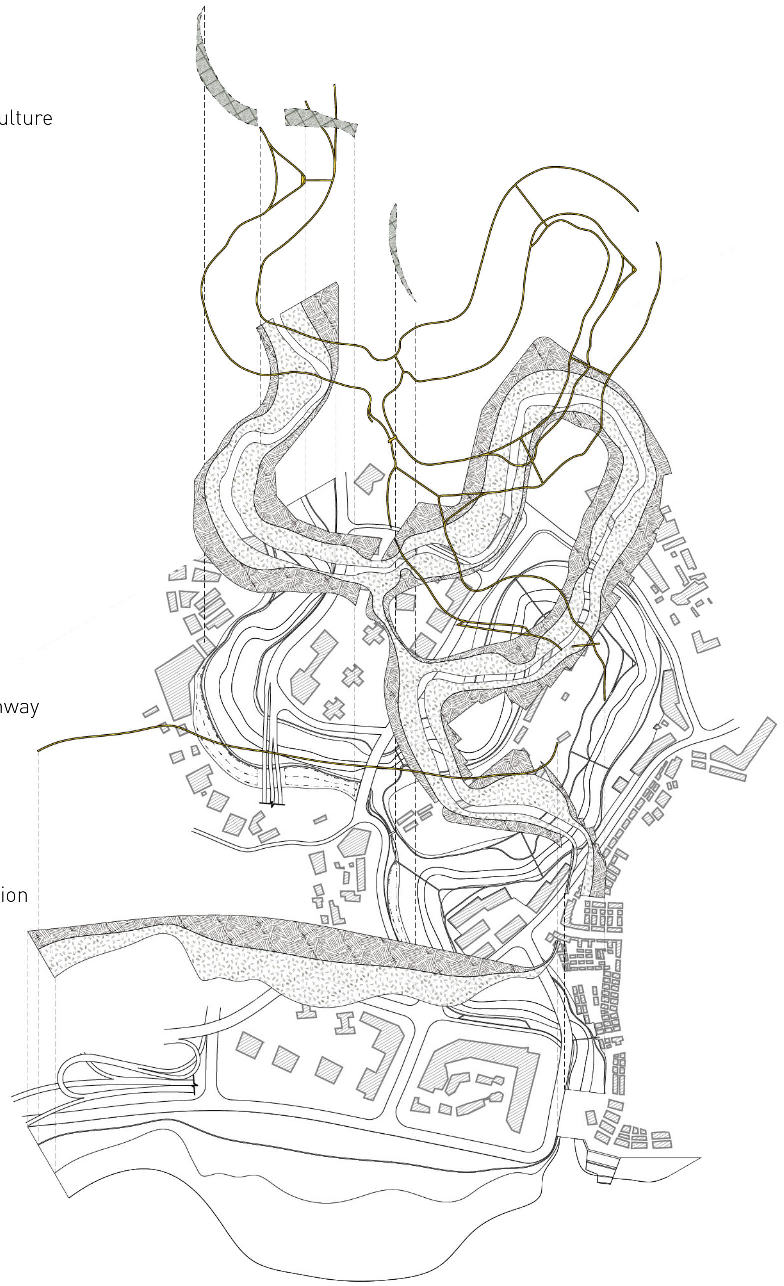
Flood retaining facility



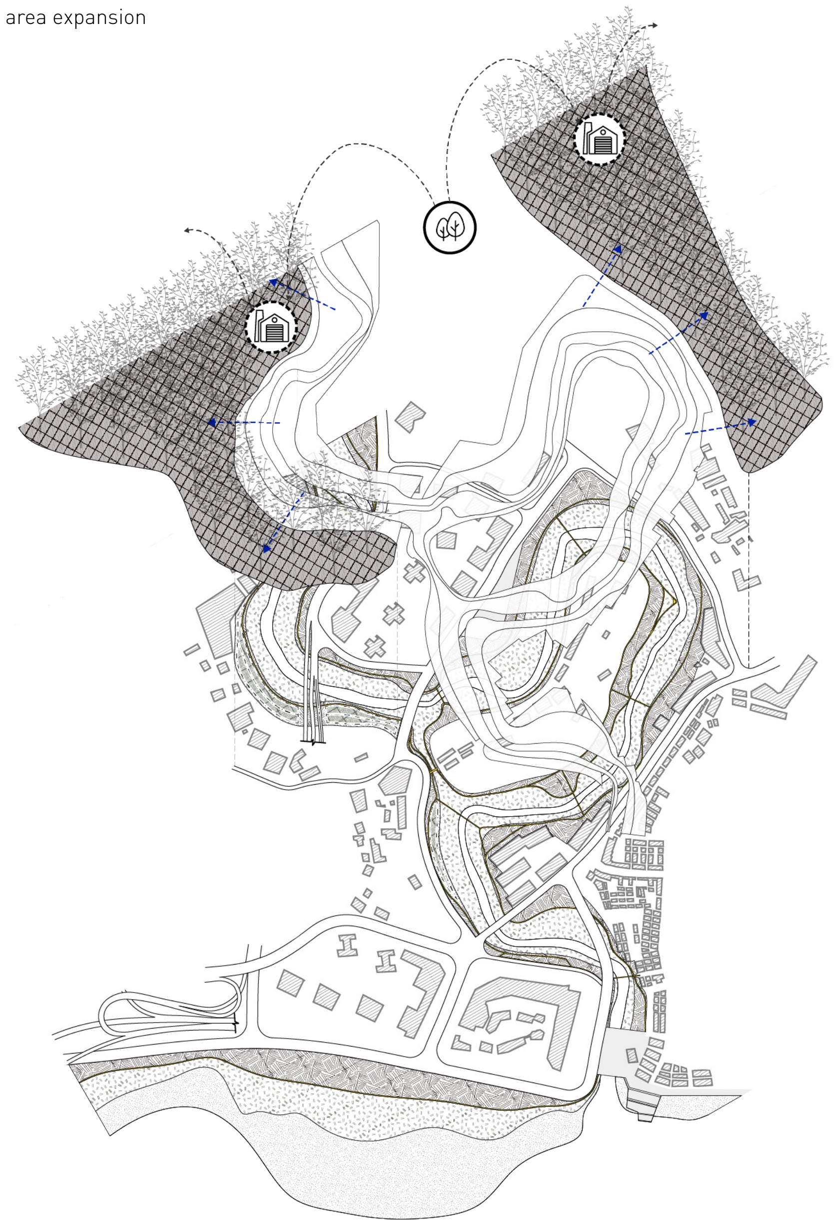
Urban agriculture

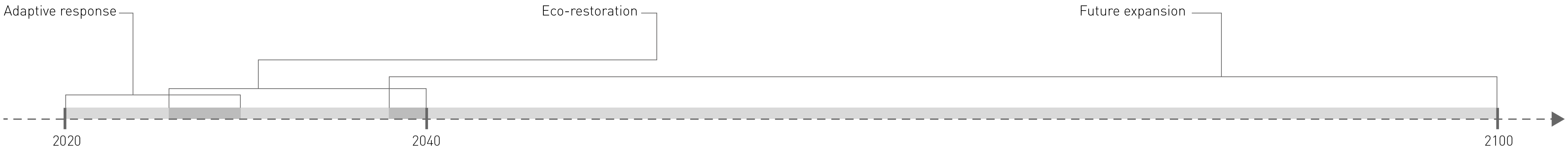
Leisure pathway

Eco restoration



Natural area expansion





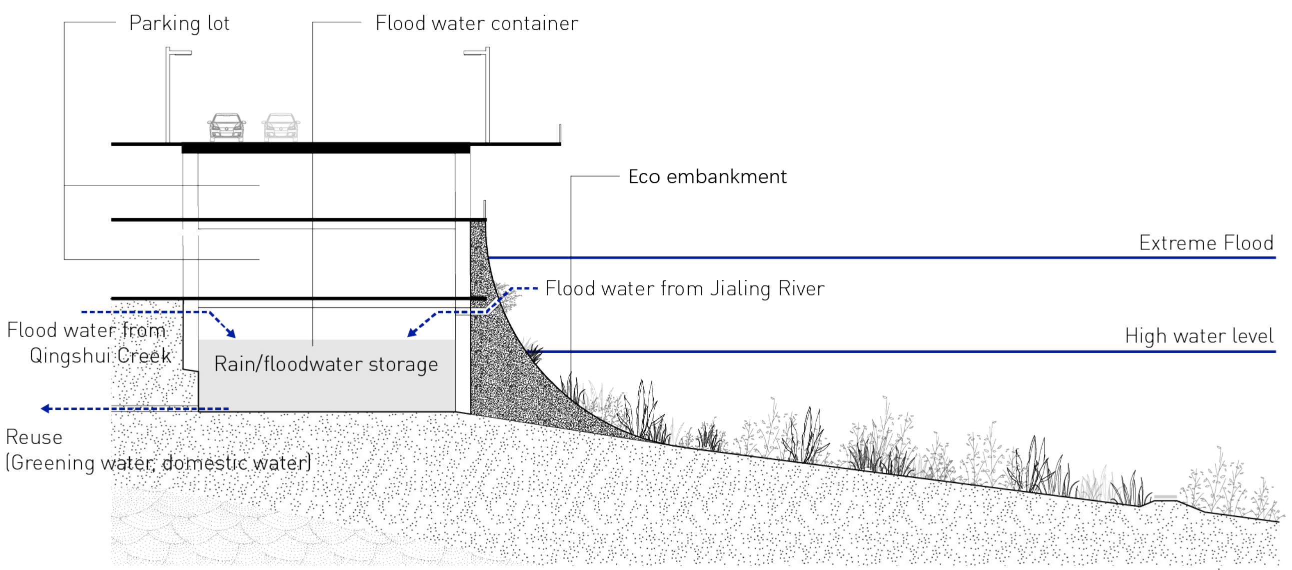
Plan


N
1
2
Legend
Sandy embankment
Low grass zone
High grass zone
Ecodyke&bridge
Urban farming
Rainwater park
Bioswale
Urban palaza
Pathway
0
100
200

- Vertical

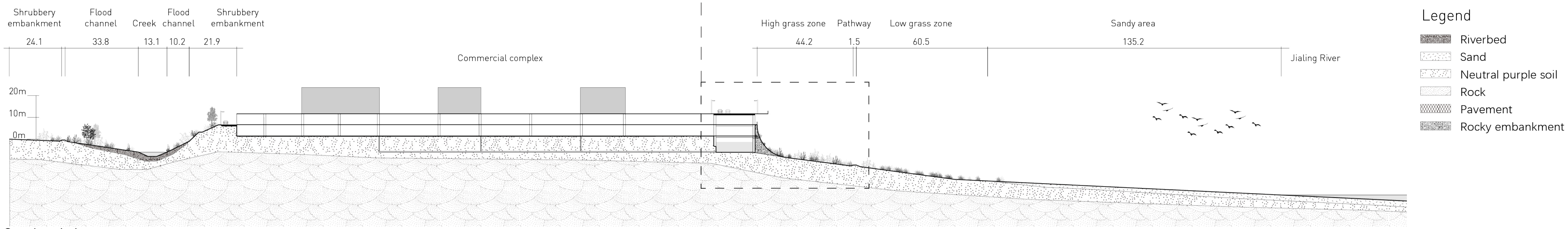
TIntervention is manifested in the vertical direction of the site as changes in infrastructure, topography, and vegetation populations.

In section 1-1, the viaduct and the three-dimensional parking lot under the viaduct are transformed, making use of the existing structure under the viaduct to construct the flood water container. Use the container to control the runoff volume into the Jialing River, store and reuse the local storm flood water. Planting vegetation that can stabilize the soil and increase the natural water storage capacity in the riverfront area where the soil is originally exposed. Thereby adding more green and blue infrastructure to the riverfront area. And use trail connects the riverfront area with the urban environment. providing local residents with high-quality leisure spaces.



Biome

	Low grass zone	High grass zone	Flood channel	Shrubbery embankment
Fauna	Egretta garzetta Pelodiscus sinensis Pica pica Spotted dove Little grebe	Egretta garzetta Pica pica Sparrow Bambusicola thoracica Spotted dove Little grebe	Apodemus draco Fejervarya multistriata Mauremys reevesii Pelodiscus sinensis Bufo gargarizans Mallard Little grebe Egretta garzetta Sparrow Rattus nitidus	Spotted dove Anourosorex squamipes Apodemus draco Micromys minutus Pica pica Sparrow
Flora	Hemarthria compressa Carex thomsonii Pogonatherum paniceum Cynodon dactylon Polygonum lapathifolium	Miscanthus sinensis Saccharum spontaneum Phragmites australis Phragmites karka	Lycium chinense Phragmites australis Phragmites karka Carex thomsonii Hemarthria compressa Cynodon dactylon Salix variegata	Polygonum lapathifolium Lycium chinense Swida paucinervis Campylotropis macrocarpa Carex thomsonii Cynodon dactylon Hemarthria compressa

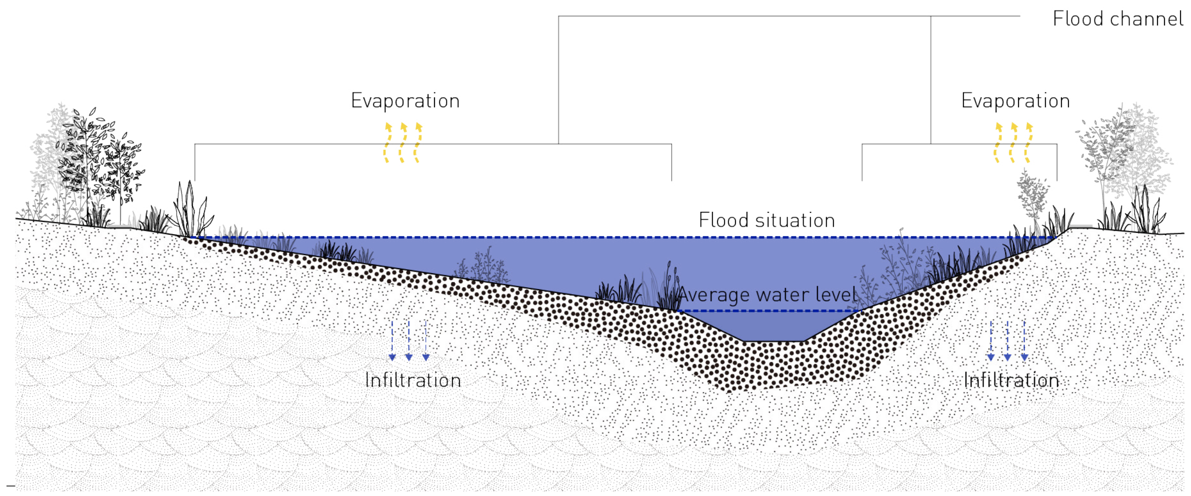


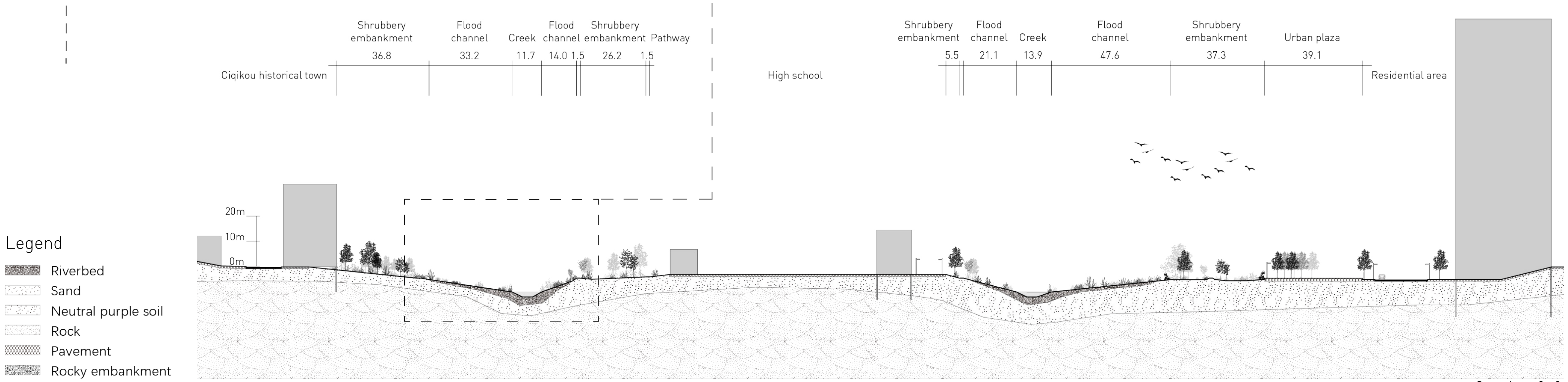
Section 1-1

Biome

	Flood channel	Shrubbery embankment	Urban plaza	Creek
Fauna	Apodemus draco Fejervarya multistriata Mauremys reevesii Pelodiscus sinensis Bufo gargarizans Mallard Little grebe Egretta garzetta Sparrow Rattus nitidus	Spotted dove Anourosorex squamipes Apodemus draco Micromys minutus Pica pica Sparrow	Spotted dove Anourosorex squamipes Callosciurus erythraeus Micromys minutus Pica pica Sparrow	Pelteobagrus fulvidraco Mauremys reevesii Pelodiscus sinensis Fejervarya multistriata Bufo gargarizans
Flora	Lycium chinense Phragmites australis Phragmites karka Carex thomsonii Hemarthria compressa Cynodon dactylon Salix variegata	Polygonum lapathifolium Lycium chinense Swida paucinervis Campylotropis macrocarpa Carex thomsonii Cynodon dactylon Hemarthria compressa	Chinaberry Paper mulberry Black locust Chinese firo Koelreuteria bipinnata Glossy privet Distylium chinense	

In Section 2-2, the original hard river bank is softened, and flood channels are added on both sides of Qingshui Creek. Thereby increasing the natural water storage capacity, improving the flood resilience of the site when dealing with local storm floods, and protecting the fragile old communities around. Cultivate various vegetation populations on the flood channel and both sides. Ecologically, it improves the site's ecology resilience when facing the disaster, enriched biodiversity, and provided habitat for wild animals. At the same time, the open green space also provides high-quality leisure spaces for surrounding residents.





Section 2-2

- Flood resilience performance

Under extreme conditions, such interventions can effectively provide a safe urban environment and protect the lives and properties of local residents. As shown in the sections and plan, when the flood occurs and the water level of the Jialing River rises, the eco-embankment can protect the urban environment from the impact of transit floods. When heavy rain occurs, the water level of Qingshui Creek rises, and the flood will flow into the flood channel as a buffer zone or be stored in a flood water container instead of directly flowing into the Jialing River. Since both the Qingshui River and the flood channel are soft and permeable, when the rainwater flows through, it will slow down and filter out some of the pollutions. This series of processes could help to alleviate the instantaneous peak flood pressure during heavy rains. In addition, when the water level changes, the landscape of Qingshui Creek will also change, which forming a dynamic ecological landscape system.

A view of Qingshui Creek

Low water level (170m above sea level)

Medium water level (175m above sea level)

Extreme flood (195m above sea level)

Fig.50. Situations under different water levels, edited by author

Fig. 51. After the flood, maintenance personnel repair the infrastructure, Ciqikou, Chongqing, shoot by Gou, Y. edited by author

09. Conclusion & Reflection

Conclusion

- Research & method

The main part of the research is inductive research which the base on the pragmatic worldview. The methodology chapter is built to tackle the season flood issues and brings the co-benefits such as the social-spatial coherence in upstream of the Yangtze River. The research is based on theories such as multi-scale strategy, nature-based solutions, ecosystem services, and participator approach and includes mixed method, which concludes quantitative and qualitative method.

- Analysis

After the preliminary literature review and theoretical research, the analysis part responded to the first sub-question. Human activities, especially the expansion of the urbanized area, have caused a huge increase in the area of the impermeable areas. That inevitably increases the volume of surface runoff and the speed of runoff convergence, thereby exacerbating the problem of urban flooding. Therefore, human impacts on floods often occur in the process of human activities. However, the impact of nature on floods is more macroscopic and has a longer period. In southern China, the summer monsoon will bring a lot of precipitation, and climate change will significantly affect the monsoon. Global warming makes monsoons bring more precipitation, thereby increasing the probability of floods occur and increasing the intensity of a single flood.

- Assessment

According to the results of the analysis part, the assessment part answers the second sub-question. The flood has a huge impact on the city's macroeconomics, the lives of residents, and the safety of individuals' life and property. In terms of macroeconomics, apart from direct damage to factories and farmland, the destruction of transportation facilities, communication facilities, power facilities, and other infrastructure caused by floods will also have a great impact on the economy of the city. In terms of residents' lives and property safety, there are a large number of residential communities and individual shops located in the flood hazard area. Every occurrence of flood will affect their normal life, causing economic and even loss of life.

In this part, try to use a quantitative method to evaluate the impact of the flood on the city. Evaluate the loss of different river corridor areas when they are affected by different levels of floods. So as to help understand the impact of floods on the city.

- Projections& Intervention

According to the results of the analysis part and the assessment part, as well as the discussion of different stakeholder priorities, the projections part initially explore the third and fourth sub-questions. In this chapter, through the exploration of the scenario, the possibility of solving urban flooding problems under only constructed systems and only nature systems is discussed. Their respective advantages and disadvantages are also discussed. And through the scenario, the intervention principles of increasing urban flood resilience combining the method of constructed system and the method of nature system is proposed. And discussed the method of intervening floods which occurs in the different kinds of water on different scales. Although this part does not directly answer the third and fourth sub-questions, the intervention principle summarized in this part can be used as a guideline to guide different sites to answer the third and fourth sub-questions.

- Design experiment

Based on all the previous sections, design experiment responded to the third and fourth sub-question. In this part, the urban design is used as a tool to increase the flood resilience of the originally fragile urban riverfront area. And in this process, will combine both natural system and constructed system. The design was implemented in Nanbin road-Danhui road area and Ciqikou area, which are extremely vulnerable to floods. It includes flood resilience design for three different levels of water systems (River, Creek, and runoff) and applies both high and low intervention hybrid solutions. And discussed the possible benefits to society, economy and ecology after implement the flood resilience design.

This part also responds to the main question, but the answer to the main question is not only the design of this part. It also includes the methodology, analysis, assessment, and intervention used in this study. These parts as a whole answer the main question of the research.

Reflection

- The relationship between research and design

The research about flood hazard and flood resilience is a broad topic considering it could include different spatial and time scale and different elements (from natural to society). The first research shows that the complex issue is accelerated due to the conflict between human activities and nature. This revealed the major problem fields that would have to be targeted during the design phase. The further research about water safety, water conflict and water opportunity. The following research focused on water safety, water conflict, and water opportunity, and the relationship between them, combined with relevant research on flood sensitivity, thus forming a set of flood influence evaluation indicators and flood sensitive elements for the study area. This set of indicators and elements can classify the flood susceptibility of the river corridor areas that suffer flood hazard, and provide more targeted guidance for flood resilience design. The choosing location of design will also be based on these indicators. At the same time, the river corridor flood resilience design is also the test to testing if the result of the research is effective. To conclude, research and design are certainly supporting each other and serve the goal of flood resilience future.

- Advantages and limitations of the methodology

According to the literature review and related background research, the core of seasonal flood problem in the upper reaches of the Yangtze River shows on the technical system and the natural system. The methodology framework and the analytical framework of this study are all based on this. The advantage of those methodologies is in the process of research on this methodology and subsequent design, discussion, and research on flood issues will be more focused, and the design guidance will be more targeted. But the limitations of the methodology are that some potential factors related to the flooding may be overlooked in the research. For example, policy system. Due to the strong top-down policy implementation power in China, the formulation of policies will greatly affect the floods influence and the way people respond to floods. For example, the policy shift from high-speed construction to cautious urban development. It may cause people to pay attention to the natural water system and natural water storage capacity, thereby alleviating flood pressure. However, policy systems, especially future policy changes, are hard to predict. Therefore, this study based on the current policies, and future policy changes are not included.

When selecting and evaluating the design test locations, the flood influence assignment is used to select the most vulnerable area, which could implement flood resilience design in advance. The flood influence assignment is based on the relevant research, the elements related to flood impact will be quantified base on the same standard and be accumulated, in order to compare the severity of flood vulnerabilities of each location. The advantage of this evaluation method is that it uses the same set of evaluation criteria, so the flood vulnerability of sites with similar characteristics can be quickly compared. This system could be generalized and can be used in the upstream Yangtze River cities outside the research scope. At the same time, when evaluating each site, because there are different elements, in addition to comparing the flood vulnerability of different sites horizontally, it can also help understand the situation of different elements within a site, understand the reasons for flood vulnerability, and helps to carry out better flood resilience design. And the limitation is that the research about the quantitative flood influence is relatively limited now. Although the assignments used in the study is based on the research did by Merz and Annegret H. Thieken (2004), Mancusi et al. (2015), Pan (2020), Huang et al. (2020), and Liu et al. (2020), this assignment still has certain limitations on accuracy. The result of the assignment can be used to represent a relative trend or state, but cannot accurately represent the degree of flood influence of different sites.

- Data collection

As a research needs quantitative analysis and simulation, the data accuracy will influence the research outcomes a lot. For this research, a large amount of GIS data is needed, however in China, the historical database of cites is not sound, and for some geography data, although it is open, it is hard to access and not very precise (30 meters accuracy). As for the timeliness of data, it is hard to find the up-to-date data in China, but as the study is more about the trend, therefore the data which is not that timeliness is still accessible.

However, there is always data that is not available, so some conversion is required. During the flood influence assignment, there is a vulnerable index that is the proportion of the tertiary industry at the community scale. Economic data under this scale needs to be obtained from the local government department (or may not be available for the public). In the assignment, this data is essential, so this data is converted into the proportion of commercial land which has similar connotations.

Overall, although it is very difficult to obtain the latest data, most of the data in this study can guarantee certain accuracy and timeliness, and for the data that is completely unavailable, this study also uses data that has similar connotations to represent.

- Project and research generalise

The research is focus on the seasonal flood in upstream Yangtze River, and trying to implement the flood resilience urban environment along the river corridor. The research is choosing Chongqing as the case study location due to it is the biggest city in upstream Yangtze River. However, the methodology and design principles used in this study have the potential to be applied to most cities in the upper reaches of the Yangtze River, because Chongqing and other cities in the upper reaches of the Yangtze River have similar urban morphology, geographic characteristics and economic development characteristics. Also, the flood influence assignment can also be used for flood sensitivity assessment of river corridor sections in other cities.

However, different cities and different river corridor sections of the same city have similarities and also have great differences. In research and design principles, more emphasis is placed on commonality, but in actual river corridor design, the characteristics of each city, site, local natural environment, social background, etc. all need to be respected. The generalize of the research should not be copied exactly the same, but should be used according to local conditions.

- Scientific relevance

Due to climate change and the extension of urban areas, the conflicts between the water system and urban environments are more severe. The increasing extension of urban areas leads to the massive construction of impermeable pavements, caused the increase of surface runoff, constantly increasing the threat of flood. Large amounts of researches and studies are investigating this issue. Solutions like nature-based solutions and water sensitive design are widely implemented.

Most of the existing researches on flood issues in the Yangtze River Basin focus on the plain cities in the middle and lower reaches of the Yangtze River, and the research on the flood conditions of the upper mountain cities is insufficient. The nature-based solution and water sensitive design in the urban design mentioned above are also mostly used in plain cities. In this study, Chongqing, the largest mountainous city in the upper reaches of the Yangtze River, was used as the research object. Therefore, this study's methodology and evaluation process can fill in the research deficiencies in this area. Although this research has data and method limitations, the research results can also be used as a reference for other future related research. In the design experiment, the research tried to apply the nature-based solutions and water sensitive design based on the characteristics of mountainous cities. When applying these theories in the mountainous city, the complexity of topography can bring more possibilities. The results of the design can also be used as a reference for the future flood resilience design of mountainous cities.

The main current solution for flood issues in the Yangtze River basin is emergency measures. In this study, urban design is also used as a flood control tool. Under the national policy of the Yangtze River basin ecology restoration, this research attempts to combine ecological restoration and flood control, which brings ecological advantages while more effective flood control.

- Societal relevance

Design a flood-resilient city is not only just about increasing the environmental resilience and infrastructures itself, it could also have the potential to bring long-term co-benefits to society and economy. By implementing more flood resilience to the urban area, it could promote the relationship between inhabitants and water systems, and increase social justice. By designing a hybrid-flood defense system on riverfront areas, it also increases the accessibility for local residences to the natural environments and possibilities for more high-quality public spaces.

On the other hand, the more resilient urban riverfront will also contribute to protecting the safety of the lives and properties of local inhabitants. Most of the time, the people who are easily affected by floods are the low-income groups and the flood caused them more losses than other people. In that case, a more floods resilient city means a city has higher social justices.

- Ethical Considerations

As a research project which will involve different aspects and elements, especially social elements, the discussion and analyses throughout the research will maintenance the highest level of objectivity. Each part of the research will be based on valid data and will not include researcher's personal emotions and positions. All data for this project will be obtained from publicly available information such as government websites and journals. If the data will collect via individual participators, all data contributors will be treated anonymously for this project and full consent should be obtained from the participants prior to the study.

With the introduction of low-income groups, the project has to deal with less fortunate people in society. This requires a way of handling these groups of people with respect and thoughtful consideration. And at the research, any deception or exaggeration about the aims and objectives of the research must be avoided.

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11. Appendix

Scenario generation

What is the effect of this scenario on:	**Adaptive Flood** In the flood defense of the city, the urban environment will adapt the flood, and leaving the space for water. City will go backwards and there is a certain distance between the city and the water. The residents who originally lived in this area need to leave	**Defense Flood** In the flood defense of the city, the hard infrastructure and centralized water management are wildly used. Then flood issue will be solved only by the heavy engineering based solutions.
Mitigating or adaptive impact	In the case of non-serious floods, the impact of floods on the city can be well mitigated, and in extreme cases, the speed of instantaneous floods can be slowed down. The retreat of the city can leave room for the ecosystem, enhance the ecological diversity of the city, and enhance the adaptability of the city to floods in the future. Such behavior is more sustainable in the long run, and the maintenance cost is relatively low. As time goes by, its role in reducing the impact of disasters and improving flood adaptability will increase.	It plays a significant role in mitigating flood risks. In this scenario, hard flood control infrastructure will be massively used. This method can effectively control floods and protect city safety on a certain scope. However, with a series of uncertain issues such as climate change that may occur in the future, the future flood situation may change, but artificially constructed facilities lack adaptability to such changes.
Flood safety	In the face of small and medium-sized floods, it can effectively block or reduce the hazards of floods, and play a role in protecting urban facilities and the safety of citizens' lives and properties. However, this effect decreases sharply as the flood intensity increases. In the face of extreme floods, such an approach may have little effect.	Under the existing flood conditions, this scenario is the most direct and effective way to control floods and protect the essential flow of the city and the safety of citizens' lives and properties. However, with the increasing uncertainty in the future, in the long term, artificially constructed facilities lack future adaptability. Therefore, under the threat of future floods which might be caused by different conditions, such facilities may not be able to protect residents as effectively as they are now. Even sometimes it will have a counter-effect, such as bringing about some secondary disasters.
Impact on resilience	Generally speaking, the resilience of cities will increase. From the perspective of ecology, large tracts of riverbank space and the space surrounding the main runoff are returned to the natural ecosystem, which enhances the ecological diversity and the complexity of the population, thereby enhancing the resilience of the ecosystem in the face of disasters. From the perspective of flood control, in the transformation from hard urban land to permeable natural land, water permeability has been increased, runoff velocity has been reduced, urban natural water storage capacity has been improved, floods have been dispersed, and cities have become more resilience during heavy precipitation and floods. From the perspective of society, the natural riverfront can be used as a high-quality public space to provide a large number of activities and communications for nearby residents, enhance community cohesion, and thereby enhance social resilience. However, when implementing the adapt strategy, some communities or houses may be in areas that are extremely vulnerable to flooding. Therefore, how to resettle this part of residents needs to be carefully considered.	The resilience of the city will remain unchanged or slightly enhanced. From the perspective of flood control, although the city's natural water storage capacity has not changed significantly, a more complete water management system will undoubtedly increase the city's ability to store floods, discharge rainwater, and respond to sudden heavy precipitation. Thereby improving the city's ability to deal with the flood and flood resilience. From the perspective of society, for communities in high-risk areas, there should be corresponding emergency response plans and emergency evacuation plans. Due to the construction of infrastructure and subsequent maintenance, more employment opportunities may be generated, and the increase in employment can bring the enhancement of social resilience.

Impact on Eco life	The ecology will be more balanced, and the diversity will increase significantly. The independent natural patches in the city can be interconnected through natural corridors, alone the main runoff, to form a more stable overall ecosystem and achieve their own balance. The fragile ecosystems along the banks of the river will have the opportunity to gradually become richer, forming a fluctuating zone ecosystem composed of herbs, shrubs, small animals and insects.	Under this scenario, eco life will become more separated, and the edge between urbanized areas and nature will be clearer. Due to the use of a large amount of artificial infrastructure, the city is divided into risk areas and safe living environments. This will cause the urbanized area and natural area are separated by infrastructure. At the same time, due to the possible further expansion of the city, the eco life in the city will become more separated. The green space and natural system in urbanized areas will exist as independent patches because they assume more of a landscape and recreational role rather than an ecological role.
Influence on climate	The newly added green space to adapt to the flood can effectively improve the microclimate of the city and alleviate the heat island problem in highly urbanized areas. From a regional perspective, the newly added green space increases the green rate of the city, thereby promoting the absorption of more greenhouse gases and achieving the effect of slowing down the climate change and global warming.	As a large amount of artificial infrastructure will be built newly, the city and the natural environment are relatively more independent, and rainwater and surface runoff are managed more intensively. This process may lead to a large amount of carbon emissions, thereby exacerbating the existing climate crisis. In this scenario, the microclimate inside the city may not improve obviously due to the separation layout of the unsystematic green space.
Impact on Social life	Different communities will shift from being independent to being closely connected, and within the community, the cohesion of residents will also be strengthened. More green spaces bring more well-being to residents, and these spaces include not only larger public spaces along the banks of the river, but also root-shaped green corridors extending into the interior of the city along with the main runoff. And these spaces provide good carriers for social life such as community management, communication, and even the local economy. The scenario creates the possibility to better meet the needs of different locals and can take into account the disadvantaged groups.	Hard infrastructure could ensure the safety of the community. Although it separates the urbanized areas from the real natural areas, hard infrastructure can effectively ensure the safety of the community and the public facilities when the flood comes, therefore enhance the sense of safety of the community and keep the current social structure. For some disadvantaged groups who originally lived in the hazard area, this will undoubtedly guarantee their existing living foundation and social status, and keep them away from risks.
Impact on economy	The adaptation scenario applies deep ecological technology, the economy will become more resilient and recycle, and will change a lot on the local scale. The new solution will not drag down the economy. On the contrary, in the long run, it can promote the development of the economy, especially in the local scale. The growth of nature not only brings additional economic value to the surrounding urban areas, but also promotes the development of local circular economy. The increasing nature will also increase the attractiveness of a city, thereby attracting more tourists and promoting the development of local tourism.	In a short period of time, a large number of hard infrastructure constructions will undoubtedly increase employment, drive the development of related industries, and thus stimulate the economic development of the city. In the long run, due to maintenance needs, certain jobs will also be created. But generally speaking, this method will stimulate the economy in a short-term. After a lot of construction, the demand for related industries and employment will drop, and even cause the problem of overcapacity. Therefore, the transformation of the industry and employment after the boom is particularly important, and the goal of the transformation should be to form a more sustainable industrial chain.
Infrastructure	Today's infrastructure and flow corridors have had a great negative impact on the natural environment and led to the loss and fragmentation of habitats. In the adaptation scenario, the man-made infrastructure needs to affect the natural water system as little as possible, and increase the penetration and water capacity as much as possible, such as the use of more	Hard infrastructure includes hard embankment, floodwall, reservoir, dyke, canal and so on. This is a strong control technique, and effective results can be seen in a short period of time. Hard infrastructure can very effectively protect the safety of the urban environment and communities within a threshold, but its price may be the lack of natural potential and connection.

	permeable roads. At the same time, increase the frequency of use of green infrastructure to enhance the water resilience of the city and reduce the conflict between the urban environment and the natural water system.	
Public space	Taking natural flood control requirements as the first design element, a large number of natural public spaces will be created, and at the same time some of the original public spaces will return to nature, reducing the impact of extreme weather on the city. Streets, tiles and other impermeable materials will be replaced by natural materials such as grass, trees, and plants. By increasing the number of green plants, the flora and fauna will be more closely linked to form a natural flow, and the border between urban and nature will become blurred. More green public spaces will be open to people of all classes, which will result in forming local social groups with different residents from different layers of the society.	Due to the improvement of urban safety, a large quantities of public spaces and structures in the flood risk area will be preserve. Hard infrastructure will cut off the public space connection between urban and natural area to a certain extent, but the necessary corridors will be preserved. It opens under non-extreme weather conditions, preserving the connection between the city and nature. Public space will also be combined with these hard infrastructures to form new landscape structures and features. Under the premise of satisfying safety, it will enrich the level of urban public space and provide the same safe public space for people of different classes.