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Urban Village Renewal Guided by Flood Resilience: A Case Study of Lijiao Village, Guangzhou

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摘要

全球气候变化导致极端天气出现的频率和强度骤增，城市雨洪灾害日益严重。高速城市化发展产生的城中村作为城市中建筑密度高、管理混乱、基础设施陈旧的区域，在极端天气时更突出了内涝风险高的问题，具体表现在暴雨过程中地表的径流深度较高、径流系数较大等相关评价指标。一部分珠三角地区的城中村原为传统村落，其独特的水利景观，如水系、基塘等，本身就具备较强的雨洪灾害应对能力和景观价值。由此可见，城市化发展带来的影响不仅是城中村应对雨洪灾害能力的不足，还包括城中村环境品质的下降。因此，探索雨洪韧性导向下的城中村改造策略是具有理论和实践意义的。

本文以此背景针对雨洪韧性相关理论以及雨洪韧性城市设计的概念和方法进行了一定的分析和总结，结合现代雨洪韧性城市设计和传统村落治水生态智慧的案例学习，提炼出雨洪韧性城市设计的原则及策略。在此基础上，本文以广州市沥滘村作为实践对象，通过对设计区域的雨水廊道分析、基于 SCS-CN 模型的内涝模拟分析、基于 SWMM 模型的内涝风险评估，选择具有针对性、因地制宜的改造策略。最后，在韧性水系统构建、多用途空间塑造两个视角展现沥滘村改造策略的应用以及环境品质的优化效果，同时基于 SWMM 创建改造后沥滘村的水文模型，再进行内涝风险评估，对改造前的评估指标对比，验证改造后沥滘村的雨洪韧性提升效果。

综上，本文希望能够通过上述理论分析及策略探索，提升沥滘村的雨洪韧性及环境品质，同时为城中村的改造设计提供新思路。

关键词：雨洪韧性 城中村改造 SWMM 内涝模拟分析 SCS-CN

Abstract

Global climate change has led to a sudden increase in the frequency and intensity of extreme weather, and urban storm water disasters are becoming increasingly serious. Urban villages generated by high-speed urbanization development, as areas in the city with high building density, chaotic management and outdated infrastructure, highlight the problem of high risk of internal flooding during extreme weather, which is reflected in the high runoff depth and large runoff coefficient on the surface during heavy rainfall and other related evaluation indicators. A part of the urban villages in the Pearl River Delta region were originally traditional villages with unique hydraulic landscapes, such as rivers and dike-ponds, which themselves have strong rain and flood disaster coping capacity and landscape value. It can be seen that the impact of urbanization development is not only the inadequacy of urban villages' ability to cope with rainfall and flood disasters, but also the degradation of the environmental quality of urban villages. Therefore, it is of theoretical and practical significance to explore urban village renewal strategies under flood resilience orientation.

In this paper, the author analyzes and summarizes the theories related to flood resilience as well as the concepts and methods of resilient urban design for flood control, combines modern flood resilient urban design with case studies of traditional village water management and ecological wisdom, and refines the principles and strategies of resilient urban design for flood control. On this basis, this paper takes Lijiao Village in Guangzhou City as a practical object, and selects a targeted, site-specific renovation strategy through rainwater corridor analysis of the design area, inundation simulation analysis based on the SCS-CN model, and inundation risk assessment based on the SWMM model. Finally, the application of the renewal strategy of Lijiao Village and the optimization effect of environmental quality are shown from the perspectives of resilient water system construction and multi-functional space shaping, while the hydrological model of Lijiao Village after the renewal is created based on SWMM, and then the flooding risk assessment is carried out to compare the assessment indexes before the renewal to verify the effect of flood resilience enhancement of Lijiao Village after the renewal.

In summary, this paper hopes to improve the flood resilience and environmental quality of

Lijiao Village through the above theoretical analysis and strategy exploration, as well as to provide new ideas for the renovation design of urban villages.

Keywords: flood resilience, urban village renewal, SWMM, inundation simulation analysis, SCS-CN

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Chapter 1 Introduction

1.1 Research Background

1.1.1 Policy Background: "Resilient City" has been upgraded to national planning

The Proposal of the Central Committee of the Communist Party of China on Formulating the Fourteenth Five-Year Plan for National Economic and Social Development and the Visionary Goals for 2035, released at the end of 2020, also proposes to strengthen the renovation of old urban neighborhoods and community construction, enhance urban flood control and drainage capacity, and build sponge cities and resilient cities. Therefore, to improve the flood resistance of cities by building resilient cities is a realistic requirement for China's cities to achieve high-quality development. This is the first mention of the concept of "resilient city" in China's five-year plan。

1.1.2 Social Background: Various factors lead to frequent floods

The Intergovernmental Panel on Climate Change (IPCC) publishes its Sixth Assessment Report Group I Working Paper, Climate Change 2021: The Natural Science Basis, in August 2021. The report shows that global temperature rise is expected to reach or exceed 1.5°C in terms of average temperature change over the next 20 years. Climate change will intensify in all regions in the coming decades. As temperatures rise further, changes such as more intense rainfall and flooding, more severe droughts, coastal erosion, and sea level rise will occur in multiple combinations in different regions[1].

In May 2010, several provinces and cities in southern China were hit by several rounds of exceptionally heavy rainfall and flooding. The China Meteorological Administration (CMA) monitored that compared to previous years' floods, rainfall in most areas of the Yangtze River basin increased by more than 20% compared to previous years. 20 July 2021, Zhengzhou experienced rare and sustained heavy precipitation weather, with heavy and very heavy rainfall

[1] IPCC. Climate change 2021: the physical science basis [M/OL]. 2021 [2021-08-06]. https://www.ipcc.ch/report/ar6/wg1/#FullReport

in the city, and a cumulative average rainfall of 449 mm. The disaster caused a total of 380 deaths and disappearances in Zhengzhou, and direct economic losses of 40.9 billion yuan.

This shows that China's flooding by heavy rainfall is becoming increasingly serious and the situation is not optimistic.

1.1.3 Subject Background: The necessity of combining flood resilience theory with urban village renewal

With the development of urbanization, the overdevelopment of urban villages has destroyed the original environment and texture of the villages, resulting in water-related problems that are bringing about increasingly serious crises and losses in Guangzhou's urban villages. The most obvious phenomenon is the illegal expansion and high density development that has encroached on the original water system and reservoirs of the villages. These phenomena pose two main problems:

First, the risk of waterlogging in urban villages has increased. Most urban villages in Guangzhou have a long history and have developed a unique set of stormwater management methods during the long development of the villages, mainly using natural and artificial rivers and ponds to drain surface runoff formed by rainfall within the village directly to external rivers or ponds through the natural work of topographic elevation changes. Natural water systems and ponds have the advantage of high drainage capacity and storage of runoff, which can meet the needs of flood control under large intensity rainfall. However, in today's urban villages, the phenomenon of river filling, canalization and pipelining is prominent, and a large number of rivers and ponds have been encroached upon. The underground pipe network has replaced the original water system as the main drainage system of the villages, but with the increasing proportion of impervious surface and building density, the rigidly designed drainage network no longer meets the flood control and drainage needs of urban villages under extreme stormwater conditions.

Second, the environmental quality of urban villages has declined. Water bodies have high landscape and ecological values, which can provide waterfront leisure activity space, visual enjoyment and pleasant microclimate environment, which have strong attraction to residents.

The encroachment of waterbodies has greatly reduced the environmental quality of urban villages.

Flood resilient urban design is based on the principles of flood resilience, which can improve the quality of the urban environment while maximizing the city's ability to cope with stormwater hazards[2]. The drainage system of urban villages based on the natural water system in the past also reflects the principles of robustness and redundancy of flood resilience, so in the renewal practice of urban villages, corresponding strategies can be proposed to reduce the risk of flooding and improve the environmental quality based on the principles of flood resilience. Therefore, as an important topic in urban design discipline, it is meaningful to explore the integration of flood resilience with urban village renewal.

1.2 Project Introduction

1.2.1 Project Background

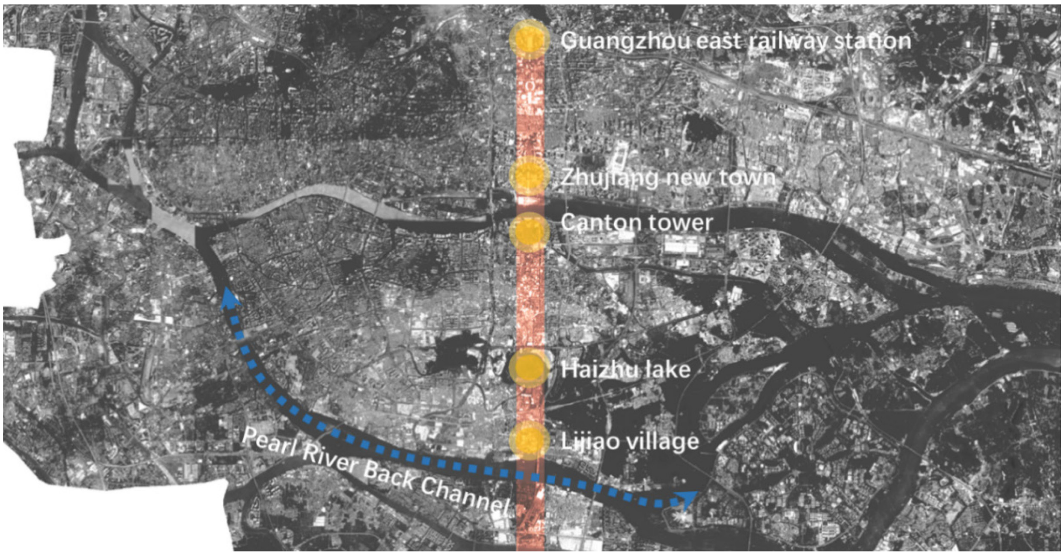

Figure 1-1 The relationship between Lijiao village and new urban central axis
Source: Self-drawn by the author

Lijiao Village is located in the southern part of Guangzhou's Haizhu District, close to the back channel of the Pearl River, north of Haizhu Lake and Haizhu Wetland Park, and is an important node in the southern section of Guangzhou's new urban central axis. The Lijiao area is the intersection of the Pearl River back channel and the city's new central axis. Because of

[2] Zhou Yinan,Li Baowei.Resilient Urban Design For Flood Control [J].PLANNERS，2017,33(02):90-97.

its location and the rich ecological resources around it, it is important for the urban development of Haizhu District and Guangzhou City to renew the area, promote the upgrading of land resources, and explore its potential for improvement.

The village of Lijiao has a long history and developed from a net village in the traditional village type of the Pearl River Delta. By reviewing historical satellite map data, the village of Lijiao in 1969, as shown in the map, had a complex net system of water that divided the village into several groups of varying sizes and shapes. Outside the village, there are dense dike-ponds, each physically separated by a small dike, but actually the dike is reserved with pipes or holes for hydrological exchange between the dike-ponds thus forming a holistic, adaptive and self-organizing water storage network. The water system inside the village is based on natural water system through the artificially built canals and the dense dike-ponds outside the village, which can effectively and quickly respond to the sudden disaster of rain and flood by saving rainwater and discharging the excess rainwater to the external rivers during the flood season. Traditional stormwater management mechanisms and methods for net villages will be introduced in detail in Chapter 3 with case studies.

Figure 1-2　Historical satellite map data in 1969
Source: The National Reconnaissance Office，NRO

Figure 1-3 Satellite map of Lijiao Village status
Source: Baidu map

After the reform and opening up, the rural economy began to transform, and Lijiao Village was inevitably caught up in the urbanization process. As shown in the figure, the agricultural land outside the village was transformed into industrial and residential land, with dense factories and warehouses replacing the original dike-ponds, thus gradually eating away at the village's fabric. Due to the uneven and uncoordinated rapid development of urbanization, many urban villages are lagging behind the pace of development and are outside of modern urban management. As a result, a large number of illegal buildings have encroached on the original public space, leading to increased building density and fragmentation of public space, which has reduced the environmental quality of urban villages[3]. Satellite maps and field research have shown that most of the river in Lijiao Village has now disappeared, along with the waterfront space, as shown in the picture, the only river left in the once intertwined water system is Lijiao River.

[3] Cai Yijun."Legal and Harbor"——Research on the Protection and Renewal of Traditional Villages in Lekchu Ancient Village，Guangzhou [J].JUSHE,2017(24):46+158.

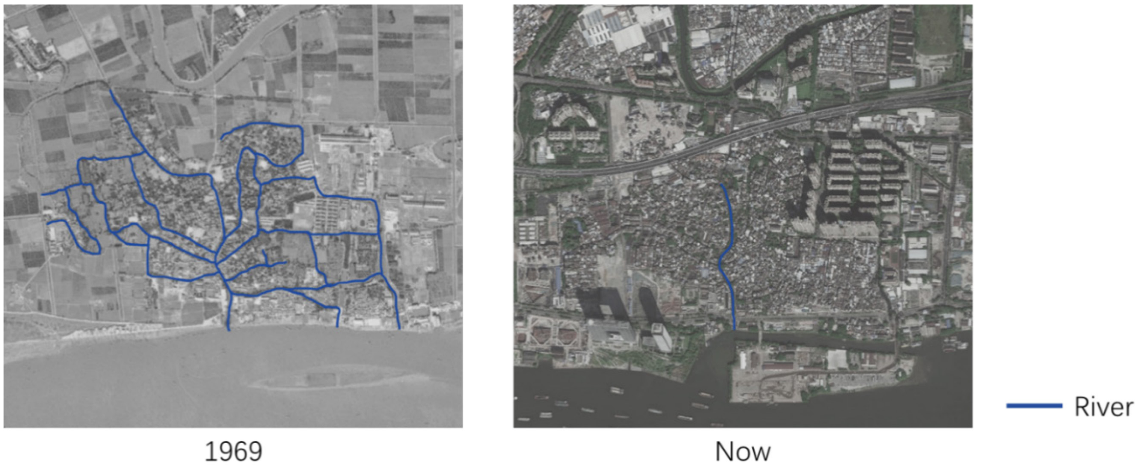

Figure 1-4 Water system development in lijiao village
Source: Self-drawn by the author

After urban development, the Village abandoned its once efficient ecological stormwater management facilities and adopted engineered municipal pipes as the primary means of stormwater management for the Village. Engineered municipal pipes are generally only able to withstand rainfall within the specified standards, and the system is highly susceptible to collapse when rainfall hazards outside the standard range occur. This is the main reason for the frequency of flooding in the Lekki area whenever extreme weather is encountered. According to flooding data, typhoon 8309, typhoon 9316, typhoon "Dove" and typhoon "Mangosteen" have caused flooding in many parts of Lijiao in recent years.

In 2018, Guangzhou Haizhu District Government proposed to focus on building "a district, a valley, a bay, a belt" four functional areas to promote the efficient and orderly development of industrial space. The four functional areas are: Pazhou Digital Economy Reform and Innovation Pilot Zone, CU International Innovation Valley, Haizhu Innovation Bay, Xinjiao Road - Haizhu Lake Innovation Belt[4]. One of the mentioned Haizhu Innovation Bay includes Lijiao Village and its surrounding area, whose detailed control plan is shown in the figure. The plan does not preserve the traditional fabric of Lijiao Village, but rather uses a similar incremental development model. Although it is possible to achieve a high level of flood resilience and high-quality public space in this area through conventional urban design methods

[4] Chen Jiawen.Fully explosive! The industrial development plan of Haizhu District in Guangzhou for the next 17 years has been determined[J].Real Estate Guide,2018(11):30-31.

of flood resilience, Lijiao Village will fade from Guangzhou's urban memory, and its stormwater management measures and water system landscape, which originally embodied traditional ecological wisdom, will gradually disappear from view with urbanization.

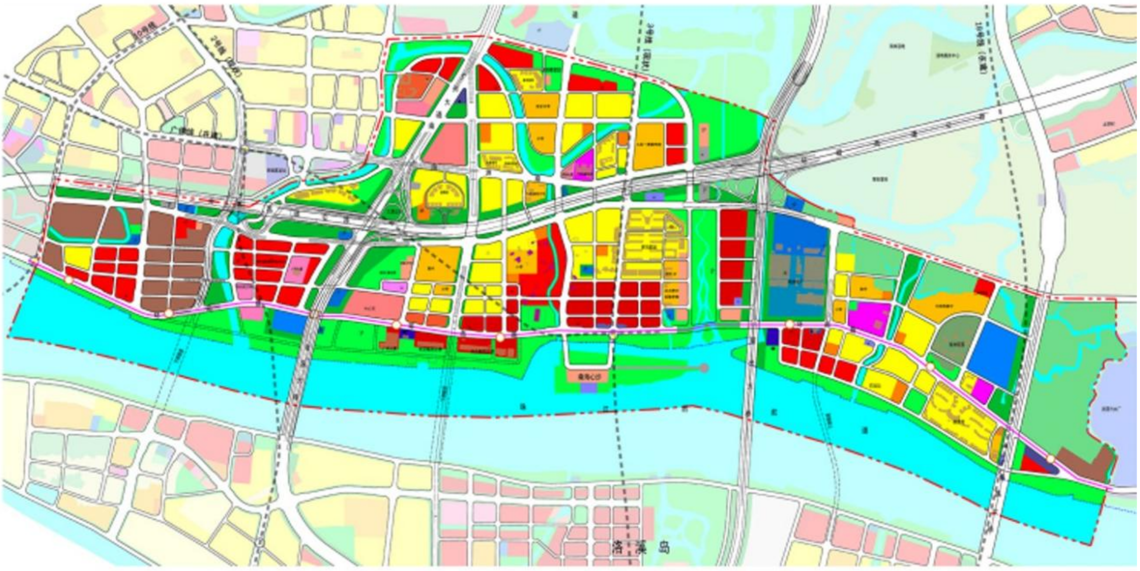

Figure 1-5 Haizhu Innovation Bay Urban Design and Detailed Control Plan
Source: www.gzlpcgov.cn

1.2.2　Design Scope

In this paper, the main area of Lijiao Village will be appropriately retained, and on this basis a new master plan will be recomposed in conjunction with the land use of the existing Haizhu Innovation Bay Detailed Control Plan.

According to historical satellite images from 1969, the western part of Lijiao Village is a large base pond, which has played a vital role in flood control and drainage of Lijiao Village by storing excess rainwater in the past. Therefore, this paper focuses on the renovation of Lijiao Village and the urban area to the west of Lijiao Village, as shown in the figure. In the subsequent chapters, the renovation strategies and applications for Lijiao Village will be based on the above master plan and design scope.

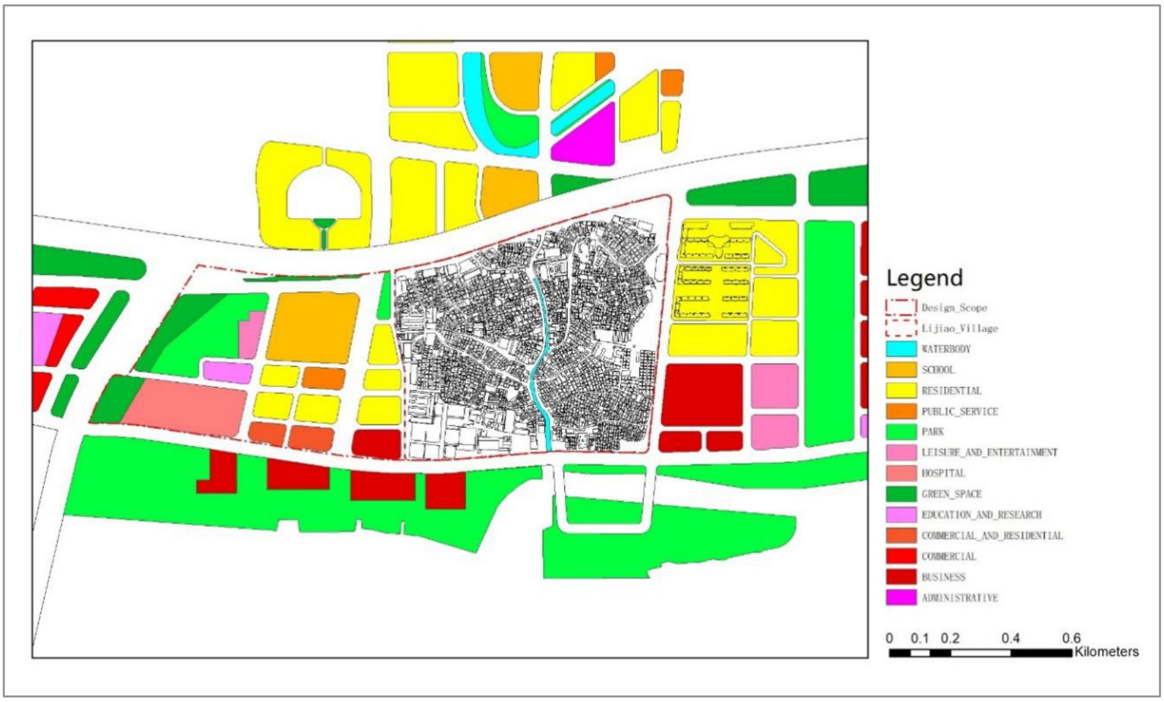

Figure 1-6 Design scope and land use
Source: Self-drawn by the author

1.3 Research Subject

1.3.1 Flood Resilience

The term "resilience" originally referred to the ability of a system to maintain its stability and sustainability in the face of external disturbances. The meaning of "resilience" has undergone several transformations in different disciplinary contexts. In engineering, "resilience" refers to the ability of an object to return to its initial state after physical deformation by external forces; in ecology, "resilience" emphasizes the ability of an object not only to return to its original state, but also to reach a new equilibrium under external[5]. In the field of ecology, "resilience" emphasizes the ability of an object not only to return to its original state, but also to reach a new equilibrium under external shocks; in the field of social sciences, the interpretation of "resilience" is mainly from the perspective of sustainable development, focusing on the ability of the system to adapt and change in response to stress, so the resilience perspective in this field is also called "social resilience".

[5] Klein R， Nicholls R J， Thomalla F . Resilience to natural hazards: How useful is the concept? Environmental Hazards, 5(1/2), 35-45[J]. Environmental Hazards, 2004, 5(1-2):35-45.

This paper studies flood resilience with ecological resilience as the theoretical framework, aiming to provide theoretical support for the design strategies of practice objects, and further understand and generalize the concept of flood resilience theory as well as the content and methods of flood resilience-oriented urban design through the basic research on resilience theory and resilient cities.

1.3.2 Urban Village Renewal

This paper aims to eliminate the negative factors of existing urban villages through the theory of flood resilience, and to reduce the impact of stormwater disasters on urban villages and improve the quality of urban public space by translating the theory of flood resilience into practical strategies and applications.

1.4 Research Purpose and Significance

1.4.1 Research Purpose

The stormwater hazards in urban villages have complex disaster-causing mechanisms as well as serious disaster impacts, while urban villages have insufficient ability to cope with stormwater hazards, showing characteristics of weak resistance to disturbance, weak regulation and control, and weak emergency response. In some urban villages in the Pearl River Delta region, urbanization has destroyed the original water system and farmland of the villages, and due to the adverse effects of poor regional drainage facilities, large proportion of impervious surface and high building density brought by overdevelopment, not only is the spatial quality of these urban villages seriously threatened, but the flood resilience of the villages is also being reduced.

Therefore, this paper explores urban village renewal strategies from the perspective of flood resilience, taking the Lijiao area of Guangzhou City as an example, with the following two objectives:

(1) Enhancing the flood resilience of Lijiao Village

The core concept of rainwater resilience theory is " living with floods", which coincides with the concept of water control in the traditional villages in the Pearl River Delta region of China. This paper analyzes the traditional water control methods of Lijiao Village and related existing cases based on the basic research of flood resilience theory. In order to clarify the influencing factors of rainwater resilience in Lijiao Village as an entry point for retrofitting strategies and to provide a reference for the effectiveness of the retrofit, this study uses SWMM software to develop a hydrological model for Lijiao Village to simulate its stormwater storage and retention capacity under extreme weather conditions. Finally, the design area was analyzed for inundation areas and rainwater corridors, and this was used as an entry point to explore flood resilience enhancement strategies applicable to urban villages based on the traditional stormwater management patterns previously developed in Lijiao Village.**(2) Optimizing the environmental quality of Lijiao Village**

Flood resilient urban design refers to urban design oriented to flood resilience, which guides the optimization of urban spatial environment through the principles of flood resilience. Urban village renovation is an important topic in the discipline of urban design, and the concepts and methods of rainwater resilient urban design are applicable to it. In practice, however, specific problems still need to be analyzed. In the case of Lijiao Village, for example, the original water system in the village is both part of a water system with a strong flood discharge capacity and a cultural landscape with a regional character. This paper will integrate flood resilience enhancement strategies based on the principles of flood resilience and propose a renovation strategy for spatial environmental quality enhancement in urban villages.

1.4.2 Research Significance

(1) Theoretical significance

Current urban design for flood resilience focuses on modern urban functions such as campuses and older neighborhoods, most of which were built in the recent past and often use engineered municipal pipes as the primary stormwater management measure. In the later renovation of its flood resilience enhancement, the original stormwater management measures are only engineering facilities but do not have any landscape value and regional characteristics, so the renewal scheme will inevitably be homogenized.而 Some of the urban villages are developed from traditional villages, and the original water system of these villages contains the concept of " living with floods" and has certain regional characteristics and landscape value. If we continue to follow the conventional approach of urban design for rainwater resilience in urban village transformation, we will easily ignore the regional characteristics and landscape value of traditional village water systems, thus inevitably causing the homogenization of village space with other urban spaces.

This study hopes to analyze the current situation of urban villages and traditional stormwater management methods in depth from the perspective of flood resilience, integrate traditional water system landscape into urban village renovation strategies, and provide a certain complement to the related research on resilient urban design for flood control.

(2) Practical significance

By investigating the hydrological soil conditions of Lijiao Village, the imperviousness ratio, and its surrounding land use information, we gain insight into the environmental quality and inundation risk of the urban village, analyze the source of the problem, and provide a reliable analytical basis and scientific proof for a flood resilience-oriented renewal strategy for Lijiao Village.

Through the study of flood resilient urban design methods and related case studies, the methodology and strategies are provided for flood resilient oriented renewal of Lijiao Village, and also for other urban villages' flood resilient renewal.

By combining traditional ecological stormwater management strategies with modern flood resilience measures, we explore a mutually beneficial symbiotic relationship between urban villages and cities from the perspective of flood resilience. To establish a shared water system between urban villages and urban areas, and at the same time enhance the flood resilience of both, realizing the effect of one plus one more than two.

1.5 Research Content and Framework

1.5.1 Research Content

This paper uses the theory of flood resilience as a guide, and through a field study of Lijiao Village in Guangzhou, we conclude that Lijiao Village has major problems in coping with floods, which indirectly lead to the degradation of the environmental quality of Lijiao Village. The SWMM software was used to model and simulate the changes in variables related to flood resilience in Lijiao Village. After thorough research and analysis, the authors propose measures and methods that are consistent with the renewal of Lijiao Village. This paper is discussed through six specific chapters, with Chapters 4, 5, and 6 being the key chapters of this paper.

The first chapter is the introduction. It is mainly to analyze the background of the selected topic, the purpose and significance of the study, and to introduce the background and current status of the practical project to provide the basis for the renovation design in the later chapters.

Chapter 2 provides a theoretical overview and analysis of the concepts of "resilience and resilient city" and "resilient urban design for flood cotrol", respectively. The section on resilience and resilient city explains the development and concept of resilience as well as the concept and principles of resilient city, which provides the foundation for the overview of resilient urban design for flood control. By briefly outlining the concept of flood resilience theory and its relationship with urban design, the section on flood resilient urban design introduces the key to this paper, namely the concept and methodology of resilient urban design for flood control, as the main theoretical basis for this paper to explore urban village renewal strategies.

Chapter 3 systematically analyzes traditional and modern practice cases from the perspective of flood resilient urban design, confirming the principles of flood resilience, and drawing on the design strategies of the cases to provide design ideas for the renewal practice of Lijiao Village.

Chapter 4 presents the inundation simulation analysis and risk assessment of the design area based on the hydrological and topographic data information released by field research and other authoritative scientific institutions. The locations of potential rainwater corridors and inundation areas in the design area are extracted and calculated through the hydrological analysis tool of ArcGIS and SCS-CN model. The SWMM software was used to develop a hydrological model for Lijiao Village to assess its stormwater response capacity under different return period precipitation scenarios using several key resultant data.

In Chapter 5, the design principles applicable to the renewal of Lijiao Village will be extracted from the flood resilience theory and case studies in conjunction with the inundation simulation analysis and risk assessment in Chapter 4. Following the above design principles, and taking into account the current situation, renewal strategies aiming at improving flood resilience and environmental quality will be proposed.

Chapter 6 is about the application of design strategies based on the renewal of Lijiao Village. The design scheme will be described in three dimensions: general layout, resilient water system construction, and public space design. Finally, SWMM software is used to build a hydrological model for the renewal scheme to verify its effectiveness in coping with stormwater hazards.

1.5.2 Research Framework

The research framework of this paper is shown in figure.

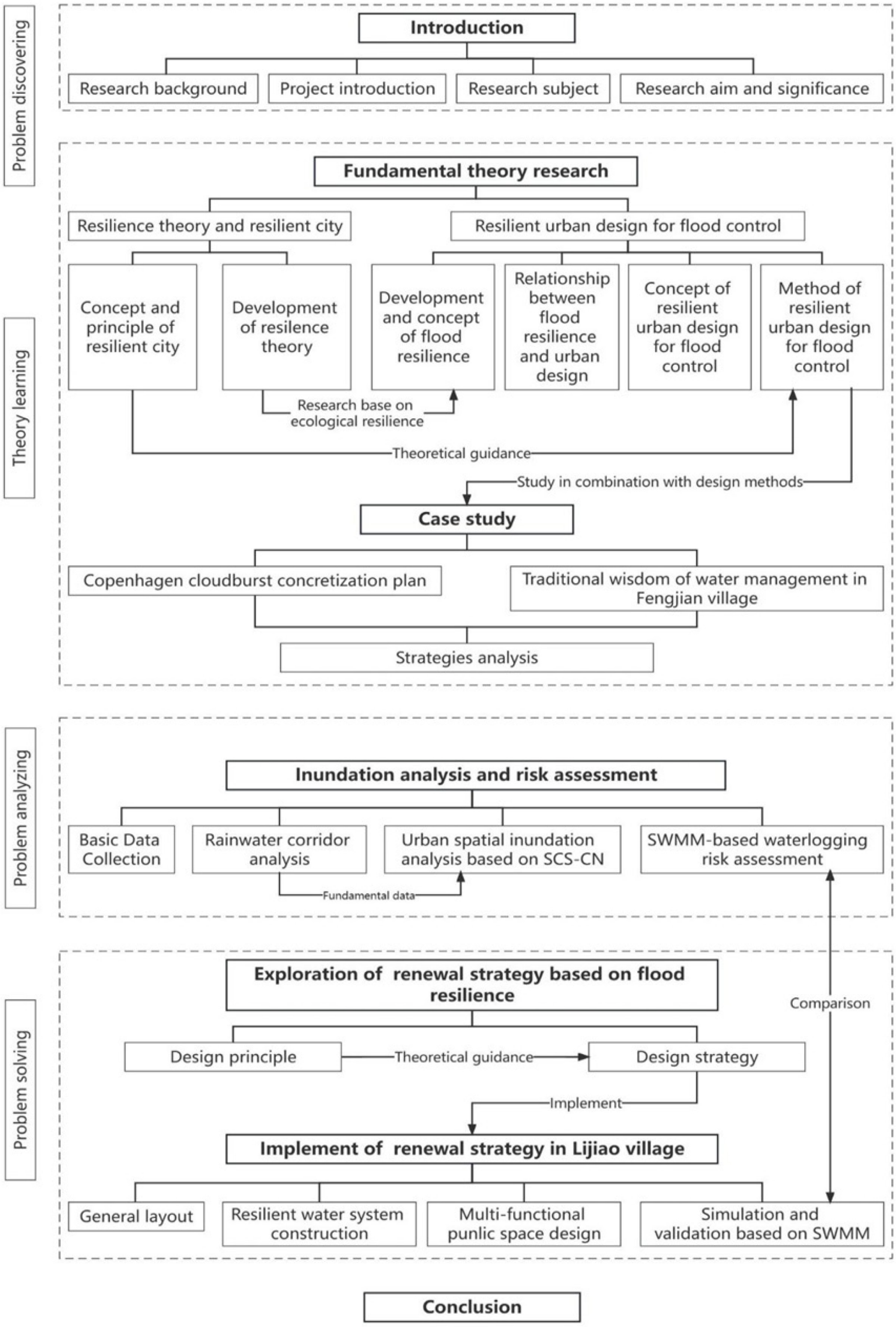

Figure 1-7 Research framework

Source: Self-drawn by the author

Chapter 2 Fundamental Theory Research

2.1 Resilience and Resilient City

2.1.1 The development of resilience

The term resilience was originally applied to physics to describe the ability of an object to resist external forces. The connotation of the concept of "resilience" is constantly evolving and has gone through three stages since its origin: engineering resilience, ecological resilience, and socio-ecological resilience[6].

The concept of "engineering toughness" is mainly applied to mechanical professions, which focuses on a single ultimate equilibrium state and emphasizes the speed of the system to return to the equilibrium state, and is defined by Myron et al. in 1982 as the time for a system to return to its original steady state after a disturbance[7]. Engineering toughness is characterized by the belief that the system has a unique and most stable equilibrium, from which the equilibrium point is considered unstable, and the whole system emphasizes efficiency, stability and predictability.

The concept of "ecological resilience" was first introduced by Holling in 1973[8]. Ecological resilience is defined as the ability of a system to withstand perturbations and reorganize itself without changing its own structure and function. The emphasis is on the system's ability to resist, absorb, repair, enhance, and learn from disturbances to reach a new state of equilibrium, and on the ability to develop sustainably.

Because of the development nature of the social system and the growth needs of the economic system, the internal system faced by the research and application practice of primality theory has become more complex, and the corresponding system is influenced by external disturbance factors has become more complex and variable. Simmie and Martin in 2010 proposed social-ecological resilience, also known as revolutionary resilience[9]， the study of

[6] Li Tongyue. New Progress in Study on Resilient Cities [J]. International Urban Planning, 2017, 32(5): 15-25

[7] Myron, B, Fiering. A screening model to quantify resilience[J]. Water Resources Research, 1982.

[8] Holling CS. Resilience and Stability of Ecological Systems[M]. Annual Review of Ecology and Systematics, 1973, 4(4): 1-23.

[9] Simmie J. Martin R. The economic resilience of regions: Towards an evolutionary approach. Social Science

tangibility has been introduced from the natural field to the social field by incorporating more disciplines such as social-economic management. Greater emphasis is placed on learning, adaptive and innovative skills, commonly applied in the field of resilience research involving social factors.

2.1.2 The concept and principles of resilient city

Between 2001 and 2007, extreme climate change brought about frequent global natural disasters causing concern among ecology, environment and planning scholars, and the concept of resilience was gradually applied to the guiding system of urban systems to cope with disasters, extending to resilient cities. 2003 Godschalk proposed the concept of resilient city, formally applying the concept of resilience to urban planning and management[10]. After 2008, the uncertainties faced by cities broke through the realm of disasters, and complex urban environments such as global financial crisis, public health events, and extreme disasters pushed resilient city research into the direction of predicting sudden environmental changes, assessing environmental risks, and improving urban disaster-bearing adaptability. Since then the definition, principles, and applications of resilient city have been expanded and enriched the connotation of resilience concept.

Resilient city covers the self-adaptive ability of all systems in the city. The city has the ability to adapt to changes in the external environment when facing disasters and other changes, to keep the basic structure of its normal operation from being destroyed, to restore the normal order of the city in time after the basic structure is damaged, and to continuously learn to adjust the internal structure to better cope with external disturbances[11]. To sum up, a resilient city has three main characteristics: resistance, adaptability, and recovery.

The principles of resilient city are basically the same as those of resilience. Godschalk summarized redundant, diverse, efficient, autonomous, robust, interdependent, adaptable, and cooperative, eight principles of resilience, which became the main development direction of

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Electronic Publishing, 2010, 3(1): 27-43.

[10] Godschalk D R . Urban Hazard Mitigation: Creating Resilient Cities[J]. Natural Hazards Review, 2003, 4(3).

[11] Chen Changkun,Chen Yiqin,SHI Bo,Xu Tong. An model for evaluating urban resilience to rainstorm flood disasters [J].China Safety Science Journal,2018,28(04):1-6.DOI:10.16265/j.cnki.issn1003-3033.2018.04.001.

resilient city afterwards.

Resilient principle	Description
Redundant	With a number of functionally similar components so that the entire system does not fail when one component fails
Diverse	With a number of functionally different components in order to protect the system against various threats
Efficient	With a positive ratio of energy supplied to energy delivered by a dynamic system
Autonomous	With the capability to operate independently of outside control
Robust	With the power to resist attack or other outside force
Interdependent	With system components connected so that they support each other
Adaptable	With the capacity to learn from experience and the flexibility to change
Collaborative	With multiple opportunities and incentives for broad stakeholder participation

Table 2-1 The principles of resilient city and resilience
Source: Bibliography

2. 2 Resilient Urban Design for Flood Control

2. 2. 1 Development and Concept of Flood Resilience

Europe has formed more mature results in the research of flood resilience in the early stage, the representative cities are Netherlands, Paris, etc. The representative scholar is Professor K. M. De Bruijn from Delft University of Technology, and the representative international conference is the International Conference on Flood Resilience (ICFR) held in University of Exeter in 2013. Related research results mostly focus on conceptual interpretation, advocating integrated water management for flood resilience, theoretical framework construction and resilience measurement assessment, etc.[12] In these studies, flood resilience is mostly considered to be the ability of a system to withstand, absorb, and recover from a flooding hazard [13].

Combined with related research results, the theoretical structure of flood resilience can be classified based on three aspects: engineering resilience, ecological resilience, and social

[12] Schuetze T, Chelleri L. Climate adaptive urban planning and design with water in Dutch polders[J]. Water Science and Technology, 2011, 64(3): 722-730.

[13] MA Bo.Multi-Level Decomposition Research on Control Index of Sponge City Construction from the Perspective of Flood Resilience[D].Hunan University,2019.DOI:10.27135/d.cnki.ghudu.2019.000024.

resilience. As shown in the table different theoretical frameworks of flood resilience differ in terms of concept, practical content, etc.

Classification	Concept	Equilibrium state	Practice contents
Engineering flood resilience	Provide flood buffer time and space through ecological functions or management measures	Single equilibrium state	Urban spatial planning and sustainable stormwater management
Ecological flood resilience	Planning or adjusting infrastructure to withstand floods	Multiple equilibrium state	Municipal drainage works, levees, etc.
Social flood resilience	Improving adaptive learning capacity to cope with future floods through crisis management and disaster impact reduction	No equilibrium state pursued	Forewarning, risk assessment, emergency response, traffic evacuation, financial support, government assistance, etc.

Table 2-2 Classification of resilience
Source: Bibliography

Liao Guixian, a Hong Kong scholar, first introduced the concept of flood resilience to China, using ecological resilience as a theoretical framework, arguing that flood resilience is defined by floodability and reorganization, and is carried by ecosystems, and is not engineering resilience to resist and recover[14]. Combining resilience with urban water systems, Yu Kongjian composes the concept, connotation, and strategy of resilience, in which he proposes structural and non-structural strategies that also correspond to the ecological and social aspects of flood resilience in practice[15]Based on the concept of flood resilience, Zang Xinyu proposed a strategy based on ecological resilience, which includes improving the proportion of floodable areas, stormwater retention capacity and purification capacity[16].

[14] Liao Guixian,Lin Hejia,Wang Yang. A Theory on Urban Resilience to Floods—A Basis for Alternative Planning Practices [J]. International Urban Planning,2015,30(02):36-47.

[15] Yu Kongjian,XU Tao,Li Dihua,WANG Chunlian. Progress in the study of urban water system resilience [J]. Journal of Urban Planning,2015(01):75-83.DOI:10.16361/j.upf.201501011

[16] ZHANG Rui,ZANG Xinyu,CHEN Tian. Research on the Renewal Planning Strategy of Old Residential District

The core concept of flood resilience can be summarized as living with floods and adapting cities to the laws of natural growth, which is reflected in the ecological aspect as an adaptive strategy based on the natural environment and emphasizing the adaptability of urban systems to floods. Reflected in the social aspect is a learning strategy based on disaster warning, emergency response and other management measures, focusing on accumulating experience and continuous learning from each rain and flood disaster to strengthen the resilience of urban systems to cope with floods The engineering resilience in response to the stormwater disaster in the ability to adapt, learn, recovery is much less than the ecological resilience, generally can only withstand the specified standard of stormwater, when the occurrence of stormwater disaster outside the standard range, the engineering system is very easy to collapse. Therefore, engineering, ecological, and social flood resilience will generally co-exist in flood resilience management, which integrates to enhance all aspects of the system's ability to cope with flooding and ensure a virtuous cycle when the system responds to periodic flooding.

The research object of this paper is only one component of the urban system. The social dimension of flood resilience tends to develop management strategies for the macro level of the whole urban system, while ecological flood resilience focuses on the design of urban space at all levels. Therefore, the research in this paper focuses on ecological flood resilience.

2.2.2 Relationship between Flood Resilience and Urban Design

Urban design is a comprehensive discipline, a means of putting meaning into practice through form. The design of the urban spatial environment is a core content of urban design. As an ecological aspect of "meaning", flood resilience also has the ability to generate the corresponding spatial environment[17]. Pattern and Process theory demonstrates a strong correlation between landscape form, flow process and scale, and this theory was later extended to the field of urban spatial planning to establish the correlation between urban design and urban hydrological characteristics and water management. Subsequently, many scholars began to conduct research based on the relationship between flood resilience and urban design.

Based on Resilience to Flood— A Case Study of Chuanfuxincun Community[J].China Garden,2019,35(02):64-68.

[17] S.T.A. Pickett,M.L. Cadenasso,J.M. Grove. Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms[J]. Landscape and Urban Planning,2003,69(4).

For example, Novotny et al. conducted a study on sustainable communities driven by urban water systems and proposed planning principles and specific strategies for water resilient cities by discussing the classification of urban water issues[18]; Pickett et al. bridge the gap between ecology and urban design based on resilience theory[19]. In fact, design practice predates theory, and many cities around the world have accumulated valuable experience in enhancing flood resilience from ancient times to the present, such as Singapore, Barcelona, and Amsterdam. The Atlas of Dutch Water Cities provides a detailed introduction to the Dutch experience. It divides Dutch cities into three types, namely coastal cities, river cities, and swamp cities, and summarizes the spatial design of different Dutch cities over the centuries according to their "water fetishes", reflecting the direct influence of flood resilience on urban morphogenesis.

2.2.3 The Concept of Resilient Urban Design for Flood Control

In a narrow sense, resilient urban design for flood control refers to the design and integration of the environmental spatial elements that make up a city, such as land use, neighborhood structure, texture type, building units, landscape and infrastructure systems, based on the principles of flood resilience, in order to maximize the city's ability to cope with floods while improving the quality of the urban environment. A broad approach to resilient urban design for flood control focuses not only on design as a theoretical form of spatial planning, but also on its connotations as an applied form, including the social and economic dimensions of design organization, realization, and related elements of urban management. The discussion in this paper is limited to the narrow scope of resilient urban design for flood control, focusing on the interaction between flood resilience and the urban spatial environment.

Similar concepts to resilient urban design for flood control were first introduced in the United States in 1977 as Best Management Practices (BMPs)[20], and have since influenced

[18] Novotny V, Ahern J, Brown P. Water centric sustainable communities: planning, retrofitting, and building the next urban environment[M]. John Wiley & Sons, 2010.

[19] Resilience in ecology and urban design: Linking theory and practice for sustainable cities[M]. Springer Science & Business Media, 2013.

[20] George Ice. History of Innovative Best Management Practice Development and its Role in Addressing Water Quality Limited Waterbodies[J]. Journal of Environmental Engineering,2004,130(6).

other countries to develop different management experiences such as Low Impact Development (LID)[21], Water Sensitive Urban Design (WSUD)[22], Sustainable Urban Drainage Systems (SUDS)[23], and Sponge Cities[24]. The differences between these concepts are shown in the table. It can be seen that complete urban water management includes three aspects, namely water resources management, stormwater management and wastewater reuse, which are also elements of water sensitive urban design. It is generally believed that resilient urban design for flood control only includes stormwater management in water sensitive urban design, but in fact, resilient urban design for flood control also includes water resources management and wastewater reuse related to stormwater disasters, and the three are interrelated and inseparable. Many methods of enhancing urban flood resilience often also have a water management or wastewater reuse role, such as collecting rainwater for resource use through cisterns in some places, which also shares the flow pressure of the drainage system during peak stormwater periods and enhances urban stormwater disaster response capacity. In addition, the concept of stormwater management differs between resilient urban design for flood control and water sensitive urban design. The former emphasizes more on the response to occasional stormwater hazards compared to daily stormwater management, which covers urban stormwater management.

Concept	Content	Description
Best Management Practices	Including four aspects of prevention, water source control, hydrological correction, and reducing the transport distance of pollutants from the water source to the stormwater	A method of water pollution control, used not only for early industrial and municipal wastewater control, but also for stormwater and wetland management, which

[21] Liu Tianqi,Lawluvy Yelly,Shi Yang,Yap Pow Seng. Low Impact Development (LID) Practices: A Review on Recent Developments, Challenges and Prospects[J]. Water, Air, & Soil Pollution,2021,232(9).

[22] Rashetnia Samira,Sharma Ashok K,Ladson Anthony R,Browne Dale,Yaghoubi Ehsan. A scoping review on Water Sensitive Urban Design aims and achievements[J]. Urban Water Journal,2022,19(5).

[23] Damien Tedoldi,Ghassan Chebbo,Daniel Pierlot,Yves Kovacs,Marie-Christine Gromaire. Impact of runoff infiltration on contaminant accumulation and transport in the soil/filter media of Sustainable Urban Drainage Systems: A literature review[J]. Science of the Total Environment,2016,569-570.

[24] Yin Dingkun,Chen Ye,Jia Haifeng,Wang Qi,Chen Zhengxia,Xu Changqing,Li Qian,Wang Wenliang,Yang Ye,Fu Guangtao,Chen Albert S.. Sponge city practice in China: A review of construction, assessment, operational and maintenance[J]. Journal of Cleaner Production,2020(prepublish).

Concept	Content	Description
	receiver via surface runoff or groundwater; exploring the potential of water in shaping the urban environment	emerged in the late 20th century, with much of the discussion today focused on the latter; mainly through land use adjustments to moderate the impact of urban surface runoff on water quantity and quality, and can be divided into structural and non-structural methods
Low Impact Development	Small-scale development; control urban runoff; protect water resources; often used in rural areas or where there is a high proportion of public space	It is an integrated approach to land use and engineering design for stormwater runoff management, emphasizing the protection and use of the natural characteristics of the site and the maintenance of the original water ecology of the site.
Water Sensitive Urban Design	Integrating urban design, water body and stormwater management measures to collectively enhance social, visual, cultural and ecological values	An integrated approach to land use and engineering design that integrates the urban water cycle, including stormwater flooding, surface water, wastewater management and clean water supply, to mitigate urban environmental degradation and enhance aesthetic quality
Sustainable Drainage Systems	Focus on the water system itself; easy to manage; consumes no or little energy; flexible in use; takes into account environmental ecological and aesthetic values	The system is used to reduce the impact of new or existing urban development on surface water discharges; it simulates natural systems through cost-effective strategies that focus on the three stages of rainwater collection, storage and purification before discharge
Sponge city	The main emphasis is on the natural accumulation,	Through strengthening urban planning and construction

Concept	Content	Description
	infiltration and purification capabilities of the urban surface, similar to that of water-sensitive urban design for stormwater management, with no emphasis on response to episodic events	and management, the ecosystems of buildings, roads, green spaces and water systems play a role in rainwater absorption, storage and infiltration and slow release, effectively controlling rainwater runoff and achieving natural accumulation, natural infiltration and natural purification of the development method

Table 2-3 Similar concepts to resilient urban design for flood control
Source: Bibliography

2.2.4 Approach to Resilient Urban Design for Flood Control

The key to driving the design of the urban spatial environment through flood resilience is to make good use of the principles of flood resilience to develop effective response methods and make scientific decisions in the urban design process. These approaches respond to the core issues of urban design, including land use optimization, urban structure organization, and multifunctional space shaping.

(1) Optimizing land use based on the principle of resilience

Urban flood resilience is closely related to the land use pattern. A land use pattern adapted to the geohydrological conditions can avoid the occurrence of rainfall hazards to the maximum extent and reduce the mutual interference between the artificial environment and the natural water system, thus improving urban flood resilience[25].

This paper focuses on land use optimization at the city and neighborhood scale, mainly in terms of functional layout. A site-specific layout of open space based on potential rainwater corridors can avoid threats to concentrated areas of people. In the functional layout, an in-depth field research should be conducted first, namely an analysis of the topography, hydrology, rainfall, etc. within the catchment area where the site is located; Secondly, based on the

[25] Zhang Ge. Study on Stormwater Management Mode Based on Land Use Pattern Optimization [D].Zhejiang University ,2013.

characteristics of the site, we develop a targeted stormwater management model, such as maximizing stormwater retention in higher terrain areas to reduce flooding pressure in lower areas, and promoting rapid stormwater discharge in lower terrain areas to prevent flooding, etc., and then propose an adaptive urban functional layout plan.

(2) Organizing the urban structure according to the principle of resilience

The urban structure is the skeleton of a city, which describes the relationship between the partial and overall locations, including elements such as street layout, building arrangement and public space organization. An urban spatial structure with good flood resilience can promote drainage, water storage and in place absorption of water bodies, maximizing the effectiveness of urban flood resilience. In this process, flood resilience becomes the driving force for shaping the characteristic urban fabric.

The net villages in China's Pearl River Delta region use drainage and water storage to organize village space with surface water systems as the core to cope with flooding. The spatial pattern is dominated by a variety of water bodies inside and outside the village, which are mainly divided into rivers and ponds in the watershed outside the village and rivers in the village. Drainage system to the river as the leading, the road and its two sides of the ditch is generally the same structure with the river, play a supporting role in drainage. The water system and roads lay the foundation for the structure and layout of the village, and the buildings are laid out in groups to form the unique fabric of the net village on this basis. Ponds inside and outside the village serve as water storage for stormwater management and are usually located at a lower elevation to collect more runoff during the flood season. In the development of the village, this spatial structure is continuously improved to form a regional landscape with rainfall adaptation.

Compared with the ancient urban water management concept, the contemporary theory of flood resilience not only continues and renders the traditional surface water system with drainage and water storage as the core approach, but also focuses more on the ability of nature to absorb rainwater in place. Natural in place absorption can be controlled at the source, not only to reduce surface runoff pollution and recharge groundwater, but also, and most importantly, to use the natural storage function to enhance the resilience of cities to cope with rainfall floods and reduce the pressure of artificial drainage and water storage downstream.

(3) Shaping multifunctional space according to the principle of resilience

Sustainable urban drainage systems include elements such as green roofs, depressions, courtyard ponds, ditches, storage ponds and wetlands, which are also referred to as blue and green infrastructure. Blue and green infrastructure has good flood resilience and can greatly reduce surface runoff. Since rain and flooding are only episodic events, in normal times, blue and green infrastructure can be used for other purposes, such as overlaying slow walking systems, interaction spaces and green landscapes, to enhance resilience and gain social and economic benefits at the same time, thus achieving a multi-win situation.

The design of urban public space should fully consider the integration with blue-green infrastructure to create multi-functional space, and the extensive river restoration movement in recent years is a good example of multi-functional space shaping. In the process of profit-oriented rapid urbanization, urban rivers have been heavily buried due to excessive occupation of urban land. The river restoration movement reclaims the value of the urban waterfront space by removing the cover and restoring the historic river. These restored rivers can be used not only to alleviate stormwater problems, but also to combine with recreational and commercial facilities to create attractive and vibrant urban spaces. In addition to rivers, similar urban multifunctional spaces include roads, squares, courtyards, parks and flyovers.For example, the Water Square in Rotterdam, Netherlands. The design of Water Square Benthemplein is an innovative twofold strategy that combines water storage and improves the quality of urban public space. Most of the time the square is dry and used as a recreational space for youth sports and play. When confronted with heavy rainfall, the square changes from its usual appearance and function, becoming a temporary rainwater storage facility[26].

(4) Integrating urban systems based on the principle of resilience

Ecological thinking has expanded the disciplinary boundaries of urban design, presenting an integrated multidisciplinary character. The traditional approach of relying on drainage engineers to design piping networks to cope with urban flooding is already stretched to the limit, and an interdisciplinary dialogue is needed to build a more powerful response system. To deal

[26] DE URBANISTEN. Water Square Benthemplein in Rotterdam, the Netherlands[J]. Landscape Architecture Frontiers,2013,1(4).

with stormwater disasters, we should not only stay at the level of drainage and landscape system design, but also extend to the whole urban system such as streets, public spaces and buildings, and use urban design as a method to think and solve problems at a broader level, so as to obtain greater benefits from the synergy of the system.

2. 3 Brief Summary

The first part of this chapter is a fundamental study. It mainly introduces the origin and evolution of resilience theory, and clarifies the concept of resilience in each development stage and the content of concern. Based on the resilience theory, the concept of resilient city is introduced, and the principles of resilience and resilient city are summarized using the literature review method to provide guiding meaning for the subsequent design of urban village renewal.

The second part of this chapter aims to summarize and refine the approach of resilient urban design for flood control for the subsequent practical strategies. First, the development and concepts of flood resilience are reviewed to clarify the research focus and the problems addressed by flood resilience. Then, the relationship between flood resilience and urban design is clarified, as well as the role that flood resilience can play in urban design. Finally, the method of urban design for flood resilience is proposed on the basis of the concept of resilient urban design for flood control.

In the next section, the study will move from theoretical research to the study of existing practice cases to further learn and generalize practical strategies from the perspective of flood resilience and resilient urban design for flood control.

Chapter 3 Case Study

3.1 Copenhagen Stormwater Management Plan

3.1.1 Brief Description

Copenhagen has a temperate maritime climate with mild seasons. From August 2010 to August 2011, Copenhagen was hit by three consecutive heavy rainstorms, which caused severe waterlogging. The most serious one was the very heavy rainfall on July 2, 2011, which was the heaviest rainfall Copenhagen has experienced since 1986, with an average rainfall of 30-90 mm in 24 hours[27].

In the face of increasingly frequent flooding, the City of Copenhagen is committed to building a greener, more sustainable and The Copenhagen Municipality is committed to building a greener, more sustainable and resilient city to meet the future needs of the people living in Copenhagen. To this end, the Copenhagen City Council has focused on a series of climate adaptation efforts to address the challenges of flooding caused by heavy rainfall after these events. The Copenhagen Climate Adaptation Plan and the Copenhagen Stormwater Management Plan were completed in 2011 and 2012, respectively, to guide the construction of future urban drainage and flood control projects[28].

The overall strategy of Copenhagen storm water management plan is based on blue and green facilities as the core, supplemented by gray facilities. Compared with the traditional plan, it further reduces the construction of facilities and pipelines, adopts refined and humanized design of green space and water city space, reasonably organizes urban surface runoff, abates the impact of extraordinarily heavy rainfall on residents' life, and is easier to build and implement.

Firstly, a high-precision hydraulic model was established based on natural geographical

[27] Fu Zhengyao,HAN Wei,Zhang Xiaoxin,Lv Huanlai. Copenhagen Stormwater Management Planning Practices and Insights[J]. Beijing Planning and Construction,2022(04):18-23.

[28] Wang Jiangbo,Yu Yang,Gou Aiping.Copenhagen Climate Adaptation Planning and Insights[J].Anhui Architecture,2020,27(05):28-30.DOI:10.16330/j.cnki.1007-7359.2020.05.013.

conditions and detailed data to carry out the assessment of the current waterlogging risk[29]. Based on the assessment results and the future construction plan, a "five-finger" drainage channel was arranged in the core area of Copenhagen's old city, combining the current river network, green corridors, major traffic arteries and other passages to form a macro stormwater management pattern.

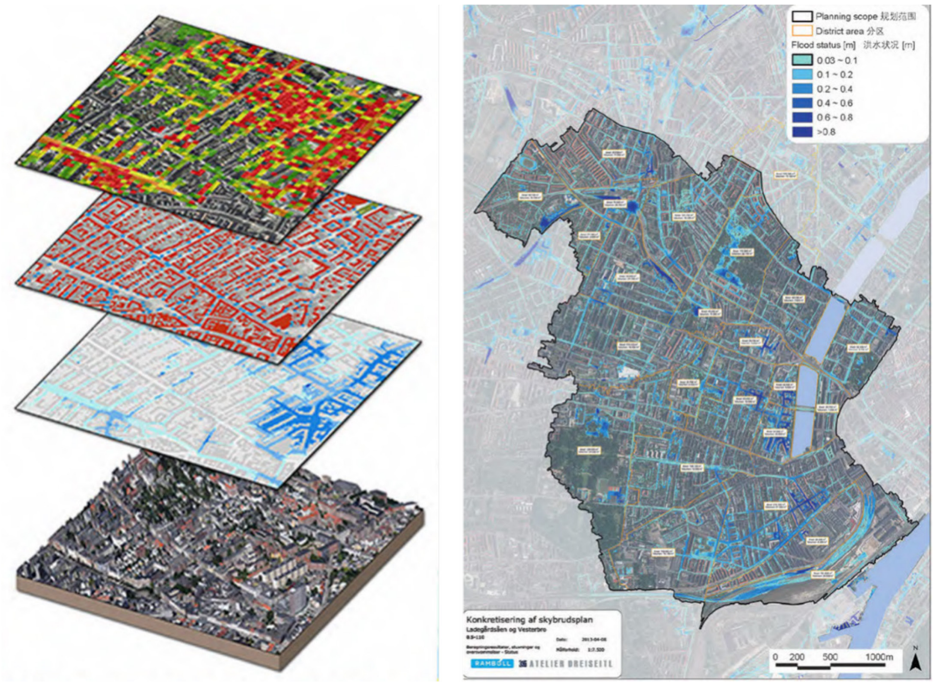

Figure 3-1 assessment of the current waterlogging risk
Source: Bibliography

[29] Søren HVILSHØJ,Anna Aslaug LUND,Neil Hugh McLean GORING,Cathy LV. COPENHAGEN CLOUDBURST CONCRETIZATION PLAN, DANMARK[J]. Landscape Architecture Frontiers,2016,4(5).

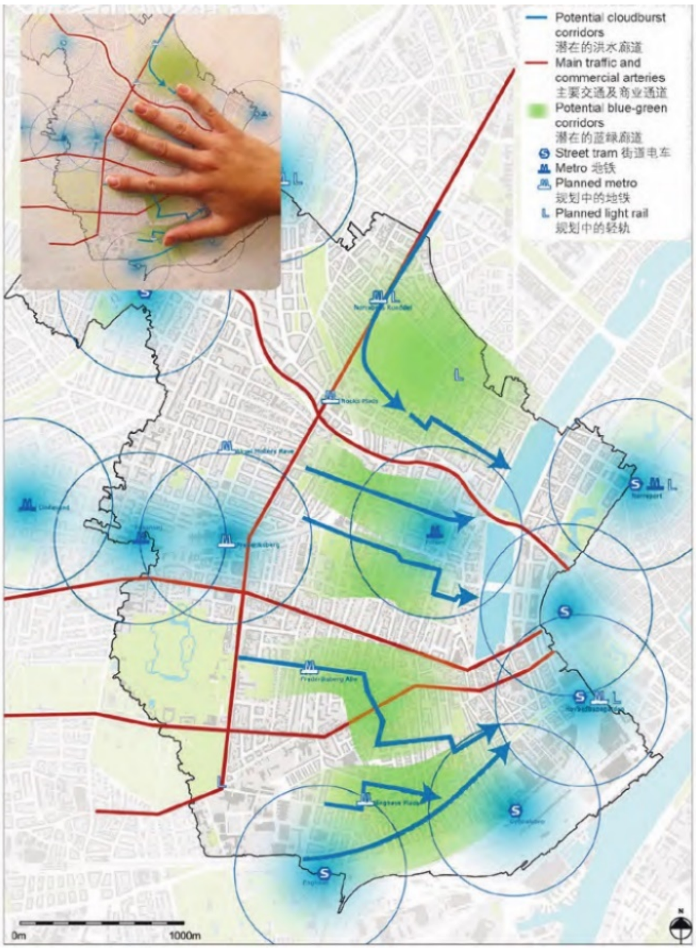

Figure 3-2 "Five-finger" drainage channel in Copenhagen Stormwater Management Plan
Source: Bibliography

For common urban space patterns such as city streets, green parks and squares, the technical team proposes refined design solutions for eight types of storm water management measures. Public spaces such as green areas and squares can be transformed by means of microtopography to form rain gardens with pleasant landscapes and stagnant functions. Optimize the vertical direction of roads and the function of roadside green belts to form organized runoff discharges and store and purify them in situ. Urban streets can use the finely designed vertical height difference of urban streets to delineate "safe passage sections" and "flooded areas", making full use of street space to store rainwater under different rainfall conditions. For urban roads, it is also possible to change the slope of the road cross-section and build a V-shaped urban road section, transforming traditional streets into storm water adaptive streets. This change not only reduces the space occupied by the road, but also increases the water retention capacity of the road and can reduce pedestrian wading, which can meet the needs of both daily use and response to extreme rainstorm weather.

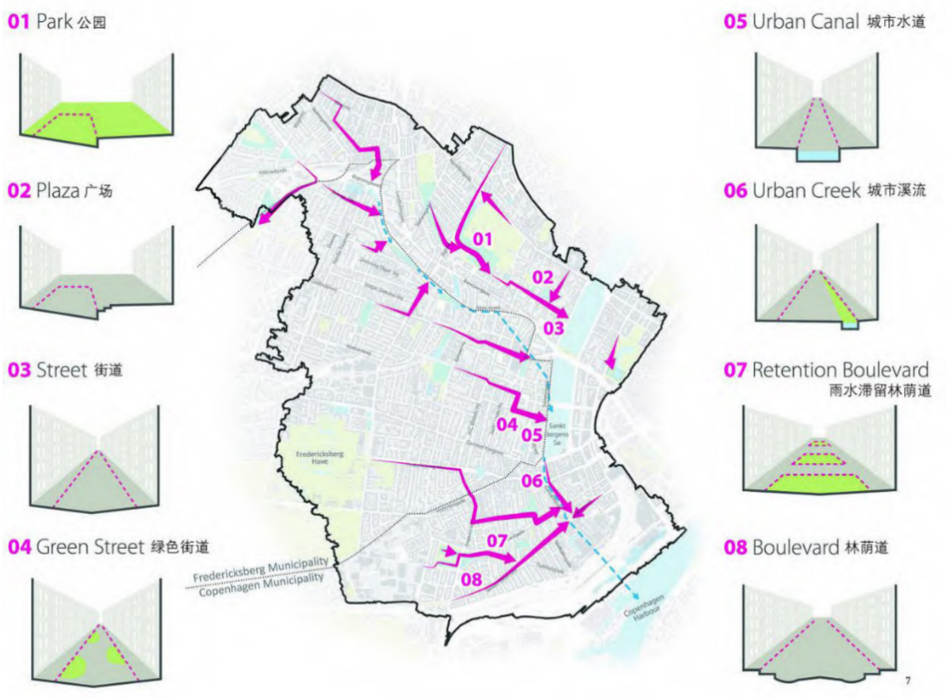

Figure 3-3 Eight types of storm water management measures for common space

Source: Bibliography

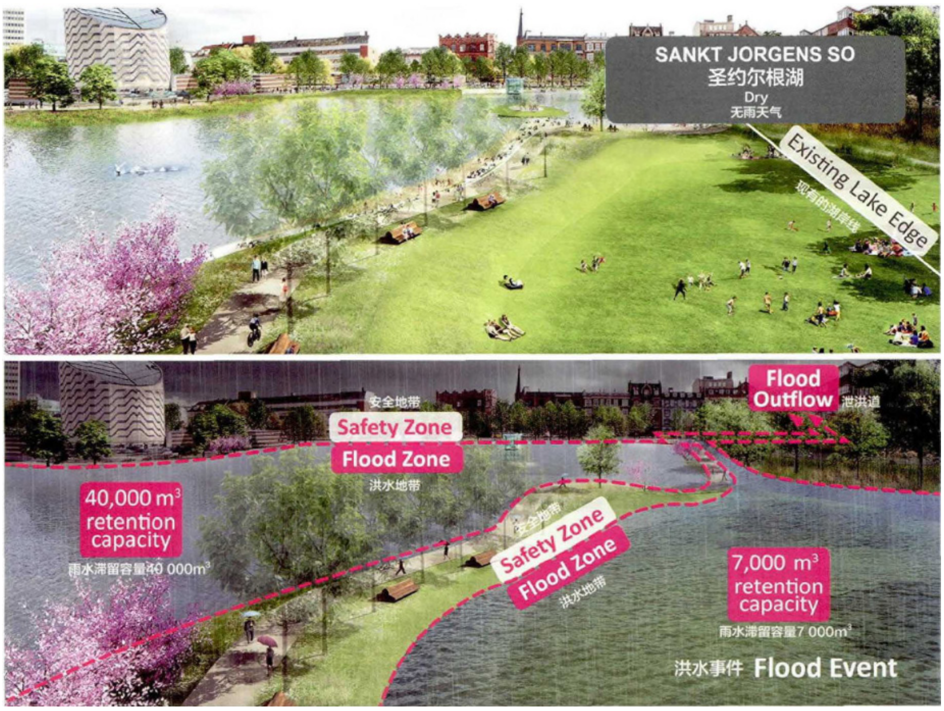

Figure 3-4 multifunctional waterfront parks

Source: Bibliography

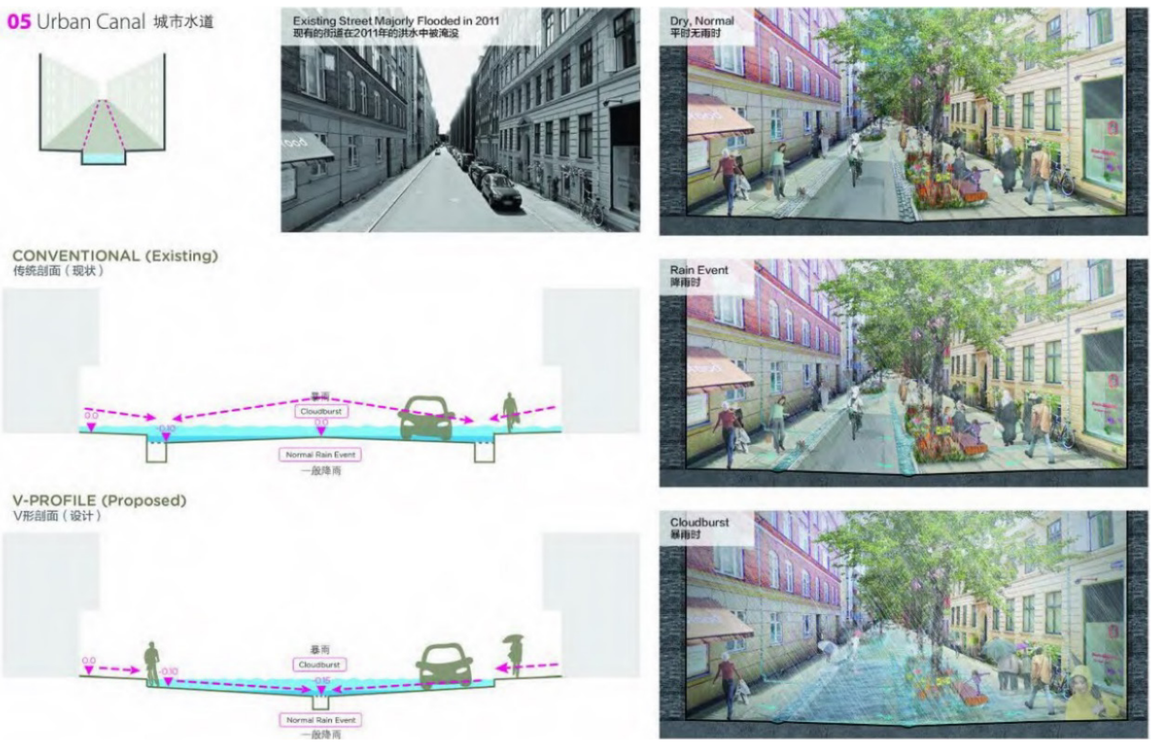

Figure 3-5 Stormwater adaptive street
Source: Bibliography

The transformed parks and gathering spaces enhance the recreational value of the city, such as transforming road green belts into low-lying green parks, which can be used as resting places for citizens when there is no rain, storing rainwater when there is rain, and eliminating the need to renovate existing stormwater pipes; transforming existing low-lying ponds into multifunctional waterfront parks that are accessible to citizens, creating biological habitats, sandy beaches and diverse recreational spaces while maintaining and improving the current urban structure. The park will maintain and improve the existing urban structure, creating habitat for living creatures, a sandy beach and a variety of recreational spaces, as well as temporarily accommodating large amounts of flood water in extreme weather conditions and protecting the surrounding area from flooding. The microclimate of the city is also improved, and the collaboration with transportation planning contributes to urban safety and convenience.

3. 1. 2 Strategy Analysis

The strategies proposed in the Copenhagen Stormwater Management Plan are consistent with the principles of flood resilience. This paper explores the connection between its design approach and the principles of resilient cities from the perspective of urban public space design, and summarizes the five principles guiding the Copenhagen Stormwater Management Plan, which are the principles of a redundant, diverse, robust, interdependent and adaptable approach.

The principle of redundant resilience is demonstrated by the fact that the entire resilient system uses many components with duplicate functions, so that when one component fails, the entire system does not fail. In the Copenhagen Stormwater Management Plan, measures with rainwater storage functions include urban roads with V-shaped sections, squares and parks with microtopographic modifications; Measures with rainwater retention features such as rain gardens, rainwater retention boulevards, green streets, etc.; Measures with rainwater drainage functions include storm drains, urban waterways, and green streets, which are grey infrastructure. Each function has different forms of measures to ensure that the entire resilient system in Copenhagen can operate stably in response to stormwater.

Copenhagen's resilient system has many different components for water storage, detention, and drainage functions to protect Copenhagen from the threat of storm water, following diverse resilience principles.

The robust principle of a resilient system is reflected in its ability to cope with stormwater. Copenhagen has constituted a sound stormwater management system through flood risk assessment, planning of drainage channels, and development of targeted urban space design strategies, sufficient to meet the expected design criteria of no surface water in a 10-year period of rainfall and no more than 100mm average depth of water on roads in a 100-year period of rainfall conditions.

The adaptable principle of resilient system is reflected in the flexibility of urban space function conversion. For example, the road green belt is transformed into a low-lying green park, which can be used as a resting place for citizens when there is no rain and storing rainwater when there is rain.

The interdependent principle of resilient systems is reflected in the interconnectedness and mutual support of the functional components of the system. That is, it reflects the holistic nature of the stormwater management system. For example, by connecting a V-section street to a rain garden, when the street reaches its stormwater holding limit, runoff can be discharged to the rain garden; and when the rain garden reaches its storage limit, runoff can be shared to the street or other urban spaces connected to the street that have water storage functions.

3.1.3 Reference meaning

The implications of Copenhagen's storm water management plan for this paper are mainly at the macro level of planning and at the level of public space design.

At the urban planning level, Copenhagen has a macro stormwater management pattern in the form of "five fingers" through flooding simulation assessment, combined with the existing river network, green corridors, traffic road network and other channels in the core area. Therefore, a thorough study and hydrological analysis of the design site will help to establish a scientific and effective stormwater management pattern.

At the level of shaping urban public space, Copenhagen proposes corresponding design strategies for different urban space patterns. These strategies meet the basic needs of modern urban activities and do not affect the original function of urban space, but rather improve the flood resilience and optimize the environmental quality based on the original function through the method of resilient urban design for flood control.

3.2 Traditional Ecological Wisdom of Flood Control in Fengjian Village

3.2.1 Brief Description

The net village in the Pearl River Delta are mainly located in Xingtan Town, Foshan, and the representative one is Fengjian Village, which is located in the north of Xingtan Town and frequently near the Shunde River, a tributary of the Xijiang River. The spatial form of the water township mainly relies on the natural water system of rivers and surges to divide it, while a large area of dike-ponds surrounds it. The river is winding, the buildings and roads are built according to the water system, and the village is natural and organic[30].

Fengjian Village has a well-planned site selection and water system construction strategy for coping with rain and flooding, in addition to storing excess rainwater to develop local agriculture and farming.

[30] Yang Donghui.Reasarch of Teaditional Village Drainage Spatial Form of The Pearl River Delta Based on Flood Control and Waterlog Draining[D].Harbin Institute of Technology,2015.

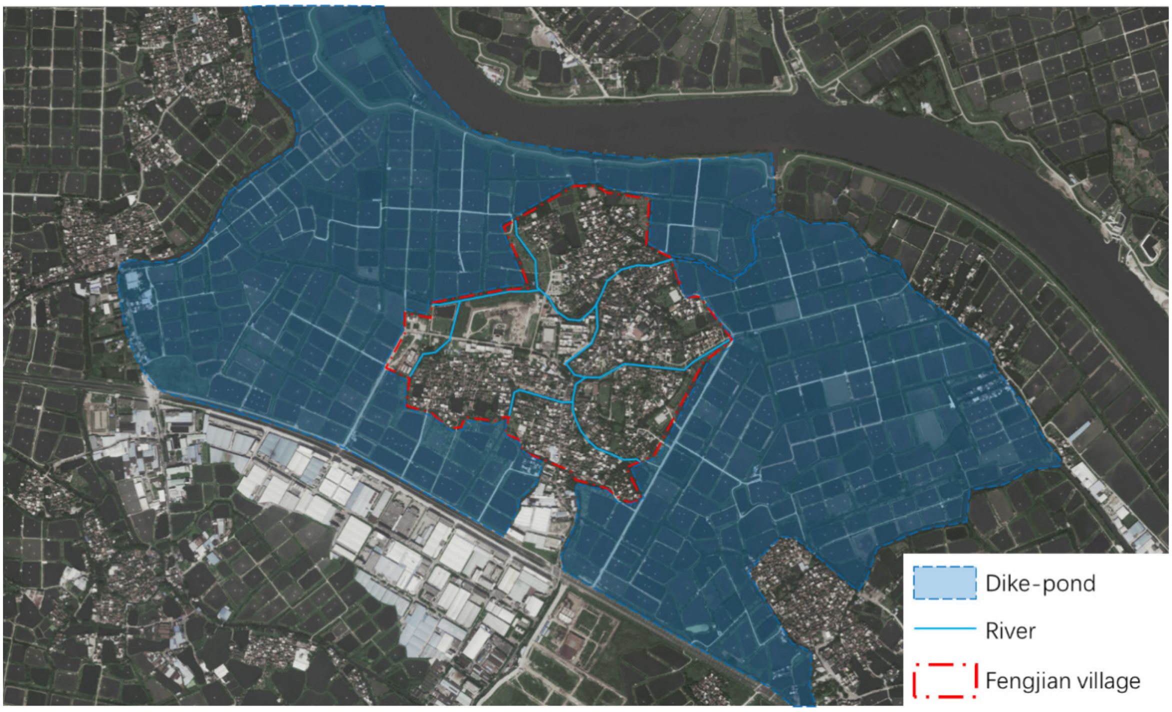

Figure 3-6 Dike-ponds and river in Fengjian village
Source: Self-drawn by the author

(1) Natural water system with flood control

The diverse water forms inside and outside Fengjian Village dominate and define the spatial layout of the village. At the same time, these natural water systems themselves serve as flood control. At the village level, they can be divided into internal linear rivers and surges as well as faceted dike-ponds.

There are two types of rivers: internal and external. The former is not directly connected to the external river system, but is usually a network of rivers composed of tributaries of the internal water system. These tributaries divide the village into small clusters of different sizes and shapes, which themselves have the function of water storage and drainage, and also undertake the internal traffic of the village. The other is the main river directly connected to the external water system, which has the function of flood discharge and discharges the rainwater collected from the internal tributaries of the village to the surrounding water systems.

Dike- pond is a unique water landscape in the traditional villages of the Pearl River Delta. In the long-term agricultural practice, in order to solve the problem of storm water flooding and flood risk caused by water above the fields, the people of the Pearl River Delta transformed the low-lying land, dug the land into ponds and piled mud into the dikes, forming the agricultural form of dike-pond system. The dike-pond consist of a pond and a dike surrounding the pond, and together with ditches, internal rivers, external rivers and dikes, they form a system. The large outer river embankments, inner river embankments and small internal embankments are interconnected, and the surrounding rivers and canals are connected to carry out the hydrological cycle together with the dike-ponds. Aquaculture is carried out in the ponds and accepts a large amount of surface runoff generated centrally for water storage during the flood season; fruit trees, mulberry trees, sugar cane, etc. are planted on the base and perform flood control functions to prevent pond flooding during the flood season, forming mixed agriculture while achieving rainwater storage[31].

[31] Wang Min,Wang Fangxinyi.Analysis and Insights of Ecological Wisdom of Stormwater Management in Traditional Rural Settlement from the Perspective of Resilience—Case Study of Pond-paddy Field System and Dike-pond System [J].Residential Technology,2021,41(02):39-44.DOI:10.13626/j.cnki.hs.2021.02.008.

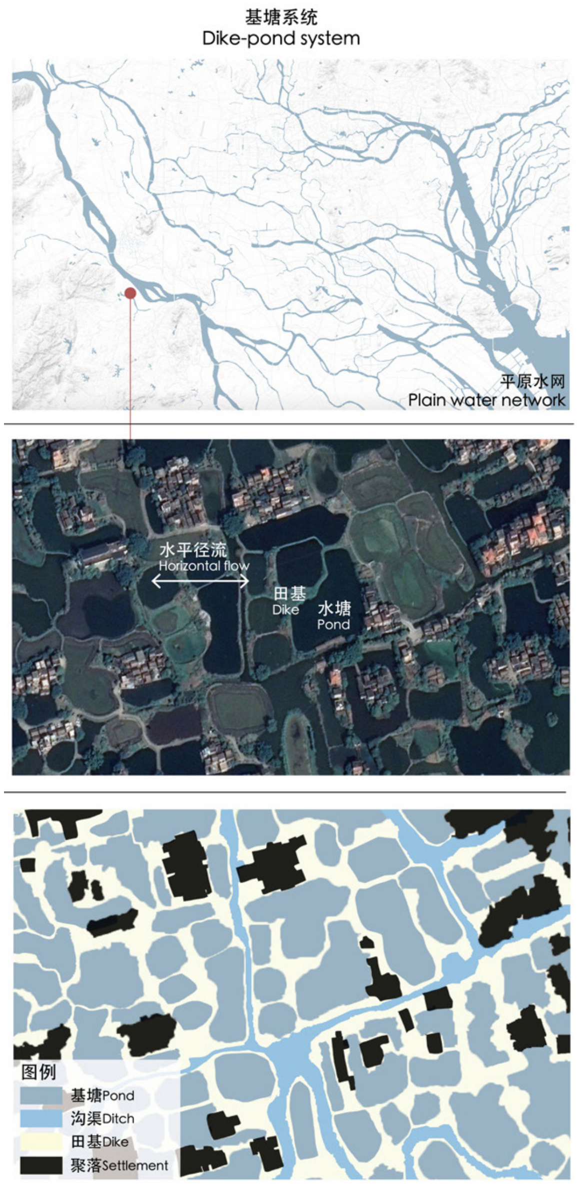

Figure 3-7 The environmental fabric and machanism of dike-pond system
Source: Bibliography

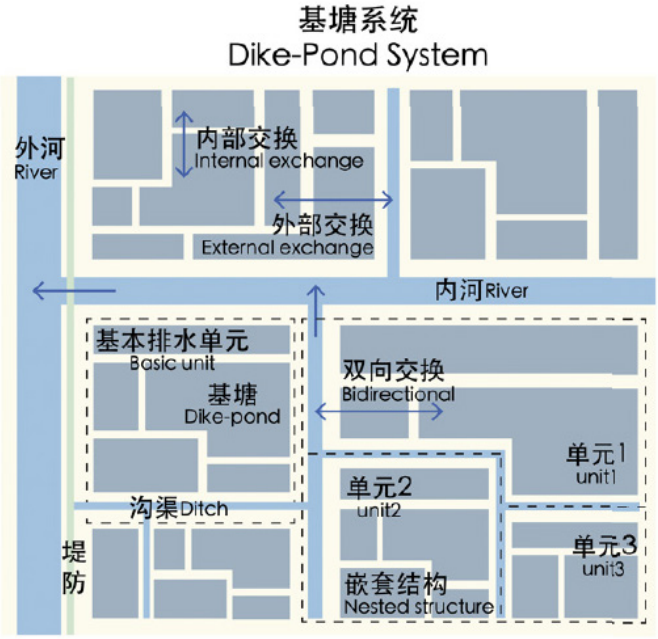

Figure 3-8 dike-pond system operation mechanism
Source: Bibliography

(2) Flood control considerations in site selection

Site selection is an important foundation for village planning and construction, and requires consideration of a variety of influencing factors. Among them, water is one of the decisive factors. Usually, a village needs to be located close to a water source to meet the needs of production and living, but also to avoid water in order to prevent potential flooding hazards to the village.

Site selection based on the water system pattern can greatly avoid flooding of the village. Fengjian Village is located in the lower reaches of the Xijiang River basin, which has abundant rainfall and water resources all year round. The topography is a dense alluvial plain with a network of rivers, fertile land and convenient transportation, which is suitable for the survival and development of the village. However, it cannot be ignored that the dense river system also creates a major flooding potential. Therefore, Fengjian Village was chosen to be located in a higher part of the river network plain and at the bend of the river system to minimize the risk of scouring of the village foundation and overflowing of the river watercourse.

Excavation of the dike-pond according to local conditions is conducive to flood control. In ancient times, the Pearl River Delta was a "low-lying, flood-prone" place. Most of the areas were below 1m above sea level, and during periods of heavy rainfall, the Pearl River water system would leak out and cause flooding. In order to avoid flooding, the villagers invented the dike-pond model based on the full use of low-lying ponds. The naturally formed depression ponds are dug through and linked together to increase the flood storage capacity. This model not only prevents flooding and flooding, but also fully utilizes local water resources to promote production, realizing the paradigm of harmonizing production and living with the environment, which is a compound and efficient land use model.

(3) Road path and drainage storage system

The village's well-developed drainage system as well as the storage system mainly in the dike-ponds play an important role in flood control. The main waterway of Fengjian Village is both the main route for navigation and the main drainage channel for flooding in the village. Connecting the natural and artificial water systems inside and outside the village ensures the connection between the village water system and the surrounding rivers, lakes and other water environments as well as the integrity of the water cycle. In order to meet the needs of life and to facilitate the extraction of water from various parts of the village, tributaries are excavated on the basis of the natural river system, and the water network is expanded in all directions, slowly forming the next level of the river, reflecting the evenness. The high-density layout of the river network has an extremely strong flooding effect. On this basis, villagers also take into account the needs of travel traffic, so the planning of paved streets and lanes parallel or perpendicular to the river gorge and other traffic roads.

At the same time, these transportation systems play an important role in the flood control and drainage process of the villages. For example, the roads are mostly paved with long stone slabs or bricks, with gaps in between to facilitate rainwater infiltration. Build linear drainage ditches under the road lanes or on both sides of the road lanes. The residential buildings near the river drain water directly to the river gorge, while the buildings far from the river gorge drain through drainage ditches. The drainage ditch next to the alleyway drains the water to the drainage ditch at the upper level and eventually into the river. Finally, the rainwater is discharged through drainage culverts and drainage inlets on the barge. This multi-level and perfect drainage system efficiently solves the flooding problem.

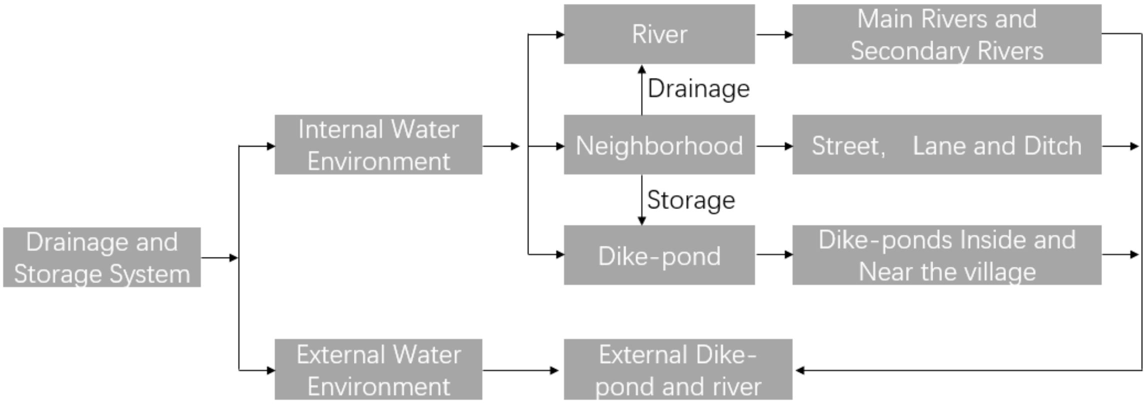

Figure 3-9 Drainage and storage system operation mechanism
Source: Bibliography

(4) Integrated land and water agricultural practices: mulberry-based fish ponds

In addition to its role in flood control and drainage by retaining and saving rainwater, the dike-pond system has also led to the development of a special model in agriculture, the mulberry-based fish pond. Fengjian village is one of the important bases of historical mulberry-based fish ponds, with mulberry planting and sericulture as the core, prompting the local agriculture, animal husbandry and fishery to be organically knitted together as a whole.

Developed in the 14th century, the mulberry-based fish pond consists of fruit trees planted on a dike and a central fish pond, a unique model of mixed farming invented by local people in flood prone natural conditions. In the early 17th century, this system became a combination of mulberry trees and tetras in fish ponds, forming an economic model of integrated silk fisheries until it reached its peak in the 1920s. This was followed by a depression in the global silk market and a sharp drop in the price of silk, which eventually forced people to seek other alternatives to silk for their dike-pond crop mix, such as bananas and sugar cane. The dike-pond system is world-renowned for its advantages of rational circulation of energy and materials, not only as a self-sufficient and efficient way of land use, but also as an effective use of the special terrain of the area. People use the pond mud dug out from the ponds to build the surrounding dikes and plant mulberry trees on them to raise silkworms. The pupae, as well as the leftover leaves and dung, are excellent feed and can be recycled to feed fish. In the pond, the leftover fish feed and fish manure are rich in organic matter, which is decomposed by microorganisms in the pond and falls to the bottom of the pond to increase the fertility of the mud. Finally, by digging up the pond mud every year and piling it back into the dam, people increase the fertility of the soil and thus provide nutrients for the mulberry trees[32].

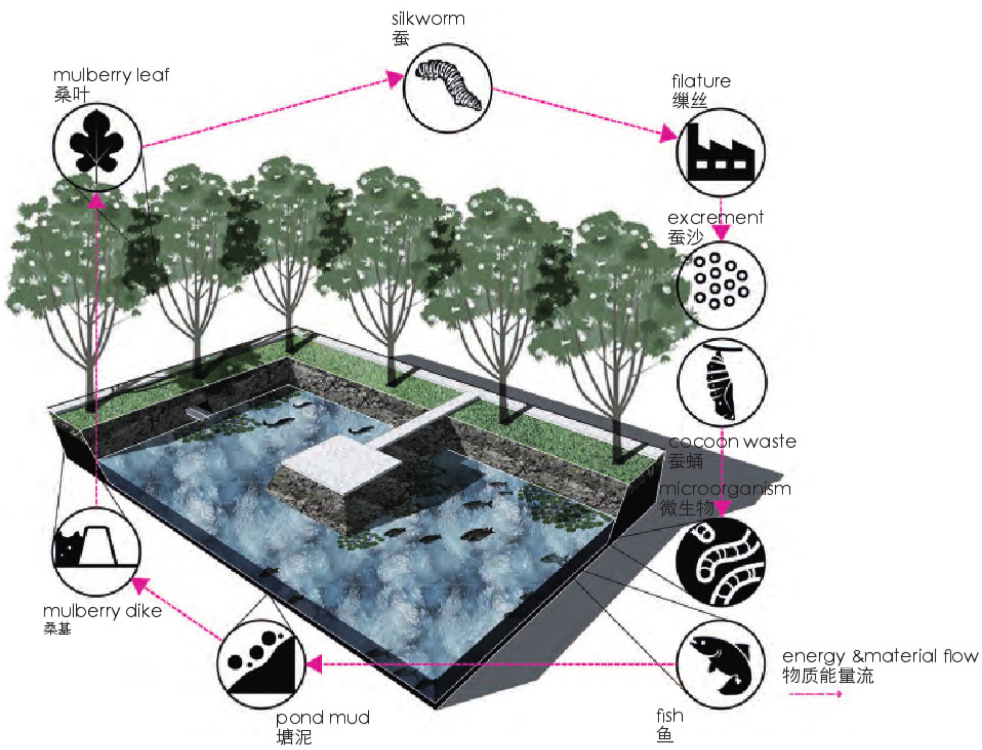

Figure 3-10 Mulberry-based fish pond model
Source: Bibliography

The mulberry-based fish pond model of agriculture not only increases the resilience of the village to rainfall flooding, but is also sustainable in terms of material and water recycling.

3. 2. 2 Strategy Analysis

The flood control strategy of Fengjian Village has many similarities with modern flood resilience theory. The principles of flood resilience can also be analyzed from the flood control and drainage patterns of the village space. The redundant principle is reflected in the large, repeatedly arranged dike-ponds outside Fengjian Village. The horizontally nested layout of the dike-pond units has sufficient storage units and water storage capacity to ensure that excessive runoff from the village can be accommodated during the flood season.

[32] Sun Chuanzhi,Steffen Nijhuis,Gregory Bracken.Learning from Agri-Aquaculture for Multiscale Water-Sensitive Design in the Pearl River Delta [J].Landscape Architecture,2019,26(09):31-44.DOI:10.14085/j.fjyl.2019.09.0031.14.

The diverse principle of resilience is reflected in the function of flood control measures. The rainwater management in Fengjian Village focuses on "integration of drainage and storage", and the function of flood prevention and drainage measures is mainly drainage and storage, such as dike-ponds, rivers, roads, ditches, etc. A single flood control and drainage measure also has more than one function, reflecting the diverse principle. For example, the river with natural barge not only has the function of water storage and drainage, but also has the ability of water stagnation; the road with stone tiles can both drain and infiltrate rainwater.

The robust principle of resilience is reflected in the fact that the entire water system and its components are not susceptible to damage. The entire water system can be protected from damage caused by rain and flooding through appropriate planning and the use of natural terrain and water bodies; In the components of the water system, Fengjian Village also applied some reinforcement measures, such as planting crops on the field base to enhance the flood control capacity of the dike-pond, and using stone bricks and concrete to build hard barges to enhance the flood safety of the river.

The adaptable principle of resilience is reflected in the planning layout of Fengjian Village based on flood control and drainage, and the village will be sited in a higher location in the plain, adapting to the topography so as to avoid flooding caused by heavy rainfall; Second, the site-specific development model of excavating dike-ponds to store rainwater and developing agriculture and farming on that basis embodies the adaptable principle.

The interdependent principle of resilience is reflected in the interconnectedness and support of the components in the water system. For example, the dike-pond units in the dike-pond system are responsible for water storage, while ditches and rivers connect the individual dike-pond units and discharge the runoff collected by themselves to the dike-ponds, and the dike-ponds can also exchange hydrology with each other through ditches and rivers. In the dike-pond system, the dike-pond is complemented by the ditch and the river, and each component is indispensable.

3.2.3 Reference meaning

Compared with modern case examples of resilient urban design for flood control, the traditional approach to stormwater management is not only consistent with the principles of flood resilience, but also better able to highlight the locality of the landscape in the design. For example, the natural water system in Fengjian village provides the basis of landscape elements for the shaping of the village waterfront space. The water system can be combined with regional waterfront landscape elements such as arch bridges, banyan trees and piers to form a rich and diverse public space.

The sustainable mulberry fish pond model based on flood control and drainage measures cleverly combines hydrological landscape and agriculture and farming to form a material organic cycle. In contemporary cities, although they no longer rely on agriculture and livestock development, they can learn from this model of combining stormwater management measures with industrial functions to enrich the urban space.

3. 3 Summary

This chapter introduces and analyzes a contemporary urban design case and a traditional village case from the perspective of flood resilience, aiming to sort out and summarize the advantages of modern and traditional flood resilience measures and methods, and provide feasible strategies for the practice of flood resilience in the Lijiao area.

Contemporary urban design practices for flood resilience have abandoned the rigid thinking of the past and developed principles and measures for flood resilience with the core concept of "living with floods". Various flood control strategies based on the principle of flood resilience can effectively respond to flood hazards and can be integrated into urban space as landscape elements, but a single design approach can easily lead to homogenization of urban landscape and the lack of urban locality.

Therefore, in the process of flood resilient urban design, the most direct way to preserve the locality is to summarize and refine the local traditional flood control measures and water landscape, and combine them with modern flood resilience measures.

Based on the case studies in this chapter, this paper will propose a territorial and resilient strategy for the renewal of Lijiao Village from the perspective of resilient urban design for flood control in Chapter 5.

Chapter 4 Inundation Analysis and Flood Risk Assessment

The medium used in this paper for stormwater corridor analysis and inundation analysis is ArcGIS software. The rainwater corridor analysis mainly uses the hydrological analysis module in ArcGIS to construct a valid rainwater corridor in the design area by extracting a certain threshold value of the results obtained from the analysis; The inundation analysis is based on the stormwater corridor analysis to delineate the watershed, and jointly with the SCS-CN method, the location and extent of urban spatial inundation within the design area is calculated through the surface volume tool of ArcGIS; The inundation risk assessment is based on a hydrological model constructed by SWMM software, which simulates precipitation scenarios with different return periods and is quantified by several indicators to provide reference for subsequent design strategies.

All the above analyses and assessments are supported by the basic data information from the preliminary research. Except for the final part of the flooding risk assessment, part of the results of the first two analyses will also be used as the data basis for the subsequent analyses The specific workflow is shown in the figure.

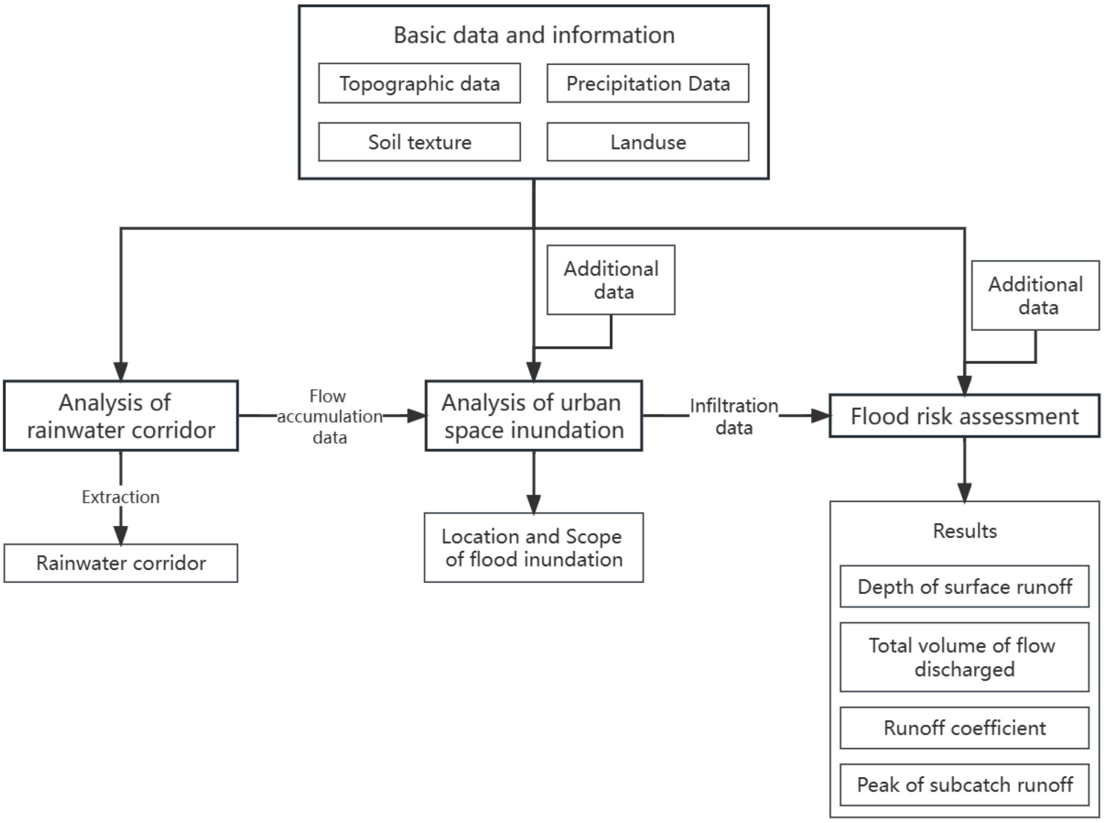

Figure 4-1 Overall workflow
Source: Self-drawn by the author

4.1 Fundamental Data Collection

4.1.1 Topographic Data

Lijiao is located in the southern part of Haizhu District, Guangzhou City. The terrain is flat and typical of plain terrain, with elevations ranging from 3.5 meters to 12.1 meters. The topographic data used in this paper is derived from geospatial data cloud, 12m accuracy DEM (Digital Elevation Model). The DEM elevation information and image data of the design area are shown in the figure.

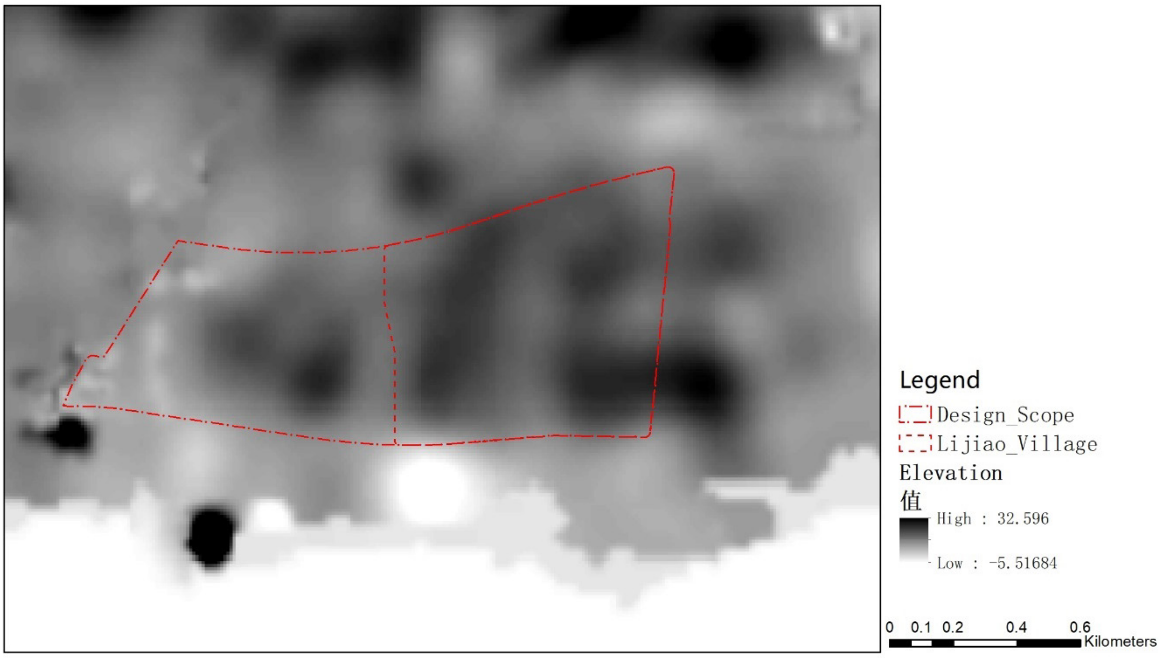

Figure 4-2 DEM data information
Source: Self-drawn by the author

4.1.2 Soil texture

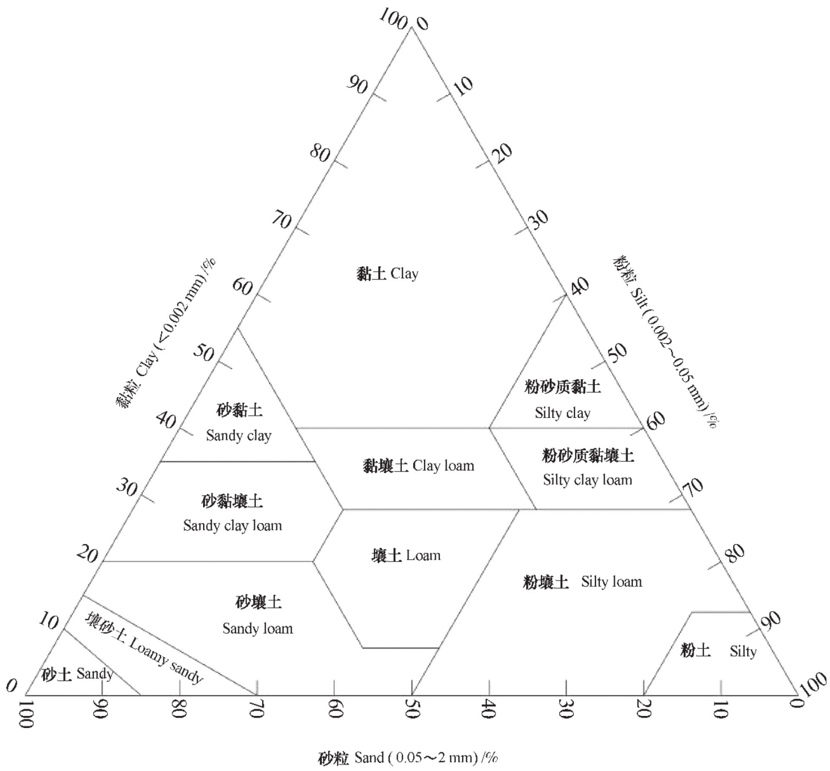

Figure 4-3 U.S. system classification standards for soil texture
Source: Bibliography

Soil texture is one of the important physical properties of soil, reflecting its water-holding and aeration properties. The mainstream classification standards for soil texture are mainly the U.S. system and the international system. Since some of the hydrological analysis methods used in this paper were developed by the U.S. Department of Agriculture (USDA), the U.S. system soil classification standards are used in this paper. The spatial distribution of soil texture in Guangzhou was extracted from the data on the spatial distribution of soil texture in China published by the Resource Environment Science and Data Center, Institute of Geographical Sciences and Resources, Chinese Academy of Sciences, and found that the soil texture composition in the Lijiao area was 22% clay, 47% sand and 31% silt. According to the United States Department of Agriculture (USDA) Soil Texture Classification Standards[33]， The soil texture of the design range is loam.

[33] Wu Kening,ZHAO Rui.Exploration of soil texture classification and its application in China[J].ACTA PEDOLOGICA SINICA,2019,56(01):227-241.

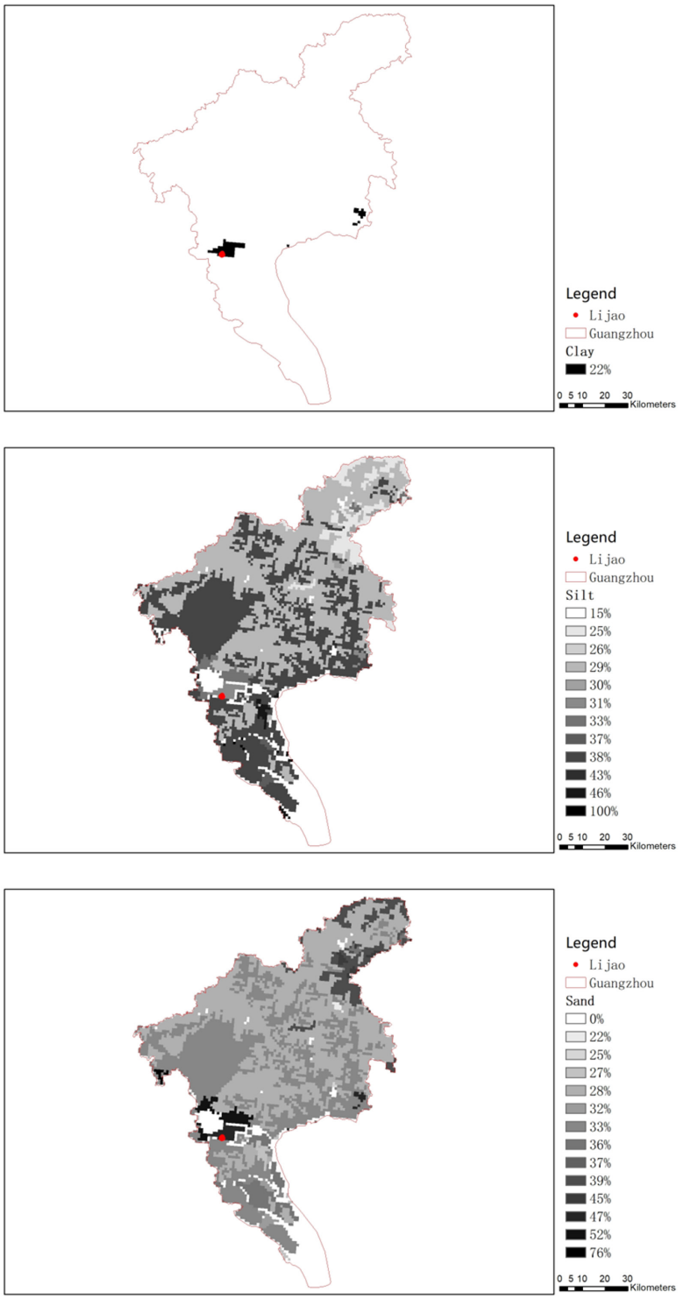

Figure 4-4 Soil texture composition in Guangzhou
Source: Self-drawn by the author

4.1.3 Precipitation Data

Precipitation is a direct factor to generate urban flooding hazards, and when studying urban flooding hazards generated by heavy rainfall, measured precipitation data or designed precipitation models are often used for simulation. Currently, studies on various types of risk hazards focus more on those extreme events that may bring losses, and the design of storm models is in line with the extreme value theory in disaster risk studies.

Therefore, the design storm model is chosen for the study in this paper. In 1957, Keifer and others proposed an inhomogeneous synthetic storm process line model, the Chicago rainfall process line model, based on the relationship between rainfall intensity, ephemeris and frequency when studying the Chicago pipe network system, which is widely used abroad[34]. In 1998, Chinese scholars such as Cen Guo Ping used the fuzzy identification method to study the Chicago rainfall process line, and the analysis showed that the model is consistent with the characteristics of heavy rainfall in China, and is applicable to rainfall of any heavy rainfall calendar time, only the average intensity differs[35].

Rainstorm intensity formula generally refer to the water supply and drainage design manual, see formula (4-1):

$$Q=\frac{A(1+CLgP)}{(t+b)^{n}} \tag{4-1}$$

Where: Q is the rainstorm intensity (L/(s·hm^2)); A is the precipitation amount (mm) for different return periods; C is the rainfall variation parameter; P is the rainfall return period (a); t is the rainfall duration (min); b and n are constants reflecting the variation of the design rainstorm intensity with the duration of the calendar.

Guangzhou central urban area (Yuexiu District, Liwan District, Haizhu District, Tianhe District, Baiyun District, Nansha District) rainstorm intensity formula is shown in the formula (4-2):

$$Q=\frac{3618.427(1+0.438LgP)}{(t+11.259)^{0.750}} \tag{4-2}$$

[34] Kibler D F. Urban stormwater hydrology[M]. American Geophysical Union, 1982.

[35] Cen Guoping,Shen Jin,Fan Rongsheng.Research on Rainfall Pattern of Urban Design Storm[J].ADVANCES IN WATER SCIENCE,1998(01):42-47.

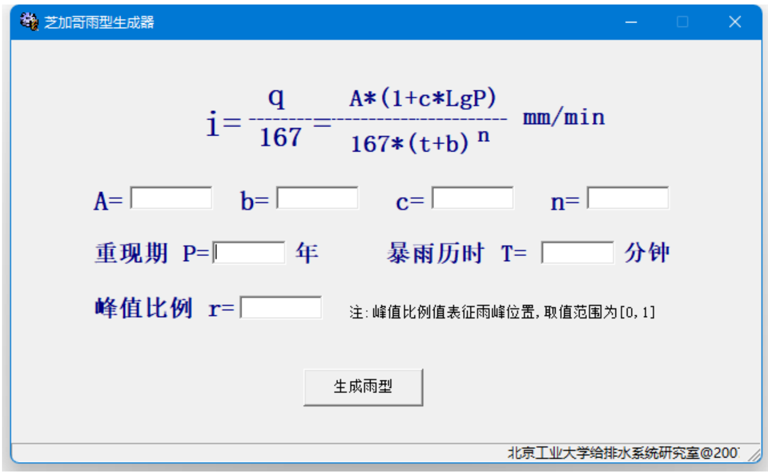

Figure 4-5 Chicago Rain Pattern Generator software

Source: Chicago Rain Pattern Generator software

The above relevant parameters were input into the Chicago Rain Pattern Generator software, the peak ratio was set to 0.4, and the rainstorm duration was 120 minutes, and the rainfall process was simulated and calculated when the return period was 10 years, 20 years, 50 years, and 100 years, as shown in the figure with the table.

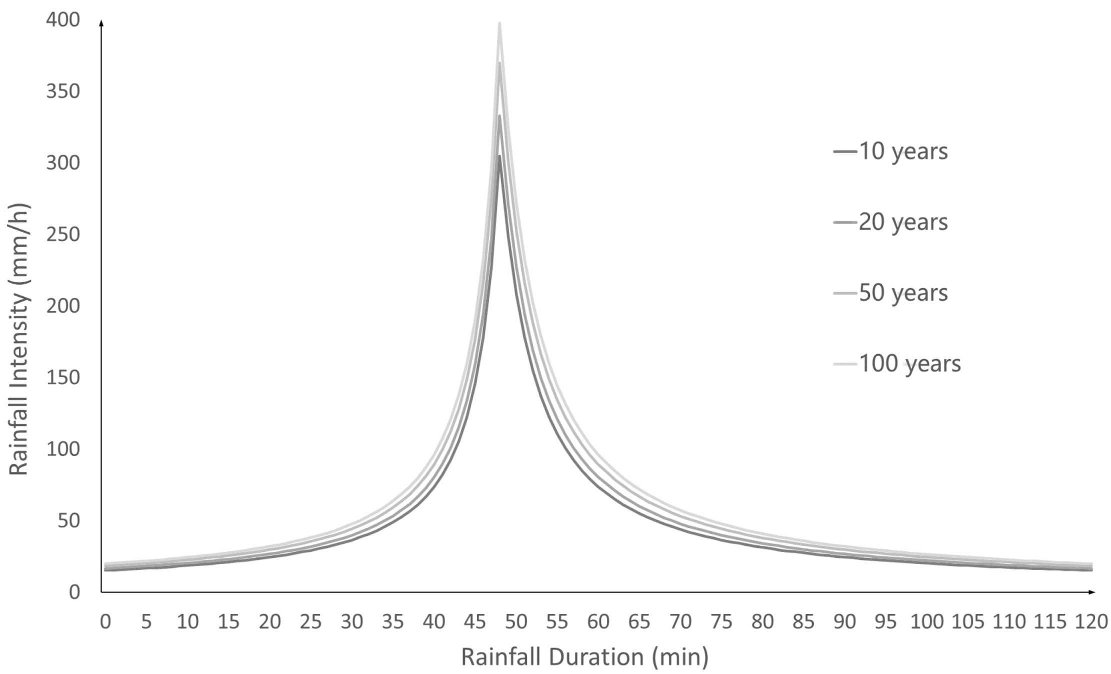

Figure 4-6 Rainfall intensity time curve

Source: Self-drawn by the author

Rain Duration (min)	Rainfall Intensity (mm/min) 10 years	20 years	50 years	100 years
0	15.186	16.578	18.414	19.806

Rain Duration (min)	Rainfall Intensity (mm/min) 10 years	20 years	50 years	100 years
1	15.468	16.884	18.756	20.178
2	15.762	17.202	19.116	20.562
3	16.068	17.538	19.488	20.958
4	16.386	17.886	19.872	21.378
5	16.722	18.252	20.28	21.81
6	17.07	18.636	20.706	22.266
7	17.436	19.032	21.15	22.746
8	17.82	19.452	21.612	23.25
9	18.222	19.896	22.104	23.772
10	18.648	20.358	22.62	24.33
11	19.092	20.844	23.16	24.912
12	19.566	21.36	23.73	25.524
13	20.058	21.9	24.33	26.172
14	20.586	22.476	24.966	26.856
15	21.144	23.082	25.644	27.582
16	21.732	23.724	26.358	28.35
17	22.356	24.408	27.114	29.166
18	23.022	25.134	27.924	30.036
19	23.736	25.914	28.788	30.966
20	24.498	26.742	29.712	31.956
21	25.308	27.63	30.696	33.018
22	26.184	28.584	31.758	34.158
23	27.126	29.616	32.904	35.388
24	28.146	30.726	34.134	36.714
25	29.244	31.926	35.472	38.154
26	30.444	33.234	36.924	39.714
27	31.752	34.662	38.508	41.418
28	33.18	36.222	40.242	43.284
29	34.752	37.938	42.15	45.336
30	36.486	39.828	44.25	47.598
31	38.406	41.928	46.584	50.106
32	40.554	44.274	49.188	52.908
33	42.96	46.902	52.104	56.046
34	45.678	49.866	55.404	59.592
35	48.768	53.244	59.154	63.624
36	52.314	57.114	63.456	68.25

Rain Duration (min)	Rainfall Intensity (mm/min) 10 years	20 years	50 years	100 years
37	56.418	61.59	68.43	73.602
38	61.218	66.828	74.25	79.86
39	66.894	73.026	81.132	87.264
40	73.698	80.46	89.388	96.15
41	81.996	89.514	99.456	106.974
42	92.298	100.764	111.948	120.414
43	105.378	115.044	127.818	137.478
44	122.454	133.68	148.524	159.75
45	145.5	158.838	176.478	189.816
46	177.99	194.31	215.88	232.2
47	226.476	247.236	274.692	295.452
48	304.758	332.7	369.642	397.584
49	248.208	270.972	301.056	323.814
50	207.906	226.974	252.174	271.236
51	177.99	194.31	215.88	232.2
52	155.046	169.26	188.052	202.266
53	136.98	149.544	166.146	178.704
54	122.454	133.68	148.524	159.75
55	110.55	120.69	134.088	144.222
56	100.65	109.878	122.076	131.304
57	92.298	100.764	111.948	120.414
58	85.176	92.988	103.308	111.12
59	79.038	86.286	95.868	103.11
60	73.698	80.46	89.388	96.15
61	69.018	75.348	83.718	90.042
62	64.89	70.836	78.702	84.654
63	61.218	66.828	74.25	79.86
64	57.93	63.246	70.266	75.576
65	54.984	60.024	66.684	71.73
66	52.314	57.114	63.456	68.25
67	49.896	54.474	60.522	65.094
68	47.694	52.068	57.846	62.22
69	45.678	49.866	55.404	59.592
70	43.83	47.85	53.16	57.18
71	42.126	45.99	51.096	54.96
72	40.554	44.274	49.188	52.908
73	39.096	42.684	47.418	51.006

Rain Duration (min)	Rainfall Intensity (mm/min) 10 years	20 years	50 years	100 years
74	37.746	41.202	45.78	49.242
75	36.486	39.828	44.25	47.598
76	35.31	38.544	42.828	46.062
77	34.212	37.344	41.49	44.628
78	33.18	36.222	40.242	43.284
79	32.214	35.166	39.072	42.024
80	31.302	34.17	37.968	40.836
81	30.444	33.234	36.924	39.714
82	29.634	32.352	35.946	38.658
83	28.866	31.518	35.016	37.662
84	28.146	30.726	34.134	36.714
85	27.456	29.976	33.3	35.82
86	26.802	29.262	32.514	34.968
87	26.184	28.584	31.758	34.158
88	25.596	27.942	31.044	33.39
89	25.032	27.324	30.36	32.658
90	24.498	26.742	29.712	31.956
91	23.982	26.184	29.088	31.29
92	23.49	25.644	28.494	30.648
93	23.022	25.134	27.924	30.036
94	22.572	24.642	27.378	29.448
95	22.146	24.174	26.856	28.89
96	21.732	23.724	26.358	28.35
97	21.336	23.292	25.878	27.834
98	20.952	22.872	25.416	27.336
99	20.586	22.476	24.966	26.856
100	20.232	22.086	24.54	26.394
101	19.89	21.714	24.126	25.95
102	19.566	21.36	23.73	25.524
103	19.248	21.012	23.346	25.11
104	18.942	20.682	22.974	24.714
105	18.648	20.358	22.62	24.33
106	18.36	20.046	22.272	23.958
107	18.084	19.746	21.936	23.598
108	17.82	19.452	21.612	23.25
109	17.562	19.17	21.3	22.914

Rain Duration (min)	Rainfall Intensity (mm/min)			
	10 years	20 years	50 years	100 years
110	17.31	18.9	21	22.584
111	17.07	18.636	20.706	22.266
112	16.836	18.378	20.418	21.96
113	16.608	18.132	20.142	21.666
114	16.386	17.886	19.872	21.378
115	16.17	17.652	19.614	21.096
116	15.96	17.424	19.362	20.826
117	15.762	17.202	19.116	20.562
118	15.564	16.986	18.876	20.304
119	15.372	16.782	18.642	20.052
120	15.186	16.578	18.414	19.806

Table 4-1 Precipitation time series
Source: Self-drawn by the author

4. 2 Rainwater Corridor Analysis

4. 2. 1 Analysis Method and Workflow

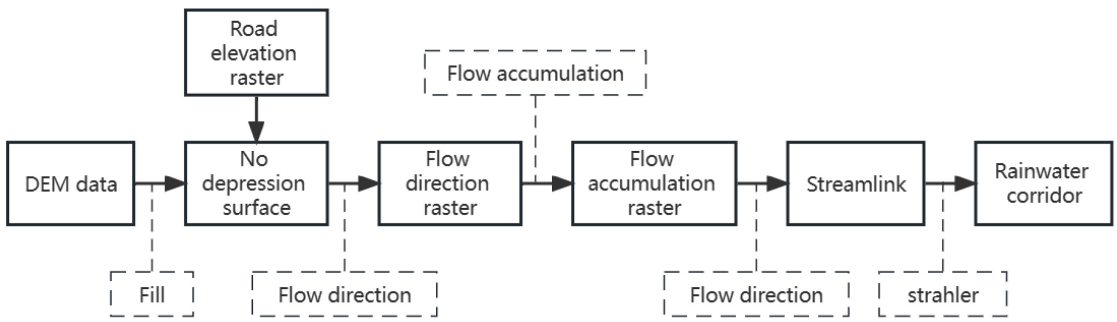

Figure 4-7 Workflow of rainwater corridor analysis
Source: Self-drawn by the author

In this study, ArcGIS hydrological analysis module was used to analyze the potential rainwater ecological corridors within the design area. Firstly, the original terrain map was analyzed for depression filling and the Fill tool was used to create a depression-free shaped surface[36].

[36] Hu Xi. Developing aqua-green ecological corridor network based on rainstorm and flood security [D].Hunan University,2020.DOI:10.27135/d.cnki.ghudu.2020.004019.

Since the design site of this paper is based on the detailed control plan of Haizhu Innovation Bay, the influence of the small height difference between the road and the surrounding plots on the analysis results should be considered in the hydrological analysis. Therefore, before flow analysis, it is necessary to adjust the terrain based on the depression-free surface combined with the height difference of the road. The operation tool mainly uses the raster calculator tool, and the processing process and results are shown in the figure.

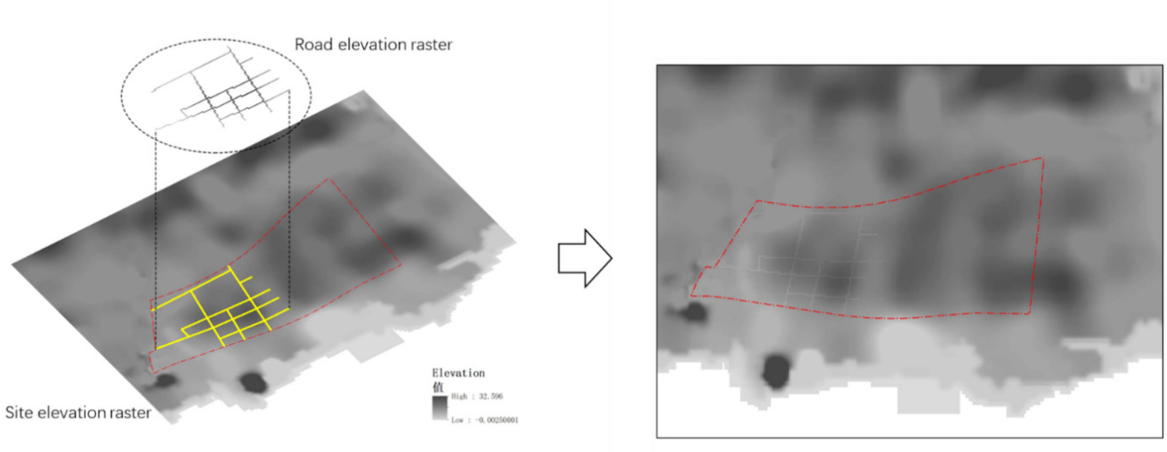

Figure 4-8 DEM data adjustment

Source: Self-drawn by the author

Next, use the Flow direction tool in ArcGIS hydrology module to create the flow direction raster of surface runoff, and then use the Flow accumulation tool to calculate the flow accumulation of the flow direction raster formed by the above operation one by one to generate the flow accumulation matrix, that is, the flow raster of surface runoff. On this basis, the stream link tool was used to set the cumulative threshold of water flow to extract high sink image elements to generate the sink network, and after several times of debugging, 132 was set as the flow threshold for this study to obtain the rainwater sink corridor.

4. 2. 2 Rainwater Corridor Extraction

The results after using Strahler method to classify the rainwater corridor levels are shown in the figure. The level of the corridor indicates the direction of runoff, and there are four levels of corridors in the design scope. The level of the corridor can indicate the flow direction of runoff, for example, in the figure below, runoff originates from the end of the primary corridor and flows through the second, third or fourth level corridor in order. At the same time, the higher the level of the corridor indicates the higher the volume of runoff accumulation. The rainwater corridors within Lijiao Village are Level 1 and Level 2 corridors, which basically coincide with Lijiao River, but the location is slightly deviated due to the accuracy of the model. All levels of rainwater corridors exist outside of the Village, with parks and public green spaces having higher levels of rainwater corridors, mainly Level 3 and Level 4 corridors, and roads having lower levels of potential rainwater corridors, with only some sections having Level 1 and Level 2 corridors.

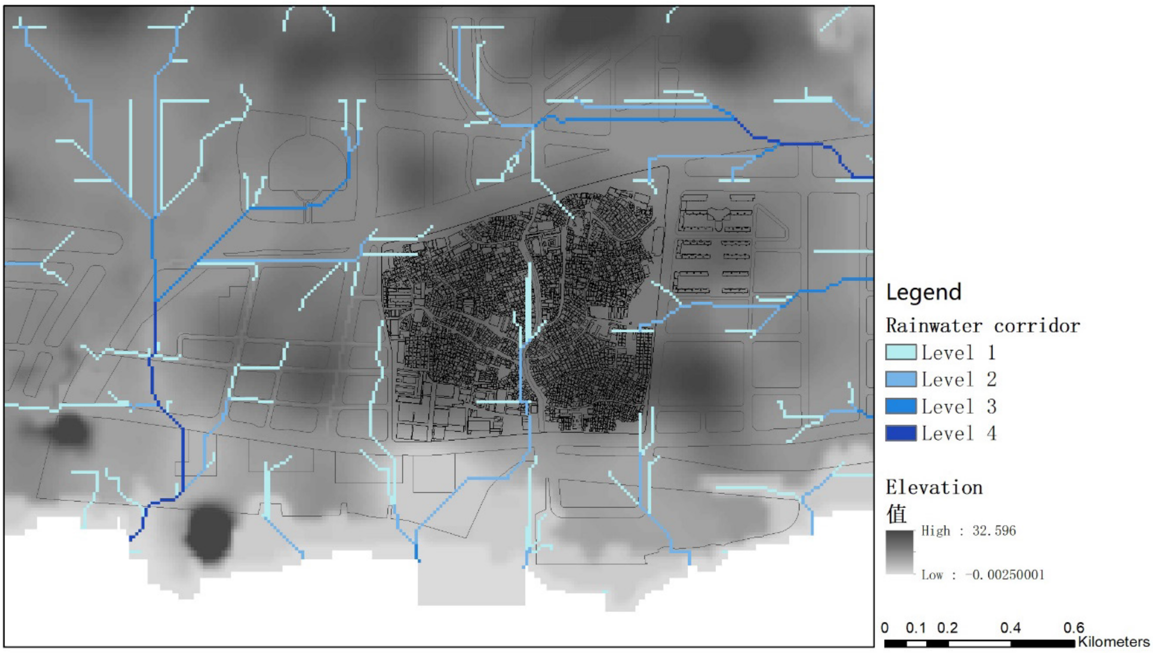

Figure 4-9 Classification rainwater corridor
Source: Self-drawn by the author

4. 3 Urban Spatial Inundation Analysis Based on SCS-CN Model

4. 3. 1 Introduction of SCS-CN Model

The SCS-CN model is a small watershed flow production model proposed by the USDA Soil Conservation Service in the 1950s. Flow production is the process by which storm water forms runoff after infiltration, depression filling, and evaporation. The model considers the influence of underlying surface conditions on runoff generation, has a simple structure and few input parameters, and is suitable for runoff simulation in watersheds of different scales, and has been widely used at home and abroad[37]. The basic principle of SCS flow production model is the rainfall runoff relationship and water balance equation considering the underlying surface conditions. The USDA Soil Conservation Service has analyzed the rainfall-runoff relationship in the SCS model, Equation (4-3), through extensive research data.

$$\frac{F}{S}=\frac{Q}{P-I_a} \tag{4-3}$$

Where: P is precipitation (mm); Q is runoff volume (mm); I_a is initial rainfall loss (mm); F is late rainfall loss (mm); S is the maximum possible retention in the watershed, i.e., the upper limit of late loss[38].

According to the principle of water balance: the amount of precipitation is equal to the sum of the runoff volume and the initial loss of rainfall and the later loss, if the rainfall does not reach the initial loss, then no runoff is generated, and the formula of flow production (4-4) is obtained.

$$Q=\frac{(P-I_a)^2}{P+S-I_a}, P > I_a \tag{4-4}$$

The initial loss amount I_a is not easy to find in the process of stream production flow, the empirical relation I_a= 0.2 S is introduced, and the final production flow formula is shown in Equation (4-5)

$$Q=\frac{(P-0.2S)^2}{P+0.8S}, P > 0.2S \tag{4-5}$$

The maximum possible retention in the basin S is related to the causeless parameter CN (Curve Number). CN is a comprehensive parameter reflecting the characteristics of the watershed before precipitation and is related to the degree of pre-wetness, slope, vegetation, soil type and land use status. According to the CN value matrix established in the study of CN values in the SCS model in the relevant literature and the results of remote sensing classification of land use in the region, the CN values of different types of land use can be determined, and the relationship between S and CN values is shown in Equation (4-6)

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[37] Wu Ankun, Huang Yu, Zhang Shuxia. Risk assessment of urban flooding based on SCS model[J].J. of Institute of Disaster Prevention ,2020,22(02):50-57.

[38] Zhang Xiaohan, Sang Guoqing. SCS-CN Application of SCS-CN Model in Runoff Calculation of Small Watershed[J].YELLOW RIVER,2022,44(05):35-39+45.

$$S=\frac{25400}{CN}-254 \tag{4-6}$$

4. 3. 2　Analysis Method and Workflow

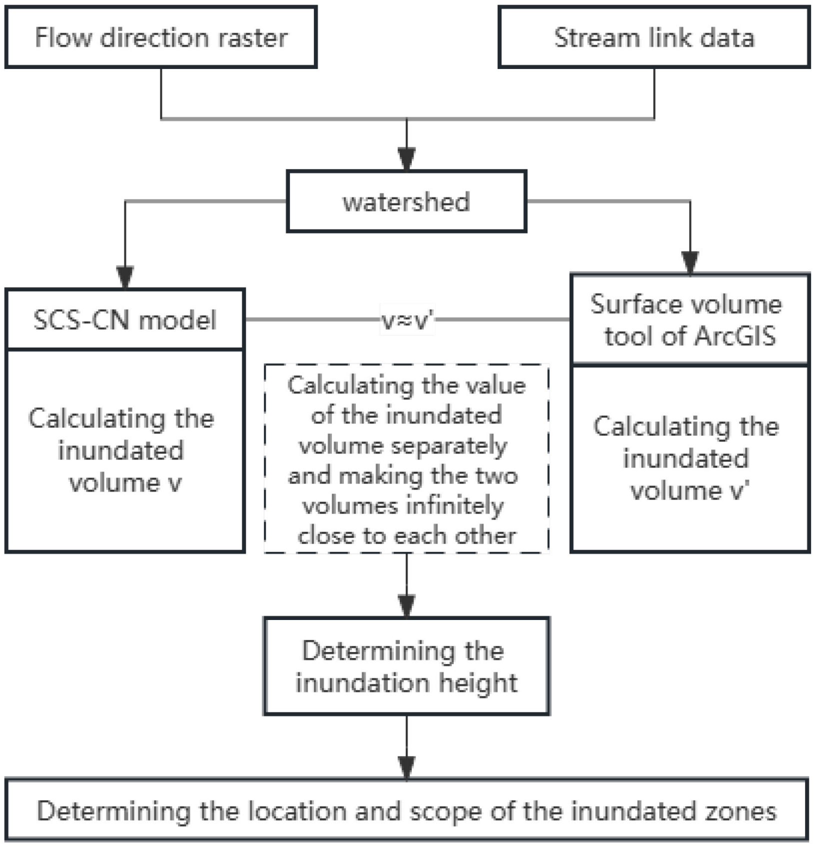


Figure 4-10 Workflow of inundation ananlysis
Source: Self-drawn by the author

In this paper, the coupled SCS-CN model and ArcGIS is used for urban spatial inundation analysis. First create a watershed involving the design area based on the flow direction raster and stream link data obtained in the previous analysis as shown in the figure[39]; Calculation of inundation volume values for each watershed under different return periods of precipitation by SCS-CN model; The Surface volume tool is used to calculate the inundation elevation of each watershed under different return periods of precipitation, after continuously adjusting the value

[39] DING Siyuan，WANG Ning，NI Lili，et al. Study on the Inundation Risk of Disaster Space in the Min Delta Urban Agglomeration based on SCS-CN and GIS Coupling Model[J]. Journal of Catastrophology，2022，37（1）：171-177. doi：10.3969/j. issn.1000-811X.2022.01.029.

of the converging reference inundation volume; Finally, the location and scope of the inundation areas within the design area were determined.

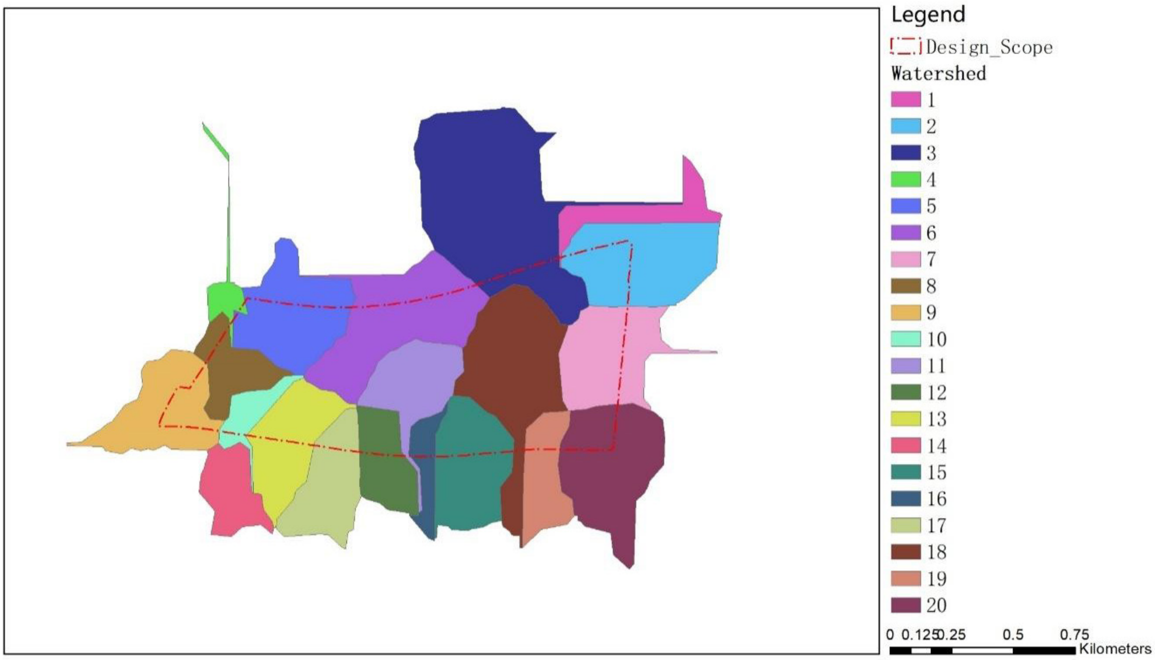


Figure 4-11 Watersheds related to the design scope
Source: Self-drawn by the author

4. 3. 3 Determination of CN Value

Before using the SCS-CN model for runoff simulation, the CN value of each watershed parameter should be determined first. The CN value determination method used in this paper is the table search method, which is based on the CN value retrieval table provided by SCS to determine the CN value based on soil texture and land use.

The SCS model is divided into four hydrological soil groups, A (permeable), B (more permeable), C (less permeable), and D (impermeable), based on soil water infiltration capacity and soil texture structure as shown in Table[40]. The soil texture in the study area of this paper is mainly loam, which corresponds to the CN value of group B of the hydrological soil group.

[40] Barrales V , Sf L . SCS - NATIONAL ENGINEERING HANDBOOK. 1971.

Hydrologic Soil Class	Soil Texture	Final Infiltration Rate (mm/h)
A	Sandy, Loamy sandy, Sandy loam	> 7.5
B	Loam, Silty loam	3.8-7.5
C	Sandy clay loam	1.3-3.8
D	Clay loam, Silty clay loam, Clay, Silty clay, Sandy clay	< 1.3

Table 4-2 CN value search table
Source: Self-drawn by the author

This paper is based on the classification and determination of CN values for grasslands, waterbody, city and buildings in the global land cover dataset (UMD) constructed by the University of Maryland, USA, as well as the green space ratio requirements for different land uses in the Guangzhou Greening Ordinance and the Guangzhou Urban and Rural Planning Technical Regulations[41]. The CN values corresponding to the land use associated with this study were obtained by weighting the percentage of green space and buildings in a single plot and the corresponding CN values. The green space ratio and its CN value for Lijiao Village and other land uses are shown in Table.

Classification in UMD	Hydrologic Soil Group			
	A	B	C	D
Grassland	30	58	71	78
City and Building	81	88	91	93
Waterbody	99			

Table 4-3 CN value in UMD
Source: Bibliography

Land use and Lijiao Village	Green Space Ratio	CN
Administrative	35%	77
Business	10%	85
Commercial	10%	85
Commercial And Residential	15%	83
Education And Research	40%	76
Green Space	100%	58
Hospital	40%	76

[41] Wang Jiahu, Liang Juping, Li Li, Wu Chen, Luo Jiaxi, Liu Yubing. Calculation of field flood totals in watersheds without historical measured runoff data using the SCS model[J]. China Rural Water and Hydropower, 2017(12):70-74+80.

Land use and Lijiao Village	Green Space Ratio	CN
Lijiao Village	25%	80
Leisure And Entertainment	35%	77
Park	95%	58
Public Service	40%	76
Residential	30%	79
Road	15%	83
School	40%	76
Waterbody	0%	99

Table 4-4 Land use and green space ratio of design scope
Source: Self-drawn by the author

Finally, by combining the vector data of watersheds and land use using the joint tool of ArcGIS, the area and percentage of land use in each watershed can be obtained, and then the final CN value of the watershed can be obtained by weighting process as shown in Table.

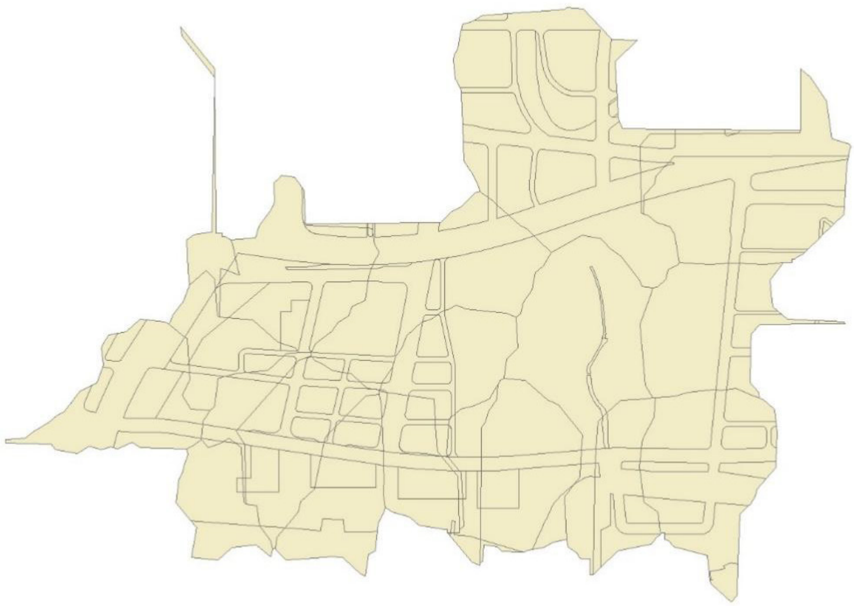


Figure 4-12 Land use in each watersheds
Source: Self-drawn by the author

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
1	66780.92	Road	60097.42	89.99%	81

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijiao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
		Administrative	4238.86	6.35%	
		Residential	168.79	0.25%	
		Green Space	1943.68	2.91%	
		Lijiao Village	332.15	0.50%	
2	181571.95	Road	64483.60	35.51%	78
		Residential	35937.79	19.79%	
		Residential	564.34	0.31%	
		Residential	6368.95	3.51%	
		Green Space	138.20	0.08%	
		Green Space	22594.94	12.44%	
		Lijiao Village	51484.12	28.35%	
3	384871.67	Road	126805.17	32.95%	79
		Park	81.96	0.02%	
		Waterbody	1277.02	0.33%	
		Park	180.10	0.05%	
		Residential	5777.37	1.50%	
		Park	20408.39	5.30%	
		Waterbody	24367.68	6.33%	
		School	28661.15	7.45%	
		Administrative	7725.35	2.01%	
		Residential	21918.34	5.69%	
		Residential	8851.03	2.30%	
		Residential	30830.53	8.01%	
		Residential	21809.82	5.67%	
		Residential	1463.14	0.38%	
		Residential	539.00	0.14%	
		School	25673.52	6.67%	
		Green Space	5598.04	1.45%	
		Lijiao Village	52904.08	13.75%	
4	26703.07	Road	24694.46	92.48%	82
		Road	1087.61	4.07%	
		Green Space	920.99	3.45%	
5	158971.25	Road	55143.46	34.69%	76
		Residential	5869.09	3.69%	
		Green Space	333.93	0.21%	
		Road	34113.61	21.46%	
		School	19036.31	11.97%	
		Leisure And Entertainment	9436.63	5.94%	

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijiao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
		Park	21882.28	13.76%	
		Green Space	3270.14	2.06%	
		Green Space	9885.80	6.22%	
6	212372.69	Road	44629.54	21.01%	79
		Residential	808.12	0.38%	
		Residential	10418.70	4.91%	
		Residential	5580.91	2.63%	
		Residential	2005.42	0.94%	
		Green Space	227.20	0.11%	
		Road	31591.19	14.88%	
		Residential	510.17	0.24%	
		Residential	25.32	0.01%	
		Residential	2760.89	1.30%	
		Public Service	8022.13	3.78%	
		School	42416.60	19.97%	
		Park	5250.41	2.47%	
		Green Space	1155.91	0.54%	
		Lijiao Village	56970.07	26.83%	
7	148703.31	Road	16621.06	11.18%	80
		Residential	16972.76	11.41%	
		Residential	11161.46	7.51%	
		Residential	661.96	0.45%	
		Business	8049.84	5.41%	
		Lijiao Village	95236.21	64.04%	
8	73460.47	Road	13419.98	18.27%	68
		Road	6707.64	9.13%	
		Leisure And Entertainment	837.02	1.14%	
		Education And Research	5355.99	7.29%	
		Hospital	10458.63	14.24%	
		Park	26757.06	36.42%	
		Green Space	9971.49	13.57%	
9	137858.50	Road	80748.68	58.57%	74
		Commercial	3.93	0.00%	
		Park	11534.60	8.37%	
		Green Space	5868.34	4.26%	
		Green Space	6550.92	4.75%	
		Road	1663.30	1.21%	

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijiao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
		Hospital	11281.12	8.18%	
		Park	30.18	0.02%	
		Green Space	17115.92	12.42%	
		Green Space	3061.50	2.22%	
10	38760.45	Road	5000.54	12.90%	76
		Business	284.10	0.73%	
		Park	2235.39	5.77%	
		Road	4443.52	11.46%	
		Education And Research	4114.92	10.62%	
		Hospital	22729.33	58.64%	
11	105931.94	Road	865.46	0.82%	80
		Business	1068.76	1.01%	
		Park	1171.91	1.11%	
		Road	22894.72	21.61%	
		Residential	9719.28	9.18%	
		Residential	7968.88	7.52%	
		Residential	6400.56	6.04%	
		Residential	113.17	0.11%	
		Business	3278.31	3.09%	
		Public Service	605.72	0.57%	
		Lijiao Village	51845.18	48.94%	
12	79885.35	Road	9218.24	11.54%	76
		Business	17522.54	21.93%	
		Park	21812.31	27.30%	
		Road	13844.86	17.33%	
		Residential	6301.54	7.89%	
		Residential	1187.76	1.49%	
		Business	9998.09	12.52%	
13	122073.61	Road	13837.26	11.34%	75
		Business	2365.66	1.94%	
		Business	13016.57	10.66%	
		Park	30104.34	24.66%	
		Road	19721.81	16.16%	
		Residential	5503.73	4.51%	
		Residential	10108.63	8.28%	
		Residential	5501.67	4.51%	
		Commercial And Residential	125.64	0.10%	

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijiao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
		Commercial And Residential	7546.78	6.18%	
		Public Service	630.22	0.52%	
		Education And Research	505.90	0.41%	
		Hospital	13105.39	10.74%	
14	71213.78	Road	21204.83	29.78%	65
		Business	877.10	1.23%	
		Park	49131.85	68.99%	
15	138480.72	Road	25219.48	18.21%	74
		Business	14264.11	10.30%	
		Park	44055.16	31.81%	
		Lijiao Village	54941.97	39.67%	
16	39734.63	Road	8932.03	22.48%	75
		Business	1443.95	3.63%	
		Business	1171.65	2.95%	
		Park	9784.64	24.62%	
		Road	2093.27	5.27%	
		Residential	9.87	0.02%	
		Business	1022.17	2.57%	
		Lijiao Village	15277.05	38.45%	
17	111020.11	Road	39671.14	35.73%	75
		Business	15970.85	14.39%	
		Park	34912.08	31.45%	
		Road	4244.89	3.82%	
		Residential	5581.71	5.03%	
		Commercial And Residential	10472.30	9.43%	
		Commercial And Residential	167.14	0.15%	
18	216897.83	Road	22903.03	10.56%	80
		Park	2202.48	1.02%	
		Lijiao Village	187563.62	86.48%	
		Waterbody	1639.36	0.76%	
		Waterbody	2589.36	1.19%	
19	78857.00	Road	35065.46	44.47%	75
		Park	11803.35	14.97%	
		Park	7539.25	9.56%	
		Park	552.51	0.70%	

Watershed	Area of Watershed (m^2)	Type of Landuse & Lijao Village	Area of Landuse in Watershed(m^2)	Percentage of Landuse in Watershed	CN
		Park	1375.16	1.74%	
		Lijiao Village	20849.78	26.44%	
		Waterbody	1671.48	2.12%	
20	185854.22	Road	77806.92	41.86%	75
		Park	25102.14	13.51%	
		Park	12141.04	6.53%	
		Business	9419.34	5.07%	
		Business	1029.46	0.55%	
		Business	12756.25	6.86%	
		Park	7095.19	3.82%	
		Park	6031.74	3.25%	
		Lijiao Village	34472.13	18.55%	

Table 4-5 CN value for each watersheds

Source: Self-drawn by the author

4. 3. 4 Inundation Volume and Elevation Calculation

In this paper, we use the surface volume tool of ArcGIS to obtain the inundation elevation of each watershed by back-propagating the inundation volume calculated by the SCS-CN model in the following steps.

(1) First, the CN value of each watershed is substituted into equation (4-6) to obtain the maximum possible retention S in the watershed, and then the results obtained and the rainfall for the 10, 20, 50 and 100 years return periods are brought into equation (4-5) to obtain the runoff volume Q for each watershed as shown in the table;

(2) According to the relationship between runoff rate and inundation volume (4-7), the value of inundation volume for each watershed can be found in the table;

$$Q*A=V \tag{4-7}$$

Where: Q is the runoff volume (mm); A is the area of the watershed (m^2); V is the inundation volume (m^3)

(3) Finally, the surface volume algorithm in ArcGIS software is used for the proportional calculation, and its mechanism of action is to calculate the passive inundation volume and

determine the inundation elevation in the three-dimensional geographic space, as shown in figure. By debugging the input elevation information several times, the final inundation elevations for each catchment area under 10, 20, 50 and 100 years return periods were determined as shown in the table.

Watershed	Potential maximum retention (S) (mm)	Total rainfall (P) (mm)				Actual amount of direct surface runoff (Q) (mm)			
		10 years	20 years	50 years	100 years	10 years	20 years	50 years	100 years
1	59.58					50.12	57.60	67.73	75.53
2	71.64					44.36	51.46	61.11	68.60
3	67.52					46.24	53.46	63.28	70.88
4	55.76					52.13	59.73	70.00	77.91
5	80.21					40.74	47.55	56.88	64.13
6	67.52					46.24	53.46	63.28	70.88
7	63.50					48.16	55.51	65.49	73.19
8	119.53					27.79	33.42	41.28	47.51
9	89.24					37.27	43.80	52.78	59.79
10	80.21	97.09	106.00	117.77	126.67	40.74	47.55	56.88	64.13
11	63.50					48.16	55.51	65.49	73.19
12	80.21					40.74	47.55	56.88	64.13
13	84.67					38.98	45.66	54.81	61.94
14	136.77					23.55	28.71	35.98	41.78
15	89.24					37.27	43.80	52.78	59.79
16	84.67					38.98	45.66	54.81	61.94
17	84.67					38.98	45.66	54.81	61.94
18	63.50					48.16	55.51	65.49	73.19
19	84.67					38.98	45.66	54.81	61.94
20	84.67					38.98	45.66	54.81	61.94

Table 4-6 Potential maximum retention and Actual amount of direct surface runoff

Source: Self-drawn by the author

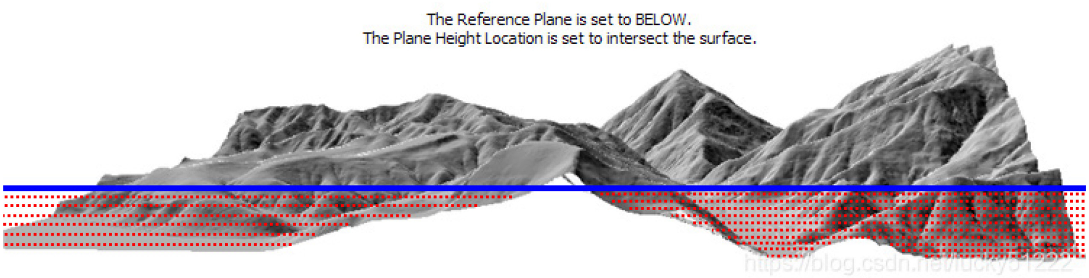


Figure 4-13 Principle of inundated volume calculation

Source: https://pro.arcgis.com/zh-cn/pro-app/2.6/tool-reference/3d-analyst/surface-volume.htm

Watershed	Area of Watershed(m^2)	When the return period is 10 years		When the return period is 20 years		When the return period is 50 years		When the return period is 100 years	
		Inundated volume (m^3)	Inundated elevation (m)	Inundated volume (m^3)	Inundated elevation (m)	Inundated volume (m^3)	Inundated elevation (m)	Inundated volume (m^3)	Inundated elevation (m)
1	66780.92	3347.08	4.22	3846.72	4.27	4522.89	4.34	5044.24	4.4
2	181571.95	8055.39	5.93	9342.84	5.99	11096.11	6.06	12455.02	6.11
3	384871.67	17796.64	6.32	20576.99	6.4	24355.17	6.49	27278.30	6.55
4	26703.07	1391.92	6.15	1595.02	6.17	1869.33	6.2	2080.48	6.22
5	158971.25	6476.11	4.99	7559.55	5.05	9041.63	5.11	10194.64	5.16
6	212372.69	9820.21	6.95	11354.41	7	13439.22	7.06	15052.20	7.11
7	148703.31	7161.36	8.26	8255.01	8.31	9738.05	8.37	10883.47	8.42
8	73460.47	2041.82	4.4	2455.33	4.45	3032.77	4.51	3489.78	4.56
9	137858.5	5138.23	4.6	6038.49	4.65	7275.81	4.71	8242.23	4.74
10	38760.45	1579.01	4.09	1843.17	4.13	2204.53	4.18	2485.66	4.21
11	105931.94	5101.54	7.47	5880.63	7.62	6937.11	7.72	7753.07	7.78
12	79885.35	3254.34	1.84	3798.78	1.93	4543.55	2.05	5122.96	2.15
13	122073.61	4759.02	3.04	5573.74	3.1	6690.81	3.18	7561.56	3.24
14	71213.78	1677.23	0.95	2044.63	1.02	2562.37	1.1	2975.24	1.16
15	138480.72	5161.42	-0.85	6065.74	-0.77	7308.65	-0.67	8279.43	-0.6
16	39734.63	1549.05	-0.59	1814.24	-0.53	2177.84	-0.45	2461.27	-0.4
17	111020.11	4328.10	0.3	5069.05	0.4	6084.97	0.53	6876.88	0.62
18	216897.83	10445.52	2.26	12040.71	2.39	14203.87	2.56	15874.57	2.68
19	78857	3074.23	1.63	3600.52	1.67	4322.12	1.74	4884.61	1.78
20	185854.22	7245.50	3.03	8485.89	3.25	10186.60	3.56	11512.30	3.79

Table 4-7 Inundated volume and elevation of rainfall for four return periods

Source: Self-drawn by the author

4. 3. 5 Spatial Location and Extent of Inundation Area

The spatial analysis tool of ArcGIS was used to analyze the inundation extent generated by different return periods to obtain the design range inundation extent distribution, and the results are shown in figure. As can be seen from the figure, the inundation areas within the design area are mainly located in the public green space and park parcels in the west, the commercial and residential parcels in the middle and close to Lijiao Village, and the eastern part within Lijiao Village. The inundation area of the western park and greenbelt parcel is large and the spatial pattern of the inundation area as shown basically matches the pattern of the rainwater corridor; The extent of the inundation zone for the central commercial and residential parcels is more clearly differentiated between the extent boundaries when experiencing 10 years return period and 50 years return period stormwater; The inundation area in Lijiao Village is located in an open space within the village and the contours of the inundation area are roughly the same as the contours of the surrounding building fabric, reflecting the siting of the village away from flooding.

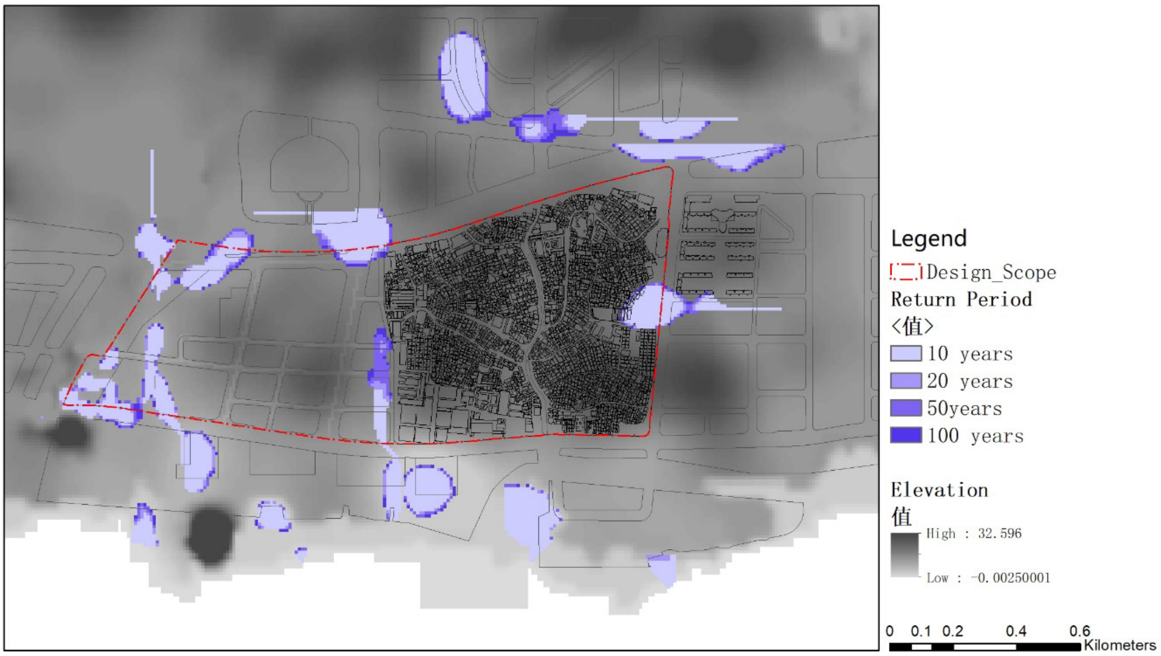


Figure 4-14 Spatial location and range of inundation area
Source: Self-drawn by the author

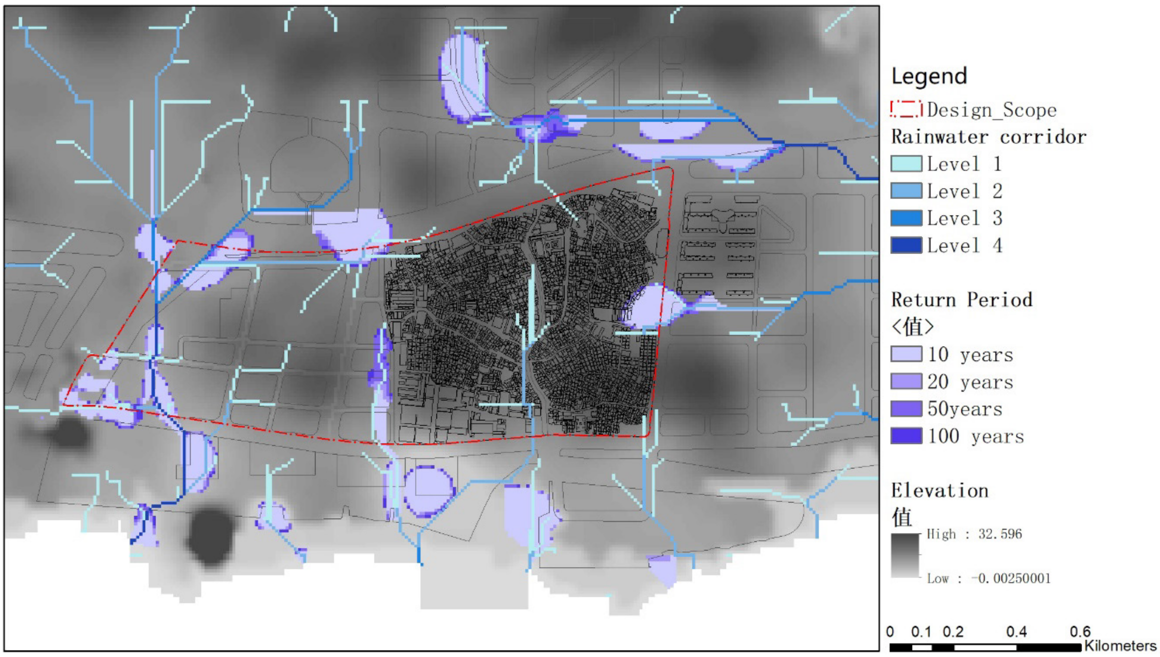


Figure 4-15 Relationship between inundated area and rainwater corridor
Source: Self-drawn by the author

4.4 Flood Risk Assessment Based on SWMM Model

4.4.1 Introduction of SWMM software

SWMM (Storm Water Management Model) is a dynamic precipitation-runoff simulation model developed by the EPA (Environmental Protection Agency). Since its development in 1971, it has been developed to SWMM version 5.2.2. This stormwater modeling software can both dynamically simulate pipe network runoff and single or continuous water quality and quantity, and is more frequently used in the planning and design stages[42]. It can better quantify the data on the flood resilience of the study target area, according to which the changes and comparisons of the data related to the regional flood resilience before and after the optimization measures are taken can be analyzed and summarized in the later stage to find out the specific research results and the effect of regional flood resilience improvement.

4.4.2 Model Parameters Supplement

[42] Wang Rui. Construction and simulation of drainage pipe network model based on SWMM model in a Feihe area of Hefei City [D].Anhui Jianzhu University,2021.DOI:10.27784/d.cnki.gahjz.2021.000425.

The data required for SWMM model simulations can be divided into two categories: hydrological parameters and hydraulic parameters. Most of the hydraulic parameters are deterministic parameters, with a clear physical meaning, can be obtained through direct measurement or experimental calculations, such as conduit length and section, conduit slope, junction depth and other specific spatial physical parameters. Most of the hydrological parameters are experiential parameters with vague physical meanings. It is necessary to clarify the basic thresholds based on their characterized physical meanings, and then rate them based on the actual measured data of the project experiments, such as the descriptive characteristic physical parameters of imperviousness and roughness of the underlying surface[43].

In the specific modeling process, SWMM requires three main types of data: junction data, conduit data and subcatchment data. Naming all conduits, junctions and subcatchments before creating the model helps to organize and modify the required parameters more intuitively. The names of the conduits, junctions and catchments are shown in the figure, with the letter L for the conduits, the letter J for the junctions and the letter S for the subcatchments.

[43] Tao Wenhua. Construction of SWMM model for urban stormwater and research on LID comprehensive effectiveness Evaluation Method[D].Wuhan Institute of Technology,2022.DOI:10.27727/d.cnki.gwhxc.2022.000538.

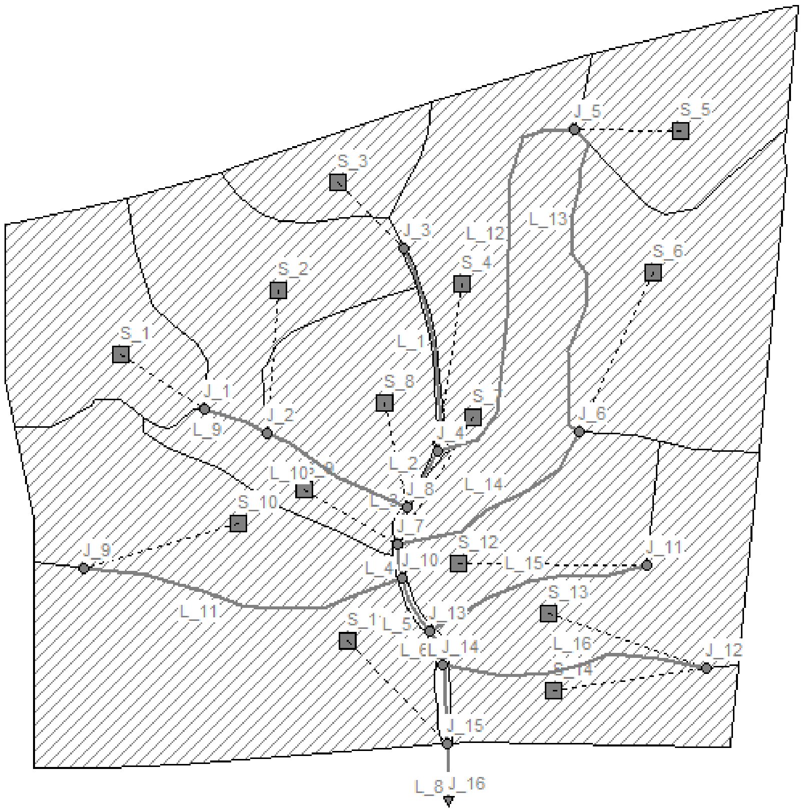


Figure 4-16 The names of the conduits, junctions and catchments
Source: Self-drawn by the author

(1) Junction and Conduit Parameters

The node and pipe data are mostly hydraulic parameters, which can usually be obtained by direct measurement from the CAD of the plan. The conduit module in the SWMM model can be used to simulate non-underground pipe network facilities such as rivers and ditches in the region, and the junction module mostly represents the connection between rainwater wells or pipe modules, as shown in figure. However, in the process of collecting relevant parameters, urban villages such as Lijiao Village have no unified planning of municipal pipe network facilities during the development process, except for Lijiao River for which more complete data are available, other conduits and junction data are more difficult to collect. This paper uses field research methods combined with historical information on the evolution of the water system in Lijiao Village to ensure the maximum restoration of the current situation of pipe networks and junctions in Lijiao Village in the absence of perfect information. The access to junctions and conduits data is shown in the table.

Classification of parameter	Parameter	Access Way
Junctions	Location	Historical Information and Field Research
	Initial Depth	Tide-Gauge Station
	Max Depth	Reference
Conduits	Location	Historical Information and Field Research
	Shape	Field Research
	Length	Calculation of ArcGIS tools, Historical Information and Field Research
	Inlet/Outlet Node	Historical Information
	Offset	Field Research
	Roughness	SWMM User's Manual

Table 4-8 Access Way of junction and conduit parameters
Source: Self-drawn by the author

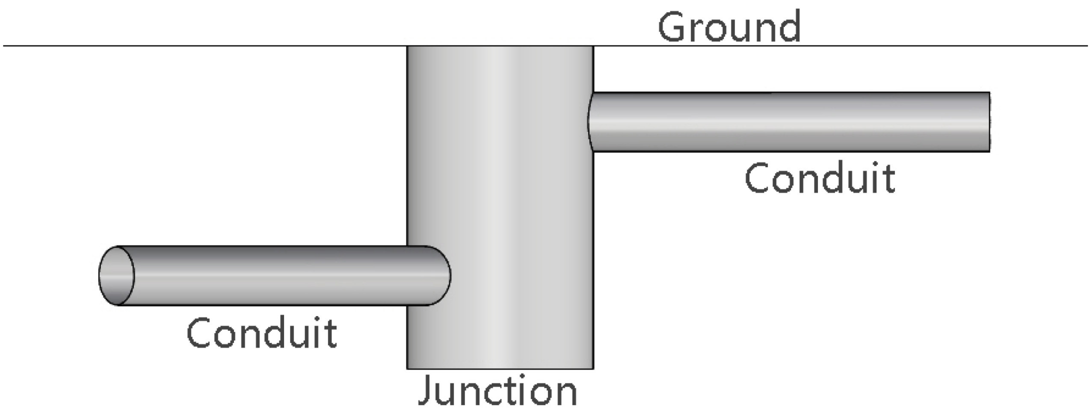


Figure 4-17 The relationship between conduit and junction
Source: Self-drawn by the author

The modeling location parameters of the junctions and conduits can be determined by referring to the past water system alignment. Lijiao Village is a typical Lingnan water village, the village was originally densely packed with rivers and surges that formed a perfect drainage system, but today, only the mainstream Lijiao River remains, and all other tributary surges have been filled in as part of the village roads. The field research found that in the past used to be the confluence of tributaries and Lijiao River still exists at the discharge of stormwater pipes, which can determine the junctions with Lijiao River, and can be roughly inferred that the current municipal pipe network and the past water system there is the possibility of overlap. Since the conduits and junctions in the SWMM model are only conceptual representations, changes in the location of some of the pipes will not have much effect on the final simulation results as long as the main conduits are identified. The location of the final conduits and junctions are shown in the figure.

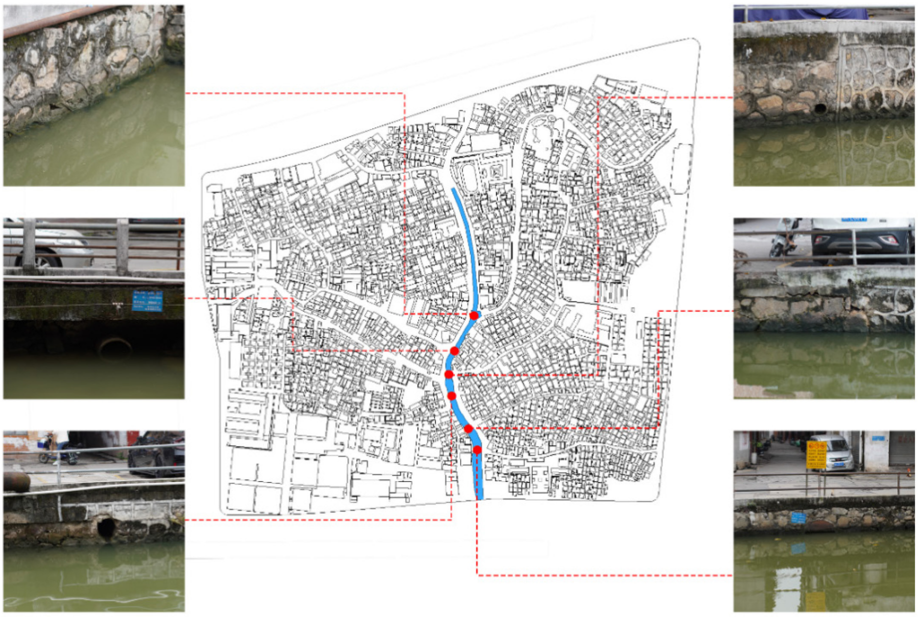


Figure 4-18 Existing pipe outfall in Lijiao Village
Source: Self-drawn by the author

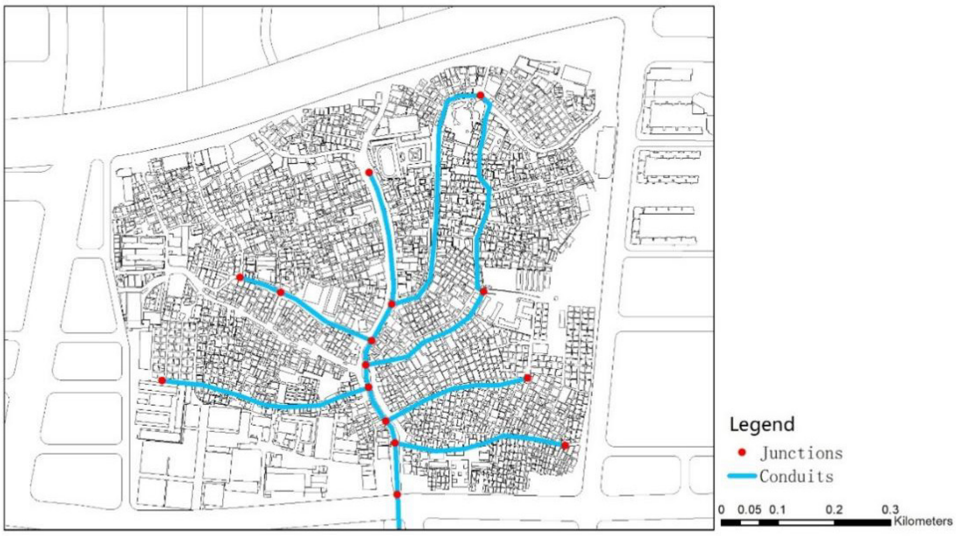


Figure 4-19 Location of conduits and junctions
Source: Self-drawn by the author

The initial depth of the junction is related to the height of the water level in the connected conduits. In the drainage system of Lijiao Village, only the water level height of Lijiao River exists, so only the node associated with Lijiao River has the initial depth, i.e., the water level height of Lijiao River. As Lijiao Chung is connected with the Pearl River back channel, so this paper selects the average value of the highest annual tide level of the Pearl River back channel measured by the Fubiaochang Station as the initial depth of the junctions.

Waterway		Pearl River Back Channel
Tide-Gauge Station		Fubiaochang Station
Years of data		1973-2011
High Tide Level (m)	Average Value	5.80
	Highest Value	7.66
Low Tide Level (m)	Average Value	4.41
	Lowest Value	2.80
Annual Maximum Tide Level (m)	Average Value	7.12
	Highest Value	7.53
Annual Minimum Tide Level (m)	Average Value	3.59
	Lowest Value	2.80

Table 4-9 Pearl River back channel water level
Source: Bibliography

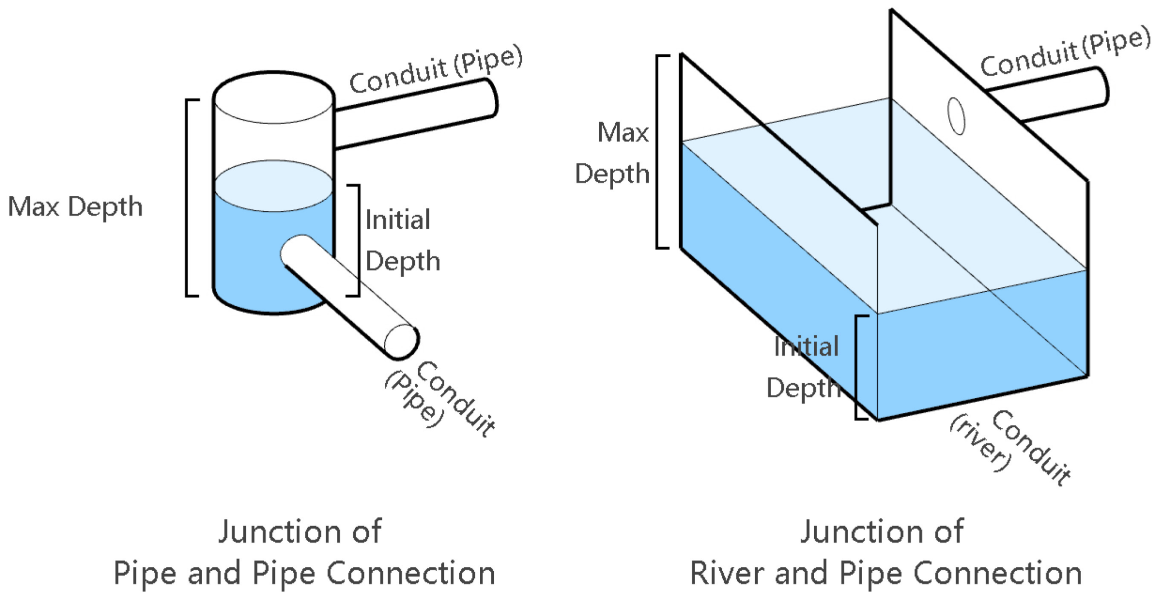


Figure 4-20 Schematic diagram of maximum depth and initial depth
Source: Self-drawn by the author

The maximum depth of the node is the depth of a rainwater well in a conventional underground pipe system, but express the connection between underground pipes and rivers when generally for the height of the river cross-section. According to the mapping results of the control line adjustment demonstration report of Lijiao River in Haizhu District, the section height of Lijiao River varies from 3 to 3.22 meters, mainly depending on the location of the section.

The shape of the conduit is the geometric information of the conduit in cross-section. The two main types of conduit involved in the flooding risk assessment for Lijiao Village are underground conduits and river channels. According to the mapping results of the report on the control line adjustment demonstration of Lijiao River in Haizhu District, the cross-sectional shape of Lijiao River is rectangular. In this paper, we use the junctions associated with Lijiao River, and divide Lijiao River into seven consecutive conduit sections, and calculate the average width of each conduit section as the modeling width parameter of the section. The section height parameter for each conduit section in the Lijiao River is the maximum depth of the upstream node of the conduit. As the L 8 pipe section is not part of the Lijiao River, its shape parameters need to be determined from DEM data and CAD topographic maps; According to field research observations, the underground conduits within the village of Lijiao are round in shape and range from 0.35 to 0.65 meters in diameter. The detailed shape parameters of each conduit are shown in the table.

Conduit	Shape of Conduit	Diameter (m)	Photos
L 1	Rectangular	3*6	None
L 2	Rectangular	3*7	None
L 3	Rectangular	3.16*10	None
L 4	Rectangular	3*12	None
L 5	Rectangular	3*11.3	None
L 6	Rectangular	3*14.5	None
L 7	Rectangular	3*16.8	None
L 8	Rectangular	3*37	None
L 9, L 10	Circular	0.5	

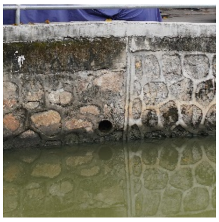
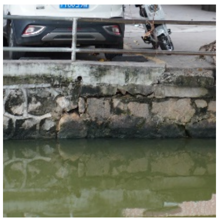
Conduit	Shape of Conduit	Diameter (m)	Photos
L 11	Circular	0.5	
L 12	Circular	0.35	
L 13, L 14	Circular	0.4	
L 15	Circular	0.45	
L 16	Circular	0.65	

Table 4-10 Detailed shape parameters of conduit section
Source: Self-drawn by the author

The length parameters of the conduit can be derived from the computational geometry tool in GIS after determining the location information, and all the length parameters of the conduit are shown in the table.

Conduit	Length (m)
L 1	240.2261215
L 2	73.69170094
L 3	46.17899278
L 4	39.61430439

Conduit	Length (m)
L 5	68.57851836
L 6	43.15975945
L 7	90.97585449
L 8	67.2846479
L 9	77.26764146
L 10	183.2527872
L 11	378.7454197
L 12	465.9027266
L 13	374.1449582
L 14	257.9383861
L 15	266.7620538
L 16	309.1902787

Table 4-11 Length parameters of the conduit

Source: Self-drawn by the author

The upstream and downstream node parameters of the conduits depend mainly on the runoff flow direction of the conduits. A check of local history reveals that the Lijiao River was in the past the mainstream of the entire Lijiao Village water system, collecting and discharging runoff from other branches into the Pearl River back channel. The elevation analysis of the topography of Lijiao Village shows that the elevations of the east and west banks of the river are significantly higher than the area where the Lijiao River is located, and the hydrological analysis in Section 4.2.2 also proves that there is a certain amount of flow in the area covered by the Lijiao River, so the runoff flow direction of the Lijiao Village drainage network can be deduced, and the upstream and downstream junction parameters of the network can be derived by combining the network and junction parameters, as shown in the table.

Conduit	Inlet Node	Outlet Node
L 1	J 3	J 4
L 2	J 4	J 8
L 3	J 8	J 7
L 4	J 7	J 10
L 5	J 10	J 13
L 6	J 13	J 14
L 7	J 14	J 15
L 8	J 15	J 16
L 9	J 1	J 2
L 10	J 2	J 8
L 11	J 9	J 10

Conduit	Inlet Node	Outlet Node
L 12	J 5	J 4
L 13	J 5	J 6
L 14	J 6	J 7
L 15	J 11	J 13
L 16	J 12	J 14

Table 4-12 Outlet and inlet parameters of the conduits
Source: Self-drawn by the author

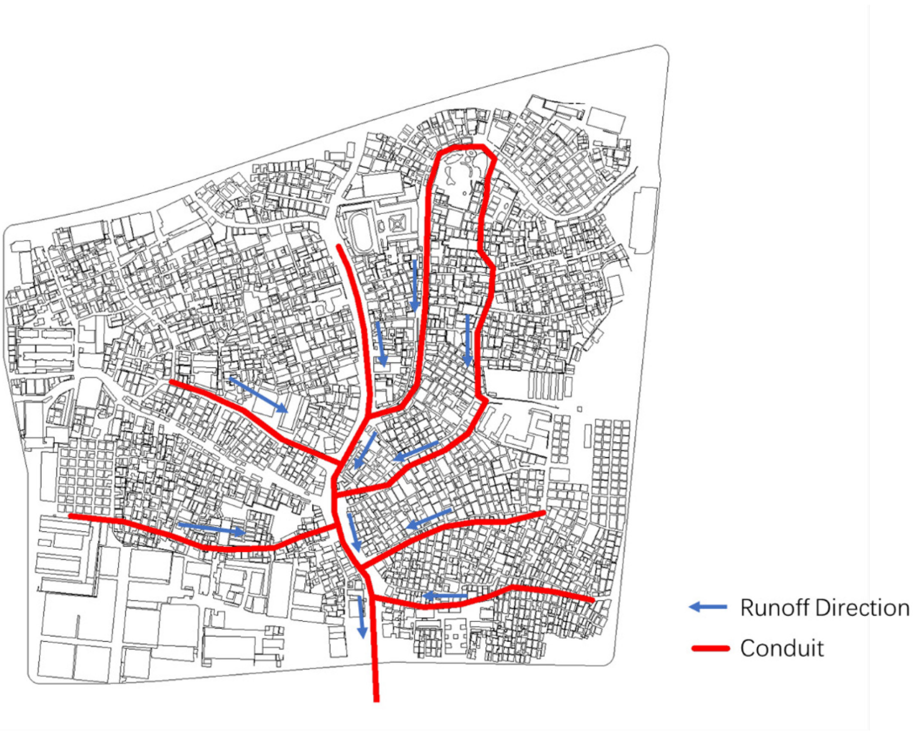


Figure 4-21 Flow direction of the drainage network
Source: Self-drawn by the author

The offset parameter of the conduit refers to the distance from the bottom of the conduit to the bottom of the upstream or downstream junction, and indicates the spatial relationship between the junction and the conduit in the vertical direction. Therefore when the conduit offset parameter is 0 and the height of the conduit shape is equal to the maximum depth of the node, it can be used for modelling of the river channel. According to the research and calculation, the required conduit offset parameters for this paper are shown in Table.

Conduit	Inlet Offset (m)	Outlet Offset (m)
L 1	0	0
L 2	0	0
L 3	0	0

Conduit	Inlet Offset (m)	Outlet Offset (m)
L 4	0	0
L 5	0	0
L 6	0	0
L 7	0	0
L 8	0	0
L 9	0	0
L 10	0	2.22
L 11	0	2
L 12	0	2
L 13	0	0
L 14	0	2.16
L 15	0	2
L 16	0	2

Table 4-13 Conduit offset parameters
Source: Self-drawn by the author

The roughness coefficient of the conduit is expressed by the Manning coefficient n, which is a coefficient to reflect the influence of the roughness of the wall of the conduit on the water flow, i.e., the rougher the surface of the material, the higher the Manning coefficient. The material of the Lijiao River is brick and stone, and the material of the underground conduits is concrete and steel. The Manning coefficient corresponding to different conduit types and materials can be taken from the table in the SWMM manual, as shown in the table.

Conduit Material	Manning n
Asbestos-cement pipe	0.011 - 0.015
Brick	0.013 - 0.017
Cast iron pipe	
- Cement-lined & seal coated	0.011 - 0.015
Concrete (monolithic)	
- Smooth forms	0.012 - 0.014
- Rough forms	0.015 - 0.017
Concrete pipe	0.011 - 0.015
Corrugated-metal pipe	
(1/2-in. x 2-2/3-in. corrugations)	
- Plain	0.022 - 0.026
- Paved invert	0.018 - 0.022
- Spun asphalt lined	0.011 - 0.015
Plastic pipe (smooth)	0.011 - 0.015
Vitrified clay	
- Pipes	0.011 - 0.015
- Liner plates	0.013 - 0.017

Table 4-14 Manning coefficient of pipe
Source: SWMM user's manual

Channel Type	Manning n
Lined Channels	
- Asphalt	0.013 - 0.017
- Brick	0.012 - 0.018
- Concrete	0.011 - 0.020
- Rubble or riprap	0.020 - 0.035
- Vegetal	0.030 - 0.40
Excavated or dredged	
- Earth, straight and uniform	0.020 - 0.030
- Earth, winding, fairly uniform	0.025 - 0.040
- Rock	0.030 - 0.045
- Unmaintained	0.050 - 0.140
Natural channels (minor streams, top width at flood stage < 100 ft)	
- Fairly regular section	0.030 - 0.070
- Irregular section with pools	0.040 - 0.100

Table 4-15 Manning coefficient of river channel
Source: SWMM user's manual

(2) Subcatchment parameters

The parameters of the subcatchment can be divided into two categories, one is deterministic parameters, which have clear physical meaning and can be calculated according to the actual situation; the other is non-deterministic parameters, which have some meaning and mainly rely on experience to determine. The main parameters and access to the subcatchment are shown in the table.

Classification of Parameters	Parameter	Physical Significance	Access Way
Certainty parameters	Area	Area of the subcatchment	Calculation by ArcGIS tools
	Width	Characteristic width of the overland flow path for sheet flow runoff	Calculation by ArcGIS tools
	Slope	Average percent slope of the subcatchment	Topographical information, Calculation by ArcGIS tools

Classification of Parameters	Parameter	Physical Significance	Access Way
Uncertainty parameters	Imperv	Impervious Surface Coverage	References, Calculation by ArcGIS tools
	N-Imperv	Roughness of impervious area	SWMM User's Manual
	N-Perv	Roughness of pervious area	SWMM User's Manual
	Dstore-Imperv	Depth of depression storage on the impervious area	SWMM User's Manual
	Dstore-Perv	Depth of depression storage on the pervious area	SWMM User's Manual
	Curve Number	Dimensionless parameter for describing the relationship between rainfall and runoff	References
	Conductivity	Ease of fluid movement through the soil	SWMM User's Manual
	Drying Day	Drainage time of the soil	References

Table 4-16 Main parameters and access to the subcatchment
Source: Self-drawn by the author

In this paper, 14 subcatchments are divided based on historical hydrological data and the current location information of conduits and junctions, and the outlet of each subcatchment is set to the nearest junctions as shown in figure.

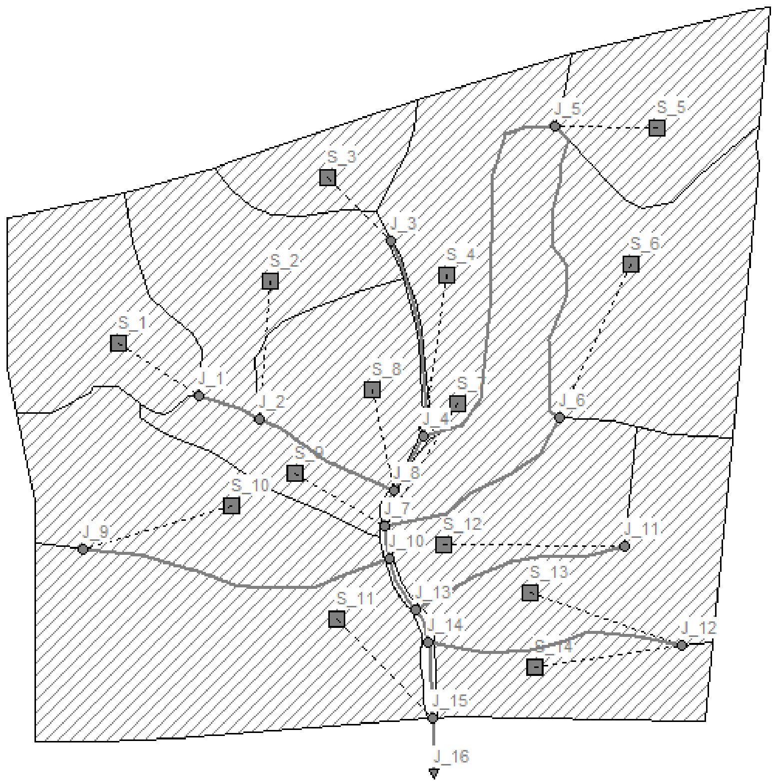


Figure 4-22 Outlet of each subcatchment
Source: Self-drawn by the author

The deterministic parameters of the sub-catchments all need to be calculated on the basis of the raw data using the tools of ArcGIS. Area parameters can be calculated directly using computational geometry tools; In this paper, the calculation of Width parameter is chosen by dividing the area parameter by the longest value of surface runoff, which can be obtained by ArcGis measurement tool; Slope parameters can be obtained by entering DEM data into ArcGis' Slope tool and then averaging the results using the Zonal Statistics tool; Imperv parameters were selected from the global 30m impervious-surface dynamic dataset from 1985 to 2020 using time-series Landsat imagery on the Google Earth Engine platform produced by Zhang, Liu et al. The impervious-surface distribution for the design horizon 2020 is shown in figure [44], The percentage of impervious area for each subcatchment was then calculated by averaging

[44] Zhang X, Liu L, Zhao T, et al. GISD30: global 30 m impervious-surface dynamic dataset from 1985 to 2020 using time-series Landsat imagery on the Google Earth Engine platform[J]. Earth System Science Data, 2022, 14(4): 1831-1856.

using the Zonal Statistics tool of ArcGIS. The deterministic parameter values for all subcatchments are shown in table.

Figure 4-23 Impervious-surface distribution for the design horizon 2020
Source: Self-drawn by the author combine with bibliography

Subcatchment	Area (ha)	Width (m)	Slope %	Imperv %
S 1	4.429256	141.17	1.58709	100
S 2	4.818406	153.54	1.559876	100
S 3	1.925578	95.84	1.417576	100
S 4	4.514405	92.08	1.037286	100
S 5	4.067282	138.08	1.638275	85.3
S 6	6.905732	162.89	1.701383	87.3
S 7	4.18298	80.46	1.433445	100
S 8	3.555878	140.47	1.40871	100
S 9	1.745098	53.08	1.105944	100
S 10	5.696674	157.61	1.747658	100
S 11	8.995878	174.75	3.065339	94.7
S 12	3.449154	121.8	2.05182	97.2
S 13	4.986684	157.95	2.255836	100
S 14	2.943264	96.85	4.164425	100

Table 4-17 Certainty parameters of all subcatchments
Source: SWMM user's manual

The uncertainty parameters of subcatchment mainly include N-Imperv, N-Perv, Dstore-Imperv, Dstore-Perv, Curve Number, Conductivity, and Drying Day. where N-Imperv, N-Perv, Dstore-Imperv, and Dstore-Perv describe the roughness coefficients of the permeable and impermeable portions of the subcatchment and the depth of ponding before rainfall; Curve Number, Conductivity, and Drying Day describe the infiltration capacity of the soil in the subcatchment. The uncertainty parameters of all subcatchments are taken with reference to SWMM User's Manual and some parameters of 4.3.3, and the results are shown in table.

Subcatchment	N-Imperv	N-Perv	S-Imperv	S-Perv	Curve Number	Conductivity	Drying Time
S 1	0.012	0.15	1.5	5	88	39.62	7
S 2	0.012	0.15	1.5	5	88	39.62	7
S 3	0.012	0.15	1.5	5	88	39.62	7
S 4	0.012	0.15	1.5	5	88	39.62	7
S 5	0.012	0.15	1.5	5	88	39.62	7
S 6	0.012	0.15	1.5	5	88	39.62	7
S 7	0.012	0.15	1.5	5	88	39.62	7
S 8	0.012	0.15	1.5	5	88	39.62	7
S 9	0.012	0.15	1.5	5	88	39.62	7
S 10	0.012	0.15	1.5	5	88	39.62	7
S 11	0.012	0.15	1.5	5	88	39.62	7
S 12	0.012	0.15	1.5	5	88	39.62	7
S 13	0.012	0.15	1.5	5	88	39.62	7
S 14	0.012	0.15	1.5	5	88	39.62	7

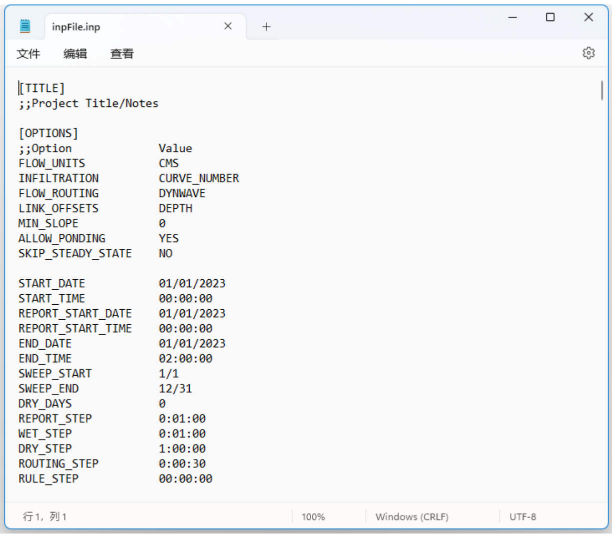
Table 4-18 Uncertainty parameters of all subcatchments

Source: SWMM user’s manual

4. 4. 3 Model Construction

The SWMM software only supports the inp file format, which is a text editor that organizes the model data blocks, while the SWMM model data blocks are divided into simulation condition data blocks and base data blocks. The simulation conditions data blocks can be entered directly in the SWMM platform, including the rainfall conditions, the simulation method, the simulation time and the simulation step size. The basic data blocks are divided into subcatchments, conduits, and junctions, all three categories of data blocks are processed by ArcGIS software. However, there is no direct data interface between ArcGIS and the SWMM model, so the data from the personal database mdb file created by ArcGIS must be exported to an inp file for editing before it can be added to the SWMM model. The model construction is done as follows[45]:

(1) Open the SWMM software, set each unit of the model to match the metric units of the input parameters, as well as the time parameters of the reporting step consistent with the precipitation time series, and then save the model and obtain the initial inp file with all the basic setting options and contents as shown in figure.




```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CMS
INFILTRATION         CURVE_NUMBER
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        YES
SKIP_STEADY_STATE    NO

START_DATE           01/01/2023
START_TIME           00:00:00
REPORT_START_DATE    01/01/2023
REPORT_START_TIME    00:00:00
END_DATE             01/01/2023
END_TIME             02:00:00
SWEEP_START          1/1
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          0:01:00
WET_STEP             0:01:00
DRY_STEP             1:00:00
ROUTING_STEP         0:00:30
RULE_STEP            00:00:00
```

Figure 4-24 SWMM basic setting options and contents
Source: SWMM software

(2) Open the personal geodatabase file of ArcGIS, find the data tables of junction, conduit and subcatchment respectively, and then paste each of their attribute parameters into the inp file at the corresponding location. Junction attribute parameters pasted into the [JUNCTIONS], [COORDINATES] data block; Conduit attribute parameters pasted into the [CONDUINTS], [XSECTIONS], [VERTICES] data blocks; The subcatchment property parameters are pasted into the [SUBCATCHMENTS], [SUBAREAS], and [INFILTRATION] data blocks. The [JUNCTIONS] property parameter setting, [CONDUINTS] property parameter setting, and [SUBCATCHMENTS] property parameter setting are shown in the figure.

[45] Fu Chao. Simulation of Urban Waterlogging of Certain district in Handan Based on SWMM Model [D].Hebei University of Engineering,2020.DOI:10.27104/d.cnki.ghbjy.2020.000120.

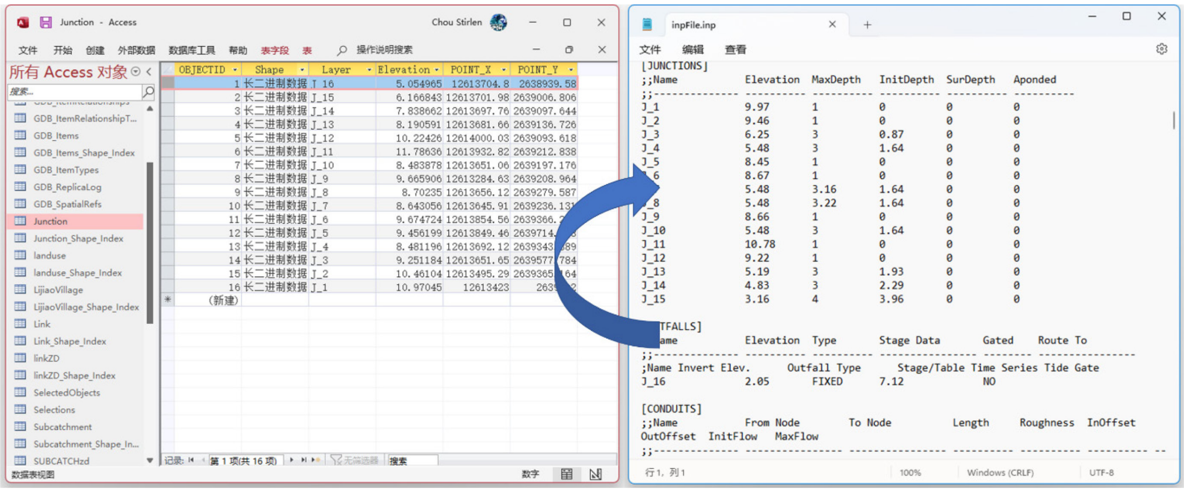


Figure 4-25 The [JUNCTIONS] property parameter setting

Source: Self-drawn by the author

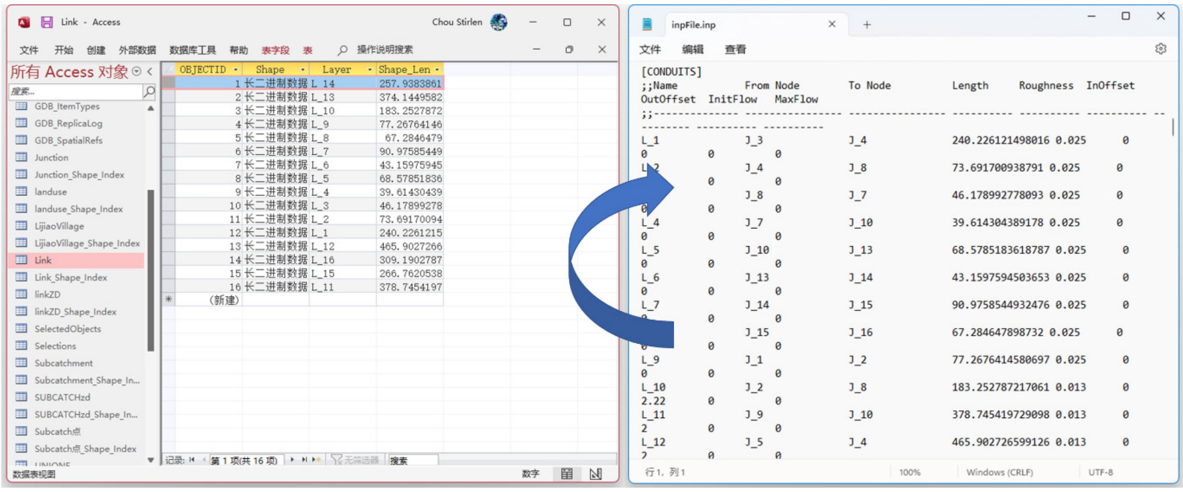


Figure 4-26 The [CONDUINTS] property parameter setting

Source: Self-drawn by the author

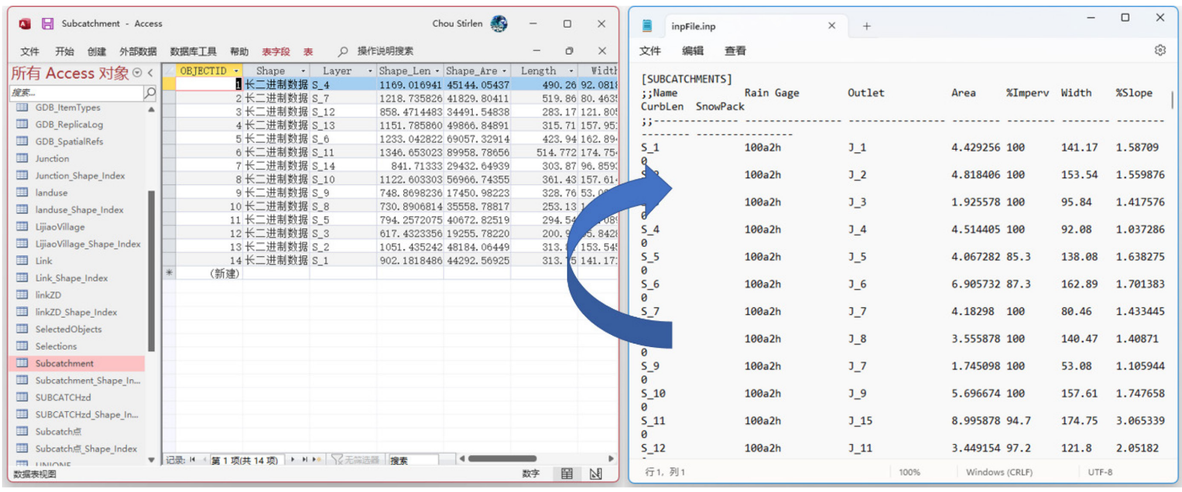


Figure 4-27 The [SUBCATCHMENTS] property parameter setting

Source: Self-drawn by the author

(3) Paste the precipitation parameters calculated by the Chicago Rain Simulator for each return period into the [TIMESERIES] data block.

(4) Open the inp file by SWMM software to check the junctions, conduits, subcatchments and other property parameters. After checking, the model is basically completed. The model includes 14 subcatchments, 16 conduits, 15 junctions and one outfall, and the software interface is shown in figure after the SWMM model is completed.

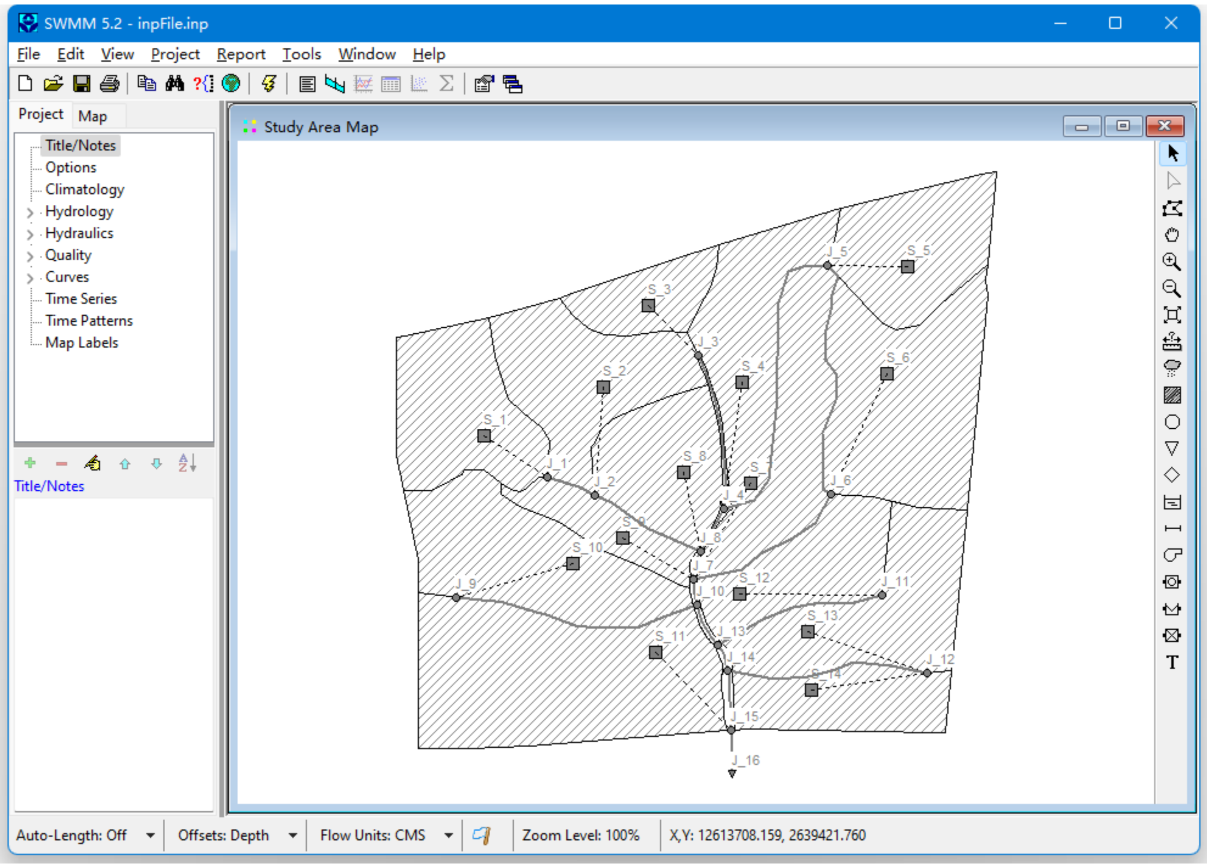


Figure 4-28 SWMM software interface
Source: SWMM software

4. 4. 4 Assessment results

The SWMM assessment results refer to the depth of surface runoff and total volume of flow discharged, runoff coefficient, and the number and duration of flooded junction. These results will be used as reference variables to analyze and compare the retrofitted model later in Chapter 6 as a quantitative basis for judging the degree of design scope flood resilience enhancement after renovation.

The design return periods of the SWMM model input rainfall are 10 years, 20 years, 50 years and 100 years respectively, see subsection 4.1.3 for specific rainfall characteristics, the simulation time is set to 2 hours, and the simulation result recording time step is 2min.

The SWMM model meets the requirements for different recurrence period rainfall scenarios, for example, the model surface runoff continuity error is -0.17% and the flow routing continuity error is -1.64% for 20 years, which is within 2% of the simulation error requirements. The simulation error analysis is shown in figure.

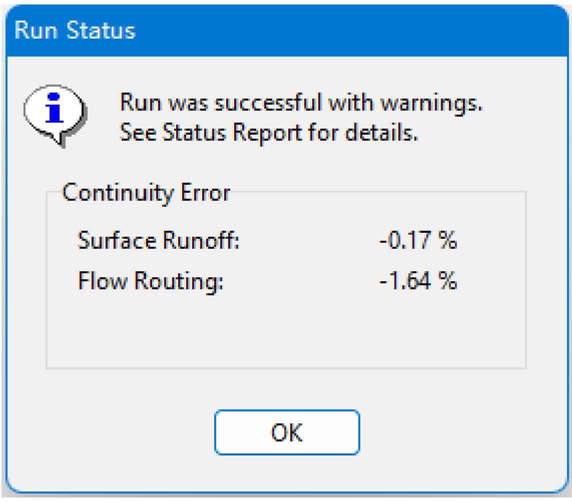


Figure 4-29 Simulation error analysis
Source: SWMM software

(1) Total volume of runoff and runoff coefficient

Total volume of runoff is the sum of runoff volumes from all subcatchments. Total volume of runoff is positively correlated with precipitation return period level, i.e., the higher the precipitation return period level, the greater the total runoff, the village have poor flood resilience.

Return Period	Total volume of runoff (10^6 L)
10 years	55.51
20 years	60.86
50 years	67.69
100 years	73.34

Table 4-19 Total volume of runoff
Source: Self-drawn by the author

The runoff coefficient is the ratio of total runoff volume to total precipitation, and the peak of subcatch runoff refers to the maximum value of runoff volume in the subcatchment area in the precipitation time series. Both data reflect the site's ability to retain and infiltrate stormwater runoff. In general, the lower the green space ratio and the flatter the terrain, the higher the runoff coefficient and peak of subcatch runoff, and the lower the flood resilience.

The runoff coefficients of Lijiao Village under the four return periods are shown in table.

Return Period	Runoff coefficient
10 years	0.921
20 years	0.925
50 years	0.929
100 years	0.932

Table 4-20 Runoff coefficient

(2) Number of flooded junctions and flooded duration

Generally speaking, the number of flooded junctions and their flooded duration are related to the terrain, impervious surface ratio, green space ratio, etc. The more the number of flooded junctions and the longer the flooded duration, the poorer the flood resilience[46]. (a) From the results of the internal flooding assessment, there were eight flooded junctions in Lijiao Village during the 10-year and 20-year return period rainfall, with one node located at the connection between the project pipeline and Lijiao River and the remaining seven junctions located in the tributaries; There are seven flooded junctions, all located in tributaries, when experiencing 50- and 100-year return period precipitation. In addition, as shown in the table, the flooded duration of each flooded junctions is positively correlated with the return period.

Junction	Hours flooded in different return period (h)			
	10 years	20 years	50 years	100 years
J_1	1.56	1.59	1.62	1.65
J_2	1.38	1.5	1.6	1.63
J_5	1.59	1.62	1.64	1.66
J_6	1.58	1.6	1.63	1.65
J_7	0.01	0.01	None	None
J_9	1.52	1.55	1.58	1.6
J_11	0.7	0.77	0.86	0.93

[46] Wang Shang.Research and Analysis of the Community Flood in Dongchangfu District of Liaocheng City Based on the Resilience Theory[D].Qingdao University of Technology,2020.DOI:10.27263/d.cnki.gqudc.2020.000072.

J_12	0.8	0.88	0.98	1.06

Table 4-21 Flooded duration of each flooded junctions
Source: Self-drawn by the author

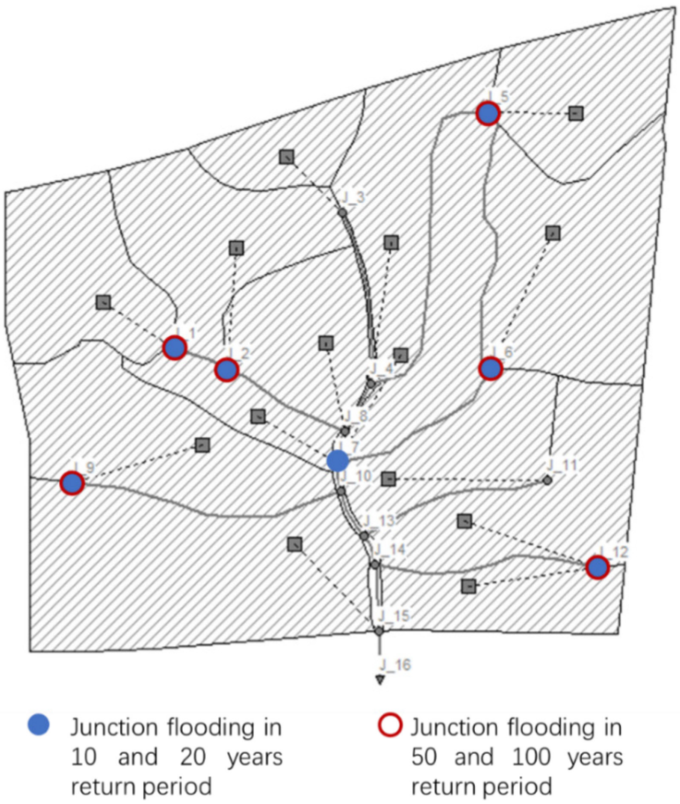


Figure 4-30 Flooded junctions
Source: Self-drawn by the author

Chapter 5 Exploration of Renewal Strategy of Lijiao Village Based on Flood Resilience

5.1 Design Principle

Chapter 2 mentions that Godschalk summarized eight principles of resilient cities. These principles can be classified into urban environmental dimensions as well as social and economic dimensions. In the case study in Chapter 3, it has been demonstrated that the principles of resilience at the dimension of the urban environment are applicable to the construction of a flood resilient city. Likewise, the principles of diverse, redundant, interdependent, robust, and adaptable at the urban spatial dimension can be used as guiding principles for the renewal of the Lijiao village.

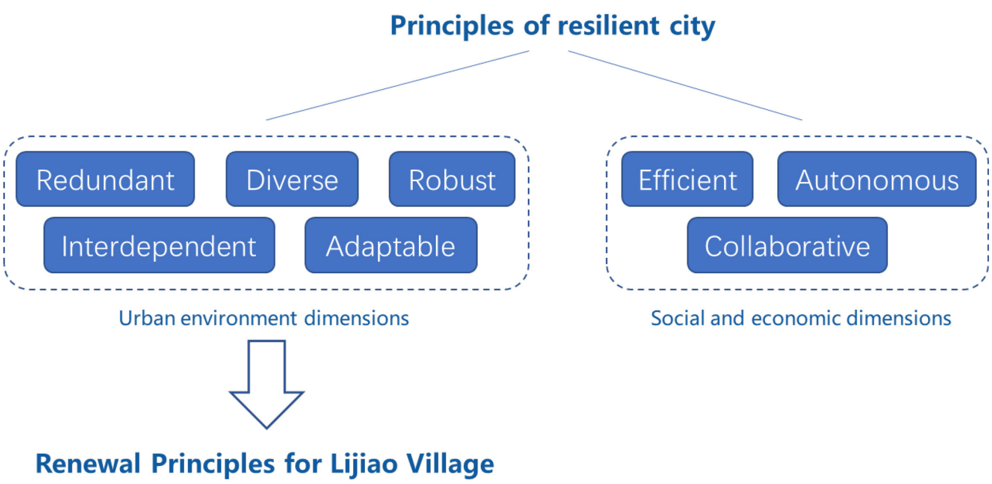


Figure 5-1 Principles of resilience renewal in Lijiao Village
Source: Self-drawn by the author

5.1.1 Principle of Diversity

The principle of diversity means that the function of the water system should be diversified, and should include at least four functions of drainage, storage, retention and infiltration, which is the essential difference between the resilient water system and the municipal engineering pipe network. In the past, traditional villages were equipped with well-functioning water systems that could flexibly respond to different levels of precipitation and flooding. However, with the construction of urbanization, most of the traditional villages have developed into urban villages, losing their function of storage and retention.

Based on the SWMM model created for Lijiao Village in Chapter 4, the current stormwater management functions in Lijiao Village are relatively homogeneous, with a predominantly drainage approach and a lack of functional diversity; The imperviousness of the entire area is also above 90%, with an extreme lack of infiltration facilities; The exterior of the village also does not provide water storage facilities to connect to the drainage system. Therefore, the diverse principle of resilience applies to the renewal strategy of Lijiao Village.

5.1.2 Principle of Redundancy

The principle of redundancy refers to the extensive use of functional modules in the water system in order to avoid the failure of a single functional module leading to the collapse of the water system. The case study of a water village represented by Fengjian Village gives insight to this paper: the large repeatedly arranged dike- pond units form a base pond system, and when faced with extreme rainfall, all dike-pond units will collectively accept rainwater runoff, and when a particular dike-pond reaches its water storage limit, hydrological exchange will occur spontaneously between the dike-ponds to share the runoff. This is also very revealing for the flood resilience enhancement of Lijiao Village. According to the results of the analysis in Chapter 4, the current status of the water system in the urban village with a single function also limits the redundant layout design of other functional components. Therefore, the construction of water systems in urban villages also needs to increase the redundancy of functional components based on the principle of diversity to enhance the ability to cope with flooding.

5.1.3 Principle of interdependence

The principle of interdependence refers to the interconnection and support between the components of the system. However, according to the rainwater corridor analysis in Chapter 4, the drainage system in Lijiao Village lacks connections to the surrounding rainwater corridor and, due to the lack of functional diversity in the water system, connections and support to other functional components do not exist.

In the case of Fengjian Village, the principle of interdependence can be expressed as the relationship between the dike-ponds and the ditches and inland rivers within the dike-pond system. The ditches and inland rivers provide the basis for hydrological exchange and runoff discharge between the dike-ponds, while the dike-ponds share the rainfall pressure for the ditches and inland rivers, which are interconnected and complementary to each other to form an orderly and efficient system. This has implications for the enhancement of flood resilience in Lijiao Village. In practice, the combination of multiple functional components can be explored based on the functional diversity of the water system, thus enhancing the integrity and resilience of the water system.

5.1.4 Principles of Robustness

The principle of robustness means that the water system can effectively cope with flooding without being damaged. The principle emphasizes living with floods based on the concept of resilience and building a robust water system by enhancing the floodability of the area, percentage of floodable area, etc., rather than relying on rigid resilience measures. According to the inundation simulation analysis and the inundation risk assessment in Chapter 4, there are extensive inundation areas in and around Lijiao Village, and some nodes of the drainage system within Lijiao Village also flooding during heavy rainfall events. These resultant surface weather extremes can lead to flooding in the village of Lijiao and in the surrounding area, threatening the reliability and robustness of the water system. Therefore, it is necessary to follow the principle of robustness in the design of the renewal of Lijiao Village.

5.1.5 Principle of Adaptation

The principle of adaptation means that the resilient water system should fully consider the integration with the urban space and adapt to the functional conditions of the urban public space. The Copenhagen Stormwater Management Plan takes into account the different functional applications of urban spaces under stormwater conditions and daily conditions in the shaping of urban public spaces, enhancing the urban flood resilience and optimizing the environmental quality at the same time. This also has great implications for the design of the renovation of Lijiao Village. The current high building density in Lijiao Village has resulted in insufficient and fragmented public space, and the only remaining drainage water bodies do not provide a high-quality public space environment for the village due to their lack of management and poor sanitary conditions of the waterfront space. Therefore, the development of appropriate strategies based on the principle of adaptation is conducive to enhancing the environmental quality of public space in Lijiao Village.

5. 2 Design Strategy and Measure

The first part of this chapter describes the principles of resilience that apply to guide the Lijiao Village renewal strategies. The second section will use the case studies in Chapter 2 to organize the design strategies guided by the five principles of resilience as shown below, which will guide the final Lijao Village renewal practice in combination with the analysis and assessment results in Chapter 4.

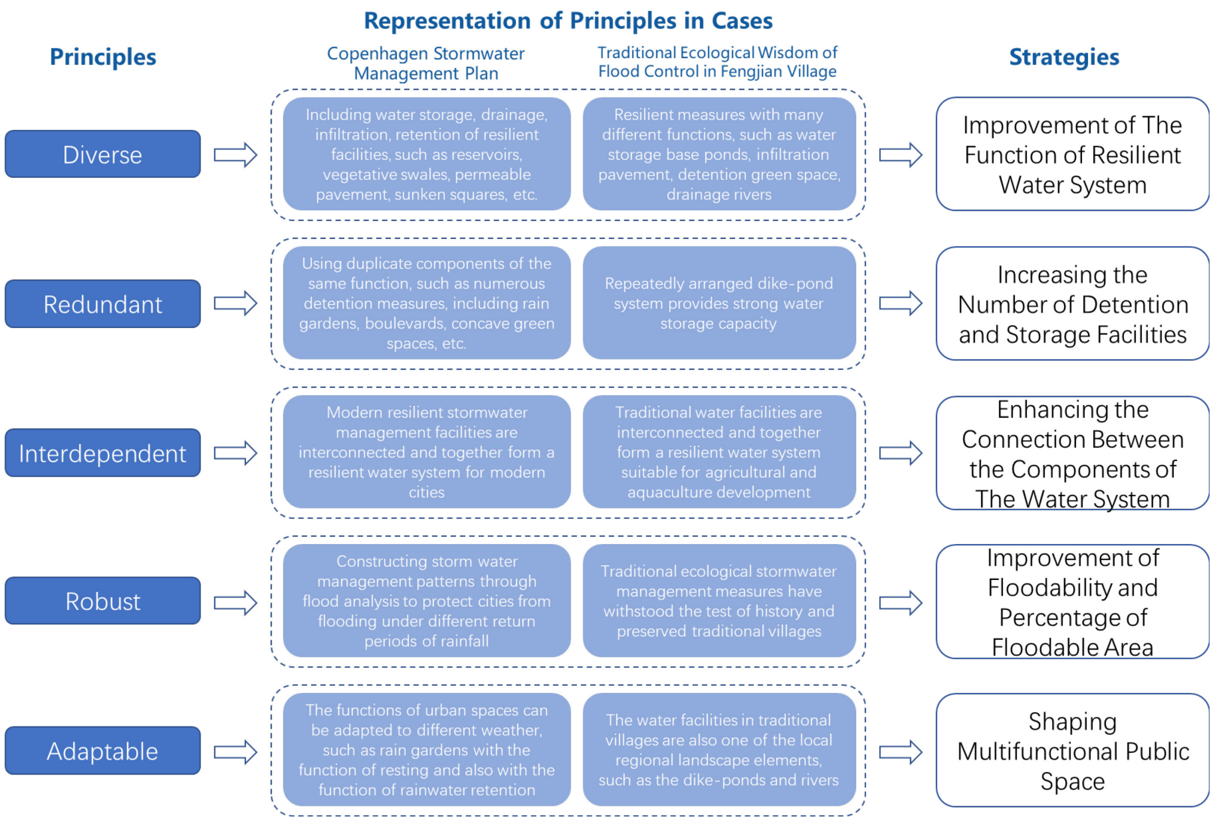


Figure 5-2 Strategies generation

Source: Self-drawn by the author

5. 2. 1 Improvement of The Function of Resilient Water System

Based on the diverse resilience principles to supplement rainwater storage, detention and infiltration for the Lijiao Village. Complementing and enhancing the storage capacity of rainwater can delay the duration of flood peaks, relieve pressure on municipal pipes, and reduce runoff volume. Complementing and enhancing rainwater retention capacity helps to slow down the time of runoff formation, extend the time of rainwater infiltration, and recharge the groundwater content. Replenish and enhance the infiltration capacity of rainwater has the effect of reducing the amount of rainwater discharge, reducing the flow of runoff, and containing groundwater resources[47]. Improving the function of resilient water systems in urban villages can help improve the flood resilience of urban villages.

Common rainwater storage facilities are mainly rain barrel, water reservoir, etc. Rain barrels can collect and store rainwater and use it for irrigation, firefighting, etc. except for drinking, and can be located above or below ground, and are suitable for sites with small areas or limited space development; Reservoir can be a small pool, can also be a larger area of landscape water bodies, the former in the storm season rainwater storage role is limited, the latter has a better rainwater storage role. However, both of these measures need to occupy urban public activity space, while the multifunctional sunken square can act as a reservoir to collect and store runoff during heavy rainstorms, and enhance the leisure activities for residents in daily life. Common rainwater retention facilities are mainly bioretention facilities, generally installed at a location lower than the road, with representative recessed green spaces, rain gardens, green roofs and vegetative swale, etc. Their role is mainly to mitigate the flood flow during heavy rainfall, replenish groundwater, etc. Common rainwater infiltration facilities mainly include permeable pavement, green areas, etc. The main function is to make rainwater infiltrate naturally and slow down the generation of urban flooding.

The layout and design of stormwater management facilities is flexible and versatile, and a single facility can have multiple functions by combining with other facilities. For example, a river in Fengjian village with a natural barge that has both discharge, storage and retention functions; The concave green space has its own infiltration function and is modified by microtopography to add storage and retention functions. In the practice of Lijiao Village renewal, it is also possible to flexibly combine different functions of stormwater management facilities according to the site conditions.

[47] Liu Hanyu.Strategy of campus green space renovation based on Chenghongresilience——a case study of Wenhua Road Campus of Henan Agricultural University[D].Henan Agricultural University,2021.DOI:10.27117/d.cnki.ghenu.2021.000400.

5.2.2 Increasing the Number of Detention and Storage Facilities

Based on the redundant principle of resilience increase the number of some kind of stormwater management facilities in the design of the renewal of Lijiao Village. In Chapter 4, this paper uses SWMM software to develop a hydrological model for Lijiao Village, containing 14 subcatchments. If the whole Lijiao Village is considered as a complete resilient water system, each subcatchment is a subsystem of the complete system, with its own functional components. If each subsystem is connected to each other in a certain way, once the rain and flood disaster occurs and the functional components within the subsystem are damaged and there are no other components to make up for it, the collapse of the subsystem will probably cause the whole system not to function properly. Therefore, adequate detention and storage facilities can give the resilient water system with a strong enough self-adaptive, self-regulating capacity, when a component is damaged, other components can compensate, thus ensuring the normal operation of the system.

However, due to the development and construction needs of modern cities and industrial development patterns, it is difficult to realize the storage of rainwater in the form of a large dike-pond system as in traditional villages. Therefore, in the renewal practice of Lijiao Village, due to its high building density and tight land use, the design strategy for redundancy should be based on small-area unit modules that can be flexibly arranged, such as green roofs that can be used to increase the number of detention facilities, or rainwater tanks that can be arranged to increase the number of storage facilities by making full use of the fragmented public space in the village to achieve the design purpose of redundancy.

5.2.3 Enhancing the Connection Between the Components of The Water System

Based on the principle of interdependent resilience in the design of the renewal of Lijiao Village to strengthen the connection between the various components of the water system. The relationship between the components of the water system should not be completely independent of each other, the components of the system are interconnected and support each other more conducive to enhance the system's flood resilience. In the practice of flood resilient cities, the connections between system components can exist between the same functional components or between different functional components. For example, in the practice of stormwater management planning in Copenhagen, the drainage facilities in the city, mainly blue and green infrastructure, are interconnected and supported to form a large drainage network; The green street approach is to connect V-section streets to detention facilities such as ecological tree ponds, where stormwater runoff flows from the street to the detention facility, relieving the pressure of discharging from the street, while also nourishing vegetation and replenishing groundwater. In a word, the connection between the components must follow the natural law of stormwater runoff direction, the purpose of which is to better play the functional advantages of each component and improve the design area's flood resilience.

In the case of the renovation of Lijiao Village, a drainage network with interconnected discharge components can be constructed at the village and urban area levels based on the stormwater corridors involved as the basis for the entire resilient water system; At the level of urban plots or residential clusters, various different functional rainwater management facilities can be connected in series from top to bottom appropriately, giving full play to the advantages of each functional component and producing the effect of one plus one more than two, for example, the interconnection of components in residential clusters can be green roofs to rain barrels or green areas, rain gardens and other green infrastructure located on the ground and then to drainage networks such as rivers and pipes, and then flow to the final outfall; The approach at the street level is similar to that at the residential cluster level, except that fewer components are involved because the source of runoff tends to start at ground level or at a stormwater management facility located at ground level and then flow through the drainage network to the final outfall. The specific design plan may be different for each parcel or group, and the layout and design will be tailored to the local conditions, so that the functional advantages of each component can be brought into play.

5. 2. 4 Improvement of Floodability and Percentage of Floodable Area

Improving the floodability and the percentage of floodable areas in the village and urban areas of Lijiao based on the principle of robustness and resilience is conducive to enhancing the resistance to stormwater hazards. Before introducing strategies to increase the floodability and the percentage of floodable areas, this paper clarifies a concept - floodable land, which is defined as land that has the ability to store and transfer flood water without further internal or external damage. Floodable lands can be subordinate to any nature of land, not just those that are undeveloped or green spaces such as wetlands. Floodable land promotes the flood carrying capacity of the city, so flooding in floodable lands is benign. In large combined areas, floodable land can reduce flood peaks to reduce overall flood impacts. Other things being equal, more floodable land means higher floodability. The floodable area ratio is the proportion of floodable land area to the affected area, but it is worth emphasizing that even cities with a 100% floodable area ratio can be damaged by very large flooding events.

Through the inundation analysis in Chapter 4, there are several flooding affected areas within the design area. In the renewal of Lijiao Village and the practice of surrounding urban design, the affected areas can be transformed into floodable land by setting up suitable rainwater retention, storage and infiltration facilities according to local conditions in order to enhance the ability of Lijiao Village and surrounding urban areas to cope with stormwater disasters. In addition, the SWMM-based risk assessment also found flooded junctions in Lijiao Village, which reflects the lack of robustness of Lijiao Village in coping with stormwater hazards. However, if the problem of flooded junction is to be solved, it is not enough to base on a robust strategy alone; it requires a combination of other principles and strategies to enhance the storage, infiltration, detention, and discharge capacity of the Lijiao village in a holistic manner in order to achieve a fundamental solution.

5.2.5 Shaping Multifunctional Public Space

Shaping multifunctional village and urban public spaces based on the adaptive principle of resilience is conducive to improving flood resilience as well as environmental quality. Stormwater resilience-oriented public space design in the renovation of Lijiao Village can enhance the quality of the environment through several stormwater management measures.

(1) Drainage measure

Restoration of the original river in Lijiao Village. Compared to municipal engineering pipes, the river has better stormwater drainage and storage capacity, and combined with waterfront recreational and commercial facilities, it can also enhance the spatial vitality and landscape value of the village; The use of V-road section of the road instead of the existing traditional road section, can give the road a certain rainwater storage and retention function at the same time, during heavy rainfall hours also makes the road with normal traffic function.

(2) Storage measure

The use of sunken square form instead of the conventional square form, can make the square in the flood season to have the ability to collect and store rainwater, in the daily also have the function of the square, to provide people with public activities place; Setting up cisterns or rainwater wetlands in large urban public green areas or parks can enhance the city's water storage capacity while enriching the city's landscape elements.

(3) Retention measure

By lowering the middle carriageway to below the sidewalk on both sides, the green street is divided into a "safe passage section" and a "flooding area", where the carriageway can be used as a flooding area during heavy rainfall, while the pedestrians on both sides are provided with a safe space for walking. Usually, water retention facilities such as ecological tree ponds are also installed between the carriageway and the pedestrian to enhance the water retention capacity of the green street; Stormwater retention boulevards are also one of the common water retention measures. They are made by setting up continuous concave green spaces in the middle of the road so that the runoff from the road can be collected and detained during storm periods.

(4) Infiltration measure

Infiltration measures are relatively simple compared to the previous three, with general practices such as laying permeable pavement and installing green space, which often do not involve terrain modification.

5. 3 Summary

This chapter summarizes and refines the resilience principles derived from previous studies to derive design strategies and measures applicable to the renovation of Lijiao Village, with the aim of improving the flood resilience and environmental quality of Lijiao Village. Among them are the resilience principles of diversity, redundancy, interdependence, and robustness and the design strategies derived from them aim to enhance the ability of Lijiao Village to cope with stormwater hazards, namely flood resilience, and the resilience principle of adaptation and the strategies derived from it aim to enhance the environmental quality of Lijiao Village. The next chapter will show how design strategies are applied in practice

Chapter 6 Implement of Renewal Strategy in Lijiao Village

6.1 General Layout

6.1.1 Master Plan

Based on the previous rainwater corridor analysis, inundation simulation, and design strategies, the master plan of the Lijiao Village renovation scheme is shown in the figure, and the specific design logic and generation will be shown in subsequent sections of this chapter. The renovation scheme recovers most of the original river in Lijiao Village and expands on this to the urban area to the west, then connects to the Pearl River back channel, creating a framework for a resilient water system that covers the entire design area. Urban spatial elements such as public green spaces, buildings, and roads in the urban areas to the west of Lijiao Village are also organically integrated with the water system framework to enhance the drainage system of Lijiao Village while improving the flood resilience of the external urban areas. Due to the high building density in Lijiao Village, it is not possible to use the limited public space to set up sufficient resilient stormwater management facilities such as retention and infiltration, so green roofs become the best choice for resilience enhancement in Lijiao Village, and the design plan selects flat roofs in Lijiao Village for green roof improvement.

The design of the public space is also centered on the framework of this resilient water system, and the specific design content will be introduced in the subsequent part of this chapter.

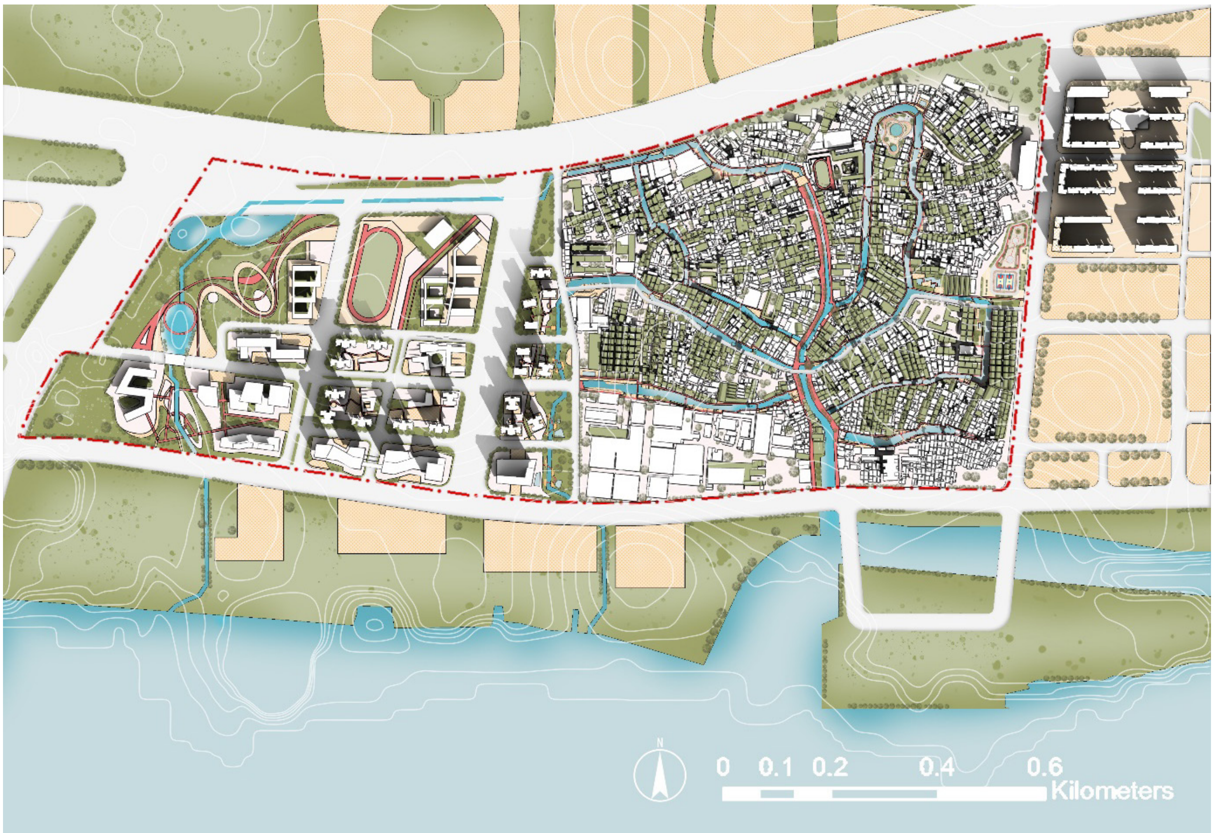


Figure 6-1 Master plan of Lijao renewal
Source: Self-drawn by the author

6.1.2 Relationship and Integration of Water System and Urban Structure

The resilient water system consists of two main parts, one is the resilient drainage system that serves as the framework of the whole system, including blue and green infrastructure, such as rivers, vegetative swales and other facilities; the other part is the module of rainwater storage, retention and infiltration facilities set up in accordance with the framework of the resilient drainage system, including green roofs, rain gardens, concave green spaces and other measures.

The resilient drainage system extends from the village of Lijiao to its western urban area. The resilient drainage system within Lijiao Village is homogeneous with the village fabric, pedestrian traffic and roads in the village, with sidewalks arranged on both sides of the river, and platforms designed to buffer pedestrian traffic at the street entrances of the village grouping and at the beginning of the bridge connecting the two measured sidewalks. Resilient drainage systems in urban areas are partly homogeneous with roads and partly organically integrated with urban green spaces. In addition, the layout of the building is adjusted according to the shape of the drainage system to obtain a good landscape effect and high-quality public space, as shown in the figure, the layout of the residential area is based on maintaining a certain buffer distance from the drainage system and forming a unique and pleasant waterfront space through the placement of public green space, leisure walkways, water-friendly platforms and other elements.

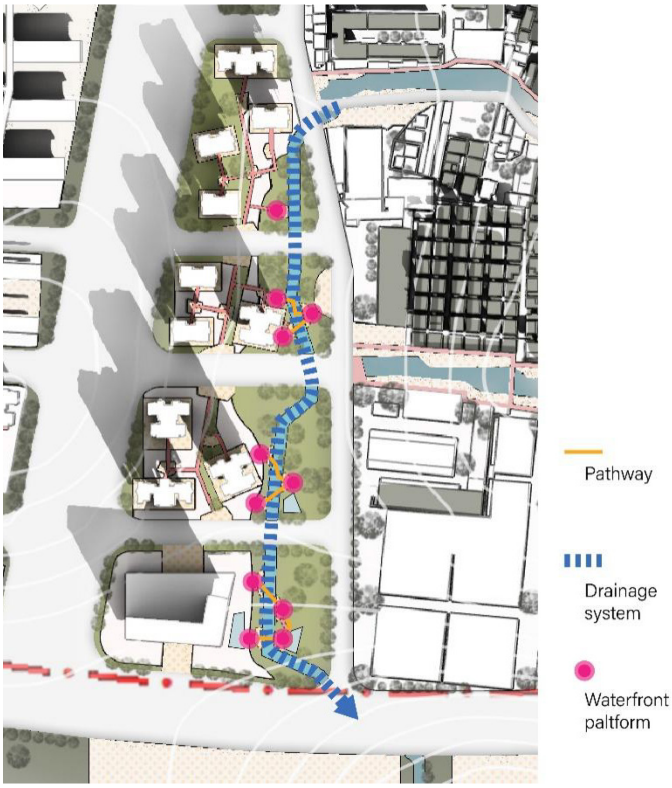
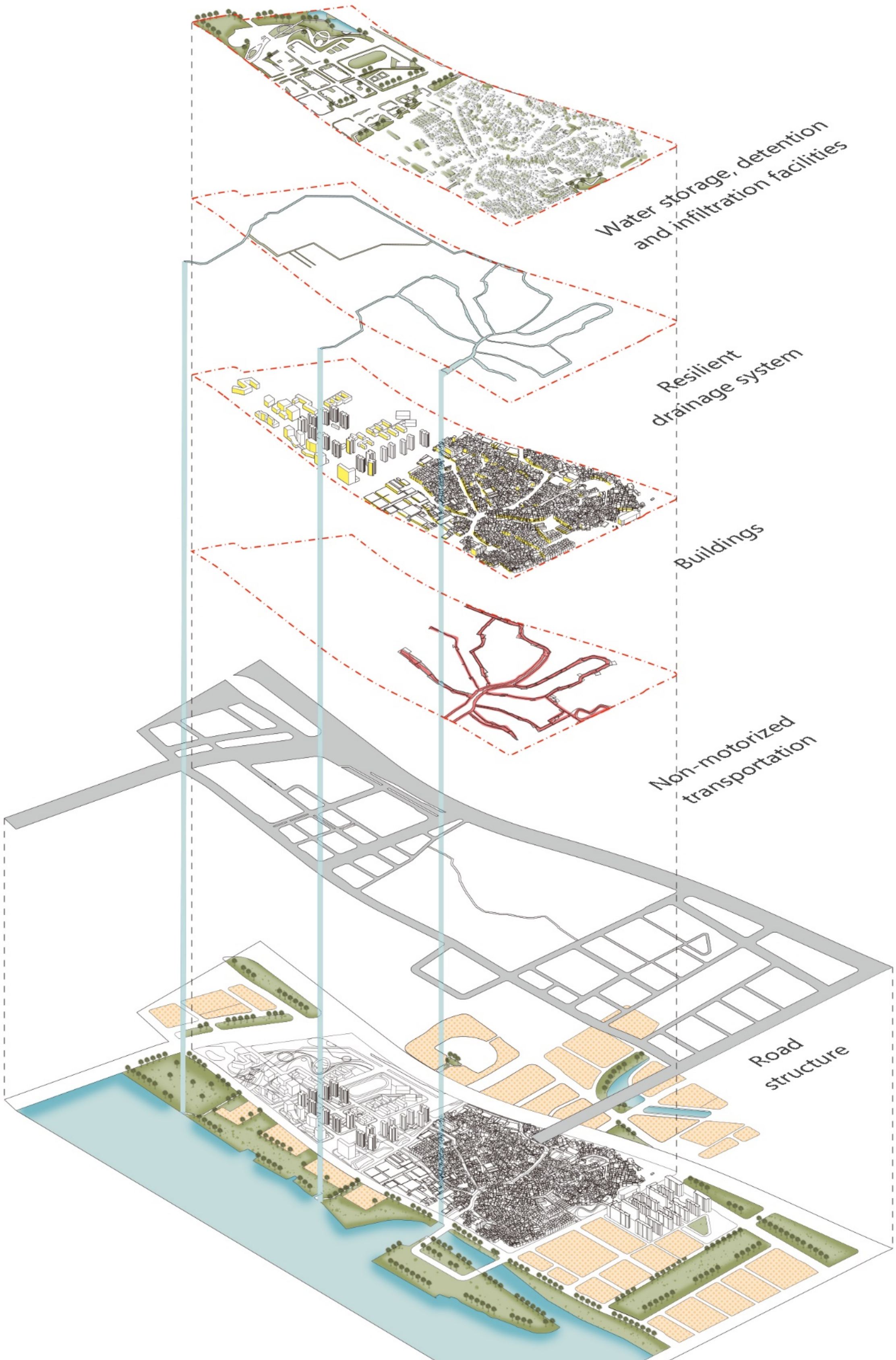


Figure 6-2 Relationship between buildings layout and river form
Source: Self-drawn by the author

Rainwater storage, retention and infiltration modules are not only attached to the resilient drainage system, but also generally relate to the urban structure as landscape elements in the urban space. As shown in the figure, the layout of the rainwater storage, retention and infiltration facility modules has a high degree of integration with the road structure and architectural texture, and can be interconnected through the drainage system to enhance the connection of each component.

The relationship between the resilient drainage system and the rainwater storage, retention and infiltration facility modules and the urban fabric is shown in the figure.



Water storage, detention
and infiltration facilities
Resilient
drainage system
Buildings
Non-motorized
transportation
Road
structure

Figure 6-3 Relationship and Integration of Water System and Urban Structure
Source: Self-drawn by the author

6. 2 Resilient Water System Construction

6. 2. 1 Drainage System Construction

The drainage system is the structural foundation of the entire resilient water system, and the storage, retention and infiltration facilities will be laid out with the drainage system as the framework. The construction of a drainage system involves the principles of interdependence, robustness and adaptability, which itself serves as a channel for the interconnection of storage, retention and infiltration facilities, and is an important factor in determining the robustness of the overall resilient water system. In addition, the water body itself provides landscape value for the shaping of multifunctional spaces. The construction of a resilient drainage system consists of two main parts:

(1) Restoration of part of the river according to the historical distribution of the water system

In the classification of traditional villages in the Pearl River Delta, Lijiao Village belongs to the net water village type. Therefore, a resilient drainage system within the village of Lijiao can be constructed based on the distribution pattern of water systems that existed in the past. However, due to the high building density in Lijiao Village, the phenomenon of building additions and unauthorized construction is more serious, and some buildings need to be removed to meet the physical space requirements for the restoration of the river, in addition to providing sufficient space for the creation of a comfortable and pleasant waterfront street space. The construction process and results are shown in the figure.

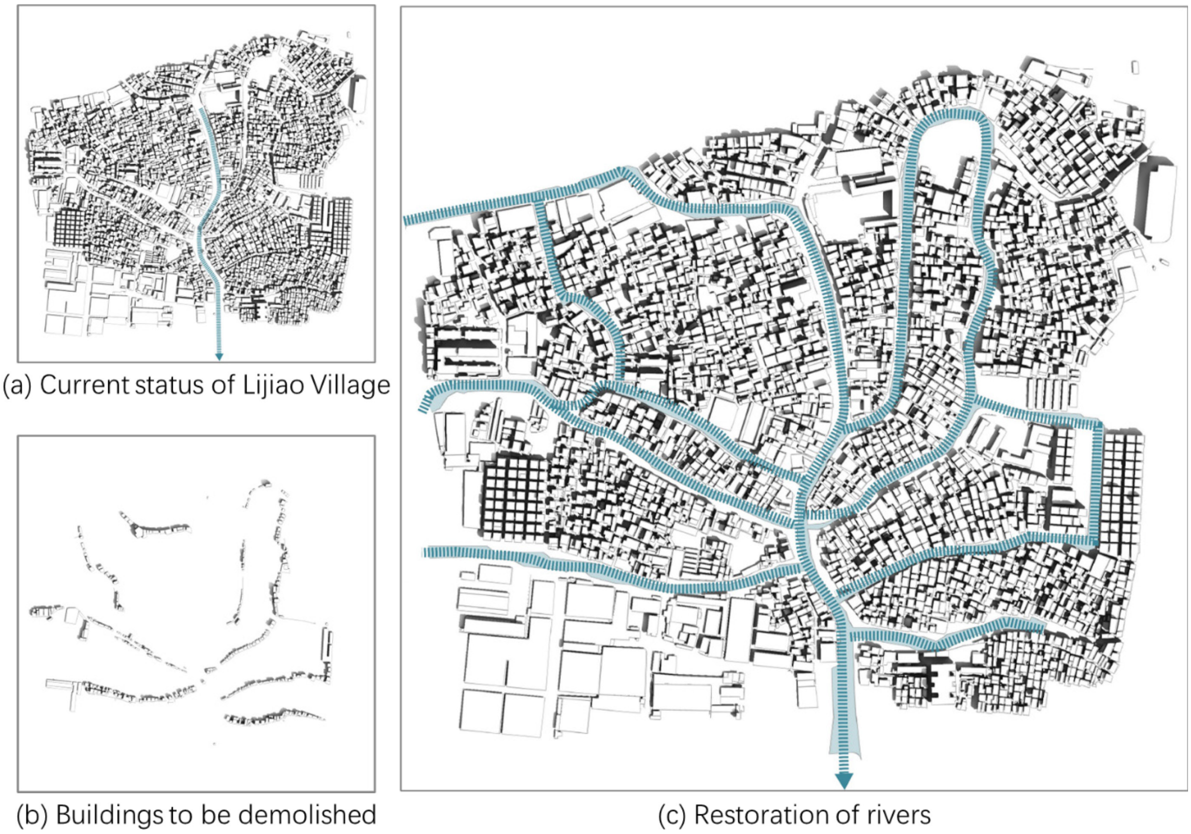


Figure 6-4 Construction process and results of drainage system in Lijiao village
Source: Self-drawn by the author

(2) Construction of blue and green infrastructure based on rainwater corridors

The resilient drainage systems constructed in the urban areas outside of the village are not as well constructed as the historical water systems available within the village, and the modern urban structure does not necessarily have the topographical conditions to restore the historical water systems. Therefore, resilient drainage systems in urban areas can be constructed based on the results of the rainwater corridor analysis in Chapter 4.

The resilient drainage system in urban areas uses both green infrastructure and blue infrastructure measures. The blue infrastructure, mainly using river channels to enhance the resilience of the components, will be applied in the area where the rainwater corridor is formed closer to the water system in Lijiao Village and will form a larger resilient drainage system together with the river channels within Lijiao Village. The green infrastructure is mainly based on vegetative swales, set in the middle or on both sides depending on the conditions of the adjacent roads, which are constructed at a distance from the water system of Lijiao Village. The process of constructing a resilient drainage system in the urban area and overall is shown in the figure.

Figure 6-5 Construction process and results of drainage system in urban area
Source: Self-drawn by the author

Finally, the river in the urban area is connected to the river in Lijiao Village, creating a stronger, more complete and resilient drainage system, as shown in the figure.

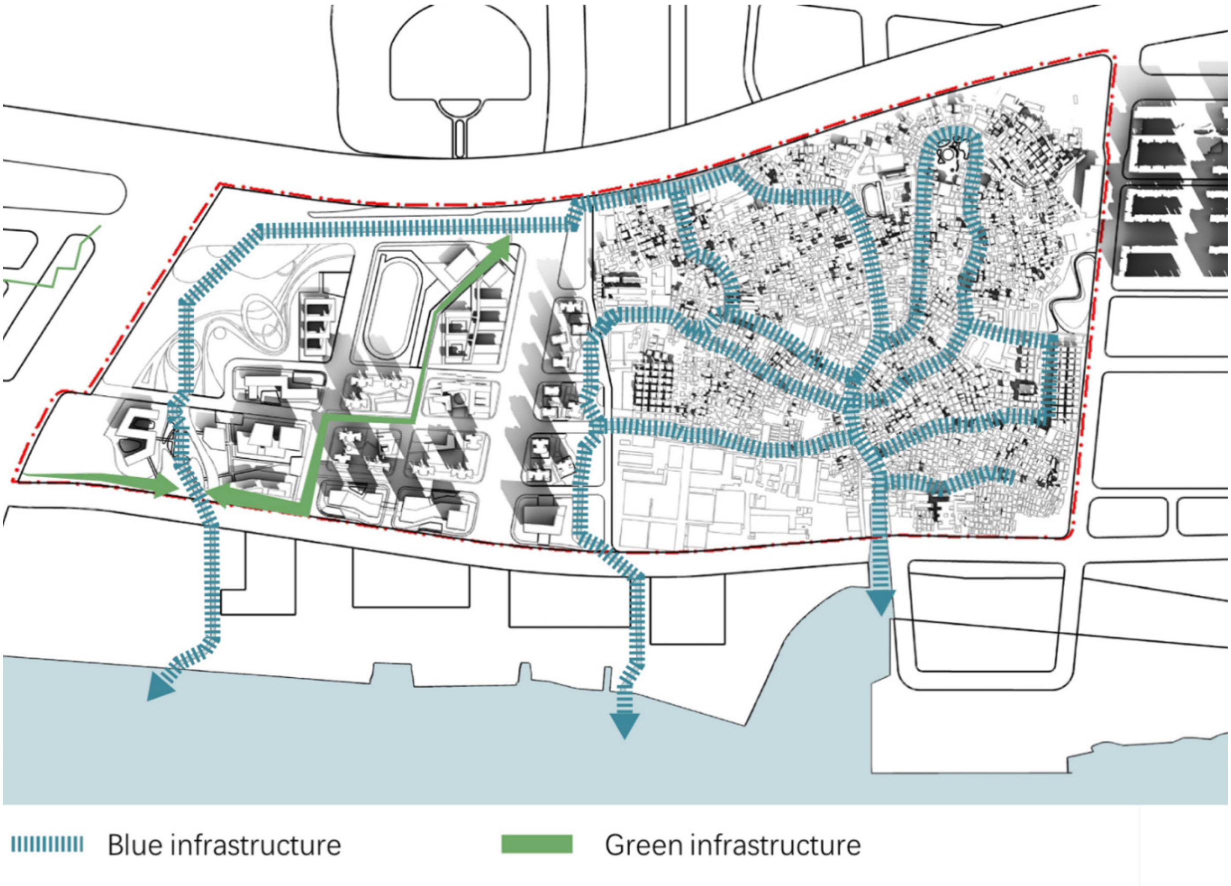


Figure 6-6 Complete resilient drainage system
Source: Self-drawn by the author

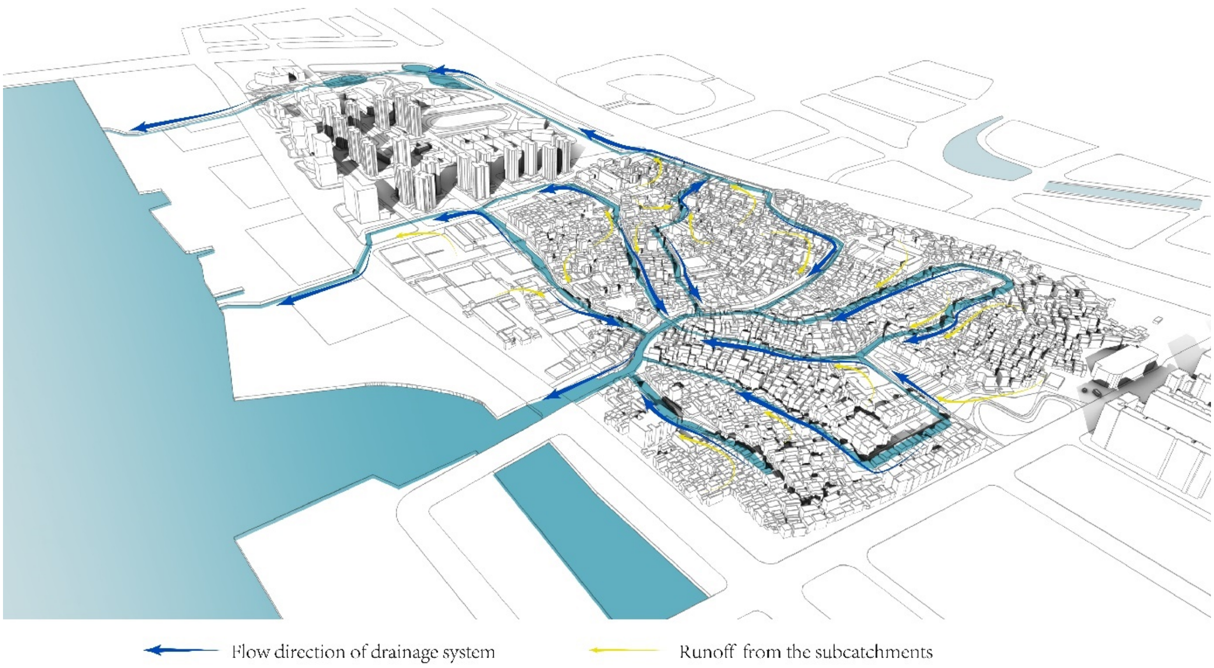


Figure 6-7 Aerial view of the complete resilient water system

Source: Self-drawn by the author

6. 2. 2 Storage Facility Layout

The design strategy involved in the layout of the storage facilities is to increase the number of storage and retention facilities. This is achieved by increasing the number of different types of storage facilities in the renovation scheme, avoiding the situation where only a single facility is limited by site conditions in the design layout. Therefore, three main types of storage facilities of different scales are used in the renovation scheme of Lijiao Village, namely rain barrels, reservoirs, and stormwater wetlands, in order to cope with the layout constraints of different site sizes.

(1) Rain barrel

Rain barrels are often used around buildings, which can directly collect rainwater from roads, roofs and green areas, reduce rainwater discharge and improve the drainage capacity of drainage systems, and the stored rainwater can be used for toilet flushing and irrigation after treatment. In urban villages and areas with dense buildings, rain barrels are one of the easiest LID measures to implement[48]. The rain barrels of the Lijiao Village renovation scheme are mostly located in the courtyard space formed between the buildings, and it is necessary to ensure that there are rain barrels in each sub-catchment area. The locations of the rain barrels are shown in the figure.

[48] Qin Zhiyu.Study of effects on runoff reduction and controlin typical northern urban areas in differentscenarios—take the main urban area of HandanCity as an example [D].Hebei University of Engineering,2021.DOI:10.27104/d.cnki.ghbjy.2021.000685.

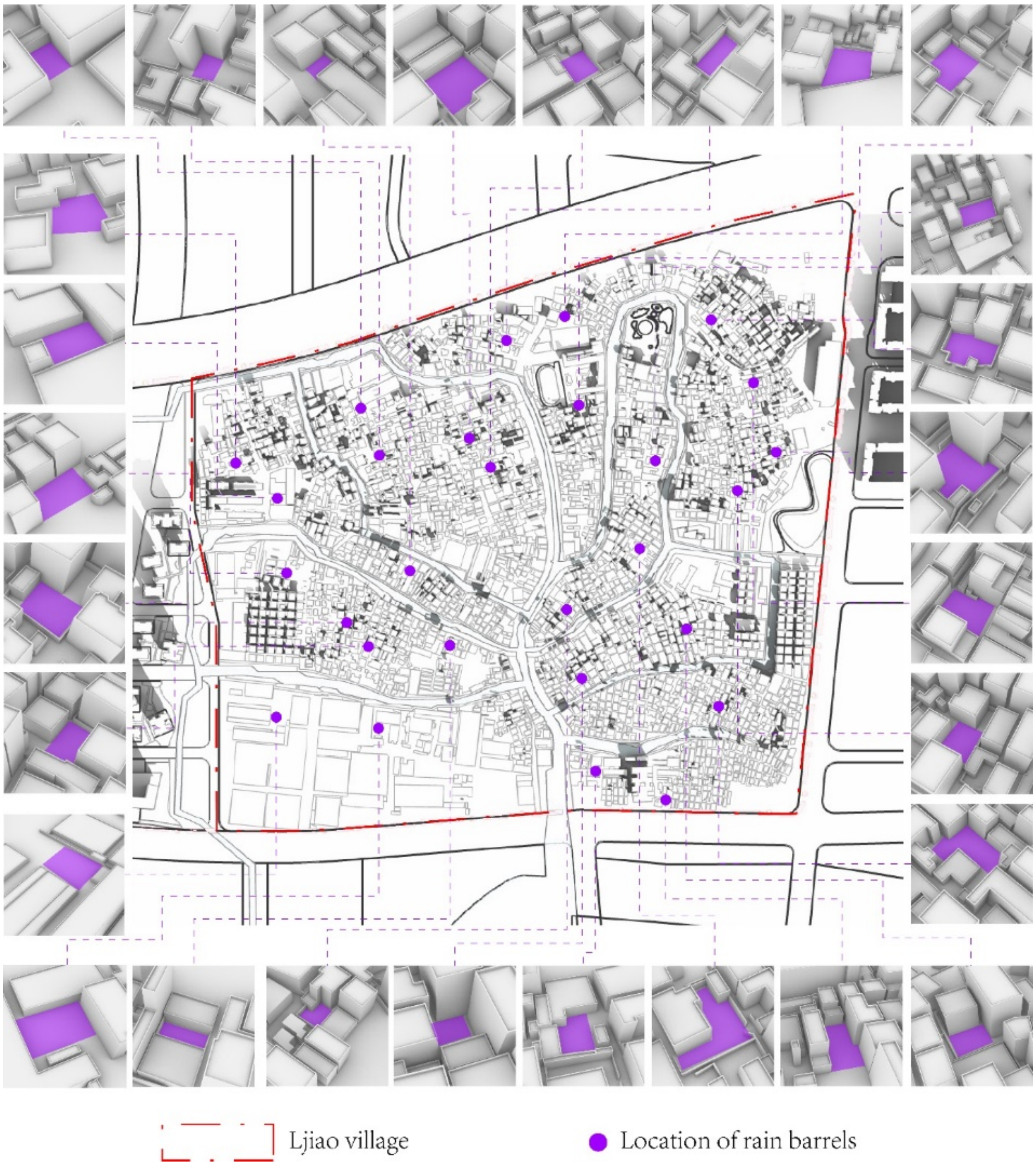


Figure 6-8 locations of the rain barrels
Source: Self-drawn by the author

(2) Reservoir

The reservoir is mainly used for the public space near the water system, which not only has certain rainwater storage capacity and landscape value. Usually only a large number of reservoirs work together to provide a strong water storage capacity, but the renovation scheme has very limited public space where reservoirs can be installed. Therefore, the reservoir in this scheme is more landscape than water storage, and can only be used as an assistant module to enhance the resilience of the water system.

Based on the inundation area scope obtained from the inundation analysis in Chapter 4 and the drainage system constructed in the above section, the layout process and results of the reservoir module are shown in the figure.

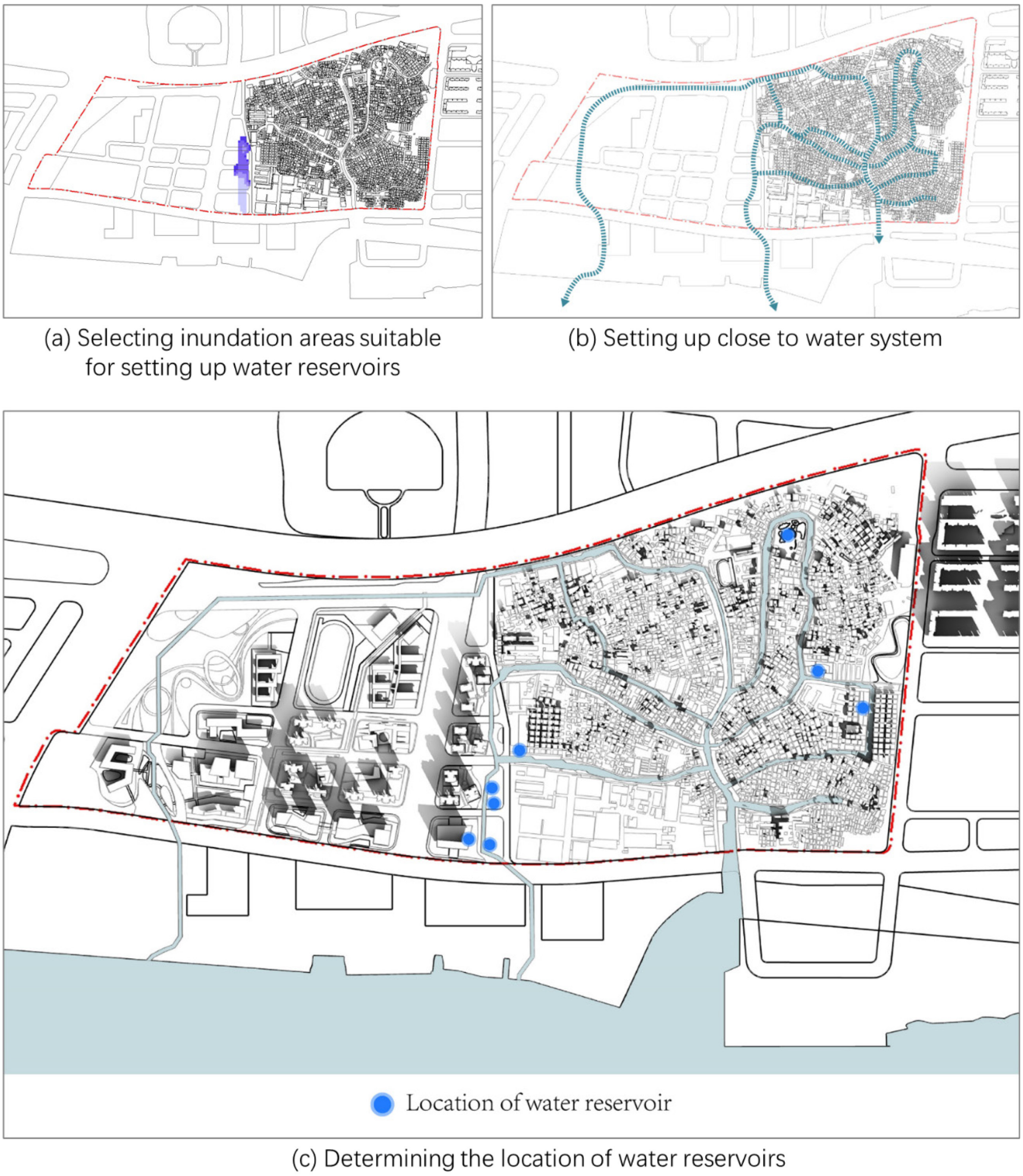


Figure 6-9 Layout process and results of the reservoir module
Source: Self-drawn by the author

(3) Stormwater wetland

As an important resilient stormwater management facility, stormwater wetlands have the functions of storing rainwater, purifying water quality and optimizing water resources utilization. Wetlands are usually sited in less developed depressed areas around urban areas. In addition, in combination with its own water needs, it needs to be close to waterways and other water systems to ensure that the wetland can carry out the hydrological cycle even in the low rainfall season, as well as to facilitate the adjustment of water storage during the rainy season[49].

Combining the scope of the inundation area and the land use situation, the only locations in the renovation scheme that meet the above site selection conditions are the public green space in the site and the park parcel. The layout process and results of the stormwater wetland are shown in the figure.

(a) Green space and park plot (b) Inundation area

(c) Determining the location of stormwater wetland

Figure 6-10 Layout process and results of the stormwater wetland
Source: Self-drawn by the author

[49] Huang Zhimin.Urban stormwater wetland design based on sponge city perspective[J].Engineering Technology Research,2021,6(17):240-241.DOI:10.19537/j.cnki.2096-2789.2021.17.105.

Finally, combining the process and results of the above-mentioned types of storage facility layout, the storage facility layout of Lijiao Village are shown in the figure.

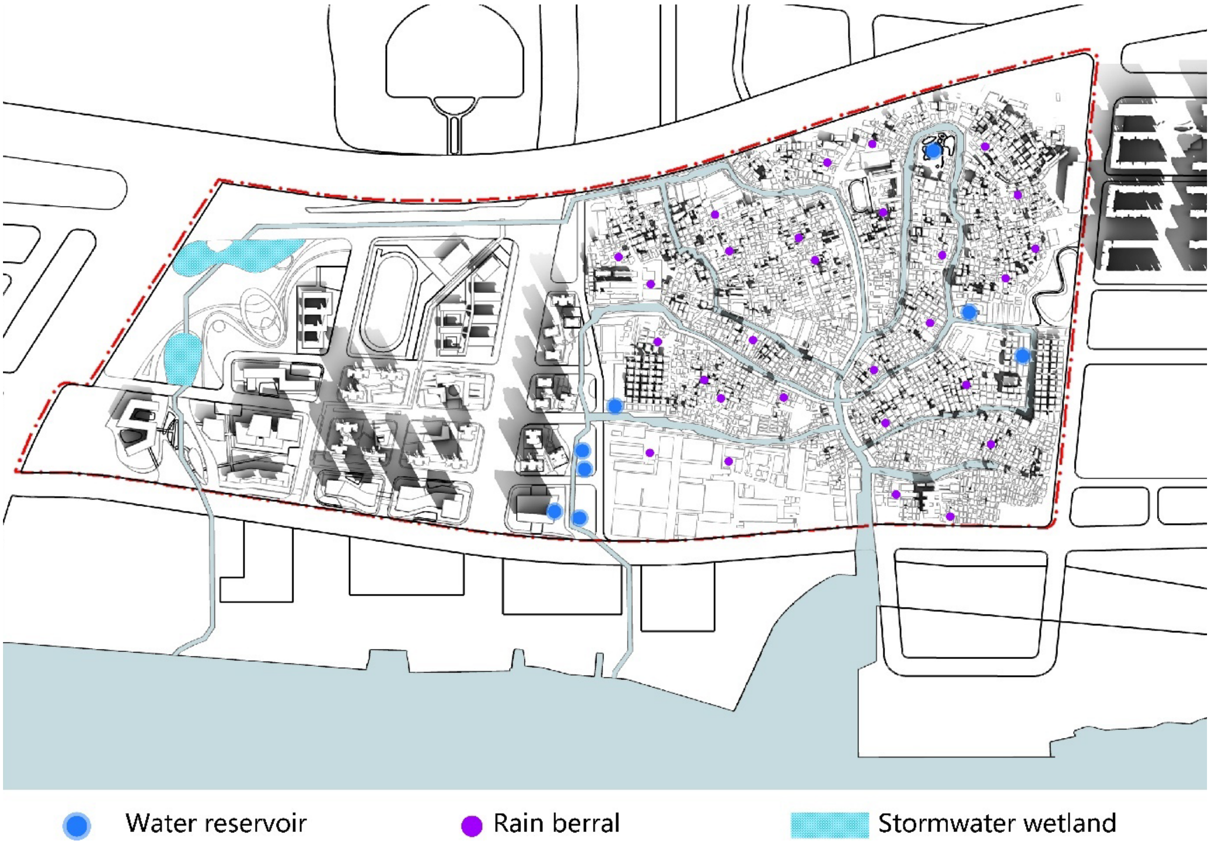


Figure 6-11 Storage facility layout
Source: Self-drawn by the author

6. 2. 3 Retention and Infiltration Facility Layout

The layout of retention and infiltration facilities involves two design strategies to increase the number of retention facilities and to increase the proportion of floodable areas. In general, most retention facilities have rainwater infiltration capabilities; therefore, this paper describes the retention and infiltration facilities in one section. The retention and infiltration facilities used in the Lijiao Village renovation program are as follows:

(1) Green Roof

In the current situation of Lijiao Village, the impervious area mainly originates from the building roofs. Making full use of the building roof space for rainwater runoff control can effectively improve the city's ability to regulate flooding, of which green roofs are a common way. Green roofs can increase the area of urban green space as well as the pervious area of the underlying surface. The main role in the construction of flood resilient cities is the ability to store and delay the formation of roof runoff in the roof, which has now become an effective way to mitigate urban stormwater[50].

It can be seen that the application of green roofs plays a vital role in enhancing the stormwater retention and infiltration capacity of the high building density of Lijiao VillageThe renovation scheme chose to set green roofs on all flat-roofed buildings within Lijiao Village to achieve the best renovation results. Since some of the buildings in Lijiao Village are factories, their sloped roof forms are not suitable for the installation of green roofs. Therefore, green roofs are basically installed on residential buildings. The application of green roofs in the renovation of Lijiao Village is shown in the figure.

Figure 6-12 Application of green roofs in Lijiao village
Source: Self-drawn by the author

[50] Wang Lei, Zhang Shaosong, Liang Jingkun, Ma Aihua, An Qi, Qian Liuyang. Green Roof Stormwater Control and Benefit Analysis Based on SWMM Model[J].Water Resources and Power, 2023,41(02):65-69. DOI:10.20040/j.cnki.1000-7709.2023.20221400.

(2) Rain garden

Rain gardens are smaller-scale green space landscapes with ecological retention ponds as the main expression, and they are also the terminal of urban stormwater management.[51]. By collecting rainwater gathered from roofs, roads, etc., and retaining it in the lower concave rain garden. The rainwater that infiltrates into the soil is stored in the reservoir after being adsorbed by plant roots and purified by soil microorganisms. The saturated rainwater will be discharged into the surrounding river and lake system through the pipe network. As the rainwater management system closest to nature, it can not only contain groundwater and recharge water, but also alleviate urban flooding problems, which is an important way to build a flood resilient city.

The small-scale landscape form of the rain garden is applicable to the design of fragmented public spaces in Lijiao Village. In the renovation scheme, rain gardens are set up in the waterfront resting platforms, courtyards and other non-traffic functional public spaces. The specific rain garden layout is shown in the figure.

[51] Sun Kuili,Sun Kuiyong,Yang Bo.Foreign rain garden construction practice and experience inspiration[J].SHANXI ARCHITECTURE,2014,40(19):216-218.DOI:10.13719/j.cnki.cn14-1279/tu.2014.19.123.

Figure 6-13 Rain garden layout
Source: Self-drawn by the author

(3) Concave green space

A concave green space is a stormwater management facility where the height of the green space is lower than the surrounding ground level. The recessed green space consists of two parts: plants and fillers, which can be flexibly applied to many scenarios such as urban roads, parks, residential areas and schools by adjusting surface runoff, reducing runoff pollutants and replenishing groundwater through infiltration, retention and adsorption.[52].

In the renovation plan, the layout of the recessed green space is mainly determined according to the flooded area and the already existing green space. On this basis, elements such as walking paths and open spaces can be added to further develop its landscape value. The specific layout process and results are shown in the figure.

[52] Zhang Guoqing,Study on the effect of recessed green space on the control of stormwater runoff[J].URBAN ROADS BRIDGES&FLOOD CONTROL,2021(06):154-156+166+20.DOI:10.16799/j.cnki.csdqyfh.2021.06.040.

(c) Determining the concave green space

Figure 6-14 Layout process and results of concave green space
Source: Self-drawn by the author

(4) Sunken square

As one of the most common forms of connection between ground and underground public spaces in cities, sunken squares not only create more open spaces for urban residents, but their special semi-open form and spatial height difference can also be used to temporarily store runoff and detain rainwater during extreme weather..

In the renovation practice of Lijiao Village, the inundated area close to the drainage system can be used to design a sunken square. The sunken square can be used as a floodable area to accept runoff during heavy rainfall and drain to the river nearby, in the daily lives to provide a place for people to activities. The site selection basis and results of the sunken square are shown in the figure.

Figure 6-15 Site selection basis and results of the sunken square
Source: Self-drawn by the author

(5) Permeable pavement

Permeable pavement has a drainage and infiltration function, which can collect rainwater in the drainage process and supplement groundwater sources while infiltrating, alleviating urban flooding in the rainy season and improving the ecological environment of the city[53].

In the renovation scheme of Lijiao Village, permeable pavement can be applied to the design of the pedestrian system and the resting platform on both sides of the river, as shown in the figure.

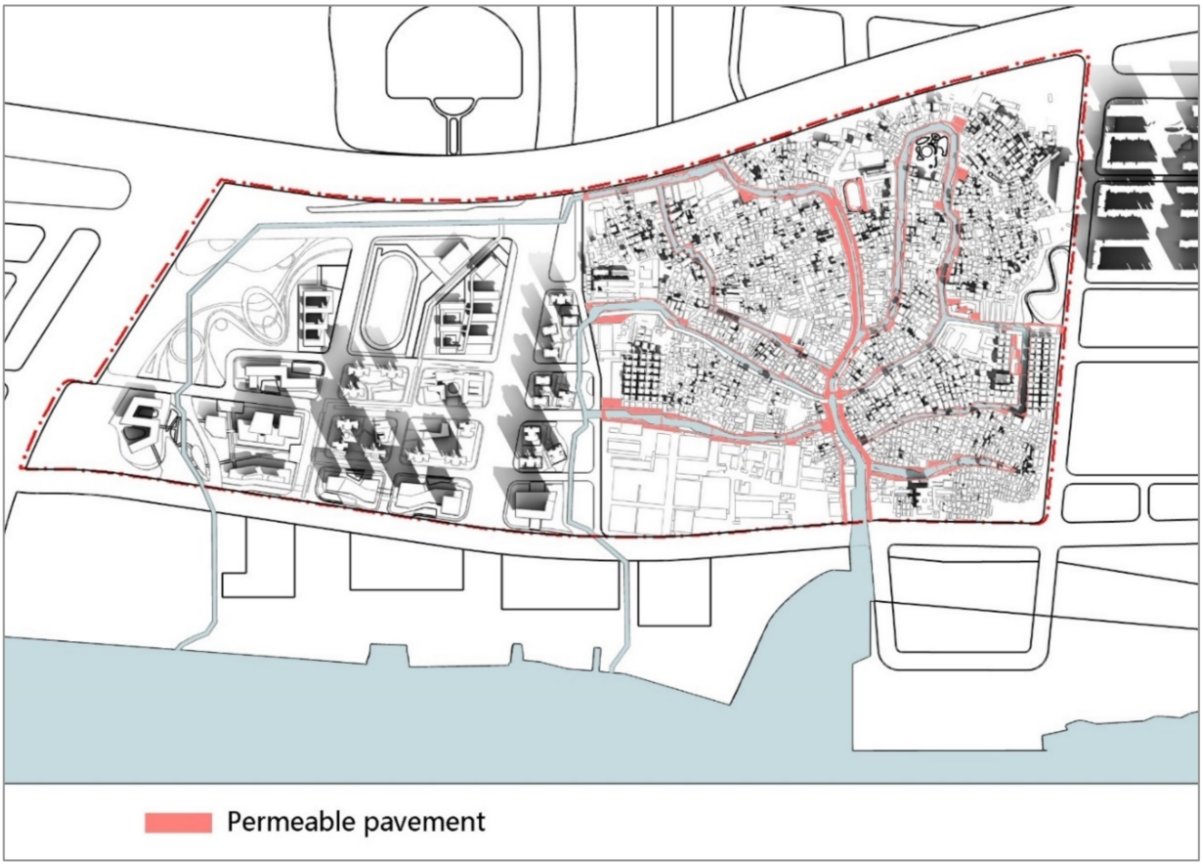


Figure 6-16 Permeable pavement layout
Source: Self-drawn by the author

The overall layout of the retention and infiltration facilities is as follows.

[53] Zhang Xiaoyun. Permeable Pavement Materials and Their Application in Cities[J].China Construction Decoration,2022(14):78-80.

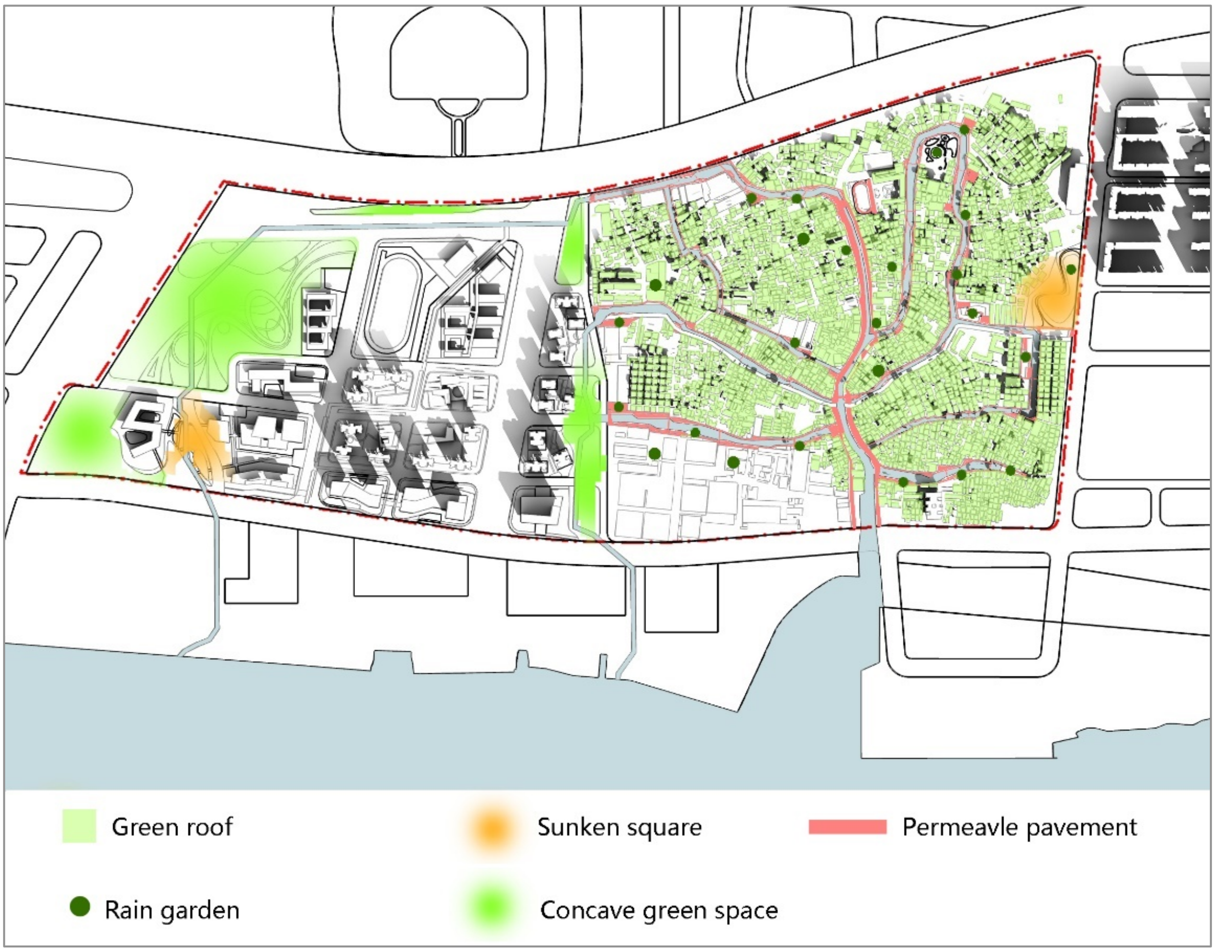


Figure 6-17 Overall layout of the retention and infiltration facilities
Source: Self-drawn by the author

6. 2. 4 Brief Summary

The content of this section is mainly based on the overall resilient water system construction process, in which the resilient drainage system as the basic framework of the water system, rainwater storage, retention and infiltration facilities based on this framework for layout, and connected to the drainage system, together to form a fully functional, diverse components, redundant, robust system.

The complete layout of the resilient water system is shown in the figure below.

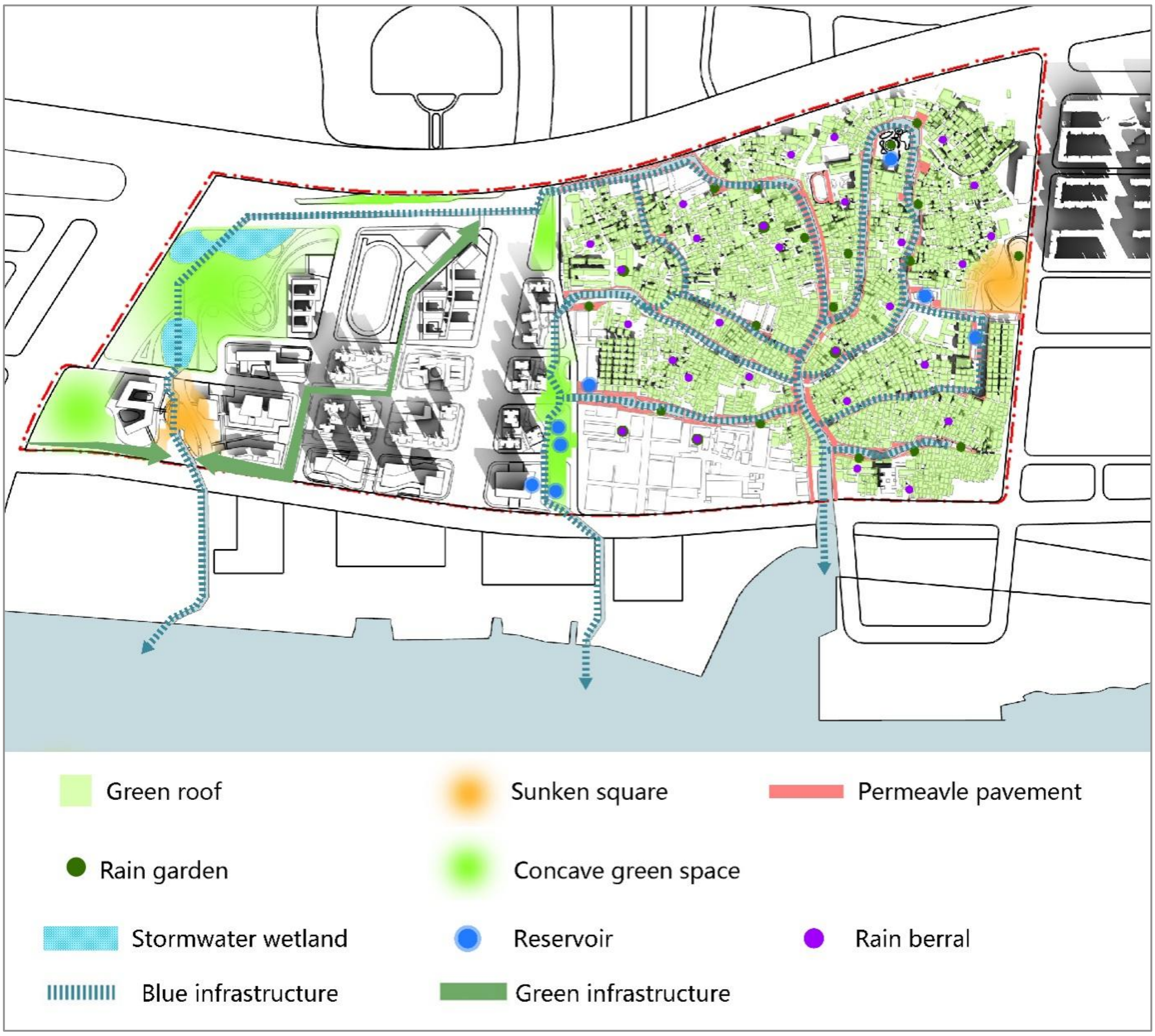


Figure 6-18 Complete layout of the resilient water system
Source: Self-drawn by the author

6. 3　Multifunctional Public Space Shaping

The shaping of multifunctional spaces is a core component of the practice of flood resilient urban design. Resilient water systems are constructed with diverse drainage, detention, storage, and infiltration facilities, such as rivers, concave green spaces, reservoirs, and stormwater wetlands. This section focuses on the design of the public space, combined with the above-mentioned resilient stormwater management facilities, to ensure that the resilient facilities can cope with extreme rainstorms, while exploring the role and value of resilient facilities in improving the quality of the environment, and creating a multifunctional public space with the ability to cope with sudden rain and flooding, but also able to carry daily activities.

Different facilities will bring their unique landscape value and spatial interaction experience to public space, and the diversity of facilities also gives the combination of various facilities and other public space elements in public space design more diversity and more possibilities to be shaped. In this paper, three characteristic and representative public space types are chosen to implement the public space of Lijiao Village, namely, street, community park, and sports field.

Figure 6-19 Location of street, community park and sports field
Source: Self-drawn by the author

6. 3. 1 Street

In the construction of the macro resilient water system, the renovation scheme restores the original water system of the village and uses the water system as the framework of the whole resilient water system. These water systems are also homogeneous with linear spaces such as pedestrian systems and roads, and in this pattern of spatial composition it is easy to create public spaces that are resilient and interesting. The elements and forms of the street space are shown in the figure.

Figure 6-20 Elements and forms of the street space
Source: Self-drawn by the author

Huanxiu Street is the only street within Lijiao Village that connects the exterior roads to the east and west. Therefore, carriageways are provided in the renewal of Huanxiu Street to facilitate urban traffic, and also to enhance the road's ability to cope with rain and flooding through micro-terrain modification. In addition, the eastern part of Huanxiu Street is located in a inundated area, and the shaping of the street space in this part needs to take into account design strategies to improve floodability. This shows that Huanxiu Street has the most complete traffic and landscape elements of the village street system and is the only street where inundated areas exist. Therefore, this section introduces the practice of multifunctional shaping of street space, taking Huanxiu Street as an example.

(a) Connectivity (a) The relationship between inundated area and Huanxiu Street (a) Scope of Huanxiu Street

Figure 6-21 Street site selection basis
Source: Self-drawn by the author

The types of streets can be classified as inundated streets and non-inundated streets in terms of how they respond to rainfall flooding and whether they are located in the inundation area. Considering the accessibility between the streets on both sides of the river or the sunken space, the street system will set up air corridors as nodes of the street space in combination with buffer spaces such as waterfront platforms at approximately every 100 meters or at the intersection of roads. And because of the different stormwater management facilities used in the inundated and non-inundated areas, the two street space types are designed differently.

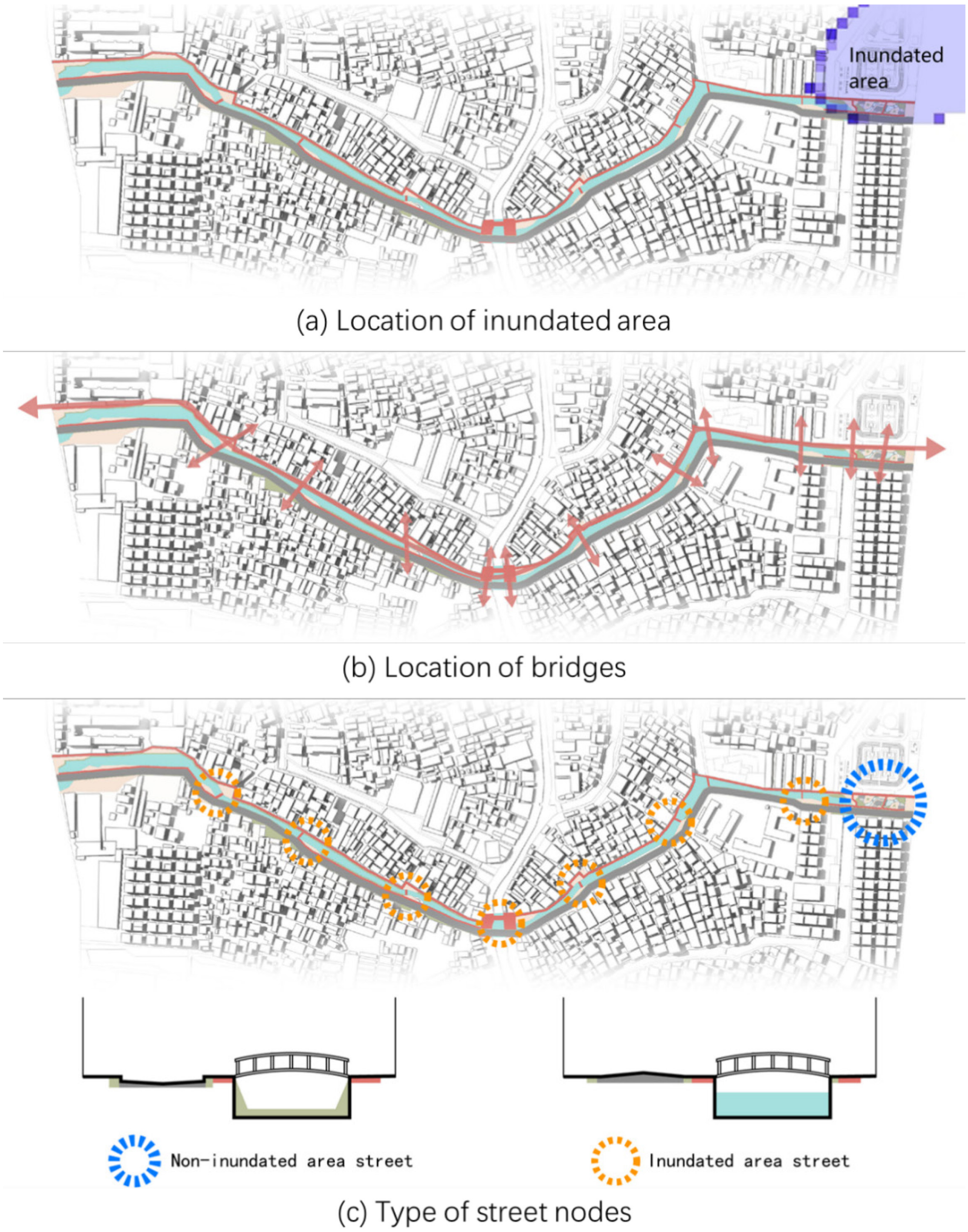


Figure 6-22 Generation of street nodes
Source: Self-drawn by the author

(1) Inundated area streets

The shaping of the street space in the inundated area is exemplified by the street node in the figure.

Figure 6-23 Site of inundated area street node
Source: Self-drawn by the author

Unlike streets in non-inundated areas, the composition of streets in inundated areas does not include a river, but rather a sunken space in which the river is replaced. Because rivers are impervious surfaces, and sunken courtyards consisting of green space, permeable pavement and other resilient facilities have a strong infiltration capacity, and the sunken terrain modification also allows streets located in inundated areas to retention and temporary storage of excess runoff during heavy rainfall, reducing the drainage pressure on the rivers. The master plan of the street node in the inundated area is shown in the figure.

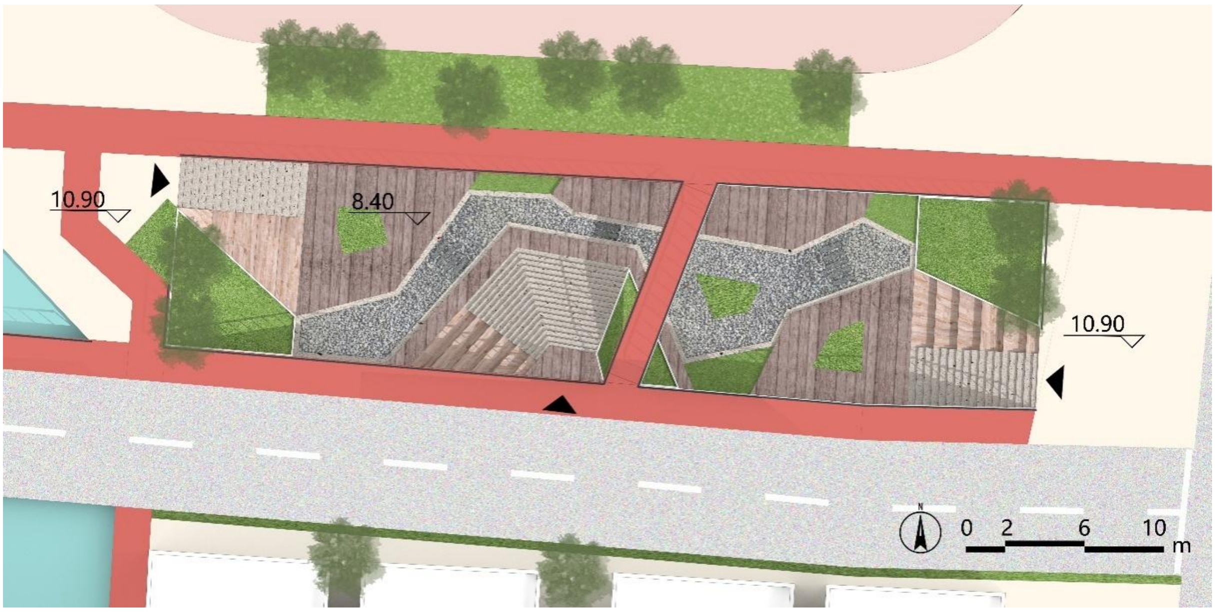


Figure 6-24 Master plan of inundated area street node
Source: Self-drawn by the author

Considering the connectivity between the residential areas and sports fields on both sides of this street node, the street design in the inundated area adds a air corridor over the sunken space, and also increases the level of the street space.

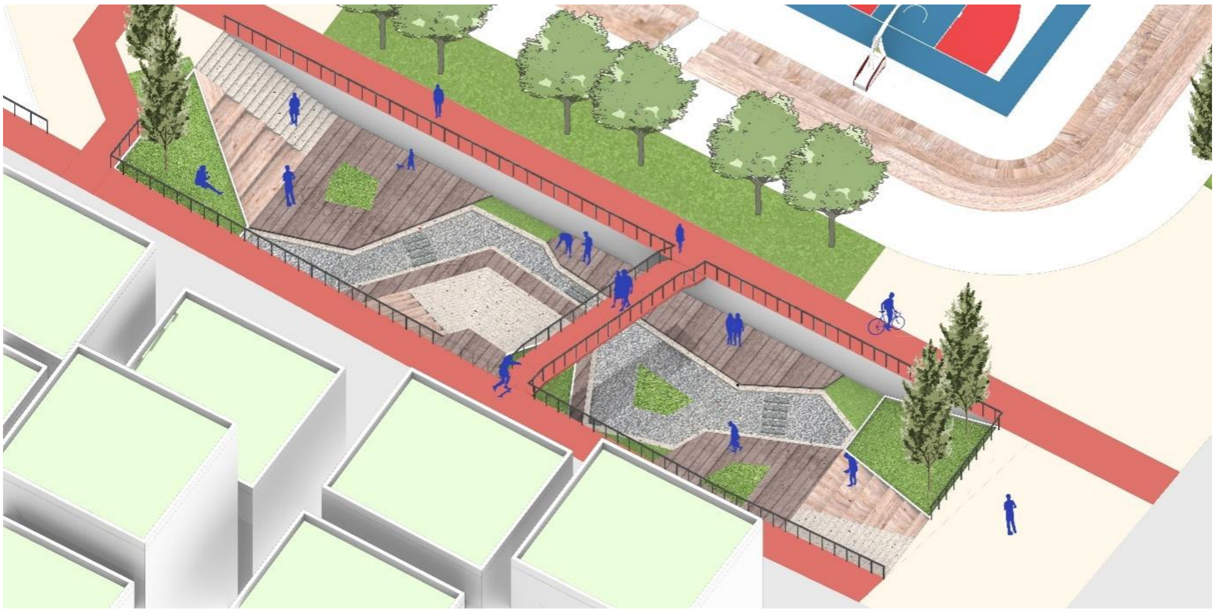


Figure 6-25 Aerial view of inundated area street node
Source: Self-drawn by the author

The resilient stormwater management mechanism can be understood from the section of the street space nodes in the inundated area.

During normal rainfall, the concave V-section design of the road will collect rainwater in the middle rather than on the entire road surface, minimizing the impact of road surface water on vehicular traffic; Vegetative swales on both sides also prevent rainwater collected by the road from spreading into the residential area; Permeable pavement design for pedestrian walkways to enhance the flood resilience of the street; The sunken space between the pedestrian walkways can be used to retention and infiltrate rainwater into the ground through permeable wooden decks, gravel pavement, and green space.

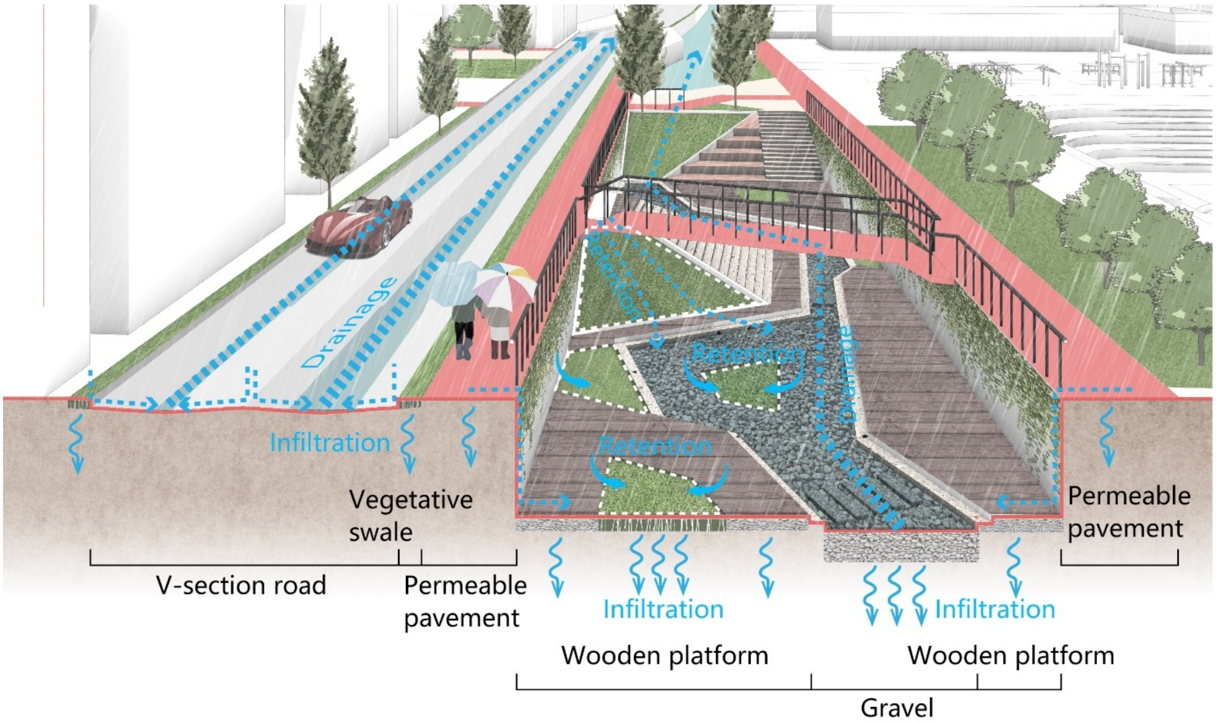


Figure 6-26 Resilient stormwater management mechanism of inundated area street
Source: Self-drawn by the author

When experiencing extreme rainstorms, the street node is more prone to waterlogging than other street nodes because it is in the inundated area. The concave roadway as well as the sunken courtyard can serve as a space to detention and temporarily store stormwater at this time, and then drain it to the river when the storm is over. On the one hand, it relieves the drainage pressure of the river, and on the other hand, it provides safe traffic space for pedestrians in extreme weather.

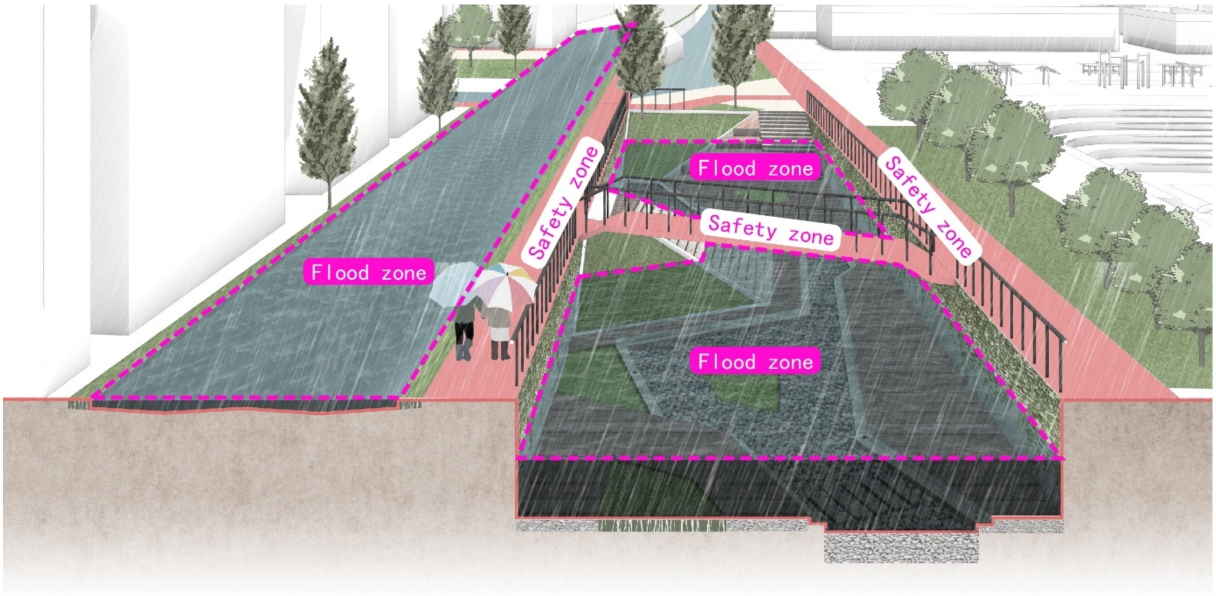


Figure 6-27 Provide safe areas for pedestrians during extreme weather
Source: Self-drawn by the author

After comparing and calculating the inundation volume and the volume of runoff accommodated by the sunken space and other storage and retention facilities, the inundation elevation due to rainfall for four return periods of 10, 20, 50 and 100 years is shown in the figure. The sunken space of this street node in combination with other storage and retention facilities can better reduce the impact of flooding on the village.

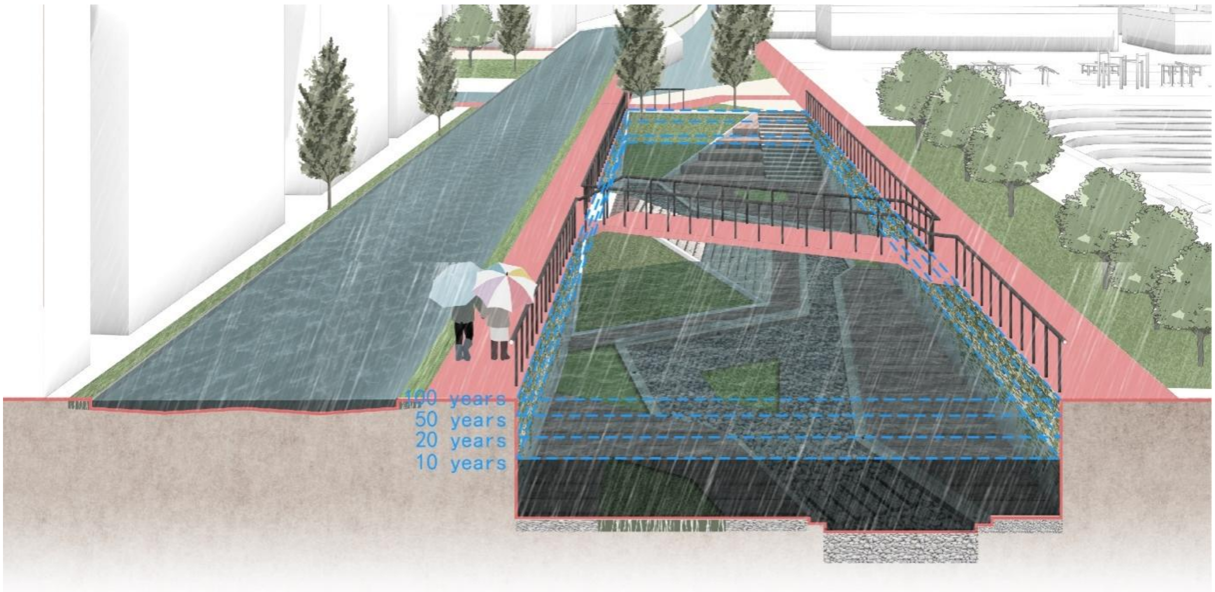


Figure 6-28 Inundation elevation due to rainfall for four return periods
Source: Self-drawn by the author

The sunken courtyard can be used in a variety of scenarios in different weather conditions.

Under normal rainfall, the wooden deck and stone slab above the gravel pavement are protected from ponding water, which is retained on the gravel pavement and forms a stream landscape. At this time, people can pass through the sunken courtyard normally without being troubled by waterlogging.

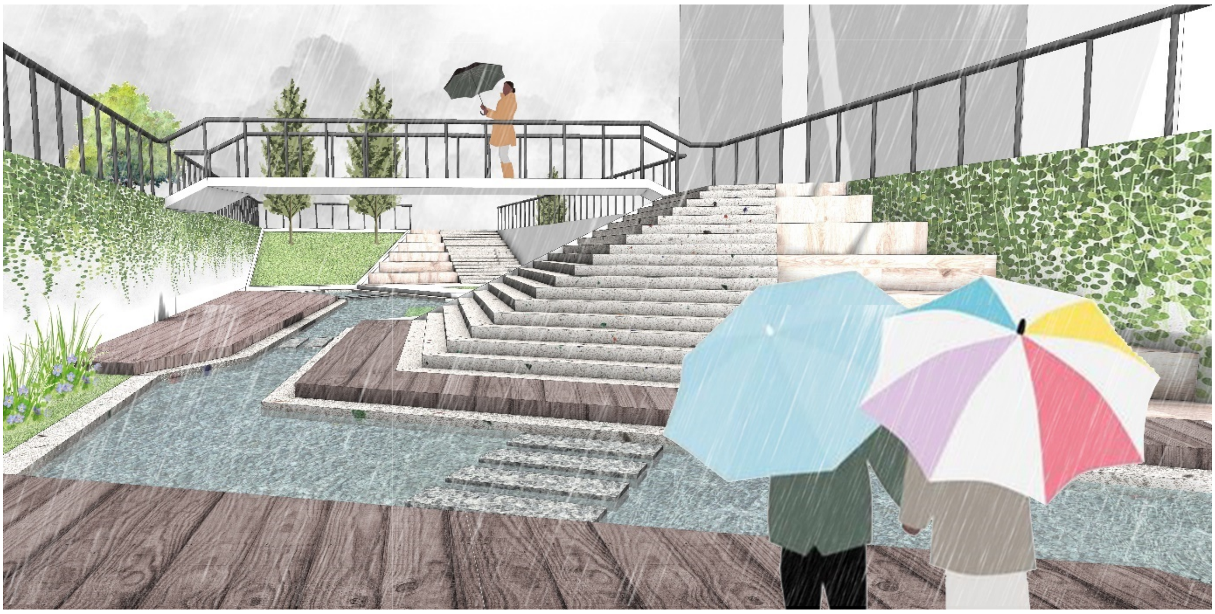


Figure 6-29 Usage scenarios in mormal rainfall weather
Source: Self-drawn by the author

After the rainfall is over, the water on the gravel road will slowly infiltrate, during which time the stream landscape will remain for some time for children to play.

Figure 6-30 Usage scenario after the end of rainfall
Source: Self-drawn by the author

In daily weather, the sunken courtyard has multiple uses. The steps connecting the ground can be used for rest, entertainment and communication, the wooden decks and steps can provide space for people to walk, and the air corridors make it easier for pedestrians to pass on the sidewalks on both sides, while the use of various materials adds to the landscape level and interest of the space.

Figure 6-31 Daily weather usage scenarios
Source: Self-drawn by the author

(2) Non-inundated area streets

The non-inundated area street space is shaped by the street node in the figure as an example, and its design should take into account the integration with blue and green infrastructure.

Figure 6-32 Site of Non-inundated area street node
Source: Self-drawn by the author

On the one hand, blue and green infrastructure can improve the drainage, retention and infiltration capacity of streets. Impervious roads are where streets are weak in coping with rain and flooding, but by micro-topography, designing the road section into a triangle, and setting up retention and infiltration facilities such as grass vegetative swales and rain gardens on both sides of the road, it is possible to prevent waterlogging on the road, or runoff generated from the road from harming other areas. In this way, runoff from the road surface will flow from the road surface to the vegetative swales and rain gardens on both sides, and when both reach their retention limits, the runoff will join the river and eventually discharges to the outside Pearl River. In addition, installing permeable pavement in the pedestrian system to increase its infiltration capacity also helps to improve the flood resilience of the street. This shows that all resilient facilities and spatial structures are organically integrated and complementary.

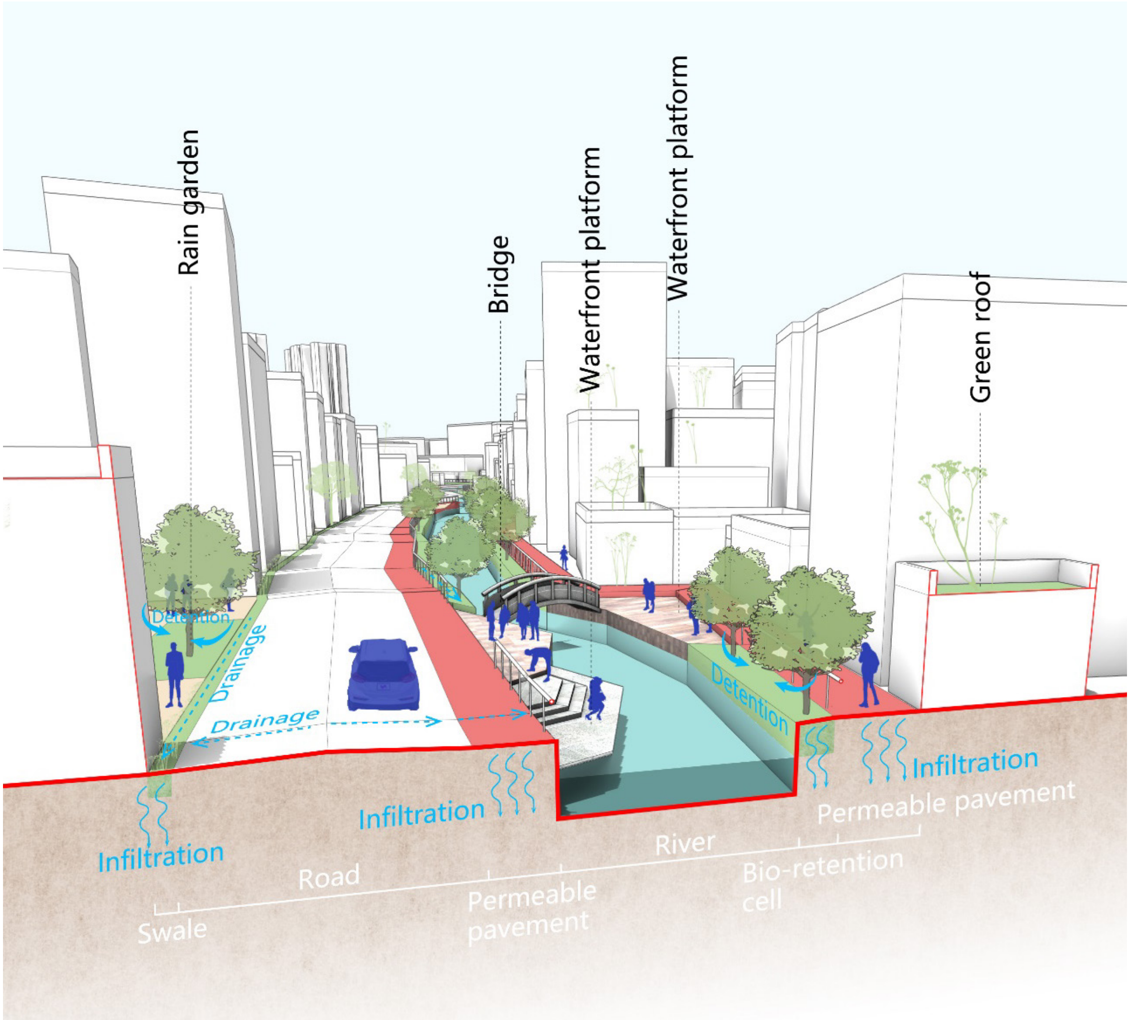


Figure 6-33 Resilient stormwater management mechanism of non-inundated area street
Source: Self-drawn by the author

On the other hand, blue and green infrastructure can beautify the street environment and enhance the environmental quality of the street. Rain gardens play a role in the design of roadside buffer spaces to add layers to the landscape and help improve the environmental microclimate. Vegetative swales on both sides of the road not only provide visual guidance for drivers and pedestrians, but also create a buffer space for the road and the buildings next to it. The design of the street space also makes use of the river to set up three spatial elements: a waterfront platform, a bridge and greenery along the river. Waterfront platforms increase the possibility of interaction with water and enrich people's water-friendly experience; The waterfront platform connecting the two banks with a bridge increases the accessibility of the space on both banks while adding landscape elements; The design of greenery along the shore further enriches the landscape level on the basis of the above-mentioned space, and also helps to improve the environmental microclimate.

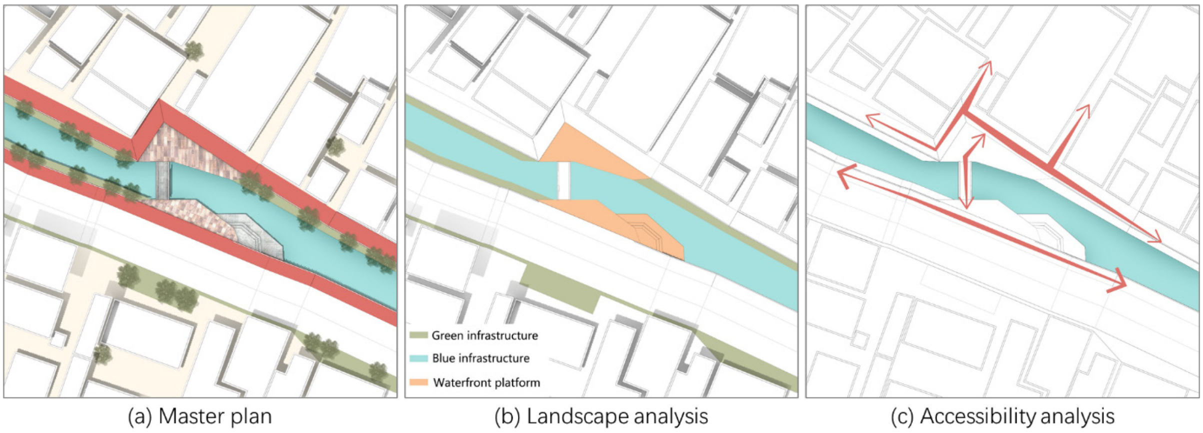


Figure 6-34 Environmental quality of the street ananlysis
Source: Self-drawn by the author

The waterfront platform, tree and bridge also correspond to the three regional spatial elements of dock, banyan tree and arched bridge in traditional net water villages. These three elements are usually composed as street nodes and stay spaces in traditional villages for residents to rest and relax. In the design of public space, the spatial elements of these three traditional villages are translated by combining modern design approach to increase the spatial level and landscape of the street and enrich people's walking experience.

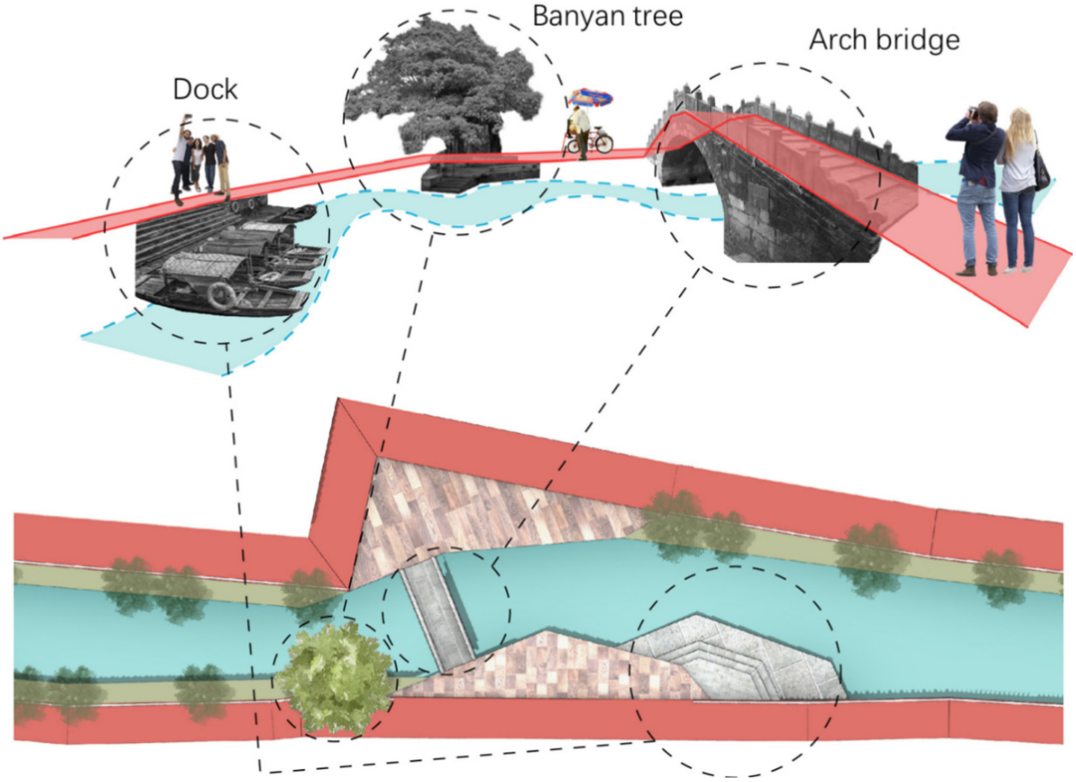


Figure 6-35 Application of traditional village landscape elements
Source: Self-drawn by the author

Figure 6-36 Non-inundated street usage scenarios
Source: Self-drawn by the author

6. 3. 2 Community Park

The community park in Lijiao Village is the main public place for residents to conduct their daily leisure activities and is one of the most crowded public spaces in the village, so it is necessary to enhance the environmental quality of the park and thus stimulate its vitality.

The master plan of the community park is shown in the figure. Its function in the resilient water system is storage and retention, mainly through facilities such as reservoirs and concave green space to achieve, this type of facility has a high potential landscape value。 Therefore, the community park can be shaped by adding an elevated corridor to further take advantage of the landscape of the blue and green infrastructure and enhance the interest and aesthetics of the community park.

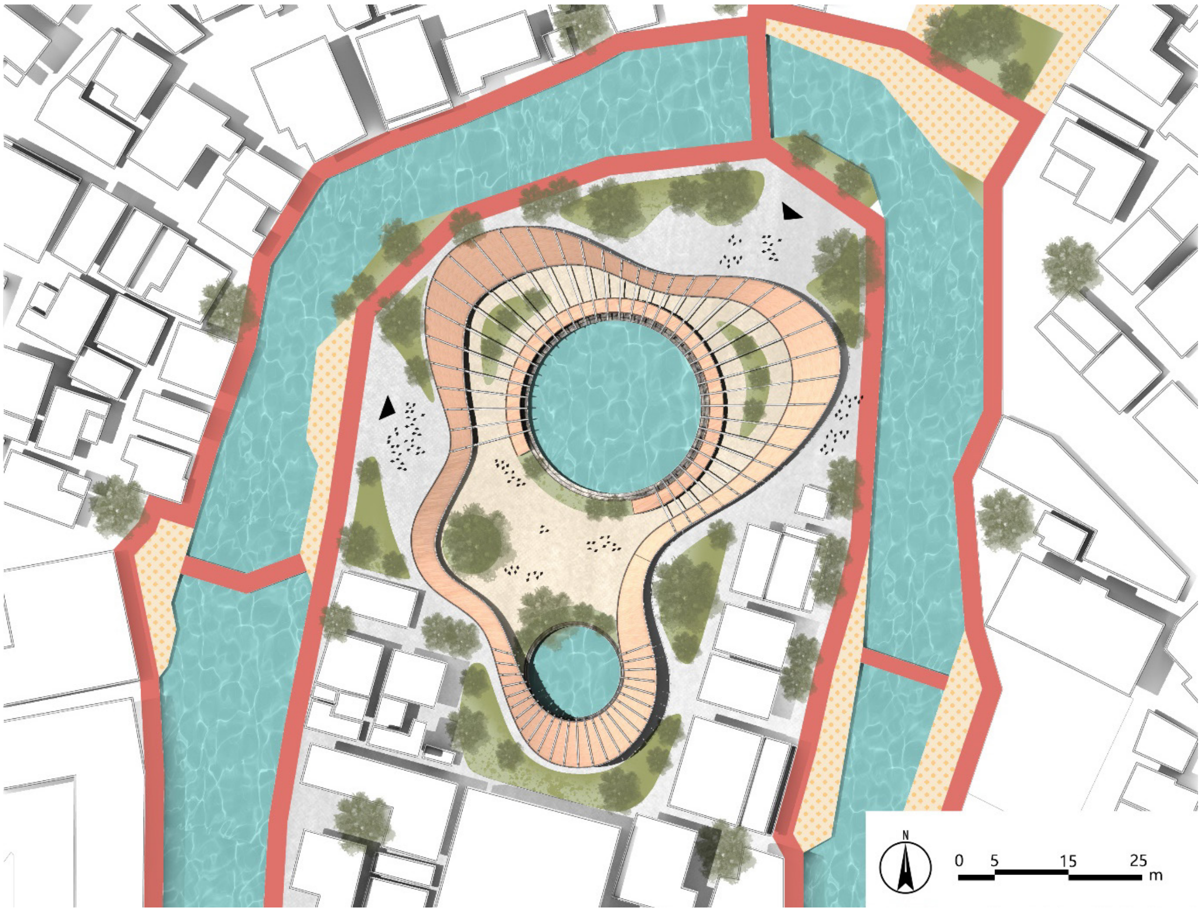
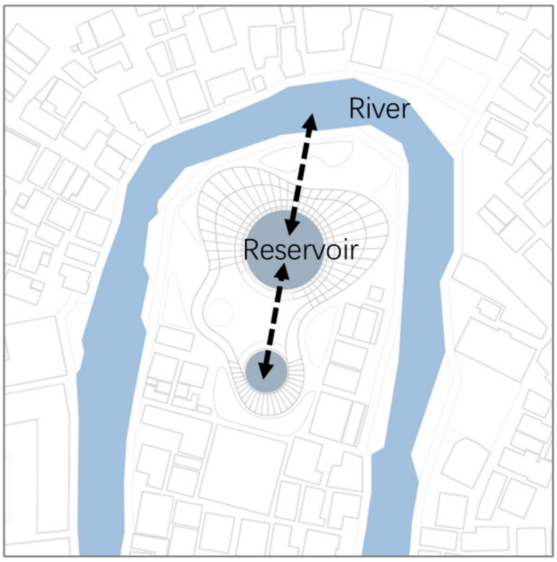
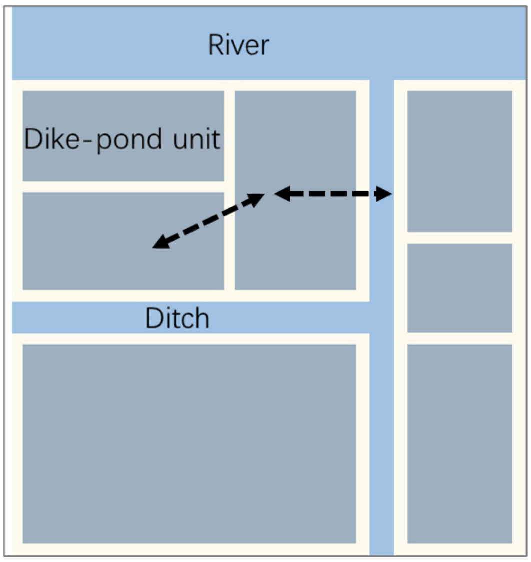


Figure 6-37 Master plan of community park
Source: Self-drawn by the author

The design of the community park retains the circular square in the original site. Considering the diversity of landscape elements in the park and the weak storage capacity of the park, this paper transforms the square into a reservoir and adds an extra reservoir based on this, using the enclosed space formed by the surrounding buildings. On the one hand, it enables hydrological exchange between the reservoirs like the dike-pond system, which can be dynamically adjusted during stormy weather, thus enhancing the storage capacity. On the other hand, the cistern is one of the important landscape elements in the park. In the layout, the location of the cistern can be used to control the primary and secondary relationship and form of the master plan.



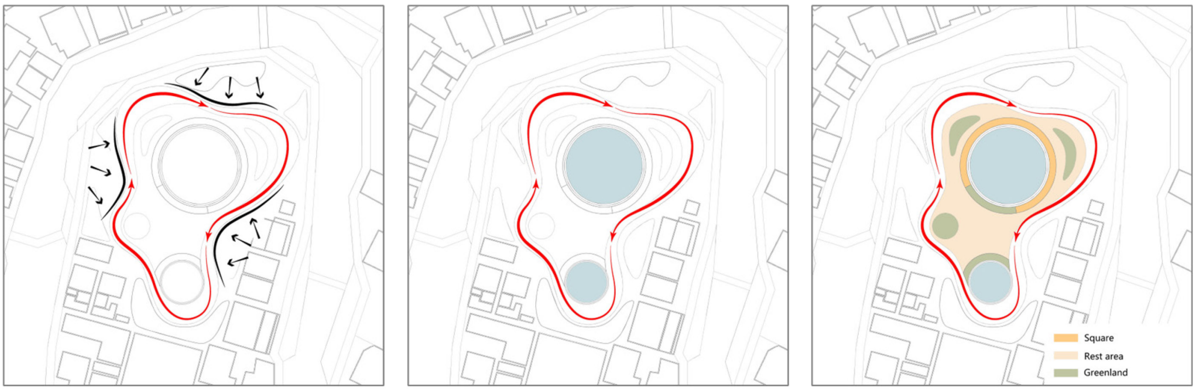
(a) Hydrological exchange between reservoir and river



(b) Hydrological exchange between dike-pond unit and ditch

Figure 6-38 Design of water storage system based on dike-pond system
Source: Self-drawn by the author

The two reservoirs with a clear primary and secondary relationship provide the morphological basis for the design of the park's touring and recreational pathway, which is combined with the park entrance and the setback space from the surrounding buildings to form the basic form of the pathway. The resting space and green space between the walkway and the reservoir serve to enrich the visiting experience of the residents.



(a) Setback entrance and building buffer area

(b) Generating pathway form based on the reservoir

(c) Addition of square, rest area and Greenland between the pathway and the reservoir

Figure 6-39 Generation of park form
Source: Self-drawn by the author

In addition, the southern end of the pathway is provided with a second floor resting platform in accordance with the height of the surrounding environment. On the one hand, the design of different heights adds interest to the space, and on the other hand, it can provide people with a rich view of the landscape under different weather conditions.

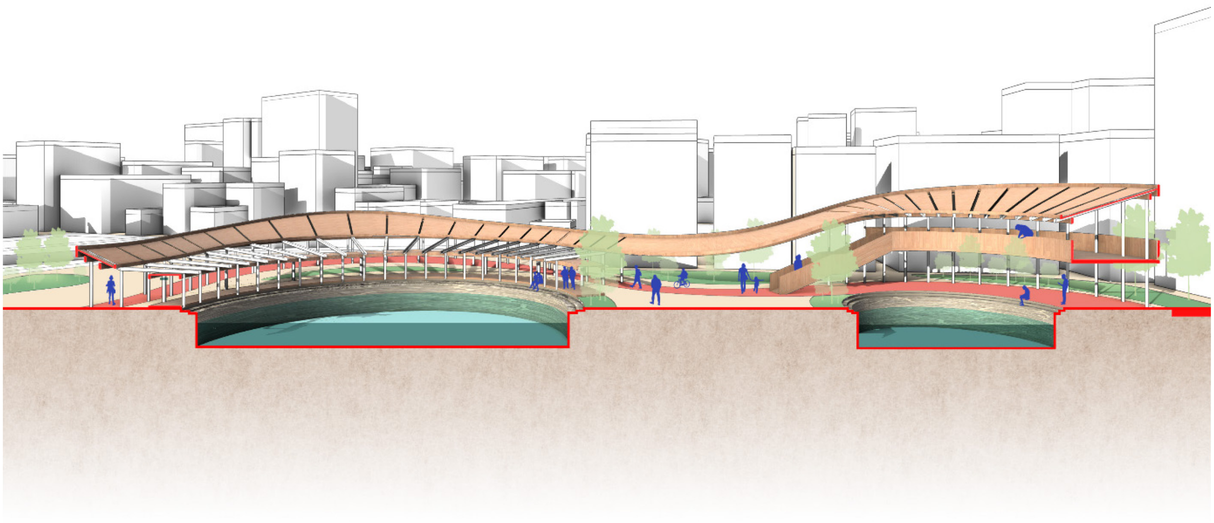
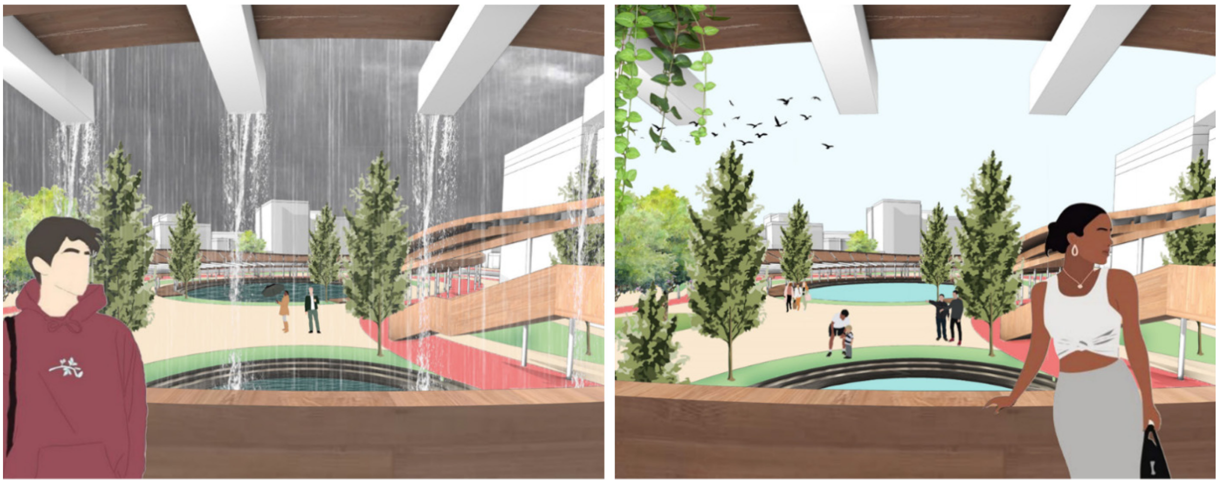


Figure 6-40 Section of the community park
Source: Self-drawn by the author



(a) Stormy weather (b) Sunny weather

Figure 6-41 Usage scenarios in different weather
Source: Self-drawn by the author

The roof form of the walkway is generated according to the low south and high north park surroundings, providing shelter from the rain in case of heavy rain. In addition, the rainwater collected on the roof can be discharged to a reservoir through a drainage pipe on the roof and then to the river outside the park.

Several green areas have been installed in the park to enhance the stormwater retention capacity. Also, it can share the runoff for the reservoir during heavy rainfall.

The mechanism for operating the park's resilient stormwater management facilities is shown below.

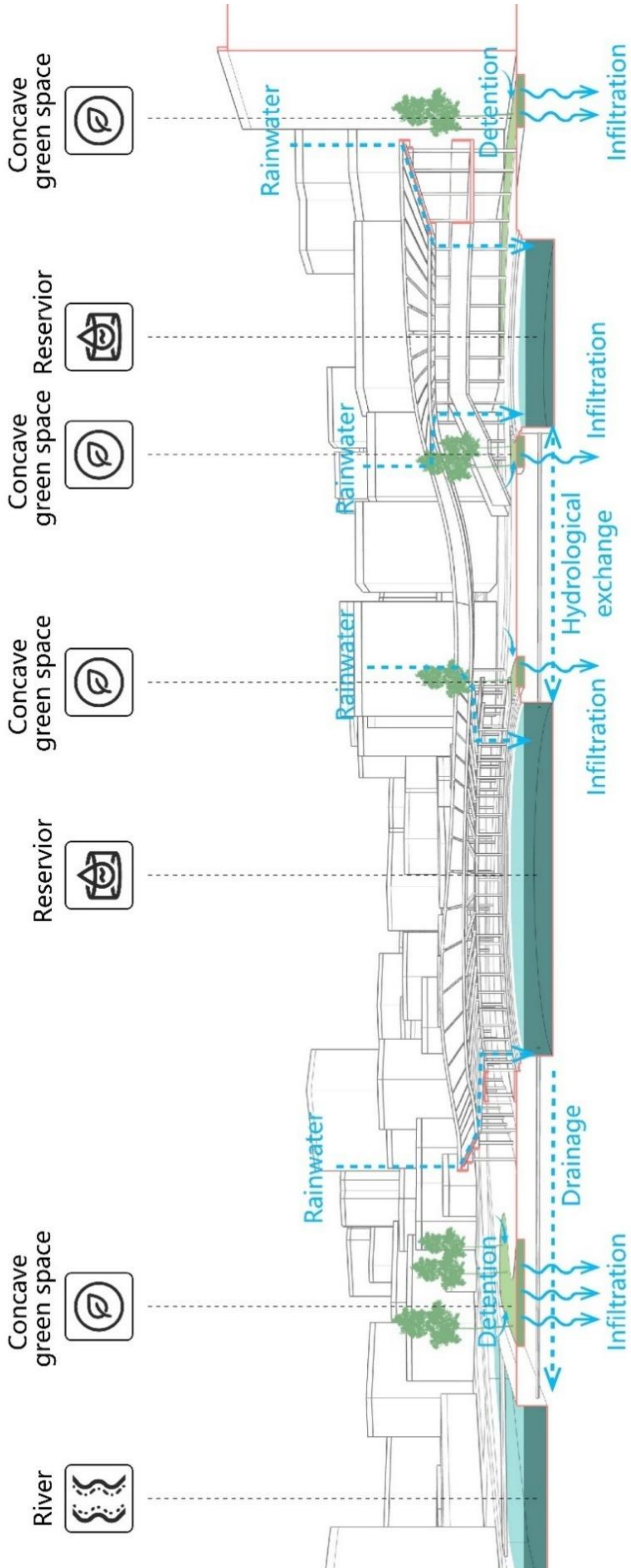


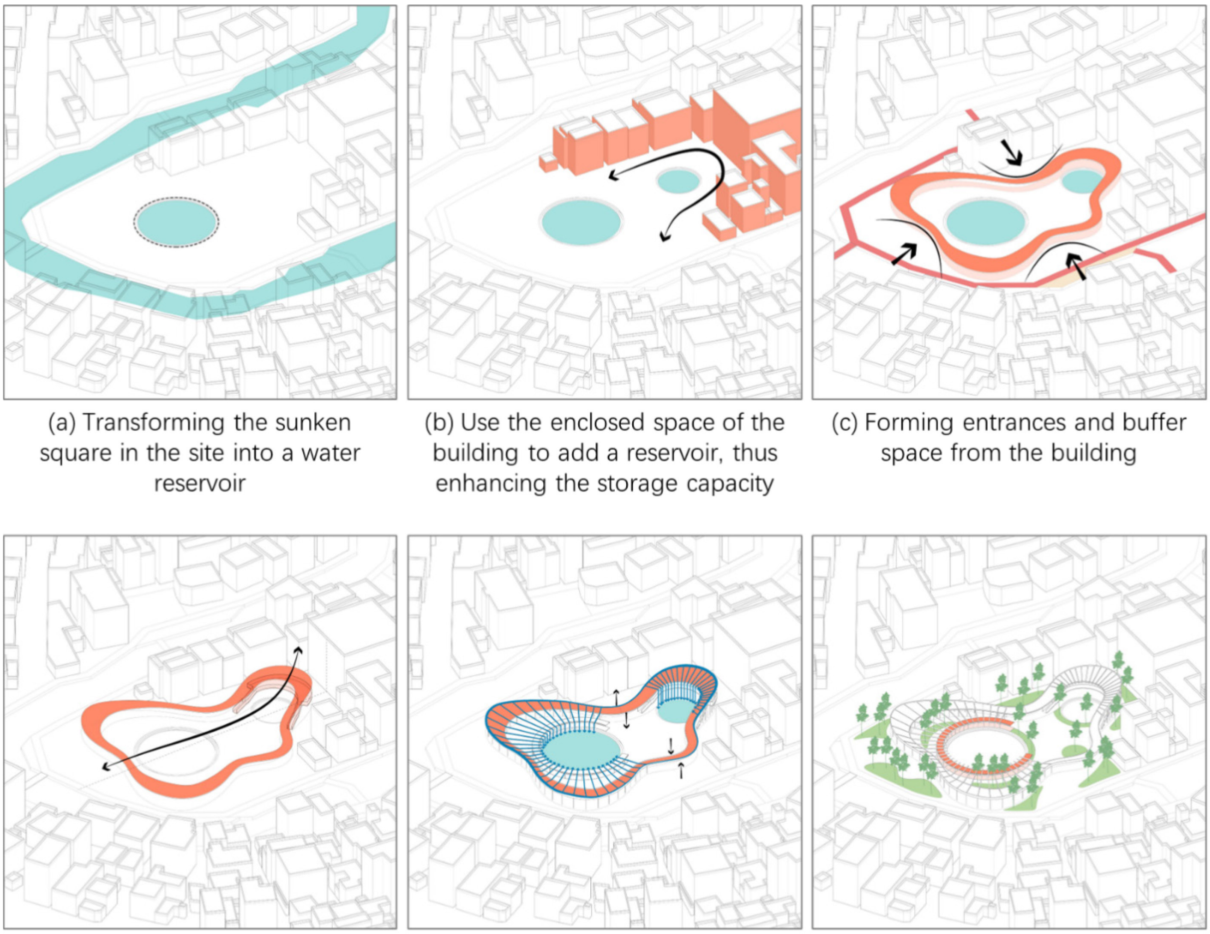
Figure 6-42 Resilient stormwater management mechanism of community park

Source: Self-drawn by the author

While collecting and storing rainwater on rainy days, the overhanging drainage pipes on the roof present the process of rainwater confluence through the form of water curtain in the shaping of the park landscape, forming a unique rainwater landscape.

Figure 6-43 Water landscape formed by roof drainage
Source: Self-drawn by the author

In summary, the generation process of community parks and as shown in the figure. First, the sunken square reserved for the site was transformed into a landscape reservoir. Then use the enclosed space of the buildings around the park to add another reservoir, and on this basis connect the two reservoirs together to enhance the water storage capacity and dynamic regulation of runoff. Then adjust the shape of the pathway according to the entrance and the buffer space between the pathway and the building, and set the roof of the pathway according to the height of the surrounding environment on this basis to ensure that the walkway can be used normally even in rainy days. The roof slope is adjusted so that most of the runoff collected by the roof during rainy days can be discharged into two reservoirs. Finally, stormwater retention facilities such as concave green space and common green space are incorporated to enhance flood resilience and landscape effects.



(a) Transforming the sunken square in the site into a water reservoir

(b) Use the enclosed space of the building to add a reservoir, thus enhancing the storage capacity

(c) Forming entrances and buffer space from the building

(d) Determine the form of the corridor roof according to the height of the surrounding buildings

(e) Changing the slope of the roof and setting up roof drains to facilitate rainwater collection

(f) Setting up green infrastructure to enhance flood resilience and environmental quality

Figure 6-44 Community park design process

Source: Self-drawn by the author

After the above scheme generation process, the final effect of community park space shaping is shown in the figure.

Figure 6-45 Axonometric view of community park
Source: Self-drawn by the author

6. 3. 3 Sunken Sports Field

Given the high population density of Lijiao Village and the limited public space in the village that does not provide sufficient public activity space for residents, adding diverse public activity spaces is necessary for the renewal of Lijiao Village. The village of Lijiao has a depression area located to the east of its boundary adjacent to the road that can serve both residents within Lijiao and those outside the village for recreational sports, making it ideal as a site for a public sports field. However, according to the results of the inundation analysis in

Chapter 4, this site would be inundated during a storm with a return period of 10 years or more.

Therefore, the design of a multifunctional sports field that can accommodate people for sports and recreational activities on a daily basis and temporarily hold and detain runoff during heavy rainstorms to relieve the village's stormwater pressure is an important part of the renewal of Lijiao Village.

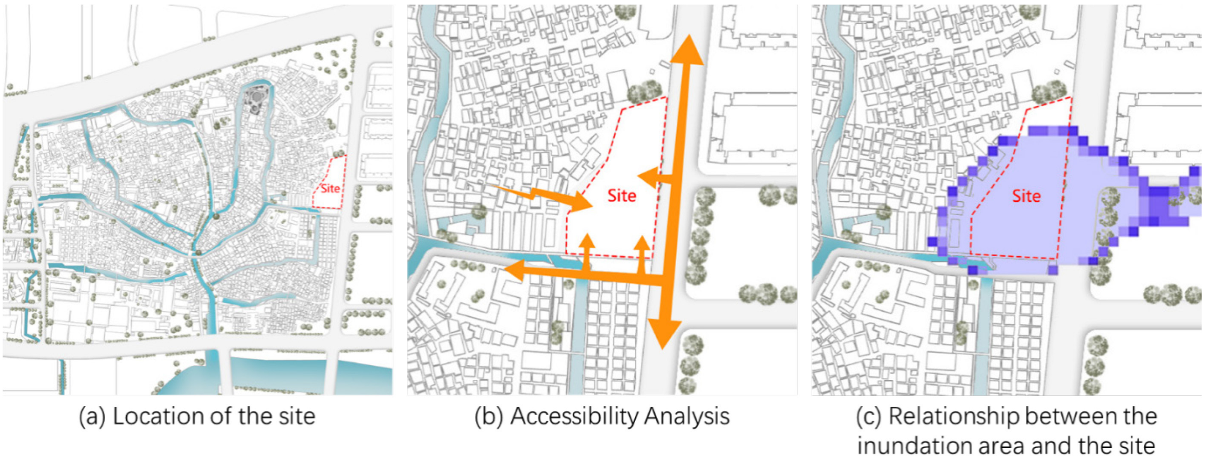


Figure 6-46 Site analysis
Source: Self-drawn by the author

According to the field research, the age composition of the population in Lijiao Village includes children, youth, and elderly. Children are mainly from the village's elementary schools and kindergartens, but also from the children of village residents.青 They are mainly migrant workers who come to Guangzhou, or staff of stores in the village, and generally tenants of residences in Lijiao Village. The elderly are generally local residents within the village of Lijiao, and a few are tenants.

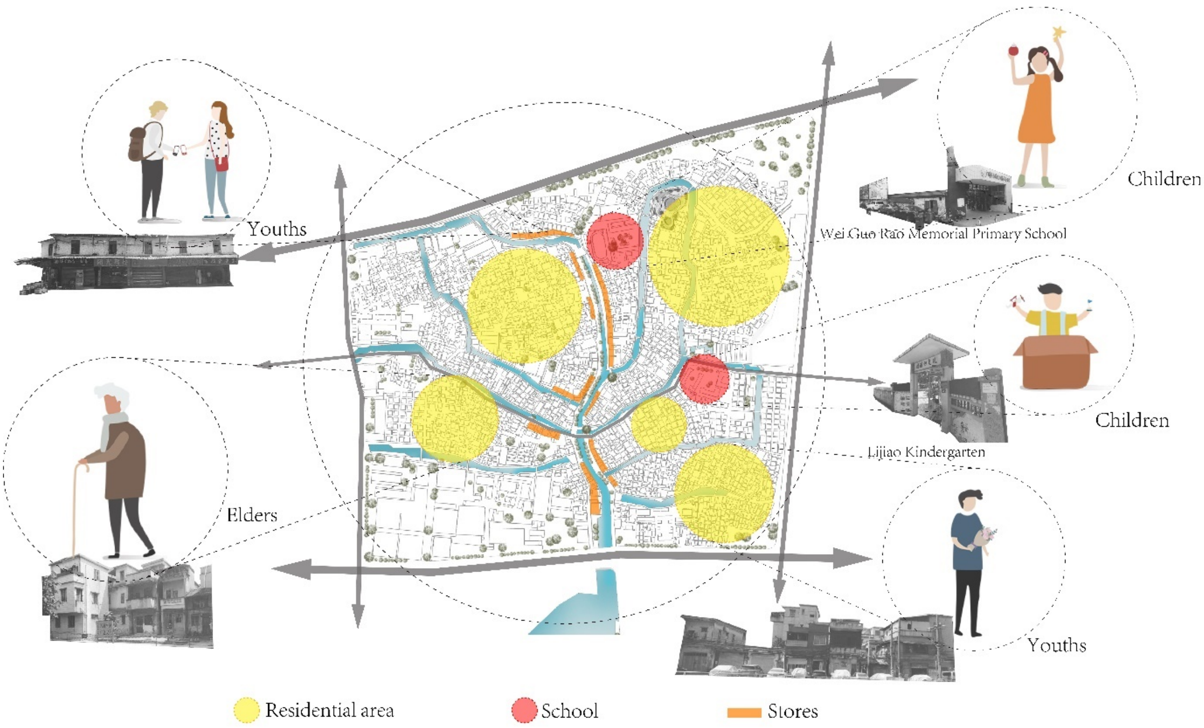


Figure 6-47 Crowd composition analysis
Source: Self-drawn by the author

Different age groups have different needs for daily activities; children's activity needs should focus on vitality and education; youth's activity needs are dominated by sports, parties and other leisure activities involving different levels of intensity; The daily activities of the elderly should focus on safety and wellness and should not be strenuous sports. Therefore, creating sites that meet the daily activity needs of residents of different age groups is the key to shaping multifunctional public spaces.

The following is a list of activities that are suitable for residents of different age groups.

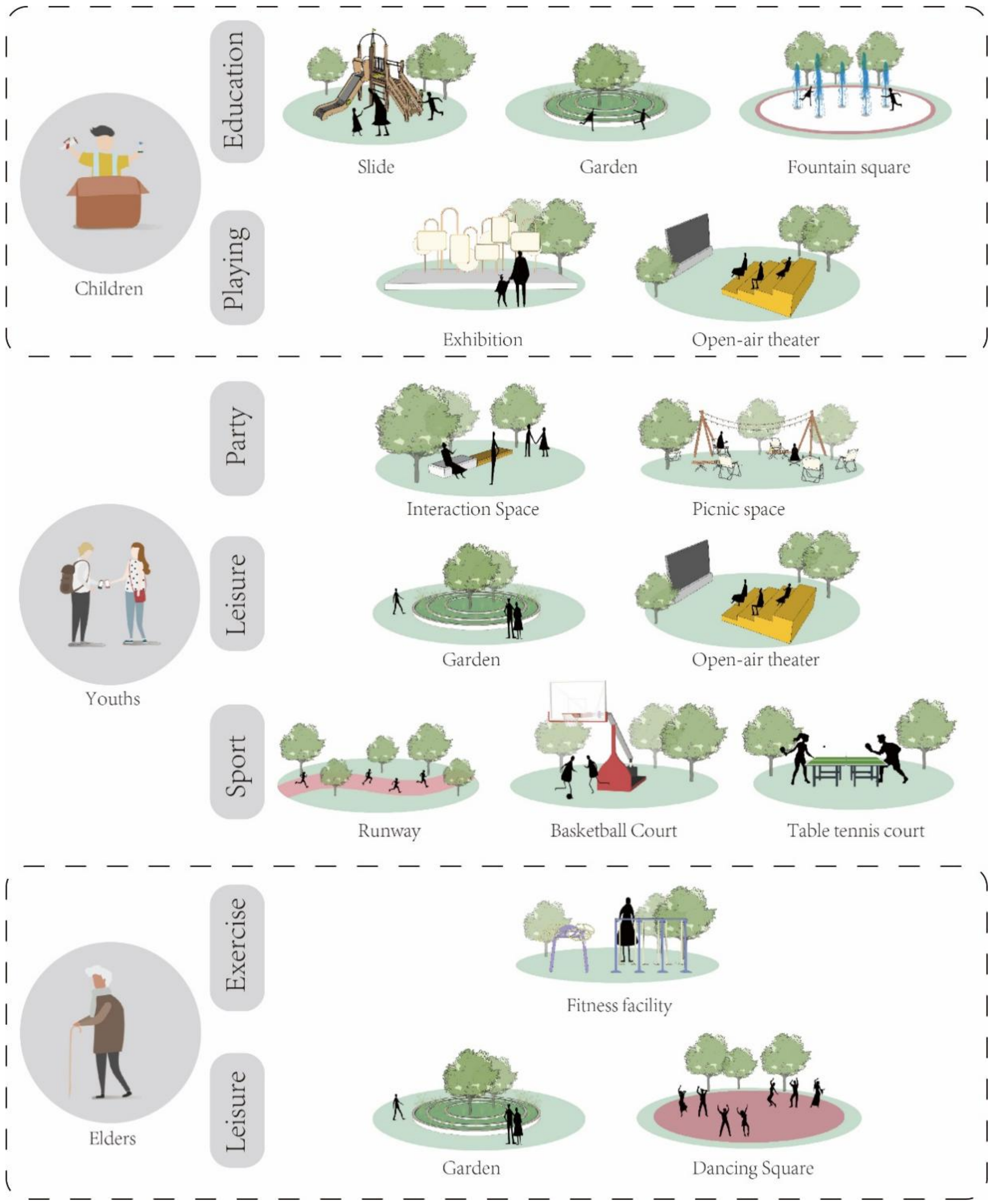


Figure 6-48 Functional Requirements Analysis
Source: Self-drawn by the author

Since the site is oriented north-south, the east and west sides are longer and the south and north sides are shorter, which is more in line with the layout requirements of most sports fields. Therefore, in the process of site design, the main functions can be laid out based on the north-south axis, and then the functional sites, buffer spaces and site entrances that require less area can be laid out to the east and west.

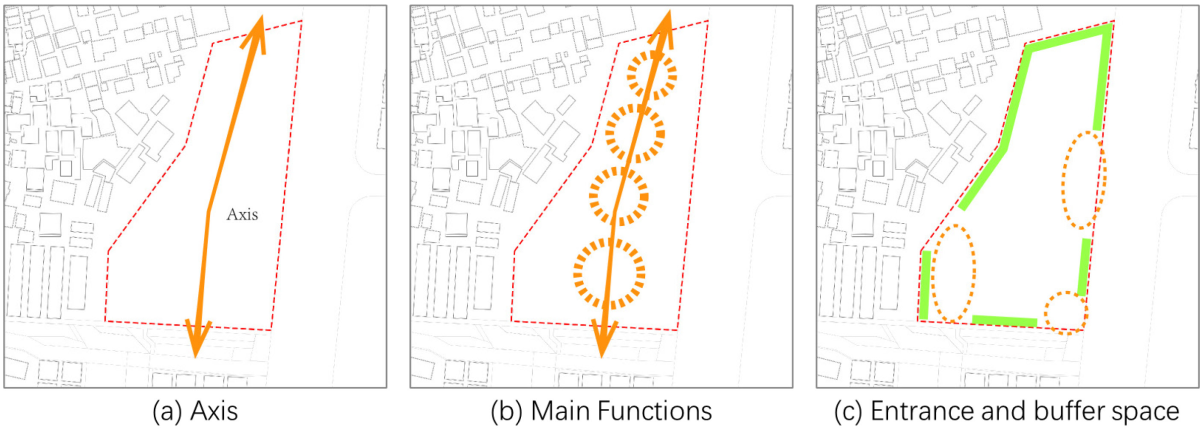


Figure 6-49 Design Concept
Source: Self-drawn by the author

The site of the sports field is depressional terrain, which can easily become a inundated area during stormy weather. According to the strategy of improving the floodability and shaping the multifunctional space, the design of the sunken sports field should be adapted to the site, using the topographic features of the depression combined with the functional space required by the site. Firstly, the terrain needs to be micro-transformed by flattening the terrain in steps according to the slope of the terrain; then dividing the larger area to form a basketball court and a square space; finally, using the slope generated after flattening the terrain to generate steps to provide people with viewing and resting functions.

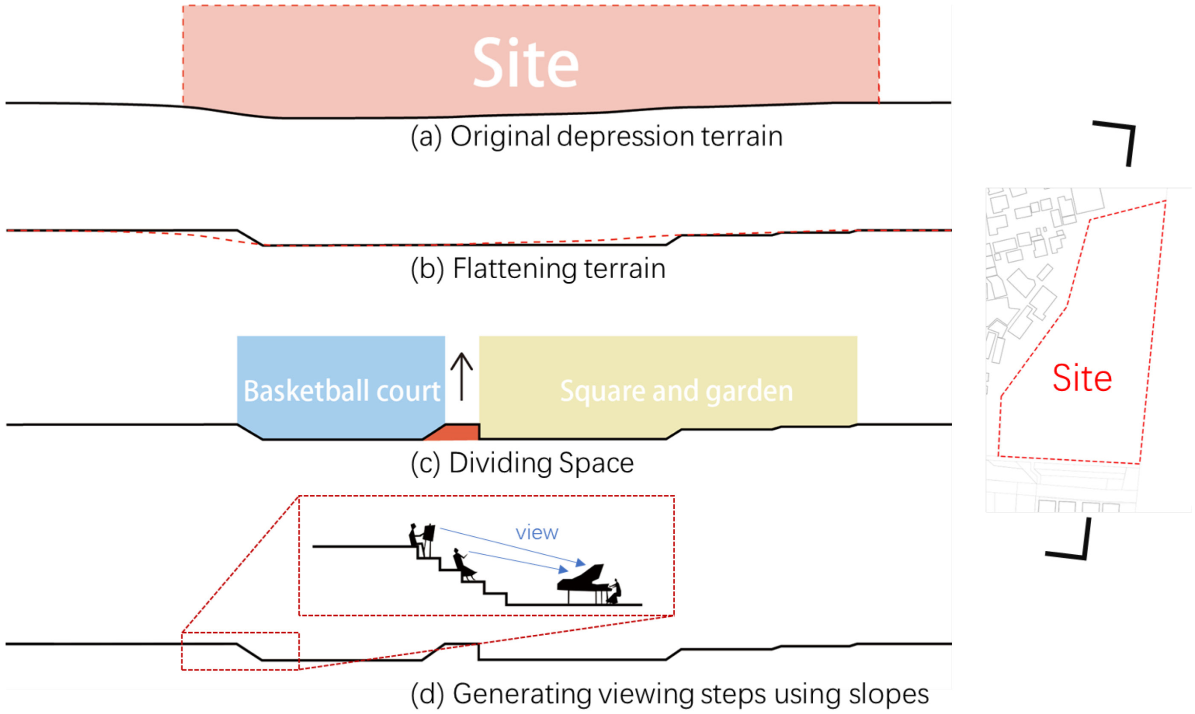


Figure 6-50 Micro-terrain modification
Source: Self-drawn by the author

The general layout is shown in the following general plan. Two basketball courts are arranged in the site to meet the sports needs of young people as much as possible. To the north of the basketball court are two sunken fountain squares and a sunken garden that provides residents with a venue for exhibitions, open-air movies, walks and gatherings, and coexists with the two basketball courts on a central axis. The site also has a circular running path around the sunken square and garden, with a total length of 248m, which can basically meet the villagers' needs for running and other activities. In addition, children's activity areas, table tennis courts, public fitness facilities and other functions that require less space are set up on the east and west sides of the site, making flexible use of the fragmented space in the site.

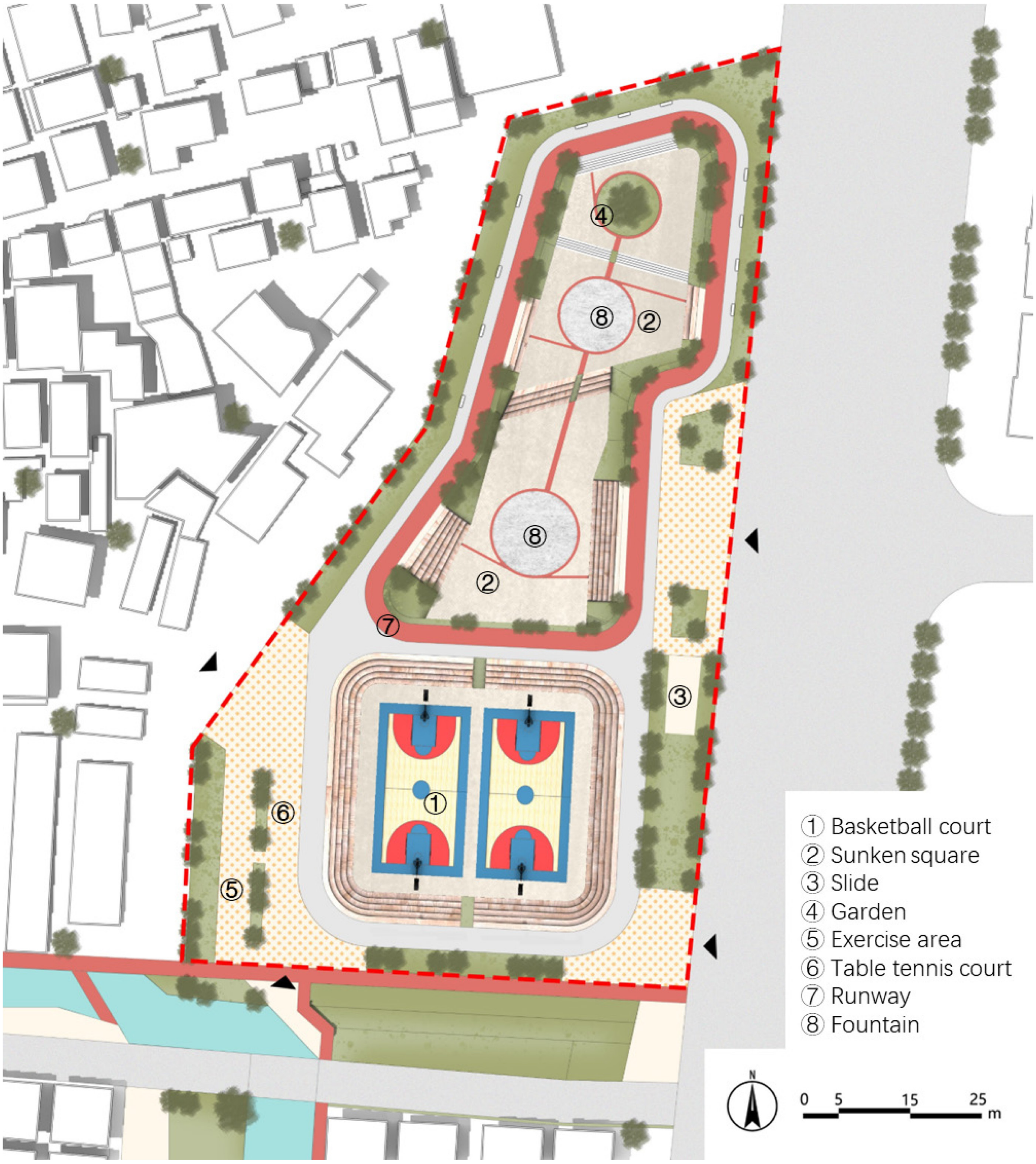


Figure 6-51 Master plam of community park
Source: Self-drawn by the author

The completed sports field after the renovation is shown in the figure below. The sunken squares and basketball courts are based on the depression topography of the site, with bleachers and resting areas, which can provide space for people to rest and communicate. The sunken square, as the largest public space in the site, can carry more cultural activities, such as exhibitions and open-air movies. The design of the different activity areas in the stadium incorporates green infrastructure to further enhance the quality of the environment and the vitality of the space.

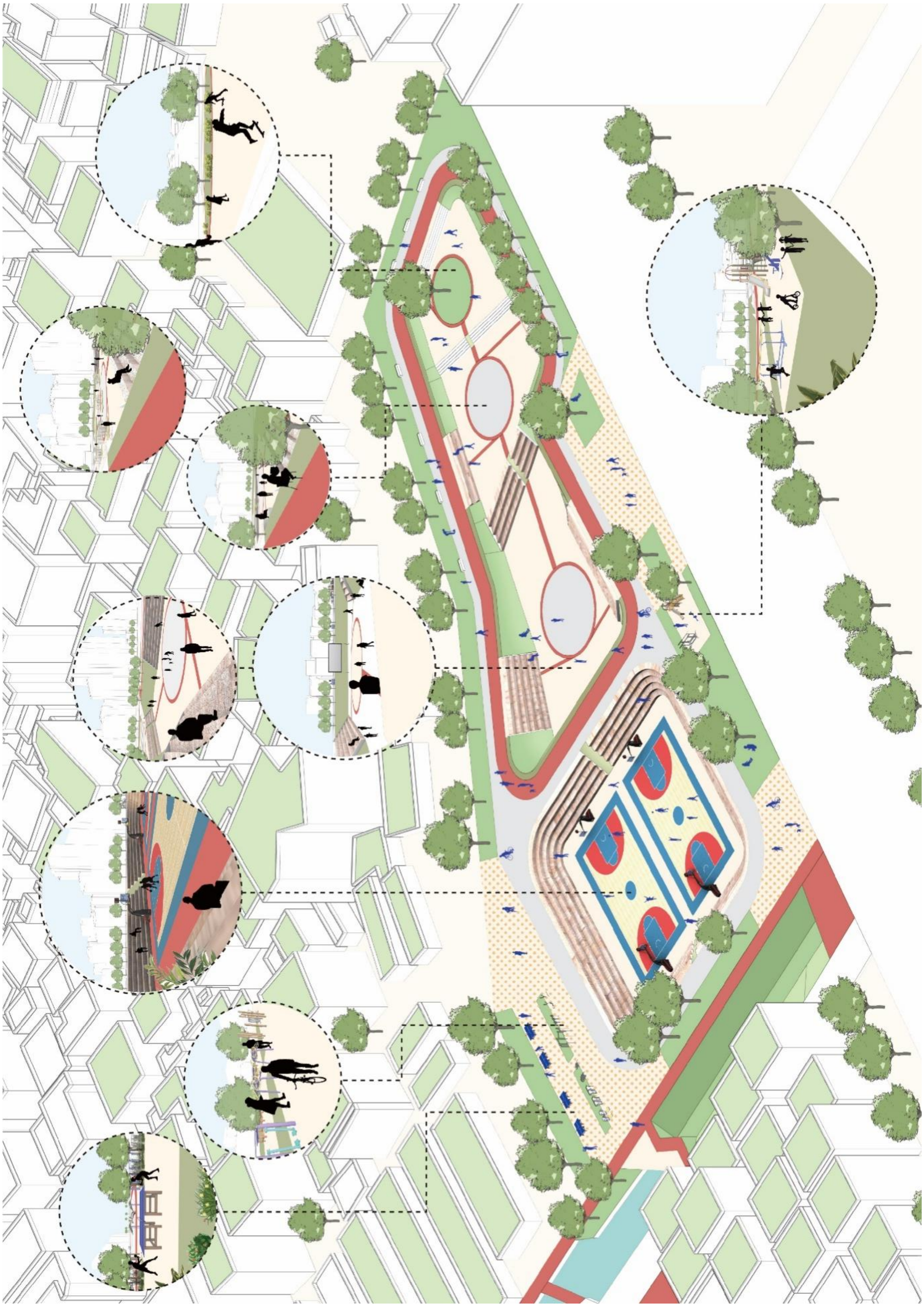


Figure 6-52 Multiple use scenarios for sunken sports fields

Source: Self-drawn by the author

In terms of coping with rainfall hazards and enhancing flood resilience, the design of the sunken sports field draws on the flood control and drainage mechanism of the dike-pond system in the net water villages of the Pearl River Delta. The dike-pond system increases the water storage capacity and redundancy of the water system by connecting multiple dike-pond units in series. In the design of the sunken sports field, the hydrological exchange and dynamic adjustment mechanism of the dike-pond system in response to floods can be realized by connecting the sunken sports field and the sunken square in series to prevent a particular storage unit from collapsing when the water storage limit is exceeded. Under daily weather conditions, the highest water level of the river is lower than the lowest elevation of the sunken space, and the flap valve between the two is closed, which can effectively prevent water from the river from pouring into the sunken space and ensure the safety of the residents' daily public activity space. During heavy rainfall, the sunken basketball court and square will collect and store rainwater. If the water level in the sunken space is higher than the river outside, the valve between the two will be closed to prevent runoff from the site from flowing into the river, increasing the drainage pressure, and when the storm is over, the valve will be opened and the runoff from the site will be discharged; If the water level of the river is higher than the water level stored in the site, the valve will be opened and the sunken space will share the flood pressure of the river.

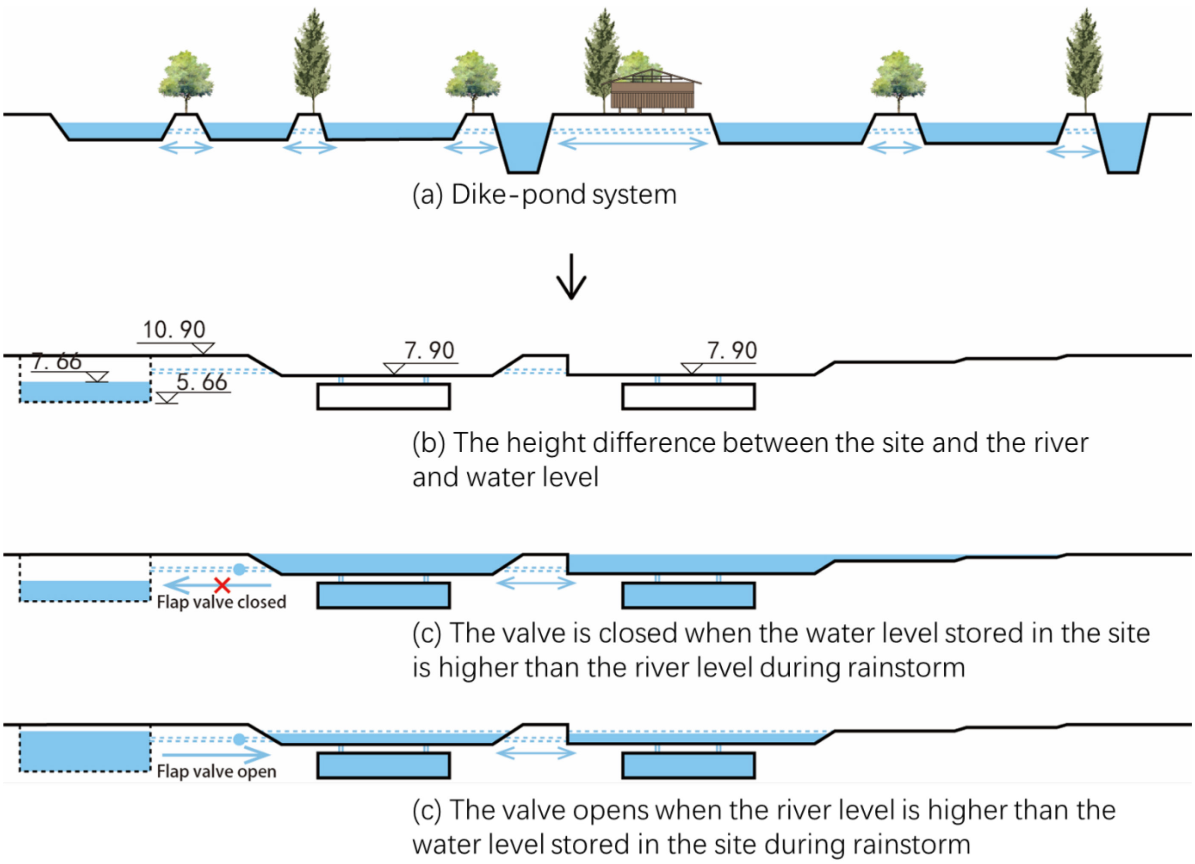


Figure 6-53 Design of water storage system based on dike-pond system
Source: Self-drawn by the author

The inundation volume calculation in Chapter 4 shows that the inundation volume formed by rainfall in the watershed where the sunken sports field site is located is 7161.36 m^3, 8255.01 m^3, 9738.05 m^3 and 10883.47 m^3 for four return periods of 10 years, 20 years, 20 years and 100 years, respectively. The extent of the inundation zone of the sports field under the four recurrence periods, as calculated by the storage capacity of the site, is shown in the figure.

Figure 6-54 Simulation of inundation states under four return periods

Source: Self-drawn by the author

In summary, it is totally inadequate to rely on them only to retain and store the stormwater runoff from the watershed where they are located. Therefore, it needs to be combined with other retention and storage facilities outside the sports field to meet the demand for temporary storage of storm water runoff. There is a large concave green space on the south side of the field, which can be connected with the retention and storage facilities inside the sports field to achieve stronger retention and storage effect. In addition, an underground space has been added to the sunken plaza for rain barrels to improve the water storage function of the sports field. The operation mechanism of the whole retention and storage system is shown in the figure below.

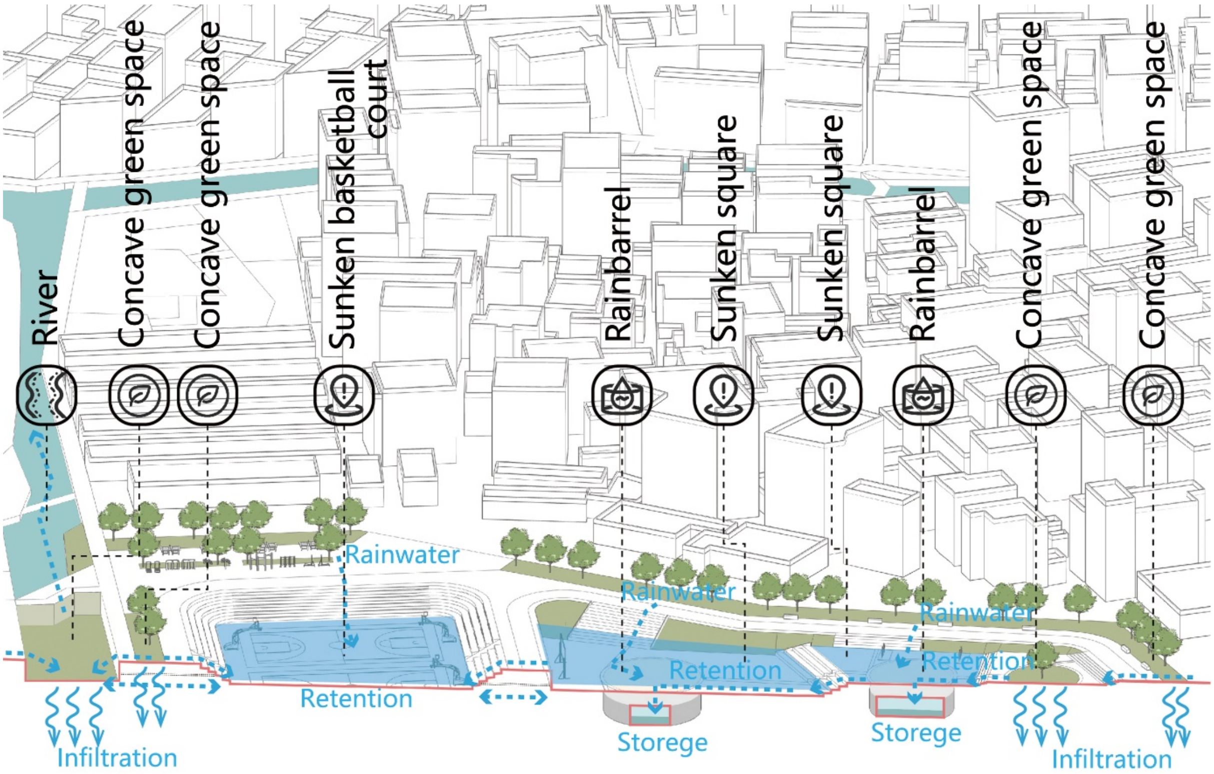


Figure 6-55 Resilient stormwater management mechanism of sunken sport fields
Source: Self-drawn by the author

The sunken square retains rainwater during heavy rainfall and filters and stores it in underground rain barrels. On a daily basis, this stored and purified rainwater can be used for fountains in squares, increasing the use of stormwater management facilities in the landscape.

Daily

Stormy Weather

Figure 6-56 Usage scenarios in different weather
Source: Self-drawn by the author

6. 4 SWMM-Based Simulation and Validation

6. 4. 1 Model Construction

In order to demonstrate the rainstorm response capability between the former Lijiao Village water system, the modified Lijiao Village water system, and the entire water system including the external urban area, as well as the degree of resilience improvement of the latter two. Two hydrologic models were created for the final validation of the Lijiao Village renovation scheme, the renovated Lijiao Village water system and the overall water system including the external urban area.

The method and steps of SWMM model creation have been described in Chapter 4, so they are not repeated in this chapter. The results of the construction of the two models are shown in the following figures.

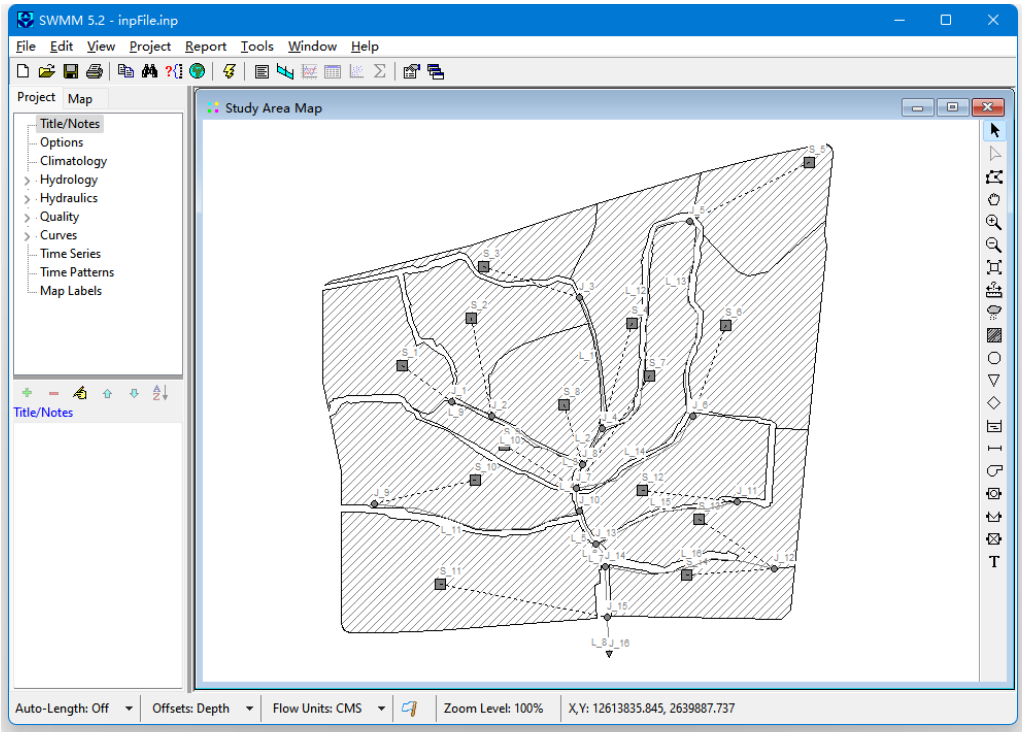


Figure 6-57 SWMM model of renewed Lijiao village without urban area
Source: SWMM software

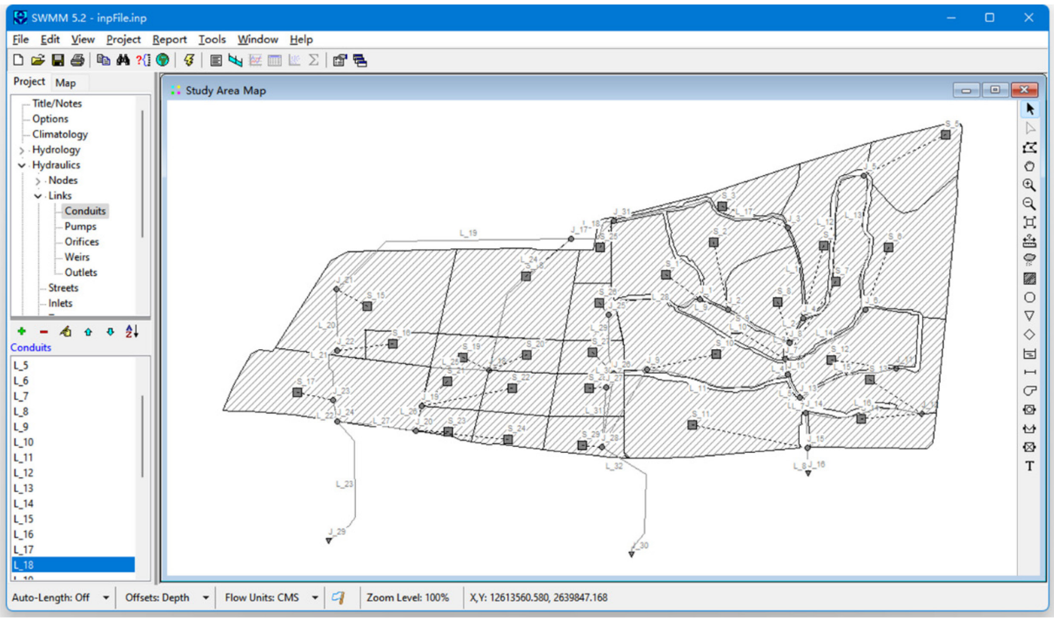


Figure 6-58 SWMM model of renewed Lijiao village with urban area
Source: SWMM software

The parameters of the two SWMM models are shared. The subcatchment parameters are shown in the figure.

Subcatchment	Curve number	Conductivity	Drying Time	OutID	Area	%Imperv	Width	Slope
S_1	65	39.62	7	J_1	4.43	27.1	141.17	1.59
S_2	67	39.62	7	J_2	4.82	35.9	153.54	1.56
S_3	65	39.62	7	J_3	1.93	25.3	95.84	1.42
S_4	67	39.62	7	J_4	4.51	36.4	92.08	1.04
S_5	65	39.62	7	J_5	4.07	22.8	138.08	1.64
S_6	65	39.62	7	J_6	6.91	42.7	162.89	1.70
S_7	65	39.62	7	J_7	4.18	27.6	80.46	1.43
S_8	65	39.62	7	J_8	3.56	33.5	140.47	1.41
S_9	65	39.62	7	J_7	1.75	32.6	53.08	1.11
S_10	65	39.62	7	J_9	5.70	29.6	157.61	1.75
S_11	80	39.62	7	J_15	9.00	82.5	174.75	3.07
S_12	65	39.62	7	J_11	3.45	38.4	121.80	2.05
S_13	68	39.62	7	J_12	4.99	37.2	157.95	2.26
S_14	67	39.62	7	J_12	2.94	35.7	96.85	4.17
S_15	58	39.62	7	J_21	8.79	13.4	163.04	2.76
S_16	76	39.62	7	J_22	1.49	54.6	75.04	2.39
S_17	67	39.62	7	J_23	8.14	48.6	147.50	2.38
S_18	76	39.62	7	J_17	7.40	43.8	172.83	1.39
S_19	79	39.62	7	J_18	1.35	75.6	83.09	1.12
S_20	76	39.62	7	J_18	1.54	74.2	73.89	2.22
S_21	79	39.62	7	J_19	1.56	77.1	79.25	2.35

Subcatchment	Curve number	Conductivity	Drying Time	OutID	Area	%Imperv	Width	Slope
S_22	79	39.62	7	J_19	1.97	79.5	88.07	3.02
S_23	85	39.62	7	J_20	1.09	82.6	68.73	2.41
S_24	85	39.62	7	J_20	1.56	83.7	73.50	3.82
S_25	58	39.62	7	J_31	1.11	7.5	55.27	1.15
S_26	79	39.62	7	J_25	1.87	36.5	95.51	1.14
S_27	79	39.62	7	J_26	1.44	38.1	75.23	2.02
S_28	79	39.62	7	J_27	2.07	33.6	91.80	2.40
S_29	85	39.62	7	J_28	2.01	68.2	84.83	2.74

Table 6-1 subcatchment parameters

The conduit parameters are shown in the figure. Among them, L_24, L_25, L_26 and L_27 are green infrastructure and others are blue infrastructure.

Conduit	Inlet Node	Outlet Node	Length	Manning N	Inlet Offset	Outlet Offset
L_1	J_3	J_4	240.23	0.025	0	0
L_2	J_4	J_8	73.69	0.025	0	0
L_3	J_8	J_7	46.18	0.025	0	0
L_4	J_7	J_10	39.61	0.025	0	0
L_5	J_10	J_13	68.58	0.025	0	0
L_6	J_13	J_14	43.16	0.025	0	0
L_7	J_14	J_15	90.98	0.025	0	0
L_8	J_15	J_16	67.28	0.025	0	0
L_9	J_1	J_2	77.27	0.025	0	0
L_10	J_2	J_8	183.25	0.025	0	2.22
L_11	J_9	J_10	378.75	0.025	0	2
L_12	J_5	J_4	465.90	0.025	0	2
L_13	J_5	J_6	374.14	0.025	0	0
L_14	J_6	J_7	257.94	0.025	0	2.16
L_15	J_11	J_13	266.76	0.025	0	2
L_16	J_12	J_14	309.19	0.025	0	2
L_17	J_3	J_31	497.51	0.025	0	0
L_18	J_31	J_17	140.96	0.025	0	0
L_19	J_17	J_21	659.82	0.025	0	0
L_20	J_21	J_22	160.85	0.025	0	0
L_21	J_22	J_23	146.49	0.025	0	0
L_22	J_23	J_24	56.96	0.025	0	0
L_23	J_24	J_29	358.41	0.025	0	0
L_24	J_17	J_18	423.18	0.025	0	0

L_25	J_18	J_19	252.85	0.025	0	0
L_26	J_19	J_20	67.90	0.025	0	0
L_27	J_20	J_24	206.71	0.025	0	7.81
L_28	J_1	J_25	273.40	0.025	0	0
L_29	J_25	J_26	154.36	0.025	0	0
L_30	J_26	J_27	45.97	0.025	0	0
L_31	J_27	J_28	155.63	0.025	0	0
L_32	J_28	J_30	353.95	0.025	0	0
L_33	J_9	J_26	86.48	0.025	0	0

Table 6-2 conduit parameters
Source: Self-drawn by the author

The junction parameters are shown in the figure. In addition, J_16,J_29and J_30 are outfall, which are consistent with the outfall parameters in Chapter 4.

Junction	Invert Elev.	Max.Depth	Init.Depth
J_1	9.97	3.00	0.00
J_2	9.46	3.00	0.00
J_3	6.25	3.00	0.87
J_4	5.48	3.00	1.64
J_5	8.45	3.00	0.00
J_6	8.67	3.00	0.00
J_7	5.48	3.16	1.64
J_8	5.48	3.22	1.64
J_9	8.66	3.00	0.00
J_10	5.48	3.00	1.64
J_11	10.78	3.00	0.00
J_12	9.22	3.00	0.00
J_13	5.19	3.00	1.93
J_14	4.83	3.00	2.29
J_15	3.16	4.00	3.96
J_17	3.69	4.00	3.43
J_18	5.96	0.00	0.00
J_19	2.39	0.00	0.00
J_20	1.67	0.00	0.00
J_21	2.82	5.00	4.30
J_22	1.30	6.00	5.82
J_23	0.93	7.00	6.19
J_24	1.10	7.00	6.02
J_25	4.80	3.00	2.32
J_26	4.62	3.00	2.50
J_27	4.56	3.00	2.56

Junction	Invert Elev.	Max.Depth	Init.Depth
J_28	2.32	5.00	4.80
J_31	3.95	4.00	3.17

Table 6-3 junction parameters
Source: Self-drawn by the author

The resilient measure parameters are shown in the figure[54]. Since the mechanism and function of the reservoir is similar to that of the rain barrel, the rain barrel module is used instead of the reservoir in the simulation validation in order to unify the calculations.

Type	Parameter	Rain barrel	Concave green space	Permeable Pavement	Vegetative Swale	Stormwater Wetland	Green Roof	Rain Garden
Surface	Barrel Height (mm)	1500	150	2	200.00	2000	45.00	100.00
	Surface Roughness	None	0.4	0.014	0.24	0.24	0.10	0.30
	Vegetation Volume Fraction	None	0.15	0	0.15	0	0.60	0.40
	Surface Slope %	None	1	1	2.00	1	2.00	0.50
Soil	Thickness (mm)	None	300	None	None	300	150	500
	Porosity	None	0.502	None	None	0.501	0.45	0.50
	Field Capacity	None	0.15	None	None	0.284	0.20	0.02
	Wilting Point	None	0.048	None	None	0.048	0.10	0.10
	Conductivity (mm/hr)	None	4.73	None	None	30	12.50	10.00
	Conductivity Slope	None	10	None	None	30	10.00	10.00
	Suction Head (mm)	None	30	None	None	30	110	3.50
Pavement	Thickness (mm)	None	None	100	None	None	None	None

[54] Bi Zhaohui.Simulation of rain flood control effect on urban community using LID measures based on SWMM model[D].Beijing Forestry University,2020.DOI:10.26949/d.cnki.gblyu.2020.001261.

Type	Parameter	Rain barrel	Concave green space	Permeable Pavement	Vegetative Swale	Stormwater Wetland	Green Roof	Rain Garden
	Void Ratio	None	None	0.15	None	None	None	None
	Impervious Surface Fraction	None	None	0	None	None	None	None
	Permeability (mm/hr)	None	None	250	None	None	None	None
	Clogging Factor	None	None	0	None	None	None	None
Storage	Thickness (mm)	None	200	300	None	2000	200	None
	Void Ratio	None	0.6	0.6	None	0.6	0.50	None
	Seepage Rate	None	3.3	3.3	None	3.3	0.10	None
	Clogging Factor	None	0	0	None	0	0.00	None
Drain	Flow Coefficient	6.97	None	0	None	6.97	None	None
	Flow Exponent	0.5	0.5	0.5	None	0.5	None	None
	Offset (mm)	4	None	0	None	4	None	None
	Drain Delay (hrs)	6	None	None	None	6	None	None

Table 6-4 resilient measure parameters
Source: Self-drawn by the author

6.4.2 Total volume of runoff and runoff coefficient

Simulations of four recurrence period precipitation processes based on the renovation model for the Lijiao Village area yielded the following total volume of runoff and runoff coefficient data.

Return Period	Runoff coefficient	Total volume of runoff (10^6 L)
10 years	0.52	30.21
20 years	0.54	34.10
50 years	0.56	39.41
100 years	0.58	43.56

Table 6-5 Total volume of runoff and runoff coefficient in Lijiao village without urban area
Source: Self-drawn by the author

Simulations of four return period precipitation processes based on the renovation model for the village of Lijiao, connect to the urban area, resulted in the following total volume of runoff and runoff coefficient data.

Return Period	Runoff coefficient	Total volume of runoff (10^6 L)
10 years	0.52	30.21
20 years	0.54	34.10
50 years	0.56	39.41
100 years	0.58	43.56

Table 6-6 Total volume of runoff and runoff coefficient in Lijiao village with urban area

Source: Self-drawn by the author

The authors compiled and analyzed data related to the total volume of runoff and runoff coefficient for the Village of Lijiao. It was found that the total volume of runoff and runoff coefficient of Lijiao Village remained the same regardless of whether it was connected to an urban area.

But comparing to before the renovation, there is a significant change in total volume of runoff and runoff coefficient. The total volume of runoff reduction rates for the retrofit scenarios were 45.5%, 43.8%, 41.6%, 40.6% under the 10, 20, 50 and 100 years return period precipitation, respectively. The runoff coefficient reduction rates for the retrofit scenarios were 43.2%, 41.6%, 39.7%, 37.7% under the 10, 20, 50 and 100 years return period precipitation, respectively.

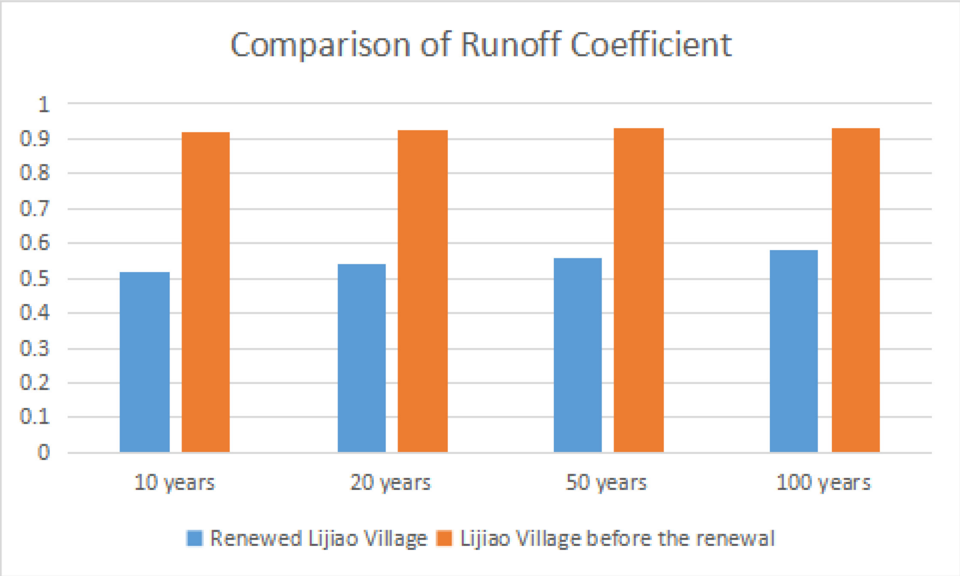


Figure 6-59 Comparison of runoff coefficient
Source: Self-drawn by the author

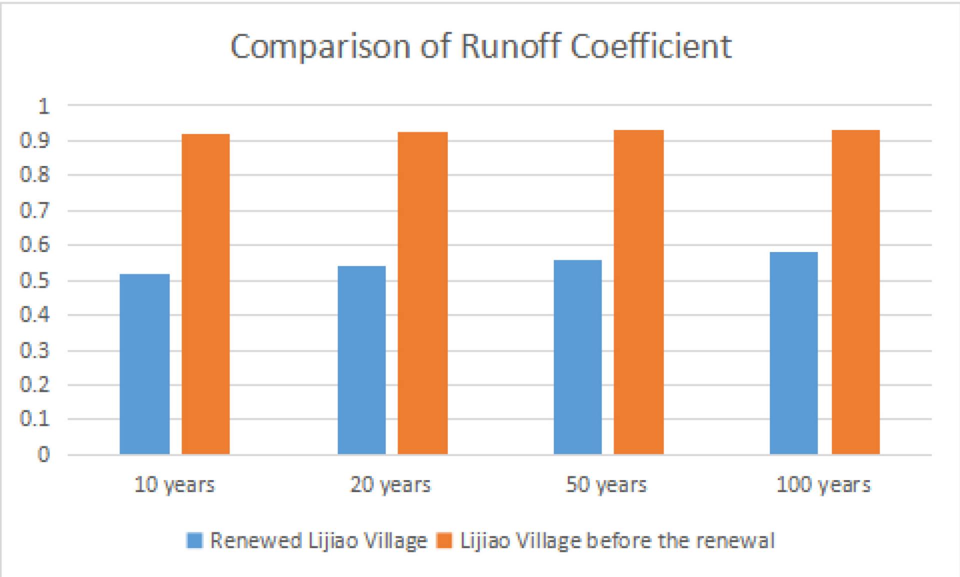


Figure 6-60 Comparison of total volume of runoff
Source: Self-drawn by the author

Therefore, it can be seen that the renewal strategy has a significant effect on the infiltration and retention capacity improvement of Lijiao Village

6. 4. 3 Total Volume of Flow Discharged of Lijiao Village

The impact of connecting to the urban area water system on Lijiao Village's ability to cope with heavy rainfall can be learned by comparing the total discharge volume of Lijiao Village after the renovation with that of Lijiao Village without connecting to the urban area water system. By looking at the J_16 outfall, the total volume of flow discharged from Lijiao Village under the four return periods of precipitation is as follows.

Return Period	Renewed Lijiao Village without Urban Area	Renewed Lijiao Village with Urban Area
10 years	44. 548	39. 746
20 years	48. 166	42. 957
50 years	53. 147	47. 363
100 years	57. 040	50. 810

Table 6-7 Total vloume of flow discharged in Lijiao village before and after combining urban area

Source: Self-drawn by the author

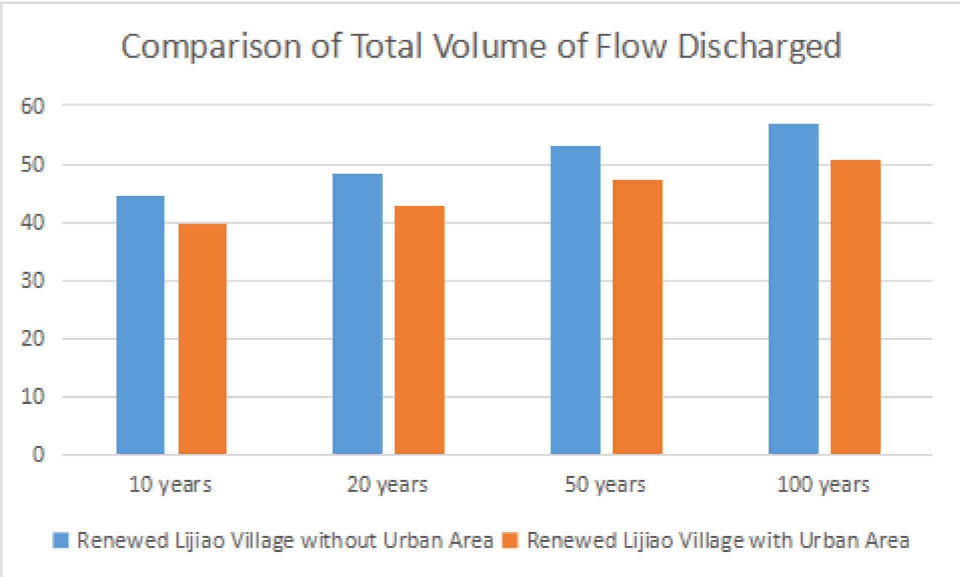


Figure 6-61 Comparison of total volume of flow discharged

Source: Self-drawn by the author

The study showed that there was a significant reduction in the total volume of flow discharged of Lijiao village with an average reduction of 11.37% after connecting to the water system of the urban area. The external urban area water system accommodates some of the runoff from Lijiao Village, reducing the flooding pressure on the village water system and reflecting a stormwater management role similar to that of the dike-pond system.

6. 4. 4 Number of Flooded Junctions

The renewed Lijiao Village does not experience flooded junctions whether or not it is combined with an urban area. This is due to the effect of all the resilient stormwater management facilities in the renovation scheme working together to enhance the drainage, storage, retention and infiltration capacity of Lijiao Village in all aspects, together forming a robust resilient water system.

Conclusion

Taking Lijiao Village as a practical object, this paper explores a series of regeneration strategies based on theories related to flood resilience, and applies them to both the general layout and public space design. From the perspective of flood resilience enhancement, the renovation strategy has improved the drainage, storage, retention and infiltration capacity of Lijiao Village in all aspects, thus improving flood resilience, as evidenced by comparing the depth of surface runoff and runoff coefficient before and after the renovation. In terms of environmental quality improvement, the renovation strategy has brought a series of vibrant and interesting public spaces around the water system, such as streets, parks and sports fields, which have effectively improved the village's environment and increased the number of places for residents' activities.

Compared with previous studies, this paper considers how to enhance environmental quality at the same time from the urban design level based on the discussion of flood resilience enhancement strategies. We analyze the engineering nature of the stormwater management facilities as an element to enhance the quality of urban space, analyze their landscape effect and the way they interact with people, so that the stormwater management facilities are no longer an often neglected role in the urban space, but become both landscape elements and interactive facilities in the urban space, with multifunctional. For example, the river between the streets and roads is an important part of the resilient drainage system and an integral part of the landscape elements of Lijiao Village. The sunken square and basketball court provide a place for public activities for residents and a resilient facility to detain and temporarily store runoff during heavy rainfall.

This paper also has some shortcomings. In the creation of the hydrological model of the current situation of Lijiao Village, there is a lack of realistic municipal pipe network models and parameters, so there may be some internal flooding problems that are not detected in the simulation of it. In addition, in the inundation analysis based on the SCS model, the parameters used in the process of obtaining CN values are also mostly empirical parameters, and the final simulation results may have slight errors due to the lack of real site data. However, the core of this paper is to explore a method to improve the quality of urban space combined with stormwater resilience, so these shortcomings do not affect it much.

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序号	作者（全体作者，按顺序排列）	题　　目	发表或投稿刊物名称、级别	发表的卷期、年月、页码	与学位论文哪一部分（章、节）相关	被索引收录情况

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