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Comprehensive planning of drainage and waterlogging prevention layout based on urban double repair concept

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ABSTRACT

In order to improve the drainage and waterlogging prevention capacity of the existing urban drainage system, scientifically and reasonably formulate the drainage and waterlogging prevention planning scheme to ensure the safety of urban drainage and waterlogging prevention. The comprehensive planning method of drainage and waterlogging prevention layout based on the concept of urban double repair is studied. Analyze the general situation of the concept of urban double repair, and study the related theories of urban double repair. Taking Yucheng County as the research object, the concept of urban double repair is introduced into the comprehensive planning of drainage and waterlogging prevention layout, the hydraulic model of the main pipe of drainage network is constructed, and the comprehensive planning scheme of drainage and waterlogging prevention layout is formulated. The results show that the scheme can effectively improve the drainage and waterlogging prevention performance of the existing urban drainage system and ensure the safety of urban drainage and waterlogging prevention.

Keywords: Urban double repair; Drainage and waterlogging prevention; Sponge city; Hydraulic model; Comprehensive layout planning

1. Introduction

Urbanization is an inevitable process of the development of human society. Urbanization not only promotes the rapid development of the national economy and the improvement of the economic structure, but also promotes social progress [1–3]. However, while urbanization brings great convenience to people, the rapid development of cities also leads to the deterioration of the environment. Especially in recent years, with the development of urbanization, the rapid growth of the urban population has had a significant impact on the hydrological and hydraulic characteristics of the city, artificially reduced the city's drainage capacity, and made the city's waterlogging more serious [4]. Due to global climate change, extreme weather such as heavy rain has a significant impact on social management, urban operation, residents' production and life. In addition, the construction of infrastructure such as drainage and waterlogging prevention in some cities is still relatively backward, and the work on the regulation and storage of rainwater, flood control, and flood control is still weak, resulting in severe rainstorms and waterlogging [5–8]. In order to ensure the safety of people's lives and property, improve the level of urban disaster prevention and mitigation, and strengthen urban drainage and waterlogging prevention, it is very important to scientifically formulate urban drainage and waterlogging prevention layout plans [9–11]. The basic task of urban drainage and waterlogging prevention projects is to protect the city from the threat of waterlogging, to ensure the safety of life and property of the majority of urban residents and the normal order of production and life in the city. Concerning the overall situation of the healthy development of new urbanization, it is necessary to do a good job in the construction and management of urban drainage and waterlogging prevention facilities, and scientific and

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rational planning schemes for urban drainage and waterlogging prevention should be formulated.

At present, scholars in related fields have carried out research on drainage and waterlogging prevention planning, and have made great progress. Jiménez et al. [12] propose a multi-criteria planning framework for locating and selecting sustainable urban drainage systems in integrated urban areas. Implementation of sustainable urban drainage systems is increasing because of their advantages over runoff control. This study develops a multiscale approach for integrated urban areas that allows analysis of the environmental, social and economic aspects of sustainable urban drainage implementation according to multiple objectives, namely runoff management, water quality improvement and livable facility development. Targets were identified through workshops involving key stakeholders, and spatial analysis was performed to prioritize urban drainage sub-basins. On a local scale, potential areas are analysed to determine the potential for the implementation of sustainable urban drainage systems. Reza and Wulandari [13] present the analysis and design of a drainage system planning study, the case study being the Graha Wisata Sidoarjo residence. Graha Wisata Sidoarjo Housing is located in Lebo Village, Sidoarjo District, Sidoarjo County, covering an area of 470,000 m^2. The house passes through the Anak Afvoer Sidokare waterway, and as the land functions change, it is necessary to analyze the capacity of the Anak Afvoer Sidokare watershed. The rainfall data used is the maximum annual rainfall at the Summit Sidoarjo Ketintang Durungbedug Rain Gauge Station. The rainfall analysis method adopts the Log-Pearson III method. Using the Nakayasu method, the 25 y planned flood flow in the Anak Afvoer Sidokare watershed is 450.55 m^3/s. While the existing over with dimensions of 10 m × 4.172 m has a capacity of 537.39 m^3/s, the cross-section of the Son Afvoer-Sidokare channel has no overflow.

Based on the above analysis, a comprehensive planning study of drainage and waterlogging prevention layout based on the concept of urban double repair is proposed. Taking Yucheng County as the research object, taking the concept of urban dual repair as the guide, and taking the construction of "sponge city" as the goal. Use Infoworks ICM to build the hydraulic model of the main pipe of the drainage network, and formulate a comprehensive planning scheme for the drainage and waterlogging prevention layout. This scheme can significantly enhance rainfall infiltration, reduce surface runoff, and alleviate urban waterlogging. In order to ensure the safety of urban drainage and waterlogging prevention, the drainage and waterlogging prevention capabilities of the existing drainage system must be effectively improved.

2. Overview of urban dual repair concept

"Double urban repair" is a theory proposed to solve the problems caused by the extensive development model of urban construction in the past and to explore a new model of urban connotative development under the background of stock planning [14–17]. Its theory includes two aspects: urban repair and ecological restoration. The main goal of "ecological restoration" is to create a suitable living environment, and gradually improve the self-healing function of the urban ecosystem by reducing the damage to the ecosystem caused by urban development activities, so that it can resist external intrusion. Even if the external ecological environment has undergone great changes, the urban ecosystem can still continuously adjust itself in dynamic changes, gradually establish a new balance, and finally restore the urban ecosystem to its original state. "Urban repair" is not simply to fill space, but to repair and improve infrastructure and urban social context in a step-by-step manner. Through comprehensive and systematic restoration and compensation of urban functions, the urban environment will be improved, the quality of urban life will be improved, and the needs of residents will be met.

2.1. Origin and development of urban dual cultivation theory

With the implementation of reform and opening up, the level of urbanization has ushered in rapid development, and the urban population has continued to increase rapidly, achieving remarkable achievements, but at the same time, it has also brought some problems. For example, urban development pie, low land use efficiency, urban resources and environmental carrying capacity, urban management capacity does not match the speed of construction, "urban disease" is increasingly serious, and urban features lack characteristics.

In response to these problems, in 2014, the national level proposed a new type of urbanization strategic plan, which proposed to comprehensively improve the quality of urbanization, accelerate the transformation of urban development models, and improve the ability of urban sustainable development. In the context of new urbanization, urban and rural planning methods have also been transformed. Existing planning has gradually replaced expansion planning. Progressive, sustainable, and intensive land use has become the dominant direction of urban and rural planning. The urban space development model is gradually dominated by the improvement of connotation. "Ecological restoration, urban repair" was proposed in 2015. At the Central City Work Conference, the necessity and urgency of transforming the city were put forward, and all relevant departments were required to do a good job in planning and implementing the city's three-dimensional space, plane coordination, landscape features, and continuation of the context. At the same time, it is emphasized that urban construction should be combined with the natural landscape pattern, take nature as beauty, vigorously restore the urban ecology, and integrate the natural landscape into the city. Since then, the concept of urban dual cultivation has emerged.

2.2. Theoretical connotation of urban double repair

"Double urban repair" is based on the problems of extensive urban management, inefficient land use, and mediocre space in the process of rapid economic development, aiming to solve urban development problems. The theory of "city double repair" is put forward as the most effective platform to promote the integration of planning, construction and management. Ecological restoration should use a scientific approach, a systematic perspective, and the principles of safety and benefiting the people [18]. Urban repair covers not only the repair of urban space, infrastructure, and urban landscape, but also the improvement of urban functions. This not only requires systematic investigation and research and the wisdom of planners, but also requires the participation of all sectors of society and the government's responsibility to safeguard public interests.

"Double urban repair" requires work from two directions. "Ecological restoration" mainly covers four main sections: repairing mountains and water, utilizing urban wasteland and building green space systems. Use the theory of ecological restoration to restore the urban natural landscape pattern, improve the function of the urban ecosystem, and reshape the relationship between the urban natural environment, artificial environment and urban residents. "Urban repair" mainly includes improving infrastructure and improving public space. "Urban repair" includes six aspects: improvement of infrastructure, improvement of public space, improvement of travel environment, renovation of old buildings, inheritance of history and culture, and reshaping of the times. Adopt "small-scale" and "progressive" methods to avoid large-scale demolition and construction, and on the basis of retaining the original spatial pattern, improve the level of urban public services, strengthen the carrying capacity, continue the cultural genes, and highlight the unique charm.

2.3. Theories related to urban dual cultivation

The concept of "sponge city" is widely used to describe the ability of modern cities to absorb, store and use rainwater. A "sponge city", also known as a "water-resilient city", shows the city's "resilience" to rainwater. When rainfall occurs, it can be absorbed and stored on the spot to supplement groundwater, and during drought, the stored rainwater can be released and utilized in time to realize the on-demand transfer of rainwater resources in the city. The establishment of a set of urban water resources facilities system with strong adaptability and elasticity can greatly improve the anti-interference properties and capabilities of urban water systems. Sponge city construction is a systematic construction project, which mainly includes four aspects: First, the city must maintain a certain scale of surface water and wetlands to store rainwater resources. The second is to adopt a low-impact development strategy, which requires the entire process from planning and design to implementation and management to achieve minimal disturbance to the ecological pattern. The third is to restore ecological corridors, build water circulation systems through blue belts and green belts, and improve their ecological service functions. The fourth is to build ecological drainage facilities, and give full play to the absorption and infiltration of rainwater by green squares, sports fields, and parking lots.

3. Comprehensive planning method of drainage and waterlogging prevention layout

3.1. City profile

3.1.1. Basic situation

Yucheng County is located in the eastern part of Henan Province, south of the old route of the Yellow River, and is the border of the three provinces of Henan, Shandong and Anhui under Shangqiu City. It is adjacent to Xiayi in the east, Shangqiu New District in the west, Bozhou City in Anhui Province in the south, Dangshan County in Anhui Province in the northeast, and Shanxian County in Shandong Province in the north across the old road of the Yellow River. The county seat is located in the southwest of the intersection of Longhai Railway and Shanbo Highway. It is 23 km away from Shangqiu City in the west and 240 km away from Zhengzhou City. It is 120 km east to Xuzhou City, an important town in northern Jiangsu, 60 km south to Bozhou, and 45 km north to Shanxian County, Shandong Province. After the adjustment of the jurisdiction, the total area of the county is 1,432 km^2.

Yucheng County has a long history and rich cultural heritage. It has 26 provincial and municipal intangible cultural heritages such as the National Intangible Cultural Heritage of Mulan Legend and Huagu Opera. The geographical location of Yucheng County is very good. The current situation mainly includes Lianhuo Expressway, Jiguang Expressway, and Yucheng Station on Longhai Railway. Provincial highway S208 and S324 pass through the city, with convenient transportation and good geographical location. The county has 25 towns, 10 townships and 15 townships, with a total population of 1.1294 million. The overall planning of the central urban area of Yucheng County is shown in Fig. 1.

The central area of Yucheng County is: the central area of Shangqiu, the integration of urban and rural areas, the hardware equipment manufacturing industry, the food production base in eastern Henan, the green cycle, and the ecological and livable city with outstanding culture. By 2020, the urban population will reach 300,000, the urban construction land area will be 32.97 km^2, and the per capita construction land area will be 109.91 m^2. By 2035, the population of the city center will reach 530,000, the scale of construction

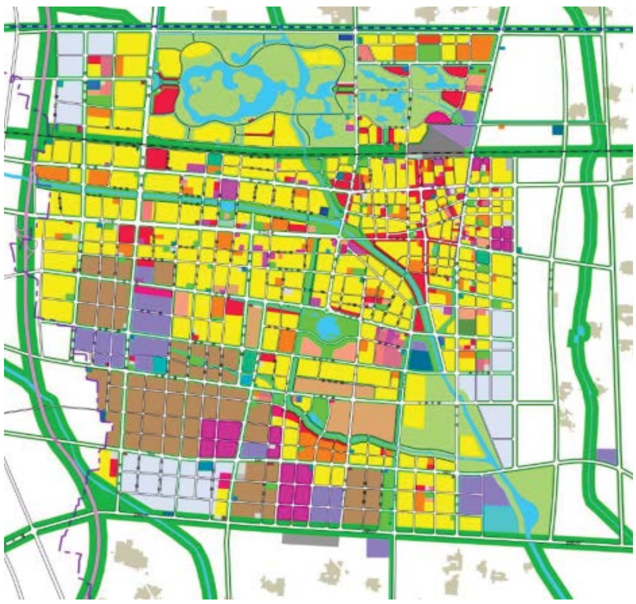

Fig. 1. Overall planning of central urban area of Yucheng County.

land will be 56 km^2, and the per capita construction land will be 105.64 m^2.

3.1.2. Hydrological status

The main rivers in Yucheng County include the old Yellow River, Honghe, Qiulonggou, Liugong River, Xianghe, Dongshahe, Baohe, Jimingou, Beihuimingou, Zhougou, Xinmingou, Wuhe, Wenminggou and Shenshagou, South Huimin ditch, Luo ditch, Fumin ditch and so on. Reservoirs include Wang'anzhuang Reservoir and Shizhuang Reservoir. The county's Gouhe belongs to the Huaihe River Basin and is a seasonal river formed by years of scouring and artificial excavation along the slope. There are 7 backbone rivers of more than 100 km^2, 9 tributaries of 30–100 km^2, and 20 tributaries of 10–30 km^2 in the basin.

3.1.3. Current situation of urban drainage and waterlogging prevention

The rivers in the planning area of Yucheng County include Xianghe River, Shangzhou-Zhouyong Canal, Niuhe River, Central Main Canal, Shizi River, Yunliang River, Dongsha River, Baihe River, etc. The river can be used as a drainage channel.

- *Xianghe River*: Gaozhuanghu in Dahou Township flows into Xiayi County, with a length of 40.788 km. The inbound watershed area is 28 km^2, the outbound watershed area is 256 km^2, the maximum bottom width of the river is 31 m, the maximum design flow is 116 m^3/s, the water depth is 3 m, and the slope is 1:3. The last full governance was in 1971. In March 1998, the urban section from Xulou Bridge to Datong Road and Bridge was rehabilitated, with a length of 2,500 m. In December 2006, the section from Nanguan Bridge to Sanzuolou Gate in the county seat was rehabilitated, with a length of 2,000 m. In 2013, the section from Datong Road Bridge to Nanguan Bridge in the county seat was rehabilitated, with a governance length of 1,000 m.
- *Shang-Zhou Yong Canal*: It starts from Zhoukou Town and passes through Huaiyang County, Zhecheng County, Taikang County, Shangqiu City, Yucheng County, Xiayi County and Yongcheng County, a total of 225 km. The end point is Confucius Mountain in Yongcheng County. The Shahe River is connected to the Yellow River, Xincai River, Heihe River, Guohe River, Huiji River, Jianghe River, Dasha River, Gusong River, Tuohe River, Qiulonggou and Wangyin River.
- *Niuhe River*: It starts from Niulou Village in the north of Yucheng, and the downstream enters Xianghe River along the Yellow River Road. The river is closed by cover plates in the urban section and has not been rectified yet.
- *Central trunk channel*: The area is 6 km long, the design water level is 2.5 m, the bottom width is 8 m, and the design flow rate is 30 m. The main channel is a water diversion channel, mainly for water diversion, and also for waterlogging removal. This section of the river is being rehabilitated.
- *Cross River*: It is one of the main tributaries of the Yunliang River, originating from the mouth of the canal and entering the Xianghe River downstream, with a total length of 3.62 km. Most of the river course has been rectified.
- *Yunliang River*: It originates from the south of Sizhuang, the suburban township of Yucheng County, and flows through the suburban township, Liudian Township, and Dahou Township, and enters the Xianghe River, with a total length of 9.3 km. The current state of the river section is in a natural state and has not been rectified.
- *Dongsha River*: It is the largest tributary of the Fen River. Its source is Pankouji in Lizhuang Township, Shangqiu City, and flows into Yucheng County from Tianzhuang Village in Liudian Township. It flows through the four townships of Liudian, Dahou, Wenji and Zhanji, and flows into Xiayi County in Shagangdian Village, Zhanji Township, with a length of 25.5 km. The inbound watershed area is 145.3 km^2, and the outbound watershed area is 320.3 km^2. The maximum bottom width of the basin is 25 m, the maximum flow is 105 m^3/s, the maximum water level is 3 m, and the slope is 1:3. The last full governance was in 2013.
- *Baihe River*: The upstream starts from the central trunk channel, and the downstream joins the Xianghe River.

3.1.4. Distribution of waterlogging-prone points in urban areas

The overall terrain of the urban area of Yucheng County is slightly inclined from northwest to southeast, and the slope is small, and the overall slope is between 0.15%° and 0.2%°. As the terrain of the urban area is generally unfavorable for drainage, but most of the rivers in the existing built-up area are large outer rivers and remain connected, so the urban waterlogging situation is not serious. According to the survey, Yucheng County currently does not have a large flood-prone area, but only in some areas prone to flooding, mainly in the following places: Lijiang Road and Longhai Railway set up trading flood spots. The newly built Longhai Railway establishes a trading flood point. The Longhai Railway on the Yellow River Road stands as a trading flood point. Xiaoxiao Road New Road North is prone to flooding. Renmin Road Cultural Louis Waterloo Point. The waterlogging-prone point of Chengxin Avenue, Zhicheng Eighth Road. Zhixin all the way to the Louis flood point of the Lijiang River. Zhixin 3rd Road, Lijiang Luluo Point. Industrial Avenue, Dongming Luluo Point. Go to Lushan Lushan Lushan Lulu Point on Chengsi Road.

3.2. Constructing the hydraulic model of the main pipe of the drainage network

3.2.1. Infoworks ICM hydraulic model

Infoworks ICM can comprehensively simulate the urban rainwater circulation system, and more realistically reflect the interaction between the rainwater pipe network system and the receiving water body.

The pipe network confluence model reflects the process of the flow pattern and flow change of the surface rainwater collected into the pipe network. The calculation principle of Infoworks ICM for the pipeline flow model is as follows:

$$\frac{\partial Z}{\partial x}+\frac{\partial C}{\partial u}=0 \quad (1)$$

$$\frac{\partial Z}{\partial x}+\frac{\partial}{\partial u}\left(\frac{C^2}{Z}\right)+bZ\left(\cos\varepsilon\frac{\partial n}{\partial u}-\phi+\frac{C|C|}{M^2}\right)=0 \quad (2)$$

In Eqs. (1) and (2), Z is the cross-sectional area, C is the flow rate, u is the length of the pipe in the direction of water flow, ε is the angle of the horizontal line, n is the water depth, φ is the slope of the bottom of the pipe, b is the acceleration of gravity, x is represents the time, and M represents the water delivery rate.

The calculation of rainstorm intensity is based on rainfall analysis, and statistical analysis is carried out according to the precipitation process data for many years. The calculation equation of the rainstorm intensity of this scheme is:

$$q=\frac{637\cdot(1+\lg w)}{t^{0.576}} \quad (3)$$

In Eq. (3), w is the return period of the design rainstorm, which is calculated based on the general regional standard of 3 y, and the important regional standard is 5 y. t is the design rainfall duration, and its calculation equation is as following:

$$t=t_1+t_2 \quad (4)$$

In Eq. (4), t_1 is the surface water collection time, t_2 is the time when rainfall occurs in the pipeline, and the equation is:

$$t_2=\sum\frac{l}{60v} \quad (5)$$

In Eq. (5), l is the length of each section of the pipe, and v is the flow rate at full flow.

3.2.2. Capacity assessment of current urban drainage and waterlogging prevention system

The drainage system in the central urban area of Yucheng County has been gradually formed after years of construction, and it is still being perfected. Most of the drainage system in the old city adopts the collecting system, and the rainwater is directly discharged into the Xianghe, Niuhe and other rivers through the existing confluence pipes and drainage channels, but the rainwater diversion project in the old city is currently underway. The newly built Xicheng District and Nancheng District, such as Industrial Avenue, Dongming Road, Jiangsu-Zhejiang Avenue, Zhicheng 4th Road, Zhixin 1st Road, etc., basically adopt the rainwater and sewage diversion system.

As of the end of 2017, the total length of municipal rainwater pipelines in the central urban area of Yucheng County was about 103 km, mainly laying on Songshan Road, Mulan Avenue, Lushan Road, Chengxin Avenue, Industrial Avenue, Zhixin 2nd Road, Zhixin 3rd Road, Jiangsu and Zhejiang Avenue, and Kedi Avenue, Cangjie Avenue, Zhicheng Fourth Road, Zhujiang Road, Dongming Road, Yiyin Avenue, Xiangjiang Road, Hanjiang Road, Lijiang Road, Zhicheng Eighth Road and other roads.

This planning is based on the urban topography, the rainstorm intensity formula and the current construction of rainwater pipes. Using infoworks software, through the modeling of the urban drainage network, the urban drainage network is analyzed and evaluated, and the evaluation results are shown in Table 1.

3.2.3. Urban waterlogging risk assessment

At present, there are few river systems in the urban area of Yucheng County, and the main drainage river system in the urban area is the Xianghe River. The main drainage channels in the old city are Niu River and the central trunk channel. The rest of the drainage channels include the Shang-Zhou Yong Canal, Shizi River, Yunliang River, Baihe River, Dongsha River, Xianzhuanggou, etc. These rivers form a large drainage system in the planning area of Yucheng County. Since these rivers can be kept unblocked, the urban waterlogging situation in Yucheng County is not serious.

According to the topography of the planned urban area, the condition of the underlying surface, and the current situation of the construction of urban drainage pipes, combined with the statistics of the urban management department on the current waterlogging-prone points in the urban area. This planning uses Infoworks software to establish a model of the urban drainage system to assess the risk of waterlogging in the planned urban area of Yucheng County. According to the evaluation results and the statistics of waterlogging prone points in the current urban area by the urban management department, 10 waterlogging prone points in the current urban area are listed in the planning. The high, medium and low risk areas of waterlogging in the planning area are shown in Fig. 2.

The urban waterlogging risk assessment is shown in Table 2.

3.3. Formulate a comprehensive planning scheme for drainage and waterlogging prevention layout

3.3.1. General

3.3.1.1. Planning principles

- *The principle of overall planning and consideration*: The formulation of the comprehensive planning of drainage and waterlogging prevention layout should follow the overall urban planning, comprehensively consider the overall

Table 1
Evaluation table of drainage capacity of current drainage pipe network

Design standards	Pipe network (km)
<Once in 1 y	29.6
Once in 1–2 y	41.9
Once in 2–5 y	36.9
≥5 y once	12.8

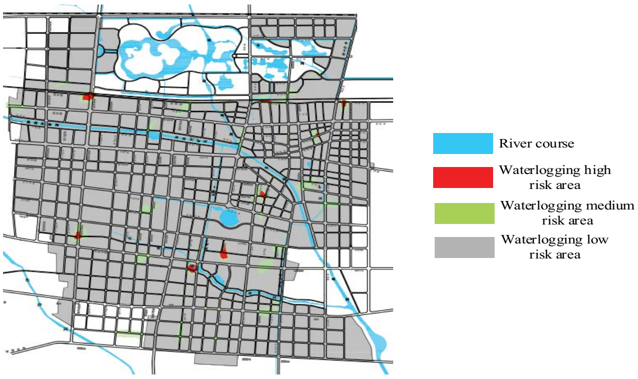

Fig. 2. Waterlogging risk zoning map.

Table 2
Urban waterlogging risk assessment table

Waterlogging risk area	Area (km^2)
High risk	0.25
Medium risk	2.01
Low risk	53.72

situation of the city, and make overall arrangements to make the layout of urban rainwater drainage facilities, waterlogging prevention facilities, and low-impact development facilities scientific and reasonable. Focusing on urban drainage and waterlogging prevention, while taking into account the non-point source pollution of early urban rainwater and the reuse of rainwater, the urban living environment can be improved.

- *Highlight the principle of urban double repair*: The overall planning of the urban drainage and flood control system in Yucheng County will take the low-pollution development of small towns as the main control indicator. Formulate construction plans for facilities such as "storage, stagnation, infiltration, purification, use, and drainage", so as to reduce the runoff coefficient of rainwater in Yucheng County, increase the amount of rainwater infiltration and utilization, and realize the construction of "sponge city".
- *The principle of systematic coordination*: The planning of land use, road traffic, flood control, vertical, green space system, urban river, and water system planning in urban planning has been systematically planned [19]. Reasonable layout of the planned facilities, and reasonable feedback and suggestions for the relevant planning.
- *The principle of advanced nature*: Emphasizing the advanced concept and technology, adapting measures to local conditions, and adopting a combination of "storage, stagnation, infiltration, purification, utilization, and drainage" methods to achieve the purpose of ecological drainage and comprehensive waterlogging prevention. Clarify drainage channels, division of areas, layout of drainage pipe network, determine the diversion of rainwater and sewage, drainage pipelines, pumping stations and other drainage systems reconstruction and construction, rainwater drainage, and dredging and remediation of river systems.
- *Principles of sustainable development*: Adhere to resource conservation, environmental protection, develop comprehensive utilization of rainwater, and steadily improve the utilization level. Make intensive use of land for various drainage facilities and make reasonable planning for them. To strengthen the regional ecological protection work.

3.3.1.2. Planning scope

The planning scope is the central urban area of Yucheng County, with a planned construction land area of 56 km^2.

3.3.1.3. Planning period

The planning period is: near-term 2025; long-term 2035.

3.3.1.4. Planning objectives

The urban flood control and drainage system should aim at "complete functions, safe and efficient, economical and reasonable, and coordinated measures" to improve the urban flood control, drainage and drainage capacity and ensure urban public safety.

3.3.2. Urban rainwater runoff control and resource utilization

3.3.2.1. Urban stormwater runoff control

According to the requirements of the urban low-impact development (LID) and the urban dual-repair concept, the scheme takes the low-impact development and construction mode of Yucheng County as the evaluation index. Under the guidance of urban double repair, various measures such as "infiltration, stagnation, storage, purification, utilization, and drainage" are used together. Improve the capacity of urban flood control and waterlogging storage, strict land use plan, strengthen rainwater collection and use, reduce runoff, and improve the overall control rate of annual runoff. The overall goal of the "sponge city" in Yucheng County is to achieve a total annual runoff control rate of 70%.

- *Runoff control method*: At present, the generally accepted runoff control method is to rationally utilize landscape and other available space, and realize runoff control by increasing infiltration amount and stagnant storage of rainwater. The properties of the underlying surface are different, and the infiltration ability of rainwater is also different. The runoff coefficient can be used to evaluate the infiltration ability of different ground properties to rainwater. In urban construction, the method of overdue storage regulation is the most effective means of runoff control. As long as there is enough space for the overdue adjustment and storage method, theoretically, it can be stored in unlimited capacity. At the same time, the stored rainwater is also easy to reuse, saving water resources. In urban planning and construction, it is recommended that all underlying surfaces that may be delayed in regulation and storage should take certain measures to delay regulation and storage of rainwater to control runoff.
- *Runoff control goals*: This plan proposes two goals for the comprehensive runoff coefficient of rainwater in the

central urban area of Yucheng County: After the reconstruction of the old urban area, the comprehensive runoff coefficient shall not be higher than that before the reconstruction. The comprehensive runoff coefficient of the new city cannot be greater than 0.5.

- *Control measures for runoff coefficient*: Due to the large service scope of this planning, the construction of the rainwater infiltration system should be adapted to local conditions and dispersed. Including artificial ponds, sunken green spaces, rainwater storage systems, ecological grass ditch, permeable pavement ground, artificial wetlands, etc., combined with urban inner lakes, natural ponds and low-lying areas.
- *Planning and layout of related facilities*: According to the overall urban planning, 639.16 ha of green space is reserved in the urban construction land. The plan recommends that all new and reconstructed green spaces in the urban area in the future should be constructed as concave as much as possible, and the overall proportion should not be less than 70%. This plan preserves the northern forest park of Yucheng County. In this planning, within the planning scope of the entire city, 1 lake is planned, 1 existing lake and 1 pond are reserved, and 2 large urban wetlands are set up to achieve the purpose of accumulation and infiltration. The plan clarifies that in the construction of new cities, the permeable ground should reach more than 40%.

3.3.2.2. Runoff pollution control

In the early stage of rainfall, the pollutant content in rainwater is higher, which is called first rain. In the early stage of heavy rain, rainwater will wash away urban roads, buildings, and waste, carrying a large amount of nitrogen oxides, heavy metals, organic matter and pathogens. This kind of rainwater penetrates into the surface layer and affects the groundwater, which will seriously affect the water security of the city.

Yucheng County is rich in urban water resources. The main goal of intercepting rainfall runoff in the early stage is to control runoff pollution. Therefore, in the prevention and control of rainfall runoff pollution, it is extremely important to appropriately increase the interception to reduce its impact on surface and groundwater resources. Combined with the fact that the initial rainwater pollution in the central urban area of Yucheng County is relatively light and the local economic conditions, this plan determines the initial rainwater interception amount in Yucheng County to be 5 mm.

3.3.2.3. Rainwater resource utilization

The utilization of rainwater resources is to take rainwater storage, infiltration, use and dispatch measures on the roofs, roads, parks and squares of public buildings in residential areas to reduce rainwater runoff, reduce flood peak flow, and prolong rainwater confluence. At the same time, it can supply natural water in the city, alleviate the water resource crisis, maintain the ecological balance of water, and prevent the ground from collapsing.

The key to the utilization of urban rainwater resources is how to effectively utilize rainwater resources, relieve water resources tension, and relieve the pressure of flood control in cities. Turn urban floods into water resources, improve the urban natural environment and water ecosystem, and adjust the unbalanced urban water resources in various urban areas.

3.3.3. Planning and layout of drainage pipe network settings

3.3.3.1. Drainage system

Some areas of the old urban area of Yucheng County currently adopt the drainage system of interception and confluence, which is effective in preventing pollution in peacetime, but the first rain runoff overflowing during the rainy season will still pollute the river and cause damage to the urban environment. Therefore, in order to better prevent pollution and maintain the urban environment of Yucheng County, the plan divides the drainage system of Yucheng County into "complete diversion". In the planning and approval of new projects, renovation projects and expansion projects in the planning area, they are strictly required to conduct drainage design and construction according to the diversion system.

3.3.3.2. Drainage partition

The plan divides the central urban area of Yucheng County and its surrounding areas into 10 rainwater drainage zones based on the urban topography, the layout of rivers, and railway trunk lines, combined with the actual construction conditions and urban planning of the urban area.

3.3.3.3. Drainage network planning

The selection of the form of drainage pipes, combined with the terrain and geological conditions of Yucheng County, the urban roads are recommended to adopt the form of hidden pipes or hidden culverts. In areas where discharge conditions are restricted (such as low-lying areas or at the beginning of a pipeline), open channels can be used for drainage.

3.3.3.4. Drainage pipe calculation

The formula for calculating the design flow of the drainage channel in this scheme is:

$$Q = \alpha \cdot q \cdot S \tag{6}$$

In Eq. (6), α represents the flow of rainfall, q represents the intensity of rainfall, and S represents the area of rainfall. The runoff coefficient is an indicator that reflects the ratio of runoff to rainfall in the process of surface rainfall. In the design of urban drainage pipes, the runoff coefficient must be determined according to the type of surface cover, and in the aggregate catchment area, the average flow coefficient is calculated by the following equation:

$$\alpha = \frac{\sum \beta_i \cdot \chi_i}{S} \tag{7}$$

In Eq. (7), β_i represents the area of various ground surfaces in the catchment area, and χ_i represents the flow corresponding to various ground surfaces. Different types of surface runoff coefficients are shown in Table 3.

Table 3
Runoff coefficients of various types of ground

Ground type	Runoff coefficient
Various roofing, concrete or asphalt pavements	0.9
Boulder pavement or asphalt-surfaced gravel pavement	0.6
Graded gravel pavement	0.45
Dry masonry or gravel pavement	0.4
Unpaved soil pavement	0.3
Park or green space	0.15

3.3.3.5. Drainage pump station planning

In order to solve the problem that the urban rainwater is difficult to discharge into Xianghe, Baihe, Yunlianghe and Dongshahe by gravity flow, 11 rainwater and sewage pumping stations are designed with a regeneration cycle of 5 y, and are inspected according to the flood control standard of once in 20 y. In order to solve the problem of easy waterlogging of the overpasses along the Longhai Railway, two railway overpasses including Lijiang Road and Xinjian Road are planned to plan the interchange drainage pumping station. The design recurrence period of the drainage pumping station is 10 y. The buried integrated drainage pumping station can be constructed according to the site conditions. When the new railway interchange is designed, the design and construction should be synchronized, and the drainage pumping station of the hub should be checked and accepted simultaneously. The scale of the drainage pumping station is specifically determined according to the site conditions of the catchment area, the catchment time, the runoff coefficient and the vertical design of the road.

3.3.3.6. Pipeline location planning

According to the current situation of rainwater pipe location in Yucheng County, combined with the actual situation of the area, it is proposed to set up rainwater pipelines below the non-motor vehicle lane. The north side is set with east-west direction, and the west side is set with north-south direction, and the width is greater than 40 m on both sides.

3.3.4. Urban waterlogging prevention system planning

According to the results of waterlogging risk assessment in each area of Yucheng County, in order to reduce the risk of waterlogging in the city from the source, the planning proposes the following adjustment suggestions for the land use nature and vertical control of some plots in the urban area.

3.3.4.1. Nature of land use

- *Land for low-impact development facilities*: This planning implements the requirements of low-impact development and construction and achieves the urban runoff control target. Guided by the concept of urban double repair, the construction of sponge city is realized, combined with the overall urban planning, 639.16 ha of green space has been reserved in the urban construction land, including parks, sunken green spaces, grass-planting ditch and other forms.
- *Land for river courses*: In this plan, 6 main river courses are reserved in the central urban area of Yucheng County, namely Xianghe River, Shangzhou-Zhouyong Canal, Niuhe River, Central Main Canal, Shizi River, Yunliang River, etc. The water system formed by these channels and ditches can not only form a beautiful water landscape, but also be used for infiltration, stagnation, regulation and storage, and drainage of rainwater. The land for these river courses has been planned and controlled in the overall urban planning, and will not be adjusted in this planning.
- *Land for runoff pollution control facilities*: In order to control the initial rainwater pollution in this planning, 16 initial rainwater storage tanks are set up in the urban area.
- *Suggestions on the construction of urban green space*: The plan suggests that all new and reconstructed green spaces in the urban area in the future should be constructed as concave as much as possible, and the overall proportion should not be less than 70%. The green belts on both sides of the Huancheng Road and the Transit Road are equipped with grass-planting ditch to promote the storage and infiltration of rainwater.

3.3.4.2. Vertical control

For the medium-risk areas and high-risk areas in the newly planned urban area, it is recommended to increase their vertical planning. The current topography of these areas is relatively low-lying. During heavy rains, if the water level of the downstream river is supported, the rainwater will overflow from the pipes. There are also some local depressions lower than the surrounding area, such as the blockage of the external drainage rainwater pipes and the poor drainage, which will form water points. Therefore, the planning suggests that when building the urban area, it should be raised by a combination of earthwork balance and outbound earthwork. The planned ground elevation of these areas should be more than 1 m above the design water level of the rainwater receiving channel, thereby fundamentally reducing the risk of waterlogging.

For the medium-risk areas and high-risk areas in the current urban area, it is already difficult to carry out vertical transformation. The planning will combine the current conditions, formulate targeted drainage plans according to local conditions, and solve them from the aspect of engineering measures. For example, a rainwater pump station will be built for the railway overpass along the Longhai Railway, a new rainwater main pipe will be added in the old city, and the existing ponds will be retained.

3.3.4.3. Urban inland river system comprehensive management planning

In order to ensure the drainage of rainwater in the urban area and prevent the occurrence of waterlogging, a total of 6 main rivers have been reserved in the urban area, namely Xianghe River, Shangzhou-Zhouyong Canal, Niuhe River, Central Main Canal, Shizi River, and Yunliang River. Among these rivers, the upper reaches have a larger area and belong to the flood control rivers, such as Xianghe River, Shangzhou-Zhouyong Canal, Niuhe River and the upper reaches of the Central Main Canal. Other rivers are inland rivers in the urban area, and their function is to discharge the rainwater in the urban area and take into account the needs of landscape. The plans for each inland river are as follows:

- *Central trunk channel*: In this plan, this section is planned to be a trapezoidal cross-section open channel, and ecological slope protection is used on both sides to absorb and infiltrate rainwater. It is calculated that when the central trunk canal experiences a heavy rainstorm once in 20 y in the urban area of Yucheng County, the flow rate of Xianghe River to the planned G343 section is about 23.3 m^3/s. The plan adopts a trapezoidal section, the slope is protected by a three-dimensional soil and water protection blanket, and the turf is planted after the surface planting soil is leveled. The roughness is taken as 0.025, the bottom width of the river channel is planned to be 8.0 m, the slope ratio is 1:3, the effective water depth is not less than 2.5 m, and the longitudinal slope of the river channel is 1/7000.
- *Cross River*: It is planned to adopt a trapezoidal cross-section open channel with a gentle slope, and ecological slope protection on both sides of the river will be used to absorb and infiltrate rainwater. It is calculated that when the Shizihe River experiences a heavy rainstorm once in 20 y in the urban area of Yucheng County, the flow rate from the Xianghe River to the Yunliang River is about 24.5 m^3/s. The plan adopts a trapezoidal section, the slope is protected by a three-dimensional soil and water protection blanket, and the turf is planted after the surface planting soil is leveled. The roughness is taken as 0.025, the bottom width of the river channel is planned to be 10.0 m, the slope ratio is 1:3, the effective water depth is not less than 2.5 m, and the longitudinal slope of the river channel is 1/5000. The flow of the west branch of the Cross River is about 15 m^3/s. The plan adopts a trapezoidal section, the slope is protected by a three-dimensional soil and water protection blanket, and the turf is planted after the surface planting soil is leveled. The roughness is taken as 0.025, the bottom width of the river channel is planned to be 8.0 m, the slope ratio is 1:2, the effective water depth is not less than 2.5 m, and the longitudinal slope of the river channel is 1/5000.
- *Yunliang river*: It is planned to use a trapezoidal cross-section open channel with a gentle slope, and ecological slope protection on both sides of the river will be used to absorb and infiltrate rainwater. It is calculated that when the Yunliang River experiences a heavy rainstorm once in 20 y in the urban area of Yucheng County, the flow rate of the section from Chengsi Road to Shizihe is about 27.9 m^3/s. The plan adopts a trapezoidal section, the slope is protected by a three-dimensional soil and water protection blanket, and the turf is planted after the surface planting soil is leveled. The roughness is taken as 0.025, the bottom width of the river channel is planned to be 10.0 m, the slope ratio is 1:2.5, the effective water depth is not less than 2.5 m, and the longitudinal slope of the river channel is 1/6000.

3.3.4.4. Layout of urban waterlogging prevention facilities

- *Urban waterlogging drainage channel*: This planning is to solve the problem of waterlogging leakage in the urban area, especially the problem of rainwater leakage exceeding the design standard. According to the terrain conditions and external drainage conditions of Yucheng County, combined with the distribution of natural drainage ditches and culverts, the drainage channels for rainwater are planned.
- *Urban rainwater storage facilities*: In this plan, combined with the natural conditions of Yucheng County and the overall urban planning, priority will be given to the use of reservoirs, lakes, natural pits, urban wetlands, and storage tanks in urban areas and peripheral areas for storage. If necessary, the concave green space can be used for temporary rainwater storage.

4. Simulation evaluation and analysis of the effect of the comprehensive planning scheme of drainage and waterlogging prevention layout

4.1. Underflow nodes with different return periods

When the rainfall exceeds the load capacity of the pipeline, the rainwater will overflow from the rainwater pipe network to form an overflow node. Under the rainfall conditions of different return periods, the quantity statistics of different overflow sections are shown in Table 4.

Under different rainfall return periods, it is generally believed that the overflow of rainwater wells is greater than 5 m^3, which means that the capacity of rainwater wells is insufficient. In the process of urban waterlogging, the overflow point with the overflow volume of more than 1,000 m^3 often becomes the main overflow point that causes the waterlogging. According to Table 4, it can be seen that the drainage condition of this scheme has been greatly improved. There is no large-scale stagnant water in the planned area,

Table 4
Statistical table of the number of node overflows in different rainfall return periods

Rainfall return period	Overflow volume (m^3)					
	<5	5–50	50–100	100–500	500–1,000	>1,000
1	120	1	0	0	0	0
2	119	1	1	0	0	0
3	115	3	2	1	0	0

Table 5
Statistical table of pipe network capacity in different return periods

Rainfall return period	Pipe network carrying capacity					
	$K_s < 1$		$1 \le K_s < 2$		$2 \le K_s$	
	Amount/piece	Proportion/%	Amount/piece	Proportion/%	Amount/piece	Proportion/%
1	121	100%	0	0	0	0
2	121	100%	0	0	0	0
3	120	99.17	1	0.83	0	0

no major overflow points of waterlogging, and no waterlogging disasters in the city, which meets the corresponding planning goals.

4.2. Bearing capacity of the pipeline network under different return periods

The pipeline network in the planning area belongs to the newly-built pipeline network, and the construction standard of the pipeline network shall be constructed according to the design standard of the rainstorm recurrence period of 3a. Therefore, when using the model to evaluate the capacity of the rainwater pipe network in the planning area, under different rainfall scenarios, whether the rainwater pipe network can meet the requirement that the rainstorm recurrence period is 3a has become the focus of this research.

The overload factor K_s can be used to evaluate the drainage capacity of the pipe network. When the overload factor K_s is less than 1, it means that the water in the pipeline does not fill the pipe diameter; when the overload factor K_s is greater than 1, it means that the water in the pipeline has filled the pipe diameter. In this case, the subdivision can be continued. When the overload coefficient K_s is greater than 1 and less than 2, the hydraulic slope is greater than the pipeline slope, which is due to the insufficient drainage capacity of the downstream pipeline, which leads to poor drainage in this section. When the overload coefficient K_s is greater than 2, the hydraulic gradient is less than the pipeline gradient, which is due to poor drainage due to insufficient drainage capacity.

This paper evaluates the new drainage system based on the planned pipe network model, simulates and analyzes the carrying capacity of the rainwater pipe network under different design rainfall conditions, and identifies and judges whether the planned rainwater drainage system can meet the planning requirements. The statistics of pipe network capacity in different return periods are shown in Table 5.

It can be seen from Table 5 that the drainage pipe network system in the entire planning area in this planning scheme is in good condition. The reason is that there are a large number of drainage outlets in the area, there are several open channels nearby, and the inspection wells are close to the rainwater outlets that are discharged to the open channels. When the rainfall return period is 3a, the number of overload coefficient K_s greater than 1 and less than 2 is 1, accounting for 0.83%. At this time, the hydraulic gradient is greater than the pipeline gradient, and the drainage of this section is not smooth due to the insufficient drainage capacity of the downstream pipeline.

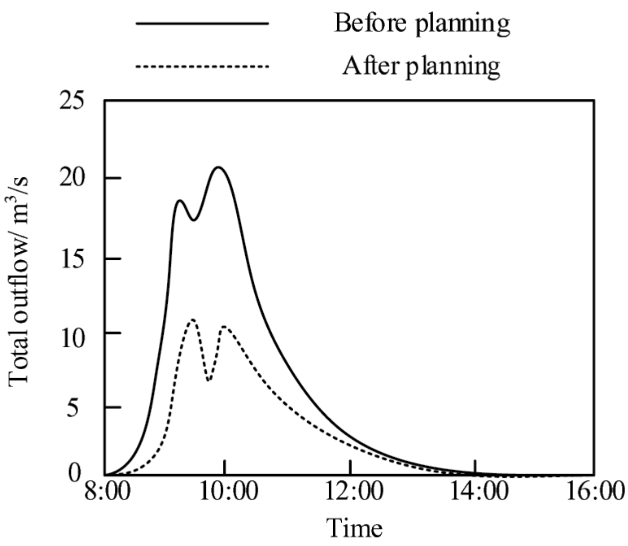

Fig. 3. Effect of planning scheme under the same rainfall conditions.

4.3. Effect of the planning scheme under the same rainfall conditions

The effect of the planning scheme under the same rainfall conditions is analyzed by the model, as shown in Fig. 3.

It can be seen from Fig. 3 that under the same rainfall conditions, the total outflow after the implementation of this planning scheme decreased from 16.12×10^4 m^3 to 9.28×10^4 m^3, a decrease of 41.89%. The peak flow was reduced from 21,379.5 to 10,683.6 m^3/s, with a reduction rate of 50%. It can be seen that the use of this planning scheme can significantly enhance rainfall infiltration, and reduce ground runoff can effectively reduce urban waterlogging.

5. Conclusion

Taking Yucheng County as the research object, guided by the concept of "double repairs in cities", aiming at the construction of "sponge city", combined with the current natural conditions, this paper puts forward a comprehensive planning and research on the layout of drainage and waterlogging prevention based on the concept of double repairs in cities. Using Infoworks ICM, the hydraulic model of the main pipe of the drainage pipe network was built, and a comprehensive planning scheme for the drainage and waterlogging prevention layout was formulated. The research results are as follows:

- Scientifically and rationally determine the planning objectives, and formulate a comprehensive planning scheme for the layout of drainage and waterlogging prevention. This scheme can significantly enhance rainfall infiltration, reduce surface runoff, and play a significant role in alleviating urban waterlogging.
- The drainage situation of this scheme has been greatly improved. There is no large-scale stagnant water in the planned area, no major overflow points of waterlogging, and no waterlogging disasters in the city, meeting the corresponding planning objectives.
- The drainage pipe network system in the whole planning area in this planning scheme is in good condition, which can effectively improve the drainage and flood control capacity of the existing urban drainage system and ensure urban drainage and flood control.

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