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Ecological optimal layout method of rainwater accumulation pipe network in Sponge City under the influence of small seepage

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ABSTRACT

Under the influence of small seepage, a proposed solution to effectively address the problem of rainwater regulation and storage in Sponge City and improve water quality, is the ecological optimal layout method of rainwater garden pipe network in Sponge City. To analyze the relationship between rainwater garden and Sponge City, it takes a research area in Ningnan County, Liangshan Prefecture which focuses on two aspects including the ecological plant configuration and filler configuration of the pipe network. The SWMM model is used to simulate the change of run-off before and after the ecological optimal layout of the pipe network, the change of flood peak lag time, the change of rainwater outflow time, and the change of pipeline regulation and storage status, so as to analyze the effect of ecological optimal layout and design the ecological optimal layout plan of rainwater garden pipe network in Sponge City. The results and analysis showed that the ecological optimal layout scheme can improve the storage and water quality of the Sponge City, and provide technical support for the reconstruction of the Sponge City under the influence of small seepage.

Keywords: Small seepage; Sponge City; Rainwater garden; Network ecology; Optimized layout; SWMM model

1. Introduction

With the acceleration of China's urbanization process and the rapid development of gray infrastructure, the proportion of hardened surface area increases, the permeability decreases, the proportion of surface run-off increases, and the urban drainage system is overloaded, which makes it difficult to meet the high-intensity rainstorm, leading to the frequent occurrence of the phenomenon of "City Looking at the Sea" [1]. The urban rainfall run-off carries a large number of suspended solids, nutrients, heavy metals, oils and pathogenic bacteria, etc. These pollutants directly enter the urban receiving water through the surface run-off, not only damaging the water ecology, but also threatening human health [2]. According to the 2016 Water Resources Bulletin, among the 118 lakes in the country, poor V lakes with extremely serious pollution account for 58.5%. The eutrophication of 78.6% of lakes is prominent, and the water environment quality is not optimistic.

In order to solve the problems of urban waterlogging, non-point source pollution and water shortage caused by the urbanization process, experts and scholars around the world are actively seeking a new type of urban rainwater and flood management technology [3]. "Sponge City" refers to the goal of alleviating urban waterlogging, reducing run-off pollution load and improving urban water environment by giving priority to the use of natural drainage system and maintaining the hydrological characteristics before and after urban development and construction through various ecological drainage facilities. Rainwater garden is

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a new type of green rainwater infrastructure integrating rainwater infiltration, collection, storage and purification based on the concept of "Sponge City". In recent years, it has been widely used in residential areas, streets, parks, campuses and parking lots in developed countries such as Europe and the United States [4].

Rainwater garden refers to a kind of urban landscape that uses trees, shrubs, flowers and other plants in the relatively low terrain areas of the city to throttle and initially purify the rainwater, and strengthen the infiltration efficiency of the area to achieve the reduction of rainwater run-off and the recycling of rainwater. Rainwater garden, also known as biological detention facilities, refers to the use of plants, soil and microorganisms to purify the quality of rainwater in low-lying areas where plants grow, reduce run-off discharge by increasing the retention time of rainwater and improving soil permeability, recharge groundwater or reuse the collected rainwater for urban miscellaneous water such as landscaping and toilet flushing [5]. The rainwater garden is the main force to build a Sponge City, and is a rainwater storage device adapted to the natural geographical conditions to realize the resource management of rainwater [6]. At the same time, the landscape treatment method is used to make plants and materials become the protagonist of the garden, to revitalize the rainwater facilities and create an artistic "Rainwater Bank" [7]. In addition to its practical rainwater regulation and storage function, it should also be endowed with higher ornamental value, making it a basic unit to solve the urban storm flood problem and build a Sponge City [8].

The rainwater garden has been gradually used in the design. The rainwater garden covers a small area, has high-cost performance, and is relatively cheap compared with other facilities, and has strong practicability. Rainwater garden is arranged around residential area, park green space, roads and parking lot. With the expansion of the city, the area of urban residential areas has also expanded. Residential areas account for a large proportion in cities. Therefore, it is very important to solve and manage the rainwater in residential areas. The rainwater garden in the residential area not only solves the problem of rainwater, but also solves the ecological landscape; The park green space belongs to the larger part of the urban greening area. The introduction of rainwater utilization facilities in the park can alleviate the greater pressure of rain and flood. The combination of green facilities and green space can be used as a large rainwater treatment organ in the city. The rainwater garden can utilize rainwater to some extent, alleviate flood, supplement and purify groundwater by combining other facilities, such as comprehensive utilization and complementary grass planting ditches, reservoirs, rainwater wetlands and other elements; The use of rainwater gardens in roads and parking lots mainly considers the purification of water quality and the reduction of rainwater run-off. The pollutants in the parking lot and on the road will be washed into the water with a large amount of rain. If discharged into the river along the drainage pipe, it will pollute the water quality [9]. The use of rainwater garden can not only make the road safer and easier to operate, but also filter the water quality, alleviate the pressure of flood and waterlogging. The development of rainwater garden in China is still at a rising stage, and the country vigorously advocates the recycling of rainwater, which has been implemented in urban development. China has done a lot of research on rainwater gardens, but the micro-configuration methods and some technologies should be further deepened [10].

When studying the control effect of rainwater garden on the heat pollution of rainwater run-off, Xu et al. [11] believed that the smaller the rainfall intensity is, the lower the temperature of the filler layer is, the higher the temperature of rainwater run-off is, and the more significant the control effect of rainwater garden on the heat pollution of rainwater run-off is. This experiment mainly studied the control effect of the temperature of the filling layer of the rainwater garden on the thermal pollution of the rainwater run-off. The research results are valuable, but the research factors are relatively single.

When studying the application of rainwater garden in the Yueyang Project of the Yangtze River Protection Project, combined with the actual greening land of the community, Pi et al. [12] adopted the sponge transformation method of rainwater garden, sunken green space and other design concepts, and concluded that the sponge transformation function should be defined in combination with the geographical environment, so as to ensure the retention, infiltration and absorption of rainwater in the rainwater garden and prevent waterlogging in the community. This research conclusion is enlightening to this study, but its applicability is limited to the Yangtze River Protection Yueyang Project.

Wang et al. [13] considered that adding a forebay in the rainwater garden system could significantly improve the purification capacity of rainwater and remove pollutants in the water when studying the effect of the forebay rainwater garden system on the rainwater purification in the industrial area. But this study does not analyze the specific regulation and storage capacity of the forebay to meet the application requirements under the influence of seepage.

Based on previous research, this paper summarizes the design steps and planning content through the integration and research of rainwater garden data, combining with relevant cases, and combining with the relevant concepts of Sponge City, studies the ecological optimal allocation of rainwater garden, and puts forward more practical guidance for the design ideas and concepts of rainwater garden, aiming at providing more complete and comprehensive theoretical support for the practice of rainwater garden.

2. Ecological optimal layout method of rainwater garden pipe network in Sponge City

2.1. Ecological layout objectives of rainwater garden pipe network

The rainwater garden is mainly composed of five parts, from top to bottom, including aquifer, cover layer, planting layer, filling layer and gravel drainage layer, usually including pre-treatment facilities and overflow facilities. Each structure has different ecological and structural functions:

(1) Aquifer: store rainstorm run-off and deposit some pollutants;
(2) Cover layer: select bark to create an environment conducive to the growth of microorganisms and reduce the erosion of run-off on fillers and soil;

(3) Planting layer: it is composed of commonly used sand, soil or organic matter to provide nutrients and growth environment for plants;
(4) Filling layer: natural or artificial materials with strong permeability, mainly sandy soil, slag and gravel, are selected to systematically control rainstorm run-off and main bearers of pollution load;
(5) Gravel drainage layer: it is composed of gravel or spall with small particle size, and drainage pipes are set at the bottom to drain the infiltration rainwater.

According to the soil permeability and functional requirements, the rainwater garden is divided into natural infiltration type and recycling type, and according to the different use requirements, it is divided into rainwater garden for the purpose of controlling run-off pollution and for the purpose of controlling run-off [14].

2.2. Relationship between rainwater garden and Sponge City

City is an organism. It has its own life cycle and personality characteristics, and its own life cycle and development track. In order to maintain the good operation of a city, all its components must cooperate with each other and work together [15].

Ecological infrastructure is the flesh and blood of the city, providing the natural services needed by the city. It covers a wide range, including not only urban green space, but also forestry system, agricultural system, natural reserve system, etc. The construction of ecological infrastructure is to maintain the structural integrity of nature and ecology to make it possible to provide the required ecosystem services for the city [16]. The relationship between rainwater garden and Sponge City is shown in Fig. 1.

In Fig. 1, as an eco-technical means at the micro-level of the ecological infrastructure, the rainwater garden is equivalent to one of the cells in the urban organism. It works together with other ecological facilities, and countless cells work together in an orderly manner to jointly maintain the operation of urban organisms. In the Sponge City theory, the relationship between rainwater garden and city can be described as the relationship between "sponge cell" and "urban sponge". As one of the many sponge cells, the rainwater garden has both landscape and ecological characteristics, and it covers a wide range. At the same time, it is also known as the "small pore" of the Sponge City. Therefore, the existence of rainwater gardens should be orderly or rule based. This requires us to find a reasonable method at the planning level so that every rainwater that can be treated and purified can be treated and every rainwater garden can play its due role [17].

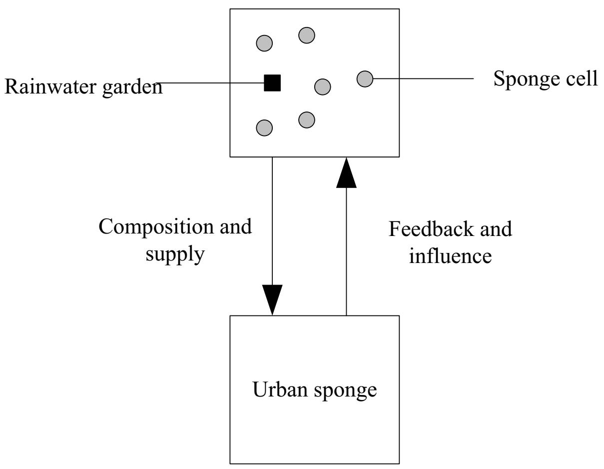

Fig. 1. Relationship between rainwater garden and Sponge City.

2.3. Overview of the study area

Ningnan County is located in the southwest of Sichuan Province, on the west bank of the middle reaches of the Jinsha River, and faces Qiaojia County across the Jinsha River in Yunnan Province. It has undulating mountains and ravines, with an altitude span of 585~3,919 m, and a relative height difference of 3,334 m. It has typical mountain landform characteristics. The average annual temperature is 19.3°C, the average annual sunshine duration is more than 2,230 h, the annual frost-free period is 320 d, and the average annual precipitation is about 960 mm. It has a three-dimensional agricultural climate characteristic with distinct dry and wet seasons, and is suitable for the growth and reproduction of a variety of animals and plants.

The groundwater resources in the area are rich and the types are relatively complete. Due to the influence of stratum, rock, structure and landform, the groundwater shows great differences. The types of groundwater in the area are mainly bedrock fissure water and quaternary loose accumulation pore water.

The bedrock fissure water is mainly karst fissure water, and a small part of basalt fissure water and clastic rock fissure water. Except for the large flow of individual karst fissure water, other water volumes are less than 101 s. Except that some of the water is discharged into the Heishui River through the Yinchang Valley, the rest is diverted to irrigation and becomes one of the pore water supply sources. Bedrock fissure water is controlled by lithology and structure. Its burial, recharge, migration and discharge conditions are complex. The hydraulic connection between water-bearing fissures is poor, and it is mainly recharged by atmospheric precipitation infiltration.

The general trend of groundwater in the study area is controlled by the north-south direction, and generally moves from north to south towards the Jinsha River. It mainly recharges river water, and Jinsha River is the underground drainage base level. The chemical types of groundwater in the working area are mainly calcium bicarbonate type water and calcium magnesium bicarbonate type water. Generally, it is neutral water, with pH value of 6.5–8.0 and salinity of <1 g/L. Due to the shallow burial depth of quaternary pore water, there is still serious pollution of groundwater in the densely populated area of Ningnan County. Shallow groundwater in the working area, especially in loose accumulation, has a negative impact on the stability of geological disasters such as landslides.

Ningnan small watershed is located in the middle reaches of the Jinsha River. Ningnan County and Qiaojia County are located on both banks of the Jinsha River, with an area of about 100 km^2. The towns and villages in the region are mostly concentrated, with a concentrated population and a high density; The engineering construction and other important infrastructure are concentrated, the social economy is developed, the human engineering activities are intense, the surface water and groundwater are rich, the gully erosion is serious, the impact on the natural environment and geological environment is extremely prominent, and it is easy to cause the frequent occurrence of geological disasters such as landslides, collapses, debris flows, etc.

Therefore, the ecological layout of urban pipe network in this region is one of the core issues in the process of urban development.

When calculating the simulation results of the optimal rainwater garden configuration, firstly the ecological plant configuration and ecological filler configuration results are confirmed. Among them, in the process of ecological plant configuration of rainwater garden pipe network, according to the topographic relief form characteristics around and inside the rainwater garden, the rainwater garden is divided into three planting areas with different terrain. The first area is the bottom of the rainwater garden, which is the main functional area of the rainwater garden. It is mainly used to collect rainwater run-off around. According to the characteristics of concentrated rainfall in spring and summer, this area is prone to intermittent flooding and is the wettest area in the three areas. Therefore, in the process of plant selection, the waterlogging resistance of plants and the ability to reduce run-off pollutants should be considered; Zone II is located between Zone I and Zone III, with relatively large topographic fluctuation and inclined drape shape. When configuring plants, the area should be fully considered to be vulnerable to rainwater run-off erosion and rainwater accumulation. The selected plants should have good slope protection ability, namely, plants with deep roots and stable growth, and have a certain water and moisture resistance. It should avoid selecting plants with higher plants to avoid lodging, that affects the landscape effect; Zone III is the weir body area of the rainwater garden and the surrounding area is relatively flat. The weir body is mostly ridge-shaped, and the rainwater retention time is relatively short. Therefore, this area is relatively short of water compared with the former two, and it is located at the periphery of the rainwater garden. Therefore, in the process of plant allocation in the Zone III, the drought resistance ability of plants should be fully considered, and the selected plants should bear the impact generated when the surrounding run-off flows to the rainwater garden; In the process of ecological filling configuration of rainwater garden pipe network, the artificial filling layer of rainwater garden can enhance the drainage performance of rainwater garden and remove pollutants such as solid suspended particles and phosphorus. The artificial seasoning layer of the rainwater garden is designed as a layered mode, from top to bottom, it is composed of vegetation, 20 cm soil, 20 cm fine sand, 15 cm coarse sand, 15 cm gravel and cushion. The soil has a certain capacity of adsorption and degradation of pollutants. Generally speaking, the greater the adsorption intensity is, the faster the concentration of pollutants decreases, and the shallower the depth of pollutants entering the soil layer is. At the same time, the soil creates a suitable living space for microorganisms. In the test, layered fillers are selected for comparative study. The upper layer is soil, which is the main carrier of substrate and microorganism, and fine sand, coarse sand and gravel are used as the skeleton of soil particles to improve the hydraulic load performance of the system, and increase the porosity, which is conducive to the circulation of air inside the system. At the same time, the biofilm formed on the surface of the medium provides a certain growth environment for microorganisms.

2.4. Simulation of rainwater garden configuration effect based on SWMM model

SWMM model is a dynamic hydrological model that simulates the urban rainwater process and water quality monitoring. Through a series of rainwater sub-areas that can produce run-off or pollutants, infiltration, transmission and storage, the simulation of hydrology, hydraulics and water quality can be realized. The process is rigorous and highly generalized, and can reflect the basic process of rainwater flood formation. The simulation process of SWMM model mainly includes three models, namely rainfall, surface run-off and pipe network confluence model.

2.4.1. Rainfall model

According to the Code for Design of Outdoor Drainage (2014 Edition) (GB 50014-2006), the designed calculation model of rainfall intensity j is:

$$j = \frac{38.3623 + 39.0267\lg T}{\left(t + 19.1377\right)^{0.975}} \tag{1}$$

where t and T are rainfall duration and rainfall return period, respectively. The Chicago rain pattern is adopted for the design rain pattern, and the return period is in line with the local flood control standard.

2.4.2. Small seepage influence model

2.4.2.1. Surface run-off model

The surface run-off generation model is applicable to the calculation of the process from rainwater infiltration to overflow and ponding. Its operation is to divide the research area into multiple catchment surfaces according to different land types and regional drainage trend, and each sub-catchment surface can be divided into three types, namely, the impermeable surface with low-lying storage capacity, the impermeable surface without low-lying storage capacity, and all the permeable surfaces. The three types of surface run-off are calculated separately, and then the total run-off of the whole sub-catchment surface is obtained by adding (Fig. 2).

The characteristic width of the sub-catchment area has the greatest effect on the calculation of run-off yield, which is the most important parameter in the calculation of run-off yield of SWMM model. The characteristic width can affect the surface concentration time and peak value. There are many methods to calculate the characteristic width of sub-catchment area. There are two commonly used methods, which are area divided by flow length and area square; The calculation method of the characteristic width of the square root of the area is relatively simple, which assumes that the sub-catchment area is rectangular; No matter what calculation method is used, as long as the feature width is within a reasonable range, it will have little impact on the results.

When rainfall infiltrates into the soil in the unsaturated region, it can be interpreted as the process of rainfall infiltration. The run-off generation mechanism in urban areas is based on the percolation run-off generation mechanism of Horton's run-off generation theory; The key of this process simulation is to calculate the ground infiltration capacity.

2.4.2.2. Surface confluence model

When the rainfall is in progress, after the rainfall infiltrates into the unsaturated region, when the rainfall has no time to enter the soil and the unsaturated region becomes saturated, the rainfall will generate surface run-off, which requires the calculation process and simulation of surface run-off. The run-off generalization is shown in Fig. 3.

Water volume and water depth change with time, so when calculating the two variables, they are calculated according to the principle of conservation of matter, namely water balance.

Urban development and construction will significantly change the micro-topographic characteristics of the surface, and thus have an important impact on the division of sub-catchment areas and the characteristics of surface run-off. Scientific delineation of catchment areas and rapid extraction of relevant hydrological parameters are the important basis for the construction of urban hydrological models. Horton is selected as the infiltration mode of the model, and OUrlet is selected as the catchment mode. Finally, using SWMM to simulate the surface run-off process requires a series of input parameters, including deterministic parameters and empirical parameters. The deterministic parameters are mainly the basic data of the catchment area (such as slope, width, impermeability, etc.), in which the slope is obtained by ArcGIS slope extraction tool, and the width is obtained by dividing the area by the flow length. In this paper, the flow length is calculated by using a breakpoint on the boundary that is farthest from the outlet. The impermeability of the catchment area is determined by the type of underlying surface and its impermeability. The empirical parameters need to get the range of each parameter through the SWMM model manual and local hydrological department data. In order to improve the accuracy of parameters, the model parameters are determined according to the field survey, the practical experience of local hydrological practitioners and the published research results in similar regions (Table 1). The obtained parameters are taken as input, and the continuous Eq. (2) and Manning Eq. (3) are used to solve the output results of evaporation, infiltration and run-off.

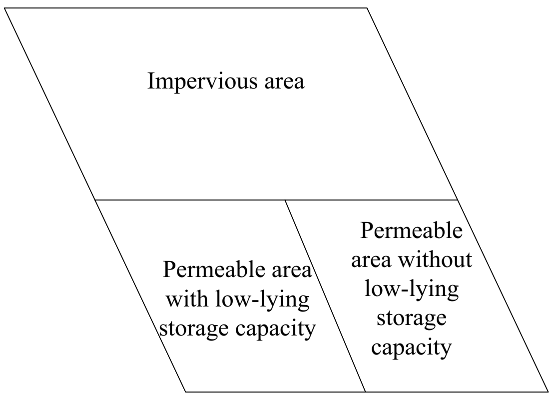

Fig. 2. SWMM model sub-catchment generalization.

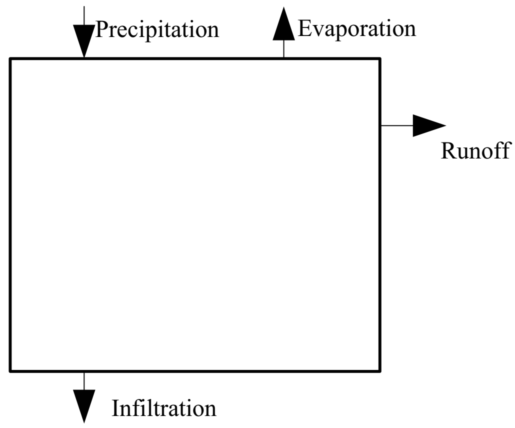

Fig. 3. Run-off generalization.

Table 1
Model parameters

Parameter name	Physical significance	Reference value
N-Imperv	Manning coefficient of impermeable zone	(0.11,0.24)
N-Perv	Manning coefficient of permeable zone	(0.15,0.80)
Destore-imperv	Storage depth of depression in impervious area (mm)	(2.5,4.5)
Destore-perv	Water storage depth of permeable area depression (mm)	(2.54,7.62)
Zero-imperv	Percentage of water catchment unit without depression and impervious area (%)	(5,85)
Maxrate	Maximum infiltration rate (mm/h)	(25,120)
Minrate	Minimum penetration rate (mm/h)	(1.0,5.0)
Decay	Permeability attenuation coefficient	(2,7)

$$\frac{dU}{dk} = B\frac{dk}{dt} = Bj^{n} - P_0 \quad (2)$$

$$P_0 = U \times \frac{1}{m} \times \left(s - s_p\right)^{\frac{5}{3}} \times R^{\frac{1}{2}} \quad (3)$$

where d and U represent the derivative and total water volume, respectively; k and B are surface water depth and catchment area, respectively; t and j^n are rainfall time and net rainfall intensity; P_0 and m are run-off flow and Manning roughness coefficient, respectively; s and s_p are the surface water depth and the maximum depth of surface water storage; R is the average depth of the catchment area.

2.4.3. Pipe network confluence model

During the transmission and storage of surface run-off, it is necessary to converge through the pipe network, so the simulation process needs to be included in the SWMM model. In the SWMM model, the calculation of the pipe network confluence model is derived from the conservation of mass and momentum.

2.4.4. Low-impact development measure simulation

The Low-impact development module has been added in SWMM5.0. In the SWMM model, the LID module includes common facilities such as green roofs, rainwater gardens, and grass ditches [18–20]; Its simulation of the above facilities is a comprehensive hydrological and hydraulic module. According to the water balance method, the corresponding mathematical and physical equations are established using the nonlinear reservoir method to obtain the results.

The specific rainwater treatment diagram of LID facilities is shown in Fig. 4.

It outputs results in various forms, especially the LID module added in the version after SWMM5.0. Through the simulation of rainfall and continuous rainfall, the layout and design of LID facilities can be realized. The structure of the SWMM model is shown in Fig. 5.

In Fig. 5, according to the characteristics of the study area, it is divided into several sub-catchment areas. In each catchment area, the surface run-off generation and confluence processes of sub-catchment areas divided into permeable and impermeable surfaces are calculated, respectively, and the confluence routing is carried out. Combining the deterministic parameters and empirical parameters, the optimal layout of rainwater garden pipe network is confirmed.

3. Results and analysis

The SWMM model is used to simulate the existing pipe network system in the study area, and the results are shown in Table 2.

As shown in Table 2, under the condition of small seepage, there are 21 pipes with overload time exceeding 1 h; There are 18 pipes with the ratio of maximum flow to full normal flow greater than 1. The operation interface of rainwater garden in SWMM software is shown in Fig. 6. The specific setting values of its main parameters are shown in Table 3.

Table 2
Overload of existing pipelines in the study area

Content type	Numerical value
Number of pipes overloaded for more than 1h/piece	21
Number of overloaded pipes	26
Number of pipes with maximum flow and normal flow ratio greater than 1	18

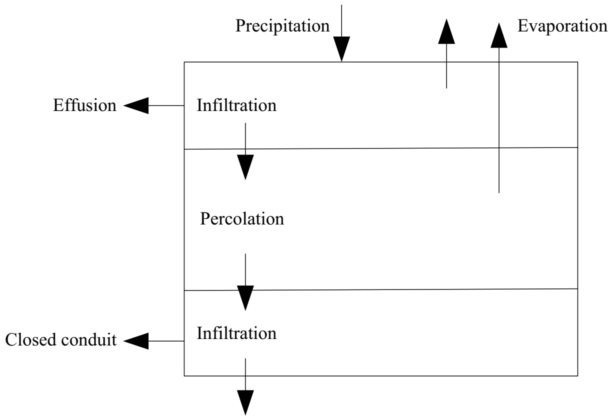

Fig. 4. Specific LID facility rainwater treatment diagram.

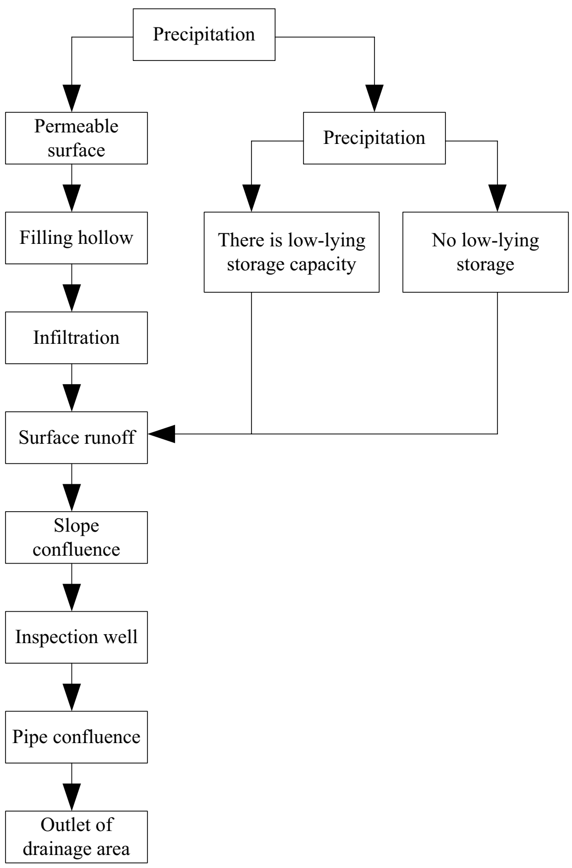

Fig. 5. SWMM model structure.

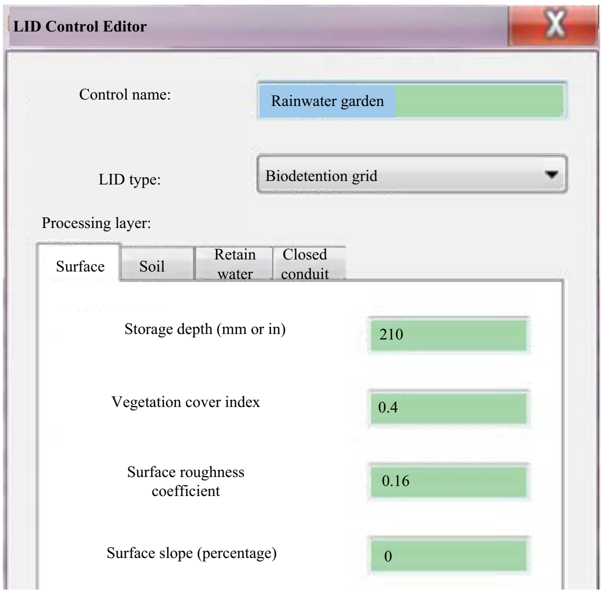

Fig. 6. Operation interface of rainwater garden in SWMM software.

Table 3
Operation interface of rainwater garden in SWMM software

LID facilities		Numerical value
Surface	Impoundment depth (mm)	210
	Vegetation cover index	0.4
	Manning value	0.16
	Surface slope (%)	0
Pavement/ soil	Thickness (mm)	310
	Porosity	0.5
	Water production capacity	0.26
	Hydraulic conductivity	81
	Hydraulic conductivity gradient	10.1
	Water absorption (%)	71
	Permeability	–
	Blocking factor	–
Retain water	Altitude	201
	Porosity	0.76
	Hydraulic conductivity	6
	Blocking factor	0
Closed conduit	Drainage coefficient (mm/h)	0
	Drainage index	0
	Offset height of culvert (mm)	0

Under the use of the method in this paper, the specific structure of the rainwater garden in the study area is shown in Fig. 7.

In Fig. 7, there are three rainwater gardens arranged in the rainwater garden. The areas of rainwater gardens 1, 2 and 3 are 39, 32 and 39 m^2, respectively. The rainwater gardens 1 and 2 belong to the riverside green rainwater

Fig. 7. Concrete structure of rainwater garden.

garden. The plants with strong comprehensive drought resistance, waterlogging resistance and decontamination ability and good landscape effect are selected to construct the typical plant models of this type of rainwater garden. The plants are selected, such as *Sedum lineare Thunb.*, *Phnom Penh Ophiopogon japonicus*, *Hosta undulata*, *Euphorbia fortunei*, *Panax notoginseng*, *Pennisetum alopecuroides*, *Miscanthus sinensis 'Variegatus'*, *Miscanthus sinensis 'Morning light'*, *Miscanthus sinensis Cv.*, *Miscanthus sinensis 'Zebrinus'*, *Lysimachia chinensis*, and *Hydrocotyle vulgaris* are configured. This type of area is the first area where the rainwater run-off from the green land enters the rainwater garden, so low and impact-resistant plants are selected for configuration; In the Zone II, plants such as *Hosta undulata*, *Miscanthus sinensis 'Variegatus'*, *Pennisetum alopecuroides*, *Miscanthus sinensis 'Morning light'*, *Miscanthus sinensis Cv.*, and *Miscanthus sinensis 'Zebrinus'* are planted. These plants also have strong resistance to the impact of run-off. In the first zone, the plants are equipped with *Lysimachia chinensis* and *Hydrocotyle vulgaris*.

Herbal plant varieties used include: *Cynanchum communis*, *Lysimachia chinensis*, *Euphorbia fortunei*, *Prunus vernicifolia*, *Eruca variegata*, *Eruca tenuifolia*, *Morning light*, *Acorus tatarinowii*, *Ophiopogon japonicus Phnom Penh*, and *Eruca rosea*. In combination with the key points of plant configuration in the rainwater garden, typical herbaceous plant models are configured. *Prunus vernicifolia* and *Lysimachia chinensis* have strong waterlogging resistance and high plant height, so they are planted in Zone I prone to waterlogging; However, plants such as *Miscanthus sinensis*, *Miscanthus sinensis 'Variegatus'*, *Miscanthus sinensis 'Morning light'* and *Miscanthus sinensis 'Zebrinus'* also have relatively strong waterlogging resistance, with wide root distribution, no obvious stem diameter of plants, and are not easy to collapse when suffering from a large amount of rainfall run-off, which can effectively prevent soil erosion, so they are planted in Zone II; However, *Auspicious grass*, *Hydrocotyle vulgaris*, *Phnom Penh Ophiopogon japonicus*, and *Acorus calamus* have strong drought resistance ability, and the plants are relatively low. Planting them in the Zone III can play a better role in consolidating the weir body of the rainwater garden, and can also create a more three-dimensional rainwater garden landscape with other plants. Table 4 shows the details of rainfall conditions in the study area.

The application effect of the method of this paper in different rainfall duration conditions is shown in Table 5.

As shown in the data in Table 5, when the rainfall duration is 3, 6 and 9 h, respectively, the use of this method can reduce urban run-off and flood peak volume. The lag time of flood peak is only 11 min for 3 h, and the maximum outflow time is 273 min under the condition of rainfall duration of 9 h, which indicates that the method in this paper has the capacity of regulation and storage, but the rainfall duration will affect the use effect of this method.

Taking the rainfall duration of 3 h as the experimental environment, under this condition, the removal effect of three rainwater gardens on total phosphorus in rainwater is shown in Table 6.

As shown in Table 6, the outflow of total phosphorus in rainwater is less than the inflow, but the outflow of rainwater garden is significantly different before and after the use of the method in this paper. Before the use of this method, the outflow of total phosphorus in rainwater is less than that after use. The removal rate of total phosphorus in rainwater by this method is not less than half of the inflow, which shows that this method has good ecological effect.

Table 4
Details of rainfall conditions in the study area

Operating mode	1	2	3
Rainfall duration (h)	3	6	9
Rainfall (mm)	10.9	30.3	11.1
Mean value of rain intensity (mm/h)	0.9	1.7	2.1
Seepage mode	small	small	small

Table 5
Application effect of this method in different rainfall duration conditions

Rainfall duration (h)	3	6	9
Run-off reduction rate (%)	15.29	12.31	11.35
Peak flow reduction rate (%)	11.71	4.02	1.52
Flood peak lag time (min)	11	9	8
Outflow time (min)	51	141	273

In order to analyze whether the application effect of the method in this paper has available value, the methods in Xu et al. [11], Pi et al. [12] and Wang et al. [13] are taken as examples to compare the pipeline overload after the four methods are used. The comparison results are shown in Table 7.

According to the analysis of Table 7, under the use of the methods in Xu et al. [11], Pi et al. [12] and Wang et al. [13], the number of pipes overloaded for more than 1h in the study area is more than that of the method in this paper, and the regulation and storage capacity of the method in this paper is relatively good. After the use of the method in this paper, the number of pipes overloaded for more than 1 h, the number of pipes overloaded, the number of pipes with maximum flow and the proportion of normal flow greater than 1 are all 0.

4. Discussion

Suggestions for operation and maintenance of rainwater garden in Sponge City are:

4.1. Improve the preliminary preparations for the maintenance of rainwater garden

In the construction of rainwater garden, the geographical environment conditions should be fully considered, and reasonable planning should be carried out. Taking the local geographical environment characteristics as an important indicator, the control indicators for the maintenance of the rainwater garden will be established and built into a control system. This system will be combined with

Table 6
Removal effect of rainwater garden on total phosphorus in rainwater

Time	Rate of inflow (mg)	Outflow (mg)	
		Before use	After use
0.0	160	50	100
0.5	60	10	30
1.0	170	60	90
1.5	100	40	60
2.0	70	20	40
2.5	80	30	50
3.0	30	5	20

Table 7
Pipeline overload after four methods

Comparison content	Methods in this paper	Reference [11] method	Reference [12] method	Reference [13] method
Number of pipes overloaded for more than 1 h/piece	0	15	10	15
Number of overloaded pipes (piece)	0	20	10	20
Number of pipes with maximum flow and normal flow ratio greater than 1/piece	0	10	7	9

the urban geographical environment to carry out the construction planning of the rainwater garden [18].

4.2. Strengthen the planning and management of rainwater garden

In the construction of rainwater garden, several elements need to be planned, including water resources operation, water supply and drainage, urban operation planning, urban flood control and drainage system planning. For a city, the transportation network is an important planning project. When planning the rainwater garden, traffic conditions of the city should be considered, and the pipe network should be laid along the planned roads as the trunk. In the planning of rainwater garden, after the urban infrastructure planning is completed, the land usage in the city should be determined. The supervision of land planning should be strengthened and included in the regulation index. For facilities that do not meet the regulation index, measures should be taken to adjust and solve the issues [19].

4.3. Strengthen the maintenance and management of rainwater garden

Urban public projects, such as the construction of urban roads, urban drainage facilities and urban gardens, should be supervised by relevant administrative departments, and all supervisory responsibilities should be fulfilled. The entrusting party is responsible for implementing measures that have no impact or addressing problems that have not been properly maintained and managed.

In summary, the concept of "Sponge City" requires urban construction to adapt to the laws of the natural environment and ensure the city operates efficiently. During the rainy season, cities should have a good "water absorption" function and "water storage" function, and be able to use these water resources reasonably to ensure the reasonable use of water resources, just like a sponge [20].

5. Conclusion

Rainwater garden has become an important technical measure for modern rainwater management and control because of its characteristics of reducing rainstorm run-off, reducing pollution load, replenishing groundwater, high landscape value, low construction and maintenance management costs, etc. As one of the sponge cells in the Sponge City, the rainwater garden is also under construction today when the Sponge City is in full swing. But the construction of rainwater garden is not blind, it should be planned and adapted to local conditions.

Through in-depth research and analysis, this paper draws some conclusions, hoping to do its part and play a role in attracting jade.

(1) The proposal of Sponge City provides new opportunities for the development and construction of rainwater garden. Through the development of rainwater garden and the planning of Sponge City, this paper analyzes the regulation and storage effect of rainwater garden on the city, and puts forward the design strategy of ecological optimal layout.
(2) By standardizing the design of the rainwater garden, the design steps and various design methods of the rainwater garden are proposed, which can make the rainwater garden set up more scientifically under the premise of microscopic planning.
(3) According to the planning design and design steps of the rainwater garden, a successful case is cited to prove its practical significance.

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