

Optimization Simulation of Sponge City Landscape Pattern based on SWMM Model

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Abstract. With the acceleration of urbanization in China, the impermeable area of cities has increased dramatically, and the problem of urban flooding has become more and more serious, so China has put forward the concept of sponge city based on the concept of low-impact development. In this study, the central urban area of Shenyang New City in Liaoning Province is taken as the study area, the rainfall process of different recurrence periods is constructed by using the storm intensity formula, and the landscape pattern optimization is carried out in the study area based on the concept of sponge city, and the Storm Water Runoff Management Model (SWMM) is used to simulate the differences in surface runoff and rainwater regulation capacity under the two scenarios of the pre-planning scheme and the optimization scheme of the landscape pattern, and to analyse the effects of the optimization scheme of the landscape pattern on the urban surface runoff and rainwater regulation capacity of the city. The results show that the surface runoff and stormwater control capacity of the city are affected by the rainfall reuse scenario. The results show that the total runoff and runoff coefficient in the study area tend to increase with the increase of the rainfall return period; the runoff coefficient of the landscape pattern optimization scenario decreases significantly under the same rainfall return period, and the reduction of the total runoff increases gradually, and the reductions under the return periods of 1 year, 3 years, 5 years, and 50 years are 2.94, 3.58, 3.72, and 4.19 mm, respectively; The corresponding reduction rates are 23.9%, 16.4%, 14.3% and 9.3%, respectively; the optimized scheme can meet the requirements of controlling the rainfall of 20.8 mm at the rainfall return period of $p=1$, not overloading the stormwater pipe network at $p=3$ and not overflowing the river at $p=50$.

Keywords: SWMM Model; Optimization Simulation of Sponge City Landscape Pattern; The Problem of Urban Flooding.

1. Introduction

With the accelerated urbanization process in China, urban development has caused serious damage to the water system. The sharp increase in urban impervious surfaces and the decrease in soil infiltration capacity have led to a decrease in rainwater infiltration, increasing runoff, and most of the rainwater runoff can only be discharged through the stormwater pipeline network, which interrupts the urban water cycle system and makes the problem of urban waterlogging more and more serious. In order to solve the rainwater management problems in the process of urbanization, China has taken low impact development (low impact development, LID) as the core concept, combined with the actual development needs, and put forward the concept of sponge city, which figuratively points out that in the aspect of rainwater management, the city has a good ability of accumulation, infiltration and purification, i.e., the city is able to act like a sponge with good "The way of construction mainly includes the protection of pre-development water systems, the restoration of damaged water environments, and the integration of low-impact development measures in urban landscape design .

At present, most of the relevant domestic studies focus on small-scale areas, and lack of research on the impact of landscape pattern on sponge city construction in large-scale areas. The urban landscape pattern can analyze the impact of land use and landscape pattern changes on the ecological environment, and at the same time, the construction of sponge city can also reflect the changes of landscape pattern. In this study, we take the central city of Shenyang New City as an example to optimize the urban landscape pattern, and use the Stormwater Runoff Management Model (SWMM)

simulation and analysis to compare the runoff volume and stormwater regulation capacity of two scenarios before and after landscape pattern optimization, and explore the impact of urban landscape pattern on sponge city construction, with a view to providing a reference for the study of optimizing the landscape pattern of sponge cities at the urban scale.

2. Study Area and Methodology

2.1 Overview of the Study Area

Shenfu New City (41°67' -42°07' N, 123°48' -123°88' E) is located in the eastern part of Shenyang City and the western part of Fushun City in Liaoning Province, which is a new area to promote the integration of Shenyang Economic Zone in recent years. zone, which is a new type of area to promote the integration of Shenyang Economic Zone in recent years, with a total planning area of 605.34 km². The study area is the center city of Shenfu New City and the core functional group of the area, with Shenji Expressway as the northern boundary, east-west to the red line boundary of the connection zone, and south to the western section of Sufu Railway and the administrative boundary of Dongling District, with a total land area of 205.55 km², and the construction land area of 118.21 km². The study area has a mesothermal continental monsoon climate, with four distinct seasons, an average annual temperature of 7.7 °C, an annual precipitation of 654-769 mm, with precipitation concentrated in April-October, accounting for more than 90% of the annual precipitation, and less than 10% of the precipitation from November to March, with an average monthly precipitation of less than 20 mm, and the largest annual precipitation in July, which is 156.22 mm. Due to the monsoon climate, the highest average monthly rainfall is in July-August, which is prone to urban flooding. The study area is rich in water systems, with eight rivers, mainly the Hun River. The south bank of the Hun River is dominated by commercial and residential land use and industrial land use, while the north bank of the Hun River is dominated by residential land use and ecological green space. The study area was originally the floodplain of Shenyang city, and the overall topography is high in the north and south and low in the center. When heavy rainfall occurs, the study area not only needs to regulate the runoff volume in the area, but also needs to regulate the runoff discharge of the whole Shenfu New City.

2.2 Research Methodology

2.2.1 Selection of Storm Rainfall Patterns

Rainfall in this study area is mostly single-peak type short-time heavy rainfall, characterized by short duration and uneven rainfall intensity. Most scholars at home and abroad use the Chicago rain type in urban stormwater runoff modeling, and the effect is better. Therefore, the Chicago rain type is selected as the design storm rain type for this simulation and is based on the relevant technical guidelines such as the "Technical Guidelines for Preparation of Urban Storm Intensity Formulas and Determination of Design Storm Rain Type.

From 2000 to 2016, Shenyang had the highest proportion of rainfall events lasting 120 min to the total rainfall events. According to the formula of storm intensity in Shenfu New City and the formula of Chicago rain pattern, r is selected as 0.4 to get the design rainfall with a rainfall duration of 2 h and a return period of 1, 3, 5, 10 and 50 years, respectively, and then this design rainfall is brought into the SWMM model. The pre-planning scheme of the study area was compared with the landscape pattern optimization scheme to analyze and explore the regulating effect of landscape pattern optimization on runoff volume and urban drainage capacity under the sponge city concept.

2.2.2 Quantitative decomposition of landscape schemes

According to the relevant norms and studies, combined with the actual situation of the study area, according to the function of each control partition, from the perspective of low-impact development, the study area is divided into 11 control partitions (a total of 4 major categories), and each type of control partition has a different rate of integrated runoff control, and the control partition has a total

annual runoff control rate in the range of 70% to 80%, corresponding to the rainfall in the range of 17.5 to 25.0 mm.

The storage volume for each control subdivision in the study area is equal to the sum of the storage volume and infiltration volume for each low-impact development facility, where the storage volume for each low-impact development facility is equal to the product of the area of the facility and the depth of storage, and the storage volume is equal to the product of the number of storage facilities and the volume of the storage facility.

The total annual runoff control rate for each control subdivision was determined using the total annual runoff control rate as a function of design rainfall. The total annual runoff control rate for the stormwater system within the planning area of the study area was obtained by weighting the total annual runoff control rate for each control subdivision with the catchment area of each subdivision. The above steps were repeated until the target of 75 percent of the total annual runoff control rate within the study area planning horizon was ultimately met, and the storage volume for each control subarea was then determined.

2.3 Parameterization

According to the sub-catchment parameters, hydraulic characteristic parameters and rainfall characteristics of the study area, the parameters are set to construct a complete SWMM rainfall runoff model for the study area and the model parameters are calibrated. The model parameters are mainly divided into two parts: deterministic parameters and empirical parameters, in which the deterministic parameters, such as sub-catchment area, slope, impermeability, etc., can be obtained from the existing data; the empirical parameters need to be set within the range of empirical values given in the modeling manuals or related literature. The values of the model parameters are mainly obtained from the SWMM user manual, relevant references, existing master plan drawings, and actual quantitative calculations (Table 1). After preliminary calculation, the integrated runoff coefficient of the planning study area is 0.46, which meets the empirical value standard of integrated runoff coefficient. For the stability of the model under different rainfall conditions, the model was verified with multiple rainfalls of different recurrence periods (1, 2 and 3 years), and the runoff coefficients of 0.45, 0.54 and 0.59 were obtained through simulation for different rainfall processes, which were all in line with the standard of empirical value of the integrated runoff coefficient. It indicates that the parameter settings have good adaptability within the range of return periods specified in the code and can be used for simulation analysis in the study area.

Table 1. City integrated runoff coefficient empirical value

Regional situation	Rate of runoff
Densely built central area	0.6~0.8
Densely built residential areas	0.5~0.7
Sparsely built residential areas	0.4~0.6
Very sparsely built residential areas	0.3~0.5

2.4 Optimization of Sponge City Landscape Pattern

2.4.1 General Optimization of the Landscape Pattern

Combining the current situation of the study area with the pre-planning scheme, the landscape pattern of the study area will be optimized (Table 2): widen the ecological corridors on both sides of the Hun River After optimization, these sites will be adjusted to other land use; the commercial land and residential land above the wetland park on the south bank of the Hun River will be adjusted to other land use; and part of the industrial land on the west side of the study area will be adjusted to cultivated land or other land use as the urban flood relief channel.

Table 2. Comparison of land use indicators in different scenarios

Plan type	Pre-planning programme		Landscape pattern optimization plan	
Land use type area and rate	Area(km ²)	Rate of total area (%)	Area(km ²)	Rate of total area (%)
Green space	41.4	34.4	51.43	41.8
Public green space Protective green space	13.38	9.9	13.23	12.15
	27.83	23.9	37.15	31.8
Water zone and others	88.11	-	93.11	-

Overall optimization of sponge city landscape pattern in the study area, following the principle of "keeping small rainfall, no stagnant water in medium rainfall and no flooding in heavy rainfall", adopting the layout pattern combining points, lines and surfaces, and establishing a network formed by three-level corridors and nodes to store and purify rainwater floods step by step to satisfy the demand of rainfall in different recurrence periods, and at the same time, optimizing the ecological landscape pattern in the study area. Optimize the ecological landscape pattern of the study area.

2.4.2 Quantitative Landscape Program for Each Control Subdivision

Aiming at the current situation and planning characteristics of the study area, a low impact development measure program is set up. Firstly, combining the information of urban functional zoning, water system planning and stormwater drainage planning, the study area is divided into 11 sponge city construction control zones, with an area of 7.76-47.59 km², of which the first, second and third control zones are ecological zones; the fifth, eighth, tenth and eleventh control zones are industrial parks; the sixth and ninth control zones are residential zones; and the fourth and seventh control zones are commercial and recreational zones. Secondly, the following LID measures are selected in combination with low impact development measures: permeable pavement, vegetation buffer zone, rainwater tank, sunken green space, rain garden, artificial wetland, storage pond, ecological tree pond, grass planting ditch, interceptor ditch, etc.

2.5 Scenario Modeling in SWMM

The two scenarios before and after optimization were simulated in the SWMM model, firstly, the study area of the pre-planning scenario was divided into sub-catchment areas and generalized, secondly, the model parameters were set and calibrated, and finally, the surface runoff was simulated to analyze the total runoff volume of the sub-catchment areas and the ponding of water at the drainage outlets for each rainfall recurrence period. For the optimized scheme, due to the optimization of the landscape pattern and the application of LID measures, the river and stormwater pipe network in the generalized structural diagram are adjusted, and the constructional parameters for LID control are set. The surface runoff under different rainfall recurrence periods before and after the optimization of the landscape pattern is simulated, and the simulation result data are compared to analyze its regulation of rainfall in the study area.

3. Results and Analysis

3.1 Impact of Landscape Pattern Optimization on Surface Runoff

This study sets up two scenarios, the pre-planning scenario and the optimization scenario of urban landscape pattern. The pre-planning scenario is simulated with the original green space and water system conditions in the study area, while the optimization scenario optimizes the urban landscape pattern holistically by connecting the spaces of urban green space, urban water system and riparian buffer zones to form a resilient ecological control system and setting the parameters of the LID measures in SWMM.

It was found through simulation that under four different scenarios with return periods of 1 year, 3 years, 5 years and 50 years, the rainfall in the pre-planning scenario increased from 33.84 mm to 67.73 mm when the return period was increased from 1 year to 50 years, and the corresponding runoff volume for each return period increased from 15.21 mm to 49.22 mm, which is a 2.2-fold increase, and with the increase of the return period the infiltration volume increased from 13.77 mm to 17.88 mm, an increase of 29.9%, indicating that the infiltration volume of rainwater is obviously smaller than the runoff volume. In the optimized scenario, the return period increases from 1 year to 50 years, which is exactly the same as the rainfall in the pre-planning scenario. The runoff volume corresponding to each return period increased from 12.27 mm to 45.03 mm, an increase of 3.7 times, and its infiltration volume increased from 14.21 mm to 19.00 mm, an increase of 33.8%. Under the 1-year, 3-year, 5-year and 50-year return periods, the reduction of total runoff in the study area by the optimized scheme was 2.94, 3.58, 3.72 and 4.19 mm, with the reduction rates of 23.9%, 16.4%, 14.3% and 9.3%, respectively. It shows that with the increase of the return period, the reduction of the total amount of runoff by the optimized scheme increases gradually, but the corresponding reduction rate decreases gradually.

3.2 Impact of Landscape Pattern Optimization on Urban Stormwater Regulation Capacity

Under the rainfall conditions of 1-year return period, the surface runoff volume changed a lot before and after optimization, among which, the infiltration volume increased by 3.2%, the runoff volume decreased by 23.9% and reached the design rainfall of 20.8 mm, which indicated that the optimization of the landscape pattern of the study area could satisfy the requirement of "small rain can be retained".

In order to quantitatively analyze the impact of low-impact development measures on runoff in the study area, the main runoff convergence node J74 in the sixth control area was selected, and by comparing the runoff simulation results of this node before and after the implementation of low-impact development measures, it can be concluded that the low-impact development measures have a certain effect on controlling and reducing the runoff in this area. By comparing the process of rainfall-runoff change with time before and after the implementation of low-impact development, it is found that the medium peak value and peak moment have a big change, and the peak value is 24.56 and 19.10 m³·s⁻¹, respectively, which is reduced by 28.6%; the occurrence time is the 54th and 57th minutes, respectively, which is lagged by 3 min. Reasonable arrangement of low-impact development measures can effectively control and reduce urban flooding, mainly in the reduction of flood peak flow, delay the time of flood peak occurrence, so as to reduce the drainage pressure of the traditional urban stormwater network system.

Before optimization, the simulation of the pipe section flow under the 3-year reproduction period is carried out, in which 72 sections of the pipe are overloaded for 0.01~1.15 h. According to the analysis of the impact on the urban traffic and other aspects, the overloading of the pipe section is divided into three levels: 0~0.5 h is a safer section, where the accumulated water can be discharged quickly through the urban rainwater pipe network within 0.5 h. 0.5~1 h is a flood-prone section, and the accumulated water stays for a period of time at the surface during the period of 0.5~1 h. >1 h is a flooded section, where the pipe section has difficulty in meeting the surface drainage capacity of the surrounding sub-catchment areas. During 0.5~1 h, the water stays on the surface for a period of time; >1 h is the flooding section, and the pipe section has difficulty in meeting the surface drainage of the surrounding sub-catchments. For the simulation of pipe segments in the study area, there are 56 safer segments and 16 flood-prone segments, and there are no flooded segments under the 3-year return period.

The optimization is based on surface zoning, making full use of the topography and terrain, and relying on the primary and secondary regional water systems, which are discharged into the vicinity. In its simulation, the original drainage gates are connected to the regional water system as much as possible in the form of open canals and open ditches. The peak of runoff in the sub-catchment area occurs after 55 min of precipitation, so the simulation results with larger runoff will be obtained in

the range of 55 or 60 min after precipitation. The optimized water networks are all able to accommodate the rainfall of one in three years, and there is no overloading of pipe sections, and the utilization rate of pipe sections is at 73.7%, which is relatively high.

In the simulation analysis of rainfall in the study area within a 50-year return period of 2 h, the depth of water accumulation in sub-catchments and nodes as well as the pipe section capacity of the urban stormwater drainage system, including urban green infrastructure, were analyzed. In terms of sub-catchments and nodes, as the stormwater pipe network has exceeded the design return period standard under strong rainstorm conditions, losing the role of fast drainage, water accumulation in the city is inevitable, and the pipe sections are overloaded in this case through relevant studies and flood prevention standards; while in the adjusted system of urban green infrastructure, the overall smoothness basically meets the requirements of the city's flood prevention.

Simulation analysis of surface runoff and infiltration under different return periods, and simulation calibration for different rainfall return periods need to achieve the goal, that is, rainfall return period $p = 1$, the study area to seepage storage and retention of the main, control rainfall can be designed to achieve the norms of the rainfall; rainfall return period $p = 3$, the stormwater network is able to carry the surface runoff, there is no accumulation of water points, and the network has a higher utilization rate, and the economy of the strong; When the rainfall return period $p=50$, the main measurement of flood control effectiveness, that is, whether the river can accommodate surface runoff under strong rainstorms.

4. Discussion

When carrying out sponge city construction, the SWMM model simulation can be used to analyze and evaluate the runoff volume and rainwater regulation capacity of the study area. Through the analysis of the current situation and construction needs of the study area, a suitable urban landscape pattern optimization scheme can be determined, which can effectively alleviate urban flooding and complete the construction of sponge city under the overall scale of the city. Therefore, the optimization of urban landscape pattern and sponge city construction should be closely linked to provide more effective measures for the construction of urban stormwater resilience system.

The study area belongs to the planning area and the pipe network system is not built, so there is no rainfall runoff measured data. In this study, the proposed method for calibrating urban rainfall runoff model parameters based on runoff coefficients under the scarcity of calibration data takes the runoff coefficients as the objective function for model parameter calibration, and the main parameters of the model are calibrated by comparing the integrated runoff coefficients used in the design of the urban stormwater pipeline network and the runoff coefficients obtained from the simulation calculation of the SWMM model. It is difficult to obtain a unique optimal solution set for the model parameter calibration inversion problem, and there are often multiple solution sets with "different parameters and the same effect" phenomenon. In order to obtain a satisfactory solution within the minimum range, it is necessary to make full use of a variety of information. A common approach is to add calibration information through the stormwater network monitoring system. In this study, other a priori information (e.g., integrated runoff coefficients) is used to increase the amount of information for model parameter calibration, to obtain better estimates of model parameters, and to reduce model inaccuracies due to parameter uncertainty.

In order to ensure the implementation of the landscape pattern optimization scheme, based on the land suitability evaluation, spatial control measures are applied to coordinate and manage the scheme. Based on the optimization scheme, the study area is divided into different spatial control areas, including prohibited construction area, restricted construction area, suitable construction area and urban built-up area, and different spatial control measures are formulated. Practical implementation of sponge city construction from planning to government participation can realize sustainable urban development.

Acknowledgments

National Natural Science Foundation of China Youth Program (52308070).

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