Research of Sponge City Landscape Planning Based on Landscape Security Pattern

Yu Shi¹, Jun Li¹*, Tiemao Shi², Daixi Xiu² and Yaqi Chu³

¹ School of Design and art, Shenyang Jianzhu University, Shenyang110168, China  
² School of Architecture College, Shenyang Jianzhu University, Shenyang110168, China  
³ School of Architectural Engineering, Shenyang University, Shenyang110044, China

Email: ljjun618@163.com

Abstract. With the rapid urbanization and increasing urban impervious areas in China, the construction of the sponge city has gradually turned to the urban ecological space planning. Based on the theory of landscape safety pattern, the construction of sponge city should improve the rainwater management system from multiple scales and enhance the function of urban landscape space. Firstly, the paper describes the ecological basement elements of the sponge urban landscape safety pattern, as well as the steps and technical methods of sponge urban landscape planning. Secondly, taking Shenfu New City as an example to elaborate the method of sponge urban landscape planning from multiple scales, the landscape ecological planning. The approach is introduced into the theoretical method of sponge city construction, and the feasibility of the study is illustrated by verification of model, which provides new ideas and methods for sponge urban landscape planning.

Keyword: Landscape security pattern, Sponge city, Landscape planning, LID.

1. Introduction

With the rapid process of urbanization in China, the destruction resulting from the urban development to natural hydrological conditions is gradually appeared. The increasing of urban impervious surface and the decrease of soil infiltration capacity have led to the decrease of rainwater infiltration and the continuous increase of surface runoff. The rainwater can only be discharged through the rainwater pipeline network, which causes the urban waterlogging, pollution of surface runoff, shortage of water resources and so on [1-2]. China Sponge City Construction Guide (2016) for first proposed that urban development and construction should protect water ecologically sensitive areas, reasonably determine the spatial boundary of urban growth and the urban scale, to prevent the disorderly spread of city. The intensive development model of ia adopted to guarantee the urban ecological space [3]. Different from the traditional perspective of urban water supply and drainage engineering, the sponge city has gradually turned to the perspective of comprehensive urban ecological space planning.

Many academic theories and technical measures of domestic and overseas experts come into being such as Best Management Measures (BMPs), Low Impact Development System (LID), Sustainable Drainage System (SUDS), Water Sensitive Urban Design (WSUD), Green Rainwater Infrastructure (GSI). Most of which are the treatment for meso-micro-scale rainwater conditions from the engineering perspective [4], while there is less research on the stormwater management system planning related to urban-scale integration of urban space and integrated water resources management. From the perspective of urban space planning, Dr Kongjian Yu, a scholar in the field of landscape, proposed the concept of building a sponge city based on the theory of landscape security patterns,
which combines the stormwater management system with urban infrastructure [5], to realize the availability of urban rainwater, to improve the application research of multi-scale storm flood management system, and to enhance the functional value of landscape space of city.

2. Landscape Security Patterns of Sponge City

2.1. Theory of Landscape Security Patterns of Sponge City
The theory of landscape security patterns (SP) believes that there are some potential spatial patterns in the landscape, which are composed of certain key parts, locations and spaces. They are one of the methods to identify and establish ecological infrastructure [6]. This method uses the principles of landscape ecology, by analyzing and simulating the landscape process, to establish a spatial structure and model for the optimal use of landscape ecosystems which will maintain the integrity of the ecological process with the least land and the minimum ecological structure, to realize the effective control of ecological process [7]. For the water ecological process, there is also a corresponding landscape security pattern. Based on the urban planning and construction, this security pattern is finally implemented as a water ecological infrastructure (sponge system) composed of water areas, green spaces and wetlands. The construction of the sponge city is the construction of the corresponding water ecological infrastructure, so the landscape security pattern can be regarded as the basic skeleton of the sponge city, supporting its construction and development. The focus of the sponge city construction is to identify the key space and locations and to find out their spatial relationships based on urban planning, so as to establish a water-centric landscape security pattern [5].

2.2. Content of Landscape Security Pattern of Sponge City
Unlike traditional pipeline-based methods of water supply and drainage, Sponge City takes low-impact development (LID) as its core concept and adopts source-typed and decentralized measures to maintain the hydrological characteristics before its development by various technologies such as infiltration, retention, storage, purification, utilization and drainage [8], to establish a systematic, holistic and cross-scale water ecological infrastructure. Since water is a cyclical fluid and it is closely related to landscape elements, the elements affecting the security pattern of the sponge city landscape not only exist in the water itself, but also in the entire ecosystem. The ecological base elements with water as the core are composed of natural elements (including landform elements, water elements, etc.) and biological elements (plant and animal elements). The purpose of the construction of the landscape security pattern of sponge city is to connect natural elements and biological elements to form a network. The topography, soil erosion, water conservation, rain and flood safety, plant coverage and biological abundance are needed to be considered into the network. The landscape security pattern of the sponge city can be further determined by combination of these six ecological sensitivity elements with water as the core.

3. Landscape Planning for Sponge City Construction

3.1. Steps of Landscape Planning for Sponge City Construction
Generally, there are several steps for landscape planning of sponge city. First, from the perspective of macro-pattern construction, a landscape security pattern with water as the core is established should divide forbidden-restricted construction areas and other areas according to three-level security pattern of bottom line (low), normal (medium) and satisfactory (high) [9]. It should be clarified with land layout and spatial scope of avoiding, controlling and guiding construction, which makes construction of urban flood control system more effectively, and protect and restore biodiversity. At the same time, it plays a important role in rain and flood management, water quality purification and urban microclimate adjustment and so on. Secondly, it should be carried out with sponge system planning, identifying the spatial location of water ecological infrastructure (sponge system) according to the landscape safety pattern, so as to determine a optimization plan of the sponge landscape system. Based
on the urban expansion bottom line and rigid framework, the sponge landscape system planning can be effectively implemented into specific areas. Finally, from the perspective of micro-scale level, based on land-using control in sponge system, the green ecological infrastructure is under planning and designing. Namely, it is the application of multi-level low-impact development technology measures, which is the technical guideline for specific landscape measures.

3.2. Technical Method of Landscape Planning for Sponge City Construction

3.2.1. Information Extraction and Model Building. According to the current situation analysis of the ecological environment of the studied area, the six ecological sensitivity elements of the topography, soil erosion, water conservation, rain and flood safety, plant coverage and biological abundance are selected. The superposition method is used for comprehensive analysis to obtain the ecological evaluation of the corresponding element. The obtained DEM file via analytical techniques and the raster file containing regional information are used to analyze the ecological environment of the studied area. With the help of Space Syntax, its aspect analysis, slope analysis, inverse distance interpolation method and reclassification tool are used to process the file to obtain single factor data. Then, the analysis function of ArcGIS is used for overlay analysis, to realize basic information extraction and model establishment, and to provide a basis for follow-up research.

3.2.2. The Low-impact Development (LID). It is an ecological rainwater management method which uses soft projects like vegetation networks to control and treat rainwater runoff in the studied area, and uses ecological processes such as infiltration, filtration, storage and evaporation to maintain the hydrological balance before and after the development of the studied site, and the use of decentralized landscape facilities to treat and repair rainwater runoff [10]. The low-impact development facilities include the sunken green space, permeable paving, green roof, grass ditch, rain garden and other small measures. The selection of measures is based on the following aspects. First, it is to analyze the natural conditions of the studied area (such as climatic conditions, drainage area, precipitation pattern, land use properties and so on). Second, it is necessary to determine the type of hydrological management required for the development of the studied area (including flow control, detention, storage, filtration, infiltration and biological treatment). Thirdly, the hydrological models is used to simulate the hydrological cycle of low-impact development measures in the site with different layouts, while meeting the constraints and local regulations of the studied area.

3.2.3. Quantitative Decomposition Method of Landscape Planning. According to relevant specifications and research by Yunchao Fu et al. [11], combined with the actual situation of the studied area, according to the functions of each control zone, from the perspective of low-impact development, the studied area is divided into several control zones. For each type of control zone, the comprehensive runoff control rate is different, and the rainfall corresponding to the total annual runoff control rate is also different.

The regulated storage volume of each control zone is equal to the sum of the regulated storage volume and the infiltration volume of each low-impact development facility. The regulated storage volume of each low-impact development facility is equal to the product of the facility area and the water storage depth. The regulated storage volume is equal to the product of the number of facilities and the volume of storage facilities. The calculation formula of the design rainfall volume for the low-impact development rainwater system is:

$$H = \frac{V}{10\phi F}$$

Where $H$ is the design rainfall of each zone (mm), $V$ is the regulated storage volume of each zone (m$^3$), $\phi$ is the comprehensive rainfall runoff coefficient of each zone (after the sponge measures are implemented), $F$ is the area of each zone (hm$^2$).

The functional relationship between the control rate of total annual runoff and the designed rainfall
volume is used to determine the control rate of total annual runoff of each control zone. Through the weighted average of the control rate of total annual runoff of each control zone and the catchment area of each zone, the control rate of total annual runoff of the rainwater system within the planning scope of the studied area is obtained. Then repeat calculations for the above steps are conducted until the annual runoff control rate within the planning scope of the studied area is 75%. Finally, the regulated storage volume of each control zone is determined.

3.2.4. The Simulation and Analysis of Rainfall and Runoff. The SWMM is used to simulate rainfall and runoff in the studied area. Firstly, it should to generalize the sub-catchment areas. Namely, the studied area is divided into several sub-catchments, and then it is needed to set the the sub-catchment parameters, hydraulic characteristic parameters (i.e. hinge point) and rainfall characteristic parameters. Finally the surface runoff and infiltration volume under different return periods are simulated and analyzed, and the targeted parameters in different return periods of rainfalls is simulated and checked.

4. Empirical Research on Sponge City Landscape Planning

4.1. Brief of Studied Area
Shenfu New City (41°2’N, 123°55’E) is located in the connection zone of Shenyang city and Fushun city, located in the east of Shenyang city and the west of Fushun city, Liaoning province (figure 1), with a total planned area of 605.34 km². The central urban area of Shenfu New City is also the core functional group of the area. The land is bounded by Shenji expressway on the north side, and the east-west direction is up to the border of the connecting red lines, and south direction is up to the western section of Sufu Railway and the administrative boundary of Dongling District. The land area is 205.55 km², and the construction-using land area is 118.21 km². The studied area belongs to a mid-temperate continental monsoon climate, with an average annual temperature of 7.7°C and an annual precipitation of 654~769 mm. The precipitation is mostly concentrated in April to October, accounting for more than 90% of the annual precipitation. The largest rainfall is in July with the precipitation is 156.22 mm. The water system in the area is relatively rich with 8 rivers like Hun River. The south bank of the Hun River is dominated by commercial residential land and industrial land, while the north bank of the Hun River is dominated by residential land and ecological green space. The studied area was originally a flood discharge area of Shenyang city. The overall terrain is high in the north and south and low in the middle. When there is heavy rainfall, the studied area not only needs to adjust the runoff in the area, but also the runoff discharge of the entire Shenfu New City. As a new development area of northern cities, Shenfu New City’s sponge city landscape planning practice provide basis and reference for urban water safety and landscape planning.

![Figure 1. Schematic diagram of the studied area.](image-url)

4.2. Construction of Landscape Security Pattern
According to the current situation of Shenfu New City, the obtained DEM file via analytical
techniques and the raster file containing regional information are used to analyze the ecological environment of the studied area. The six ecological sensitivity elements of the topography, soil erosion, water conservation, rain and flood safety, plant coverage and biological abundance are selected. With the help of ArcGIS to create the spatial distribution of multiple elements, different weight values according to their importance are assigned. Based on the spatial computing function of ArcGIS for superimposition. After knowing the spatial distribution characteristic of limiting elements affecting the main ecological problems of Shenfu New City, the landscape security pattern of Shenfu New City is achieved.

Figure 2. The landscape security pattern of Shenfu New City.

In the planning of Shenfu New City, the layout and control of land using for water ecological infrastructure are mainly accomplished through the division and index control of the prohibited and restricted construction areas. The division of prohibited and restricted areas is mainly based on the landscape security pattern (figure 2). The bottom line security pattern is a low-level landscape security pattern where construction in the area should be prohibited, and where the key protection and strict control shall be implemented. The general security pattern is a medium-level landscape security pattern where different protection measures should be proposed to maintain and restore the balance of the ecosystem based on different restrictions of development level. The satisfactory security pattern is a high-level landscape security pattern where appropriate development and construction activities should be allowed in the region. At the same time, in order to meet the requirements for basic farmland and construction land in the General Development Conceptual Plan for the Shen-Fu Connection Zone, the statistics for landscape pattern and land area can be obtained based on the construction results of the landscape safety pattern.

4.3. System planning of Sponge Landscape
Based on the landscape security pattern of Shenfu New City, a series of landscape system planning strategies are adopted for the central urban area to realize the construction of a sponge city, which provides foundation for urban landscape system planning and design.
4.3.1. System Optimization Strategy of Sponge Landscape. To optimize the sponge landscape system in the studied area, the strategies can include the following aspects. It is needed to widen the ecological corridors on both sides of the Hun River, to connect the two ecological corridors from the north to the south, and to strengthen the connection between the north and south banks of the Hun River. The mountains on the south of the Hun River are mainly used for ecological tourism, where is unsuitable for development-used but for forest land or other land after optimization and adjustment. Some plots in the ecological industrial zone, the south of Hun River, are unsuitable for construction areas, where these plots will have other use after optimization. The commercial land and residential land on the wetland park on the south bank of the Hun River all are adjusted to other-used land. On the west side of the studied area, part of the industrial land is adjusted to cultivated land or other land as urban flood discharge channels.

4.3.2. Overall Construction of Sponge Landscape System. Combining the optimization strategy of the landscape system, the studied area adopts a layout mode that combines points, lines and planes, and finally establishes a network of three-level corridors and nodes, which gradually intercepts and purifies rainwater, and meets the needs of rainfall in different return periods which is help for the the overall construction of the landscape system.

The first-level corridor refers to the riverside green belt of Hun River in the studied area. Due to the special topographical conditions, the Hun river system is the main drainage channel and basically undertakes most of the surface runoff discharge in the studied area. It is an important axis of the construction by of sponge city of Shenfu New City. The secondary corridor refers to the ecological corridor arranged along the Lagu River and the Sha River, which mainly connects the ecological landscape on both sides of the Hun River and enriches the water resources environment. It is not only the basis for the construction of the sponge city of Shenfu New City, but also undertakes functions of urban greening and recreation. Features. The three-level corridor refers to the formation of a ring-shaped water network by connecting potential rivers and improving the tributary water network, which provides a natural landscape environment for the studied area and realizes the function of regulating rainwater runoff.

These nodes are mainly divided into large-scale biological retention areas and biological retention areas. The large-scale biological retention areas are mainly located in the large-scale green parks on the north bank of the Hun River. With natural conditions, reservoirs can be established, where are used as recreational green spaces and can be play the role of flood prevention to retain a large amount of rainwater during return periods. The biological retention area is mainly in the form of parks and open spaces, and the water system is appropriately introduced in this area, and local plants are planted. The overall landscape ia a natural ecological wild area where can improve the quality of the urban environment and at the same time play a role in flood regulation.

4.3.3. Quantitative Plan of Sponge Landscape in Each Control Zone. According to the planning structure of the sponge landscape system in the studied area, a landscape quantitative plan for low-impact development measures is set up. First of all, combined with the urban functional zoning, water system planning, rainwater drainage planning and other data [12], the studied area is divided into 11 sponge city construction control zones, covering an area of 7.76~47.59km². 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 areas. The fourth and seventh control zones are commercial and leisure zones. Secondly, combined with low-impact development measures, the following LID measures are selected such as permeable pavement, vegetation buffer zone, rainwater tank, sunken green space, rainwater garden, constructed wetland, storage tank, ecological tree pond, grass planting ditch, interception ditch and so on. Different control zones should choose appropriate LID measures according to their functions and land-used conditions. Finally, combine the distribution of green space and water system in each control zone to determine the scope of their control indicators, including the rate of sinking green space and the rate of biological
retention facilities. If the annual runoff control rate in studied area is 75%, the control indicators of the control rate of total runoff, the rate of sinking green space and permeable paving of each control zone are determined.

4.4. Application of Low-Impact Development Measures and Landscape Design

4.4.1. Low-impact Landscape Design Based on Matrices. The construction-used land in the studied area occupies a large proportion, and hard construction land is its main matrix. The runoff control rate of the hard underlying surface is low, and the permeability is insufficient. The LID measures is selected based on the suitability of the matrix to achieve the goal of low impact development. At present, the commonly used LID measures suitable for the matrices of the studied area mainly include the permeable pavement, sinking green space and so on. According to the characteristics of the matrices of the construction land, the low-impact development measures are selected and the landscape design is carried out at the same time.

Permeable paving [13] is a ground paved method with special materials to promote the infiltration of rainwater. According to the site conditions of the studied area, the permeable floor tiles, wooden paving and pebble paving can be selected as permeable materials. Among them, secondary roads and large areas with small loads can be paved with permeable floor tiles. For example, the parking lots can be paved with grass-inlaid bricks. As car exhaust and tire wear have a certain pollution impact on rainwater, plants of water resistance and anti-pollution plants should be considered. According to the functional requirements of the plaza zone, wooden paving or pebble paving can be laid on this area. Since the drainage slope of the plaza needs to be controlled within 1% to 3%, the buried water pipes in the permeable gravel layer will collect the infiltrated rainwater and transmit it to the Hun River. Finally, pebble should be paved on the walkway.

The sinking green space [14] is also a low-impact development measure to improve the permeability of the matrix. It can dispersely divided on zone with high rainwater runoff. Depending on the different forms of the zones, the method of combining with wood paving is adopted by raising the pavement to make the rainwater naturally flows into the green space that is flush with the road, and the green space is more sinking than the pavement. The green space is also can be directly set in the sunken part of the zone, so that the rainwater can directly flow into the green space, which plays the role of rainwater collection and purification to obtain the best ecological benefits. In addition, it can also be designed in low-sunken areas where are served as a rainwater catchment surface and have a relatively low elevation. The selection of plants is mainly herbaceous with strong flood resistance and long-lasting water retention capacity. At the same time, it should combine with the large area of arbor forest to form a unique landscape.

a) Low-impact Landscape Design of Linear Corridors:

A corridor is composed of linear water systems and its protective green spaces. According to the current ecological conditions, ecological functions and requirements of sponge city construction, there are different levels to form a water ecological network system composed of different levels of linear corridors and connecting node elements. The level-control management is used to make the network integral, systematic and highly relevant. In the low-impact design, the artificial wetlands, riparian buffer zones and grass ditch are selected to enhance the landscape design of linear corridors [15].

The first-level corridor is the Hun River system in the studied area (figure 3a). A large number of wetlands are used to design ecological revetments on the banks of the riverside, where the slope is maintained at 5%-10%. With native plants, the riverside plant communities composed of moisture-tolerant plants, aquatic plants and floating plants is formed. The plant filter belts are set to purify the inflow of rainwater. The wooden platforms in the wetlands are set for recreation and viewing. The secondary-level corridors are two vertical water systems (Xiaoshao River and Lagu River) perpendicular to the Hun River (figure 3b). Due to rapid rain in summer and lack of water in winter, it is advisable to set up grass-planting ditches along both sides of the road with dry grass-planting ditches with strong water holding capacity. The width of the bottom is controlled at 1.2-1.5m and the
depth is 500mm where the curve setting type is adopted. The length of runoff path is extended to collect overflow rainwater from roads, sunking green space, rain garden and to discharge them into the river, improving the landscape effect (figure 3c). Then the permeable pavement resting platform is partially set to connect the plants and ditches under the platform to ensure the regulate storage and purification of rainwater, and for people to rest and play at the same time. The third-level corridors refers to the tributaries of other water systems. The smaller tributaries are combined with isolated green spaces as ditches, which not only facilitates the drainage of various control zones, enhances the circulation of the urban water system, but also promotes the construction of urban water landscapes to meet the residents’ needs for a hydrophilic environment.

Figure 3. The river section of Shen Fu New City.

b) Low-impact Landscape Design of Multi-Level Nodes
According to the structural characteristics of the landscape system in the studied area, the design divides the landscape nodes into urban green spaces, urban water systems, water catchment nodes and other different levels. At different scales, it is possible to choose LID measures such as the permeable paving, sumping green spaces, rainwater gardens, artificial wetlands and so on. In addition, according to the required functions of the area, combined with traditional landscape planning, it is effective to design low-impact landscapes of multi-level nodes.

For important nodes in the studied area, for example, the establishment of ecological wetland protection areas in the landscape design of the HunRiver riverside, it is needed to minimize the negative impact of man-made construction on the natural resources of the site. The Landscape nodes such as hydrophilic squares, riverside recreational belts, wooden plank road platforms is set correspondingly. Combined with LID measures according to functional requirements, the water-permeable pavements on the part of roads the square and park are paved. At the same time, combine with the geographical terrain, the sumping green spaces, rain gardens and other LID measures are set dispersedly, to carry out nearby rainwater infiltration and purification treatment. The plant grass ditch is arranged on both sides of the road as rainwater channel, where the rainwater is transported to the end storage facility for centralized treatment and discharged into Hun River. For the rainwater runoff generated by the green spaces in the site, because of its low pollution, it can directly flow into Hun River through the planting ditch.

4.5. Model Check
The two scenarios before and after optimization are simulated in the SWMM model. First, for the pre-planning plan, the studied area is divided into subcatchment areas and the studied area is generalized. Secondly, the model parameters are set and verified, and finally the surface runoff is simulated. It is needed to analyze the total runoff of the subcatchment and the water accumulation of each drainage outlet during each rainfall return period. For the plan after optimization, due to the optimization of the landscape pattern [16] and the application of LID measures [17-18], the rivers and pipeline network in the generalized structure diagram have been adjusted, and the structural parameters of the LID control are set correspondingly. The surface runoff under different rainfall return periods before and after the optimization of the landscape pattern is simulated in SWMM model, compared with the simulation data, and its regulation of rainfall in this studied area can be analyzed (figure 4).

![Figure 4. Change in total discharge runoff at different return periods.](image)

By simulation, the results showed that the total runoff and runoff coefficient in the studied area show an upward trend with the increase of the rainfall return periods. Under the return period of same
rainfall, the runoff coefficient of the landscape pattern optimization program decreases significantly, and the reduction quantity of the total runoff gradually increases. The reductions under the one-year, three-year, five-year and 50-year return periods are 2.94, 3.58, 3.72 and 4.19mm respectively. The corresponding reduction rates gradually decrease, respectively 23.9%, 16.4%, 14.3% and 9.3%. The optimized program can meet the requirements that the control rainfall is 20.8mm when the rainfall return period is 1(p=1), and the rainwater pipeline network is not overloaded when p=3, and the river channel does not overflow when p=50.

5. Conclusion
The example studied above shows that the theory and method of sponge city landscape planning are applicable to multi-scale and multi-level conditions, which has strong feasibility in actual construction. The study starts from the perspective of urban space planning, based on the theory of landscape security pattern, it is focused on strengthening the connectivity of the landscape system, enriching the levels of landscape structure, enhancing the regulating function of ecological infrastructure, which provides new ideas and methods for the construction of sponge cities.

The landscape security pattern should be the basic framework of the landscape planning of sponge city, which the natural ecological conditions should be utilized with maximizing the rainwater retention efficiency of the water-core ecological infrastructure, to provide multi-level and multi-scale space carriers for the application of low-impact development measures. With the technical support of multi-source data, combining the landscape planning with the stormwater management, based on effective control of stormwater runoff, the functional value of the urban landscape space is enhanced, and the safety requirements of urban stormwater development is guaranteed, which provides theory and method support for the construction of sponge cities in China.

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References
[1] Grimm N B, Faeth S H, Golubiewshi N E, et al. 2008 Global change and the ecology of cities Science 219: 756-760.
[2] Yu K J, Li D H and Yuan H 2015 Sponge city: Theory and practice City planning 2015 (6): 26-36.
[3] Ministry of Housing and Urban-Rural Development 2014 China Sponge City Construction Guide Beijing: Ministry of Housing and Urban-Rural Development.
[4] Che W, Yan P and Zhao Y 2014 Development and analysis of international updated stormwater management system China Water & Wastewater 30 (18): 45-51.
[5] Yu K J, Hong W and Li Q 2014 Sponge city practice: landscape planning of beijing yanqi lake ecological development demonstration Zone Beijing Planning Review 2014 (1): 26-31.
[6] Wu J G 2007 Landscape Ecology Pattern, Process and Hierarchy Beijing: Higher Education Press.
[7] Yu K J, Li D H and Liu H L 2011 Anti-planning Approach Beijing: China Architecture Publishing & Media Co., Ltd.
[8] Qiu B X 2015 Sponge City (LID): Connotation, Approach and Prospect Construction Technology 2015 (1) 11-18
[9] Zhong C 2016 The construction method of sponge city based on the theory of landscape ecology Chinese Overseas Architecture 2016(7): 121-123
[10] Lu T 2019 LID Low-Impact Development: Urban Design Manual Jiangsu: Phoenix Science and Technology Press.
[11] Fu Y C, Wang J L and Zhou B 2017 Construction of Index System for Low-Impact Development Planning of Chengdu Directly Managed District in Tianfu New District, Sichuan Planner 33 (10): 95-100

[12] Ministry of Housing and Urban-Rural Development 2006 Engineering Technical Code for Rain Utilization in Building and Sub-district (GB 50400-2006) Beijing: Ministry of Housing and Urban-Rural Development

[13] Zhang W, Che W and Wang J L 2011 Using green infrastructure to control urban rainwater runoff China Water & Wastewater 27 (4): 22-27

[14] Ma S S, Zhuang B Y and Zhang X B 2014 Analysis on the reduction effect of the series connection of green roof and sunken green space on flood peak China Water & Wastewater 30 (3): 101-105

[15] Liu W, Chen W P and Peng C 2015 Research and utilization progress of low-impact development technology for urban stormwater management Chinese Journal of Applied Ecology 2015 (6)1901-1912

[16] Wang R S, Li F and Han B L 2014 Urban compound ecology and ecological space management Acta Ecologica Sinica 34 (1): 1-11

[17] Urban Drainage and Flood Control District 2010 Urban Storm Drainage Criteria Manual: Stormwater Best Management Practices Denver, CO: Water Resources Publications.

[18] Vogel J R, Moore T L, Coffman R R, et al. 2015 Critical review of technical questions facing low impact development and green infrastructure: A perspective from the Great Plains Water Environment Research 87: 849-862