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Stormwater management of urban greenway in China

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Abstract: In order to improve the stormwater regulation functions of urban greenways, on the basis of literature research and case study, the relationships between urban greenway and low impact development (LID) and green stormwater infrastructure (GSI) are analyzed. Then the classification system of urban greenways is proposed based on their stormwater regulation function, and the suitable technical measures for stormwater management which can be used in different kinds of greenways are selected. According to China's urban planning system, the greenway planning method combined with the urban drainage system is developed, and the design methods of the greenway stormwater system and individual stormwater facilities are put forward. The relationships between the greenway stormwater system and other systems are also analyzed in terms of stormwater inlet, vertical design and overflow. Finally, the waterfront greenway and street greenway demonstration projects in Jiaxing City which adopts the above concept and method are introduced. The results show that the reduction rates of annual total stormwater runoff and average total runoff contaminants (TSS) of the stormwater system are not less than 30% and 40%, respectively.

Key words: greenway; stormwater management; low impact development; green stormwater infrastructure

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Greenways are networks of land containing linear elements that are planned, designed and managed for multiple purposes including ecological, recreational, cultural, aesthetic or other purposes compatible with the concept of sustainable land use. The modern greenway can be traced back to the planning and construction of American's parkway and park system in the late 19th century. The rapid development of greenways began from the 1990s in the U.S. The greenway with its high efficiency, connectivity, versatility and sustainability, has become one of the major initiatives for improving the environment, regulating stormwater, providing habitats, enhancing landscape features and increasing the livability in cities[1]. With the development of research and practices of greenways, it was also introduced to guide regional and urban ecological construction in China. Especially since 2010, Beijing, Ningbo, Dalian, Shenzhen, Jiaxing and other cities and regions have been invariably carrying out large-scale greenway network planning and construction.

Although the construction of greenways in China is growing fast, the functions of current greenways mostly concentrate on transport, landscaping, recreation and biological conservation, in most cases as scenic roads or ecological corridors[2-4]. However, facing the serious urban stormwater issues such as runoff pollution, frequent waterlogging and ecological deterioration, the most essential characteristics of greenways-pollution reduction, stormwater regulation, and ecological protection are usually neglected[5-6]. Therefore, there are great potential and challenges for greenway construction combined with stormwater management in terms of concept, technology, regulation and management.

1 Material and Methods

To analyze the potential of greenways on the mitigation of urban stormwater issues, materials used in this study include existing greenway research and practice data of this field in China and abroad, especially the greenway cases in Jiaxing City, China.

The methods of this study mainly include literature review, comparative analysis, and case study. By literature review, the history and latest development of using greenways as a strategy to control runoff is summarized. According to the comparison of the roles of greenways in urban stormwater management in different countries, this study puts forward the classification system of greenways, and summarizes the major hydrological functions and suitable technical measures for stormwater management of different types of greenways. Combined with Chinese current planning systems, the design and planning method of the greenway stormwater systems is first systematically proposed. By a case study, how the above method is used in practice and its effects are shown.

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2 Results and Discussion

2.1 Relationship between greenway and LID/GSI

In recent years, the concepts of low impact development (LID) and green stormwater infrastructure (GSI) have been widely applied in greenway projects, which contribute to achieving the multifunctional stormwater management objectives of greenways.

Unlike the traditional stormwater drainage system, LID emphasizes that stormwater is a resource rather than "waste". It mainly uses small, diffused, low-cost and landscaped stormwater measures to control runoff volume and pollutants[7]. GSI is similar to LID, and it provides a new concept and method for solving urban stormwater problems[8]. Compared with the traditional gray infrastructure, not only its construction and maintenance costs are lower, but it also provides more effective protection for urban water environments. Therefore, from the beginning of the greenway planning and design stage, the LID and GSI concepts and measures should be systematically considered.

LID and GSI have a wide range of environmental, economic and social benefits, and have been confirmed by a large number of researches and practices at home and abroad[9]. LID and GSI are new and efficient concepts of stormwater control and utilization, and they can achieve the low-carbon, energy-saving, ecological and sustainable development of greenways.

2.2 Research and practice of stormwater management of greenway

Researches and practices on stormwater management combined with greenways are carried out more extensively in developed countries, such as the Brooklyn Waterfront Greenway and the Atlanta greenway project in America. The Brooklyn Waterfront Greenway serves as one of the integral links of New York City's vastly growing greenway network—linking the Manhattan Greenway system, the Queens Greenway and the Shore Parkway Greenway. It chose West Street as the greenway route, and in order to construct the greenway, existing roads were converted to a one-way road and parking spaces on the street were reduced. A stormwater management plan includes methods for detention and cleaning, as well as methods for changing the discharge path of stormwater runoff[10].

Streets represent a large portion of the urban impervious area, and reasonably managing runoff from streets is critical for achieving stormwater management objectives. Meantime, most greenways are linear spaces combined with urban streets. So the green street has become a huge component of urban stormwater management and one type of greenway, in which LID and GSI are introduced into the street design, such as Portland green street facilities, the Spokane Urban Runoff Greenway Ecosystem, the San Francisco California Leland Avenue green streets project and so forth[5, 11-12].

The city of Portland built a number of green street facilities to manage street runoff, such as the NE Siskiyou Green Street, the NE Fremont Street Green Street, the SW 12th & Montgomery Green Street and so on.

Green Streets in Portland have consistently performed well through a combination of continuous flow monitoring and flow simulation tests over several years. Rain garden, street planter and stormwater curb all appear to be very effective in reducing peak flows and runoff volume while reducing the impervious area, improving aesthetics, and filtering pollutants. Peak flow from the most heavy rainfall events was reduced by 70% to 90%, with volume retention ranging from 50% to 96%[6].

In recent years, with the increasing attention to urban stormwater problems, research and applications on greenways combined with stormwater management are constantly emerging in China. Beijing University of Civil Engineering and Architecture designed the community greenway of Oriental Sun City in Beijing, and designed 23 green streets combined with the LID concept in the Guangming New District of Shenzhen[13]. Furthermore, in Dalian Eco-city Stormwater Control and Utilization Plan, one of the most important contents is using greenways to control runoff from streets, reducing pollutants and improving the present drainage standards. The community greenway of Oriental Sun City is shown in Fig. 1.

Fig. 1 Community greenway of Oriental Sun City in Beijing, China

In the transformation of Yongning River waterfront green belt in Taizhou, Zhejiang, the designers of Turenscape combined waterfront greenway with flood control, wetland purification, recreation and so on. The Houtan Park of the Shanghai World Expo Garden used the waterfront greenway to construct a wetland system, which purified water quality, improved the micro climate, and beautified the environment[14]. Fig. 2 shows the waterfront greenway in the Houtan Park, Shanghai.

Fig. 2 Waterfront greenway in Shanghai Houtan Park

In summary, as an important ecological construction strategy, the planning and construction of greenways have developed rapidly in the recent twenty years. Most of the greenways are constructed on public rights of street, and the green street has become one of the main types linking greenways and urban stormwater management. However, the systematic research on stormwater control combined with greenways for other types is seldom reported, and the key issues in planning and designing greenway stormwater systems are not discussed sufficiently. Therefore, there are still great challenges in the overall planning of greenway stormwater systems, in terms of planning, design method, technical measures and other aspects.

2.3 Classification system of greenways and suitable technical measures

According to the site location, greenways can be divided into waterfront greenway, street greenway, park greenway, community greenway and other types. The reasonable selection and arrangement of technical measures need to be based on land use types, the available space in greenways, natural hydrological conditions, stormwater control objectives, layout and cross-section of the site and other information. The major facilities include vegetated swale, rain garden, low elevation greenbelt, rain pond/wetland and so on[8, 12, 15]. Tab. 1 lists the classification system of greenways and suitable technical measures in terms of stormwater management.

Tab. 1 Classification and key technical measures of greenways

Classification	Control objectives	Technical measures	Cases
Street greenway	Mitigate waterlogging, water purification	Interception basket, low elevation greenbelt, rain garden, vegetated swale, tree planter, infiltration trenches, stormwater pond/wetland	NE Siskiyou green street in Portland, Shenzhen greenway in China
Waterfront greenway	River flood control, water purification	Vegetation buffer strips, vegetated swale, rain garden, low elevation greenbelt, stormwater pond/wetland, ecological embankment, ecological floating island	Brooklyn waterfront greenway in NYC, U. S., Jiaxing Changxiantang greenway in China
Park greenway	Water purification, stormwater utilization	Pervious paving, low elevation greenbelt, rain garden, vegetated swale, stormwater pond/wetland, multi-functional storage of stormwater	Houtan Park in Shanghai, Olympic Forest Park in Beijing, China
Community greenway	Water purification, stormwater utilization	Pervious paving, low elevation greenbelt, rain garden, vegetated swale, tree planter, infiltration trenches, multi-functional storage of stormwater	Oriental Sun City in Beijing, China, High Point community in Seattle

2.4 Planning and design method of greenway stormwater system

As greenways play a significant role in safeguarding urban water environments and stormwater management, it is essential to make greenways become the city's ecological infrastructure and hydrological regulation facilities through the planning, design, and management of greenways. According to the Chinese urban planning system, the planning and design methods of greenways can be divided into two levels, the greenway system master planning stage and the individual greenway design stage.

2.4.1 Greenway system master planning stage

At the greenway master planning stage, the planning priority is to make the greenway planning adapt to regional hydrological conditions, by rationally planning the greenway's location, size and pattern to relieve hydrological changes and stormwater issues caused by urban development. Generally, it should be based on land suitability analysis to determine the potential location of greenways. Urban flood-prone areas should be incorporated into the greenway network primarily and large-scale urban construction and development should be avoided in these areas, such as floodplains, ponds, wetlands and potential water regulation sites. At the greenway overall planning stage, the stormwater control and utilization concepts, such as LID and GSI, should be incorporated into the greenway plans, by the collaboration of different disciplines. And the greenway plan should be coordinated with relative urban special plans, including an urban flood control plan, a drainage system plan, a landscape plan, a water system plan, an environmental plan and so forth.

2.4.2 Individual greenway design stage

Because most greenways are combined with urban streets, this paper takes the street greenway as an example to introduce how to plan and design an individual greenway stormwater system[16].

1) Site investigation and analysis

The first step is to investigate the street level, function, and surrounding land use types, identify impervious areas and areas where the stormwater facilities can be located. Collect street vertical and horizontal slope data, soil types, and determine the street stormwater hydrological model (including water-logging points/areas, stormwater runoff drainage routes). Obtain the local rainfall and other climatic data, including rainfall amount, rainfall distribution, evaporation and so forth. Identify native plants and materials that are available for selection. The above information provides a basis for the planning and design of greenway stormwater systems.

2) Greenway stormwater systems design

Based on the site analysis, following the stormwater

"sources-runoff path-terminal control" principle, the spatial framework of the stormwater system in greenways can be developed. It can make runoff flow into green space and LID facilities first, thus minimizing the amount of runoff directly drained into pipes.

3) Detailed design of stormwater facilities

On the basis of the "source-midway-end" stormwater system framework, combined with the location, size, natural and other conditions of stormwater facilities, identify the types of facilities used in greenways, and then make the detailed design and calculation for the system and each stormwater facility.

2.4.3 Relationship among greenway stormwater facilities

On an urban scale, a greenway should not only absorb the stormwater runoff generated from itself, but should also play a more important role in hydrological regulation, that is receiving and treating runoff from roads, buildings, squares and other impervious surfaces surrounding the greenway. Therefore, it is significant to analyze the relationships between greenways and surrounding land and facilities, including stormwater inlet, vertical design, facilities, overflow, and etc[17].

1) Stormwater inlet

The basic requirement for applying a stormwater control function in greenways is to ensure that runoff flows into stormwater facilities, such as a low elevation greenbelt and a rain garden. Generally, there are centralized and decentralized methods for stormwater runoff entering the stormwater facilities. Concentrated import is runoff flowing into stormwater facilities through the incision on curbs or the stormwater channel under the walking trails. Dispersed inflow refers to stormwater evenly distributed into the stormwater facilities when roads and curbs are at the same levels or higher than the green spaces.

2) Vertical conditions

Under conditions of green spaces higher than surrounding roads or pavements, stormwater cannot flow into the greenway stormwater facilities by gravity. Therefore, at the beginning of greenway design, it is necessary to adjust the vertical relationship of the green spaces and the surrounding land, making the green space below or in part lower than the surrounding impervious surfaces.

3) Stormwater facilities

The vertical slope and direction of streets have a decisive influence on the flow of stormwater runoff. Stormwater facilities' type, design and construction should be determined according to the street vertical conditions. For example, rain garden, low elevation greenbelt and other source control measures are usually set at higher part of the greenway, and vegetated swale is selected to connect downstream stormwater facilities along a long slope.

4) Stormwater overflow

Stormwater overflow occurs when runoff volume exceeds the maximum capacity of stormwater facilities. There are two major overflow ways: one is through stormwater facilities incision overflowing back to the greenway, and then entering other stormwater facilities or stormwater sewers; the other is setting overflow outlets inside the stormwater facility, excessive stormwater directly overflowing into the municipal pipe network. Fig. 3 shows an example of green street stormwater management measures in New Zealand.

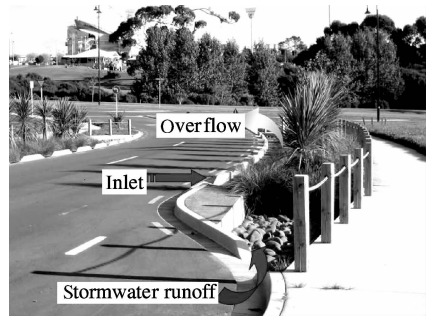

Fig. 3 Relationship between runoff and stormwater facilities

2.5 Greenway cases in Jiaxing, China

Stormwater runoff pollution and combined sewer system overflow are the major causes of aquatic environment deterioration in Jiaxing, which is located in Zhejiang province of China. To relieve urban stormwater problems and improve environmental quality, the authors participated in planning and designing comprehensive ecological greenway networks and demonstration projects based on LID concept and techniques. This paper mainly introduces the planning and design method of the stormwater system of waterfront greenways and street greenways.

2.5.1 Waterfront greenway

Waterfront green space is abundant in Jiaxing, so it is suitable for using a variety of stormwater facilities and combinations for stormwater retention, purification and transportation, such as rain garden, ecological floating island, vegetated swale, stormwater pond and wetland. Fig. 4 shows the schematic diagram of a waterfront greenway in Jiaxing. In addition to absorbing its internal runoff, it is more important to accept and treat the runoff generated by the surrounding impervious surface (such as

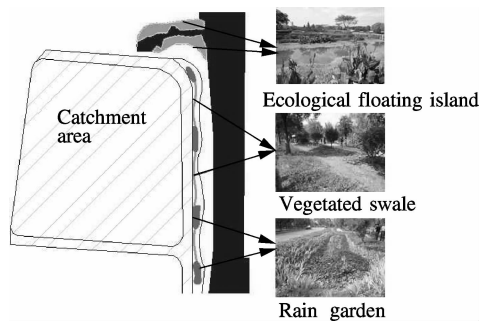

Fig. 4 Schematic diagram of waterfront greenway

squares, parking lots and residential areas). After retention, purification and transport in greenways, runoff is drained into a river finally, to avoid water pollution and waste of water resources resulting from runoff directly discharging into water bodies through municipal pipelines.

2.5.2 Street greenway

According to the type of urban streets, the degree of runoff pollution, and available green space inside and outside of the boundary lines of streets, the measures are arranged by reasonable layout to purify, store and reuse rainwater to the largest extent. Permeable pavement materials can be used at bicycle lanes and sidewalks. The height of the greenbelt inside the street red line should be below the street. And the design of facilities should closely combine with street landscape design, such as installing vegetation swale, rain garden, interception gully, tree planter and stormwater pond/wetland in the greenbelt. At the pipe-drainage area, it should make full use of the purification effect of green belts, set incisions at the street side, guide road runoff into the green space for infiltration by vertical design, and thus the runoff can be transferred into the pipe network through the overflow mouth. Fig. 5 shows the schematic diagram of street greenway in Jiaxing.

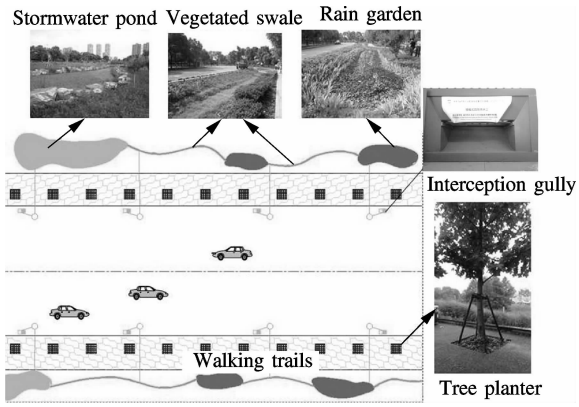

Fig. 5 Schematic diagram of street greenway

2.5.3 Environmental benefits

To meet the stormwater runoff pollution control objectives, the design rainfall amount of stormwater facilities is not less than 20 mm according to the rainfall statistical data of Jiaxing City. When the rainfall is no more than 20 mm, greenway stormwater systems can obtain total runoff that is generated from the catchment areas surrounding the greenway. Through these demonstration projects, the reduction rate of annual total stormwater runoff is not less than 30%, and annual average total runoff contaminant (TSS) is not less than 40%.

3 Conclusion

Nowadays, an increasing number of cities in China and abroad are planning and building large-scale greenway networks based on LID/GSI concepts and techniques, and stormwater management becomes one of the fundamental functions of greenways. Obviously, greenways play a crucial role in stormwater runoff pollution control, peak flow and runoff volume reduction. And it has a certain effect on improving the aquatic environment, providing habitats and enhancing urban landscape features.

However, the stormwater regulation function of greenways is not yet given enough attention in most cases[18]. With the rapid urbanization in China, there are still huge challenges to effectively integrate stormwater management with the planning and design of greenways.

To meet the increasing demands from practices and research, this paper proposes the classification system of greenways according to site location and hydrological function, and systematically summarizes stormwater technical measures suitable for different kinds of greenways. The planning and design method of the urban greenway system can be divided into the master planning stage and the individual greenway design stage, according to the Chinese urban planning system. The critical issues and methods on integrating stormwater management with greenways at both the planning and the design levels are illustrated by detailed analyses and examples. These can be used to guide the planning and design practices, and help planners, designers and engineers to better understand the relationship between stormwater systems and greenways. This paper also introduces the demonstration projects in Jiaxing City Greenway, which show the real effects of the guidance of LID and GSI concepts and the proposed design method. This study is anticipated to provide references for China and other countries to improve the stormwater management function of greenways.

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中国城市绿道雨洪管理研究

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摘要:为提高城市绿道的雨洪调节功能,在文献研究和案例分析基础上,首先对城市绿道与低影响开发、绿色雨水基础设施的关系进行了分析.然后,提出了基于雨洪调节功能的城市绿道分类系统,总结适用于不同类型绿道的雨洪控制利用技术措施.结合中国城市规划体系,提出了与城市排水系统相结合的绿道规划方法,以及绿道雨水系统和单项雨水设施的设计方法,探讨了绿道雨水系统在入流、竖向、溢流等方面与其他系统的衔接关系.最后,介绍了上述规划设计方法在嘉兴滨水绿道和道路绿道示范项目中的应用,结果表明雨洪控制利用系统对年径流总量和年均污染物总量(TSS)的削减率分别不低于30%和40%.

关键词:绿道;雨洪管理;低影响开发;绿色雨水基础设施
中图分类号:TU993.1