Coupling of urban green space system and sponge city construction

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Abstract. Through quantitatively analyzing the implementation of the sponge city concept in urban green space systems, this research explored the role of urban green spaces in collecting and using rainwater in a urban landscaping. By combining the ecological and recreional functions of the urban green spaces, as well as appropriate quantitative indexes, reasonable approaches for applying rainwater collection, infiltration and retention technologies in urban green space design and construction are suggested. Thus, the implementation of the sponge city concept in the initial planning stage of green spaces was considered. The Taihu New City in Wuxi was chosen as study case. Thus, this paper combined current planning status between green space and rainwater collection systems and analyzed them. As result, usable green spaces for the sponge city construction were obtained. Also, details on the construction characteristics of various usable green spaces were acquired. The role of these green spaces in the sponge city construction were classified and quantitatively assessed and compared with relevant standards. On the basis of guaranteeing green space intended purposes, this paper analyzed the results of coordinating the green space areas with rainwater collection systems and specified the role of various green spaces in the rainwater collection.

1. Introduction

Some consequences of modernity may threaten urban life. For instance, while some cities are often flooded by stormwater, some others are vulnerable to drought and pollution-induced water shortage. The concept of “sponge city” was officially proposed in 2013, and since the construction of this type of structures started, experts from architecture, water supply, drainage, and landscaping in China have done preliminary research on this topic in their own field.

Urban green spaces are expected to play a key role in sponge city design and construction. However, considering their intended functions for ecology, recreation, emergency sheltering and others, the focus of the experts is to explore: (a) how urban green spaces help in collecting stormwater under the premise of guaranteeing their original role; (b) how much rainwater can be carried through the total rainwater volume without negatively influencing ecological and recreational functions; and (c) what appropriate technologies can be applied.

1.1. Research background

1.1.1. Rainwater regulation system abroad. Severe environmental problems emerging as a result of urbanization include frequent waterlogging, aggravating runoff pollution, loss of water resources, and degradation of aqueous environments. In this regard, in the past 2 decades developed countries such as UK, USA, Australia, Germany and Japan have formulated the sustainable urban stormwater
development and management system by simulating natural drainage. A number of relevant countermeasures and technologies have been largely developed and applied in practices [1]. The Council for Sustainable Development (USA) suggested the concept of green infrastructure based on the theories and practices of BMPs and LID, providing strategic instructions and technological support for the construction of the “sponge city” in the field of stormwater management [1]. Germany is one of the countries that better makes use of urban rainwater. German’s MR system (Mulden-Rigolen-System) ensures infiltration efficiency by maintaining rainwater in low-lying grassland and in infiltration ditches for short and long term processes, respectively [2]. Japan has applied a rainwater retention and infiltration plan since 1980 by promoting infiltration pools, pipes and wells, penetrative pavements, infiltration side ditches, regulating reservoirs, and green spaces [2]. In the WSUD systems (water-sensitive urban design) of Australia, the rainwater bio-infiltration system (also known as stormwater bioretention, rain-gardens or biofilters) is widely applied since it displays flexible design scalability, configurations and structures, as well as the possibility of integrated beauty. Particularly, small-scale rain-gardens, large bio-retention basins, and low-lying lands can be flexibly designed with this system [3].

Other similar concepts include Sustainable Urban Drainage System (SUDS) in the UK, and the Active Beautiful and Clean Waters Program (ABC) in Singapore [4]. By integrating the theories of LID and WSUD, New Zealand established a Low-Impact Urban Design and Development System [1].

1.1.2. Problems of the sponge city construction in China. The sponge city construction in China shows potential problems related to understanding and orientation. Urban green spaces are often expected to be responsible for rainwater storage in the sponge city construction. Every facility of the rainwater garden, grass ditch and infiltration gallery, and stormwater garden type are taken as green space facilities. This situation neglects two key factors that might result in undesired consequences:

- City development conditions and population density determine the particular properties of the urban green space system in China. Almost all domestic green spaces are built with expected functions. Both, land use quality and property of urban green lines, take the ecological security and recreational needs into consideration, where the area should not be reduced and functions not be replaced, same as for the blue line water system. However, in less-populated countries, the urban green space system mainly focuses on the overall layout, not on regulatory details, and the construction of sponge city facilities does not influence its green space system layout. In the sponge city construction in China, the blind application of sponge facilities to green spaces may destroy the layout, influence basic functions, and even threaten the ecological security of these green areas.

- Urban green space system’s capacity of carrying sponge facilities. Undoubtedly, the urban green space system is an ideal sponge because of its high infiltration rate and low runoff coefficient. However, the carrying capacity of a green space system should be comprehensively studied in the sponge city construction. Sponge facilities can only be built in urban green spaces under the premise of maintaining their ultimate ecological and recreational functions. Moreover, scientificity of the green spaces, appropriate amount and reasonable construction are also the preconditions for the construction of sponge facilities.

1.2. Literature review

China officially proposed the concept of sponge city and launched the construction of sponge city in 2013. From this time on, experts from planning, ecology, architecture, water supply, drainage, and landscaping have devoted great efforts in this type of endeavor. Yu Shaowu, Ding Nian, Ren Xinxi and Yangchen introduced many forms of sunken green spaces and explained their effect in Exploration of Stormwater Storage, Infiltration and Utilization in Urban Sunken Green Spaces. They stated that the sunken green spaces can use rainwater by properly regulating the green space structure. In addition, they barely need more construction investment or energy consumption, and help reducing the degradation of the environment [5]. Su Yijing, Wang Sisi, Che Wu, Wei Yizhe and Dong Yin in Sunken
Green Spaces Based on the Concept of “Sponge City” relate the construction of sunken green spaces by integrating “sponge city” and the latest domestic and international rainstorm management concepts, trying to achieve the multiple effect of sunken green spaces such as waterlogging control, water resource utilization, and landscape embellishment [6]. Li Yongfu and Wang Dongmei in Research Progress on the Role of Sunken Green Spaces for the Storage and Utilization of Urban Rainwater reviewed domestic cases on rainwater utilization in sunken green spaces [2]. Zhang Jinlong and Zhang Zhizheng in Storage and Infiltration Capacity of Sunken Green Spaces and Its Influence Factors referred to the sunken green spaces as types of ecological rainwater infiltration facilities that are important for the infiltration, storage and utilization of rainwater runoff. Thus, they are a key factor in urban rainstorm utilization [7]. Li Junqi, Che Wu, Chi Lian and Liu Song in Key Parameters and Influence Factors for the Low-lying Green Spaces in Residential Areas, discussed fundamental parameters such as the sunken depth of the low-lying green spaces, the loading rate of the low-lying green spaces and waterlogging time, and proposed the design concepts and methods for the low-lying green spaces [8]. Fan Qunjie in Research on the Effect of Urban Green Space System in Regulating Stormwater Runoff and Reducing Pollution described the regulating effect of urban green spaces on rainwater runoff. They also demonstrated the reducing effect of urban green space systems on rainwater runoff pollution, and established a number of actions and management strategies for urban green space systems with the aim of regulating rainwater runoff and reducing runoff pollution [9].

1.3. Research objectives
In this investigation, Taihu New City in Wuxi was chosen as case study to comprehensively explore the ecological functions of urban green spaces and scientific and reasonable construction of the sponge city, in order to provide suggestions on sponge functions and quantification indexes for the carrying capacity of various green spaces so as to their original ecological functions are guaranteed.

2. Methodology
Coupling of green space system and drainage system planning: a case study of Taihu New City.

2.1. Green space system of Taihu New City
The urban green space system layout of Wuxi City highlights the integration of river regulation and construction of riverfront belt parks. Based on the natural conditions and city development tendency, green spaces were designed along rivers, lakes, roads, and mountains. Taihu New City is included in the urban green space system layout of Wuxi, “One core and dual rings, three axes and four wedges, multiple patches and parks, green corridor and water network” (figure 1). The outer ring incorporates the ecological background ring of Taihu New City that consists of Taihu Lake shelter forest and landscape woods. The inner ring incorporates Gaolang Road and Liangtang River of Taihu New City. In addition, a 100-m-wide forest belt and 400-m-wide of ecological green spaces connect the main green areas and suburban parks into a “green necklace” for the city, showing the outstanding landscaping characteristics of Wuxi. Three axis incorporate the canal eco-landscape into Taihu New City. Multiple patches and parks, including various urban parks, public open spaces and ecological green spaces are distributed in the City. In addition, the construction of the Jinkui Park, the Shangxian River Wetland Park, the Changguang River Wetland Park, multiple belt parks along Gaolang Road and the canal, and others has resulted in a ratio of 18 m² of green spaces per capita. The main framework of “five horizontal and eight longitudinal roads” and the secondary framework of “five horizontal and nine longitudinal roads” (figure 2), and 25 river systems connect the parks and green spaces to create an open green network (figure 3).

The planned green spaces in Taihu New City (excluding affiliated green spaces) make a total of 3,542 hm², of which 2,071 hm² are parks, 1,237 hm² are road protective green spaces, and 234 hm² are river protective green spaces.
Figure 1. Urban green space system structure of Wuxi City [10].

Figure 2. Road network planning of Taihu New City [11].
2.2. Rainwater planning of Taihu New City

Figure 3. River planning of Taihu New City [11].

Figure 4. Rainwater planning of Taihu New City [11].
The rainwater pipes in Taihu New City add for a total of 150 km². The pipe network is divided into 3 major rainwater drainage parts according to the functional division of the new city: eastern, central, and western area. Each of these are designed with an independent drainage system, and are further divided into many smaller independent drainage units (figure 4).

The rainwater is discharged into the rivers that were planned to accept drainage. Main drainage rivers are given in table 1.

| No. | Name                  | Origin-destination                | Remark       |
|-----|-----------------------|-----------------------------------|--------------|
| 1   | Changguang River      | Dongli Lake-Henggang Riverlet     | Main rivers  |
| 2   | Miaoqiao Riverlet     | Shangxian River-Changguang River  |              |
| 3   | Renzi Riverlet        | Miaoqiao Riverlet-Henggang Riverlet |            |
| 4   | Liangtang River       | Dongli Lake-Jing Hang Canal       |              |
| 5   | Nanda Riverlet        | Shangxian River-Li River          |              |
| 6   | Lihe River            | Liangtang River-Lake Tai          |              |
| 7   | Daxigang              | Jing-Hang Canal-Lake Tai          |              |
| 8   | Jing-Hang Canal       | Liangtang River-Wangyu River      |              |
| 9   | Henggang Riverlet     | Lake Tai-Renzi Riverlet           | Secondary rivers |
| 10  | Wuwang Riverlet       | Changguang River-Miaoqiao Riverlet |            |
| 11  | Banqiao Riverlet      | Changguang River-Miaoqiao Riverlet |            |
| 12  | Fangqiao Riverlet     | Shanxi River-Shangxian River      |              |
| 13  | Shanxi River          | Miaoqiao Riverlet-Banqiao Riverlet |          |
| 14  | Shajinggang           | Liangtang River-Nanda Riverlet    |              |
| 15  | Guanjiaqiao River     | Miaoqiao Riverlet-Qianlongqiao Riverlet |          |
| 16  | Yangmuqiao River      | Li River-Shangxian River          |              |
| 17  | Qianlongqiao Riverlet | Miaoqiao Riverlet-Shangxian Riverlet |          |
| 18  | Mianzhang Riverlet    | Jing-Hang Canal-Shajing Riverlet  |              |
| 19  | Bashiqiao Riverlet    | Li River-Daxi Riverlet            |              |
| 20  | Luqujiao River        | Li River-Jing Hang Canal          | Tributaries  |
| 21  | Kanjiiali River       | Li River-Jing Hang Canal          |              |
| 22  | Shangxian River       | Fangqiao Riverlet-Lake Tai       |              |
| 23  | Rengangzhi Riverlet   | Miaoqiao Riverlet-Renzi Riverlet  |              |
| 24  | Zhangzhuangxiang River| Dongli Lake-Shanxi River          |              |

2.3. **Coupling of the green space system and the sponge city construction in Taihu New City**

Since Taihu New City is a newly-developing area, most construction related activities should apply sponge technologies to collect and use rainwater. This paper reports on coupling the rainwater collection with its utilization in public areas such as road squares and green spaces.

The planning of the rainwater collection and the urban green space systems of Taihu New City have to consider the road network and water system of the city. For the rainwater collection system, rainwater pipes are installed along the road network, and the collected rainwater is drained to the rivers nearby. On the other side, green spaces are planned along rivers, lakes and roads so they can take advantage of the pressure in the rainwater pipes guaranteeing water supply of green spaces and in consequence, the maintenance of their basic functions (figure 5).

- The planning of the rainwater collection systems considers that all the rainwater is to be collected into the pipe network. When combining the strategies, since road green spaces and public green spaces also collect rainwater, volume entering the pipe system is reduced. The water collection in these green spaces is properly controlled, and the overflow goes into the pipes.
- All the rainwater drainage into rivers should be properly planned. Riverfront protective forest belts may also share the rainwater, which may help in reducing flood pressure. This also ensures that the forests have proper supply of the vital liquid. In this type of systems and for
control purposes, no rainwater pipes are to be installed along rivers. This is to ensure that water goes into the forest belts. Moreover, part of the rainwater from the pipes may also be available for them.

![Figure 5. Green space layout for rainwater collection.](image)

- Combining rainwater and green spaces in Taihu New City (table 2). The total size of the planned rainwater areas in Taihu New City is 2,579.46 hm², the annual runoff is 12.228 million m³. Close to the collecting space for each subarea, the usable green space for the construction of the sponge city part (excluding affiliated green space) is of 882.96 hm² (figure 6), which may eventually share the rainwater from pipelines and rivers.

| Rainwater collecting subareas | Area//hm² | Runoff//m³ | Usable green space area//hm² | Ratio of green space to rainwater subareas/% |
|-------------------------------|-----------|-----------|----------------------------|---------------------------------------------|
| Western I                     | 216.09    | 899,044.93| 100.18                     | 46.36                                       |
| Western II                    | 293.12    | 1,390,200.69| 100.20                    | 34.18                                       |
| Central I                     | 169.29    | 761,253.01| 66.58                      | 39.33                                       |
| Central II                    | 457.53    | 2,240,110.89| 141.74                    | 30.98                                       |
| Central III                   | 65.37     | 249,292.81| 35.04                      | 53.60                                       |
| Central V                     | 363.85    | 1,852,859.49| 97.80                     | 26.88                                       |
| Central VI                    | 322.08    | 1,677,378.00| 78.79                     | 24.46                                       |
| Eastern I                     | 136.40    | 739,778.83| 27.21                      | 19.95                                       |
| Eastern II                    | 75.68     | 345,029.82| 28.78                      | 38.03                                       |
| Eastern III                   | 169.32    | 857,023.22| 46.60                      | 27.52                                       |
| Eastern V                     | 310.73    | 1,216,323.57| 160.04                    | 51.50                                       |
| Total                         | 2579.46   | 12,228,292.56| 882.96                    | 34.23                                       |
Figure 6. Distribution map of usable green spaces in Central II.

3. Results
Functional purpose of urban green spaces in coupled areas depends on rainwater interception and collection capacity in the beginning, middle and end of the rainwater collection season. In addition, sponge facilities capacities including rainwater retention, infiltration, and utilization are important. By adopting the measures shown below, runoff peak flow in Taihu New City may be delayed by 4.4 min, and the annual total runoff reduced in 15.6%.

3.1. Increasing the green space area to delay the runoff peak flow
Fan Qunjie’s reported in Research on the Effect of Urban Green Space System in Regulating Stormwater Runoff and Reducing Pollution, that “as the ratio difference of green space area up to 10%, the drainage system with a larger green space ratio witnessed the runoff peak about 20 min later than the system with a smaller green space ratio did” [9]. Although the greening rate in the coupled area reaches the 34.23%, 2.2% more can be applied according to relevant standards of landscaping industry. This increment in green space would delay runoff peak by 4.4 min.

3.1.1. Increase green space in parks. According to the specifications for park green space service radius coverage included in Evaluation Standards of Urban Landscaping GB/T50563-2010, there should be a public park over 5,000 m$^2$ within 500 m from citizens’ homes. Thus, 184 green spaces should be built within the planned rainwater collecting area of Taihu New City. This means that 114 more of these spaces should be constructed in addition to the currently existing 70. According to the previously mentioned standard of 5,000 m$^2$, an additional area of 57-hm$^2$ of park green spaces should be constructed. This would improve the greening rate by 0.4%, and delay the runoff peak by 0.8 min.

3.1.2. Broaden the protected green spaces. Within the rainwater planning area of Taihu New City, the 2 grade-II rivers display a total length of 11.71 km, while for the 6 grade-III rivers the number is of 24.57 km, the 49 grade-IV rivers sum 135.86 km, the 42 grade-V rivers 65.47 km, and the 84 grade-VI
rivers add a total length of 51.36 km. The extent of protected green spaces along the rivers should comply with these numbers according to their grade as: (a) grade-I 50 m; (b) grade-II 30 m; (c) grade-III 20 m; (d) grade-IV 15 m; (e) grade-V 10 m; and (f) grade-VI 10 m (Table 3). According to this standard, an area of about 404.73 hm² of riverfront protective green spaces should be considered. This means that at least 170.73 hm² more of these areas should be built, in addition to the existing 234 hm². This would improve the greening rate by 1.2% and delay the runoff peak by 2.4 min.

Table 3. Control regulations for riverfront protective green belts [12].

| River grade   | Extent of protective green spaces | Remark                                                   |
|---------------|----------------------------------|---------------------------------------------------------|
| Grade-I river | 50 m outside from the river boundaries | For rivers with higher requirements, the greening rate should be increased by 1.2% and the runoff peak should be delayed by 2.4 min. |
| Grade-II river| 30 m outside from the river boundaries | grade or designed according to higher planning standards. |
| Grade-III river| 20 m outside from the river boundaries | can be upgraded according to the river grade. |
| Grade-IV river| 15 m outside from the river boundaries |                                          |
| Grade-V river | 10 m outside from the river boundaries |                                          |
| Grade-VI river| 10 m outside from the river boundaries |                                          |

3.1.3. Increase roof greening. According to the Ecological Water System Planning of Taihu New City, the planned roof areas reaches a number of 9,218 hm². Thus, expanding the green roofs in 10% (92.18 hm²) represents a rate increase of 0.6%, and may result in a delay of the runoff peak of 1.2 min.

3.2. Increase sunken squares and sunken green spaces to store rainwater

In the EXPO 2010 Shanghai, Rotterdam displayed its “water plaza system” provided a new option for preventing floods by optimizing the urban water circulation system. This system was built on natural terrains, and consisted of a series of pools of varying shapes, sizes and heights, connected by ditches. The place serves for recreation purposes during business hours, and in the event of a rainstorm works as a flood control system. This is because the rainwater flows to the low-level of the plaza, avoiding street flooding. All the pools conform a circulation network, where water is distributed to ditches during heavy rainfall, returning to the big pools during small rainfall. Rainwater in this system can both, flow among the pools, and be stored as a fresh water resource [5].

Table 4. Distribution of usable green spaces in the rainwater subareas.

| Rainwater subareas | Usable green space/hm² | Park green space/hm² | Protective green space/hm² | Others/hm² |
|--------------------|------------------------|----------------------|----------------------------|------------|
| A                  | 100.18                 | 37.48                | 0.31                       | 62.39      |
| B                  | 100.20                 | 26.39                | 17.91                      | 55.91      |
| C                  | 66.58                  | 61.58                | 4.27                       | 0.72       |
| D                  | 141.74                 | 118.78               | 20.45                      | 2.51       |
| E                  | 35.04                  | 35.04                | 0                          | 0          |
| F                  | 97.80                  | 24.94                | 72.01                      | 0.85       |
| G                  | 78.79                  | 52.24                | 26.55                      | 0          |
| H                  | 27.21                  | 1.14                 | 16.91                      | 9.17       |
| I                  | 28.78                  | 5.71                 | 19.94                      | 3.13       |
| J                  | 46.60                  | 17.39                | 29.18                      | 0.03       |
| K                  | 160.04                 | 26.74                | 72.11                      | 61.18      |
| Total              | 882.96                 | 407.43               | 279.64                     | 195.89     |

By building sunken squares in street parks, water retention in the green space system can be better achieved. According to the Park Design Standards, street park roads and pavement account for 10%-30% of the land use. In this paper, a value of 20% was selected. In addition, 5% was set up as the fraction of total land that is used for paved squares. As Clause 4.3.2 of the Standards specifies, “water depth of the paved-bottom waters within 2.0 m away from the bank should not exceed 0.7 m”. Thus, the sunken square depth should be 0.7 m to store rainwater. In the rainwater planning area of Taihu
New City, the usable park green space area is of 407.43 hm² (table 4), so the sunken square area (5% of the total) will be 20.37 hm², and the 0.7-m depth will store about 142,600 m³ rainwater, reducing the total runoff by 1.2%.

For high soil dampness and long-term waterlogging, there are a few alternatives of plant species that can be grown in sunken green spaces. Those species suitable for both dry and wet lands are better options, such as perennial herbs. The most selected species for sunken green spaces are rainwater garden and grass ditch. According to Clause 4 of the Technological Standards for Urban Landscaping of Wuxi City, “urban planning by considering regional characteristics of the city should take trees as the keynote because of the largest ecological quantity, the application area of trees and big shrubs should be over 70% of the total landscaping area, and the rest is lawns not under canopies and other ground covers”. Therefore, 30% of the green space can be selected as the sunken green space (i.e. 246.89 hm²), which may result in an increase in rainwater storage of 864,100 m³, reducing the total runoff by 7.1% (considering an average depth of 0.35 m.)

3.3. Increase sunken green space to enhance rainwater infiltration
In determination of the infiltration rate in the Ecological Water System Planning of Wuxi Taihu New City, the following spaces and percentages were considered: sunken green space 50%, common green space 16%, and permeable pavement 8% [13]. The infiltration rate in sunken green spaces is much higher than that of common green spaces. Therefore, by setting up a certain amount of sunken green space within the shelter forests and parks, the rainwater infiltration rate would increase, the surface runoff would be reduced without changing the properties of the green space, which may additionally enhance underground water conservation and reduce the drainage pressure of rainwater pipes.

In the event 30% of the green space was of the sunken type (i.e. building 246.89 hm² sunken green space in Taihu New City), the infiltration rate might increase in 34%, and runoff and total runoff might be reduced by 892,300 m³, and 7.3%, respectively.

It is suggested that sunken green spaces are designed as grass ditches, which serve as both, drainage and irrigation facilities according to the season. As for parks, they can be structured as rainwater gardens to satisfy ornamental, water infiltration and retention needs.

3.4. Increase tree population for water retention
Original big trees should be maintained in place, but more tress should be planted in order to help retaining rainwater during the rainfall season. According to Clause 14 in the Principle for the Construction of Wuxi Urban Landscaping, minimum rates are: “trees in green patches such as parks, small amusement gardens and courtyards should be over 5 per 100 m², those in green stripes such as roads and rivers should be over 9 per 100 m²”. Diversity of tree species is also required, and the suggestion is to have over 40 species for green spaces below 3,000 m², over 60 species for green spaces between 3,000-10,000 m², over 80 species for green spaces between 10,000-20,000 m², and over 100 species for green spaces above 20,000 m². The standard for road green spaces and protected green spaces can be moderately reduced.

4. Discussion and recommendations

4.1. Planning and design requirements for the sponge facilities in the coupled green spaces

4.1.1. Control Planning. Urban green space areas should be guaranteed: “by increasing green space areas by 10%, the runoff peak may be delayed by 20 min”. Thus, it is an essential premise for the sponge city construction to plan green lines strictly according to national standards. In view of the current conditions, Wuxi City should carry out this plan taking care of the following aspects: (a) First, the projected area of green park spaces should increase. According to the service radius coverage of a park green space indicated in Evaluation Standards of Urban Landscaping GB/T50563-2010. there should be a public park with at least 5,000 m² within 500 m of citizens’ homes. (b) Second, protective
forest belts (i.e. roads, riverfront and urban cluster green spaces) should be designed according to the standards, and a reasonable extension of the forest belt should be maintained. (c) Third, the index of roof greening should be added as construction project control. Roof greening control was extensively promoted in Taihu New City, and all roofs where people can stand up were to be designed with roof greening. However, effective application areas were extremely limited for various reasons. For example, in some cases, roof space was already occupied by external air conditioner units. On the other hand, difficulties in quantitative assessment and acceptance were also factors in the low success rate of these type of projects. It seems that, because of those difficulties, some construction units abandoned the roof greening projects. Thus, it is suggested that ratio of roof greening to total roof areas where people are able to stand should be reduced to 10%. This would help in increasing the possibility of reaching this number.

4.1.2. Design Key points. In designing landscape sponge facilities, considerations should include the fact that these type of structures should comply with the quantitative requirements of appropriate standards. Also, sponge facilities should be perfectly integrated into landscape design.

- For sunken squares, the elevation relationship among roads, rainwater collection pipes and green spaces must be properly handled, and vertical design of pathways and green spaces integrated for the rainwater collection and storage. Rainwater utilization after the runoff peak should also be taken into consideration. Most importantly, every point previously mentioned should be implemented under the premise of maintaining the recreational purposes of the square during dry seasons.
- Sunken green spaces also work as rainwater gardens and ecological grass ditches. Rainwater garden designs should first focus on the optimization of plant distribution. Plants suitable for both, dry and wet seasons are best choices for rainwater gardens. In addition, complete arrangement of trees, shrubs and herbs, determines the rainwater garden landscape. Moisture intolerant trees and big shrubs can be established on elevated dikes with thick soil layers and low moisture. Herbaceous, perennials, and even aqueous grasses and flowers can be planted in low-lying lands with thin soil layers and high moisture content.
- Ecological grass ditches are mainly applied in protected forest belts for rainwater storage purposes during rainy seasons, and the water can be used to irrigate the forest woods. This saves the cost of mobile watering. When designing ecological ditches, the whole forest should be considered. One or more rainwater pools could be built in the open forest, to a rate of no more than 10% of the total forest belt area.
- The key to roof greening design is to properly cover with soil. Considering the load bearing, a thin soil layer can be applied to increase the covering depth so water retention capacity and water permeability can be improved. Also, landform characteristics should be integrated with plant arrangements. Uniformity in covering depth is not necessary. For example, according to the Jiangsu Provincial Technological Regulation for the Application of Urban Landscape Plants, a 40-60 cm thick layer is appropriate for planting small trees; 40 cm for shrubs; 30 cm for ground covers and vines; and 20 cm for lawns. It is also recommended that mesophanerophytes be plantes as species tolerant to drought and wind are better choices.

4.2. Overall design of greening and rainwater-colling areas in planning the urban green space system

4.2.1. Micro adjustments of urban green space systems for green space functions conservation. According to Evaluation Standards of Urban Landscaping (GB/T50563-2010), the evaluation of the service radius coverage indicated that an even distribution of park green spaces is required, and 57 hm² more of these areas should be created in Taihu New City.

According to Water System Planning of Taihu New City, the creation of 170.73 hm² more riverfront protected forest belts are needed in Taihu New City.
4.2.2. The Role of various green spaces in rainwater collection (table 5).

- Sunken green spaces and sunken squares serve as the sponge facilities for park green spaces and other green spaces. The ratio of sunken squares should be within values of 5% paved squares and 0.7 m sunken depth; 30% sunken green space, with an average depth of 0.35 m.
- Sponge facilities are not to be established in road green spaces by principle. However, for green belts over 5 m wide, sponge facilities for protected green spaces can be created.
- In residential and working areas, roof greening, sunken squares and sunken green spaces can be used for rainwater collection.
- In protected green spaces, grass ditches and rainwater pools can be used as sponge facilities. The ratio of grass ditches should be of 5% of the green space area. This should be first used as a drainage facility, and also as irrigation channel in dry seasons. One or more rainwater pools can be designed in open forests, and the size maintained to a 10% of the forest belt.

| Category                        | Sponge facilities | Role                          | Area control |
|---------------------------------|-------------------|-------------------------------|--------------|
| Park green space                | √                 | Increasing planting area      | Sunken square 5%, 0.7 m deep; sunken green space 30%, 0.35 m deep; grass ditch 5%, 0.35 m deep; rainwater pool 10%, 0.35 m deep; roof greening 10%. |
| Protective green space          |                   | Increasing tree application   |              |
| Green spaces for working and residential areas |                   | Increasing storage             |              |
| Road green spaces               |                   | Increasing retention          |              |
| Others                          |                   | Purification                  |              |
|                                 |                   | Use                           |              |
|                                 |                   | Drainage                      |              |

5. Conclusion

Urban green spaces are highly efficient sponges. It is very important that planning and construction of sponge cities comply with national standards. By building sponge facilities with the premise of guaranteeing the ecological conditions and recreational purposes of green spaces, and ensuring that quantitative indexes are not disregarded, the peak runoff of Taihu New City may be delayed by 4.4 min, and the annual total runoff reduced by 15.6%. Therefore, with strict planning and design control, urban green space systems based on the coupling of urban green spaces and sponge facilities will synergistically improve individual characteristics and may be promote the construction of both urban green space systems and sponge cities.

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