Study on the Application of Rainwater Management Technology in the Space of Suzhou

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Abstract. Chinese sponge city construction is in full swing. The research of regional sponge city technology is not only important but also urgent. This paper takes Suzhou as the main research object. And through the analysis of the specific natural environment and water quality characteristics of runoff in Suzhou, Proposes that "interception" and "purification" should be the primary goals of rainwater management in Suzhou. On this basis, it puts forward that "water quality management is the main and water quantity management is the auxiliary. The management strategy of displaying the characteristics of the city and the landscape of technical facilities. "According to The comprehensive comparative analysis of objective, the conditions, pa., Artistry and ecology of the application of general technology in the United States and China, each technology is classified into three types: It use, Optional use and not it use. It is hoped to solve the confusion of the applicability of sponge technology and the harmony between engineering technology and urban art temperament in a Natural, ecological and landscape aesthetic way.

1. Introduction
Constructing rainwater system through low influence development and restoring good natural water circulation are important for urban construction in China. Countries in Europe and the United States, Japan and South Korea and other Asian countries began to carry out studies on rainwater management in the 1970s. Overseas rainwater management is mainly studied from three aspects: Rainwater Transportation, Interception and Storage. Although the methods of rainwater management in different countries are not the same, the basic methods are to use nature to purify, store and permeate rainwater in the land. Through evaporation, infiltration and runoff, nature manages rainwater and maintains water circulation. Therefore, simulating nature and using land for work is a natural, ecological and economic rainwater management method.

2. Background of Sponge City Construction in China
In December 2013, general secretary Xi Jinping stressed in his speech at The Central Urbanization Work Conference that when upgrading urban drainage system, priority should be given to the retention of limited rainwater, the use of natural forces to drain water, and the construction of spontaneous
accumulation, natural infiltration and natural purification of sponge cities. After that, each province and city responded positively and carried out the construction practice of sponge city one after another.

The basic principle of sponge city construction is to ‘follow the principle of ecological priority, combine natural ways with artificial measures, maximize the accumulation, infiltration and purification of rainwater in urban areas, and promote the utilization of rainwater resources and ecological environment protection on the premise of ensuring the safety of urban drainage and waterlogging prevention’.[1]

The technical guide of sponge city construction issued in China is an important reference for local practice. However, due to China's vast territory, from south to north to east to west, across different climatic zones, with different geographical conditions and cultural and social conditions, how to make measures according to local conditions under the guidance of /sponge city construction technology guide/, to explore appropriate local conditions of technology, has become an urgent problem.

3. Analysis of Natural Background Conditions in Suzhou
Suzhou has a unique geographical environment, the ancient city of water and land adjacent, river street parallel characteristics, creating its unique characteristics of rain management.

3.1. Climate and Green Space Conditions
The incidence, frequency, intensity, duration and total amount of rainfall are important factors affecting the efficiency of rainwater management. Suzhou is located in the lower reaches of the Yangtze River near the sea, belongs to the subtropical humid monsoon Marine climate, annual average rainfall of 1063mm. The rainfall in flood season (June-September) accounts for more than 50% of the whole year, mainly medium and light rain, accounting for more than 85% of the whole year's rainfall days.[2] According to the occurrence frequency of rainfall levels in the last ten years from 2007 to 2017, it is found that the annual rainfall in Suzhou is about 124 days, among which there are more light rain of 0-10mm, about 88 days, accounting for 71% of the annual rainfall. Heavy rain and rainstorm over 25mm is less, about 12 days, less than 1% of the annual rainfall days. (Table 1).

| Rainfall Level       | 24h Standard (mm) | Average Days (d/a) | Occurrence Frequency (%) |
|----------------------|-------------------|--------------------|--------------------------|
| No Rain              | 0                 | 241.3              | 66.1                     |
| Light Rain           | 0.1-9.9           | 87.5               | 24                       |
| Moderate Rain        | 10-24.9           | 24.1               | 6.6                      |
| The Heavy Rain       | 25-49.9           | 8.8                | 2.4                      |
| Rainstorm and Above  | 50 or higher      | 3.3                | 0.9                      |

Evaporation, infiltration and runoff constitute the natural water cycle. Figure 1 illustrates the natural rainwater management process and benefits under different rainfall conditions. When light rain occurs, the initial runoff potential is strong, with the passage of time, transpiration and infiltration become more and more obvious, and the runoff gradually weakens until it is completely absorbed. In the case of moderate rain, runoff formation time is shortened, and evaporation, infiltration and runoff are basically equivalent. Although radial flow decreases gradually with time, some rainfall still exists in the form of runoff. During heavy rain, transpiration is weak and the management process is short, so the runoff is large.[3] The annual evaporation capacity of Suzhou is 1283.8mm. Due to the large evaporation capacity, the proportion of surface runoff is about 20%. The model ratio coefficient is 0.94 ~ 1.10, and the inter-annual variation of rainfall is small. [4]
Figure 1. Process and Benefits of Rainwater Management under Different Rainfall Conditions [3]

Suzhou is a national advanced city in landscaping. By the end of 2015, 41.99% of the built-up areas and 35.10% of the urban areas in Suzhou were green. The rainfall rule dominated by light rain and the high greening rate provide excellent conditions for the utilization of rainwater management. In most cases, the effect of rainwater management can be achieved with a small amount of rainfall in figure 1.

However, Suzhou is located at the bottom of the shallow saucer-shaped plain centered on Tai lake. The terrain is mainly plain, with a low and flat terrain and an elevation of 3.5 to 5m. Most areas of Suzhou soil are common clay deposited in the Quaternary period. The maximum deposition thickness is about 200m. The topsoil layer is the accumulation of modern human activities. [5] the urban construction results in soil compaction, resulting in a low-permeability soil with a permeability coefficient <10⁻³cm/s.

The low-lying terrain and sticky soil make it difficult for rainwater to penetrate naturally, which also limits the use of many technical facilities.

3.2. Characteristics of Runoff Water Quality
Surface runoff pollution is a potential threat to surface water and groundwater. Table 2 is the basic situation of monitoring the water quality of rainwater runoff in each district, indicating the severe reality of water pollution in different functional areas. [6]

| Monitoring area       | Rainfall duration | Rho (SS) | Rho (TP) | Rho (NH₃ - N) | Rho (TN) | Rho (COD) |
|-----------------------|-------------------|----------|----------|---------------|----------|-----------|
| Industrial park,      | The 0 ~ 10 min    | 900.0    | 0.74     | 5.9           | 16.7     | 496       |
|                       | 10 ~ 30 min       | 108.5    | 0.40     | 1.8           | 5.9      | 148       |
|                       | 30 ~ 60 min       | 108.5    | 0.28     | 2.7           | 4.9      | 58        |
| Business district,    | The 0 ~ 10 min    | 634.0    | 0.94     | 7.2           | 14.6     | 854       |
|                       | 10 ~ 30 min       | 392.5    | 0.72     | 3.4           | 11.4     | 479       |
|                       | 30 ~ 60 min       | 265.5    | 0.22     | 3.0           | 4.5      | 112       |
| Residential area,     | The 0 ~ 10 min    | 786.5    | 0.26     | 4.9           | 6.5      | 183       |
|                       | 10 ~ 30 min       | 111.5    | 0.16     | 2.5           | 4.7      | 118       |
|                       | 30 ~ 60 min       | 262.0    | 0.12     | 2.1           | 5.1      | 110       |

Surface pollutants enter the receiving water body along with rainfall runoff and affect the water environment. Suzhou is a famous water network city with more than 20,000 river courses at all levels and more than 300 lakes of all sizes. The area of rivers, lakes and tidal flats accounts for 36.7% of the land area of the city. However, due to the lack of management of runoff into river channels in the past, the water quality of most rivers and lakes is poor. The main pollution indexes are ammonia nitrogen, total phosphorus, permanganate index and chemical oxygen demand. These pollution contributions are mainly from surface runoff.
Groundwater recharge is also a water environment problem that must be paid attention to. Due to excessive exploitation of groundwater, the recharge condition of deep groundwater in natural state is destroyed, which causes serious land subsidence. Suzhou is one of the 50 cities with land subsidence. Surface water pollution is serious, the recharge form of shallow groundwater is mainly vertical recharge by rainfall, and the deep groundwater is over-exploited. These grim facts show that it has become an urgent task for Suzhou's urban development to make use of natural resources to supplement high-quality water resources through natural storage, natural infiltration and natural purification.

4. Suzhou Rainwater Management Objectives and Technology

4.1. Rainwater Management Objectives
The rainfall rule dominated by light rain, high greening rate, numerous wetlands and lakes provide favorable conditions for rainwater management with green space. However, the low-lying terrain combined with relatively sticky soil, serious river and lake pollution, and the severe ‘water quality’ water shortage constitute adverse constraints. According to the above analysis, controlling runoff pollution to water source is the primary task of Suzhou rainwater management, so ‘interception’ and ‘purification’ are the primary objectives of rainwater management. Safe transport, flood reduction, groundwater replenishment and reuse are secondary sub goals. The corresponding technical strategy should be:

4.1.1. Water quality management is the main and water quantity management is the auxiliary. ‘Water quality management is the main, water quantity management is the supplement’. Priority is given to rainwater purification. While meeting the needs of purification, storage and regulation is the main task of rainwater management.

4.1.2. Natural absorption is the main, blue and green net and use. Make full use of a large number of lakes, rivers and wetlands to provide conservation land for rainwater storage and local consumption. However, there must be enough green space around the rivers and lakes. Before surface runoff enters the rivers and lakes, it should be fully intercepted, buffered and purified by the green network to protect the health of the surface and groundwater environment. Through evaporation and infiltration of water network, interception and purification of green network, blue and green network work together to maintain a virtuous cycle of urban water ecology.

4.1.3. Display urban characteristics and landscape of technical facilities. The garden city of Suzhou, the ‘Copy heaven shrink ground, recreate universe’ gardening technique has become a model of Chinese landscape, from the ‘garden in the city’ to ‘city’ in the garden, and the unique city image requires a rainwater management in the city, requires a combination of Chinese traditional garden aesthetics whose beauty lasting appeal. Through the landscaping of technical facilities, not only the urban characteristics of "the beauty of classical garden temperament" are retained, but also the environmental protection awareness of loving nature and cherishing rain water resources is enhanced through the perception of the relationship between rainfall-man-land.

4.2. Selection of applicable technologies for Suzhou greenbelt rainwater management

4.2.1. Factors considered in technical screening. Natural ecosystem has a certain bearing capacity, things in the bearing capacity within the scope of benign development, beyond the bearing capacity will be out of balance. The rainwater management technology of sponge city is restricted by the objective natural conditions such as climate, soil, greening rate, groundwater level and natural water network. The application of the technique must be analyzed according to the objective conditions. In addition, the construction and maintenance cost of rainwater management system must be considered. Engineering cost and late operating cost often become an important factor whether a
technology can be popularized and applied. Economic considerations should be accompanied by a clear understanding that rainwater management systems are not dirty or crude facilities. An open storm drainage facility is not only an engineering project, but also an urban landscape that "combines quantity, quality and recreation". [7] By the end of 2018, 108 gardens have entered the list of Suzhou gardens. Based on this background, the construction of sponge city in Suzhou must emphasize the above multiple values of rainwater facilities, emphasize the combination of technology and art, and formulate technical programs in line with Suzhou's cultural temperament and artistic characteristics, so as to harmonize rainwater management facilities with the style of the ancient city.

4.2.2. Comprehensive comparison and screening. Centering on the management objectives and management strategies, the author selected Maryland, Maine, Georgia and domestic relevant technical guidelines with an average annual rainfall of >1000mm to summarize, involving transmission facilities, sewage interception and purification, storage facilities, regulating facilities and infiltration facilities.[8] Rain water pipe disconnect technology is not listed in domestic guidelines, according to foreign experience, this time to increase this comparison. In addition, Suzhou has a large number of wetlands and lakes, which should be included in the technical considerations of rainwater management. Through the objective application conditions, economy, landscape aesthetic value and other comprehensive comparison. In order to facilitate the analysis of the landscape aesthetic value into artistic and ecological two, finally according to the objective conditions of the application of technology, Economy, art and ecology are compared comprehensively.

![Figure 2. Compares the screening process.](image-url)

By comparison, the various technologies are classified into recommended use, optional use and non-recommended use.

Recommended technologies include green roof, roof rain water pipe disconnect, sunken green space, ecological revetment, dry stream, dry grass gully, transfer grass gully, ecological drainage ditch, initial rainwater abandonment facilities, wetlands, rivers and lakes, etc. These technologies are mainly used for interception and purification, and there are no special objective restrictions on the use of conditions, low construction difficulty, easy maintenance, strong ecological function, through art design, landscape effect can also achieve good results.

The available technologies include permeable brick paving, permeable cement concrete, permeable asphalt concrete, regulating pond, regulating pond, rain-water wetland, vegetation buffer zone, simple biological detention facility, artificial soil infiltration, etc. These facilities play an active role in the interception and short-term storage of runoff, especially in the purification and diversion of the initial runoff of rainwater and the improvement of runoff loss. Permeable pavement plays a significant role in reducing the initial runoff erosion effect. However, it is mainly composed of in-situ infiltration.
Although there is a certain water storage space in the base layer and the gap between the cushion, its water storage capacity is greatly affected by the permeability of the surface layer or the base layer. Several of these techniques are applied where the structural layer needs to be adapted to the local soil, and the permeable layer should be added to facilitate the full infiltration or transmission of the trapped stream within 48 hours.

Through the comparison of objective conditions, it is found that Suzhou is beneficial to the use of most technical facilities in green space, rainfall characteristics and natural water network. But, some techniques in soil properties and underground water level has a specific conditions of use, Suzhou natural conditions can’t reach to these requirements, therefore is given priority to with infiltration of rainwater management technology, including the pits, sewer, infiltration pond, Wet planting ditch and complex biological retention facilities, cannot achieve the ideal effect in Suzhou, therefore is not recommended. (Table 3) In addition, rainwater tanks are not recommended in Suzhou because their landscape effect is not beautiful enough.

Table 3. Special Requirements for the Use of Rainwater Management Techniques.

| Elements                | Technical Name                          | American Technical Guide | Domestic Technical Index | Suzhou The Status Quo | Whether to Meet |
|-------------------------|----------------------------------------|--------------------------|--------------------------|-----------------------|-----------------|
| Soil Properties         | Infiltration Ditch                      | > 3.5×10 cm/s⁻¹          | > 10⁻³ cm/s              | Clay Poor Permeability | Does not Meet   |
|                         | Penetrating Wells                      | Best 1.4×10⁻³-2.8×10⁻³ cm/s |                         | < 10⁻³ cm/s           |                 |
|                         | The Infiltration Pond                   |                          |                          |                       |                 |
|                         | Permeable Pavement                     |                          |                          |                       |                 |
| Biological Stranded     |                                        |                          |                          |                       |                 |
| The Underground Water Level | Penetrating Wells                   | > 0.6 -1.2 m            | > 1 m                    | An average of 1.1 to 1.7 | Does not Meet   |
|                         | The Infiltration Pond                   |                          |                          | There is < 1 m        |                 |
|                         | Permeable Pavement                     |                          |                          |                       |                 |
| Biological Stranded     |                                        |                          |                          |                       |                 |

5. Conclusion
The key content of sponge city construction is to coordinate the system of natural precipitation, surface water and underground water, coordinate the water supply and drainage, and consider its complexity and long-term. Suzhou has its unique natural and cultural conditions. Since the construction of sponge city, doubts have been raised constantly. The main concerns focus on the applicability of technology and the coordination between engineering technology and urban artistic temperament. In this paper, more than 20 technologies in the United States and China are comprehensively analyzed from the objective conditions, economy, artistry, ecology and other aspects of application. It is hoped that this study can answer the above questions and provide valuable technical reference for Suzhou urban rainwater management.

Acknowledgments
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