Converting traditional landscape into resilient landscape in Zhenjiang City to manage stormwater runoff: A case study

X L Zhong¹, L J Zhang¹, H Chen¹, Z D Bao¹,², Q Q Yang¹ and N She¹,²,³

¹Sponge City Technology Research Center, China Machinery International Engineering Design and Research Institute Company, Ltd, No. 18 Mid. Shaoshan Rd., Changsha 410007, China
²Tsinghua University Innovation Center in Zhuhai, No. 101 Tangjiawan College Rd., Zhuhai 519080, China

E-mail: baozhengduo@outlook.com; nianshe@szu.edu.cn

Abstract. Since the beginning of low impact development (LID) introduced into China, the aesthetic perspective has been a big issue in LID practices. Many landscape architects viewed LIDs as a contradiction to the traditional landscape design. Therefore, a significant challenge in Sponge City construction in China is to communicate with landscape architects understanding the importance of managing stormwater runoff and pollutant removal close to the source. In this paper, we presented a framework developed for civil engineers and landscape architects working together to guide the LID or green infrastructure design. We presented a case study in China using this guideline to build a resilient landscape with aesthetics. It illustrated that the beautiful landscape could be integrated into local LID and regional green stormwater infrastructures for flood mitigation and high pollution load removal.

1. Introduction
Rapid urbanization has been causing severe water-related issues in many Chinese cities such as frequently urban floods [1,2], surface/ground-water pollution [3], groundwater depletion [4], and watershed aquatic environmental disruption [5]. To address these problems, at the end of 2014, the Chinese central government launched a nationwide program named Sponge City Innovation [6]. According to the Sponge City Development Guideline issued by the National Council of China, 70% of rainwater should be intercepted on site to recharge the groundwater and reuse [7]. The urban stormwater management would be achieved through the implementation of low impact development (LID) and green infrastructure (GI) practices [8,9], which would enhance the processes of soil infiltration, detention, storage, cleanse, then drainage and reuse of rainwater.

In 2015, Zhenjiang city was selected as a pilot city to conduct the sponge city development with a pilot area of 29.28 km² almost occupied as aged ultra-dense communities. According to the local climate and hydrological features, three objectives were proposed to be achieved with the development, included (1) no apparent surface waterlogging at 30-year interval storm events; (2) 75% of annual surface runoff captured on site; and (3) 60% of non-point sources pollutant loading (TSS) removal from surface runoff.

Since the Sponge City Innovation just has been practiced for a few years in China, a significant proportion of citizens, even some professional urban planners and designers, has not been educated well to fully understand the concept of sponge city development [6]. LID and GI practices were often
viewed as water management/treatment facilities designed by civil and environmental engineers but lost the landscape feature. However, urban water treatment/management design with LID/GI practices can be perfectly integrated with landscape design to achieve multiple objectives [10,11]. In this paper, we presented a sponge city retrofit project performed in Zhenjiang to illustrate a merged design strategy for both urban water management/treatment and landscape features.

2. Project description
The pilot areas for sponge city development in Zhenjiang is 29 km², consisting of 11 sub-catchments. Among those, Jiangbin is a sub-catchment with an area of 206 hectares, mainly occupied as ultra-dense aged communities. The domestic wastewater and rainwater from this sub-catchment were collected and conveyed with a combined sewer system (CSS). In rainy seasons, the CSS frequently failed to hold the combined flows ultimately, causing combined sewer overflow (CSO) directly discharged into the downstream Jingshan Lake without any treatment.

In 2016, integrated sponge city retrofit projects were permitted to address the storm-related issues in Jiangbin catchment. The retrofit projects objectives involved to implement source control LID practices to reduce the runoff volume and non-point sources pollutant loading into the conveyance, to enhance the conveyance system by installing a new pipe with a diameter of 2.8 m to increase flow transport capacity and to prevent waterlogging, and to construct the terminal water treatment system with GI practices to improve the water quality released to downstream or to reuse. Our project was a crucial part of the integrated sponge city retrofit projects with a primary function to treat the surface flow received from the Jiangbin catchment. Meanwhile, the project should also perform on-site runoff management.

Our project site (Sponge Park, in figure 1) locates in the west of Jingkou District in Zhenjiang, with 6 hectares footprint. The previous site land-use were 4 hectares of public green space and 2 hectares of impervious surface (Jiangbin pump station). Adjacent Jianshan Lake receives direct surface runoff discharged from the project site. The park development project was started in 2016 as an attempt to combine the sponge city development design with the landscape design. The primary objectives include: (1) design a water eco-treat/manage system to improve the water quality and control the CSO

Figure 1. Location of the Sponge Park (with orange fill), boundaries of the sponge city retrofit zone (in black frame) and drainage area (in blue frame), and areas with runoff source control practices (with blue fill).
flows from the drainage area as well as runoff generated on-site, and (2) the park was proposed to be designed as a multiple functional park providing serves for sponge city practices exhibition, sponge city knowledge education, citizen pleasure and so on.

3. Project design strategy

3.1. Water management/treatment system design

The water treatment/management processes present in figure 2. In storm events, combined sewer flows were transported to the pump station through the urban stormwater drainage network. The first flush would be captured into treatment cells to reduce pollutants loading. Then, treated water after UV sterilization and the overflows were conveyed through grass swales into the rain garden, in where the flows were ponded then infiltrated through media layers, effluent flows are discharged by underdrain into an underground storage tank with a volume of 500 m³. The stored water would be reused to supply the waterscape or irrigation with UV sterilization.

Figure 2. The water treatment/management processes.

The treatment cells consist of an on-line water treatment facility and a regional green infrastructure (shown in figure 3). The online treatment facility was installed in water transport pipelines. A patented movable weir in the facility can intercept large-size solids and capture large debris. Then flows is infiltrated through a media layer to remove TSS (diameter > 0.5 mm) and solid adsorbed pollutants. The removal efficiency of the facility could reach to 19% for TP, 20% for TN and 90% for TSS (Data provided by the Manufactory). The regional green infrastructure practice consists of a gravel layer and a high-performance permeable media layer. Organic matters, nitrogen and phosphorus, can be removed from water by microorganisms grown on the media surface. In this project, the regional green infrastructure holds a daily loading capacity of 25,000 m³. It can treat effectively treat CSO with a design flow rate of 0.28 m³/s (up to 25,000 m³/d), and adjustable to treat flows with a flow rate up to 0.56 m³/s in storm events. As designed, approximately 15% of runoff volume from a 300-hectare catchment area could be captured for treatment in a 24-hour designed storm event (total rainfall depth is 23.44 mm).
We conducted rainfall-runoff simulation with SWMM program to estimate the performance of the terminal treatment system. As shown in table 1, combined with LID practices and water treatment facilities, showed the best performance for the runoff control, pollutant loading reduction, and TSS removal.

| Parameters                  | Before retrofit | LID practices | Combined LIDs and water treatment facilities |
|-----------------------------|-----------------|---------------|----------------------------------------------|
| Annual runoff control rate (%) | 49              | 57            | 76                                           |
| Pollutant loading(t/a)      | 123.6           | 106           | 46.2                                         |
| Removal of TSS (%)          | 0               | 14.2          | 62.6                                         |

Also, different LID practices, such as permeable pavement, bio-swale, rain garden, green tree planter, green roof, and sunken square, were implemented in the project sites to control on-site generated runoff and site surrounding flows. The project site consists of 5 sub-catchments. The LIDs practices were configured in the whole project site (as shown in figure 4) to maximize the treatment performance. The modeling result showed that the total annual runoff control rate could reach to 93.83%.

![Figure 3. The online treatment structure (left panel) and the regional green infrastructure (right panel).](image)

![Figure 4. LID practices configuration in the project site.](image)
3.2. Landscape design

To well achieve the proposed objectives for water treatment and landscape features altogether, the landscape design was conducted based on LIDs design. Supplemental functions and purposes, such as living environmental improvement, sponge city practices exhibition and sponge city knowledge education, also be merged in the site landscape design. Moreover, our design followed the principles to protect the valuable existing landscape features as much as possible and to ensure the performance of LID practices. Only necessary terrain modification and engineering processes were allowed in the design.

Total 21 landscape elements were designed in the project included a sponge city exhibition center, a sunken plaza, waterscape, a children's playground, walkway, and an aerial corridor bridge and so on, the site landscape layout presented in figure 5.

![Figure 5. The site landscape layout.](image)

Our landscape design scheme was named One Ring, One Center and One Factory. One Ring referred an 800-meter fitness trail around the park retrofitted with the pervious concrete pavement practices. A percolation system was added along the trail shoulders. The practice was designed to infiltrate and detain rainwater then discharged into the waterscape. One Center referred to the open square area surrounded by footbridge to the Exhibition Center. Several LID practices were implemented in the area to improve the square landscape features and to satisfy the citizen’s pleasure needs, which could also be used for LID technique education. One Factory referred to the Jiangbin Pump Station, which contained a variety of LID facilities which were designed to address the drainage problem in the factory area and to improve the water quality of runoff effectively.

According to the landscape spatial analysis, the project site was divided into five landscape zones as Jiangbin pump station, exhibition hall zone, public pleasure square, water quality treatment and demonstration zone, and existing urban environmental restoration zone, respectively. Various elements were assigned to the zones, such as scenic galleries and bridges, hydrophilic water system, fitness area, recreation area, children's activity area, and old aged activity area. According to the location and function of the individual zone, public facilities were designed to improve the overall functional usability and meet the landscape features and functional requirements.
4. **LID practices construction specification**

To ensure the LID practices performance, the sponge city retrofit construction process had to follow several specific requirements. For example, LID practices performance for water management and treatment required that the inverts, elevations, and gradients associated with the LID practices and surrounding catchments should be carefully designed then constructed to guarantee expected hydrological features. Also, there has detail requirement for the medium applied for LID practices regarding specific design, including the permeability, gravel size, and mud content. Strict quality control in the whole processes of project construction would ensure LID practices operate successfully. Examples of LID practice and landscape construction presented in figure 6.

![Figure 6. Regional green infrastructure (up panel) and rain gardens (down panel) construction scenes.](image)

5. **Project performance**

As shown in figure 7, the sponge city retrofit zone with LID practices (rain garden in this case) illustrated a significantly improved resilient design compared with traditional design to manage urban water. Meanwhile, the project demonstrated an attractive landscape feature, as shown in figure 8.
Figure 7. Performance of LID practices in a storm event.

Figure 8. Examples of landscape feature demonstrated in the project site.

6. Conclusion
Currently, the sponge city development in China has still been in the initial stage; urban planners, project designers, and citizens may do not thoroughly understand the internal of sponge city and LIDs. The sponge city and LID practices were viewed as a lost landscape feature. The sponge city retrofit project constructed in Zhenjiang was a successful attempt to combine the sponge city development design and landscape design altogether. The project case provides a good experience for the follow sponge city development and LIDs design and construction.

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References

[1] Yin J, Ye M, Yin Z and Xu S 2015 A review of advances in urban flood risk analysis over China Stoch. Env. Res. Risk A. 29 1063-70

[2] Chen Y, Zhou H, Zhang H, Du G and Zhou J 2015 Urban flood risk warning under rapid urbanization Environ. Res. 139 3-10

[3] Li L-Q, Yin C-Q, He Q-C and Kong L-L 2007 First flush of storm runoff pollution from an urban catchment in China J. Environ. Sci. 19 295-9

[4] Huang Z, Pan Y, Gong H, Yeh P J F, Li X, Zhou D et al 2015 Subregional - scale groundwater depletion detected by GRACE for both shallow and deep aquifers in North China Plain Geophys. Res. Lett. 42 1791-9

[5] Le C, Zha Y, Li Y, Sun D, Lu H and Yin B 2010 Eutrophication of lake waters in China: Cost, causes, and control Environ. Manage. 45 662-8

[6] Wang H, Mei C, Liu J and Shao W 2018 A new strategy for integrated urban water management in China: Sponge City Sci. China Technol. Sci. 61 317-29

[7] Ministry of Housing and Rural-Urban Development of China 2014 Sponge city development guideline –Storm management system development with LID (Beijing, China: Ministry of Housing and Rural-Urban Development of China) (in Chinese)

[8] Dietz M E 2015 Low impact development practices: A review of current research and recommendations for future directions Water Air Soil Poll. 22 543-63

[9] Qin H P, Li Z X and Fu G 2013 The effects of low impact development on urban flooding under different rainfall characteristics J. Environ. Manage. 129 577-85

[10] Wolff G, Sutton S, Struck S and Lichten K edis 2010 Using the bay-friendly landscape standards to implement low impact development in the San Francisco Bay Area Low Impact Development 2010: Redefining Water in the City pp 1056-1066 (San Francisco, California: International Low Impact Development Conference 2010)

[11] Chen X, Yang Q and Yang K 2016 Construction approaches of urban spongy park based on low impact development J. Landscape Res. 8 27-30