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Issues and Strategies for Designing Flood Resilient Public Space to Achieve a Balance between Public Amenity and Stormwater Management Infrastructure

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Abstract Managing stormwater close to where it falls is an effective stormwater control method. Since public spaces are densely and widely distributed in cities, they are expected to have a positive impact on flood mitigation as a way of source control, when being integrated with stormwater management functions. However, to design a stormwater public space that balances its use as a public amenity and as stormwater management infrastructure remains an interdisciplinary challenge.This study aims to conclude a design methodology that encompasses a holistic stormwater management philosophy within the site scale, as well as spatial design strategies that make public spaces attractive amenities and part of the urban stormwater management system. To achieve this goal, first, a literature review of various influential stormwater management concepts in urban drainage that have been adopted into urban planning was conducted. Second, an empirical analysis was retrieved from two concrete public space design cases of stormwater parks in the USA and China. It is clarified that large spatial height differences, and sanitary and safety problems of the collected stormwater are two main issues resulting from the conflict between the site's managing runoff and serving as a public facility, negatively affecting the continuity of landscape effects, usability, etc. Strategies to address these issues are also concluded.

Keywords. *Flood resilience, Stormwater Park, Multifunctional Landscape Design*

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1 Research background

1.1 Public spaces' potential in improving cities' flood resilience

Over the last few decades, urbanization and climate change have increased the severity of stormwater-caused urban flooding worldwide. In particular, extreme precipitation has become more frequent as a result of climate change[1).]To find a countermeasure that mitigates the urban flooding problem, research on stormwater management has been conducted across various countries. One of the advances in recent years has been the shift from the conventional centralized drainage model to a decentralized on-site runoff management model[2)]. It is believed that by controlling stormwater close to where precipitation falls, the total and peak stormwater runoff volume could be reduced, and the risk of river or drainage sewage overflows, due to large concentrations of stormwater in a short time could be reduced.

It is considered reasonable and feasible to design public spaces to realize such kind of at-source stormwater control, as their wide and dispersed distribution of public spaces in urban areas[3)]. There are already practices of implementing stormwater management facilities in public spaces, showing the potential of public spaces being improving cities' flood resilience. For example, in Japan, rainwater infiltration and detention techniques are being implemented at the regional level, in combination with river channel improvement as an integrated countermeasure to prevent flood hazard[4)]. Infiltration measures such as the use of permeable paving in parking lots and squares, promote infiltration of stormwater into the ground. Detention measures are common in being used in the sunken square as the storage space or underground storage tanks in open spaces with drainage facilities to temporarily store stormwater on the site. At the same time, there are also researchers who think that sustainable drainage systems could have positive effects on the urban landscape as additional recreational amenities[8)]. In addition, the benefit of improving the land-use efficiency of the city could also be created, if public spaces are used as stormwater infrastructure because a parcel of land is used for stormwater management and public recreation at the same time.

Achieving the integration of stormwater management facilities and public spaces is not difficult, however, the issues lie in how to create a multifunctional public space to achieve a balance between public amenity and stormwater management infrastructure. The balance means the public space has the capacity to handle stormwater adequately and effectively as an urban drainage infrastructure and can serve as an attractive place for contributing to the reputation of cities for vibrancy and livability, and to the well-being of urban residents[5)] (Damian Collins, Sophie L. Stadler,2020) at the same time.

Common examples currently of combining stormwater management with public spaces such as the design of rainwater ponds in low-lying vacant areas, can collect stormwater, and release it at a rate that prevents flooding or erosion[6)](Bill Leber,2015). But such design does not make the site a pleasant space for citizen's group or individual activities. There are also examples in which rainwater management devices, such as rain gardens, are placed in parks or squares. Although these practices can improve the infiltration rate of rainwater in public spaces to some extent, the small scale of these devices has limited ability to improve the flood resilience of the whole space.

What are the specific challenges in designing public spaces as stormwater infrastructure and what are the strategies to solve these issues so as to derive a systematic approach to make public spaces manage runoff effectively while improving the quality of the environment as a good place for people's social activities is the concern of this article.

1.2 Previous reviews

Designing flood-resilient public space to achieve a balance between public amenity and stormwater management infrastructure is an interdisciplinary challenge. Generally, stormwater management is related to the field of urban drainage involving the knowledge of hydraulics and hydrology. The planning and landscape design of public space, on the other hand, belongs to the field of landscape architecture and urban planning. And the topics of previous studies of these two specialties haven't reached a balance as well.

On the one hand, researchers with engineering backgrounds are good at quantitatively studying the capacity of collected rainwater and improving the performance optimization of various rainwater management facilities such as rain gardens. But there is less discussion about how to translate these research results for designing attractive public space design. For example, Jing Wang et al. (2016)used SWMM to simulate and examined the runoff control effect of four different stormwater management measures schemes used on campus. In their research, the combination of using the green roof, infiltration squares, and retention pond used in the campus's public space is found to provide the best effect of runoff control for the site. Their simulation proved that multiple measures should be used so that the stormwater management ability of public spaces could be more effective. But such an ideal model does not clarify how these measures such as the pond could be placed in space to ensure visitors' convenience, because the simulation was carried out where the retention pond was simplified to a model with an area of 108 m2 and 1-meter depth on the lawn[12)]. K. Ishimatsu et al. (2016) designed a verification experiment to examine the quantitative benefits of rain gardens in dealing with small discharges of rainwater, reducing and delaying flood peaks effectively, but didn't discuss specifically how to use rain gardens for stormwater management in urban design and planning[11)].

On the other hand, researchers in the field of landscape design make efforts on summarizing the ways to achieve the integration of existing rainwater management tools with aesthetic value into the organization of public space, but there is insufficient research on constructing stormwater management systems of overall and how to quantify the stormwater management goals.

For instance, Liu et al. (2015)summarized how stormwater facilities related to the three components of stormwater runoff: conveyance, reception, and storage of runoff can be placed in the landscape design. But the method of using public space as a whole stormwater facility has not been considered.[9)]Maria Matos Silva et al. (2016,2018)studied a large number of empirical cases of stormwater facilities applied to public spaces, identifying specific public space potentialities for the application of flood adaptation measures. A proposed range of flood adaptation infrastructural strategies including three aspects of rainwater harvesting, storing, infiltrating, conveying, and tolerating were concluded[3)10)]. However, the specific design form of each function is only explained by citing examples, while the common design concept and the specific design scale approach to achieve that function are not summarized. Whether the form and scale of achieving these functions conflicts with the use of the site as a public space are also not discussed.

2 Research purpose and methodology

Based on such a research background, the argument of this article is developed under the premise that public space as a whole can be used as one of the means of stormwater control and form part of the stormwater system in urban, which is one of the countermeasures to solve the urban flooding problems. There exist common issues when creating such public spaces with stormwater management functions. For example, a typical issue that has to be considered is that making spaces for stormwater storage will result in elevation differences and make the park difficult for people to use. The strategies for design will be explored, being focused in terms of drainage stormwater management philosophy, but also from the perspective of creating spatial attractiveness and usability.

To achieve these purposes, understanding the theoretical philosophy of rainwater management is of primary importance. Different countries have developed various terms and corresponding design manuals to promote stormwater management. As stated by Tim D. Fletcher et al. (2015), terminology evolves locally and thus has an important role in establishing awareness and credibility of new approaches and contains nuanced understandings of the principles that are applied locally to address specific problems [7)]. Thus, a literature study of the influential stormwater management principles, strategies, and practices in different countries was first carried out. The similarities and differences of these mainstream stormwater management terms are sorted out and compared to sort out the fundamental stormwater management concept. And the common calculation logic and method for stormwater retention would be concluded. Furthermore, relevant cases are matched with each term so that their applications are interpreted concretely to clarify which of these ideas and strategies can be better applied in public spaces.

Then, case studies of design examples of public spaces with stormwater management were presented to understand the main issues and challenges when designing a public amenity into a stormwater management infrastructure. And the strategies for the issues will be discussed. Historic Fourth Park in the United States and Yangpu Riverside Rain Garden in China were selected based on these criteria: 1)they are public spaces with a clear positioning of being used for stormwater management; 2) they have been proven to be effective in stormwater management; and 3) they are evaluated by visitors as pleasant public spaces.

3 Influential stormwater management philosophies and their applications in urban planning and public spaces design

The history of stormwater management dates back to 1972, with the passage of the Clean Water Act[29)], where the critical problems posed by rainwater or other nonpoint sources of pollution, were recognized as being in need of planning solutions. It is now well understood that not only water quality pollution, but also the negative impacts of stormwater runoff include flooding and soil erosion. The goal of stormwater management is to reduce or eliminate the negative impacts of stormwater runoff. The management of urban stormwater has been developed over recent decades. Consequently, terminology describing the principles and practices of urban drainage has become increasingly diverse[7)](Tim D. Fletcher et al.,2015). Although some terms first appeared in the civil engineering field of urban drainage, as the connotations of the terms developed and evolved and new terms emerged, many of them embodied the connection with the integration of urban space design. For instance, a manual was stipulated by the government of Singapore for A.B.C water so that designers and engineers can better understand and implement the concept and method in it. Containing concepts, strategies, and techniques, these terms were regarded as the important basis for the concrete implementation of specific practical stormwater site design. The properties of the influential stormwater management concept and their concrete application in urban planning or urban design are summarized as shown in the table-1.

Almost all of the terminologies share the common objectives of controlling the total amount of runoff and reducing peak runoff flow, which is also reflected in the overlapping parts of these terms. As a result, design strategies and practices that allow for the management of stormwater in close proximity, such as the use of green roofs and permeable paving to promote stormwater infiltration into the ground, and measures like rain gardens that capture and retain stormwater at the source, are commonly used as practices in these various terms. This can therefore be considered a broad design philosophy for designing a stormwater public space.

Among these concepts, GI and LID are two that can be applied at the site scale. Practical projects in recent years have also shown that these two concepts have been used to a great extent in stormwater management in public places.The common stormwater management features implemented in public spaces so far fall into both of these two categories.

Table.1. The properties of the influential stormwater management Philosophys and their concrete application in urban planning or urban design based on literature reivew

Terminology	Origin	Category			Applicable scale	Focused content/ Principle	Strategies/ Practices	Practical application in urban planning or urban design	
		Techniques /Practice	Design Approach	Concept				Name	Location
Low Impact Development (LID)	Pioneered by Prince George's County, Maryland, USA, in the early 1990's,		○		Area scale	Maintain or replicate the predevelopment hydrological conditions of the site; Control stormwater at the source by the use of microscale controls that are distributed throughout the site; Advocate	Make the best use of natural areas; Minimize the area of road and driveways; Redirect stormwater away from existing storm drains and toward natural or constructed planted areas	1.Partridgeberry Place LID Subdivision	Ipswich, Massachusetts, USA
								2.Rainbow Wetland Park	Shanghai, China

					for more careful site design in the planning phases.;			
Best Management Practices (BMPs)	Referred in several sections of the U.S. Clean Water Act in 1970s	○		Area scale	Prevent or reduce water pollution resulted from stormwater runoff.	Source control BMPs: public education and outreached; Treatment control BMPs: Detention Ponds; Wet Pond/ Detention Ponds; Infiltration Basins etc.	Centennial Parklands	Sydney, Australia
Green Infrastructure (GI)	Emerged in the USA in the 1990s	○	○	Various scale	Be used outside of a stormwater context as a network of green spaces and landscape ecology; Maximize the benefits of green spaces, identifying their potential ecosystem services	Engineered-as-natural ecosystems such as green roofs, swales and rain gardens	1.NYC Green Infrastructure Program 2.The Greenways to Rivers Arterial Stormwater System (GRASS)	New York, USA Los Angeles, CA, USA
Water Sensitive Urban Design (WSUD)	Initially used in the 1992 in Australia		○	Urban scale	Minimize the impact of development on the surrounding environment and waterways. Involve treating and reducing stormwater flows, increasing soil moisture, urban greening and providing an alternative water source.	Concept design; Functional design; Detailed design; Stormwater harvesting and treatment;	Napier Park Stormwater Reuse Project	Melbourne, Australia
Sponge City	launched in China in 2013.		○	Urban scale	Refer to the ability of cities to act like sponges, with good "resilience" in terms of adapting to environmental changes and responding to natural disaster;	Three main construction approaches: ecosystem protection, ecosystem restoration and LID; Design and organize sponge systems and sponges from national, city and regional scale.	Lingang Pilot Area Project	Shanghai, China

In conclusion, LID is a site design strategy with the goal of maintaining or replicating the predevelopment hydrological conditions of the site through the use of design techniques to create a functionally equivalent hydrologic landscape[34]. Low impact can be interpreted as less disturbance of site development on predevelopment hydrological functions such as storage, infiltration, and groundwater recharge. In order to achieve this objective, the principles of low impact development are developed which could be summarized as the following points: Firstly, preserve as much of the site in an undisturbed condition, and where disturbance is necessary, reduce the impact; Secondly, control stormwater at the source by the use of microscale controls that are distributed throughout the site; Thirdly, encourage more careful overall site design approaches in the planning phases. [34][36] For example, effective strategies include narrowing the road or clustering buildings together on only a portion of the available land to leave as much of the land as possible undeveloped; redirecting stormwater away from existing storm drains and toward natural or constructed planted areas.

Green infrastructure was first coined in Florida USA in 1994. It was used to reflect the notion that natural systems are equally, if not more important, components of our "infrastructure"[38](Karen Firehoc,2010). Although when the term infrastructure is mentioned, it may be more commonly associated with gray infrastructure, referring to structures such as dams, roads, pipelines, bridges, etc., the meaning and application of gray infrastructure can be used as a reference when understanding green infrastructure. As with gray infrastructures, forests, greenery and soil also could be organized and planned as "a set of fundamental facilities and systems that support the sustainable functionality of a city". In 2007, the potential application of GI in stormwater management was realized by the US EPA and the term was thus accepted and used increasingly in stormwater management. In terms of managing stormwater, green infrastructure represents a range of measures that use plant/soil systems, or engineered systems to harvest and reuse, store, infiltrate, or evapotranspiration stormwater to reduce flows to the sewer system. The difference between the BMPs and LID is that, as for green infrastructure, the system and network formation of these facilities or practices is more emphasized. Thus, to construct a stormwater management system, the concentration, conveyance, collection, and discharge of stormwater should all be taken into account with corresponding spatial design.

4 Cases studies of public spaces with flood resilience function

In this study, Historic Fourth Ward Park in the United States and the Yangpu Riverside Rain Garden in China are selected for case studies. On the one hand, they are designed to handle up to a 100-year rainfall event and do show good stormwater management effects during actual flood events. The former plays a significant role in stormwater regulation at the community scale as a GSI (green stormwater infrastructure). The latter, as a micro-level project of sponge city, fully utilizes the design ideas of LID. On the other hand, they are, on normal days, charming public spaces with high environmental quality, drawing hundreds of visitors a day. The two cases were studied and analyzed from the aspects shown in table.2.

Table.2.Focuses of the Case Study

Item to be Examined	Specific Content

01	Project Background	Urban Planning Context Causes of Flooding
02	Planning and Design Process	Objectives Challenges
03	Stormwater Management Solution	Technical Elements Stormwater Management System
04	Landscape Design Strategies	Landscape Elements Vertical Design
05	Performances and Benefits	Runoff Control Effectiveness Utilization and Evaluation from People

4.1 Case 1: Historic Fourth Ward Park

Historic Fourth Ward Park has successfully fulfilled its flood control for its surrounding areas with its capacity to store the 27,000 m^3 of runoff from a 350-acre area which is generated in a 100-year stormwater event. It also brings additional social and economic value, such as environmental quality improvement and housing appreciation. The construction of the park includes two phases, and his case study focuses on the first phase of the park.

4.1.1 Project background

The park is located in a former industrial lowland area of the Old Fourth Ward neighborhood of Atlanta, Georgia, U.S.A. The area was famous for being susceptible to flooding caused by sewer overflows. Old Fourth Ward neighborhood belongs to the Clear Creek Basin and Clear Creek basin is a combined sewer area (CSA) of the Peachtree Creek watershed, which is one of the ten watersheds divided by the City of Atlanta's Watershed Management Department. In a Combined Sewer Area (CSA), stormwater flows enter sanitary sewers instead of flowing directly to creeks[22)].When there was heavy rainfall or snowmelt, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system and result in flooding. Portions of the combined sewer system experience overflow during a storm as small as a 5-year event. [15)18)19)]

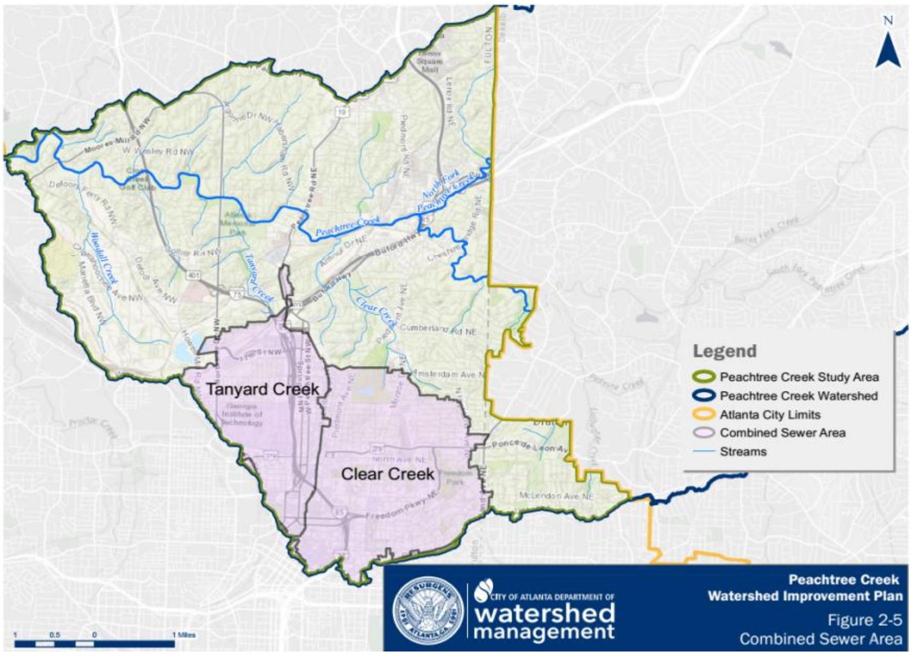

Figure.1. Clear Creek Basin in Peachtree Creek Watershed[22]

On October 16, 2002, a new Clean Water Atlanta initiative with a plan to improve the city's wastewater system was announced. The Clear Creek Basin watershed was targeted by the city and the Department of Watershed Management because of its large size, the volume of CSOs (Combined sewer overflows), and the frequency of surface flooding during rain events [15][17]. The City of Atlanta agrees to a federal consent decree to fix its chronic sewer overflows and other waste treatment problems. The city proposes a 15-year, $3 billion overhaul of the city's sewer systems.

Another background related to upper-level planning is the proposal of the construction of the Atlanta BeltLine in 2006. Atlanta beltline is a sustainable redevelopment project that will connect 45 intown neighborhoods via a 22-mile loop of multi-use trails, modern streetcar, and parks, all based on railroad corridors that formerly encircled Atlanta[16]. The site belongs to one of the neighborhoods. Therefore, the initial issue was how to use the land to provide sufficient stormwater storage for addressing flooding caused by sewer overflows and to coordinate with the construction of the Atlanta BeltLine.

Initially, a solution of adding a gigantic underground tunnel was proposed. It can increase the capacity for holding stormwater from a two-year storm event to a 100-year event at a cost between $40-70M. However, by 2003, a group led by Bill Hisenhauser, a stormwater activist and an engineer-economist, come up with an alternative approach of a park centered around a stormwater detention pond, by calculating the amount of stormwater needed to be held back, the amount of space that would be required[25]. Concerned citizens also suggested that a better investment for their community would be to detain stormwater in a lake feature rather than buried below ground in the proposed tunnel[15][24]. Eventually, Atlanta Beltline Inc. in partnership with Trust for Public Land proposed to construct the 17.5 ac park, which was desired to serve as a storm infrastructure for the neighbor and become the focal part of the Atlanta Beltline project as well. This brings the next question: What design proposal can it be, to make to well satisfy these two requirements?

4.1.2 Stormwater solutions and specific design strategies

1)The determination of the stormwater volume and the size of the stormwater park

Undoubtedly, the first concern is how to calculate the amount of stormwater needed to be handled. The total area of Clear Creek is 4.8 square miles. The park was located in one of the sub-watersheds, in which the Clear Creek Basin has 350 acres that are directly connected to the park by surface. The stormwater feature is required to be able to capture and store the amount of stormwater runoff generated from a 350-ac watershed in a 100-year rain event. The calculated amount of stormwater is 27,000m[15][18][19][20]. To make the park with enough capacity to store the possible rainwater amount of the design rainfall, the entire park is designed in sunken form and a detention pond is placed as the central piece of the park with an area of 2-ac. The lake can harvest and store a maximum volume of 8 million gals (30,000 m^3/26-ac feet) from its neighboring area, which provides capacity relief to the municipal drainage system[15].

2)The multifunctional design of the park

The rainwater management process, from runoff collection, and retention to reuse, is well-designed so that the park could function effectively as a stormwater infrastructure. There are 10 inlets to let the runoff in the surrounding area enter the park. The stormwater could be stored in the lake for 24 -36 hours. After a storm, the rainwater recedes by discharging into the municipal Combined Sewer trunk. Flow into the Highland Avenue trunk is made by a 24" line which slows discharge[18]. Additionally, should the trunk fill up, backflow preventers are installed to ensure sanitary sewer water would not re-enter the park pond. The recycled water contained in the pond could be aerated through a ten-foot waterfall and a stone water cascade to prevent it from stagnating, it can be further treated by the wetland plantings. The rainwater stored in the pond would be reused for irrigation throughout the whole park[15][18][19][20][21].

Furthermore, the vertical design of the park is based on the inundation level under different design storms so that the park could be used on rainy days safely. The changes in the park plan during the normal water level on sunny days, in one-year storm events, and in 100-year storm events have been considered and the corresponding design was made. As for the traffic flow design, two walkways are developed in the park. The lower walkway is designed to be temporarily submerged when a 100-year storm event occurs and the additional network of the road to provide circulation throughout the park, can also provide visitors with a safe route, if a 100-year storm is ever experienced. The stored volume is released in a controlled manner to the downstream trunk sewer.

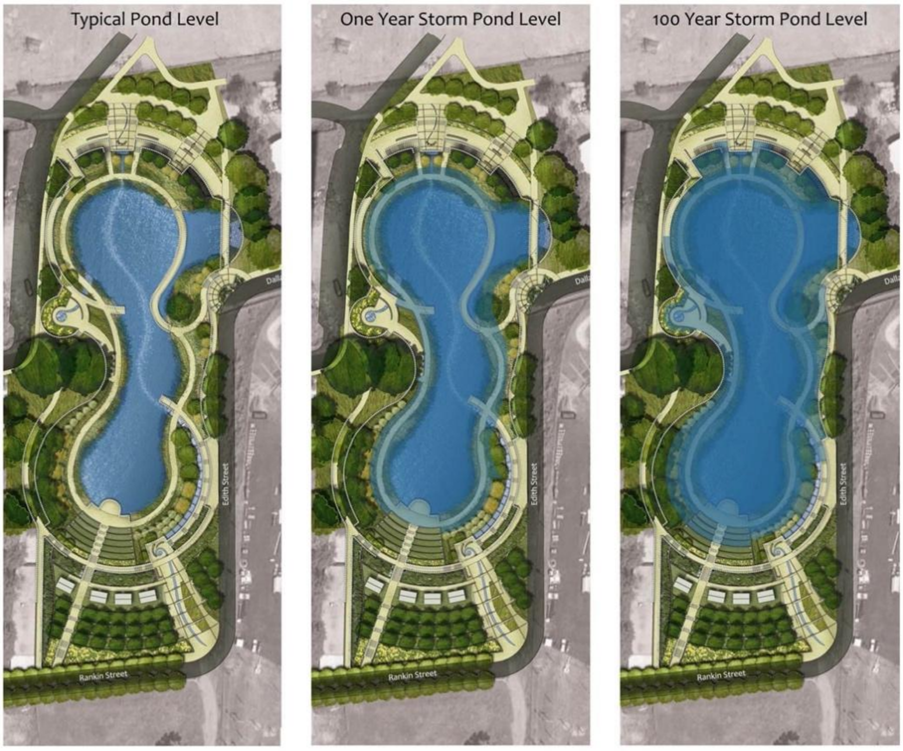

Figure.2. The park’s master plans during the normal water level on sunny days, in a one-year storm event, and a 100-year storm events have been considered [19)]

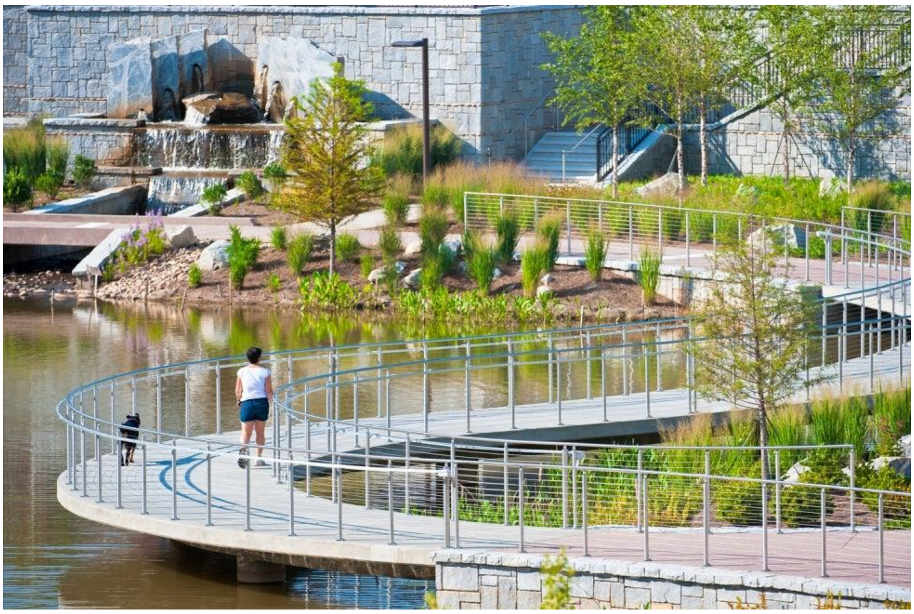

Figure.3. The lower walkway of Historic Fourth Ward Park[23)]

On the other hand, the fact that the park is attractive as a recreational place may be due to its low engineering profile. The traditional engineering component such as pipes, flared end sections, and rip rap are disguised as artistic park features. For example, four primary inlets of the park are designed as sculptural features.The aeration features are disguised as waterfalls and fountains.The design of the detention pond below the groundwater table allows for a constant inflow of water so that a permanent pool elevation of water could be maintained in daily time, keeping a good lake scenery all year round.

Besides, it also provides visitors with various spaces for different activities. The area surrounding the pond features sculptural artistic elements, curvilinear retaining walls, intricate hardscape detailing, and multiple viewing platforms. A terraced amphitheater provides a good overlook view of the park and functions as a venue for educational field trips, concerts, and other events. Consideration for safety is also well-designed. For example, because the water in the lake is not suitable for swimming or drinking, the lake is surrounded by “prickly” landscaped plantings to discourage contact with the water [15)20)21)].

4.1.3 Performance and benefits

Historic Fourth Ward Park has effectively solved the flood problem for its surrounding areas. The Modeled results from InfoWorks ICM demonstrated a reduction in peak flow rates at the connection point to the trunk sewer between 9.6 percent and 3.6 percent[19)]. There was also practical observed evidence for the effect of flood protection of the park. There was no flooding at neighboring Ponce City Market during 3 days of intense rain in July 2013 totaling 5.3 inches, as compared to catastrophic flooding of the market during 3 days of intense rain in September 2009 totaling 8.1 inches. In terms of social and economic benefits, the project provides the neighbors' residents with attractive recreational public spaces of good environmental quality. What's more, the construction of the park costs only about $25 million, in stark contrast to the $40 to $75 million estimated for traditional tunnel construction[25)].

4.2 Yangpu Waterfront Rainwater Garden

Yangpu waterfront rainwater garden was finished in 2016, as part of the Yangpu Riverfront Public Space Renovation Project in Shanghai. Based on the concept of low-impact development, the site has been transformed from an industrial depression into a multi-functional public space that retains and purifies stormwater for the site and its surrounding area.

4.2.1 Project background

Located in Yangpu district, shanghai city, China, the park is adjacent to a historic buildings group. Yang Shupu Waterworks factories were built in 1881, and a modern high-rise office building, Fisherman's Wharf, was built in 2008. The industrial background of the site dates back to 1869 when a large number of factories were built in this area for the convenience of water transportation, and the site was once a freight yard adjacent to the pier. In 2007, the entire factory area, including the current rain garden site, was almost razed to the ground for the construction of the Fisherman's Wharf II commercial office project. The site ended up as an overgrown depression, which was its most recent state before it was converted into a rain garden.

Figure.4. Changes of Yangpu Waterfront Rainwater Garden from 2004 to 2019(Source:Google Earth)

The site is close to the Huangpu River, but the major flooding problem on the site is not caused by the river, but by sewage overflows. The high-water level of Huangpu River is above 4 meters, while the elevation of most of the city ground is only about 3 meters. Therefore, the construction of flood control projects on both sides of the Huangpu River has reached the 1-in-1,000-year standard, and the top elevation of the flood control wall is about 7 meters, which highly reduces the risk of river flooding. However, it is because of the high walls that rainwater within the city cannot be discharged directly into the river, but has to pass through a series of drainage networks and enter pumping stations before being lifted into the sewage and discharged into the tributaries of the Huangpu River. Moreover, the high development of the city makes the rainwater runoff concentrate much more rapidly. When rainwater quickly gathers in large quantities in a short period of time during heavy rainfall and gushes into underground drainage pipes but cannot be discharged to the river on time, the overflow occurs and results in inundation. The flooding pattern at this location is typical of urban flooding. Therefore, one of the objectives of the site is to restore the hydrological conditions of the site, which has been changed several times through the years, to its pre-development condition. Another goal is to make the most of the site's public waterfront resources to provide a pleasant public space where citizens could enjoy the waterfront space and learn about the industrial culture of the area.[26)27)]

4.2.2 Stormwater solutions and landscape design strategies

The topography of the site, which is about 2 meters below its surrounding ground level, was retained A sunken wetland surrounded by greenery slopes was designed. As a public landscape space, the site is designed with the visitors' experience fully taken into account. A steel-framed corridor, representing the industrial historical culture of the site, is erected over the wetland to connect the main entrances of the site.

The corridor is also fully designed for various activities to increase the interactive experience of the visitors. There are landscape structures carved with the history of the site for visitors to explore and learn about the culture of the seat, as well as sunken spaces and seats for people to observe the stormwater wetlands closely along the corridor. Guardrails are set up to ensure the safety of visitors during the viewing tour. The wetland pool is surrounded by a dense planting of reeds and firs, forming a natural fence to strictly separate the pool from the land area. These plants can not only slow down the concentrate rate of runoff and filter the solid pollutant from it but also can protect pedestrians from falling into the pond accidentally. Besides the plants' design is also of a good landscape effect.

Figure-5. The steel corridor bridege across the wetland[26)]

As stormwater facility, the function of rainwater retention, purification and reuse of rainwater, etc. are also fully considered and designed. The site relies solely on topography and stormwater transport routes to achieve harvesting of stormwater from its surrounding area. The wetlands are equipped with a range of aquatic plants to purify the water. The bottom of the pool is not sealed with impermeable treatment, allowing the collected rainwater to infiltrate freely into the land and replenish the groundwater. When the water collected in the site exceeds the designed maximum level, the excess water is discharged from the overflow outlet to another catchment area. The rainwater retained in the pond will be used for irrigation within the site. After passing through the pipe facilities consisting of inlet ponds and filter ponds, rainwater will be reused within the site.

Regarding the design of the wetland water level, the designers drafted a hydraulic and hydrological mathematical model based on meteorological data and a comprehensive analysis of rainfall, runoff coefficients, infiltration coefficients, storm frequency and so on. The mathematical model was then used to simulate the changes in the water level in practical event that the rain garden collected rainwater over an area of 10,000 square meters. The water level of the rain garden was predicted to vary from 300 m^2 to 800 m^2 [27)].

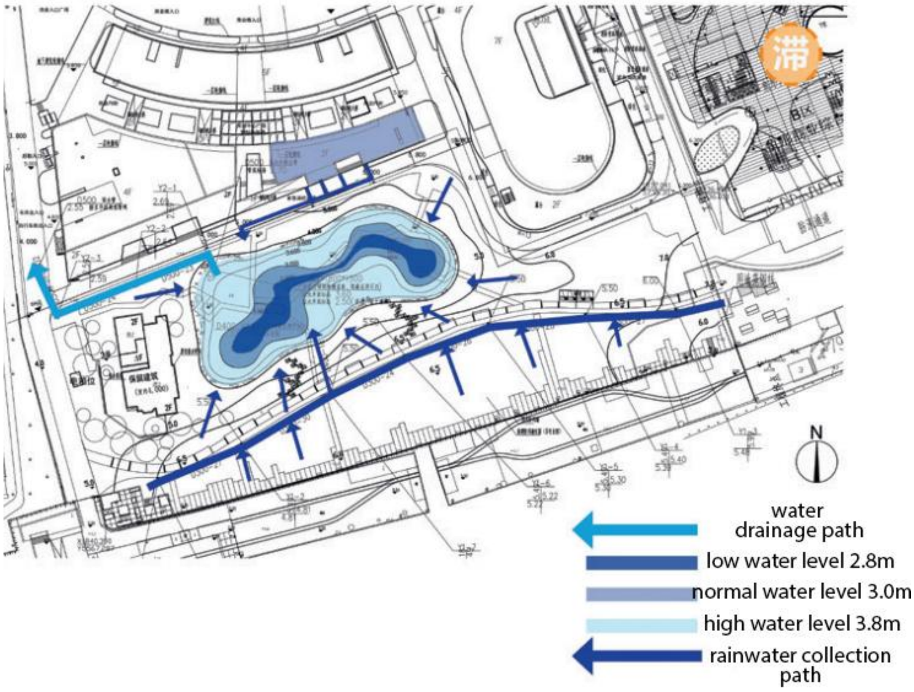

Figure-6. Water level design of Yangpu Waterfront Rainwater Garden [27)]

4.2.3 Performance and benefits

The simulation results of the hydraulic and hydrological mathematical model show that the wetland could collect and infiltrate 95% of the rainwater within an area of 10,000 square meters, with only 5% overflowing into the municipal network, which would undoubtedly minimize the pressure on the entire municipal drainage system in the area[27)]. According to the actual observation results over the past 5 years, the status of the whole water surface was basically consistent with the calculated results[27)].

This case demonstrates a new idea of landscape design that combines public space and rainwater control functions. Currently, rain gardens are now seen as an aesthetically pleasing, small-scale stormwater management practice that is designed to be distributed in small patches along urban roadsides or within green spaces. Nevertheless, just as the case shows us, a rain garden can play a more important role in urban public space. By using sunken topography to construct wetlands, a rain garden of large-scale can be created. With proper path design and planning, people can safely enter and enjoy the rain garden for a tour. What's more, the function of rainwater saving is not necessarily achieved only by placing wet ponds or installing sunken plazas in public spaces.

5 Discussion and lessons learned

5.1General principle of designing public space with stormwater management function

The practical runoff controlling performance in rainfall events of the two cases demonstrates the potential of public spaces to be used as an alternative strategy to using only gray infrastructure for stormwater management. With proper design, urban public spaces are shown to perform with the ability to manage large amounts of runoff as stormwater infrastructure, and as a pleasant public amenity as well.

In the summary of the influential terminologies in the field of urban drainage in Chapter3, it is concluded that controlling runoff amount and reducing runoff peaks are two primary principles to realize stormwater management. In order to achieve this goal, the concept of source control is mentioned in all these concepts. Measures to capture and detain stormwater runoff at the source where it falls, are effective for controlling stormwater,and reducing the risk of urban flooding. Public spaces, being scattered throughout urban space, could be used as numerous facilities that can capture stormwater at the source.

In addition to controlling runoff at the source, conveyance and receptors measure are two other important aspects of managing runoff in a site. As for conveyance measure, it is about the path through which rainwater is directed, purified, retained, and collected. The design of the rainwater transfer path needs to be considered in conjunction with the design of the topography and the site route. The common principle of designing the conveying system is to increase the absorption of rainwater, slow down the flow rate, and purify the runoff. For example, in the Yangpu rain garden, rainwater flows along the road and the lawn slope into the wetland. The grass on the slope and the aquatic plants planted around the wetland slow down the flow of runoff into the wetland and filter coarse pollutants in the runoff at the same time.

Storage can be represented by detention storage, retention storage, or storage that applies elements of both. As described earlier, stormwater storage can both intercept stormwater at the source and act as an end-of-pipe facility to reduce peak stormwater runoff, which has greater performance in reducing stormwater flooding than other measures[13].Therefore, not limited to the two cases given in this study, lots of public spaces that are positioned as flood-resilient spaces with stormwater management functions, are designed with the aim of storing large amounts of rainwater. For example, in the classic case of Water Square in Rotterdam, three sunken plazas were designed for collecting rainwater. And Rainbow Bay Park, a pilot project under the sponge city project, is designed with two wetland ponds for stormwater detention.

Figure.7. The sunken plaza of Water Square Benthemplein
(Source: Author)

Figure.8. Two wet pond are designed in Rainbow Bay Park,Shanghai
(Source: Author)

5.2 Common issues and strategies

The challenges and problems have resulted from the conflict between collecting runoff and serving as a public facility at the same time. Specifically, first, collecting stormwater requires a large space, and in a public space where the area is limited, making use of vertical space to ensure the desired volume is common, which will result in spatial height difference. As for the problems brought by the spatial height difference, firstly, the height difference will result in the division of space, a negative influence on the continuity of the landscape effect, and low useability. Secondly, the potential falling risk to visitors caused by the change of site height needed to be paid attention to as well.

Second, the collected stormwater will cause issues in the safety of the water quality of the site. If the site's rainwater harvesting facility is in the form of a lake or pond, the water contains a constant level of water by collecting rainwater that is unsanitary and unsuitable for visitor interaction. And the potential problem also comes from sudden rainstorms when the public space will function as a rainwater detention facility. When the rainwater starts to flow into the site, it is also a concern whether the visitors inside the site can be safely evacuated timely.

5.2.1. Strategies for reducing the risk of falling

To eliminate the safety risk of falling from a height, attention must be paid to vertical design. When there is a large height difference in the vertical direction, it is appropriate to divide the site into different vertical height levels, rather than simply two levels. In Historic Fourth Ward Park, the site has a large height difference, but the whole site is divided into multiple layers by plants and different landscape nodes. The scale of Yangpu rain garden is small, and the grass slope is used for preventing tourists from falling vertically. Besides, in addition to installing handrails on the waterfront trail, gently sloping berms along the waterway and large plants were used at the water's edge to eliminate the risk of visitors falling into the pool, creating better ecological and aesthetic values at same time.

Figure.9. The whole Historic Fourth Ward Park is divided into multiple layers by plants and different landscape nodes (Source: Atlanta Beltline)

5.2.2. Connecting different horizontal height spaces in a flexible way

Regarding the method of creating vertical height differences in space, the use of steps to form a sunken plaza to connect two areas of different heights is common, but not the only method. This method can be applied to smaller scale public spaces, such as Water Square in Rotterdam, where the sunken plaza is designed to collect rainwater and the height difference is dissipated by steps. However, for spaces with large height differences, using only steps to connect spaces of different heights will undoubtedly make the spatial experience boring and not conducive to visitor use.

And the approach in both two cases in the study is to gently connect areas of different heights through ramps, steps, or slopes. The corresponding landscape space is designed according to the respective characteristics of ramps and steps, to increase the attractiveness of the landscape.

In Historic Fourth Ward Park, ramps and steps are used alternately in the route design. The characteristics of ramps and steps are utilized to form pleasant landscape nodes. For example, the path to the central theater is formed by axis-symmetrical steps, so that the steps could serve as viewing places. The form of steps also reinforces the theater as a focal point on the axis(Fig.10). Besides, the pathway on the southeast side of the park, which connects the highest level of the road and the waterfront space, is also formed by steps, a step-down, river stone-lined drainage channel alongside a curving staircase with a 35-foot elevation change [15]. The entrance on the south side connecting the external road is designed as a gentle ramp, forming a viewing platform on the side near the lake. The gentle elevation is also utilized to channel water creatively so that on rainy days. This south plaza channel artfully collects and conveys storm runoff to the lake through an ephemeral drainage feature(Fig.11), which also pays tribute to the original Clear Creek that once flowed through the site.

Figure.10. The path to the central theater is formed by axis-symmetrical steps[23)]

Figure.11. The gentle elevationto channel water creatively so that on rainy days of the south plaza[23)]

In the case of Yangpu Rain Garden, the overall topography of the site is high in the south and low in the north, with the southern portion connected to the natural lawn of the waterfront space. In keeping with the natural and wild style of the entire waterfront space, the access to the site from the south is designed as a curved lawn slope that extends into the interior of the rain garden. The central area is connected to the space by a steel bridge. The steel bridge has varying horizontal heights with a sunken step that forms a platform for visitors to view the wetlands up close and a resting node for such a linear route.

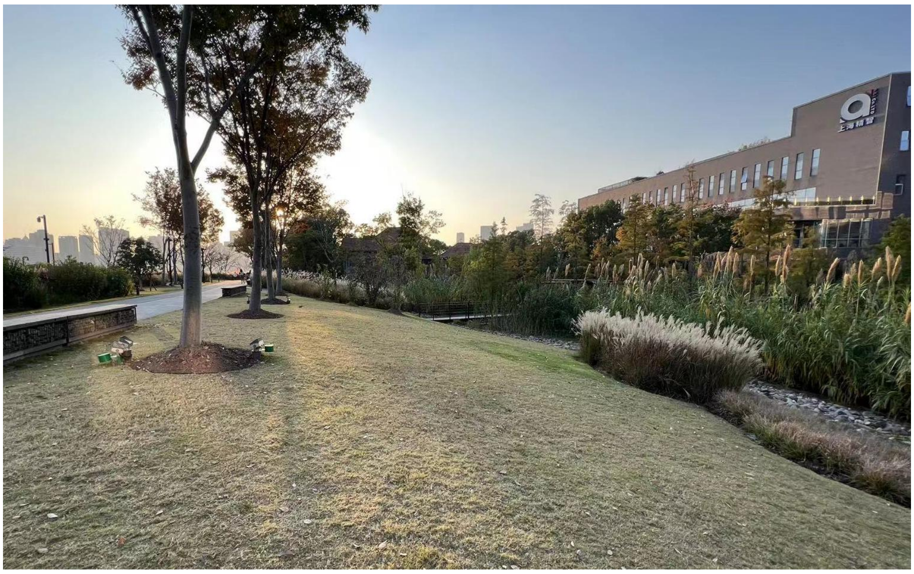

Figure.12. The greenery slope of Yangpu Waterfront Rainwater Garden
(Source: Author)

5.2.3. Strategies for making good use of the vertical difference to improve landscape values

In addition to the various ways of connecting spaces of different heights, these two parks show good examples of making full use of height differences that have been created on the site. Since height differences have been created, how to turn them into a pleasant public landscape is a new concern.

One of the design strategies is using plants to form a layered botanical landscape or wall greenery in the vertical design. For example, in Historic Fourth Ward Park, the use of vertical greenery can be seen almost everywhere as wall greenery or terrain planters to offset the oppressive feeling that high walls can bring. And in Yangpu rain garden, a large number of wetland plants were designed on the grassy slope, to improve the landscape effect of the park. A layered landscape of flat grassy slopes, towering plants, a flat wetland, and a steel bridge was formed.

Another design strategy is to make use of the height difference to design water treatment facilities. Specifically, Historic Fourth Ward Park uses the height difference to create a wall-mounted waterfall, which is designed to raise the water in the pool and then cascade down the wall. Not only a dynamic water feature could be created, but also the aeration of the water in the pool could be increased and the circulation of water in the site could be promoted.

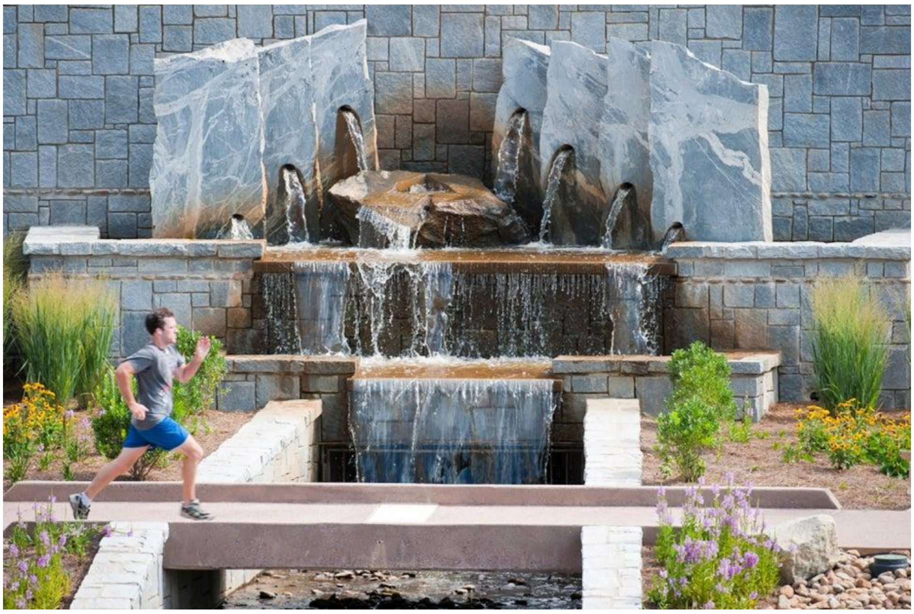

Figure.13. The wall-mounted waterfall[23)]

5.2.4. Strategies for tackling water quality problems

When the facilities used to store rainwater in public places are unnatural bodies of water, the permanent water level of the water body is usually maintained by the collected rainwater. As in the two cases in this thesis, the water in the central lake at Historic Fourth Ward Park or the wetland park of Yangpu is from collected rainwater. Rainwater contains pollutants and does not flow like natural water bodies, making water quality safety an issue.

Design strategies to address this issue are enhancing the site's stormwater purification design and promoting stormwater flowing and aeration in the pond.

In the two case studies, the purification strategy is to use wetland plants that can break down pollutants in and around the water. And stone grass slopes are designed along the stormwater collection path to filter impurities from the stormwater. For example, the grass slope in Yangpu rain garden not only provides a resting place on sunny days but also has the same function of filtering impurities in stormwater as a grass swale on rainy days.

In Historic Fourth Ward Park water aeration facilities and fountains have been installed in the pond to promote water exposure to oxygen, increasing water circulation and adding vitality to the space that can add to the visitor's experience in the public space.

Figure.14-15. The wetland of Yangpu rain garden is surrounded by a dense planting of reeds and firs, forming a natural fence (Source: Author)

Figure.16. The wetland plant and water aeration facilities used in Historic Fourth Ward Park[23)]

In both cases, the purification strategy is using wetland plants to break down water pollutants. Stony grass slopes are designed along the stormwater collection path to filter impurities from stormwater. For example, the grass slope in Yangpu rain gardennot only provides a resting place for visitors on sunny days but also has the function of filtering impurities in stormwater as a grass swale on rainy days. In Historic Fourth Ward Park, water aeration facilities and fountains have been installed in the pond to promote water exposure to oxygen, increasing water circulation, and adding vitality to the space as well, which is good for providing the visitor with more experience in the public space.

5.2.5. Strategies for ensuring visitors' security on rainy days

When a sudden rainstorm comes, the site will function as a rainwater storage facility, and rainwater runoff flowing into the site will pose a safety hazard to people still inside the site. The lesson from the two case studies is to simulate and calculate the change in the water level of the site under different rainfall recurrence periods, then design the vertical level of the site according to the change in water level.

Furthermore, design multiple traffic flows including safe escape routes. For example, in Historic Fourth Ward Park, the site is vertically designed into four major levels based on the calculated simulated water level in rainfall events at different return periods. The first level is the water surface, the second level is the part that includes the waterfront walkway and the observation deck along the lake. The third level includes some plazas and roads, the highest level is the original road and entrance plaza that surrounds the entire site. The second level is designed with some water-resistant materials and wetland plants, because of the high possibility of water immersion. The fourth level will not be submerged in rainwater even in 100-year precipitation, so people can stay safely in the highest level on rainy days. The connectivity of the route inside the site also ensures that even the first layer of visitors can quickly reach the highest layer through the route in case of unexpected rainfall. In Yangpu Rain Garden, the entire space is divided into three levels: the exterior road, the landscape steel bridge, and the wetland. The bridge is a good design to connect these three spaces, and the water level is estimated and designed not to overflow over the bridge.

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