ASSESSMENT OF THE CHALLENGES AND OPPORTUNITIES OF URBAN STORMWATER MANAGING INITIATIVES

LWS 548 Major Project

By

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Executive Summary

Climate change and urban development have overwhelmed the original urban water system in many places. The resulting series of runoff pollution, flooding, urban waterlogging and other problems threaten the health of the city and people's lives. In order to improve urban resilience, restore ecology, and promote livability, cities have embraced the concept of low impact design (LID) and are merging traditional and environmentally beneficial approaches to minimize these impacts. In this study, the rainwater management approaches developed by the city of Vancouver in Canada and Wuhan in China, were compared.

The strength and weaknesses of the strategies of the two cities were reviewed and compared using available literature, reports and government plans. The technological approaches for rainwater management were found to be similar except for the additional problem of river flooding that is an additional constraint in Wuhan. The main differences between the two approached were found to be in government policies, financial support and decision-making process. Wuhan's approach is more ambitious, focuses on a top-down approach and has more financial support, while Vancouver's approach is taking much longer to develop because of extensive community consultation and phased financial support. Both approaches have advantages and disadvantages but have the same ultimate aims.. Furthermore, several recommendations are provided to the city's policymakers.

Introduction

Due to global climate change and rapid urbanization, prominent issues such as stormwater runoff pollution, floods, and waterlogging are increasing in many cities. Rapid urbanization is transforming the landscape and changing the hydrological processes (Li et al., 2106; Udas-Mankikar et al.). The conversion of natural vegetated surfaces to impermeable surfaces is generally thought to cause that is changing in the natural water cycles and this is resulting in increased runoff volume and flood risk (Ahiablame et al., 2016). In the past 20 years, experts and scholars from various countries have put forward new urban rainwater management methods to alleviate the problems of flooding (Shao et al., 2016, Xia et al.,2017;). To address the combined issue of increasing rainfall events and more impervious surfaces, the focus of urban planners has shifted from simple drainage and engineering-only solutions to combining engineering with natural-based solutions (City of Vancouver, 2019a; Erik, 2009).

Recently, many cities have actively promoted the management and utilization of rainwater resources (City of Vancouver, 2019; Wuhan Municipality, 2016). Among them, the city of Wuhan in China began to implement the Sponge Cities policy as a sustainable stormwater management approach in 2016. Vancouver in Canada also formally proposed the Rain City Strategy at the end of 2019. These two initiatives aim to solve a series of stormwater-related problems and try to use green infrastructures and other means to make cities manage and absorb rainwater like sponges (City of Vancouver, 2019; Wuhan Municipality, 2016). Wuhan selected two demonstration zones that are comparable to Vancouver in terms of size, population, and current rainwater problems (City of Vancouver, 2019; Wuhan Municipality, 2016). Although some scholars have studied the two initiatives' challenges and opportunities separately (Bethune, 2015, Xia et al., 2017), few studies have compared the similarities and differences between the two initiatives in detail and analyzed their pros and cons. Therefore, comparing their comprehensive urban rainwater management policies with similar starting times is critical and meaningful. Udas-Mankikar et al. (2021) compared the key initiatives of some cities, including Vancouver and Wuhan, but briefly compared the scale, agency and intent aspects, and the target of the analysis is India. The aim of this study is to show what can be learnt from each approach, determine what component of the strategy is transferable and what adaptation method might not be appropriate due to differences in climatic and site conditions and established infrastructure. This article focuses on Wuhan and Vancouver and is dedicated to providing references for decision-makers in the two cities.

Objective

- Provide an assessment of two approaches from goals, technologies applications, policies, governance and finance.
- Explore the opportunities and obstacles of urban stormwater management, mitigate urban heat island effect;
- Make recommendations for both city planners, and provide references for other cities.

Method

This study is developed through relevant literature reviews and analysis of government reports. Based on the guideline and construction standards from each municipal planning and design department, the following discussion compares their similarities and differences and analyzes their strengths and limitations. The analytical framework consists of criteria in terms of goals, technology application, governance, finance, and policy.

The section of goals provides an overview of specific and measurable targets that each city wishes to achieve within a certain time. Both of the official initiative reports of the governments clearly defined their goals in the most important position at the beginning. Comparing goals can intuitively see the difficulty and scale of different plans (Wuhan Municipality, 2016; city of Vancouver, 2019a). Technology application includes the understanding of green infrastructures by different initiatives, the selection and number of technologies in projects (Li et al., 2016). Governance refers to how governments at all levels manage, act and cooperate with each other in the process of formulating policies and implementing the plan (Dai et al., 2018). Finance is a term for analyzing funding amount, source and allocation to support the green infrastructure implementation (Li et al., 2016). Finance is also an essential consideration in considering whether green infrastructure can be upgraded because the cost of projects such as pipeline separation and constructed wetlands is relatively high and requires a large amount of capital investment from the government and project executors (Ma, 2016; Udas-Mankikar, 2021). The policy section discusses how the government and executive departments plan for their respective goals, including a decision-making framework. The policy can evaluate different cities in terms of management and project implementation. Different government management methods and policy-making frameworks can greatly affect the efficiency of a project (Dai et al., 2018; Udas-Mankikar, 2021). These criteria are also frequently used in other relevant literature (Dai et al., 2018; Peng & Reilly, 2021; Udas-Mankikar, 2021).

In addition to an overview of the two policies, representative projects were selected from each city to show how green infrastructure may be used in various situations with different requirements and technical constraints. The findings are synthesized, followed by a discussion section of rationales leading to the result.

The Rain City Strategy – the City of Vancouver

For many years, Vancouver has been plagued by urban rainstorms and pollution from combined sewer overflow (CSO) (City of Vancouver, 2019a). Most of the sewer water in Vancouver only provides primary and secondary treatment (City of Vancouver, 2019a). At the same time, due to its geographic location, Vancouver is experiencing sea level rise and urban heat island effect caused by climate change and emissions from transportation (City of Vancouver, 2019a). In order to cope with these problems, Vancouver has proposed a series of development plans and policies related to rainwater management and proposed the Rain City Strategy in 2019. In the Rain City Strategy, the three main goals are to 1) improve and protect water quality, 2) increase resilience and 3) enhance livability. In order to achieve these three goals, six objectives are proposed (City of Vancouver, 2019a):

- Remove pollutants from water and air;
- Minimize effect of impermeable surfaces
- Reduce volume of rainwater entering the pipe system;
- Harvest and reuse water;
- Mitigate urban heat island effect;
- Increase total green area.

The Vancouver city government plans is to focus on two categories of projects, one is CSO-related retrofitting, and the other is to promote the construction of green rainwater infrastructure (GRI) (City of Vancouver, 2019a).

Climate of Vancouver

Vancouver is located on the west coast of the American continent and has an annual rainfall of 1200 to 1600mm. It covers an area of 114 km^2 and has a population of approximately 670,000 (City of Vancouver, 2019a). Vancouver has a temperate marine climate and is affected by prevailing westerly winds. Vancouver has modest temperature fluctuations and substantial rainfall throughout the year because of the warm North Pacific current pushed in by the prevailing westerly winds (Klock & Mullock, 2001). 70% of rain volume are light showers with less than 24mm, and 10% are extreme storms with greater than 48mm of precipitation The Pacific hurricane is the primary cause of the precipitation in Vancouver. Precipitation in Vancouver is mainly concentrated in winter from October to January (Klock & Mullock, 2001). During rainy seasons, the average temperature is between 2 and 10 degrees Celsius (City of Vancouver, 2019a).

Combined Sewer Overflow Systems (CSO) in Vancouver

Most of the Vancouver drainage system was designed and constructed in 19th century, facing serious ageing and inappropriate design problems (City of Vancouver, 2019a). At present, the combined pipes system that deals with rainwater and sewage together accounts for about 46% of the total of sewage and drainage system in Vancouver (Figure 1). The mixed pipe system will cause overflow that contain both storm water and polluted waste water into nearby watershed, which is also known as combined sewer overflow (CSO) (Phillips et al., 2012). The primarily problem in Vancouver is pollution from combined sewer overflow during storm event that impacts aquatic live and deteriorates water quality. According to the report released by the city of Vancouver (2019), nearly 33 billion litres of combined sewage were dumped from Vancouver's drainage system annually (City of Vancouver, 2019a). Therefore, the plan proposes to separate the remaining combined sewer system in the entire city by 2050 and treat sewage and rainwater separately to enhance the city's ability to adapt to heavy rains and achieve sustainable development of rainwater resources (City of Vancouver, 2019a).

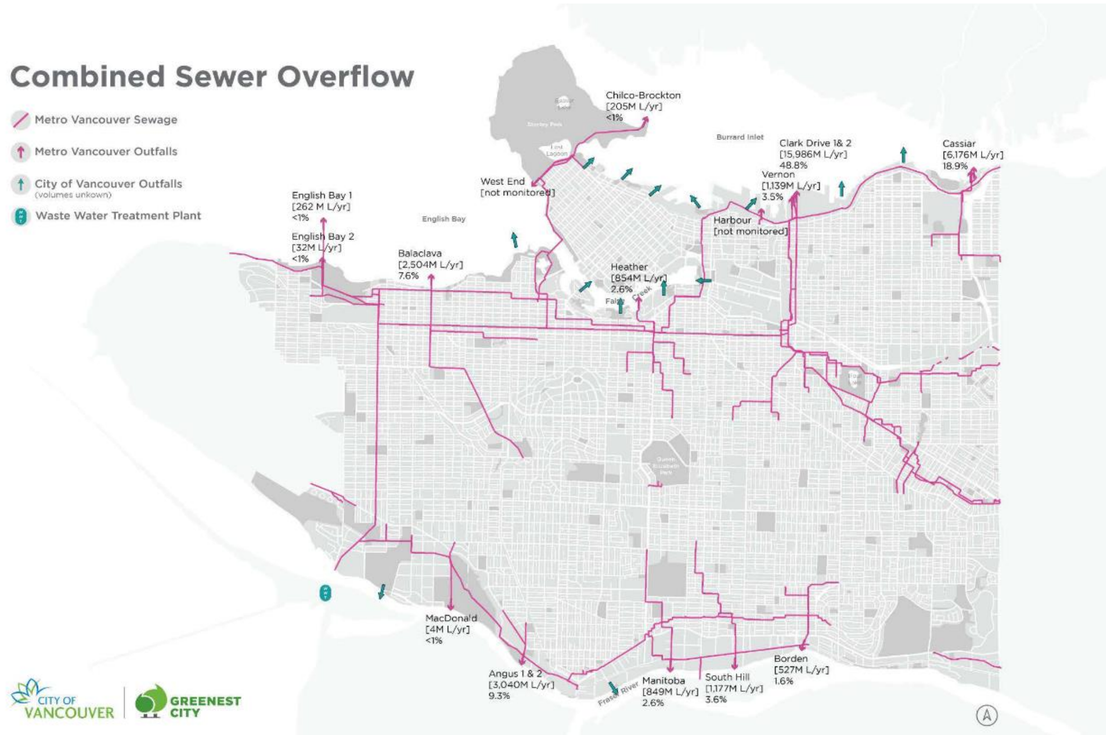

Figure 1 Combined Sewer Overflow in Vancouver (City of Vancouver, 2019a)

Green Rainwater Infrastructure (GRI) in Vancouver

According to the action plan of rainwater management in Vancouver's 19 watersheds corresponding to the four surrounding receiving waters, there are currently 238 GRI systems in Vancouver's roads and public areas, including bioretention practices; Permeable pavement areas; Subsurface infiltration trenches; Rainwater tree trenches and constructed wetlands. Bioretention systems are the most common, accounting for 59 percent of GRI assets in public spaces. Subsurface infiltration trenches and permeable pavement area each took up around a fifth of the total GRI (City of Vancouver, 2019a).

Case study in Vancouver- Olympic Village project

The Vancouver Olympic Village is located in Vancouver's southeast corner of False Creek. It was built to host the Winter Olympics in 2010. The Olympic Village was formerly a derelict industrial district in Vancouver. It became a typical sustainable community project in Vancouver and achieved the LEED Platinum Award as a result of the innovative design of green rainwater infrastructure (Bayley, R, 2014). Rainwater management in the Olympic Village has been challenging by the abundance of rainwater, runoff pollution, as well as limited land spaces. In the design process, the designer changed the previous practice of transporting rainwater through underground pipes. Through the strategy of collecting clean rainwater and polluted rainwater separately, it has been successful in managing rainwater in an efficient and environmentally friendly manner. The specific method is to transfer the dirty rainwater collected on the road surface to the artificial wetland, tree trenches and bioswale for purification before it returns to the False Creek or infiltrates into the soil. The rainwater collected on the green and blue roofs of the building is stored in a storage tank for domestic water use (Bayley, R, 2014).

This is an ingenious case showing how Vancouver urban planners are using advanced concepts of green infrastructure to manage urban rainwater. Before the Rain city strategy, Vancouver had begun to transform and construct the city through green methods, while ensuring that the project maximized public engagement. This project has a certain educational and demonstration significance. However, in recent years, the construction of such excellent cases in Vancouver has not been very fast (City of Vancouver, 2019a).

Sponge City Initiative – Wuhan Demonstration Project

Sponge city is a stormwater management initiative in Wuhan which uses mimicked processes of the natural water cycle. It was initiated by the Ministry of Housing and Urban-Rural Development in 2014. China launched the construction of the sponge city initiative in 2014. This project seeks to mitigate flooding, contamination and water scarcity issues (Li et al., 2016). The central government chose 30 pilot cities and provided them with annual financial support ranging from 400 to 600 million RMB (CAD 100 to 150 million) (The Ministry of Housing and Urban-Rural Development, 2014). Wuhan was successfully selected into the list of 30 cities (Shao, 2020).

Wuhan launched the sponge city demonstration projects and released the "Wuhan Sponge City Pilot Implementation Plan" in 2016. For sponge demonstration projects, a "2+N" mode was allocated to create 38.5km2 of sponge-like regions (Wuhan Municipality, 2016). The "2+N" paradigm refers to the two demonstration areas of Qingshan and Sixin, as well as 288 pilot projects focusing on old town retrofitting and new city development (Wuhan Municipality, 2016).

Climate of Wuhan

Figure 2 Wuhan's location and climate (Ali et al., 2018)

Wuhan, known as the "city of a hundred lakes", is located in interior China. The water system includes 165 rivers, 166 lakes, and hundreds of reservoirs with Yangtze River, one of the biggest rivers in the world across the city. (Peng & Reilly, 2021). Wuhan's built-up area is in a low-lying area, and receives 1257mm of annual precipitation (Wuhan Planning and Design Institute, 2016). The Yangtze River's flood season coincides with the rainy season, causing a high risk of flooding events (Peng & Reilly, 2021).

As it is shown in figure2, Wuhan has a subtropical monsoon climate with frigid winters and scorching summers, as well as substantial temperature variations throughout the year. Summer precipitation accounts for around 50 percent to 60 percent of annual rainfall from May to August (Wuhan Municipality, 2016). Due to the influence of the monsoon climate, the rainstorm in Wuhan is more than that in Vancouver. Also, the temperature is higher during the rainy season. In July, when it rains the most, the average temperature is 29.3 degrees Celsius. The main cause of heavy rains is the southeast monsoon from the Pacific Ocean (Wuhan Municipality, 2016).

Qingshan Demonstration area

The Qingshan Demonstration Zone is 23 km^2 large, bordered on the north by the Yangtze River and on the south by the East Lake. 280,000 people are expected to live there (Wuhan Municipality, 2016). Current drainage pipeline construction standards in this area are substandard, and are at high-risk area by urban flooding. The drainage pipes are severely degraded and disjointed. Many canals have polluted water with inferior water quality, so-called black and odorous water in Wuhan's sponge city guideline (Wuhan Municipality, 2016). The term “black and odorous water” in China is judged by 4 indicators, including transparency, dissolved oxygen (DO), redox potential (ORP) and ammonia nitrogen (NH3-N) (The Ministry of Housing and Urban-Rural Development, 2014). The indicators are listed below as table 1.

Indicators	‘Black and odorous’
Transparency (cm)	< 25
dissolved oxygen (DO) (mg/L)	< 2
Redox potential (ORP) (mV)	< 50
Ammonia nitrogen (NH3-N) (mg/L)	> 8

Table 1 Indicators of water quality for the term black and odorous water in China (adapted from Ma, 2019)

As a historic urban build-up area, the old city and old factories make up nearly half of the area. Therefore, the impervious area of Qingshan District is relatively high, at 80%. Qingshan Demonstration Area currently has 50% combined sewer with many CSO events (Wuhan municipality, 2016). It is planned to retrofit old industrial districts, shanty towns, and old residential neighborhoods with a combination of GRI and traditional engineering methods in batches in order to complete the renovation and transformation of regional cities (Wuhan Municipality, 2016).

Sixin Demonstration area

Sixin Demonstration Zone is a new city construction region in Wuhan and it is one of the three major urban sub-centers in the city. It covers around 15.5 square kilometres and is expected to have a population of 200,000 people. The rainwater drainage pipes and sewage pipes in the Sixin demonstration area are entirely separated. Based on GIS analysis, the current permeable surface area of the Sixin District is 35%. Infrastructure such as urban roadways, greening, and drainage have mostly been established.

At the same time, the area has a solid research base for non-point source pollution control, and the spatial distribution of pipes and canal systems is well-balanced. As a consequence, it is relatively easy to set up low-impact development rainwater systems, which will improve the management of water and pollution.

Case study 1 in Wuhan-Gangcheng No. 2 Middle School project

Gangcheng No. 2 Middle School is located in the Qingshan Demonstration Zone. The school is a regional low point and is situated in the catchment area. There are pollution problems such as CSO and initial rainwater runoff pollution. It is necessary to intercept point source pollution and reduce non-point source pollution. When it rains, rainwater from nearby towns and highways comes back into the school area via surface runoff, causing major waterlogging problems at the school, with a waterlogging depth of more than 1 meter. Furthermore, the water quality in the surface water canals surrounding the school far exceeds the standard, the water body and is described as black and stinky, and the school's landscape design is unsuitable (Wuhan Municipality, 2016). In essence, the Gangcheng No. 2 Middle School sponge project aims to achieve the following four objectives: Reduce pollutants, eliminate waterlogging, recycle rainwater, and improve landscape quality.

In response to these requirements, the project selected rainwater gardens, depressed green areas, interception and storage tanks, and other methods, as well as a hybrid of grey and green infrastructure for transformation. Facilities such as intercepting ditches were added to the periphery of Gangcheng No. 2 Middle School to solve the problem of external water entering the campus, and rainwater retention and infiltration facilities such as ecological dry creeks were built along the fence to effectively block and reduce the surrounding rainwater runoff. Excess rainwater is collected in the storage tank on campus and then pumped into the municipal drainage system (Wuhan Municipality, 2016).

Case study 2 in Wuhan Qingshangang Wetland project

The river channel in Qingshangang was clogged with silt and trash, reducing drainage capacity and water mobility. The sewage outlets were immediately released into the water body, resulting in severe pollution and eutrophication of the channel. The deterioration of the aquatic environment resulted in a significant loss of species. The open space around the region had been converted into shanties towns and vegetable farmlands, resulting in severely poor landscape quality. As a result, this sponge rehabilitation project intended to improve drainage capacity while also improving the area's biological environment and creating a linked public recreational park (Wuhan Municipality, 2016).

To address these issues, the project constructed a wetland that will serve as an ecological pollution treatment facility. Numerous sponge facilities, such as grass swales rainfall gardens, infiltration pavement, and rainwater storage modules, were also installed in the project area. Figure 3 shows the positive changes brought about by the implementation of this project. The sewage water is released through sponge facilities rather than going directly into the water bodies. The water quality reached the standard , and the drainage capacity of the watershed was considerably enhanced, thanks to several sponge methods (Wuhan Municipality, 2016).

figure 3 Photos from the same place in Qingshangang before and after the wetland project (Wuhan Municipality, 2018)

These two case studies demonstrated Wuhan's distinct implementation status and how to develop plans to address the city's complex polluted water bodies and potential waterlogging issues. At the same time, in order to enhance the public recognition a, Wuhan and Vancouver have kept as much green on the ground as possible and set up public access, so that these facilities can function when it rains and also serve as people's leisure and entertainment areas when it is not raining.

Summary of information of two cities

	City of Vancouver	Wuhan Demonstration Area
Area	114 km^2	38.5 km^2
Population	670,000	480,000
precipitation	1200-1600 mm	1257 mm
Planning period	2019-2050	2016-2030
Number of planned projects	63	228
Sewer treatment level	Mainly primary treatment	Mainly secondary treatment
CSO	46% combined sewer	30% combined sewer
Flooding risk	medium	High
Black and Odorous water	low	High
Current % of impervious area	49%	74 %

Table 2 Summary of general information and current situation of Vancouver and Wuhan Demonstration Area

Table 2 summarizes the basic information and current status of the Vancouver and Wuhan demonstration areas. Some of the data, such as CSO and impervious area ratio, are obtained by the weighted average of the two districts. Through comparison, it can be found that the area, population, and annual precipitation of the two cities are roughly similar. The rainfall in Wuhan is more concentrated in summer, and the rainfall intensity is higher and coincides with the flood season of the Yangtze River. Coupled with the relatively low-lying altitude and certain pipe network problems, the risk of flooding is higher.

The impervious area of the Wuhan demonstration zone is much higher than that of Vancouver. The water quality problem in the demonstration area seriously exceeds the standard, and some water bodies are black and odorous. It affects the basic living conditions of the surrounding residents. Unlike Vancouver's advanced goal of building a global livable city and improving urban resilience, the construction of sponge city concept in Wuhan is solving the problems of waterlogging and water quality in the region. Wuhan has a shorter construction period and more projects than Vancouver.

Sewage in Vancouver mainly conducts primary treatment at the Iona water treatment plant, which uses physical methods to remove sediment and solids in the water. Part of the wastewater will undergo secondary treatment in the Annacis water treatment plant. On the basis of the primary treatment, secondary treatment removes organic pollutants in the sewage through biological and chemical methods (City of Vancouver, 2019a). The sewage plants in the Wuhan Demonstration Zone are secondary treatments (Wuhan Municipality, 2016).

At present, there is no less than 600km of combined sewer in Vancouver. As of 2020, combined sewer accounts for about 46% of the 1,315km of the total pipeline network. In Wuhan, there is about 432km of pipeline that are not separated, and the combined pipeline network in the demonstration area accounts for about 30% of the total pipeline.

Technology

Technological targets & applications	City of Vancouver	Qingshan, Wuhan	Sixin, Wuhan
Planning period	2019-2050	2016-2030	2016-2030
Capture rainfall standard	48 mm	29.2 mm	43.3 mm
% of annual rainfall management	90%	75%	85%
% of impervious area that managing rainfall	40%	80%	80%
Sewer treatment upgrade plan	Upgrade to secondary treatment by 2030	100% secondary treatment	100% secondary treatment
Combined sewer separation	100% separated	90% separated	100% separated
Current & target impervious area	49% to 39%	80% to 50%	75% to 40%
Rainwater management concept	GRI	LID	LID
Major GRI/LID facilities	Bioretention; Subsurface Infiltration Tree trenches Engineered wetland Green roof Permeable pavement	Bioretention Depressed green Permeable pavement Constructed wetland Green roof Rainwater storage module	

Table 3 Comparison of technologies and objectives of rainwater management policies in Wuhan Demonstration Area and Vancouver

Technological targets

Table 3 compares the similarities and differences in technical targets and applications of the two rainwater management policies by summarizing and analyzing several municipal government reports. Rain City Strategy suggests that by 2050, the average annual rainfall will be managed to a design standard of 48 mm on 40 percent of Vancouver's impervious surfaces (City of Vancouver, 2019a). Vancouver intends to upgrade the Iona sewage treatment facility by 2030, allowing sewer water from the city to take secondary treatment. At the same time, Vancouver plan is to complete the CSO retrofit and separate the combined drainage and sewage pipe network before 2050 to eliminate the CSO problem (City of Vancouver, 2019a, 2019b).

Qingshan Demonstration Zone and Sixin Demonstration Zone have an overall volume capture ratio of the annual rainfall of 75% and 85%, respectively, corresponding to 29.2mm and 43.3mm rainfall (Wuhan Municipality, 2016). By 2030, the technical target will cover 80% of the impervious area in the region. Considering the difficulty of the rain and sewage diversion transformation of the old city reconstruction, the sponge cities plan requires the Qingshan Demonstration Area to achieve 90% of the rain and sewage pipeline separation. As the impervious area rates of the two areas are very high, the Wuhan Municipal Government requires the impervious area rates of Qingshan and Sixin to be reduced to 50% and 40%, separately (Wuhan Municipality, 2016).

LID and GRI

When comparing the two policies, Wuhan's sponge city policy emphasizes Low impact development (LID) (Dietz, 2007). The establishment of a LID rainwater system is repeatedly mentioned in the Wuhan City Sponge City Construction Guidelines., GRI is the word used in the Rain City Strategy of Vancouver. GRI is a word that has been revised in the City of Vancouver's Rain City Strategy from Green infrastructure (GI) used in the Rainwater Management Plan 2016 (IRMP). The term GRI is rarely mentioned in other cities' rainwater management initiatives. The synonymous term that can be used with GRI interchangeably is green stormwater infrastructure (GSI) (McPhillips & Matsler, 2018).

Some scholars believe that LID, GSI/GRI, and GI are the same and can be substituted for each other (Jin, 2016). These terms are roughly identical, but they reflect various technical systems and have differences in application scales, technical measures, and control objectives. The Maryland Department of Environmental Resources in

Georgia, USA, first introduced the LID concept in 1990 (Prince George's County, 1991). LID is used to control the source of stormwater, primarily through the use decentralized small-scale techniques. The core concept is to adopt appropriate site development approaches to mimic natural hydrological conditions and to take extensive precautions to minimize substantial changes in hydrological conditions and rainwater runoff caused by development (Dietz, 2007; Li et al., 2016). GI focuses on protecting and utilizing green spaces and corridors in urban planning, which will provide the city with more ecological and environmental benefits. Since then, with the increasing experience and knowledge of rainwater management, the US EPA outlined green stormwater infrastructure (GSI) for urban rainwater management in 2012 (Peng & Reilly, 2021). GSI primarily refers to engineering and technical measures that use soil and vegetation in the natural ecosystem to comprehensively control rainwater runoff, such as green roofs, rainwater gardens, and rainwater wetland, etc. which covers traditional and typical low-impact development (LID) technologies (Wuhan Municipality, 2016).

Green infrastructure, in a broader sense, can be defined as a network of natural areas and ecosystems in cities that can function as air purification, reducing heat island effects, increasing biological habitats, and also improving biodiversity. LID is an essential aspect of GI, which has increasingly expanded into an umbrella term.

Major GRI/LID facilities

Table 3 highlights the key rainwater management infrastructure by comparing the current GRI/LID projects and the action plans of the two initiatives. From the point of view of actual engineering applications, the technologies applied in the two cities are basically the same. They both use massive bioretention facilities, green roofs, permeable paving, and wetlands. Roof greening is appropriate for newly constructed regions. Green roof, according to the sponge city of Wuhan, is recognized as one of the main measures of low-impact development. Green roofs will be used on at least 20% of the rooftops of the neighborhoods in the demonstration area (Wuhan Planning and

Design Institute, 2015).

The distinction is that while tree trenches have been utilized in projects such as the Olympic Village in Vancouver, they were not employed in the Wuhan demonstration area, possibly due to the weather or the short project duration. A large number of rainwater storage facilities are implemented in the establishment of the sponge city in Wuhan (Wuhan Planning and Design Institute, 2015). Although Vancouver also used rainwater storage, its percentage is smaller than Wuhan's. This might be because of Wuhan's high risk of waterlogging. Rainwater storage space can also play a role in mitigating floods, delaying peak flows, and increasing the rate of rainwater utilization.

Policy

Rain City Strategy planning in Vancouver has taken a long time, just like other plans in the city. The process of implementing Vancouver's rainwater management plan can be divided into three stages: Ask, Try, and Do (City of Vancouver, 2019a). The Ask phase is a consultation process that is typically carried out in the form of workshops. It provides a platform for consultation and exchanges for professionals, citizens, governments, and other stakeholders, effectively promoting the development of Rain City Strategies. Another benefit of the seminar is that it can increase stakeholder interest, assist in education and publicity, and pave the way for effective policy implementation. The second stage of Try is to practice and innovate new GRI solutions, conduct public consultations, and collect feedback (City of Vancouver, 2019a). The third stage is to make amendments based on the feedback and conduct the work camp discussion with stakeholders again. After the revised draft is formed, it will be submitted to the city council, and the policy will be approved and released to the public (City of Vancouver, 2019a).

China is a unitary country with a top-down government management system. The local government obeys the policy instruments and decisions made by the central government. When the central government initiated the sponge city program in 2014, the Wuhan municipal government responded actively. The municipal functional departments took several months to release the sponge city construction plan and report to the central government to receive supervision (The Ministry of Housing and Urban-Rural Development, 2014).

Governance

In Wuhan, local governments allocate their responsibilities into several departments and develop overall strategies during the policy formulation and implementation phase. In this process, more than 14 agencies such as the Water Affairs Bureau; Munipcal Planning Bureau; Munipcal Department of Environmental Protection and Pilot Project District Government are required to work together to complete the holistic management and implementation of the sponge city project (Dai, 2018).

In contrast, Vancouver has relatively few departments involved, requiring 6 to 7 departments, including the Vancouver Board of Parks and Recreation; Planning, Urban Design, and Sustainability Department; Development, Buildings, and Licensing Department, etc. (the city of Vancouver, 2019a). Since they all had independent functions and responsibilities, during the process of adapting the Rain City Strategy, these departments had a steep period to collaborating and developing trust with each other.

Finance

The total investment in the Wuhan Pilot Sponge Cities project from 2016 to 2019 was CAD $2055 million, as illustrated in Figures 4 and 5. Three-quarters of the money came to Qingshan District, while one-quarter given to the Sixin District (Wuhan Municipality, 2016). In terms of financing sources, the central government provided 15%

of the total investment, province and local governments contributed for 34%, and social capital accounted for the remaining half (Wuhan Municipality, 2016).

The City of Vancouver planned to invest CAD $70 million from the capital budget to support the GRI, according to the 2019-2022 capital plan (City of Vancouver, 2019a). In addition, Vancouver intends to spend a total of CAD $616 million in capital investment for potable water, sewage drainage, and GRI in the Water Program over the next four years (City of Vancouver, 2020a).

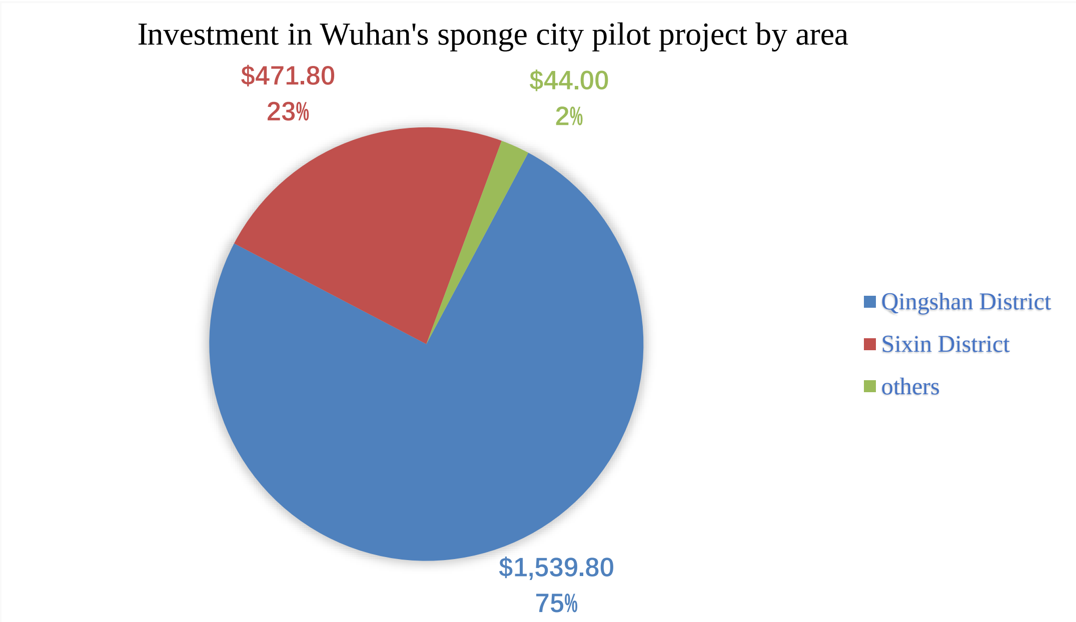

Figure 4 Investment in Wuhan's sponge city pilot project by area (adapted from Wuhan Municipality, 2016)

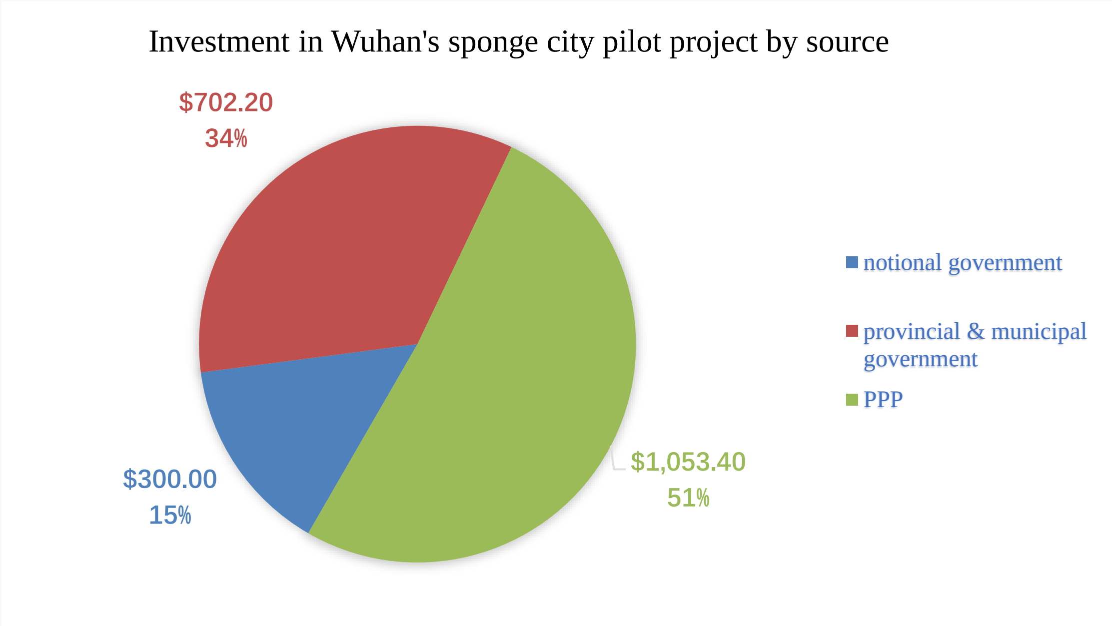

figure 5 Investment in Wuhan's sponge city pilot project by source (Wuhan Municipality, 2016)

The Ministry of Housing and Urban-Rural Development and the Ministry of Water Resources use an assessment index system to evaluate the behavior of sponge cities on a regular basis, and the ministry of finance provides funding depending on the results. Municipal governments were also encouraged to explore new ways to raise funds through Public-private partnership (PPP) (Wuhan Municipality, 2016). PPP is a type of collaboration in which the government and private sector work together to finish a project or offer services to the general public. It is based on a benefit-sharing and risk-sharing partnership that may successfully lower the project's overall cost. The government will pay a certain compensation of principal, interest and maintenance fee from fiscal revenue to the private sector for several years after the project is launched. It lessens the public sector's pressure to raise budgets and debt, allowing the public sector to develop more and greater infrastructure (Li et al., 2016; Li, 2019).

The construction of "sponge cities" in Wuhan encourages the adoption of the government-social capital partnership model. However, private investors may require a higher rate of return on investment as compensation for taking higher risks due to the discontinuity of government policies and too frequent changes. Due to the influence of numerous factors on the operating circumstances of infrastructure projects or the process of service provision, the project's profitability frequently falls short of the private partner's expectations, posing significant risks.

Discussion- Strength and limitation of two initiatives

Major differences between two initiatives		
	Vancouver	Wuhan
Climate	temperate marine;	subtropical monsoon
Dominant Storm Major flooding events Rainy season	Pacific Storms Mainly Surface runoff Winter during cold season (<10 ℃)	Southeast monsoon River flooding & Surface runoff In Summer with a hot weather (>25℃)
Topographic Setting	Sloping Terrain	Floodplain
Wastewater Treatment	Mainly Primary & Secondary	Insufficient treatment of Sewage and Industrial Effluent
Water Pollution Issues	Primarily Surface Runoff from Traffic & Combined Sewer Overflow (CSO)	Industrial & Sewage Effluent & Surface Runoff & CSO
CSO condition	46% of the sewer pipe is combined; >600km combined sewer	30% of the sewer pipe is combined; 400km combined sewer;
Primary Contaminants	Metals (Traffic) Hydrocarbons Some Nutrients & Pathogens (CSO)	Metals (Industry Sources) Sewage, Nutrients
Policy making process	Bottom up; many consultations with better stakeholder engagement longer processing time	Top down; Less consultation, only some stakeholders engaged; Shorter processing time

Governance	less departments involved; Proposed and managed by municipal government; More consultations, less effective	More department involved; Monitored and regulated by the central government; Less consultations, more effective
Financing	Mainly government capital; Limited and continuous investment: 3-year investment CAD $70 million	Government capital and PPP; Massive investment: 3-year investment CAD $2055 million
Short and long term planning & management	Focus on long term target in 2050; developing and managing GRI facilities in slower manner; Planning on selected areas	Urgent to solve short term problems; Ambitious to build Sponge city by 2030; Holistic planning on whole area

Table 4 Comparative summary of the differences between two initiatives

Table 4 summarized the major differences between Rain City Strategy and the Sponge City project. According to this study, Vancouver and Wuhan Sponge City Demonstration Zone are roughly the same in size. Both cities receive a significant amount of precipitation, concentrated in 4 to 5 months of the year. However, because Vancouver belongs to the temperate marine climate and Wuhan belongs to the subtropical monsoon climate, the rainfall in Vancouver is concentrated in the cold winter. In contrast, the rainfall in Wuhan is in the hot summer with more storms.

After the heavy rains, the Vancouver area was less affected by river flooding, and significant pollution incidents were caused primarily by surface runoffs and CSO. Wuhan is different. The Yangtze River runs through Wuhan, and the city is in a floodplain where many rivers come together. The Wuhan Sponge Municipal Demonstration Zone is threatened by both flooding from the Yangtze River and waterlogging within the city. Green roofs, permeable paving, depressed green spaces, and constructed wetland are among the LID facilities used to reduce urban surface runoff at the source and delay the peak of storm runoff by storing, controlling, and transferring precipitation. At the same time, by capturing and purifying rainwater, it effectively removes pollutants from rainfall discharge.

Due to the different political systems, the GIR approached are different. Vancouver's policymaking process involves stakeholder engagement and public participation by conducting many consultations and workshops. In contrast, China adopts a top-down decision-making mechanism, which is coordinated by the upper-level overall planning, and more efficient and takes less time. However, this causes a potential problem in that the public may not have a high degree of recognition of the project.

The Sponge City Pilot Area project in Wuhan is based on large-scale comprehensive planning of stormwater management issues in the reconstruction of old urban areas or newly built urban areas. The GRI project in Vancouver is more fragmented and smaller. The majority of land in China is owned by the government and can be planned in a cohesive way to quickly convert large-scale old shanty urban into the new residential area by demolishing and rebuilding houses. The City of Vancouver is located on the traditional, unceded and ancestral territories of the Musqueam, Salish and Tsleil-Waututh peoples. Part of the land is owned by first nations and private individuals. Therefore, Vancouver's rain city strategy can only be implemented in selected areas with limited funds and is slowly implemented through extensive consultation and negotiation with landowners and users. The overall planning strategy of the Sponge Cities can be implemented more effectively because the planning is initiated at the regional level. Therefore, Vancouver has set a long-term goal from now to 2050, hoping to gradually complete the upgrade of urban green infrastructure, while Wuhan hopes to achieve this by 2030

The construction of the sponge city in Wuhan is problem-oriented. In the short term, there are three urgent problems to be solved: waterlogging, treatment of black and odorous water bodies from sewers & industrial sources and flooding issues from the main river basins. Vancouver primarily has CSO and surface runoff pollutions. It also has self-proposed goals of enhancing livability and improving urban resilience. From the policy perspective, the approaches in both cities are still in a relatively early stage of development., Vancouver has completed a number of GRI construction projects and current finances are limited to improve rainwater management. However, given the rapid changes in the extreme climatic event, more rapid CSO conversion might be needed.

Recommendations and Conclusion

1. In terms of investment, in Wuhan's sponge city project investment comes from, 50% government and 50% PPP accounts, while Vancouver's investment mainly comes from the capital budget of the city government. Although the PPP model can solve the problem of start-up funds in a short period of time, due to the generally low rate of return on investment in green infrastructure projects, but the high cost of operation and maintenance of GRI will be problematic in the future.

   The regional large-scale green infrastructure design can systematically perform many ecological functions, If possible, urban planners should consider as much as possible that which areas in the entire watershed are vulnerable, which area need to build and update green infrastructure, if they can plan more as a whole, they can achieve the best results. However, it also brings high costs and puts greater pressure on government finances. In contrast, Vancouver's projects which takes place over longer timescales, are lower in cost, easier to complete, and have less impact on local finances.

   Financial strategies such as PPP can still be considered for Vancouver if the government's investment budget is limited. However, the current green infrastructure PPP projects still face problems because benefits are long term and operation and maintenance are underestimated

2. In terms of technical application, both Wuhan and Vancouver chose their own green rainwater infrastructure according to local conditions. Despite the fact that the concepts of rainwater management are different, they have developed slightly different action plans. For rainwater management, there are few technical barriers and the costs for GRI systems are usually lower than the traditional engineering solutions. The most critical thing for government departments is to follow through with plans in a timely manner and improving the collaborative actions between departments.

3. As for the policy, Wuhan's policy instruments are more efficient and require less public input and collaboration. However, it lacks public engagement and is easily misunderstood. Vancouver's policy design considers the interests of various stakeholders and listens to public feedback. This makes it easier to get public support and allows public participation in the maintenance of GRI systems. Building rapid green infrastructure might have significant drawbacks. For example, when a large area of infrastructure is built using existing technical means, upgrading the technology is more challenging as new knowledge emerges. As a result, it may have limited capacity in responding to climate change and extreme weather. Due to the differences in the political systems in China and Canada, both systems have advantages and constraints but both can learn from each other.

4. In recent years, both cities have developed step-by-step timely plans to upgrade their municipal infrastructure. However, climate change is speeding up. In 2021, there were more extreme weather around the world. Zhengzhou, China, has experienced a heavy rainstorm once in more than a thousand years. The

precipitation in one hour reached 580 mm, which is almost equivalent to the annual rainfall of Zhengzhou City in previous years (Chik & Na, 2021). The United States and Germany was also hit by severe rainstorms. Therefore, city planners should consider accelerating the implementation of these initiatives to cope with climate change, provide pre-treatment and mitigate the risk.

In general, Vancouver is now dealing with CSO and non-point source pollution issues. It is currently taking a long-term and progressive approach to updating the urban green infrastructure due to a limited of funding, the nature of the land, and community participation. However, due to the quick pace of climate change, Vancouver may learn from Wuhan's financial model to expand the scale of the project and prevent potential damage from more extreme weather in the future

Wuhan is mostly affected by CSO, non-point source pollution, and flooding. Due to the numerous issues that exist in historical construction, a large sum of money is currently being invested in the hopes of quickly filling the city's inadequacies. However, it may result in issues such as excessively high expenditures in the future which hard for Wuhan to afford it, completed projects that are difficult to renew, and a lack of public recognition. Another key reason why the two cities are irreplaceable is the difference in their governance and policymaking frameworks. According to the conditions of different cities, planning the construction of green infrastructure as efficiently as possible is more beneficial to the watershed.

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Appendix 1:

Summary of planned GRI project in Vancouver by watershed and sub watershed. Result is discussed in the section of Green Rainwater Infrastructure (GRI).

Watershed	IRMP Opportunities	Future GRI	Major Planning Project
Burrard Inlet			
Downtown North	2	2	1
Major Planning Project	0	0	2
Hustings Sunrise	2	1	
China Creek	2	3	1
English Bay			
Point Grey	1	0	1
Balaclava	5	0	1
Kitsilano-South Granville	1	0	1
False Creek			
Downtown South	1	3	1
Terminal	3	0	3
Cambie- Heather	6	0	3
Fraser River			
Dunbar	3	0	0
Angus	1	0	0
Marpole	1	1	0
Monitoba	3	0	0
South Hill	1	1	0
Fraserview	1	0	0
Vivian	3	0	0

Champlain	1	1	0
Still Creek	0	0	0
Total	**37**	**12**	**14**

Summary of potential and planned GRI projects.