Retrofitting Green Infrastructure for Urban Stormwater Management: A Proposal and Recommendations for the Xiamen Urban Context

By

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in partial fulfillment of the requirements of the Degree of

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Abstract

Preliminary reconnaissance undertaken in summer 2013 identified the scale of stormwater management issues in Xiamen, having frequent storm events that overwhelm the stormwater and sewer infrastructure resulting in widespread flooding. Subsequent field trips in the Xiamen urban area ascribe the flooding issues to the predominant attention that Xiamen local government has directed to stormwater management by means of underground piping systems rather than applying the role of nature and to reduce the impervious surface that has occurred with increased urbanization to reduce stormwater runoff in rate and volume. This research explored the role that green facilities play in addressing stormwater issues through the inquiry of Low Impact Development strategies and techniques. A review of three precedent cities and built projects recommends that green infrastructure at different types and scales should be collectively implemented to efficiently and significantly manage stormwater. From a long-term perspective, green infrastructure planning and implementation is inevitably linked with strong education programs, rational stormwater codes and regulations, a variety of financing and incentives, as well as an integrated and competent administration system. This research presents a design proposal for green infrastructure retrofit for a selected study block in the central area of Xiamen to help guide water sensitive urban design and development in the future. Design interventions were conducted based on a logical analysis of the existing site and context, integrating identified opportunities and constraints with the eight principles derived from the literature review and initiatives of precedent projects to achieve two basic goals: sustainable stormwater management and for the purpose of education. The design proposal intends to advance discussion by politicians, policy makers, developers, professional experts and other stakeholders in the City of Xiamen toward future sustainable stormwater management. In the conclusion, seven recommendations based on the synthesis of the literature review, key-informant interviews, built-project studies and the retrofit design proposal are proposed. If applied, these recommendations could be a catalyst to stimulate green infrastructure planning and implementation in the Xiamen urban context for years to come. This document will be submitted to Xiamen Urban Planning & Design Institute as a reference for considerations to be integrated in future city master planning policy and zoning codes and standards as needed and to inform a demonstration project to help advance long-term strategies and recommendations.

Keywords: Low Impact Development; Green Infrastructure; Flooding; Planning; Implementation; Sustainable Stormwater Management

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Chapter 1: Introduction

1.1 Problem Statement

Having experienced an unprecedented period of heavy industrialization, China has a briskly developing economy and improved living standard. This is inevitably and closely linked with a great loss of green space/infrastructure. As a Chinese citizen growing up in a rapidly developing country, I witnessed with profound impressions the implausible transformation of my hometown from "green image" into an ugly "grey portrait" in the past 20 years of urbanism. Consequently, many issues blended in our life with the imbalance of green infrastructures. For instance, aquatic systems in many locations were polluted due to the destruction of natural wetlands and riparian buffer zones. In addition, urban stormwater, which could have been managed well through appropriate green infrastructure planning, is another concern to damage the surface and ground water system.

The management of water resources is a world-wide issue of concern in urban areas. With increased urbanization, functional green space has been replaced by concrete infrastructure. This contributes to excessive stormwater runoff, and non-point source pollution. Because of its particular geographical location and climatic condition, Xiamen (my hometown) regularly experiences disruption of typhoons (heavy storms) in the summer, causing flooding due to the limited capacity of the urban drainage system. During heavy rainfall events, excessive storm water runoff mixed with sewage are conveyed through traditional drainage piping, then directly discharged into surrounding surface water system, leading to degradation of water quality.

Objectives

This practicum researched Low Impact Development strategies and water sensitive urban design approaches. These include the applications of retention ponds, green roofs, bioswales and rain gardens, and how these green infrastructures can be integrated with urban design and planning to mitigate the impact of stormwater runoff on water resources in urban areas. The research conducted an analysis of a selected mixed-use block in the Xiamen urban area, and proposed a design concept of interventions

for retrofitting practice around the principles and lessons regarding Low Impact Development. This concept presented as a potential pilot demonstration project, seeking to set the benchmark for future water sensitive urban design guidance in Xiamen. (Xiamen is a major city located on the southeast coast of China in Fujian province, with a metro area of 1,699 square kilometers (656.14 sq mi) and population of 3,531,347 (2010 Census).

1.2 Research Questions

1. Concerning Low Impact Development principles and strategies
   1a. What are Low Impact Development (LID) best practices and where are informative precedents of their application?
2. Inquiring current situation of stormwater management in Xiamen
   2a. What is the current condition of urban stormwater drainage in Xiamen?
   2b. What role does urban landscape play in Xiamen currently?
3. Facilitating sustainable stormwater management (policy-based)
   3a. What are effective ways to stimulate the implementation and proliferation of LID in Xiamen urban area?
4. Facilitating sustainable stormwater management (design-oriented)
   4a. How to apply Low Impact Development (LID) strategies into the study block, to achieve more sustainable urban stormwater management?
   4b. In what ways can the implementation of Low Impact Development (LID) strategies make the block more inviting and aesthetically pleasing?

1.3 Background of Xiamen

As the second largest city of Fujian province, Xiamen is located in the south of China, which covers a total area of 1569 km2, while the urban area on the island is 130km^2 with 2.17 million people settling on it (Yang, 2013, p.277). Because of high population density, municipal wastewater and urban stormwater pose an excessive burden on the capacity of treatment plants and water system. Due to great effort made in the establishment of urban landscape, Xiamen is famous for its particularly nice scenery and named as the “garden city on the sea” (Yang, 2013, p.277). Figure 1 shows the area and shape of Xiamen Island.

Due to its geographical location and climatic condition, Xiamen suffers from the disruption of typhoons in the summer every year, causing flooding due to limited capacity of urban drainage system. During heavy rainfall, a large amount of stormwater runoff mixed with excessive sewage are conveyed through traditional drainage system, then directly discharged into surrounding ocean and Yuandang Lake, leading to the degradation of water quality.

Specific Problems of Xiamen

Designated as an economic zone since 1981, the City of Xiamen has become extremely inviting and attractive to large amounts of immigrants to invest and/or settle in the Xiamen Urban area. The rapid urbanization of Xiamen Island has occurred with an extensive increase of impervious surface, majorly including rooftops, increased and widened roads, large surface parking. The government of Xiamen has directed predominant attention to stormwater management by means of invisible underground piping, resulting in a severe increase of stormwater runoff in rate and volume compared to the natural hydrology of predevelopment condition.

The city of Xiamen has tended to direct the urban landscape to be an aesthetically pleasing and inviting to attract more tourists. Field trips throughout the Xiamen Island summarized the dominant green features in the Xiamen Urban area as comely and orderly urban landscape, simply being a backdrop without carefully considerations for ecological processes and sustainable stormwater management.

Although heavy storms (typhoons) usually occur in the summer every year, the City of Xiamen was identified as one of the water-scarce areas in China with the water resource level of 871 m^3/capita. Even though, the government of Xiamen and developers have not tended to considered more about innovative water management to reduce sunk costs on underground infrastructure and to save water resources. There is a lack of relevant policies, specific regulations and professional guidance and assistance to gear the public attention up for sustainable and innovative stormwater management.

Study Block

The selected study block (23.5 hectares) is known as the Culture and Art Centre (CAC), located in the central urban area near the Yuandang Lake. The CAC is a mixed-use super block for office, commercial, entertainment, cultural, and residential. Preliminary reconnaissance undertaken in summer 2013 identified the scale of stormwater management issue in Xiamen, with frequent storm events that overwhelm the stormwater and sewer infrastructure resulting in widespread flooding (see Appendix C). The green infrastructure in this area is strongly based on aesthetic principles and the open space more inviting for human activities rather than water sensitive consideration. There is a high percentage of impermeable surfaces, as well as areas of current green space that can potentially be improved by applying Low Impact Development strategies.



Figure 1.1 Satellite image of Xiamen Island, showing location of the study site (red). ©Xiamen Urban Planning & Design Institute, 2011. Used with Permission.



Figure 1.2 Selected Study Block - Culture and Art Centre (CAC) and the immediate urban context. ©Xiamen Urban Planning & Design Institute, 2011. Used with Permission.

1.4 Research Methods

Research methods consist of a literature review, identification and documentation of precedent built projects, a cartographic and photographic survey and analysis of the proposed study block (the CAC block) and its immediate context, and key informant interviews (first, the preliminary interviews in Seattle and Portland, and second, feedback interview with a professional practitioner in China), to support the further development of the conceptual design and guidelines, as well as recommendations for future development in the Xiamen context.

Literature Review

The literature review includes four connected themes: 1) Definition of Green Infrastructure, 2) Effects of Urbanization on Water cycle, 3) Conventional Urban Storm Runoff Management , and 4) Understanding Low Impact Development. The first theme explored the term "Green Infrastructure" from literature and defined a specific meaning for this practicum. The second theme explored the natural process of hydrological cycle and why (how) urbanization poses threats on the water system. The third theme identified traditional approach of urban stormwater management, how it works and its related drawbacks. The final theme explored the principles, techniques and strategies of Low Impact Development to build theoretical foundation for further inquiry.

Precedent Documentation

The research explored initiatives and experience in Portland and Seattle regarding green infrastructure planning and implementation. They were selected after reviewing a longer lists of precedents. Each of the cities was described, analyzed, and contrasted. Other informative initiatives in Australia and Europe were considered. The researcher endeavored to identify potentially informative examples of practice in China. The actual precedent list was adjusted depending on developments in the research. This research made a final decision for the precedent documentation after a reviewing of broader precedents. Basically, this method of precedent documentation addressed initiatives and incentives that precedent cities apply for green infrastructure planning and

implementation. Precedent documentation also considered built-projects at different scales, identifying how these projects coordinate the integration of water sensitive aspect, adjacent urban settings and different human activities. These projects are the Shoemaker Green in Pennsylvania (US), the Tanner Springs Park in Portland (US), and the Olympic Village in Vancouver (Canada).

Study Block Analysis

The analysis of the proposed study site (the CAC block) in Xiamen focused on the general physical context and conditions. This included site observation and inventory, along with the photographic database, noting forms, features and functions of the urban setting. The analysis is closely linked with water sensitive considerations. The research primarily addressed the issues of the proposed study block; also involving the local context. Related information of the study site such as land use, public utilities, transit movement and other infrastructures, as collected from Xiamen Urban Planning & Design Institute were used to assist with the analysis and the planning and design intervention.

Key Informant Interviews

The main research instrument for this project, involving human subjects, was semi-structured interviews. The interviews were in two types: first, the key informant interviews in Portland and Seattle, and second, the feedback interviews regarding the analysis and recommendations in the precedent documentation. The key informant interviews aimed to inform the research regarding green infrastructure planning and implementation derived from initiatives and experience of Portland and Seattle, to support the development of future recommendations for the City of Xiamen. The feedback interviews were intended with engaged planning and design practitioners in China, with the intention to gather reflections and comments on the draft recommendations for Xiamen with the purpose to make the outcomes more applicable and feasible.

a) Key Informant Interviews (Participants from Portland and Seattle)

The interviewees were selected in order to clarify and inform findings about the precedent city planning, design, and policy context etc. Ideally, the interviewees would be local planner(s), architect(s), landscape architect(s), environment engineer(s), relevant official(s), and experienced practitioner(s) of Low Impact Development. Due to time and availability, there were three interviews conducted in the Cities of Portland and Seattle during a one-week field trip in September, 2014. One was in Portland and the other two were in Seattle.

The precedent documentation was composed in two sections, the first, regarding precedent cities (Portland and Seattle) and, the second, exploring three precedent built projects. The first section also provides recommendations for the City of Xiamen. The questions for the feedback interview were developed in regards to the analysis and recommendations proposed in the precedent documentation. The interview questions were prepared along with a research backgrounder and a copy of the precedent documentation for review by the participants from China.

b) Feedback Interviews (Participants from China)

It was intended in the research proposal to distribute the interview package to three or four reviewers. Ideally, the target group of relevant practitioners for these interviews would be local planner(s), architect(s), landscape architect(s), environment engineer(s), relevant official(s) and experienced practitioner(s) of Low Impact Development. The intention was to conduct interviews by email, telephone, or video-phone. Due to time and availability, only one practitioner from the China Planning and Design Institute replied and participated in the interview through email.

All informants provided their consent to participate. As indicated in Appendix B, initial contact to recruit participants was conducted through emails. Precedent city interview and feedback interview schedules (see Appendix A) along with the research backgrounder information was provided to participants, while the feedback interview document also included an attachment of precedent documentation.

Development of Conceptual Design Interventions

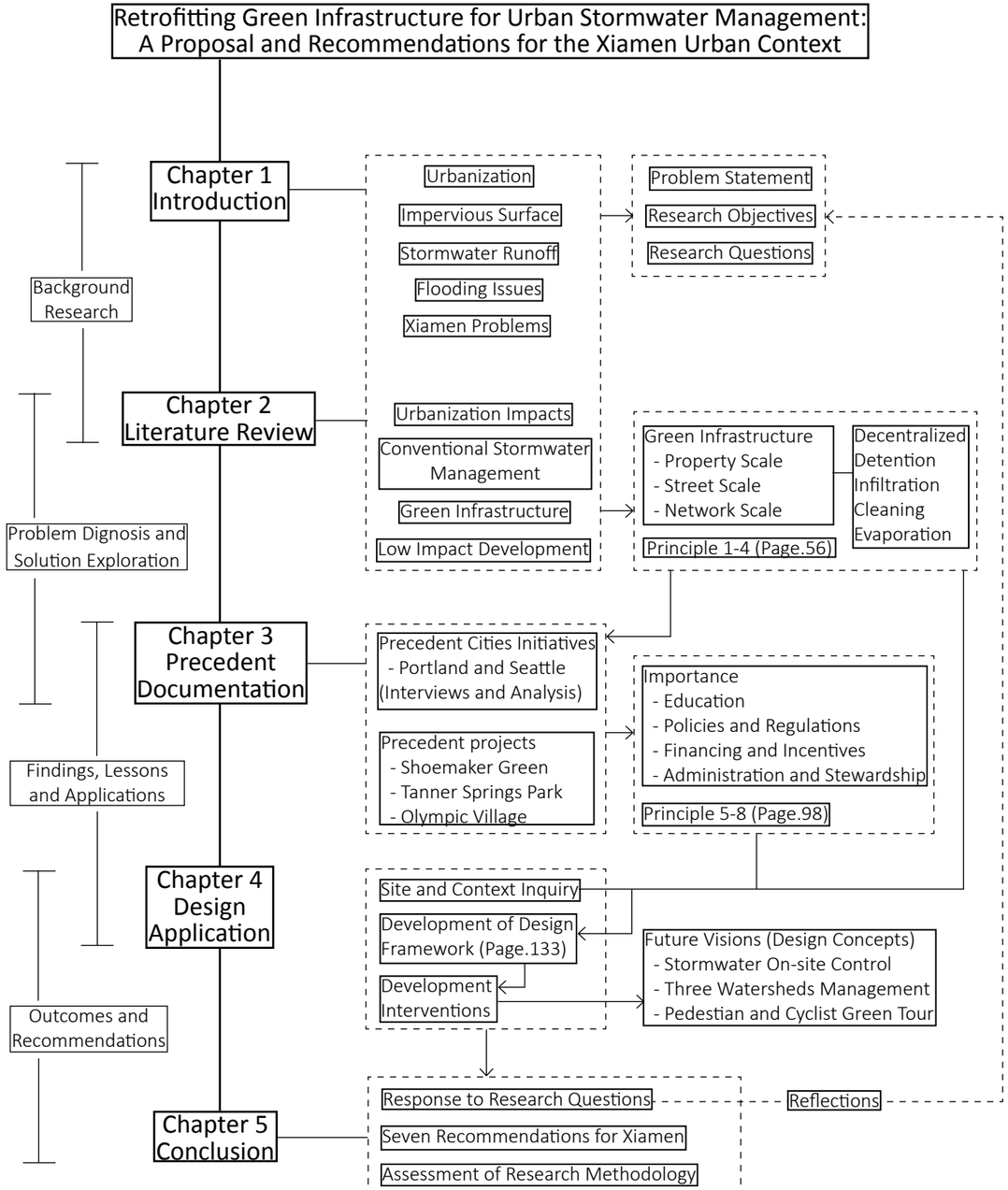
The outcomes of this research are the further development of the conceptual design of interventions to the study block, as refined/informed by the comments and suggestions from key informants, and refinement of the set of policy recommendations for the City of Xiamen.

1.6 Significance

Major change is urgently required in the existing paradigm of design and operation of blue and green assets, which currently operate as two separate systems. This research is expected to help bridge gaps among various practitioners, involving city planners, architects, landscape designers and civil engineers to cooperate and endeavor to work towards a more sustainable stormwater management for the city. The final report will be submitted to Xiamen Urban Planning & Design Institute as a reference, for considerations to be integrated in future city master planning policy and zoning codes and standards as needed. This research intends to make three main contributions to the city. First, it aims to draw more attention of practitioners to the implementation of Low Impact Development. Second, it seeks to provide synergy of the so far “decoupled” blue and green systems to provide multifunctional solutions and multiple benefits: increased facilities, flood risk management, urban heat island improvement, biodiversity, reduced energy requirements, thus increased quality of life at lower costs. Third, this project initiative intends to inform and advocate for a pilot demonstration project to guide more LID practices in Xiamen.

1.5 Research Framework

The author developed a research framework for readers to clearly realize how this research was conducted and organized, and identify what components are included in each chapters.



Chapter 2: Green Infrastructure and Stormwater Management: literature review

This Chapter presents an analysis of green infrastructure related to the management of urban storm runoff. The objective is to provide a general understanding of the problem background and establish a theoretical framework and foundation for the further research. Four themes are presented as follows:

1. To define Green Infrastructure for this study
2. To inquire how urbanization affects hydrological cycle and water quality.
3. To investigate how humans manage urban storm runoff and Xiamen conditions.
4. To identify and study Low Impact Development (LID) principles and techniques.

2.1 Defining Green Infrastructure

The concept of “Green Infrastructure” has evolved over time as defined in the literature, described as an integrated system closely linked with ecological services, and more resources efficient, adaptable and sustainable, when compared to “grey infrastructure” (TSG, 2001). Commonly, we are more familiar with grey infrastructure such as roads, buildings, sewerage, transmission lines and many other basic urban settings in our daily life. However, grey infrastructure is mostly developed in a way having less consideration from ecological perspectives. Green infrastructure has also been defined to mean the regeneration of a gray infrastructure element to a more sustainable one (Austin, 2014).

As an engineered, artificial system that simulates natural function, Green infrastructure contributes to urban sustainability since it provides social, ecological and environmental values. There are multitudes of Best Practices for Green Infrastructure in different urban facilities: stormwater system, energy system, transportation and communication systems, etc. For the purposes of this study, Green Infrastructure is used interchangeably with Low Impact Development (LID) and be focused on stormwater

management. Connectivity between areas large enough to incorporate ecological services and human activities is a critical point to evaluate green infrastructure development (Austin, 2014). Single-purpose solutions, such as bioswales, retention ponds, or rain gardens, are categorized to impoverished green infrastructure components if they are planned and designed solely and merely to address stormwater issues, without integrating other considerations of human activities, urban forms, aesthetics, etc. (Austin, 2014).

This study seeks to conduct an integral design for Green Infrastructure on the selected study block and its immediate area in Xiamen, focused on urban stormwater management, meanwhile integrating with other urban settings, to provide a more sustainable, healthy and livable urban neighborhood for citizens.

2.2 Influences of Urbanization on Hydrological Cycle

Before considering the impacts of human activities on the hydrological cycle, it is necessary to understand the overall picture of the circulation of the water in the atmosphere, ocean and land. The hydrological cycle has been recognized in literature as an unending and dynamic water system, constantly keeping the water replenished during the process of movement and exchange (Hough, 2004). As Figure 2.1 shows, the

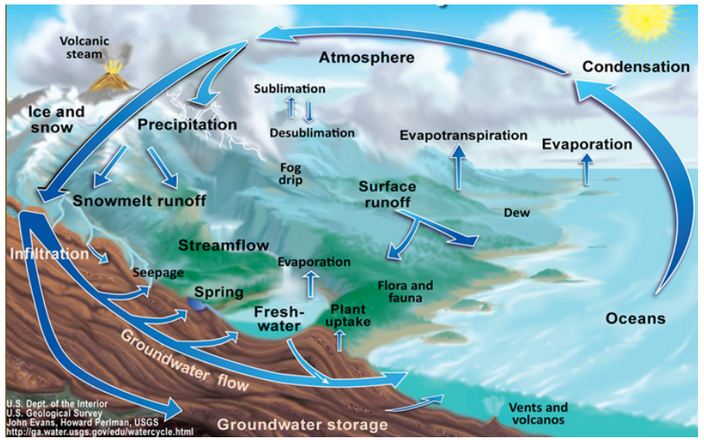


Figure 2.1 Illustration of the general complexities of the water cycle. © John Evans, Howard Perlman, USGS, 2015. Public Domain. Retrieved from:http://water.usgs.gov/edu/watercycle.html

water cycle involves evaporation of the vast quantities of water from ocean and land surfaces. In the atmosphere, the water vapour moves and circulates around the earth and produces rain and snow. When precipitation falls over the land, it may be returned to the atmosphere through transpiration of vegetation or evaporation, while others will complete a complex journey, through percolation and/or surface runoff, then back to the lakes, rivers and ocean.

As defined, stormwater runoff is “rain or snow melt that flow off the site instead of soaking into the ground” (Venhaus, n.d. p. 122). Human activities lead to significant changes in the percentage of stormwater that percolates into the ground, evaporates back to the atmosphere, and releases to the water system through runoff. With the increase of urbanization, significant natural features such as riparian zones, forests and wetlands have been replaced by concrete infrastructures and impervious surfaces that rapidly transport stormwater into water resources (Podolsky & MacDonald, 2008.). In the urban environment, paved surfaces such as conventional roads, roofs and parking lots are not able to infiltrate rainwater as vegetated land can, which even increases the runoff volume and rate of the site. As seen in Figure 2.2, for a given storm event, the urbanization contributes to the increase of stormwater runoff in (peak) rate and volume than natural context (TRC, 2010).

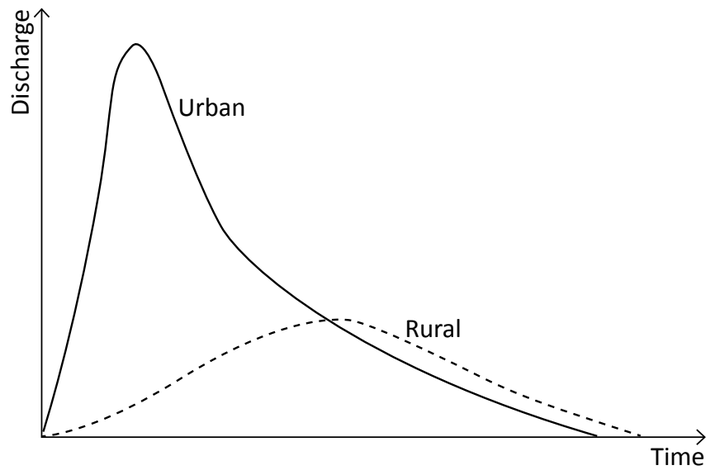


Figure 2.2 Stormwater discharge before and after urbanization

Figure 2.3 clearly demonstrates the difference of runoff condition between urban area and natural land. Compared to natural land, urban development increases 45% runoff, while leading to 35% reduction of total infiltration.

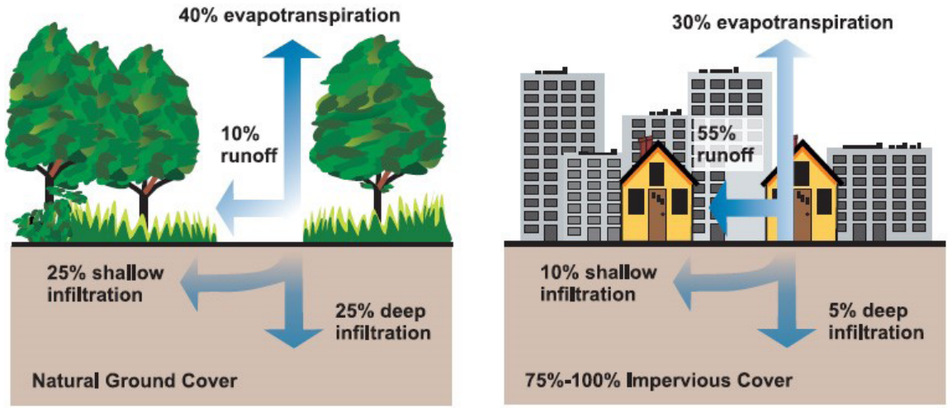


Figure 2.3 Natural and Impervious Cover Comparison. ©U.S. Environmental Protection Agency, 2014. Public Domain. Retrieved from http://water.epa.gov/polwaste/nps/urban_facts.cfm

After urbanization, the increased stormwater runoff contributes to soil erosion of stream banks, causing large amounts of sediment to enter the aquatic system (EPA, 2010). Without the filtration by vegetated areas, a lot of pollutant sources would be drained into waterways with stormwater runoff. It is recorded that common storm water pollutant sources include various aspects as following (U.S. EPA 2013a):

- Sediment
- Oil, grease and toxic chemicals from motor vehicles
- Pesticides and nutrients from lawns and gardens
- Viruses, bacteria and nutrients from pet waste and failing septic systems
- Road salts
- Heavy metals from roof shingles, motor vehicles and other sources
- Thermal pollution from dark impervious surfaces such as streets and rooftops

Under the threats of these pollutants, not only the populations of fish and wildlife, but also the diversity of native vegetation will reduce, making recreational areas aesthetically unpleasing and unsafe. Human health is also affected by pollutants contained in drinking water (U.S. EPA, 2014).

2.3 Urban Storm Runoff Management

Increased urbanization replaces green areas with impermeable surface, leading to the creation of a new hydrological environment, which has different characteristics than the hydrological cycle in the natural area. In urban area, impervious surface has no capacity to infiltrate stormwater unlike a forested land can do. Underground drainage pipes have been built up to quickly convey stormwater away from one site to another site, which not only threaten water system, but also contribute to erosion and flooding in downstream areas (Hough, 2004). Traditionally, there are two types of urban sewer systems: combined sewer and separated sewer, each are next described.

2.3.1 Conventional Sewer System

Combined Sewer: In traditional sewer systems, stormwater runoff is quickly transported through pipes, culverts, or channels and directly released to receiving aquatic systems such as lakes, wetlands and rivers. Without being processed in the treatment facility, stormwater runoff poses negative impact on the water resources used for drinking, recreation and aquatic ecosystem. As the earliest sewer system, combined sewers collect both stormwater and sanitary sewage in the same pipes (WCSO, 2008). In dry days, the sewers transport sanitary sewage to treatment plants before being released to water system. However, during the periods of heavy rainstorms or snowmelt, the large volumes of runoff combine with unprocessed raw sewage overwhelming the capacity of the system and then are released directly at the various outfalls (See Figure 2.4) (Podolsky & MacDonald, 2008). Since in CSO's, stormwater is mixed with untreated "human and industrial waste, toxic materials, and debris", various pollutants contained within such overflows have considerable impacts on public health, water activities (swimming/washing/fishing), and the aquatic ecosystem (EPA, 2004).

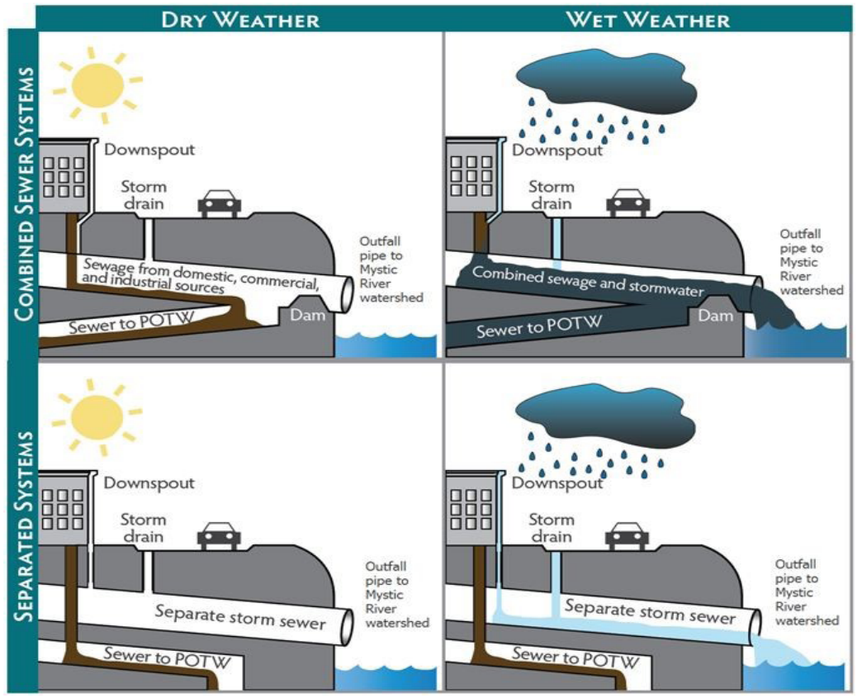


Figure 2.4 Combined Sewer System and Separate Sewer System operation in dry and wet weather. ©U.S. Environmental Protection Agency, 2004. Public Domain. Retrieved from http://www.epa.gov/npdes/pubs/csossoRTC2004_chapter02.pdf

Separated Sewer: Combined sewer systems were originally built during mid- to late- 19 century to minimize the contact between waste and humans, which were adopted by some larger cities since they were the cheapest option (EPA, 2004). As an alternative, a separated sewer system would be applicable to mitigate the impact of CSOs on the water bodies, since stormwater tend to be separated from sanitary sewer and directly drained into water ways (City of Winnipeg, 2015). However, compared to combined sewer system, this approach would be much more costly and leads to higher level of chemicals transferred to the water system as a result of all untreated stormwater released by the separated pipe during all storms (City of Winnipeg, 2015). In order to save the vast investments on a separated system and, meanwhile, mitigate the negative impact of CSOs, both the county and the city of the State of Washington control the CSOs under the average level of one per year per location. To achieve the standard, they

make effort to accumulate the stormwater during heavy rainfall and transfer it to the treatment plants afterwards, thus ensure most of the wastewater and stormwater can be processed before they are released to waterways (PH- SKC, 2010).

Except the issue of decreased water quality, conventional stormwater management systems cause many other problems. Available potable water is limited as a result of increased impervious surface that disables water infiltration and groundwater recharge. In addition, great costs and investments in retrofit and maintenance of piping would be necessary to adapt to future urban development and climate change. Moreover, the Heat Island Effect has become a common concern with increased urbanization.

2.3.2 The Xiamen Condition

As the second largest city of Fujian province (with a total area of 1569 km2), Xiamen is situated in the south of China. The area on the Xiamen Island is approximately 130 km2 with population of 2.17 million (Yang, 2013). Because the City of Xiamen is located in the sub-tropical oceanic climate zone, the annual average temperature is around 20.8 °C, with the highest temperatures (an average daily temperature of 31°C) from June to September (Osson, 2011). Xiamen has dominant precipitation during the spring summer period, with an average annual rainfall of 1314mm (XMW, 2004). Extremely heavy storm events known as typhoon usually occur from July to September.

Stormwater management and flooding

The City of Xiamen was designated as one of the four special economic zones in 1981. Since then, Xiamen has been attractive to various investments of foreign countries and overseas Chinese, and a booming population to settle in, which was under the banner of the government's reform policy. As the Xiamen Island become highly urbanized, municipal wastewater and stormwater pose an excessive burden on the capacity of treatment plants and drainage systems. Xiamen urban planning has given low priority to innovative stormwater management. Stormwater runoff is quickly directed in pipes and transferred to the receiving water bodies. Although in recent years new development projects implemented separated sewer systems, many old

areas still address stormwater and wastewater with combined sewers. Xiamen suffers from the disruption of typhoons in the summer every year, causing flooding due to the limited capacity of the urban drainage system. During heavy rainfalls, a large amount of stormwater runoff combining with excessive sewage were conveyed through the traditional drainage system, then directly discharged into surrounding ocean and Yuandang Lake, leading to the degradation of water quality.

Preliminary reconnaissance undertaken by the author in summer 2013 identified the scale of stormwater management issues in Xiamen, with frequent storm events overwhelming the stormwater and sewer infrastructure resulting in widespread flooding (See documentation in Appendix C). In 2013, two extremely heavy storms, occurring May, 16th and July, 19th were identified from the Xiamen Night Newspaper. Both storms were short in period and of high intensity. The storm of May, 16th had more than 185mm precipitation in the first 6 hours in some areas of the Xiamen Island, while the one of July, 19th had more than 150mm in 17 hours. The high level of urbanization in the Xiamen Island led to a series of concerns when heavy storm events occurred. These problems can be summarized as:

- Flooding occurred in depressed areas and areas with limited capacity of piping systems;
- Traffic congestion due to flooding events;
- Soil erosion and landslide occurred in some areas;
- Damage to vehicles, underground piping and other public infrastructure;
- High costs of clearing, renewal and maintenance of piping systems

Impervious surfaces

With the urbanization of the Xiamen Island, considerable green space such as forests, wetlands and the Yuandang harbour (now known as Yuandang Lake) have been replaced by impermeable surfaces. These hard surfaces primarily include building rooftops, different hierarchies of roads and streets, and a high percentage of parking space to meet the demand of the increasing vehicles.

In the Xiamen Island, the buildings can be generally categorized in three types, low-rise dwelling (less than 3 floors) in old villages, multi-storey buildings (5~9 floors) developed in 1990s and early 2000s, and high-rise buildings constructed in recent years. Although most of the rooftops in old villages can be accessible, they are usually utilized as recreation space or/and food gardens, rather than considering from rainwater management aspects. In terms of multi-storey buildings, some of the rooftops are pitched roofs, while some are flat and accessible. Most of these rooftops are underutilized, except a low percentage of them have been used for roof gardens. The rooftops of high-rise buildings have been designed and constructed in a variety of forms and structures that are usually inaccessible and difficult for maintenance, except some can be implemented as extensive green roofs to address rainwater.

Roads and streets are necessary for urbanization to provide the function of mobility and accessibility for human activities. Certain arterial roads such as Xianyue Road, Xiahe Road and Chenggong Road have been retrofitted widened to adapt to the increase of traffic demand. They have been designed and constructed to accommodate a large amounts of vehicles rather than provide adequate and pleasing space for pedestrians and cyclists. Parking lots contribute to a large proportion of impervious surfaces so that stormwater runoff is directed into piping and conveyed to receiving water bodies. As observed, a few small parking lots have implemented permeable paving with grass to address rainwater. However, without appropriate construction and maintenance, the majority of underlying soils of the parking lots have become highly compacted with limited capacity of infiltration. Innovative stormwater management and techniques cannot be widely applied and implemented because of the lack of government's initiatives and relevant regulations.

Green features

Due to the great effort made in the establishment of urban landscape, Xiamen is famous for its particularly nice scenery, being referred to as the "garden city on the sea" (Yang, 2013). Green areas in the City of Xiamen have been constructed primarily based on aesthetic values rather than considering ecological services. The majority of the green features in Xiamen are artificial and aesthetically pleasing, however, they provide limited capacity to address stormwater management with mounded planting beds. Red soil is a common type of local natural soil in the City of Xiamen. As reported (Zhu., etc.

2013), red soil cannot percolate water effectively with a low permeability coefficient of 1.631*10-4cm/s. However, red soil can be amended by adding 15%~35% sand and 5% humus soil to become suitable for improved water infiltration.

Water resources

The City of Xiamen has an yearly average surface water resource of 8 billion m3 and ground water of 136 millon m3. The water resource per capita (871 m^3/capita) in Xiamen is only 40% of national level and 25% of provincial level, even lower than international level (1000 m^3). Thus, Xiamen can be classified as one of the water-scarce areas. Even through, the City of Xiamen has focused on conventional piping mangement to convey stormwater away rather than harvesting stormwater for reuse. This can be attributed to the lack of relevant laws, regulatory policy and education regarding innovative stormwater mangement among the many stakeholders.

2.4 Understanding Low Impact Development

Low Impact Development (LID) is a term used to describe stormwater management strategy based on the basic principle that a natural function is the preferred approach. By managing the stormwater runoff nearby its source, LID strategy is aimed to reduce the volume and rate of stormwater runoff on site, thus to minimize the negative impact on the aquatic system (TRC, 2000). Traditionally, the stormwater management is based on the applications of gutters, curbs, pipes and canals to move the rainfall away from the site as soon as possible, without considering the threats to water bodies. Unlike conventional approach, the principle of LID relies on the “source control and infiltration, storage, filtering and evapotranspiration”, which imitates natural hydrological function (Odom, 2009). Implementation of LID considers seven basic purposes as following:

- Minimizing disturbance;
- Preserving and recreating natural landscape features;
- Reducing effective impervious cover;
- Increasing hydrologic disconnects;

- Increasing drainage flow paths;
- Enhancing off-line storage; and
- Facilitating detention and infiltration opportunities

Low impact development (LID) was first widely used in the USA in the early 1990’s. Afterwards, several projects were also implemented within Canada. Nowadays, LID principles are being applied in other countries; however, the application of LID is still infrequent and not well integrated as a new concept in some areas. Sustainably handling urban stormwater management is named by different terms in other regions. In Australia, the approach is more often called water sensitive urban design (WSUD) (Hoyer, J., etc. 2011), while in the United Kingdom, it is more often called sustainable stormwater management (SUDSnet, 2008).

2.4.1 Benefits of Low Impact Development

The application of LID contributes to multiple benefits, involving environmental, economic and social aspects. In terms of environmental benefits, increased water quality should be mentioned at first as a result of clearance of nutrients, pathogens, sediments and metal by the process of infiltration, storage, filtering, and evapotranspiration (Odom, 2009). LID imitates natural systems to collect, filter and slowly release stormwater runoff, thus reducing the frequency and duration of nuisance flooding. LID principles and strategies provide environmental benefits beyond just stormwater management and flood control. LID also contributes to erosion reduction, energy conservation, habitat protection, and improved air quality (Podolsky & MacDonald, 2008).

Regarding economic benefits, LID is less costly when compared to traditional stormwater management (Belan & Otto, 2004). The construction of conventional stormwater system usually involves hard infrastructure such as pipes, tunnels and storage system, while LID applies green infrastructure to imitate eco-hydrological function, which is less costly (Odom, 2009). In addition, economic benefits of LID also include cost-effective maintenance and replacement, reduced demands on municipal water supply, and improved property value (Odom, 2009). The facts can be proved by

relevant data of Portland LID practices provided in the precedent documentation.

From social perspective, LID brings the nature back to the urban areas, providing healthy and livable communities. Landscape-based stormwater management enhances aesthetics by incorporating green and blue networks, meanwhile creates innovative designs to facilitate social interaction with water features (Calkins, 2012). Green infrastructures allow rainwater to percolate through soil and recharge groundwater. Water reuse can be fulfilled by installing harvesting cisterns to collect stormwater for domestic uses such as landscape irrigation and toilet flushing, which saves water resource and reduces burden on municipal water supply.

2.4.2 Limitations of Low Impact Development

In order to effectively implement LID principles and strategies, the considerations should involve the evaluation of soil permeability, topography, and depth of water table. Existing regulations can be the barriers to implement LID, since different administrative regions have different rules for development, which are the combination of subdivision codes, zoning bylaws, as well as other local ordinances (CWP, 1998). Compared to the traditional approach, LID techniques often require more frequent and regular maintenance by homeowners or local government in order to proceed efficiently (Odom, 2009). In addition, the presence of potential high levels of contaminants may pose threats to the quality of groundwater (Odom, 2009). Moreover, individual LID facilities only harvests and treats limited volume of runoff, particularly during heavy storm events, without collective applications of green infrastructure at different types and scales.

2.4.3 Exploring Low Impact Development Techniques

There are a wide variety of green stormwater infrastructure at different scales (see Appendix D). At the site scale, these can be green roofs, rain gardens and permeable pavements; at the street scale, these can be bioswales and stormwater planters; at the neighborhood scale, these can be retention/detention ponds. Individual green facilities have limited capacity to address neighborhood-wide stormwater issues, unless these green facilities at different scales are widely and collectively implemented. Because of site constraints, green infrastructure at different scales and types should be designed and installed accordingly to provide an integrated green and blue network for stormwater management. Different types and scales of green infrastructure have diverse performance and effectiveness in stormwater management. More inquiry of each type of green infrastructure was conducted in a basic order, identifying design considerations, benefits and limitations. Design considerations consist of different components depending on specific green stormwater facilities. Lessons and specific design principles are summarized at the end to inform further research of green infrastructure planning and implementation, and guide design interventions for the selected study site (CAC block).

2.4.3.1 Green Roofs

Green roofs, also known as vegetated roofs, rooftop gardens, or eco-roofs, have been described as garden ecologies installed on both sloped and flat roof surfaces (UACDC, 2010). Nowadays, they are usually applied by ecological designers and urban planners under the banner of shaping a more sustainable and more regenerative city. As a green element, the applications of vegetated rooftops have been proved by many built projects that can positively contribute to our environment by alleviating developmental impacts on our planet. Green roofs are capable for sustainable stormwater management, by covering impermeable, barren rooftops with living, breathing, and pervious plant materials (Velazquez, 2005). In addition, green roofs also contribute to other benefits, such as increased air quality, energy conservation, social interaction, etc. It is indicated that durability of green roofs is approximately 45+ years, which lasts twice as long as conventional roofs do (Austin, 2014). Energy efficiency can be achieved for buildings with green roofs since less energy consumption for cooling and heating. From regional perspective, excessive applications of Green roofs link fragmented urban landscape, enhance urban ecology, and increase biodiversity as it used to be before urbanization.

Design considerations

Types of green roofs

Green roofs can be generally divided into two types: extensive and intensive (also referred to as low-profile and high profile) (Velazquez, 2005). They can be successfully applied on both new and retrofitting rooftops after complete design and analysis for practice. The most appropriate type of green roof determined for a given application mainly depends on the decision made by project owner, designer and engineer, regarding the purpose, budget, existing condition (load capacity and slope situation) .etc (Velazquez, 2005). Table 2.1 contrasts extensive green roof with intensive one, as well as the type of their combined application, and summarizes into key points for clear and efficient reviews (Vegetal i.D, n.d).

Roof frame	Concrete/wood/ steel	Concrete/steel	Concrete/steel (Max. pitch:5%)
Plant mix	Sedums, moss, perennials	Perennials, small shrubs, lawn	Shrubs, trees, lawn
Substrate thickness	2”to 6” (4 to 15cm)	5”to 12” (12 to 30cm)	12” (30cm) or more
Weight of complete system	15 to37 lbs/sq.ft. (75 to180 kg/sq.m.)	41 to102 lbs/sq.ft. (200 to500 kg/ sq.m.)	102 to 410 lbs/sq.ft. (500 to2000 kg/sq.m.)
Watering	Low water requirement	Irrigation usually necessary	Irrigation usually necessary
Maintenance	Lower	Medium	Higher
Roof Cost	$$: ($12-$25/sf)	$$$: Medium	$$$$: ($25-$40/sf)
Storm water management	Less stormwater retention benefits	Medium	More capable for stormwater management
Accessibility	Often Inaccessible	Limited	Highly accessible

Table 2.1 Properties of the main types of green roofs

Compared to intensive green roofs, extensive roof gardens basically function as stormwater and energy management systems, requesting lower structural demands on the building rooftops, since human activities are often inaccessible or highly limited on extensive green roofs. In the contrast, intensive roof gardens are accessible as an amenity for the public, so that plant diversity which includes lawn, shrubs and trees are necessary to provide recreational and aesthetical values. Because of this character, intensive green roofs request as twice thicker or even more as extensive green roofs do. Extensive green roofs are flexibly applicable on concrete, steel, or wood roof frames, while intensive ones are usually applied on concrete or steel, which have adequate loading capacity to support diverse plants and human activities as needed. Although intensive green roofs are usually more expensive, and request more maintenance and irrigation than extensive ones, they have higher capacity for stormwater retention and treatment.

Components of green roof system

Whether extensive, intensive, or somewhere in between, green roofs generally consist of those elements as indicated, which can be divided into four basic layers, from top lay down, including plant, substrate, drainage and protection layers (see Figure 2.5).

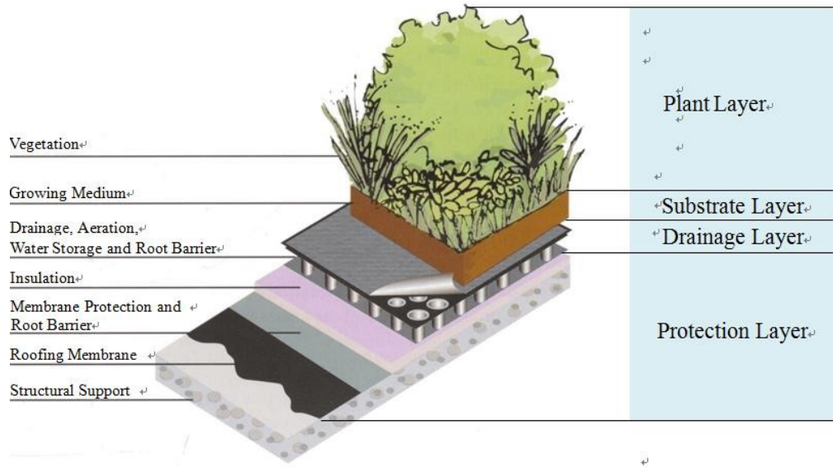


Figure 2.5 Basic components of green roofs.
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The top, plant layer, consists of appropriate vegetation contextually based on site conditions, including local climate, measured load capacity of rooftop, as well as adjacent urban environment. The substrate layer typically comprises of inorganic mineral materials (at least 80 percent) and organic materials such as topsoil (up to 20 percent) (Wong, n.d.). The growing media for plants are usually engineered and lightweight, which can be modified to improve water retention capacity. The drainage layer acts as a buffer zone, converting excess rainwater from growing media to roof outlet, which alleviates overload on rooftop and balances the air-moisture in the substrate layer. Meanwhile, the drainage layer provides water storage capacity to some extent (Wong, n.d.). The protection layer, including insulation, roof barrier, roofing membrane, and structural support, prevents building from water and roof penetrations.

Plant selection

The determination of what and where the plants should be grown normally depends on whether extensive or intensive rooftop is expected, and various factors of living condition, including precipitation, air pollution, soil depth, wind, temperature, sunlight, building height, etc. Typically, sedum, chive, carnations and thyme are succulent plants that are highly recommended as good choices to any types of rooftops, since they can be adapted to multiple sources of extreme living conditions (Vegetal i.D, n.d.). Hardier and native planting materials are usually considered unless regular irrigation and fertilization, shading facilities, and adequate maintenance and human intervention can be provided (Peck & Kuhn, n.d.). Compared to extensive green roofs, intensive ones are usually with less limited to planting choices, including trees and shrubs as they have capable growing media that can accommodate larger species. Regular maintenance is usually conducted to sustain different varieties of vegetation as intensive rooftops are expected as conventional gardens and parks that are accessible for building occupants and the general public.

Maintenance

Building owners are supposed to maintain vegetative rooftops on a regular interval. The type of upkeep activity should be in accordance to plant species and expected aesthetic appearance, especially for intensive rooftops (Vegetal i.D, n.d.). According to best management practices, maintenance usually involves regular weeding, fertilization, irrigation, and dead foliage. As recommended, the moisture level of the substrate layer needs to be inspected weekly, as adequate water should be furnished to support vegetation growth, also water acts as a significant role in preventing fire accidents (SPRI, 2010). Regular interval of maintenance activity for plants usually ranges from two to three yearly for the inspections of weeds and any damage, while irrigation, pruning and replanting should be conducted weekly (Peck & Kuhn, n.d.).Maintenance are required to not only address vegetation layer, but also the protection layer, as waterproofing membrane is critical to prevent water leaking and protect rooftop structure. More specific maintenance requirements vary in accordance with the types and scale of green roofs, and analysis of living conditions.

Benefits

For the purpose of this study, one of the greatest potential of green roofs are their capacity for stormwater retention. The rainwater retention capacity of a vegetated roof varies depending on a series of factors, including the types of plants applied, substrate thickness, porosity, under-drainage layer water retention and flow, and relief drain spacing, precipitation intensity, and climatic conditions (Vegetal i.D, n.d.). In terms of small rainfalls, most runoff will be captured and stored in the growing media and held by specialized water-holding membrane, and ultimately returned back to the atmosphere through evaporation and transpiration. Regarding heavy storms, green roofs can significantly reduce runoff volumes and peak runoff rates, thus mitigating the runoff discharge burden on urban drainage system (Podolsky & MacDonald, 2008). The contribution of green roofs for stormwater management is definitely vital in central urban areas. Usually, approximately 40-50 percent of impermeable surface in a city centre comes from conventional rooftops, which contributes to a large portion of stormwater runoff (Austin, 2014). If green roof projects can be implemented widely, a large amount of stormwater runoff reduction in rate and volume will be achieved effectively. It has been reported (Podolsky & MacDonald, 2008) that 20300 square foot green roof of Chicago City Hall can capture over 75 percent of the precipitation volume

during a one-inch storm. Another example can be referred to a demonstration project of green roof in Portland, Oregon. The examination report over a 15-month period indicates that almost 70 percent of runoff reduction has been fulfilled by the green roof with approximately four inches (10cm) of growing substrate (Wong, n.d.). Not only can green roofs contribute to the reduction in rate and volume of stormwater runoff, they also improve stormwater quality with engineered growing media, preventing nutrients (nitrogen, phosphorus, and toxins), and heavy metals (cadmium, copper, lead, and zinc) from entering aquatic system (Velazquez, 2005).

Besides the capacity of stormwater retention and treatment, green roofs are widely valuable in terms of many other benefits as summarized (see Table 2.2). These advantages are not separately taken by merely private or public, but some of them, such as noise reduction, mitigation of heat island effect, and increased aesthetic value are overlapped and beneficial for all citizens (Wong, n.d.).

Benefits/ Costs	**Benefits**	**Costs**
Private	- Reduced energy use - Extended service life - Noise reduction - Aesthetic value - Increment of property value - Food production - Recreational use	- Installation - Architecture/ Engineering - Maintenance
Public	- Reduced temperature (mitigation of heat island effect) - Reduced stormwater runoff - Increased stormwater quality - Reduced installation and maintenance costs (from widespread technology use)	- Program administration - Funding for incentives and implementations

Table 2.2 Benefit-cost elements for green roofs

Limitations

Generally, green roofs are more efficient and successful at managing small rainfalls of 0.4 inches (10mm) or less (Venhaus, n.d.). However, they are still one of the most popular green infrastructures applied to manage stormwater, since in most areas diminutive precipitation events occur more frequently throughout a year. For heavy storm events, other scales of green infrastructure on the ground such as rainwater harvesting facilities, rain gardens, and permeable pavements can be integrated with vegetative roofs to provide a complete drainage train for sustainable stormwater management. Usually, flat or slightly sloped roofs are more applicable for vegetative roofs to install. Otherwise, cross-battens should be applied to prevent soil erosion and stabilize drainage layer on a steeply sloped roofs (UACDC, 2010). Structural engineers are required before installation to assess load-bearing capability of the roof structure to safely support vegetative roofs (Austin, 2014). With higher stability, steel and concrete roofs are more suitable for green roofs than wood or older ones, so request of structure retrofitting should be evaluated when planning a green roof on either new or existing building.

2.4.3.2 Rain Garden

As known, a rain garden is one type of attractive green infrastructure, a vegetated shallow depression that captures and infiltrates stormwater runoff from adjacent impermeable surface, including rooftops, roads and parking lots. Rain gardens are commonly located at property lawn and designed as a bio-retention facility that imitates natural water retention of undeveloped areas, such as forest, meadow, and wetland, which can endure occasional temporary rainfalls and mitigate low level pollution (Emanuel, etc., 2010). It wasn’t until 1990s, when rain gardens were first developed in the United States and became increasingly applied afterwards to help improve stormwater management (Bray, etc., n.d.). Generally, rain gardens can be applied in both retrofitting project and new development, since these simple facilities do not require intricate rearrangement of the existing drainage system and are applicable in most soil conditions, as long as space permits (Bray, etc., n.d.).

Design considerations

With respect to design process and implementation of a rain garden, a series of aspects should be concerned, basically regarding location determination, adjustment of size and type, plant selection, and maintenance plan. This section analyzes and summarizes these aspects that a typical rain garden needs to consider. Practically, the applications of rain gardens are contextually diverse and based on the exact evaluation of site study and analysis.

Location determination

In terms of location determination, it is necessary to do a rainy day observation for general understanding of the existing drainage pattern on the property. With the assistance of relevant information like site plan and topographic map which can be obtained from certain departments of the local government, it would be efficient and accurate to find out how runoff flows and where rainwater collects, and help arrange an appropriate space for the rain garden.

Based on lessons from previous practices, it is recommended by authorities in the US to situate rain gardens at least 10 feet (3.48 meters) away from buildings to prevent property damage caused by water seepage into foundations (UACDC, 2010). It would be best to place rain gardens at sunny or partly sunny locations, which increases evapotranspiration rates and makes rain gardens dry out quickly between storm events. Also, plant selection would be more flexible because of more exposure to sunlight (Venhaus, n.d.). It could damage tree roots if rain garden excavation processes are conducted under large, mature trees (GSWCD, 2006). Rain gardens should not be placed at low-lying areas where water always collects after a storm event, since this phenomenon indicates that these areas are poorly drained because of compacted soil or poor landscape grading. Rain gardens are designed to infiltrate and draw down standing water within 24 hours, rather than holding water like ponds or wetlands. It is recommended that soil for a rain garden should be amended with organic material such as compost and sand to ensure efficient infiltration if needed (MSD, 2008). Almost flat or slightly sloping areas (less than 12%) are supposed to be preferred option selected for rain gardens to avoid excavation problem and make sure they can capture the most stormwater runoff from surrounding impermeable areas (MSD, 2008). Rain gardens should not be designed independently and merely focused on stormwater consideration without concerning other features of local context. It is favored to make the rain gardens merged with existing landscaping rather than float them purely and simply. Before installing a rain garden, it is recommended to consult with relevant department to accurately locate underground utilities, including buried cables, lines and pipes (Franti & Rodie, 2013). To avoid destroying underground infrastructure, safe distance should be determined according to local ordinances and zoning regulations, with which other design applications for a rain garden also need to keep consistent. Table (2.3) as follows briefly summarizes eight main points for location determination as mentioned above.

Checklist of Location Determination of a Typical Rain Garden
- Situate rain gardens at least 10 feet (3.48) away from buildings
- Place rain gardens at sunny or partly sunny locations
- Locate rain gardens away from mature trees to prevent damage to tree roots
- Keep rain gardens away from low-lying areas where rainwater collects
- Situate rain gardens on almost flat or slightly sloping areas (less than 12%)
- Make rain gardens integrated with existing landscaping rather than alone
- Consult with relevant department to accurately locate underground infrastructure
- Safe distance should be determined according local ordinances and zoning regulations to avoid destroying underground utilities (buried cables, lines and pipes)

Table 2.3 Location Determination for a Typical Rain Garden

Size and types

To determine the size of a rain garden, refers to the volume of stormwater that the rain garden is expected to hold before the water overflows from the outlet (Emanuel,

etc., 2010). The expected volume is applied to calculate the area of the rain garden, as long as the ponding depth of rain garden has been determined according to the factors, including infiltration rate and slope of selected location. The formula as follows is described to calculate the expected volume (EV), which is determined by the drain area (DA), runoff value (RV) and design rainfall depth (DRD) (Franti & Rodie, 2013).

EV = (DA1*RV1+DA2*RV2+…)*DRD

The Drain Area should be counted after site observation and analysis with assistance of site plan and topographic map or other relevant information from certain departments of local government. In terms of runoff value, it is typically indicated in Table 2.4 (Golon & Okay, n.d.). The specific runoff values for different types of surface vary contextually, which are supposed to obtain from local government. Design rainfall depth refers to local precipitation and the amount of rainfall that is expected to be collected by the rain garden.

Types of Surface	**Runoff Value**
Roof, parking lot, concrete walks, decks, patios and driveways	0.9
Lawn, woodlot, turf, playing fields and planted garden beds	0.25

Table 2.4 Runoff Value

The ponding depth designed for a rain garden depends on the rate that the water infiltrates into the soil. It is preferred to make sure the garden will fully drain in 24 hours to prevent vegetation in the rain garden from being flooded (Franti & Rodie, 2013). Ideally, the ponding depth of a rain garden range from 6 inches to 8 inches according to measured infiltration rate (6inches/day to 8inches/day). If the measured infiltration rate is 3-6 inches/day, another location with higher infiltration rate is recommended. Otherwise, more construction space and plants are necessary to ensure adequate capacity for holding water. When the measured infiltration rate is greater than 8inches/ day, the ponding depth can be set equally to the infiltration rate (Max.12inches) (Franti & Rodie, 2013). The elevation of outlet is determined and used to control ponding depth, which is measured from the surface of gardens at its lowest point. Generally, rain gardens should be from 6 inches to 12 inches for ponding depth, adding 2-4 inches of extra depth to prevent overflow (Emanuel, etc., 2010). Deeper rain garden with more than 12 inches of ponding depth would limit plant selections with the increased potential for submerged plants; human activities could be limited as well because of safety problem (Franti & Rodie, 2013). When the rain garden ponding depth (RGPD) is designed, the design area of the rain garden can be determined by the formula as follows:

Design Area= EV/RGPD= (DA1*RV1+DA2*RV2+…)*DRD/RGPD

The following step is to shape the rain gardens with determined size factors as mentioned above. In accordance with a good rule of thumb, the length of a rain garden is supposed to be perpendicular to the slope along the contour, which allows the rain garden to intercept as much stormwater runoff as possible (GSWCD, 2006). Adequate width of a rain garden not only encourages stomwater to spread evenly over the bottom of the garden, facilitating infiltration, it also provides sufficient room for growing diverse vegetation (Bannerman & Considine, 2003). Figure 2.6 indicates the width section of a typical rain garden (VicUrban, n.d.). The specific size and type of the rain garden in

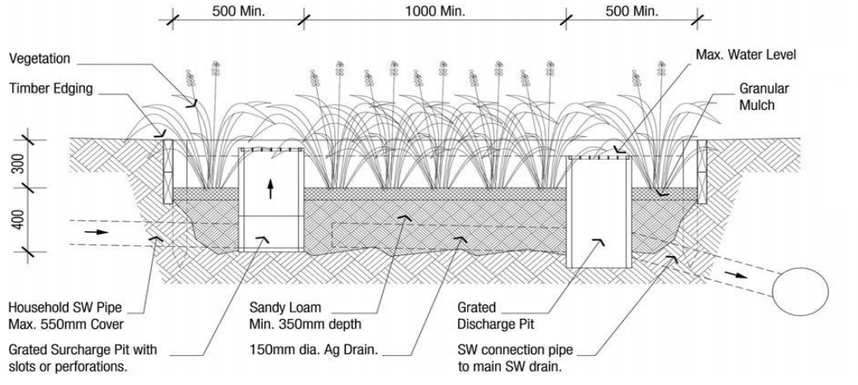


Figure 2.6 Typical Rain Garden Section (Minimum Requirements) ©VicUrban. Public Domain. Retrieved from: http://www.wsud.org/wp-content/uploads/2012/05/Aurora-Raingarden-Installation-Guide-for-Verification-manual-180607.pdf

a given location also depends on your budget, how to integrate with existing drainage system, and how to combine with adjacent landscape and amenity. Thus, the detailed design of a rain garden is not mandatorily limited to the guidelines above, which the specific decision should be made according to existing conditions.

Plant Selection

Priority should be given to native species because of their tolerance and acclimation capacity to local climate, soil, and moisture conditions, also their synergy with each other. It is important to select local plants that are competent in both temporarily wet and dry soil condition without application of fertilizers and chemicals (Venhaus, n.d.). Native plants require less maintenance, which therefore saves cost for owners. Besides those aspects as mentioned, other factors for planting considerations also involve space anticipation for full grown plants, appearances (shape, color, height and width) during different seasons, coordination with adjacent urban landscape (FCB, n.d.). It is recommended to inquire local nursery for informative planting measures and strategies.

Maintenance

Maintenance practices for rain gardens are similar to convention gardens, including removal and replacement of dying and/or dead vegetation, mulch applications, and eroded areas repairing (Venhaus, n.d.). Periodic inspections on both plants and (inlet and outlet) pipes should be conducted to maintain effective functioning and drainage of a rain garden. Selecting native vegetation for rain gardens would help reduce monitoring needs and save maintenance costs (GSWCD, 2006).

Benefits

Through infiltration and evapotranspiration, rain gardens reduce stormwater runoff in rate and volume, and contribute to ground water recharge. Stormwater infiltration by a rain garden is approximately 30 percent more than a conventional lawn (Venhaus, n.d.). Stormwater runoff from impervious areas carries lawn fertilizers and pesticides, oil and fluids from vehicles, and other substances (Bannerman & Considine, 2003).

Application of rain gardens helps settle out and filter these pollutants during stormwater infiltration through mulch layer and engineered soil (Venhaus, n.d.). Vegetation applied in rain gardens also provide water treatment through biological uptake. Although individual rain garden provides limited contribution to drainage especially in heavy storms, cooperatively their wide implementation and integration provide significant ecological values (Bannerman & Considine, 2003). In addition, rain gardens provide wildlife habitats and become inviting and aesthetically when properly designed and implemented, integrating with existing landscape.

Limitations

Possible failure of rain gardens can be attributed to multitudes of reasons, involving plants, soil condition, and drainage pipes. Extended water ponding in a rain garden not only threatens vegetation, also causes mosquito breeding and odor emissions (Venhaus, n.d.). Under-drain pipe can be installed to the underlying soil of the rain garden to reduce residence time of water. Rain gardens are vulnerable to clogging issues because of accumulated sediment, which negatively affect drainage functioning of the rain gardens (City of Edmonton, 2011). Thus, periodic maintenance and inspections after major storms should be conducted to ensure effective functioning of rain gardens. Maintenance and construction practices may contribute to soil compaction, which reduce soil permeability and disable water infiltration (Venhaus, n.d.). Another concern to a rain garden is the considerable footprint, which occupies 5 to 20 percent of the area (City of Edmonton, 2011). Moreover, without collective application, single rain garden is not competent for a large contributing drainage area.

2.4.3.3 Permeable Paving

With increasing urbanism, impervious paving has been inevitably replacing original green elements to satisfy ordinary activities of humans, especially the needs for vehicles and pedestrians. This trend increases stormwater runoff volume, causing flooding issue and degrading water quality. To mitigate this problem, permeable paving, also known as porous pavement allows stormwater to be spread out and vertically flow through

voids in hard surface to the soil underground (UACDC, 2010). Permeable pavements are typically applicable in low-traffic areas, including residential streets, parking lots, alleys and trails for both pedestrian and vehicular movement (Venhaus, n.d.). Besides stormwater treatment, permeable paving can also enhance driving safety, alleviate the urban heat island, and improve aesthetical value of landscape, etc.

Design considerations

Literature shows there are five types of pervious pavements, including permeable asphalt (PA), pervious concrete (PC), permeable interlocking concrete pavers (PICP), concrete grid pavers (CGP), and plastic grid pavers (PG). (Hunt & Collins, n.d.)

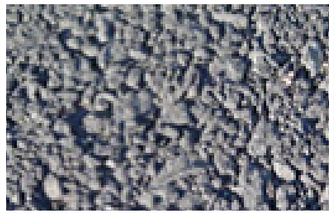
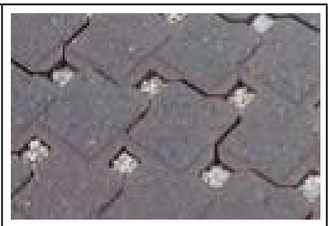
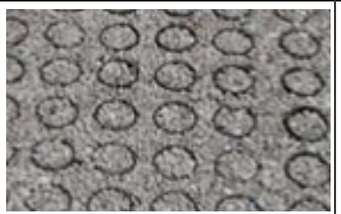
		
PA	PC	PICP
		
CGP (with grass)	PG (with gravel)	PG (with grass or gravel)

Table 2.5 Five Types of Pervious Pavements.

With the common purpose to reduce stormwater runoff, different types of permeable pavements mentioned above vary, regarding their appearance, load capacity, aesthetic value, installation, maintenance, as well as performance of stormwater management. Without blending sand in the mix, pervious asphalt and permeable concrete with high level of void ratio filter water through their porous open-cell system. However, surface clogging of pervious asphalt and permeable concrete has become the problem in their performance, which influences their capacity of stormwater runoff reduction and increases maintenance difficulty (Metrovancourver, 2012). Concrete grid pavers and plastic grid pavers appear in the similar grid systems with approximately (20-50) percentage and (90-98) percentage of voids respectively, which can be filled with gravel or soil with grass growing in the void spaces (Hunt & Collins, n.d.). Permeable interlocking concrete pavers can be various in different shapes and sizes, which consist of impermeable concrete modular pavers with highly pervious gapped and stone-filled joints that receive stormwater and allow water to infiltrate between interlocking pavers (ICPI, 2008). By contrast with porous concrete and asphalt paving, permeable interlocking concrete pavements perform more successfully in preventing clogging problem (ICPI, 2008). Practically, the selection of permeable pavements depends on analysis of traffic loads, budgets, aesthetic visions and maintenance plan, and other factors, which should be determined by designers, engineers and clients.

Tree types of permeable pavement designs

With porous open-cell system in the surface, permeable pavements enable stormwater percolate through them and be temporarily stored in the gravel reservoir underneath and infiltrated into soil sub-base (Caltrans, 2013). Generally, there are three types of pervious pavement structure, which consists of full infiltration, partial infiltration, and partial infiltration with flow restrictor. As shown (see Figure 2.7), they all have a similar structure, including surface pavement layer, reservoir layer, and sub-base. For the type of full infiltration, there is no under-drain layer, while types of partial infiltration and partial infiltration with flow restrictor include underdrains (Metro Vancouver, 2012). Surface layer is visible that people can see and the types of pavements have been mentioned above, such as permeable interlocking concrete pavers. Reservoir layer is filled with gravels to enhance load-bearing capacity vehicles and pedestrians, and temporarily store water as well. Sub-base is the layer of underlying soil with permeability to some extents, allowing water infiltration. Underdrains are usually needed when underlying soil has low level of permeability (less than 15mm/hr) (Hunt & Collins, n.d.).

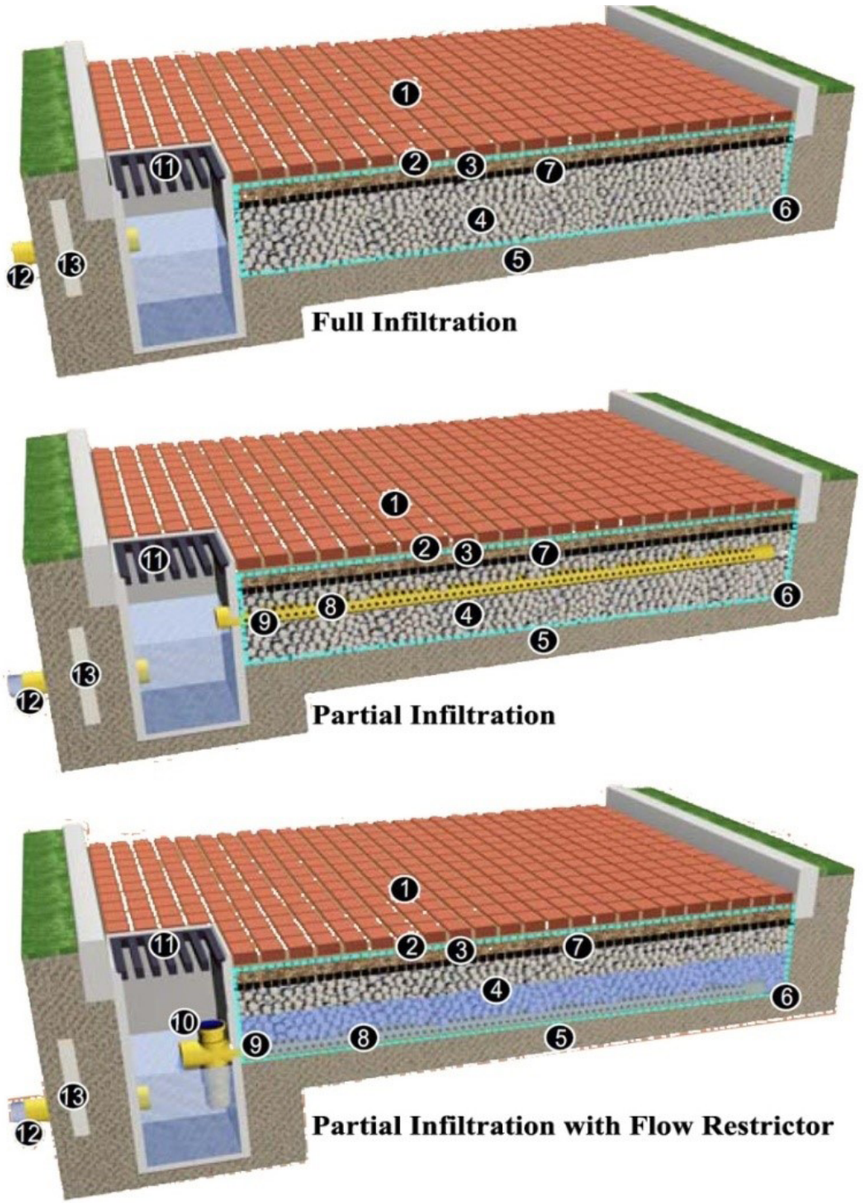


Figure 2.7 Three types of permeable paving designs. ©Metrovancourver, 2012. Used with Permission. Retrieved from: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012.pdf

Legend: (Figure 2.7)	
1	Permeable Pavers (Min.80mm thickness)
2	Aggregate Bedding Course – not sand (50mm depth)
3	Open Graded Base (depth varies by design application)
4	Open Graded Sub-base (depth varies by design application)
5	Subsoil – flat and scarified in infiltration designs
6	Geotextile on All Sides of Reservoir
7	Optional Reinforcing Grid for Heavy Loads
8	Perforated Drain Pipe 150mm Dia. Min.
9	Geotextile Adhered to Drain at Opening
10	Flow Restrictor Assembly
11	Secondary Overflow Inlet at Catch Basin
12	Outlet Pipe to Storm Drain or Swale System. Locate Crown of Pipe Below Open Graded Base (no.3) to Prevent Heaving During Freeze/Thaw Cycle
13	Trench Dams at All Utility Crossings

Benefits

Permeable pavements are designed to reduce impervious surface that facilitate rain water infiltration. They capture stormwater runoff from their pavements, also other surrounding areas such sidewalks, roadways, parking spaces, and rooftops (New Jersey, 2004). Gravel layers underneath increase storage capacity for water, allowing more residence time for water infiltration thus reduce water runoff volume and rate, especially during heavy storms. Permeable pavements help mitigate urban heat island effect through evaporation and support tree growth by filtrating rainwater to surrounding areas to be well absorbed by tree roots (Caltrans, 2013). In comparison with other types, PICP (permeable interlocking concrete pavers) contributes to sustainability at a high level, as they can be installed without binders made of oil-based materials, thus reduces carbon footprint and potential of global warming (ICPI, 2008). Applied to parking space, permeable pavements alleviate pollution source entering water system by discouraging contaminations washed from underside of vehicles (Caltrans, 2013). In addition, PICP is highly recommended as they can be more flexibly designed in regards to their color, size, and shape as needed, becoming aesthetically pleasing as a landscape feature.

Limitations

Unlike conventional pavements, permeable pavements do not feature loadbearing capacity to support heavy vehicle traffic without particular designed structure (City of Edmonton, 2011). Thus, pervious pavements are usually implemented in those areas with limited loading requirements. Those undesirable sites for permeable pavements include auto commercial services (Gas station, car wash store), truck parking areas, and industrial areas (Hinman, 2005). Maintenance and construction costs are relatively higher than other green stormwater facilities, and even more expensive than conventional pavements, which can be attributed to sufficient thicker requirement to increase water storage and adequate load-bearing capacity for vehicles (Hein, etc., 2010). However, the fact tends to be reasonable and acceptable when cost comparison considers an entire system regarding the reduction of conventional drainage infrastructure such as catch basin and underground drainage pipes for stormwater management.

2.4.3.4 Rainwater Harvesting

Rainwater harvesting is part of sustainable stormwater drainage system which is attractive to individual or business use, as water usage not only saves resources, energy and cost over time, but also helps detain water during heavy storms. Harvesting facilities can be applied to address stormwater in almost every types of land use, either high dense urban areas or rural properties (Paterson, 2010). Typically, stormwater harvesting serves either larger complexes or private buildings, which includes rainwater collection, storage, and reuse from rooftops (UACDC, 2010). Storage volumes designed for a rainwater harvesting facility are based on contributing drainage areas, as well as the intended use and demand for captured stormwater. Besides the usage for landscaping irrigation and domestic water supply, the harvesting facilities can be integrated with landscaping or architectural design such as fountains and cascade for recreational use (Hoyer, etc., 2011).

Design considerations

Because of minimal site constraints compared to other green stormwater infrastructure, rainwater harvesting facilities can be installed in most land use types such as residential, commercial, and industrial areas. Basically, the rainwater harvesting system includes three stages: capture stormwater runoff from rooftops; convey them through downspouts to cisterns for storage and purification as needed; then divert the treated rainwater for intended usage (either indoor or outdoor) through a distribution system (BWSC, 2013). Figure 2.8 indicates basic components included in a typical rainwater harvesting system.

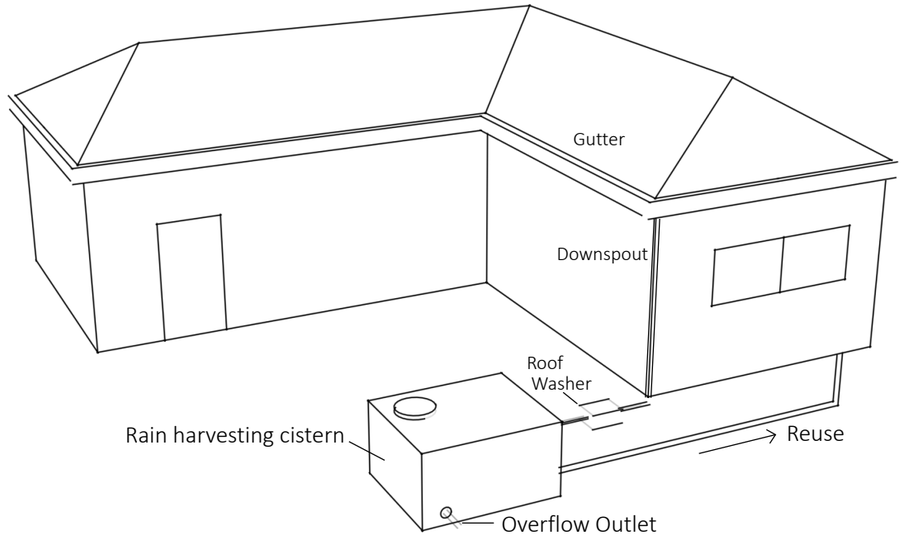


Figure 2.8 Rainwater Harvesting System Schematics

Rainwater harvesting facilities can be constructed of many types of materials such as rain barrel, slim tank, (plastic/fiberglass/metal/wood) cistern, precast ferrocement tank and bladder tank (UACDC, 2010). Their scale contextually varies, depending on the quantity of water needed for intended use and contributing drainage area. The rainwater

cisterns can be sized from hundreds of gallons for domestic uses up to tens of thousands of gallons for commercial or industrial uses (Paterson, 2010).

There are three types of tanks categorized by locations where rainwater cisterns can be installed: outdoor above-ground tanks, outdoor below-ground tanks, and indoor tanks (Paterson, 2010). Outdoor above-ground tanks can be placed closed to building and incorporated with landscape and architectural design to provide recreational use and aesthetical value. To maintain water quality and efficient water usage, relevant approaches should be applied to prevent sunlight penetration and provide frost protection for outlets (RDN, 2012). Compared to above-ground tanks, outdoor belowground tanks are usually more expensive because of excavation and installation costs. However, maintenance may be cost-effective, as they are not influenced by sunlight and frost (RDN, 2012). Regarding indoor tanks, they can be installed in garages or basements, while drainage for overflow should be efficient and sufficient to impede leakage in the foundation of buildings.

Although moderate maintenance is required for rainwater harvesting system compared to other LID facilities, rainwater collected in the cisterns should be diverted for intended use periodically between storm events to enhance storage capacity, reduce stormwater runoff volume and rate, and prevent odors (UACDC, 2010). It is necessary to inspect the mosquito screening on the overflow pipe regularly during frequent storm period and determine requirement for renewal as needed (BWSC, 2013). If budget allows, automatic devices for diverting the first flush of rainwater away from the harvesting tanks should be installed, or the inflow downspouts should be disconnected with the harvesting facilities until rain events have begun for a while (BWSC, 2013). Other regular inspections for a harvesting system involve obstruction check for gutters and downspouts, as well as any accessories related to the cisterns such as inflow and outflow pipes, and water pump, etc (Paterson, 2010).

Benefits

As part of Low Impact Development (LID) techniques, rainwater harvesting system contributes to multitudes of advantages, involving reduction of stormwater runoff in volume and peak flow rate entering to surface water system, energy and cost saving on water utility bill through reuse of water for different purposes. Rainwater harvesting facilities can provide high quality water sources without chlorine found in centralized water supplies and minimal purification or disinfection are required for non-potable use, such as toilet and sink flush (indoor), and garden watering (RDN, 2012). Rainwater harvesting system features cost-effective technique with simple design and construction and small footprints for placement, facilitating more participation, installation and sustainability at community level (Worm & Hattum, 2006). Through proper design and construction, rainwater harvesting cisterns can be integrated with adjacent urban landscape and provide water for recreational use, such as fountains and cascade.

Limitations

To efficiently maintain a rainwater harvesting system, regular inspections, facility cleaning, occasional repairs and replacements are indispensable (Worm & Hattum, 2006). Without proper and regular supervision, problems such as pipe clogging by sediments and, potential structure cracking and overflow freezing during cold season would occur (BWSC, 2013). Rainwater trapped from rooftops should not be used as potable purpose or watering food vegetation unless reliable purification and disinfection can take place before they are distributed for intended use. In addition, without regular maintenance and qualified construction, rainwater harvesting cisterns may undergo algal growth and play a role in breeding space for insects, lizards and rodents (WaterAid, 2013). Thus, proper and reliable maintenance plan should be well prepared with assistance of licensed engineer to successfully implement a rainwater harvesting system.

2.4.3.5 Bioswales

Bioswales, usually applied along roads as linear planted channels, are designed to be bioretention devices that not only convey rainwater, in which stormwater treatment also takes place in the meantime through phytoremediation (UACDC, 2010). Besides application along roads, they can be implemented in open spaces, parking lots, and other urban settings as well. After appropriate planning and design, bioswales can

be well integrated with a variety of vegetation and fit into almost any types of urban landscape. Based on existing condition, drainage pipes and gravel reservoirs can be constructed underneath bioswales, where soil permeability is limited, to enhance infiltration and storage capacity as needed (Venhaus, n.d.). The cities of Portland and Seattle are recognized for their built project initiatives and performance of bioswales in roads, streets, and parking lots, etc.

Design Considerations

Bioswales are usually installed in most developed areas, such as residential streets, business complexes, parking lots, and other types of green space. Designed as a part of a larger and complete drainage system, they can be constructed and integrated with adjacent urban landscape, as long as they are sized to address two-year, five-year, or ten year, twenty-four-hour storm events according to the standard established by local municipalities (Jurries, 2003). They can be situated along property boundaries to serve more than one properties. Because of their competency to capture sheet flows and linear feature, they are commonly applied to replace conventional drainage pipes or ditches, providing water treatment and infiltration during stormwater conveyance (City of Edmonton, 2011).

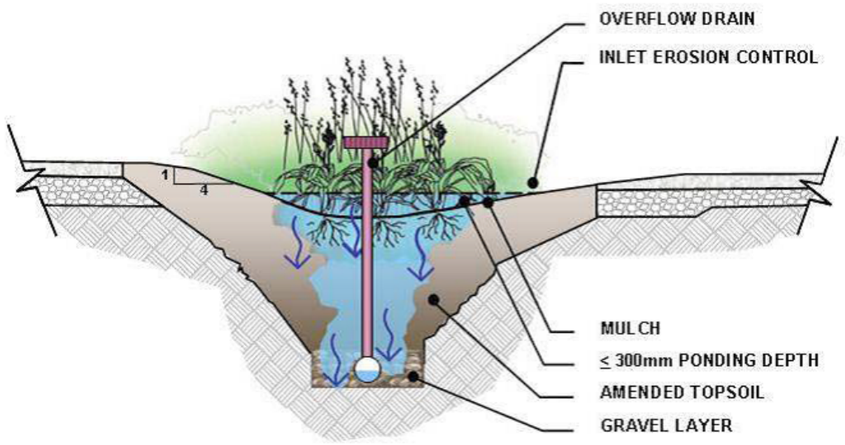


Figure 2.9 Cross-Section of a Bioswale. ©Environmental Planning group, Drainage Services, Edmonton, Alberta, 2011. Used with Permission. Retrieved from:http://www.edmonton.ca/city_government/documents/PDF/LIDGuide.pdf

As shown (see Figure 2.9), the cross section of a typical bioswale consists of four basic layers, from top down, including vegetation, amended soil, gravel reservoir and outflow drain. The cross section of bioswales can be generally shaped in three types, including “U”, “V”, and “trapezoid”, while trapezoid-shaped swales with no deeper than 1:3(vertical: horizontal) have been widely applied as the most effective shape for stormwater infiltration and treatment during conveyance (U.S. EPA, 1999). The slope limitation is applied to prevent erosion and/or slippage of the side slopes. Bottom width of the bioswales normally ranges from 0.6 feet to 2.4 feet, to allow regular mowing and avoid gully effect (City of Edmonton, 2011).

Flow velocity of stormwater runoff within a bioswale is affected by the synergy of the swale’s longitudinal slope and roughness, according to the plant selection and coverage (Jurries, 2003). Flow velocity of water in the bioswales are generally less than 140 liters/second, or erosion would be a concern caused by high water velocity (U.S. EPA, 1999). Typically, the longitudinal slope of bioswales range from 1 to 6 percent, while the optimal slope is between 1 and 2 percent (Venhaus, n.d.). To extend residence time of stormwater and reduce water velocity, check dams are recommended to be applied within the bioswales and placed no more than 20 feet apart (Caltrans, 2009). Check dams also avoid erosion damage to vegetation, increase stormwater infiltration and promote pollutant removal. Through check dams enhance water storage capacity; ponding depth of bioswales should be designed to ensure stomwater drawdown into underlying soil within 24 hours after storm events to avoid mosquito breeding. An under-drain system with valve can be applied to help control residence time of stormwater (Jurries, 2003). In order to effectively treat stormwater runoff, ponding depth of stormwater in the bioswales should not fully submerge the vegetation (U.S. EPA, 1999).

Flow velocity of stormwater runoff will be influenced by different species of vegetation so that plants with capacity to control design water flows and resist with erosive potential during heavy storm events should be selected in preference (City of Edmonton, 2011). Usually, native varieties are optimal to thrive at local site and plants with deep root system will help increase soil permeability for water infiltration. Moreover, plant selection based on species that feature water-resistant, drought and salt

tolerant not only contributes to high degree of pollutant removal, also save cost for plant maintenance (QAC, 2007). Construction, maintenance, and other development activities adjacent to or directly relevant to the bioswale should avoid soil compaction, making swales not able to efficiently absorb and infiltrate rainwater (Venhaus, n.d.). Regular and frequent maintenance practices contribute to effective functioning of bioswales. Usually, drainage inspection and damage check should be conducted annually and after heavy storm events (Venhaus, n.d.). Periodic maintenance activities also involve weeding, mowing, watering during drought season, reseeding in bare spots, and clogging clearing (U.S. EPA, 1999). The application of pesticides and fertilizers should be eliminated or minimal as needed to prevent groundwater contamination.

Benefits

Bioswales contribute to more advantages than conventional drainage system. They not only convey stormwater as drainage pipes do, also provide treatment to enhance stormwater quality through phytoremediation in the meantime. As mentioned, check dams added to a bioswale prolong residence time of rainwater in the swale, allowing for more water infiltration and pollutant removal, and reducing peak runoff flow during heavy storms. Water treatment in the vegetative swales involves removal of sediment, oil, grease, metals and nutrients at different levels (QAC, 2007). When properly and creatively designed and implemented, bioswales can take advantages of various plant materials to become aesthetically pleasing. Integrating with other landscape features make bioswales more inviting and acceptable for people. For example, bridging over swales can be attractive to the public for recreational activities and thus encourage people to be aware of sustainable stormwater management (Caltrans, 2009). Lower capital cost of bioswales is another merit in comparison with conventional drainage system. This fact has been shown by the Seattle Public Utilities that bioswales provide more significant promotion for water quality during conveyance and are more cost-effective than traditional stormwater management (QAC, 2007).

Limitations

One of the most critical limitations is that individual swale only address small areas and is vulnerable to heavy storm events as runoff flows of high velocity and large volume can threaten vegetation cover with erosion potential (City of Edmonton, 2011). To overcome this situation, application of check dams and regular maintenance are recommended for bioswale implementation and practices. Many municipalities restrict the application of bioswales by municipal code when peak discharges beyond 140 liters per second, which leads to high potential of soil erosion and is difficult to maintain (U.S. EPA, 1999). Other concerns of bioswales can be referred to potential safety issues, odor emissions, and mosquito breeding due to long term and deep ponding water remained in the bioswales (U.S. EPA, 1999).

2.4.3.6 Stormwater Planter

Stormwater planters are structural reservoirs intended to capture stormwater runoff from impermeable areas, which feature long and narrow landscaped facilities with level bottom (City of Salem, 2014). They are usually implemented along streets beside sidewalks with limited space and can be also installed immediately next to buildings. Compared to bioswales, stormwater planters contain more storage volume for stormwater in limited space (U.S.EPA, 2009). Stormwater planters not only reduce stormwater runoff, but also provide water purification through vegetation. They can be designed to accommodate trees and other vegetative species, especially native varieties, which provide attractive habitats for wildlife and also contribute to aesthetics of urban landscape.

Design Considerations

Typically, there are three types of stormwater planter, including infiltration planter, partial infiltration planter, and filtration planter. They are designed and installed based on infiltration rate and location condition (City of Salem, 2014). Infiltration planter can be applied with infiltration rate larger than 0.5 inches per hour and when the space is sufficient for construction. Otherwise, partial infiltration planter is recommended, which requires under-drain system to control stormwater overflow during extreme precipitation events. Both infiltration planter and partial infiltration planter should

be placed at least 10 feet (3 meters) away from buildings to prevent water seepage into building foundation, while filtration planter can be applied immediately next to a building as this type of planter contains under-drain system for stormwater overflow and impervious bottom to prohibit water infiltration (Paterson, 2010). Gravel layer can be added underlying growing media to enhance water storage capacity. Based on the best practices, infiltration planters and partial infiltration planters are supposed to have a minimum width of 2.5 and 1.5 feet (approximately 0.8 and 0.45 m), respectively (Paterson, 2010). Figure 2.10 typically indicates the sections of infiltration planter on the left and filtration planter on the right. They both include three common layers, vegetation on the top, followed by growing substrate, and gravel layer for water storage. Compared to infiltration planter, filtration planter has extra under-drain system for stormwater overflow because the impervious bottom prevents water infiltration into underlying soil.

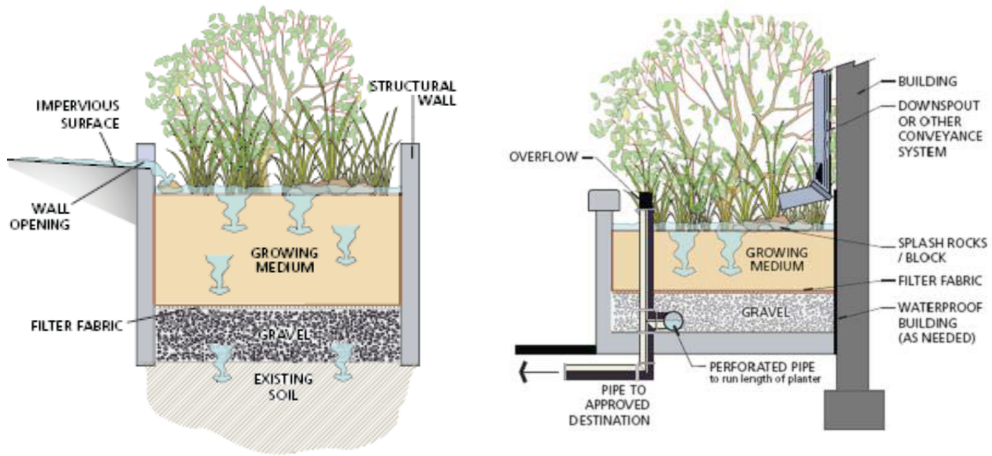


Figure 2.10: Infiltration Planter (left) and filtration Planter (right) sections. © Queen Anne's County, Centreville, Maryland, 2007. Public Domain. Retrieved from http://www.mde.state.md.us/assets/document/Design%20Manual%20Chapter%205%2003%2024%202009.pdf

Periodical inspections and maintenance, involving both vegetation maintenance and planter structural components, are significant to the efficient functioning of stormwater planters. Sediments and trash cleaning should be conducted in inlet and

outlet pipes, and curb cuts on a weekly or monthly basis to avoid clogging issues and allow for effective drainage (QAC, 2007). During dry seasons, plants including local varies are supposed to be watering as needed until the plants become established and stable (City of Salem, 2014). Maintenance activities for vegetation involve weeding, branch pruning, dead plants removing and replacing (Paterson, 2010). Excessive use of pesticides, fertilizers, and herbicides should be avoided as they have high risks in contaminating groundwater.

In order to accommodate large size species (trees and/or shrubs), a matrix of buried plastic cells assembled aligned with designed shape and size can be an alternative to regular planters as mentioned (City of Edmonton, 2011). Tree trench stormwater planter contains the similar layers with regular planters, including tree, growing media accompanied with surrounding gravels, and under-drain for overflow. As shown in Figure 2.11, the assembled matrix also provide loading-bear capacity for sidewalks while allowing for deep penetration of tree root (City of Edmonton, 2011).

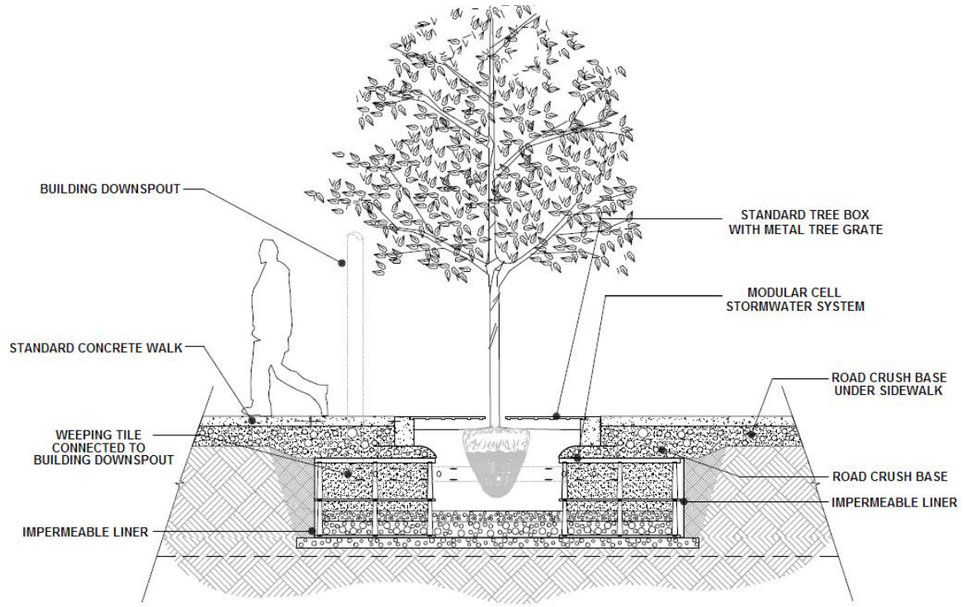


Figure 2.11 Tree Trench Stormwater Planter with Cell Structure ©Environmental Planning group, Drainage Services, Edmonton, Alberta, 2011. Used with Permission. Retrieved from: http://www.edmonton.ca/city_government/documents/PDF/LIDGuide.pdf

Benefits

Stormwater planters are capable for rainwater retention and treatment. Primary mechanisms of stomrwater planters for rainwater management includes surface infiltration, evaporation and transpiration, deep infiltration (as needed), and delayed release to other drainage system (arterial pipes or retention ponds) (City of Edmonton, 2011). Compared to other LID techniques, stormwater planters are relatively ideal for constrained sites with setback regulations, steep slopes and underlying soils of poor permeability (QAC, 2007). Although individual stormwater planter has limited capacity for large contributing drainage area, the synergy of wide-spread implementation along the length of a corridor would enhance their stormwater management capacity to a significant level (QAC, 2007). Through proper design, stormwater planters can be aesthetically pleasing as a landscape feature, which also provide attractive wildlife habitats.

Limitations

Stormwater planters have limited capacity for a large contributing drainage area that downstream drainage facilities or connection to arterial pipes are necessary to address heavy storm events. Compared to infiltration planters, filtration planters only provide rainwater detention and treatment, but not take responsibility for groundwater recharging (City of Edmonton, 2011). Stormwater planters require construction of vertical walls, which increase initial cost of installation. By contrast, filtration planters can be more costly than infiltration planters due to extra needs for pipe connection and waterproofing devices to prevent damage to building foundation.

2.4.3.7 Retention Pond

Stormwater ponds have been implemented more frequently than other smaller scales of green stormwater infrastructure to capture stormwater runoff from a large drainage area. There are several terms to describe stormwater ponds, such as retention ponds, retention basins, wet detention ponds and SUDS (Sustainable Urban Drainage System) ponds (Olsson, 2011). They are artificial facilities, which imitate naturally occurring wetlands and ponds for stormwater management. Retention ponds will be applied as the term for following presentation. Retention ponds not only contribute to reduction of stormwater runoff rate and volume, also provide significant stormwater treatment through natural functions such as sedimentation, decomposition, solar disinfection and soil filtration (Waelti, 2012). In comparison with retention ponds (wet ponds), Detention ponds (dry ponds) are normally dry between storm events. Detention ponds temporarily detain water during storm events and then slowly release stormwater through under-drain system, while retention ponds have a permanent pool to hold back a constant amount of water (TUHH, n.d.). Figure 2.12 simply indicates the basic distinction between retention ponds and detention ponds that there is an additional outlet installed to the bottom of detention pond to slowly release stormwater.

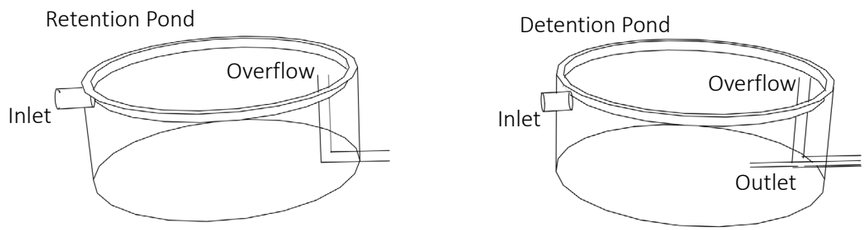


Figure 2.12 Difference between a retention pond (left) and a detention pond (right)

Design Considerations

Basically, a retention pond consists of a sediment forebay, a permanent pool and an overflow structure. Figure 2.13 shows the basic design components included in a retention pond (UDECD, 2011). A sediment forebay situated at the outfall of the drainage pipe, ditch, or swale channel directed toward the retention pond is intended to enhance water quality (DCR, 2011). The forebay extends water treatment space and period, allowing heavier particles to drop out of suspension before stormwater flow into the permanent pool, where is the settlement for lighter sediments (U.S.EPA, 1999a).

Typically, soil permeability between 10-5 and 10-6 cm/sec would be sufficient to maintain a permanent pool (U.S.EPA, 1999a). Retention ponds are inappropriate to be constructed in the areas where underlying soils provide efficient infiltration rate or/and

the precipitation events are insufficient to maintain a permanent pool of water for basic functioning (BWSC, 2013). In this case, impervious liner is supposed to be installed to the bottom of the pond to avoid high infiltration rate. Otherwise, high rate of rainwater infiltration would pollute groundwater and be not able to provide effective functioning of wet ponds (DCR, 2011).

Clearly shown in Figure 2.13, the permanent pool of a retention pond includes two zones, safety wetland bench and open water zone. Safety wetland bench goes around the open water zone and features approximately 6 to 12 inches (15cm to 30cm) deep and a minimum of 4 feet (1.2 meters) wide (UDECD, 2011). Aquatic vegetation growing

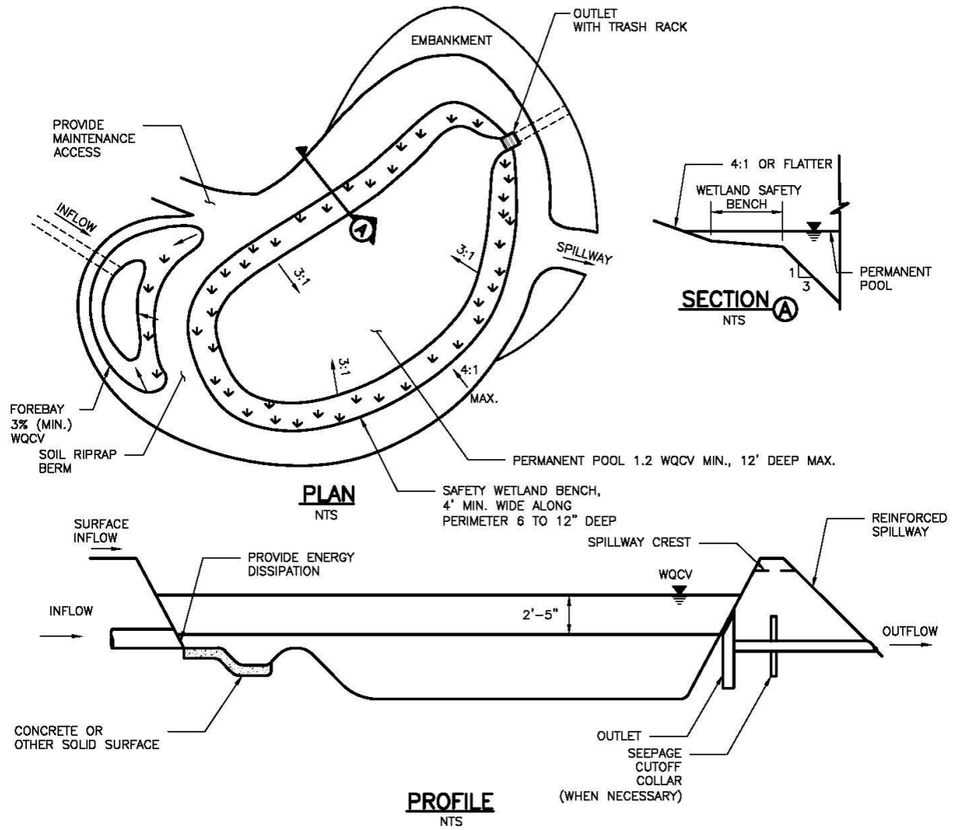


Figure 2.13 Typical retention pond plan and sections. ©Urban Drainage and Flood Control District , 2011. Public Domain. Retrieved from: http://www.udfcd.org/downloads/pdf/critmanual/Volume%203%20PDFs/USDCM%20Volume%203.pdf

within wetland bench zone help intercept and filter surface stormwater flow, protect permanent pond from soil erosion, and provide biological uptake of nutrients (UDECD, 2011). Open water zone should be deep enough to avoid resuspension of trapped sediments, while in a great depth, thermo stratification and anoxic condition would occur within bottom layer of the pond, threatening health of aquatic ecosystem. Fish and wildlife would difficultly survive in shallow basin, whereas in great depth, anaerobic condition leads to resolubilization of pollutants (DCR, 2011). Thus, pond depth should be designed no more than 20 feet (6m) with optimal range from 3 to 9 feet (1 to 3 meters) (U.S.EPA, 1999a). To ensure efficiency of water treatment, the permanent pool is supposed to accommodate stormwater runoff at a minimum volume of twice the water quality volume (BWSC, 2013). This water quality volume should be determined based on local precipitation and water quality information. A multiple stage outlet structure can be designed to provide peak rate attenuation, which can control different levels of design storms (2, 5, and/or 10-year storms), or safely accommodate the 100-year storm event in accordance with local condition and requirements (BWSC, 2013).

The embankment with reinforced spillway is recommended to enhance the integrity of retention pond system. Side slope of the embankment can be designed no steeper than 2:1 (horizontal: vertical) and by covering with turf grasses to impede erosion (U.S.EPA, 1999a). The outlet structure should be remote away from the inlet and inlet should not be fully submerged at normal water elevation (GDSDS, 2005). Retention ponds would be efficiently functioning with proper inspection and maintenance. Routine Maintenance involving embankment and planted area mowing, trash and debris cleaning, pipe clogging check, outlet structure inspections should be conducted properly to avoid expensive repairs or/and replacements due to neglect of regular maintenance (U.S.EPA, 1999a). In general, retention pond design contextually varies for each site and application, which can feature accessible, functional and aesthetical through synergy and collaboration of urban planners, landscape architects and stormwater engineers.

Benefits

Through collecting and retaining stormwater runoff, retention ponds achieve both

runoff reduction in rate and volume, and a high degree in water quality enhancement by physical, biological and chemical processes. These treatment processes reduce pollutants such as sediments, pathogens, bacteria, and nutrients (nitrate and phosphorous) (Olsson, 2011). Well-designed and constructed wet ponds provide recreational use and nature experience for the general public, increasing adjacent property values and achieving sustainability in the meantime (GDSDS, 2005). Through enhancing social interaction with the retention ponds, people tends to be aware of the environmental value of ponds especially in regards with sustainable stormwater management (Olsson, 2011). Educational achievement with particular design not only raises citizens' awareness of environment issues, but helps stimulate implementation and popularization of green stormwater infrastructure.

Limitations

Although stormwater ponds play a key role in reducing large contributing drainage areas meanwhile providing significant water treatment, their initial cost is a serious concern, especially retrofitting a wet pond in developed areas. From pervious practices, retrofitting a retention pond in the developed area would be approximately 5 to 10 times more expensive than constructing a pond with the same size in the undeveloped area (U.S.EPA, 1999a). This situation can be attributed to the limited area left for retrofitting and high cost of land in developed areas as well. Underlying soils of high permeability can be a reason for high cost of construction as modification of pond bottom should be conducted to avoid high infiltration rate and maintain a permanent pool of water for effective functioning.

2.5 Conclusion

Through identifying and studying LID principles and strategies from the literature, lessons have been learned including core theory and system of natural hydrological cycle during pre-development, performance and effectiveness of each type of LID techniques at different scales in last section, and also limitations of LID application and implementation. LID practices focus on imitating natural eco-hydrological function to reduce storm runoff rate and volume, and provide water treatment through biological uptake of vegetation, retention, infiltration, rainwater harvesting, and evapotranspiration. Findings from the literature review were concluded in four general lessons for further research and analysis in regards to green infrastructure planning and implementation. Afterwards, this research summarized four specific principles, informing design application in the Xiamen urban area.

Lesson One: Implement different scales of green infrastructure (LID Techniques) collectively. Different types and scales of green infrastructure feature distinct performance in stormwater management, while individual facilities and techniques only treats limited quantity of stormwater. However, collectively implementing green infrastructure at different scales provides significant effectiveness, which should be also connected with conventional piping to overcome heavy storms. In urban areas, natural green space and corridors have been divided by roadways and building footprints into fragmented pieces. Retrofitting green infrastructure should start with on-site control at various sizes and types, then integrate with underground pipes for potential overflow and connection of stormwater catchment sub-basins to become a complete drainage system. For new development projects, it is necessary to equally address buildings, landscapes and transportation circulations. From landscape-based approaches, green space and corridors should be combined to the greatest extent as possible and alleviate fragmentation, which will facilitate sustainable stormwater management.

Lesson Two: Integrate green infrastructure with the adjacent urban environment and human amenities. Besides the natural function beneficial for stormwater management, green infrastructure, as a landscape feature, also plays an important role in making urban environment more inviting and aesthetically pleasing. Green infrastructure planning and design should respect the existing urban setting and landscaping to ensure urban consistency and identity. Green infrastructure can be integrated with other hardscape features as needed to encourage social interaction closely occur with nature. For instance, bridging over retention ponds or bioswales, and placing benches immediately next to stormwater planters or within roof gardens create opportunities

for recreational use, and meanwhile achieving educational purpose through particular design measures.

Lesson Three: Conduct integrated design by collaboration of planner, landscape designer, architect and engineer. Although green infrastructure generally applies the same theory, imitating the natural hydrologic cycle for stormwater management, different types of green infrastructure have different levels of application and performance due to the variety in size, shape, plant section, location, maintenance and construction requirement, and limitations. Green infrastructure applications are also subject to existing conditions, such as building types and heights, precipitation, soil permeability, moisture, etc., which not only involve landscape, but also building structure and engineering aspects. Moreover, green infrastructure planning should respect with codes and regulations of local municipality. Thus, it is essential to conduct green infrastructure planning and implementation through the close collaboration and synergy of planner, architect, landscape designer, and engineer.

Lesson Four: Provide maintenance plans for green infrastructure at different scales. Unlike conventional piping, green infrastructure demands more frequent periodic maintenance, even though LID practices are commonly recognized as more cost-effective and sustainable approaches for stormwater management. Also, green infrastructure at different scales and locations require distinct maintenance and inspection activities. To save expenditure for repairing and replacement, and prolong lifespan of LID facilities, it is important to enact maintenance plans in accordance with specific scales of green infrastructure.

Connection to Design Interventions

This research identified four specific principles as the foundation to strategically and technically support design interventions for the selected study site (the Culture and Art Centre block) in the Xiamen urban area.

Principle 1: Enable water reuse for domestic demands, landscape irrigation and others
Principle 2: Implement a complete and integrated flow train system
Principle 3: Reduce impermeable paving
Principle 4: Collectively construct green infrastructure at a variety of types and scales

The first principle encourages rainwater usage for domestic demands, landscape irrigation and other purposes, as the City of Xiamen is within the areas of water shortage in China. As part of Low Impact Development techniques, rainwater harvesting systems not only reduce stormwater runoff, but also contribute to energy and cost saving on the water service. Rainwater harvesting systems usually require only a small footprint for placement and construction. When space permits, it would appear practical and necessary to apply rain harvesting systems to help mitigate stormwater impacts and conserve water resources.

The second principle refers to the application of a site-by-site basis to neighborhood-wide approach. This approach aims to form a complete and integrated flow train system for stormwater overflows during heavy storms. More potential opportunities of large-scale green infrastructure should be explored as the next receiving systems to harvest and infiltrate stormwater, rather than convey and release stormwater runoff quickly through piping. The flow train arrangement should respect the existing topography and watershed processes to minimize grading, construction and pumping demands.

The third principle seeks to maximally imitate the eco-hydrological function in the Xiamen urban area. Conventional rooftops, roads, and parking lots contribute to a large percentage of impervious surface, which increases stormwater runoff. Retrofitting these areas to be more permeable would effectively reduce stormwater runoff, enhance water quality and recharge groundwater.

The fourth principle suggests collectively implementing green infrastructure at a variety of types and scales within the study block and adjacent context, which can be referred to previously as lesson one. There are many types of green infrastructure and techniques in need of consideration for different sites and locations. In this research, design interventions should refer to specific requirements and guidance of each green facility expressed in Section 2.4.3.

Chapter 3 Precedent Documentation

This chapter includes two sections: the inquiry of initiatives and performance of Portland and Seattle in implementing LID principles and strategies from policy-based perspectives; and the analysis of typical built-projects regarding their innovative design and applications of green infrastructure for stormwater management and social engagement. The three selected built-projects are the Shoemaker Green in Philadelphia (US); the Tanner Springs Park in Portland (US); and the Olympic Village in Vancouver (Canada). These projects are of differing type, form, and scale, while fulfilling the common basic philosophy, returning natural hydrological function to urban context.

3.1 Precedent City Case Study

This study focuses on the successful experience in Portland and Seattle considered to be precedent cities regarding their implementation of green infrastructure for stormwater management. In September 2014, a one-week field trip to Portland and Seattle in the United States was conducted by the researcher. This includes three key informant-interviews, one in Portland and two in Seattle. Table 3.1 indicates the background of three professional practitioners who have been involved in the practices of LID for many years.

Key Informants	**Profession**
Emily Hauth	Environmental Scientist, Sustainable Stormwater Management, City of Portland, Environmental Services
Tracy Tackett	Planner, Professional Engineer, Green Stormwater Infrastructure Program Manager, Seattle Public Utilities
Thaddeus Egging	Professional Engineer, LEED AP BD+C | Associate, City of Seattle, KPFF Consulting Engineers

Table 3.1 Background of the Key Informants

The analyses are informed by the literature review, three informant-interviews and relevant policy documents. Illuminations from initiatives of Portland and Seattle can be basically characterized by four aspects, including education, policy and regulations, financing and incentives, administration and stewardship.

3.1.1 Education

Education plays a key role in facilitating the implementation of green infrastructure for stormwater management. The term Green Infrastructure has been defined in many ways. The term is usually unfamiliar to the general public, especially regarding the function of addressing stormwater issues, which is also referred as Low Impact Development (LID). Education and Outreach programs help citizens to be aware of the multi-function and multi-benefit of Green Infrastructure, which promotes the implementation of Low Impact Development.The planning process and implementation of green infrastructure can be conducted faster and more effectively if a municipality financially and technically supports broad education programs in the early stage (James & Lahti, 2004). Regarding the necessity of education for the general public, Egging (2014) emphasized the significance and affirmed that Seattle has been contributing in undertaking many education and outreach efforts.

> "Absolutely, it is very important. I think Seattle in general is embarking on the really strong education campaign. I live in the city and I get mailers from the Seattle Public Utility probably twice a year about how to manage stormwater and how to get better about it. I think they are doing a much better job." (Egging, key informant-interview, 2014)

Education for developers is equally critical that they can be more proactive to optimally apply LID principles and strategies to their development projects (Egging, key informant-interview, 2014). Because much of the city has been built with impervious surface, it is significant to educate landowners about the problem and encourage them to do retrofitting projects of existing areas (Tackett, key informant-interview, 2014). Various techniques are applicable to educate people. Having a public engagement committee can bridge the gap between the planning team and the general public. Seattle Public Utility grants with community-based organizations to connect with community members so that information can be efficiently provided to citizens (Tackett, key informant-interview, 2014). The City of Portland conducts education and outreach through workshops, eco-tours, a hotline and other types of technical assistance for eco-roofs and green street programs. Repetition in messaging is necessary to enhance the public awareness that green infrastructure is beneficial for stormwater management (Hauth, key informant-interview, 2014).



Figure 3.1 The rain garden of Mt. Tabor middle school in Portland. (Photo by Wang, 2014)



Figure 3.2 Stephen Epler Hall stormwater planters in Portland State University. (Photo by Wang, 2014)



Figure 3.3 Alameda Island Rain garden in Portland. (Photo by Wang, 2014)

The City of Portland implements green infrastructure programs on campus so that teenagers can engage with nature from an early age, and learn how they can coexist with the world in harmony, rather than destroying it (see Figure 3.1). Another example of education effort is the visually engaging rainwater management system installed at Stephen Epler Hall (student housing) at Portland State University (see Figure 3.2). The planter system traps stormwater runoff from both buildings and the linear plaza between them, for reuse in adjacent landscape irrigation and public restrooms in Epler Hall. This approach helps reduce the water and stormwater utility bill for Portland State University. Wherever and whatever types of green infrastructure were constructed, information signage is installed at the project sites to help citizens understand the natural function of each specific project. In Figure 3.3, the signage clearly informs people about the significance of the rain garden, and indicates the location of other stormwater facilities along the Klickitat neighborhood greenway.

Relevant statistics regarding benefits of green infrastructure implementation would better inform the general public and direct key professionals to shift the ways of thinking

towards sustainable stormwater management. The Portland Bureau of Environmental Services (BES) advocates Low Impact Development by presenting data regarding the piping conditions and history, and the benefits of green solutions. The following data was obtained from a widely-distributed news brochure"Environmental Services by the Numbers" prepared by the Portland BES (see Appendix F). The many benefits would be of great interest to both the general public and the professionals in regions where Low Impact Development is still a new concept.

The first sewer pipe was built in the City of Portland in 1864. Since then, the piping system has grown with the city and reached 2,500 miles. Today, one third of the pipes beyond 80 years old that are in needs of repair and replacement to keep working efficiently. More pipes are reaching the 80-year milestone, requiring an estimated replacement value of 12.5 billion dollars. The Portland BES has been providing a variety of green solutions to reduce demands of piping system and stormwater impacts since the early 1990s. Today, the City of Portland has owned more than 22 acres of ecorroofs, 1,500 green street facilities, 26,000 street trees and 34,480 single family homes with disconnected downspouts. This green infrastructure system contributes to 2.3 billion reduction of stormwater runoff, being harvested and filtered annually. The cost-effective benefits of Low Impact Developmment can refer to the Tabor to the River Program, which reduces the estimated cost ($144 million) for only piping solutions to $81 million using a variety of green infrastructure and LID techniques.

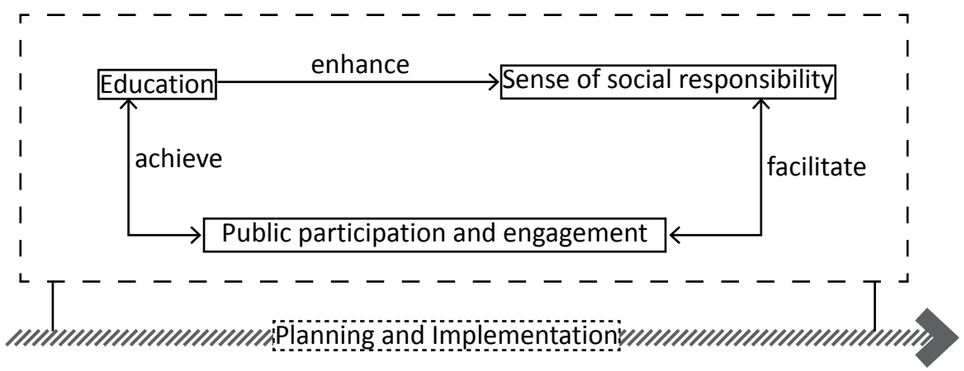


Figure 3.4 The role of education

Both Portland and Seattle have multiple great initiatives and experience in green stormwater infrastructure planning and implementation. Their success could not have been achieved without educating people through various measures. Their planning process was closely connected with public participation and engagement throughout the implementation phases. The illumination can be demonstrated by a closed-loop diagram (see Figure. 3.4), showing how education acts as a catalyst during planning and implementation.

3.1.2 Policy and Regulations

Green infrastructure planning and implementation is inevitably connected with the guidance of general development plans, and specific, integrated and complete regulatory systems. Municipalities are responsible for enacting specific statutory standards that individuals and firms are requested to act in accordance with, to regulate development and consctruction practices. Integrating Low impact Development principles and strategies in Comprehensive plans are positive first steps but lack the specific tools and measures to implement the green infrastructure principles and targets as expressed. Specific and precise development ordinances applied to implement green infrastructure strategies articulated in a comprehensive plan or land-use plan are most practical tools for achieving long-term vision. Comprehensive plans and general zoning plans can be only exercises in wishful thinking if there are no specific regulations in response (Austin, 2014).

The initiatives of Portland and Seattle in green infrastructure planning and implementation for stormwater management are derived from the federal Clean Water Act requirements, such as the Combined Sewer Overflow (CSO) Control Policy and National Pollutant Discharge Elimination System (NPDES) permit program. A numbers of other federal and state regulations like Total Maximum Daily Load (TMDL) regulations, Federal Safe Drinking Water Act, Oregon land use planning also collaboratively drive municipalities to change towards sustainable stormwater management (OEC, 2007). To comply with these rules, Portland's Environmental Services enforces municipal code to regulate stormwater management through innovative and sustainable approaches.

Stormwater planters, rain gardens, ecoroofs, natural open space, permeable pavement are all part of Portland's green system to manage stormwater and reduce drainage burden on conventional sewers (Hauth, key informant-interview, 2014). Both the Stormwater Management Manual and the Sewer and Drainage Facilities Design Manual are under the authority of the Bureau of Environmental Services, which have been adopted by City Council as an administrative rule that designers and engineers must align with when designing a project in the city of Portland (BES, 2014). The project engineer is required to contact the city authority to solve any conflicts between two complementary documents. To effectively and widely stimulate applications of LID principles and strategies, stormwater codes play an indispensable role in forcing development activities. Shifting social mindsets to be more considerate of LID is a long-term process, since the general public ususally do not realize the problem of the hidden drainage system. People usually value green landscape through esthetics in appearance rather than the natural hydrological function. Developers tend to be more interested in original development activities which save time and costs, rather than spending a whole bunch of expense on those measures that they cannot see real dollars directly. In comparision with traditional pipe system, a lot of LID principles and techniques are contextually based and have to be customized for each site, which consumes time and even has potential to conflit with current regulatory code. Tracy (2014) believed developers would not voluntarily manage stormwater on their site without stormwater requirements. For new development, it is necessary to have specific stormwater codes that request expected practices.

> " For new development, we have stormwater requirements so we tell people they have to. I don't think any developers who will voluntarily manage stormwater on their site. In West Washington we require LID to be site feasible, so a lot of us are in the process of updating our stormwater code and manual to be really prescriptive about what that means. So as the city, whatever the permit is for us to comply with the clean water act or with the state permit, we have to require that above developers. It is somthing that we totally support, so we are happy to do it." (Tackett, key informant-interview, 2014)

In the City of Seattle, Department of Planning and Development (DPD) and Seattle Public Utility developed the stormwater code. They utilize the Washington State Department of Ecology Manual as a starting point to develop their own stormwater codes. Developers are requested and encouraged to develop each parcel to mitigate stormwater as much and positive as they can through different types and scales of green infrastructure.

The stormwater codes of Portland and Seattle are stringent but developed in a meaningful way, which allows for proactive and creative thinking, while facilitating the applications of green infrastructure. In Portland Stormwater Management Manual, sustainable stormwater facilities and techniques must be implemented on both private and public property, including all roofs, streets, alleys, driveways, and sidewalks. Stormwater runoff generated from private property must be managed on private property in privately maintained infrastructure, while the portion generated from public property must be managed on public property in publicly maintained infrastructure. However, the manual includes exceptions that an applicant may request to build a shared infrastructure to manage stormwater from private and public property (BES, 2014).

1. Public street improvements require the construction of a public stormwater management facility, and there is an opportunity for a private facility to accept public runoff that cannot be managed effectively in the right-of-way.

2. The applicant clearly demonstrates that private stormwater management facilities cannot be constructed on private property (for example, when minimum zoning requirements cannot be met), and there is sufficient area in the right-of-way to construct a facility that can manage stormwater from both the street and the private property. (BES, 2014)

Both the Bureau of Environmental Services and City Council must issue a permit for a shared infrastructure in the cases mentioned. Shared facilities located in the right-of-way should be approved by the Portland Bureau of Transportation. In addition, the manual indicates that the owner of private property is required to share the expense of future operations and maintenance proportionally based on the stormwater contribution generated from private site (BES, 2014).

New stormwater codes may conflict with current policy and regulations such as land development regulations, building codes, permitting process and others. A complete procedure of comprehensive document review should be conducted to evaluate consistency and alignment with new or revised stormwater codes and requirements. In Seattle, there is a landscaping requirement document named the Seattle Green Factors, which requires planting bed to be level or mounded to avoid water retention, while new stormwater code encourages depression to hold rainwater (Tackett, key informant-interview, 2014). It is necessary to coordinate various authority departments to thoroughly review relevant municipal codes to identify conflicts and remove barriers.

> "We are currently reviewing all our city codes and there is a lot of them, not a small task... like setback requirements, how does a cistern system fit the setback requirement... My job is a lot of convening in our departmental meetings like your policy sets this and you set this,and I am trying to get this. We all need to figure out how to make the intent of yours and intent of yours, but still get this done. So what is the right way to meet them all? It takes a lot of creative thinking and comes up with a different version." (Tackett, key informant-interview, 2014)

3.1.3 Financing and Incentives

The implementation of green infrastructure can be facilitated through many ways, while financing has been identified as the most effective approach. Generally, financing includes direct subsidies and indirect subsidies.

Direct subsidies can be the funds provided by various levels of government authority. Either the federal and state governments, or local municipalities are supposed to take initiatives to push the research and implementation of sustainable development. There are many funding sources applicable to support green infrastructure planning and implementation. The Clean Water State Revolving Funding (CWSRF) program has about $50 million allocated to all the states each year for water quality improvement, which is appropriated by Congress (OEC, 2007). Oregon Watershed Enhancement Board (OWEB) grants can be applied to implement green infrastructure, conduct demonstration projects, and support education and technique programs for watershed restoration (OEC, 2007). Community Watershed Stewardship Grants in Portland push the implementation of green infrastructure through providing technical assistance and funding for community-initiated projects (EPA, 2010).

Indirect subsidies through stormwater fee discount has been mentioned by informant-interviewees as an effective tool to encourage sustainable stormwater practices on existing areas (Hauth & Tackett, key informant-interview, 2014). Both Portland and Seattle charge people for stormwater so that people have potential to receive rate rebate if they conduct green infrastructure practices to manage stormwater generated from their properties. As the stormwater fee discount does not offset the cost of green infrastructure facilities to a great extent, the city of Seattle also offers extra financial rebate within certain areas where they have the problems to encourage retrofit projects (Tackett, key informant-interview, 2014).

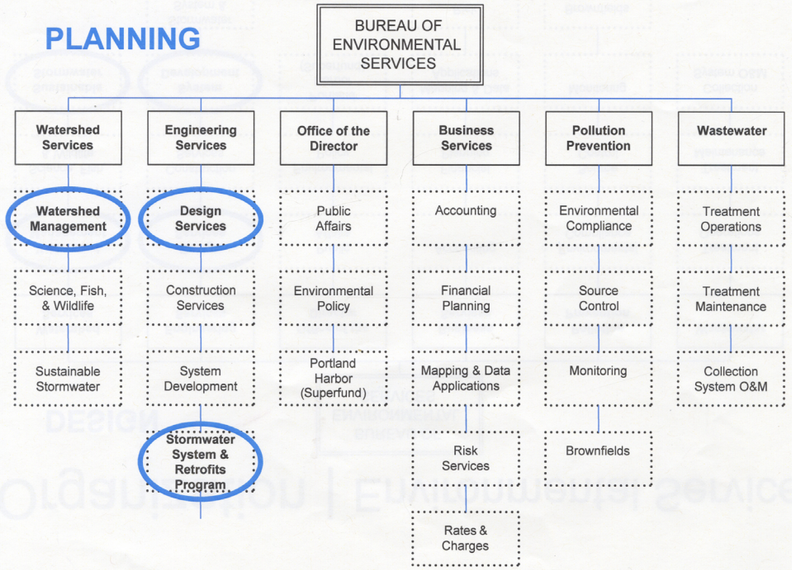
Besides financing stimulations, incentives can be tied to development regulations, providing opportunities for developers to mitigate regulatory effect on their market benefits. In Portland, the Floor Area Bonus for Roof Gardens and Ecoroofs not only facilitates more than 120 green roofs in the city, also helps developers increase economic benefits through adding allowable area (EPA, 2010).

3.1.4 Administration and Stewardship

The close cooperation and clear assignment of responsibility among different levels of government and different agencies within the same authority level positively gear up water management and improvement in the United States. Federal government provides less direct efforts on urban water management and services. However, relevant regulatory act enacted by congress directly drive states and municipalities to pay attention on the improvements of water quality and management. In addition to the national policy guidance and standards, federal government also provides valuable data and research on water management, and allocates considerable grants for states and municipalities to support local projects. Thus, the policy and financing guidance at federal government plays a key role in green infrastructure planning and implementation

Organization | Environmental Services

PLANNING



Organization | Environmental Services

DESIGN

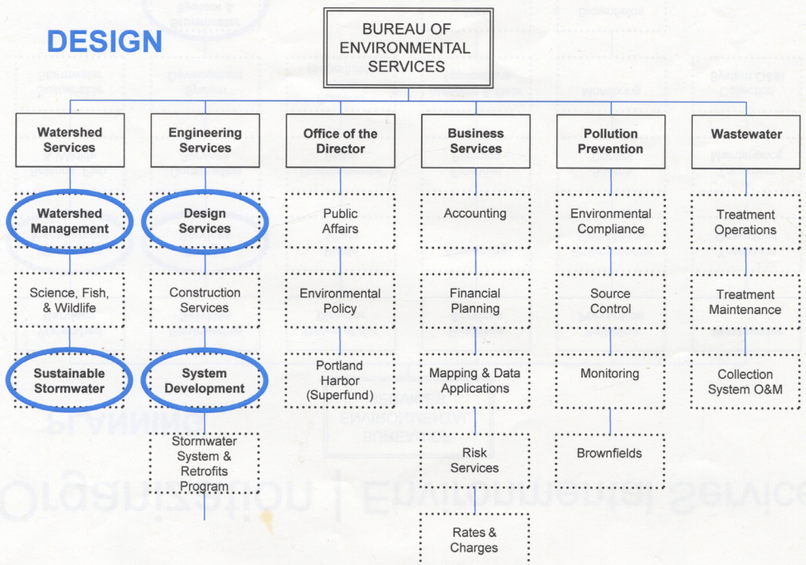
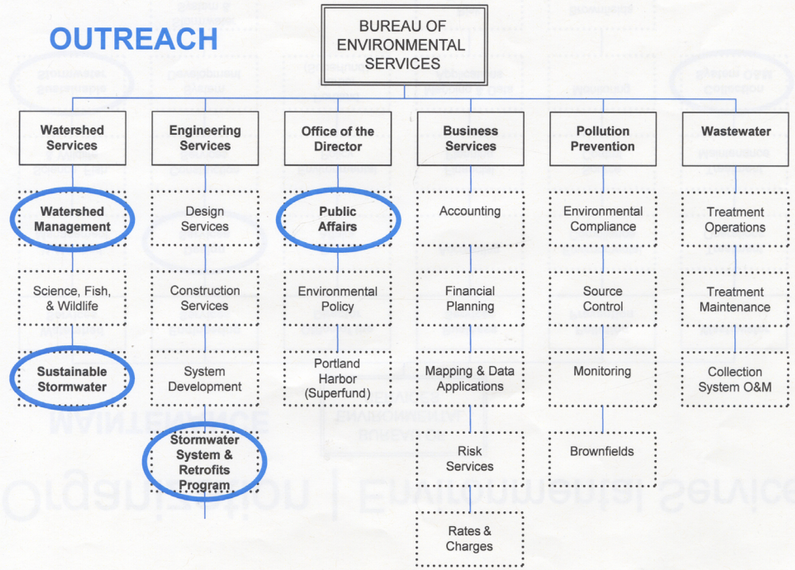


Figure 3.5 Organization of Portland's Bureau of Environmental Services. © Portland's Bureau of Enviromental Services, 2014. Used with Permission.

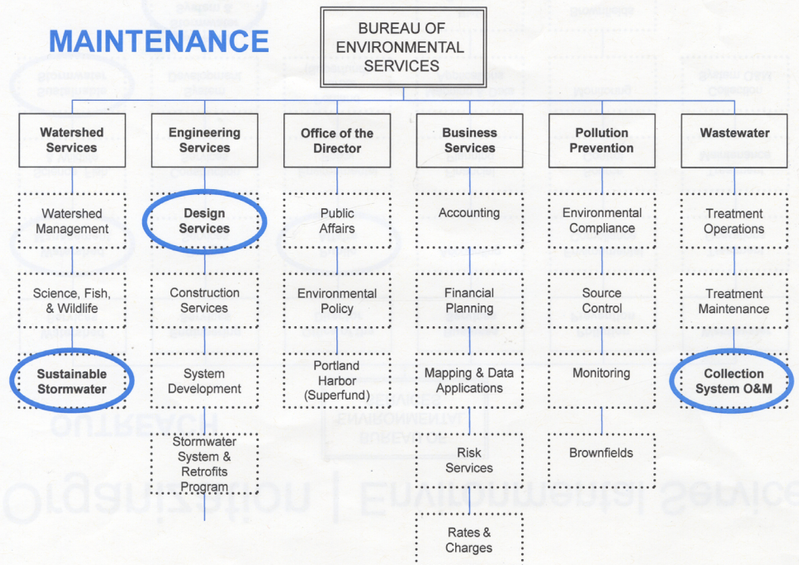
Organization | Environmental Services

OUTREACH



Organization | Environmental Services

MAINTENANCE



for stormwater management. In terms of municipalities, such as the city of Portland, effective stormwater management can be attributed to three general main points, including clear, integrated and complete stewardship structure, cross-bureau cooperation and establishment of various partnerships.

The Portland Bureau of Environmental Services (BES) is responsible for the operation and maintenance of public utilities, which includes drainage infrastructure. Therefore, improvement of stormwater management becomes their responsibility to meet relevant federal regulations as mentioned. As shown in the organization structure of BES, there are six departments in the bureau and each one includes different specific divisions (Figure 3.5) (Hauth, key informant-interview, 2014).

In the Department of Watershed Services, Sustainable Stormwater Office is focused on green infrastructure planning and implementation for stormwater management. However, the responsibility is not merely assigned to one particular office. Generally, stormwater management involves four tasks, including design, planning, outreach and maintenance. Each task has been taken over by the collaboration of specific offices across certain departments in the bureau. The synergy of different specialized officies would allow multidisciplinary experts to provide complete and efficient solutions for stormwater management. Even one particular office consists of different specialized professionals. For example, the office of Sustainable Stormwater makes up of ten professionals, including two urban planners, four landscape architects, three environmental scientists and one engineer (Hauth, key informant-interview, 2014). It is a fairly interdisciplinary area to be able to integrate these green and grey facilities in the urban fabric. The City of Portland has been successful in appointing key management personnel who are comfortable with change, eager to embrace change and can management change. They recognize risks involved in sustainable stormwater management but can make change happen to improve present situations.

Green facilities can be constructed at many locations such as rooftops, right-of-ways, parking lots, sidewalks, open space and more when space permits. This requests the cooperation of cross-bureau to come up with integral solution to meet the requirements of various municipal codes and regulations. To establish new stormwater regulations, a throughout code review should be conducted in advance to avoid inconsistencies and potential barriers. The potential documents to be reviewed may be in the charge of various authorities such as Development Services, Bureau of Housing, Bureau of Planning & Sustainability, and Bureau of Transportation. Cross-bureau cooperation also helps educate government staffs who have key influence on green infrastructure implementation.

> "Our department is across the bureau, working with transportation department, also with our urban planners too. We have been siloed in our department. For us (BES) we were working on our green infrastructure demonstration project etc. Then urban planners were kind of focusing on their areas. We are going through our 35-year comprehensive planning right now. It's been a progression to be able to talk with the urban planners, and talk about- let's bring green infrastructure into this. It has not really been part of their mindsets necessarily. They were always wondering what? Why do this? We were showing them examples, taking them on tours..." (Hauth, key informant-interview, 2014)

Eventually, the Sustainable Stormwater group convinced the urban planners of the basic principles of stormwater management and they were able to integrate relevant guidance and regulations into the comprehensive planning to push green infrastructure implementation. It was important that Sustainable Stormwater group took actions as the advisory roles to educate urban planners. Without having the urban planners involved, most of the green plans would be placed on the shelf rather than go into effect (Hauth, key informant-interview, 2014).

Establishments of various partnerships would help stimulates green infrastructure planning and implementation through different ways, either educational programs of schools, technical support and experts provided by private firms, or resource sharing between municipalities. The partnership between Portland's (BES) and Portland State University conducts the community Watershed Stewardship Program to facilitate public participation in the improvement of watershed health and management, meanwhile promote public awareness of our relatonships to the natural systems (Roseland, 2012).

Cooperation between municipalities has been proved that can accelerate the planning and implementation process (Tackett, key informant-interview, 2014).

> "We all like to collaborate and share information because it is not that old, and there is a lot of work to do." For example, Portland just gave me permission to use something (a document) they developed for me to change it and have it for the city of Seattle. Like with this stewardship manual for homeowners. I like theirs (Portland's) a lot and so instead of for us creating one, we just kind of using theirs, kind of the same like as soon as we create standard details or template or design guiding I usually circulate it to other cities... we have done a lot of right-of-way work while they were working on the property work. So we have very similar timelines just with different focuses and now we are doing all the same stuffs." (Tackett, key informant-interview, 2014)

Partnerships between municipalities to share resources and information usually save time and costs on reinventing the wheel as they are all on similar procedures, achieving the sustainable stormwater management based on Low Impact Development principles and strategies.

3.1.5 Lessons for the City of Xiamen

From preceding inquiry and analysis, lessons are discussed and summarized in four areas: education, policy and regulation, financing and incentives, and administration and stewardship.

Education

In recent years, the City of Xiamen has been progressive in guiding public participation through different measures, such as establishing government information website to demonstrate planning products and collect recommendation messages. In addition, the first floor of Xiamen Planning Institute is dedicated to exhibition use for various plans and projects. These approaches enhance public participation to some extent. However, without planning with people throughout the planning phases, it is difficult to enhance public awareness of our connections to natural systems and closely integrate citizen's ideas and future visions into practice. Education should go beyond actions in advance to facilitate the planning and implementation as much of the city is already built. Without retrofitting green infrastructure along existing streets, at existing sites, and on exiting rooftops, a green infrastructure network cannot be completely formed and function to manage stormwater issues through merely regulating new development projects. The city of Xiamen is recommended to grant for demonstration projects at various scales for education purposes. The sooner the government appropriates to lead education initiative, the faster the improvement actions can proceed. Strategically, starting with education for key political leaders and policy makers would be necessary for smart decision making and urban growth in general.

Policy and Regulation

To effectively direct and regulate new development practices and retrofit projects, specific green stormwater infrastructure manual should be addressed at the early stage. However, stormwater regulations alone would not be effective enough to direct general urban growth and land use pattern. It is necessary to integrate green infrastructure planning with other planning policies and strategies, such as compact city form, active transportation, smart growth, nature first planning and more to provide integral solutions for the entire urban fabric.

The urban growth and development in Xiamen is under the control of the urban comprehensive plan, regulatory plans, construction plans, and other specific plans as needed. The Xiamen Urban Comprehensive Plan is the statutory plan at the highest level of the planning hierarchy. This plan evolved through four versions and the city is currently directed by the latest version of 2010. Althrough these comprehensive plans have been playing an important role in providing guidance for the general urban growth and development, they still lack legal policies and rational amendment systems to ensure the seriousness and legality of those mandatory provisions in the plans. Generally, land use has been directed by investment purposes and centralized politician authority rather than under the control of comprehensive plans. Thus, it is necessary to establish complete legal system and amendment procedures to ensure the efficiency of various

provisions and guidance expressed in the comprehensive plan.

In terms of sustainable stormwater management, it is indispensable to introduce general Low Impact Development principles and strategies in the comprehensive plan contextually based on existing pipe systems and previous drainage plans. Then regulatory plans, as the implementing tool, should be promoted and updated in response to the guidance and requirements in the comprehensive plan.

Currently, in the regulatory plans, most mandatory indexes have been dedicated to regulate buildings while only the percentage of green space is for landscape requirement. There are three recommendations for the promotion of regulatory plans. Firstly, the percentage index for green space can be distributed to more types of green stormwater infrastructure, such as retention/infiltration areas, permeable pavements, or percentage of ecoroofs. Secondly, statistics index can be transferred to form-based index, which means planners are recommended to provide multiple options of scales, types and forms for green facilities based on specific sites, parking lots, sidewalks, driveways or others. This allows planners to come up with a complete and integrated natural system for the entire watershed health. The third suggestion is for planners to adjust certain indexes or requirements to provide adequate and feasible space for different types of green stormwater infrastructure, such as setback requirement or road section for stormwater planters, or particular building forms for roof gardens.

Financing and Incentives

Green infrastructure planning and implementation should address both new development areas and existing areas. Shifting the mindsets of developers and property owners to be able to voluntarily get involved in sustainable stormwater management can be a long-term process. Financing and various incentives are highly recommended as an efficient catalyst to speed up acceptance of the general public and implementation process.

First, Xiamen municipality should appropriate certain demonstration projects in advance to lead the initiatives and achieve educational purpose. Second, various financing resources either from public, private or the third sectors need to be clear, transparent and accessible for applicants. Third, stormwater fee discount approach can be applicable, while feasibility study should be conducted before put it on the ground. In terms of non-financing incentives, green infrastructure practice in exchange of Floor Area Ratio (FAR) bonus can be applied to regulatory plans with clear exchange provisions.

Administration and Stewardship

In comparison with Portland, there are more government agencies responsible for water management in Xiamen. These agencies include the Environmental Protection Bureau, Xiamen Municipal Water Conservancy Bureau, Water Resource Department, Quality Technology Supervision Department, and Xiamen Planning Institute. Decentralized responsibility makes various authorities and agencies a challenge to coordinate with each other to make informed decisions. Thus, to significantly improve stormwater management, it would appear necessary to establish dedicated stormwater solution group in one authority; either Environmental Protection Bureau or Xiamen Planning Institute, is highly recommended to take the responsibility. Second, it is important that the stormwater group consists of multidisciplinary professionals, similar to Portland (BES)'s sustainable stormwater office. Third, a cross-bureau stormwater committee could be launched to facilitate cooperation of relevant departments and allow for efficient and thorough code review. Fourth, to further stimulate the planning and implementation process, resource and information sharing can be achieved through partnering with other cities to avoid reinventing the wheel. This approach would help advocate sustainable stormwater management and speed up green infrastructure practice on national-wide context.

3.2 Precedent Projects

This section reports on three precedent built-projects. They are the Shoemaker Green in Pennsylvania (US), the Tanner Springs Park in Portland (US), and the Olympic Village in Vancouver (Canada). These projects are of differing type, form, and scale, while fulfilling the common basic philosophy, returning natural hydrological function to urban context.

The three projects are widely knowledgeable for their performance and demonstration of sustainable stormwater management. The Shoemaker Green is an open-space scale project located on the University of Pennsylvania campus that provides students a green plaza for dynamic outdoor activities. In comparison, the Tanner Spring Park tends to be a more peaceful and natural space situated on a block of north downtown area in Portland. The Olympic Village constructed a variety of green facilities and (LID) techniques at different scales. From literatures, single-purpose applications, such as rain gardens, stormwater planters or permeable paving are merely impoverished green facilities when they are implemented solely to address stormwater without considering other social issues. This section aims to seek illuminations from these three projects, regarding how they provide integrated solutions for green infrastructure implementation at different scale, location and context. The analysis of the precedent projects in this section will guide the design application for the selected study block in Xiamen. This research aimed to improve the Xiamen study block to become a potential pilot demonstration project for future water sensitive urban design guidance. In alignment with this purpose, the author particularly summarized four principles from each project characterization. Following the four preceding principles presented in the chapter of literature review, the principles are numbered from 5 to 8 in this section. These principles are explained thoroughly at the end with connection to the design application for the Xiamen block. The four principles in this section are indicated as follows:

(P5) - Principle 5: Make stormwater flow visible
(P6) - Principle 6: Integrate green infrastructure with human amenities
(P7) - Principle 7: Encourage social interaction with water features
(P8) - Principle 8: Expose principles of sustainable stormwater management

Structure of precedent project studies

The three precedent projects are next inquired and compared with a standard format, including project overview with a brief introduction table, characterization, and conclusion with an effectiveness check box.

The project overview introduces the history and background of each project, describing the location, scale and urban context, as well as the design concept and purpose with regards to sustainable stormwater management. The author also provides a brief table before project review, which includes a series of general information for orientation. The table consists of: type of project, location, latitude, av.annual rainfall, project size, context, main concept, completed time, and responsible parties.

The author inquired and evaluated each project with details in the characterization, based on literature review, key-informant interviews and/or project visits. The focus of this part is on the water sensitivity and how each project integrates sustainable stormwater management with other urban planning and design aspects, providing an esthetically pleasing and liveable urban environment for the general public.

The conclusion summarized the general performance, initiatives and critical concerns of each project, identifying main lessons that can be learned and considered as potential design strategies for the Xiamen study block. The author assessed each project through different aspects, which can be categorized into several themes, including water sensitivity, education of LID, experiences of nature, aesthetics, recreation, accessibility and usability. As identified from the literature, water sensitive urban design provides for decentralized control, detention, cleaning, infiltration and evaporation. To better understand how each project performs in effect regarding these factors, the author developed an checklist box at the end of each conclusion. The effectiveness check were classified as follows:

■■■ project performs to high effect
■■□ project performs to medium effect
■□□ project performs to low effect



Figure 3.6 Shoemaker Green on University of Pennsylvania Campus
© Andropogon Associates. Used with Permission. Retrieved from http://www.landezine.com/index.php/2013/03/shoemaker-green-by-andropogon-associates/

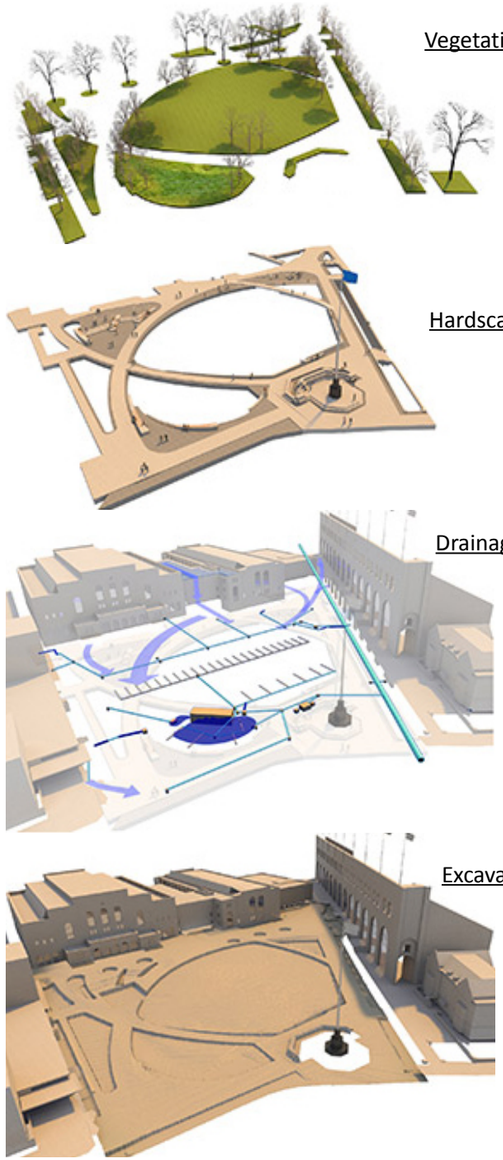
3.2.1 Shoemaker Green	
Type of Project	Open space - Park
Location	Philadelphia, Pennsylvania, USA
Geographic Coordinate (latitude)	39.951423° N
Av. Annual Rainfall	1,068 mm (see Appendix E)
Project Size	11,129 m^2 (1.1129 hectare)
Context	University of Pennsylvania Campus
Main Concept	Performing beyond sustainable urban drainage, meanwhile providing social and aesthetic values.
Completed	September, 2012
Responsible	Andropogon Associates; University of Pennsylvania; Meliora Design; etc.

Project Overview

Shoemaker Green, located in Philadelphia, is a 2.75 acres green parcel that serves as the main public space on the University of Pennsylvania (Penn) Campus. It has been rated as one of the Sustainable Sites Initiatives (SITES™) Pilot Projects, which highlights both social and ecological values and plays a demonstration role in facilitating sustainable campus design, development and maintenance in the future. This project retrofitted the campus square where used to accommodate aging tennis courts, impervious paving and several trees. Shoemaker Green is now an inviting heart and entrance of Penn's eastern district surrounded by historic athletic facilities, which performs beyond stormwater management, and meanwhile provides social, economic and aesthetic assets. The design of Shoemaker Green features sustainable urban drainage through capturing and controlling storm runoff from the site and adjacent rooftops, which is basically driven by two bioretention systems and a subsurface detention system. This project also installed a 20000 gallon concrete cistern to the east of the rain garden, underneath the pedestrian pathway to collect rainwater for landscape irrigation.

Characterization

Through the collaborative efforts of multidisciplinary experts, Shoemaker Green has been designed to provide attractive public space for social activities, also, more significantly, contribute multitudes of ecological benefits to the entire urban context. The diagram (see Figure 3.7) indicates four basic layers of this project, which includes vegetation, hardscape, drainage system, and excavation.



The innovative and sustainable stormwater management of Shoemaker Green is fulfilled through two bioretention areas and one subsurface detention system that captures 90 percent of storm runoff from the site and adjacent buildings. The subsurface detention bed is situated under the large lawn, which utilizes a portion of the original tennis court as the impervious base and receives runoff via inlets and trench drains. As the drainage layer shows, a rain harvesting cistern has been installed right below the pedestrian walkway. These systems collaborate closely through under drains (smart drains) so that the cistern can trap 20000 gallon of stormwater, then reuse for landscape irrigation between storm events. These systems include junction boxes and overflow pipes connected to the combined sewer system underlying the pathway to the north of Franklin Field, which allows for stormwater discharge from Shoemaker Green, through the combined sewer system, into the Schuylkill River less than a half-mile away during heavy storms.

Figure 3.7 Four layers of Shoemaker Green project
© Andropogon Associates. Used with Permission. Retrieved from http://www.landezine.com/index.php/2013/03/shoemaker-green-by-andropogon-associates/



Figure 3.8 Rain garden and benches of Shoemaker Green.
© Andropogon Associates. Used with Permission. Retrieved from http://www.landezine.com/index.php/2013/03/shoemaker-green-by-andropogon-associates/

The rain garden plays a key role in adding aesthetic value to the project as, compared to the large central lawn, it provides a variety of vegetations, which includes small trees, shrubs and grasses, and also contributes to increased residence time and stormwater treatment before the water are released to the underlying cistern for landscape irrigation. The 5-year ongoing monitoring study has proved the prominent value of plants and soils in stormwater treatment. The 14-month monitoring period from May 2013 to June 2014 found the levels of pollutants significantly decreased as water filtered through the system and no events of water overflow from the system occurred.

Social activities are encouraged through closely integrating amenities with green infrastructure. Stone steps were placed across the rain garden to provide pathway, seating and recreation use for the public, and also

work as a check dam to prolong residence time, contributing to increased water quality and decreased peak storm runoff. Benches made of monolithic granite were installed in accordance with the layout of the site, and designed with storm planter and permeable pavements, to deliver education of sustainable stormwater management and enhance the ecological awareness of people.

Shoemaker Green is flexible and aimed to accommodate multitudes of events at different scales, including peaceful seating, movies and concerts, outdoor classes, sport activities, as well as graduation events. To avoid soil compaction due to the foot traffic, a compost tea program has been implemented to increase organic matter within the mostly inorganic, engineered soils. This approach has become a standard maintenance strategy for the entire campus Green projects.

Summary

Shoemaker Green has successfully retrofitted the previous aging tennis courts, which was one of the most underutilized and impermeable areas on the University of Pennsylvania's campus. This project demonstrates how and what types of green facilities can be integrated to address stormwater by source control and decentralized methods before releasing to piping systems and receiving water bodies. This project was designed to capture stormwater runoff beyond the site itself from surrounding rooftops. However, I am critical that stormwater planters and rainwater harvesting systems (for reuse) could have been installed next to the buildings, which would reduce sunk cost on the construction and materials of the central underground cistern, as a less volume of stormwater runoff would be collected by the underground cistern. In terms of the education aspect, I suggest more designs such as information signage should be considered to make the innovative design concept thoroughly understood and become an impetus for future LID best practices for the entire University and urban context. The city of Xiamen can learn from the Shoemaker Green that stormwater green facilities can come in a variety of scales and shapes, depending on intended uses and drainage areas. Moreover, planners are encouraged to identify underutilized spaces and seek potential means to revive them towards multifunctional purpose and sustainability.

Water Sensitivity:	
Decentralized	■■■
Detention	■■■
Infiltration	■□□
Cleaning	■■□
Evaporation	■□□
Others:	
Education	■□□
Aesthetics	■■■
Accessibility	■■■
Recreation	■■■
Usability	■■■
Experiences of nature	■■□

Table 3.2 Effectiveness assessment for Shoemaker Green

Regarding water sensitivity, it can been seen from Table 3.2 that Shoemaker Green applies multiple decentralized methods to bring stormwater treatment closer to the natural water cycle. This project provides a high level of detention capacity with a large underground cisterns. Shoemaker Green is an aesthetically pleasing and accessible green space for people to congregate, play and rest.

Figure (3.6) Shoemaker Green on University of Pennsylvania's Campus
Source: Andropogon Associates. http://www.landezine.



Figure 3.9 The Tanner Springs Park in Portland. (Photo by Wang, 2014)

3.2.2 Tanner Springs Park	
Type of Project	Open space - Park
Location	Portland, Oregon, USA
Geographic Coordinate (Latitude)	45.531203^{o} N
Av. Annual Rainfall	1,096 mm (see Appendix E)
Project Size	4,800 m^2
Context	The Pearl District (Downtown)
Main Concept	Revitalizing natural wetland through Low Impact Development techniques and strategies for the citizens in a dense urban area.
Completed	2005
Responsible	City of Portland; Peter Walker & Partners; Atelier Dreiseitl; GreenWorks, P.C; KPFF Consulting Engineering; etc.

Project Overview

Tanner Springs Park, located at the Pearl District of Portland has become an inviting and inspiring atmosphere that brings people to the window of its history over the past 200 years of urban development. This district was previously a natural wetland of the Tanner Creek and immediately adjacent to the Willamette River on the east. Afterwards, industry activities took over this land and drained the Tanner Creek and wetland by applying subsurface channel. Over the past 30 years, this district developed from an aging industrial field towards the destination for accommodations and businesses. However, due to the past land use for industry and railways, this neighborhood has suffered from insufficiency of green space. As a result, the development of a green corridor that connects the Pearl District to the Willamette River were implemented in recent years. The master plan of this corridor created by Peter Walker & and Partners includes four parks in different forms, scales and recreational uses. As one of these green spaces, Tanner Springs Park aimed to revitalize the natural elements of this area and demonstrate the appreciation to the original wetland and its ecological services for our environment.

Characterization

Tanner Springs Park is situated on a 60×60 meters downtown block and was designed downslope from west toward east to form a retention pond that implies its original marshland state for stormwater collection and treatment. As observed by field trip, surrounding sidewalks are slightly sloped toward the inner landscape area of the park to trap storm runoff. All the rainwater that drops within the curb-line of the park is retained and cleansed within the park through soil infiltration and biological uptakes of planted biotope. A water loop system is achieved by pumping the water in the wet pond back up to a spring, then returning the water to the pond through grassed streams, which provides a continuous cleansing of the water. An overflow system has been installed to drain out excess rainwater to the sewer system during extreme storm events. Tanner Springs Park not only provides natural function for stormwater management, but also features a variety of assets that connect to its industrial and ecological history.

Source: http://www.dreiseitl.com/index.php?id=54&lang=en

Figure 3.10 Site plan of Tanner Springs Park. © Dreiseitl. Retrieved from: http://www.dreiseitl.com/index.php?id=54&lang=en

Tanner Springs Park creates recreational opportunities for children of different ages either at the spring source or within the wet pond area, enhancing their ecological awareness and respect to the nature. The walking bridge constructed right above the water enables pedestrians to access to the biotope zone and encourages close exploration. The bridge also acts as a stage that can be used for music concerts and performances. The grass steps aligned with both north and south edges of the landscape area not only conquer the difference of elevation, also provide a peaceful area for rest.

P6
P5
P7

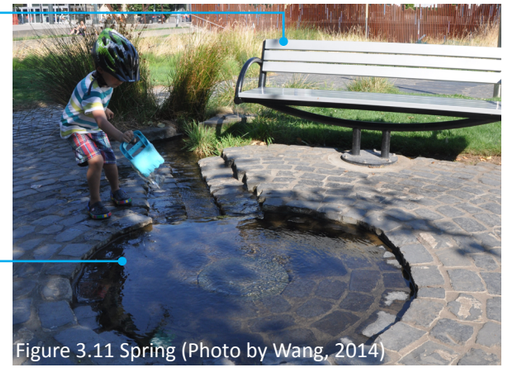


Figure 3.11 Spring (Photo by Wang, 2014)

P6
P7



Figure 3.12 Wet pond (Photo by Wang, 2014)

P6



Figure 3.13 Grass steps(Photo by Wang, 2014)

The park inspires people to appreciate the past of the city through the application of historical materials, such as the "art wall" located at the east end of the park, which is made of 99 vertical, staggered rail tracks used in the Portland rail yards during late 19th century. Another historical evidence can be referred to the materials used for paths in the park. The basalt Belgian Blocks that pave some walkways of the park formerly served as ballast on ships traveling up the Columbia River. The park also applied materials of modern styles (concrete, metal and glass) to integrate with surrounding urban setting. The leaf-shaped pavilion highlights modern atmosphere, while protects pedestrians from rainfalls and also makes the rainwater flow visible.

Street cars passing around the site make this park more accessible and attractive to tourists and citizens from other communities. The publicity boards



Figure 3.14 Pavilion (Photo by Wang, 2014)



Figure 3.15 Information Signage (Photo by Wang, 2014)

have been placed at several positions to help visitors better realize the contributions of Tanner Springs park to the integration of water management, historical memory and human activities in a dense urban context.

Summary

Tanner Springs Park shows how landscape performance can be optimized in an urban setting, increasing the opportunities for the general public to interact with nature and appreciate its historical transformation from previous wetland, through industrial period, to today's multi-functional space. Concrete edges transition to natural space and wet pond provides a low spot to trap on-site stormwater runoff. However, it was considered impractical to collect stormwater runoff from adjacent rooftops and streets, as the master plan for the Pearl District was already in place when the park was constructed. Thus, from long-term perspective, the City of Xiamen should facilitate early cooperation between urban planning and stormwater management departments in future development. In addition, a higher volume of stormwater runoff would overwhelm the pedestrian bridge on the wet pond, leading to safety issues and violating the key principle for water accessibility of this project. This inspires me to consider in the Xiamen site that design measures should be kept in balance to satisfy interests of the general public and meet the needs for water sensitivity. In addition, the material selection such as abandoned rail tracks used for the art wall and glass with steel structure used for the leaf-shaped pavilion adds historical value in a modern atmosphere. This is worth following in my own project to take surrounding context into consideration to create an inviting and inspiring urban setting.

Water Sensitivity:	
Decentralized	■■■
Detention	■■□
Infiltration	■□□
Cleaning	■■■
Evaporation	■■■
Others:	
Education	■■■
Aesthetics	■■■
Accessibility	■■■
Recreation	■■■
Usability	■■□
Experiences of nature	■■■

Table 3.3 Effectiveness assessment for Tanner Springs Park

Tanner Spring Park applies innovative designs in integrating the elevation difference and water cycle function to provide a natural wetland space, which offers a high level of cleaning and evaporation rate. Compared to Shoemaker Green, this project appears to be a more natural and peaceful space, providing a high level in education, aesthetics, accessibility, recreation features.



Figure 3.16 Olympic Village (Photo by Wang, 2014)

3.2.3 Olympic Village	
Type of Project	Residential Community
Location	Vancouver, BC, Canada
Geographic Coordinate (Latitude)	49.271632° N
Av. Annual Rainfall	1,166 mm (see Appendix E)
Project Size	7 hectares
Context	Southeast False Creek
Main Concept	Turning Southeast False Creek community into the leadership for future sustainable development, which features efficient energy solution, green buildings, sustainable drainage system, and accessible transit.
Completed	November, 2009
Responsible	City of Vancouver; Millennium Properties Ltd.; Merrick Architecture; etc.

Project Overview

As the core of Southeast False Creek community, the Olympic Village occupies approximately seven hectares, 20 percent of the total land. This project was developed for the Winter Olympic Games in 2010, providing accommodations for athletes and Olympic officials and staffs from all over the world. After the event, the Olympic Village became residential housing for the general public, which includes approximately 1,100 residential units, recreational parks and other ordinary services and amenities. This project was planned, designed and constructed in alignment with Vancouver's Greenest City targets to transform Southeast False Creek into the leadership of sustainable development in the future. With the purpose of sustainability in mind, the Olympic Village features high performance in energy efficiency, green buildings, sustainable stormwater management, and accessible transit patterns. The project received LEED-ND certificate as a sustainable neighborhood. It was first completed in Canada and has become a benchmark for future development.

Characterization

The SEFC (Southeast False Creek) Policy Statement included a series of design principles to guide development towards urban sustainability. These sustainable principles can be summarized in four basic aspects: energy, water and waste management, urban agriculture, and transportation. For the purpose of this research, a field trip to the Olympic Village was fulfilled in October, 2014, principally studying how this project performs in sustainable stormwater management, as well as other design philosophies integrated with water features.

The Olympic Village provides solutions to stormwater drainage from on-site management to neighborhood-wide approach. Walking within the neighborhood, either along the streets or weave through buildings, people can be aware of the visible water features close to natural hydrological function anywhere. Different scales of green infrastructure, such as intensive and extensive green roofs, storm planters, bioswales, and constructed wetland, have been widely applied in the Olympic Village and collectively address stormwater drainage from an innovative and sustainable perspective. The Olympic Village site has been graded to direct stormwater flows either toward the bioswale that runs north-south on the east edge or toward the west to be collected and treated by the constructed wetland of Hinge Park. Both the bioswale and wetland system are connected with the False Creek basin to release excessive stormwater runoff during extreme precipitation events. Different from the rainwater falls on the streets, those portions that fall within the building footprints are managed through a separate water cycle system. As the diagram shows, rain falling on the rooftops and podium

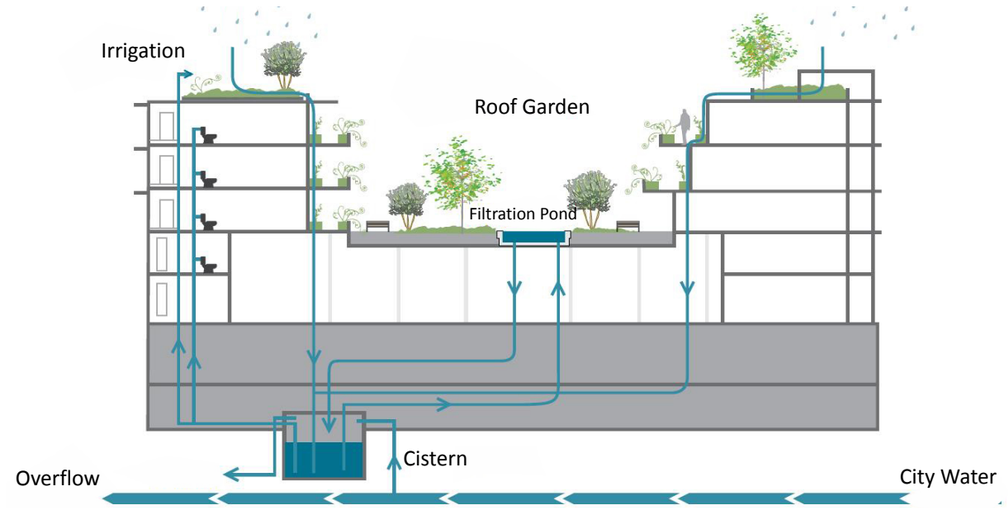


Figure 3.17 Green roofs and rain harvesting system. © Roger Bayley Inc. Used with Permission. Retrieved from: http://www.thechallengeseries.ca

areas is collected and filtered by either intensive or extensive green roofs before they are trapped in the underground cistern, then reuse for landscape irrigation and toilet flushing. The rain harvesting system and reuse of each building contributes to 50 percent of water consumption. The filtration pond located at the podium area is connected to the cistern to provide water cycle for water treatment so that increased water quality can be achieved for reuse. The green roofs of the Olympic Village are accessible and useable for social interaction and activities. Intensive roof gardens (57 percent), extensive rooftops (38 percent), and urban agriculture (5 percent) collaboratively contribute environmental, economic and social benefits to the neighborhood and the entire urban context.



Figure 3.18 Aerial rendering of the Olympic Village. © Roger Bayley Inc. Used with Permission. Retrieved from: http://www.thechallengeseries.ca



Figure 3.19 Central visible channel (Photo by Wang, 2014)



Figure 3.20 Wetland bridge (Photo by Wang, 2014)



Figure 3.21 Constructued wetland (Photo by Wang, 2014)



Figure 3.22 Pedetrian and cyclist routes (Photo by Wang, 2014)

Rainwater falling within the Olympic Village will be harvested by exposed channels situated at the center of streets and conveyed eastward to the bioswale or westward to the constructed wetland in Hinge Park. This approach reverses conventional hidden piping and makes the urban stormwater drainage visible to residents and passerby, thus enhancing their ecological awareness. Bridging over the wetland and sections of large diameter pipe are parts of the art of Hinge Park that refer to the theme of water management and sustainability, which not only provide recreational use for the general public at different ages, but also deliver ecological education. Waterfront street, divided by a central planted belt and stone seating, is dedicated to pedestrians and cyclists, which makes the Olympic Village inviting, accessible and walkable. People seated on the central stones or passing through the area can closely witness natural water cycle that begins with filtration by the vegetative swales, and then overflows into the False Creek basin through visible channels crossing the waterfront street. The Olympic Village site is served by a variety of active transportation options and accessible routes connected with the rest of the city so that the general public can conveniently travel around the site to observe and appreciate its ecological services.



Figure 3.23 Stormwater cistern 1 (Photo by Wang, 2014)



Figure 3.24 Stormwater cistern 2 (Photo by Wang, 2014)



Figure 3.25 Stormwater cistern 3 (Photo by Wang, 2014)


Figure 3.26 Stormwater planter 1 (Photo by Wang, 2014)


Figure 3.27 Stormwater planter 2 (Photo by Wang, 2014)

Rainwater harvesting cisterns were installed, either at the corner, immediately adjacent to the sidewalk, or situated at the courtyard of the buildings. The shape and size of cisterns are contextually dependent on the site constraint, specific position, as well as design storage capacity in accordance with estimated demand for retention and reuse. These cisterns are integrated with green infrastructure and amenities, providing space for rest and social activities that are close to urban stormwater management. These cisterns were designed deep adequately to increase rainwater storage capacity, but would cause risk to the public. The grated concrete covers protect people from falling risks; also make the rain harvesting system visible to residents and passerby. Stormwater planters are located at anywhere along with buildings as needed to capture and treat stormwater runoff from rooftops, which also increase aesthetic value to the site.

Summary

This project shows how green stormwater infrastructure at a variety of types and sizes can be applied in an integrated solution to address stormwater management and other social concerns in a neighborhood context. Two separated stormwater systems serve the ground area and building footprints respectively.

Above-ground rainwater harvesting cisterns in different shapes have been installed next to buildings to collect rainwater from rooftops for reuse. This approach reduces sunk cost on the demands for and construction of underground piping, and saves water resources. However, The designs of rainwater cisterns in the courtyards of Olympic Village appear to lack sufficient features to gain attention from the public. Moreover, without information signage, the sustainable stormwater strategies of the project would not be understood clearly. Various stakeholders could have worked in cooperation to create art out of the green facilities to attract and educate people with regards to sustainable stormwater management. The apparent lack of maintenance has led to eutrophication in Hinge Park where the water feature looks undesirable and inaccessible, which conflicts with the core concept of recreation and accessibility of the project.

Learning from Olympic Village, the City of Xiamen is encouraged to regulate building forms in future development, so that roof gardens can be incorporated to address rainfall and be accessible for recreation. For the Xiamen site one could also consider utilizing on-ground visible rainwater cisterns. Besides the benefits of water reuse, appropriate designs would make the rainwater cisterns become amenities that are aesthetically pleasing and inviting to the general public. It is also clear that a maintenance plan for green facilities should be carefully determined and conducted in future LID practices in the Xiamen site.

Water Sensitivity:	
Decentralized	■■■
Detention	■■■
Infiltration	■□□
Cleaning	■□□
Evaporation	■■■
Others:	
Education	■■□
Aesthetics	■■□
Accessibility	■■■
Recreation	■■■
Usability	■■■
Experiences of nature	■■■

Table 3.4 Effectiveness assessment for the Olympic Village of Vancouver

Table 3.4 indicates the Olympic Village of Vancouver has constructed a variety of green infrastructure at the property scale, street scale and network scale, which provide a high level of water detention due to water reuse using a number of rainwater harvesting systems. By applying a complete and integrated stormwater flow train from rooftops to the Southest False Creek, Olympic Village features a high level of accessibility, recreation, usability and experiences of nature.

3.2.4 Conclusion

This research explored three precedent projects and how these projects apply green infrastructure of various types and at a range of scales within the urban fabric to reduce stormwater impacts, providing integrated solutions for social interaction, educational purposes and the demonstration of susaintable stormwater management. Shoemaer Green tends to be more dynamic for social engagement with a subsurface detention/infilration system, applied to harvest stormwater, while allowing a large grassland for a variety of campus activities. Tanner Spring Park appears more nature-oriented, which provides a wet pond for recreational use and enables the water cycle through a pumping system. Olympic Village collectively implements green infrastructure at different scales, integrating with a variety of human amenities. The three projects consider integrated solutions for different uses (pedestrains/cyclists/drivers), and provide opportunities and a safe atmosphere for active transportation. Regarding Shoemaker Green, different permeable paving materials were constructed to meet the needs for pedestrains and emergency vehicles respectively. In terms of Tanner Spring Park, the block is linked with dedicated bike routes and a downtown street car line, to make the park more inviting and accessible. Olympic Village is served by different options of active transportation, connecting with the rest of the city to bring more people to visit the neighborhood. For the selected study block area in Xiamen, design interventions should respect different age groups and consider different users to provide integrated solutions for stormwater management.

Connection to Design Interventions

Following the four principles identified in Chapter Two, another four additional principles were identified from the three precedent projects to inform design interventions for the study block in Xiamen:

Principle 5: Make stormwater flow visible

Principle 6: Integrate green infrastructure with human amenities

Principle 7: Encourage social interaction with water features

Principle 8: Expose principles of sustainable stormwater management

Making stormwater flow visible allows people to realize where and how the stormwater runoff was generated, conveyed and treated. After following the water flow, people would perceive and better appreciate the function and benefits of the entire green and blue network.

Integrating green infrastructure with human amenities provides an attractive place for people to stay, rest and play. This increases opportunities for the general public to engage with different green facilities at a variety of types and scales. Besides being educational regarding sustainable stormwater management, the innovative multi-functional design would also contribute to aesthetics and recreation.

Encouraging social interaction with the water features can be achieved by making pedestrian circulation overlap with green and blue patterns, which provides space for people to have close contact with natural water systems and to appreciate the benefits of experiences with nature.

Precedents show that green facilities and parts of stormwater management systems may be concealed and contribute to an illusion that the entire system is independent of machinery. Thus, potential designs and strategies, such as information signage should be placed on site to explain the design concept to achieve educational purposes.

The four additional principles (P5-P8) provide the foundation for design interventions to call attention to the watershed processes in ways that please and educate those who visit the site. The sources of these principles can be referred to as pointed out in each precedent project study.

Chapter 4 Design Application

This research proposes a design intervention for a super block in the Xiamen central urban area, for retrofitting practice around the principles and lessons derived from Low Impact Development. This potential pilot demonstration project is intended to set a benchmark of water sensitive urban design for future development in Xiamen.

The selected study block (23.5 hectares) is known as the Culture and Art Centre (CAC) situated in the Cultural and Athletic Neighborhood adjacent to Yuandang Lake, located in the Xiamen central area. The block has been designated by the city as one of the most important destinations for working, shopping, recreation, study and sports. Preliminary field study in 2013 found this block has a high percentage (over 75%) of impervious surface and the landscape has been constructed strongly based on aesthetic value with less consideration for stormwater management.

The design proposal developed here is based on two basic goals: effective sustainable stormwater management and for the purpose of education. Green facilities with little attention to stormwater being evident would not efficiently facilitate green planning and implementation on regional context from long-term perspective. The proposal attempts to provides an integrated solution, showing how green infrastructure can be designed and constructed at different scales to reduce stormwater impacts, and to enhance public awareness regarding human relationships with natural systems.

4.1 Site and Context Inquiry

In this section, the author interpreted and illustrated existing conditions of the site and entire neighborhood, regarding current piping system, green features, circulations, social dynamics, etc. Afterwards, potential opportunities and constraints were compiled as the foundation to inform further design interventions.

4.1.1 Regional Analysis

The study block (red) named Culture and Art Centre (CAC) is situated in the central urban area of Xiamen island, adjacent to Yuandang Lake to the south. The block is approximately 2 km away from other major areas, such as Xiamen Municipal Hall, Bailu Island, Xiamen Railway Station, and the Lianban and SM commercial centres. The study block is immediately adjacent to the Athletic Centre on the southwest and surrounded by other residential blocks and certain strip malls. In addition, the CAC block is beside the Xianyue Road/Skyway, which connects Haicang District and Xiangan District that are outside the Xiamen island.

Proximity to other major hubs is a significant feature to designate the block of CAC as a key demonstration project for green infrastructure planning and implementation in the City of Xiamen. Integrating with a series of planning strategies to improve the accessibility and walkability of the neighborhood, the proposed green infrastructure interventions in this area would not only fulfill sustainable stormwater management, but also achieve educational benefits to the general public.



Figure 4.1 Location of the study block

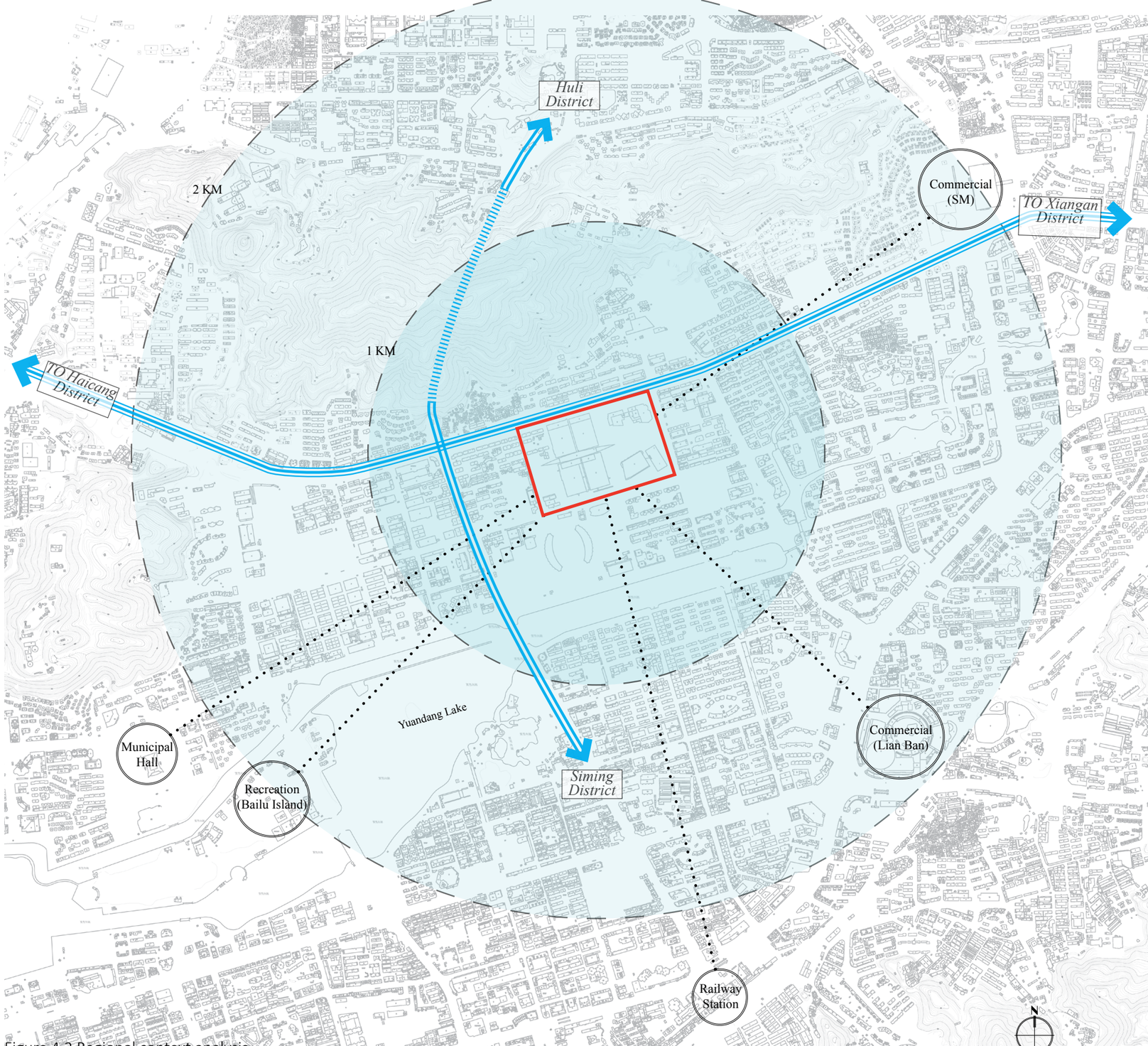


Figure 4.2 Regional context analysis

4.1.2 Watershed Analysis

Since the 1980s when Xiamen was designated as one of the Special Economic Zones, rapid urbanization has contributed extensive impermeable surface to Xiamen island. A large amount of stormwater runoff has to be conveyed through underground piping and released to receiving water bodies, including Yuandang Lake, the surrounding ocean, and other artificial water reservoirs. The Yuandang Lake is the receiving water body for a stormwater catchment area of approximately 35 km^2. Althrough the city of Xiamen is famous for its aesthetically pleasing urban landscape, these green spaces have been designed with little contribution to stormwater management regarding reducing speed of overland flow and providing for infiltration on site. The existing drainage system of the district where the study block is located, is controlled by a major piping system along roads, collecting most stormwater runoff generated from each block. The five photos (see Figure 4.5) describe the general landscape features of the neighborhood. Mostly, the large square in front of the Culture and Art Centre is covered by impervious pavement and acts more as a passage instead of an open space for social interaction and recreational use. Green space is typically mounded without water retention capacity. Moreover, the landscape in some areas lack natural aesthetics and are made inaccessible for use by fencing. The bank of Yuandang Lake is planted with trees and turf having limited capacity to harvest and infiltrate stormwater.

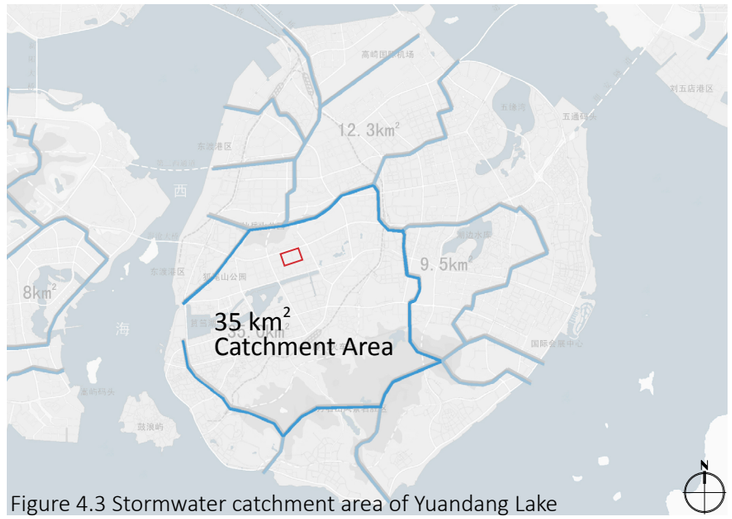


Figure 4.3 Stormwater catchment area of Yuandang Lake

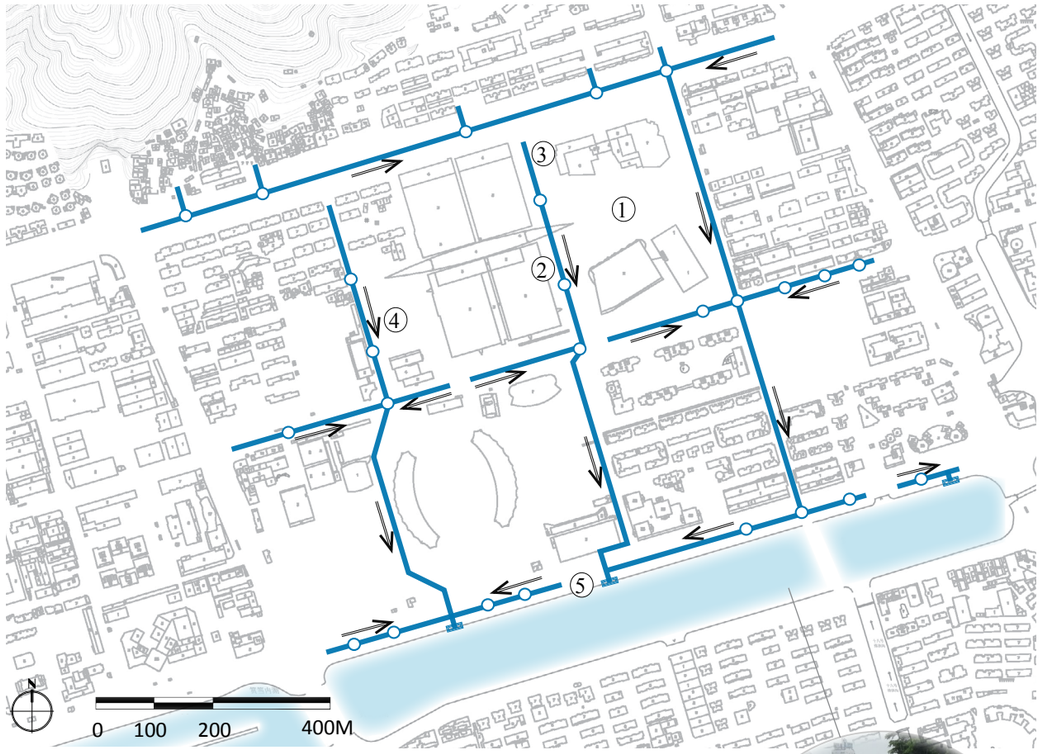


Figure 4.4 Current drainage system

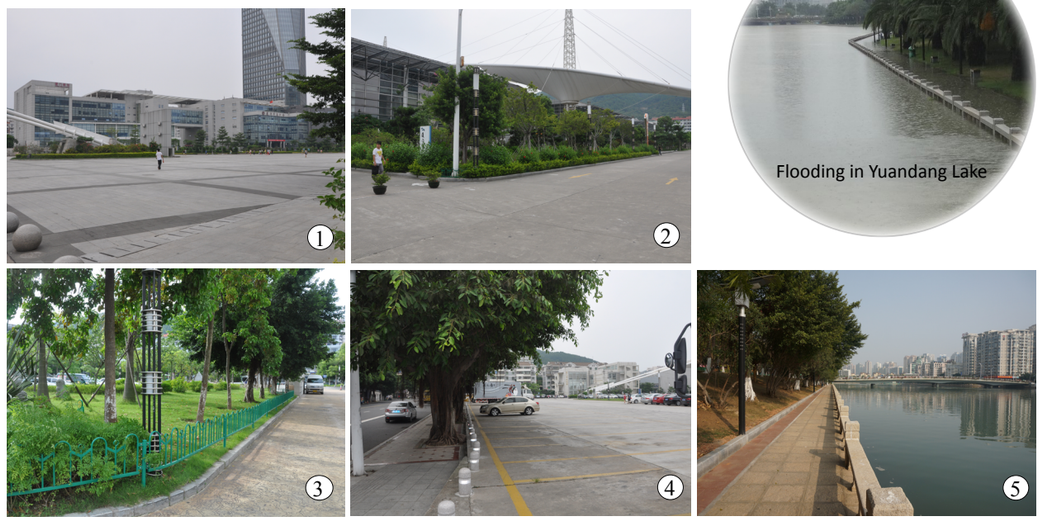


Figure 4.5 Landscape features of the study site

4.1.3 Land Use and Community Amenities

The land uses in the study block varies widely. It is a mixed-use super block for office, commercial, entertainment, cultural, and residential use, which brings the general public to use the amenities and meanwhile engage with each other. One of the most important reasons to select the Culture and Art Center (CAC) block as a key demonstration project is that Xiamen Planning Bureau is located in this block. While this block has been recently constructed, the proposed retrofit of this block would show leadership dedicated to innovative practice of ways and means to effectively addressing the pressing need to reduce the multiple impacts resulting from storm events that are expected to continue, if not increase in the future. The retrofit would allow city planners to expediently access various green facilities and efficiently improve their awareness of natural systems and the significance for sustainable stormwater management.

In the vicinity of the study block, major community amenities includes Xiamen Sport Center, Xiamen Marine College, Transportation Policy Station, Xiamen Women and Children Activity Center, affordable hotels, and several stores within the residential areas. Currently, the CAC neighborhood has approximately 18000 residents. The population of this neighborhood is not expected to increase significantly for years to come, as the municipal government has drawn attention to improve the commercial environment. Xiamen municipality designated the CAC neighborhood as a culture and sport district. However, the district seems not popular and inviting as expected, which can be attributed to the unconnected and poor commercial atmosphere and incomplete urban infrastructure. Currently, the two core visitor destinations are more than 700 meters apart. The lack of safe pedestrian and cyclist paths make them difficult to cooperatively facilitate improved social dynamics and a stronger neighborhood economy.

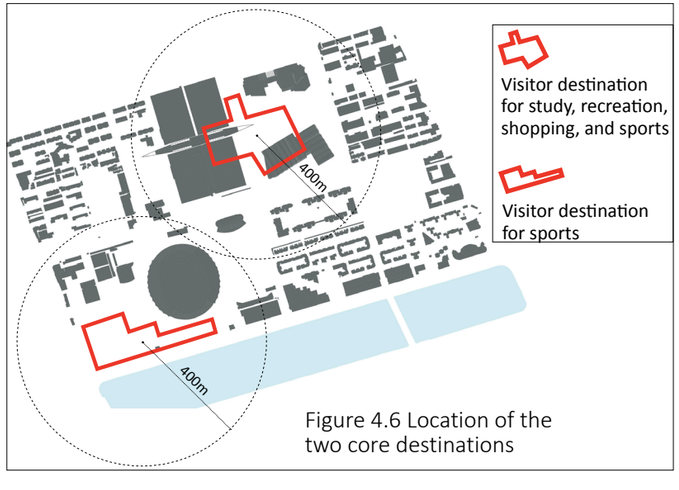


Figure 4.6 Location of the two core destinations

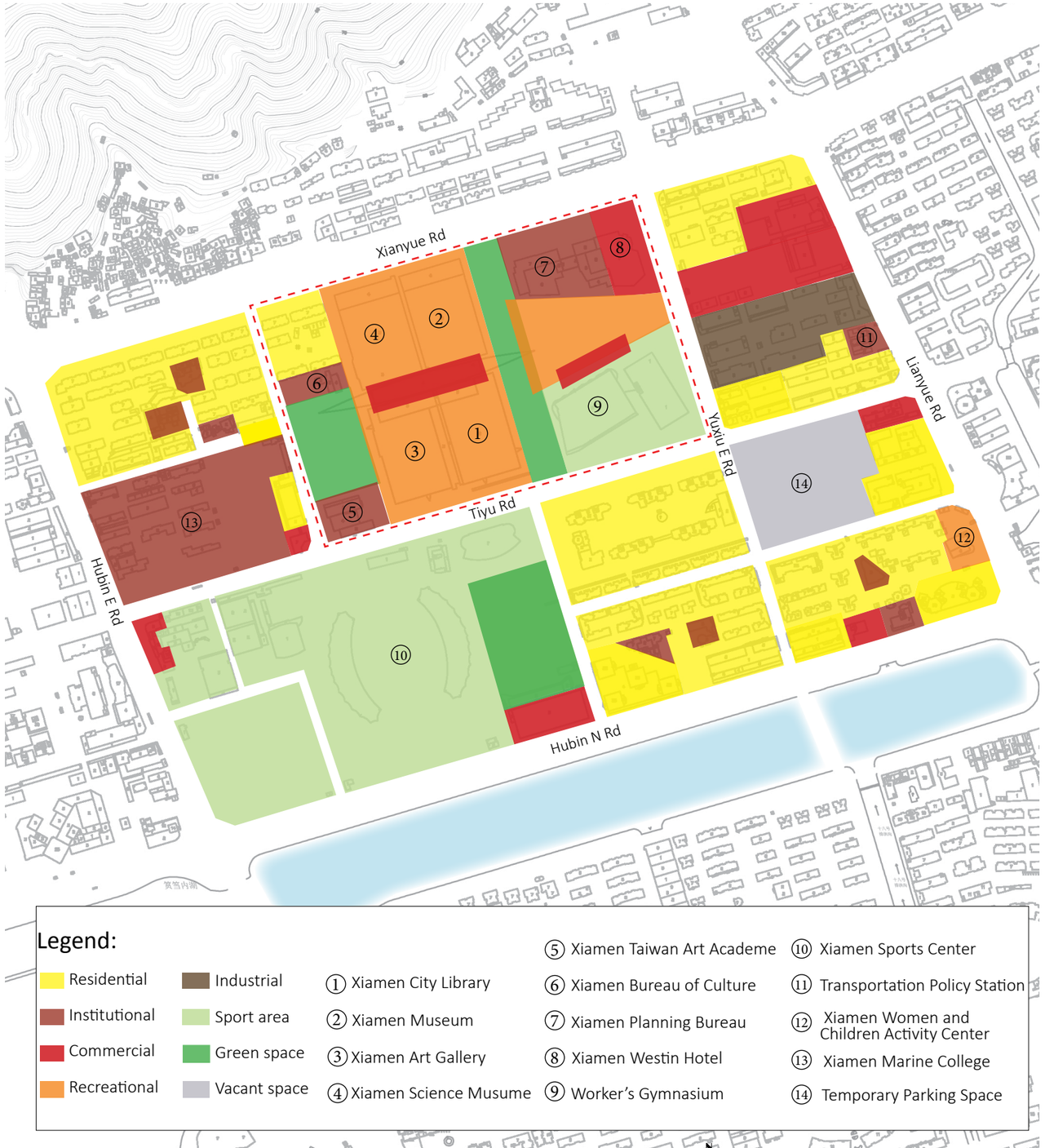


Figure 4.7 Land use and community amenities

4.1.4 Circulation Analysis



Figure 4.8 Temporary parking space (Photo by Wang, 2015)

The CAC neighborhood is bordered by Xianyue Road (north), Hubin N Road (south), Hubin E Road (west) and Lianyue Road (east). The majority of bus stops are located along these arterial road that connect the neighborhood with other communities in Xiamen. Within the neighborhood, the three bus stops are situated on Tiyu Road. As a minor arterial road, it has four lanes and carries a high traffic volume (particularly during peak hours), splitting the neighborhood into two parts. To better integrate the study block with adjacent areas and make the entire neighborhood more pedestrian-friendly, potential traffic calming measures could be applied on Tiyu Road and other streets if needed. The large vacant space (see Figure 4.8) at the corner of Tiyu Road and Yuxiu E Road is temporarily used for parking. This block has been reserved by the government of Xiamen for future commercial development to enhance the cohesiveness of the CAC neighborhood.

In the study block, social activities usually occur on the side of "square one", while "square two" is merely an empty grass space and surrounded by parking lots (Figure 4.9). However, "square one" seems not attractive to people as a place to stay and rest for long because the square is a large vacant area covered by impervious surface except two linear inaccessible green strips on the edges. "Square four" is a basketball ground open to the public for reservation. Square three" is also a basketball court between the residential buildings but is fenced for private use. Except bicycle parking lots (Figure 4.10), cyclist circulation cannot be clearly identified as there are no dedicated bike lanes so cyclists have to share the space with pedestrians and vehicles. Dedicated bike routes are highly recommended throughout the entire neighborhood to encourage more bicycle users.



Figure 4.9 Square two (empty grass space) (Photo by Wang, 2015)



Figure 4.10 Bicycle parking beside the city library (Photo by Wang, 2015)

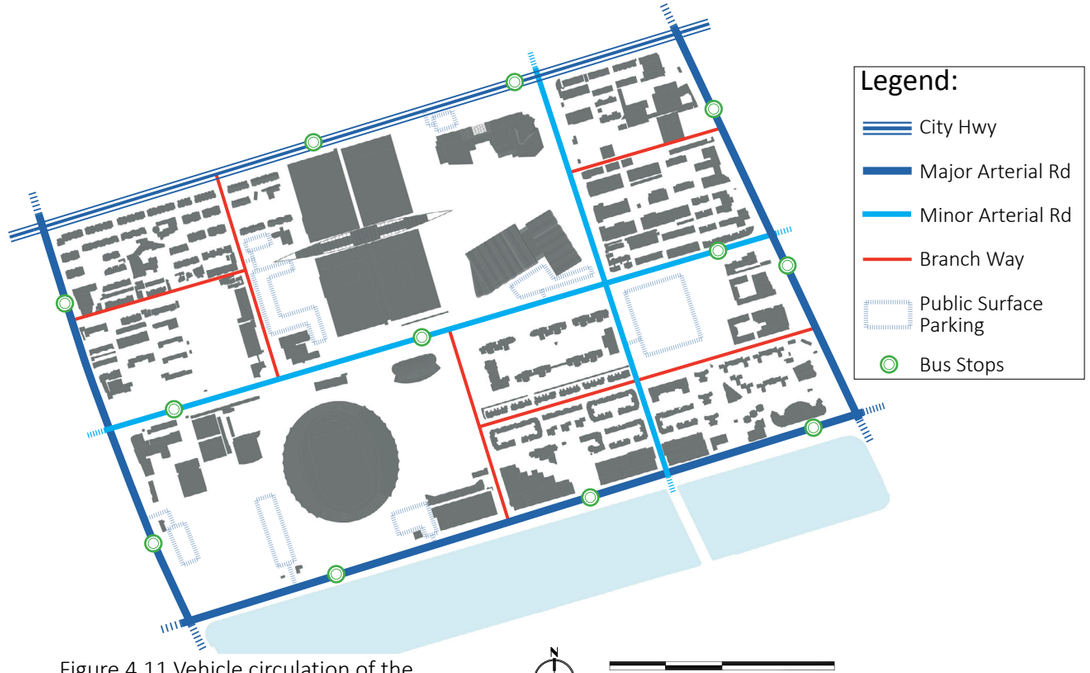


Figure 4.11 Vehicle circulation of the study block and neighborhood



Figure 4.12 Pedestrian and cyclist circulation in study block

4.1.5 Green Space Analysis

Within the study block, a variety of the green spaces of adequate scale have been highlighted, which means these areas could have been designed and constructed to be a social spot for access, stay and recreation. However the modernist design approach adopted has tended to ignore these social potentials and to reduce the role of nature to simply being a backdrop. As shown in Figure 4.14, the green space can be seen but not be engaged with. Often, green spaces are planted with plentiful and aesthetically pleasing vegetation in orderly ways without carefully considering open spaces of different scales for social congregation and interaction. The green spaces that people can access, rest and congregate within the study block are illustrated: one (Figure 4.15) is in front of Xiamen Museum, while others (Figure 4.16) are the seating areas under tree canopies along the edges of the public square. Without vegetation and human amenities, the central area of the public square is not very inviting for public congregation until certain vital social events occur throughout a year. The majority of planting beds are mounded without consideration for stormwater management. With appropriate excavation and retrofit, many of the green spaces in the study block can become water sensitive, while providing spaces for social engagement. As discussed in Chapter 2, Xiamen's local natural soil cannot percolate stormwater effectively due to insufficient permeability, but these soils can be amended by adding sand and humus soil to become capable for water infiltration. In terms of adjacent areas in the neighborhood, a range of green spaces have been explored and identified. As shown, the top three largest green spaces are considered as potential end-receiving water bodies for stormwater overflows for the study block.



Figure 4.15 Social congregation in front of Xiamen Museum



Figure 4.16 Social congregation under tree canopies



Figure 4.14 Inaccessible green space with fence

Figure 4.13 Green space analysis in the study neighborhood

4.1.6 Identifying Opportunities and Constraints

Based on previous site and context analysis, the author explored and illustrated opportunities and constraints as a reference for design interventions. The following table provides an overview of the opportunities and constraints. Further interpretation and illustrations are next eplained.

	Opportunities
1	Propose green roofs on rooftops and provide accessible roof gardens for recreation if needed
2	Retrofit basketball grounds for stormwater detention (either visible or invisible)
3	Implement pervious pavements on parking lots
4	Turn mounded planting beds to be depressed for water retention and percolation
5	Re-arrange the parking lots and propose a multi-functional stormwater park in front of Xiamen Art Gallery
6	Retrofit the green spaces in front of Xiamen Museum and Xiamen City Library for stormwater management and extend the green corridor towards Yuandang Lake
7	Revitalize abondoned golf park and provide a large-scale retention system
8	Propose subsurface detention Cisterns underlying the green spaces of Xiamen Marine College and the football field of Xiamen Sport Center to be end-receiving water bodies
9	Propose a retention system on the temporary parking square and improve commercial environment of adjacent streets
10	Propose (pedestrian and cyclist)-friendly green network throughout the neiborhood to connect potential demonstration sites
	Constraints
1	Load-bearing capacity of roof structure can be a barrier for eco-roof applications
2	Xiamen's local natural soil (red soil) is not appropriate for water infiltration
3	Underground parking and superstore would have influences on green facility design, planning and implementation
4	Xiamen's storm events in the summer are usually extremely intense in short period, which would beyond the stormwater management capacity of individual green infrastructure

Table 4.1 Overview of opportunities and constraints for design interventions

Opportunity 1

The total area of rooftops occupies a high percentage of the study block, especially the portion of Cultrure and Art Center, contributing a large volume of stormwater runoff into underground piping. Implementing green roofs would provide innovative solutions for stormwater management by source control, and potentially provide accessible roofgardens as needed. Potential areas for intensive and extensive green roofs are illustrated as seen in Figure 4.17.

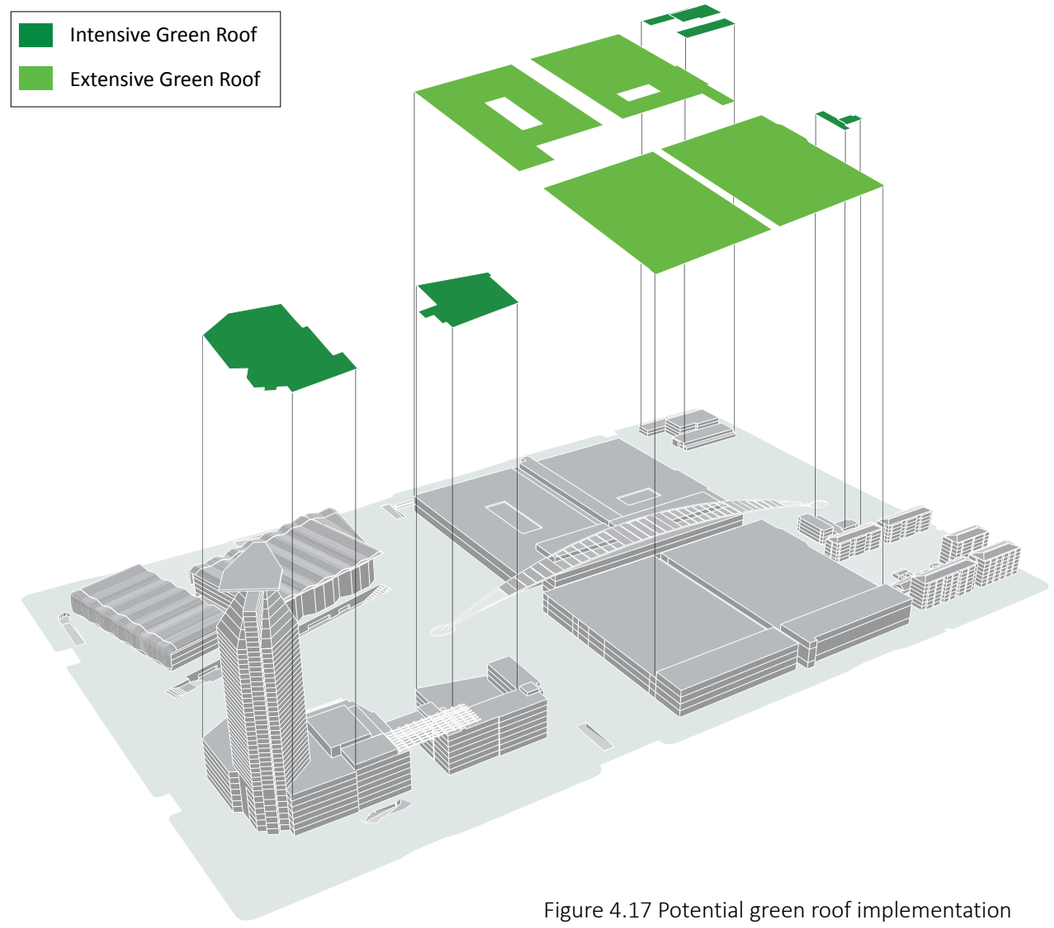


Figure 4.17 Potential green roof implementation

Opportunity 2

There are two basketball courts found in the study block, one is beside Xiamen Planning Institute and the other is located in the residential area. These areas could be retrofitted for stormwater detention. Figure 4.18 demonstrates two types of detention systems that are either visible or invisible. Although the underground detention cistern cannot be seen, other visible devices such as a surface connection trench can be applied, and information signage can be available for education purposes.

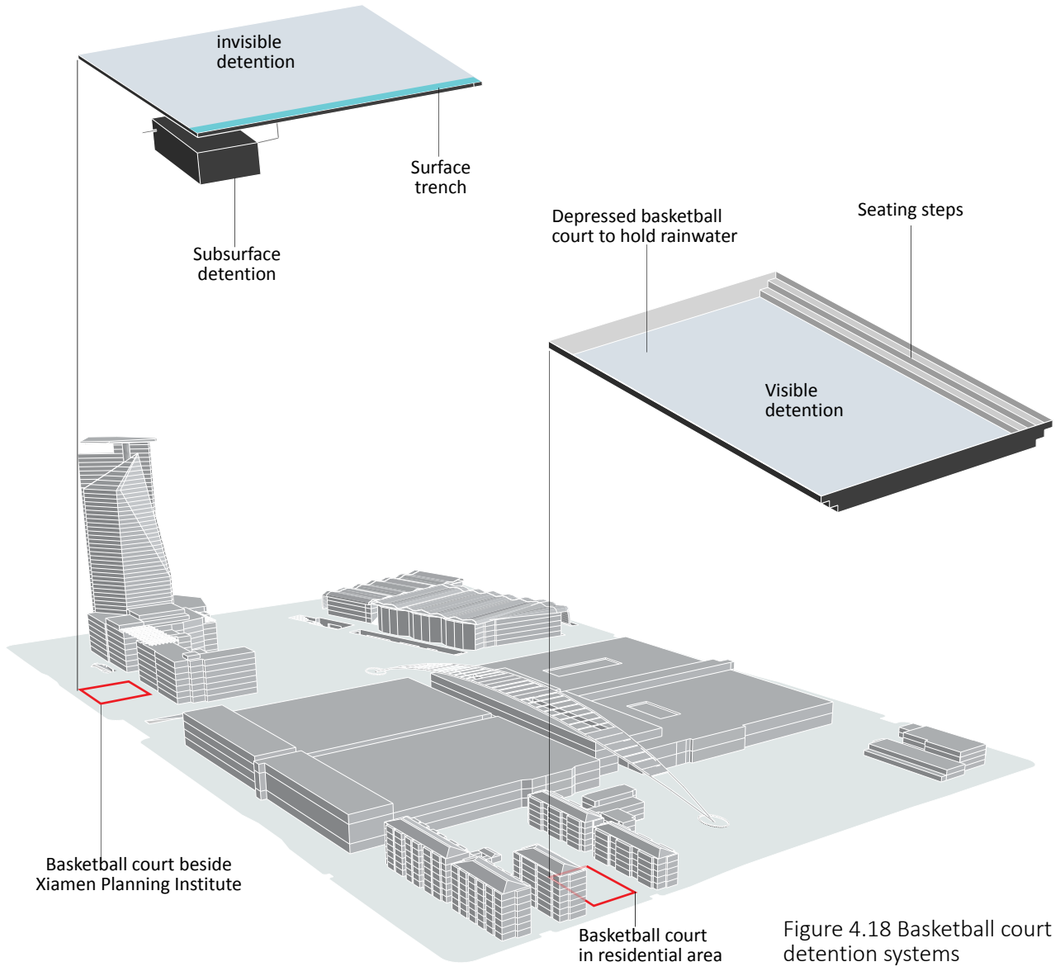


Figure 4.18 Basketball court detention systems

Opportunity 3

Traditional surface parking always contributes a large proportion of impermeable surface and pollutes stormwater due to gasoline leakage. Pervious pavements can be applied on these areas to reduce stormwater runoff (see figure 4.19 and figure 4.20). If space permits, central swales are recommended along parking lots to filtrate stormwater before discharge them to piping systems and next receiving water bodies.



Figure 4.19 Surface parking beside Xiamen Planning Institute



Figure 4.20 Surface parking beside Worker's Gymnasium

Opportunity 4

Innovative green stormwater infrastructure features can detain stormwater and conduct water treatment and infiltration. Generally, green areas of the study block are mounded so that most stormwater quickly dropping from planting beds to impervious surface and be conveyed to underground drainage. Transforming this modernist approach would be necessary to provide sustainable stormwater management.



Figure 4.21 Mounded planting bed (1)



Figure 4.22 Mounded planting bed (2)

Opportunity 5

Currently, the grass area in front of Xiamen Art Gallery is surrounded by parking lots (see Figure 4.23). It is recommended to reposition parking lots so that the priority can be given to pedestrian and cyclists instead of vehicle users (see Figure 4.24). This would improve connectivity between expected visitor destinations. Also, stormwater function, social congregation at different scales, and aesthetics can be efficiently integrated without the interference of the distributed parking lots.



Figure 4.23: Parking and green space beside Xiamen Art Center

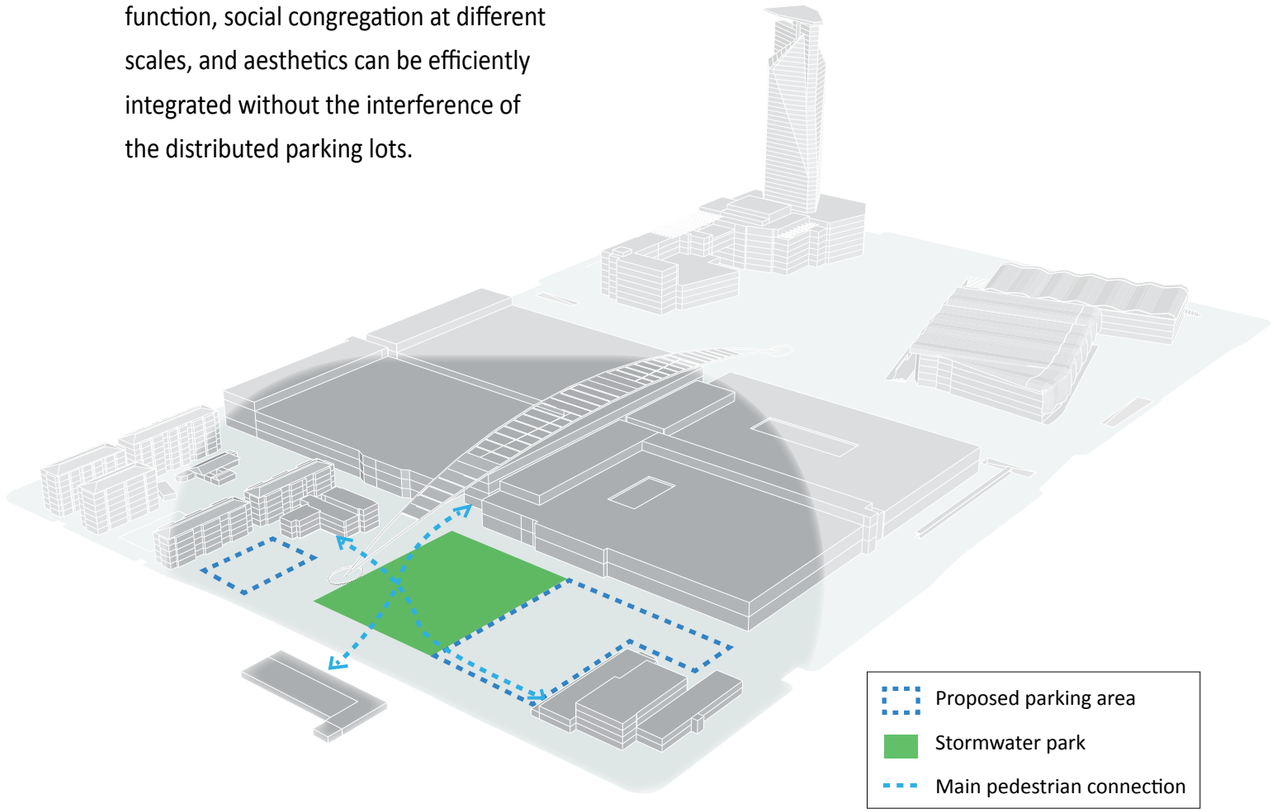


Figure 4.24 Re-arrange parking lots and green space

Opportunity 6 and 7

The green space in front of Xiamen City Library is inaccessible and covered by a range of trees and shrubs (Figure 4.26). Although the green space in front of Xiamen museum is accessible and has water features, stormwater management by nature cannot be found. This location provides an opportunity to retrofit the green spaces using innovative stormwater approaches. Also, an accessible green corridor for stormwater management and social engagement can be extended through the abandoned golf park, towards Yuandang Lake. Currently, the golf park appears underutilized and seen as a chaotic wood land (Figure 4.27). This location presents opportunity to construct a network-scale retention pond to revitalize this area for stormwater management and provide aesthetically pleasing green space for social activities.



Figure 4.26 Existing landscape in front of Xiamen City Library



Figure 4.27 Existing landscape in the abandoned golf park

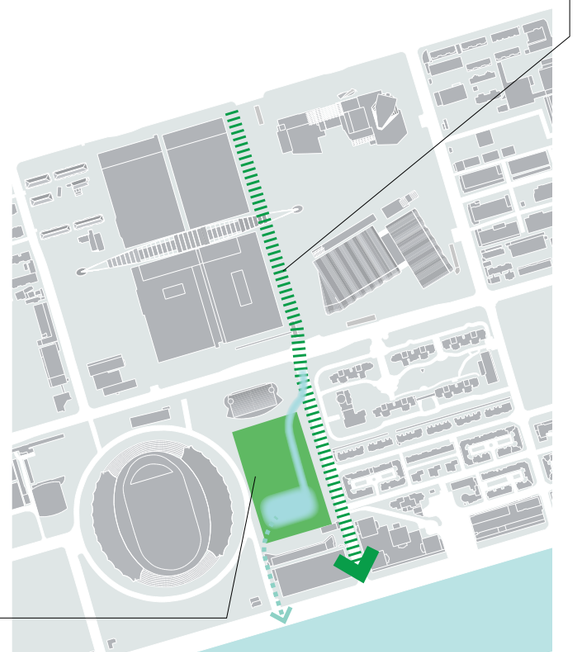


Figure 4.25 Green corridor from Xiamen Museum to Yuandang Lake

Opportunity 8

Individual green facilities have limited capacity for stormwater management during heavy storms unless larger receiving water bodies such as retention/ detention ponds are prepared to collect overflows. The author found the green spaces of the Xiamen Marine College and the football field of the Xiamen Sport Center are large enough to construct subsurface detention cisterns to detain overflows from the proposed stormwater park in front of the Xiamen Art Gallery. Between storm events, water would be released to Yuandang Lake slowly and infiltrate to recharge ground water.

Opportunity 9

The government of Xiamen intends to improve commercial environment of the CAC neighborhood to attract more visitors. The temporary parking space has been designated for future commercial development. It is highly recommended to construct a network-scale retention system within the area to collect stormwater overflows from parts of the study block. In Figure 4.28, the author highlights potential subdivisions for commercial use and stormwater management. Adjacent commercial streets in need of improvement are also indicated. This mapping would inform further stormwater flow planning, future commercial development and green network in the design interventions

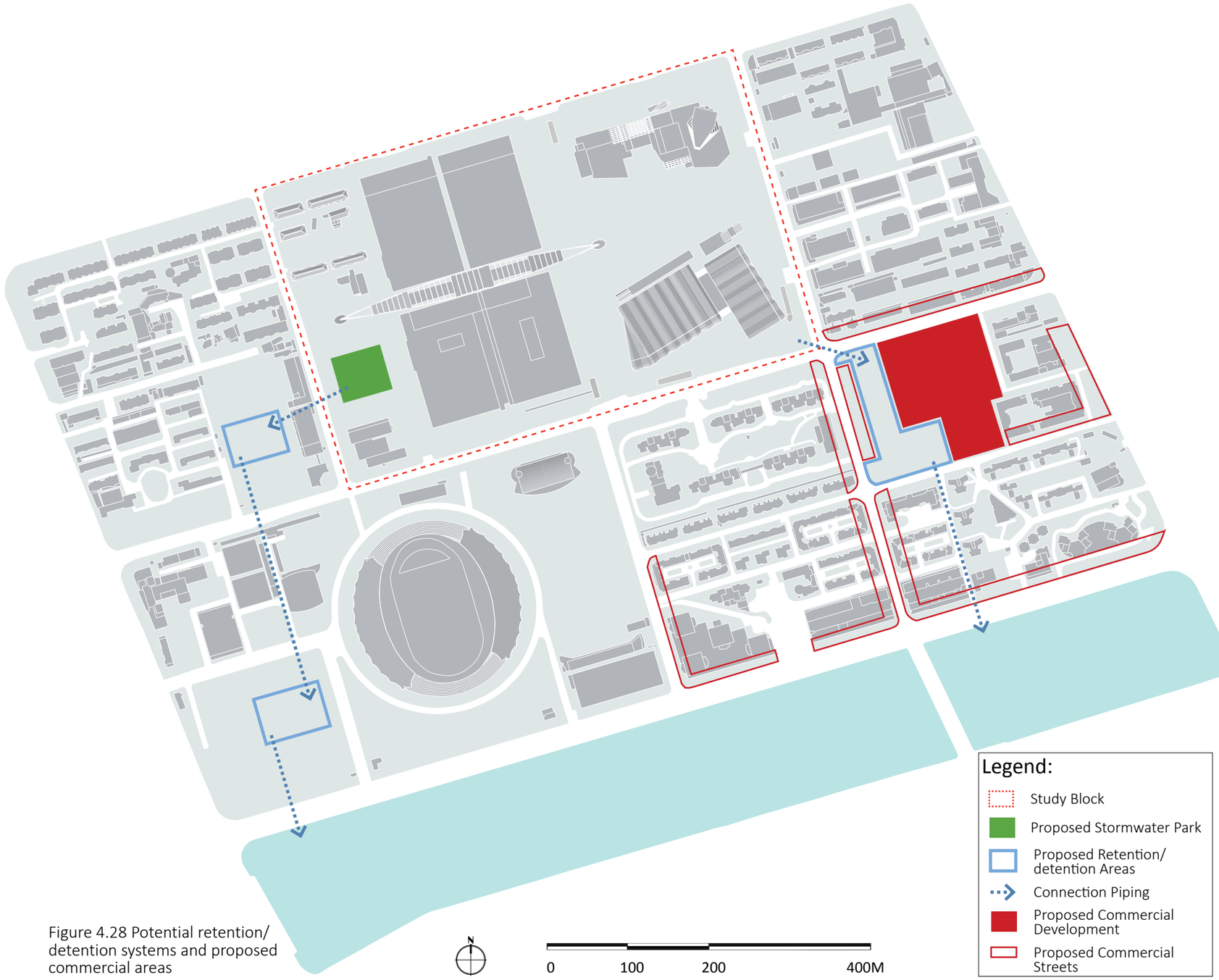


Figure 4.28 Potential retention/ detention systems and proposed commercial areas

Opportunity 10

Green infrastructure planning should be integrated with other planning strategies and techniques, such as active transportation, smart growth, and others, to make the neighborhood more pedestrian-friendly and cyclist-friendly to encourage more dynamic interaction between different destinations. For example, bike-share system can be introduced into the neighborhood, connecting CAC block, future commercial square, Xiamen Sports Center, and surrounding residential areas. Branch ways can be improved as green corridors and linked as a complete green tour that not only addresses stormwater runoff, but also provide amenities for human activities to achieve education purpose.

As seen in Figure 4.29, existing visitor destinations and proposed visitor destinations have been identified with information of linear distance between them. The average distance is more than 400 meters, beyond the desirable walking distance of the general public. In fact, people would walk more than the linear distances as indicated on the map. This mapping provides position information to inform further design interventions of a feasible and efficient green network for both pedestrian and cyclist circulations.

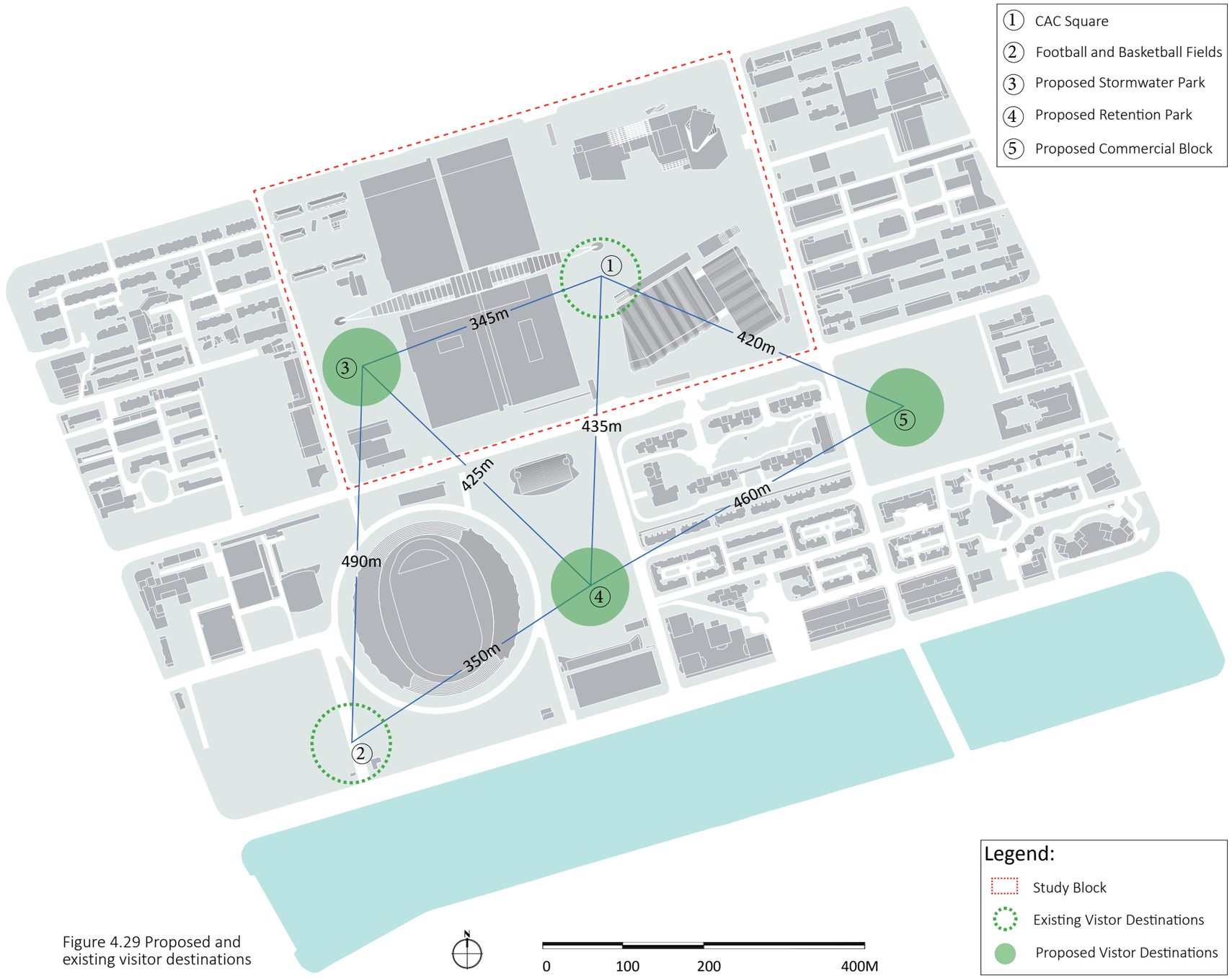


Figure 4.29 Proposed and existing visitor destinations

Constraints:

There are four constraints in need of careful considerations in future design interventions yet the author was not able to rigorously address these issues in this research due to limited timeline, funding and relevant resources.

1. Evaluation of load-bearing capacity for rooftops should be conducted in advance to avoid damage to roof structure. In this research, green roof proposals were developed on the assumption that the study block is a recently developed block with sufficient load-bearing capacity for either extensive or intensive green roofs. However, future retrofitting practices should be undertaken by an interdisciplinary group with engineers to evaluate structure capacity of the rooftops.

2. As discussed, although Xiamen's local natural soil (red soil) is insufficient for water infiltration, soil amendment can be conducted to meet the requirement. In this research, design interventions regarding sizing determination of green facilities were conducted, assuming soil permeability is appropriate for water infiltration. In future development, the types and scale of green facilities should be determined in conformity to precise water infiltration capacity of the soil.

3. Xiamen's storm events in the summer are usually extremely intense over a short period, which would be beyond the stormwater management capacity of individual green infrastructure. When space permits, adequate volume of a detention system can be installed to accommodate storms. Also, next receiving water bodies should be planned to address overflows and avoid flooding issues.

4. Underground infrastructure would have significant influences on green facility design, planning and implementation. In the study block, underground parking and shopping occupy a considerable area. In Figure 4.30, positions of underground parking and shopping are illustrated, which should be considered in next designs.

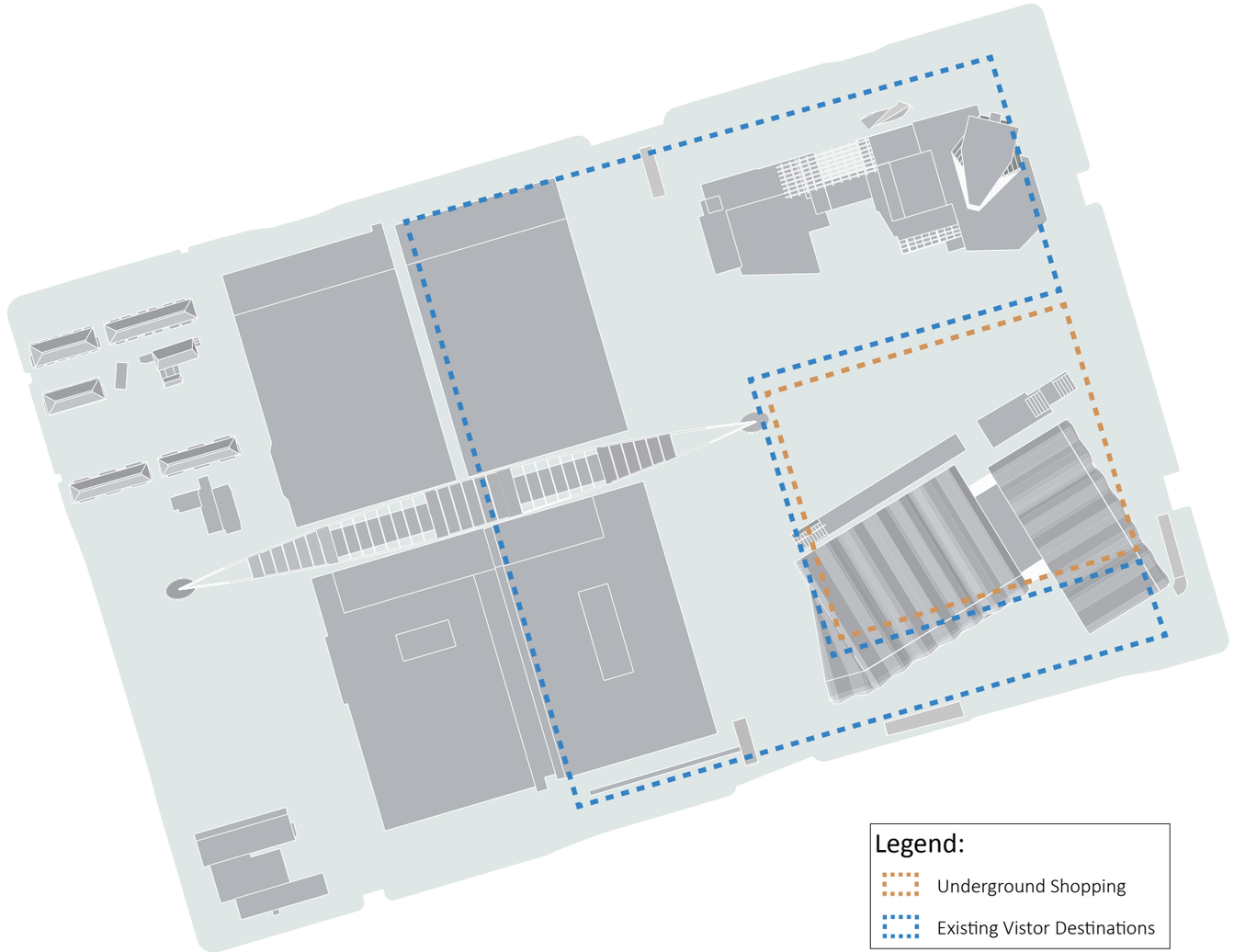


Figure 4.30 Positions of underground parking and shopping

4.1.7 Summary

The regional analysis identified the block of Culture and Art Centre (CAC) as one of the major hubs located in the Xiamen central area. The study block is surrounded by a number of residential areas, immediately adjacent to Xiamen Sports Center, and close to Yuandang Lake. The neighborhood provides a variety of assets that are attractive to those who live in the rest of the city.

The site and context inquiry explored existing green space and identified potential opportunities and locations for retrofitting practice, which should be considered in design interventions. Watershed analysis identified the major piping system of the neighborhood, which is connected to the water receiving body, Yuandang Lake. Design interventions should respect existing watershed processes, and consider how green space can be retrofitted and connected with existing piping in ways that are practical and cost-effective, while reducing overland flows to the greatest extent.

The site and context inquiry also explored existing land use of the study block and identified surrounding urban settings. Design interventions should not only consider retrofitting green infrastructure for stormwater management, but should also provide solutions regarding how these green facilities can be integrated with human activities and circulations in ways that educate and delight people who visit.

After exploring vehicle and pedestrian circulations of the study block and its adjacent areas, the author found the existing condition of the neighborhood prioritizes rights of way for vehicle users rather than pedestrians and cyclists. Gated residential areas lack permeability and accessibility for social interaction and for visitors to travel around. There are potential opportunities to provide active transportation options in the neighborhood to connect the study block with adjacent blocks and also connect the neighborhood with the rest of the city. A dedicated bike and pedestrian green route is highly recommended to link the block of CAC, the city proposed commercial block, and Xiamen Sports Center, to enhance the connectivity of the inner-neighborhood. This route should feature green infrastructure, human amenities and other demonstration means for the purpose of education regarding sustainable stormwater management practices. More details of planning and design are next explained and illustrated.

4.2 Design Framework

For the purpose of this research, the framework was developed based on two major goals: sustainable stormwater management and education/demonstration. The framework provides a foundation to support design interventions for the study block.

As shown in Figure 4.31, principles (1-4) were refined from the literature review regarding LID strategies and techniques to address stormwater issues. One of the principles suggests constructing green infrastructure at a variety of types and scales. These types of green infrastructure have been explored, interpreted and illustrated specifically in Chapter Two. Each addresses design considerations, benefits and limitations. Design interventions should refer to specific parts to identify certain techniques, standards and requirements as needed. The location of each green infrastructure has been indicated in the diagram for reference.

Principles (5-8) were identified from three precedent built projects, for the purpose of education/demonstration of innovative stormwater management. When applying these principles, design interventions should consider different age groups and different users (pedestrians/cyclists/vehicle users). Designs should call attention to the sustainable stormwater management in ways that attract and inform people of their value. Features in each precedent built project are identified as to how they are a good example of the four principles for public education. In addition, lessons with regards to LID strategies and techniques were also summarized at the end of each project study to enlighten design interventions and future green infrastructure planning and implementation in the City of Xiamen.

Potential opportunities for improvement and constraints were discussed and summarized at the end of the site and context inquiry. Based on a logical analysis of the existing site and context, design interventions should be conducted, considering identified opportunities and constraints, with reference to the eight principles derived from the literature review and initiatives of precedent projects.

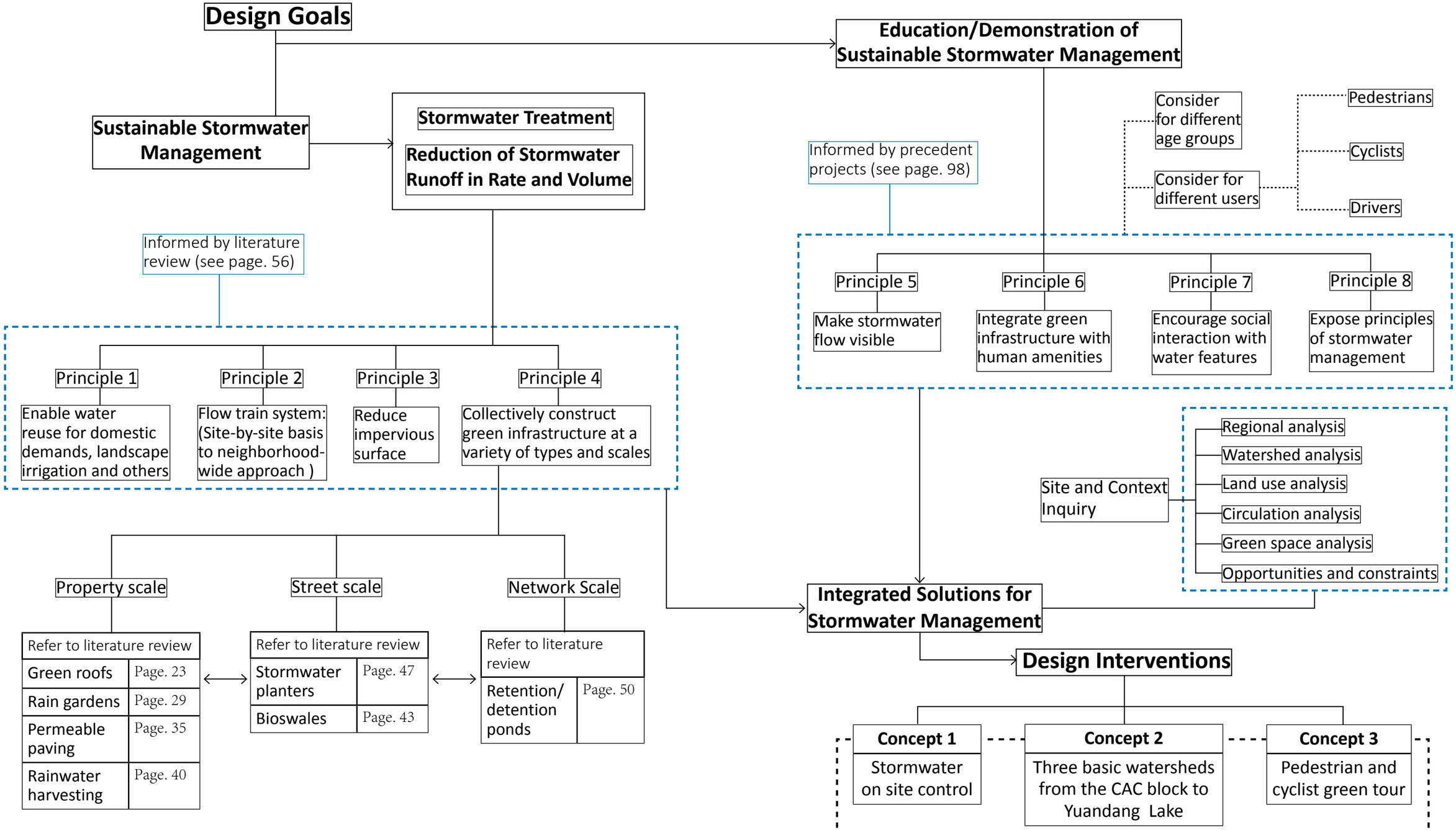


Figure 4.31 Design framework processing

4.3 Design Interventions

According to the design framework, this section provides three basic design concepts to guide future development. These three design concepts are closely integrated to achieve the goals of this study.

Concept one refers to source control before discharging stormwater to next receiving systems. The author divides the study block into small pieces and takes advantage of potential space such as rooftops and planting areas for stormwater retention as the early step of the entire flow train system. Meanwhile, rainwater harvesting system would be installed for water reuse as needed.

Concept two means overflows from the study block during extremely heavy storms would be drained discretely to three different large-scale retention/detention systems, which manages stormwater runoff from the study block towards Yuandang Lake.

In terms of concept three, the green tour would improve rights of way for pedestrian and cyclist circulations, connecting major visitor destinations and human amenities to enlighten people with regards to sustainable stormwater management.

4.3.1 Watershed Planning

Overflows of the study block were planned based on three stormwater flow direction strategies as seen in Figure 4.32. Respecting general elevation would reduce sank costs on excavation and fill projects. Proximity strategy aims to reduce the demand of connection piping and pumping systems. On property scale, general grading should be conducted from buildings to adjacent sites, then to roads. This is to avoid back flow of stormwater and damage to building foundations due to stormwater leakage.

Figure 4.33 shows the study block are divided to 14 stormwater catchment areas. Stormwater falling within the study block would be managed within each catchment boundaries respectively at early stage. Details of stormwater overflow trains are next explained.

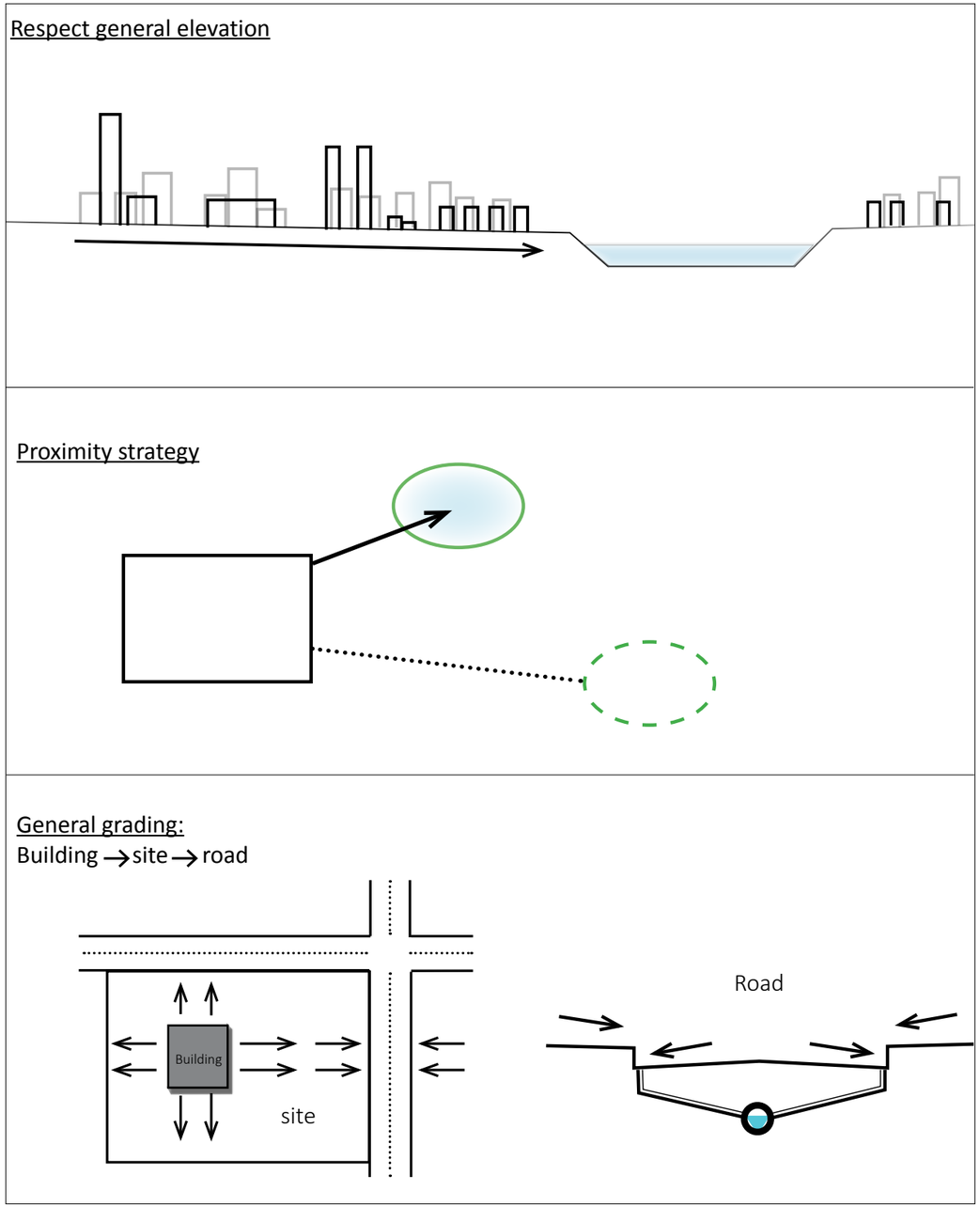
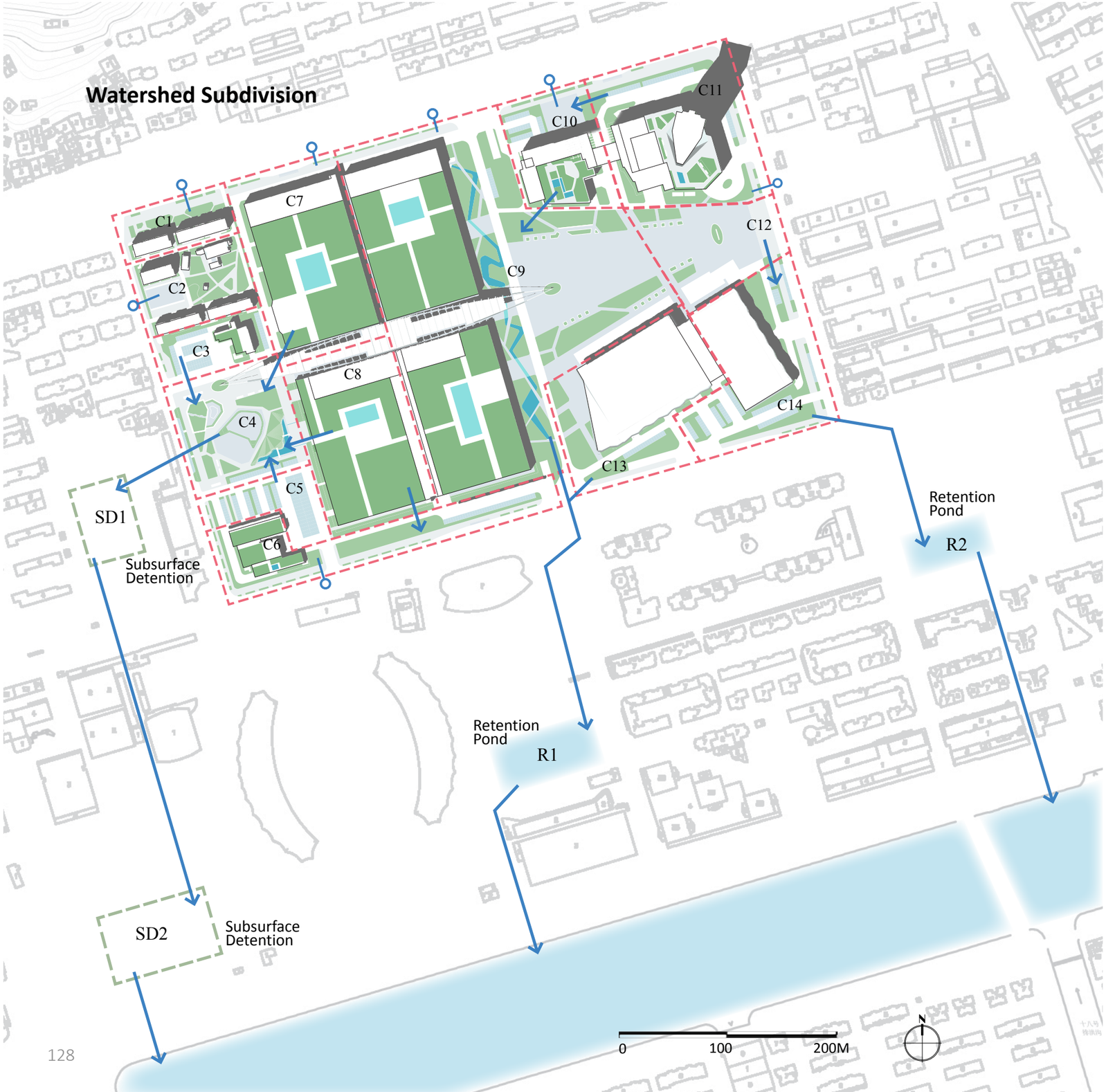


Figure 4.32 Stormwater flow direction strategies

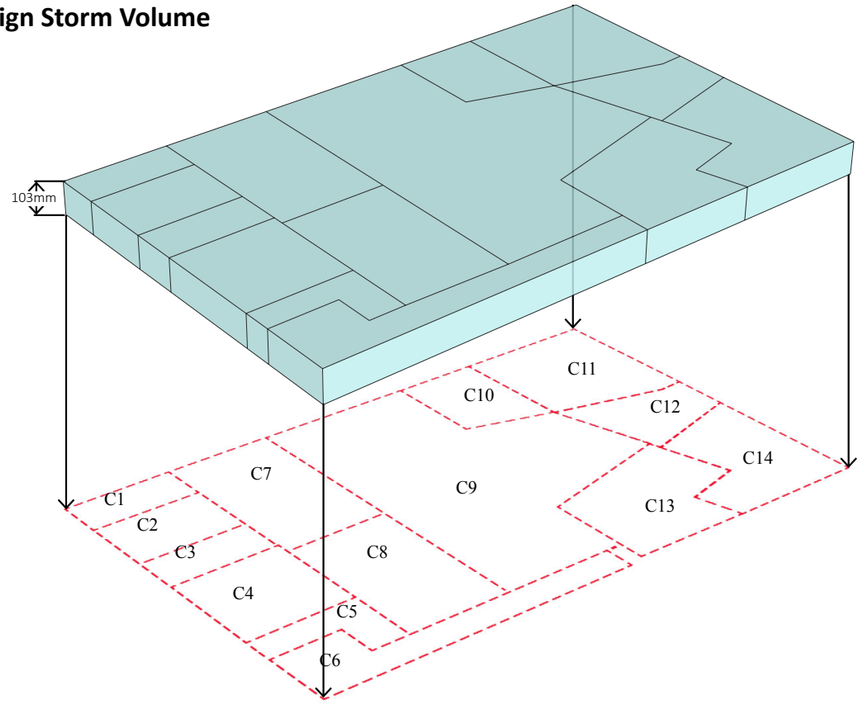


The proposed watershed subdivision of the study block is based on addressing stormwater on site first, before being conveyed and released to the next receiving systems. According to rules of thumb of LID practices, these subdivisions are designed to at least manage 2-year 24-hour storm events (103mm). During heavy storms, overflows from each site will be transferred to the Yuandang Lake through SDs (Systems of Subsurface Detention/Infiltration), Retention Ponds, or existing underground piping. Specific overflow trains from each catchment basin are indicated on the left. The proposed green infrastructure network not only contributes to stormwater reduction in rate and volume, but also improves stormwater quality.

Stormwater Overflow Trains
C1 > Existing Piping > Yuandang Lake
C2 > Existing Piping > Yuandang Lake
C3 > C4 > SD1 > SD2 > Yuandang Lake
C4 > SD1 > SD2 > Yuandang Lake
C5 > C4 > SD1 > SD2 > Yuandang Lake
C6 > Existing Piping > Yuandang Lake
C7 > C4 > SD1 > SD2 > Yuandang Lake
C7 > Existing Piping > Yuandang Lake
C8 > C4 > SD1 > SD2 > Yuandang Lake
C8 > C6 > Existing Piping > Yudang Lake
C9 > R1 > Yuandang Lake
C10 > C9 > R1 > Yuandang Lake
C10 > Existing Piping > Yuandang Lake
C11 > C10 > Existing Piping > Yuandang Lake
C11 > Existing Piping > Yuandang Lake
C12 > C14 > R2 > Yuandang Lake
C13 > R1 > Yuandang Lake
C14 > R2 > Yuandang Lake

Figure 4.33 Watershed subdivision analysis

Design Storm Volume



Catchment Area	Area (m^2)	Two-year 24-hour storm	Design storm volume (m^3) = Area(C_x)x0.103m^2
C1	5375	103mm (0.103m)	553.6
C2	8810		907.4
C3	5620		578.9
C4	13159		1355.4
C5	5123		527.7
C6	15048		1549.9
C7	21360		2200.1
C8	20105		2070.8
C9	72640		7481.9
C10	10590		1090.8
C11	21406		2204.8
C12	11305		1164.4
C13	19861		2045.7
C14	19426		2000.9

Figure 4.34 Caculation of design storm volume

Guidance for Sizing Determination

This design proposal is intended to handle with 2-year 24-hour precipitation on site before entering the next receiving systems. The table of design storm volume provides data for each catchment area that next steps of design interventions need to target. Ideally, stormwater falling on the sites should be harvested and infiltrated by green space to recharge groundwater. However, the types and size of green facilities (infiltration areas) contextually vary in accordance with site constraints and other demands. In fact, proposed green facilities may not have adquate capacity for retention and and infiltration so that additional infrastructure such as underground cisterns would be needed to manage the rest. Thus, it is necessary to establish a conceptual model to determine the storage capacity of additional infrastructure. The idea is to substract the infiltration volume and storage volume of proposed retention area from the expected rainfall volume. The amounts remaining on the site needs to be handled with additional infrastructure. This process is demonstrated below in a concept model to guide determination for the size of additional infrastructure.

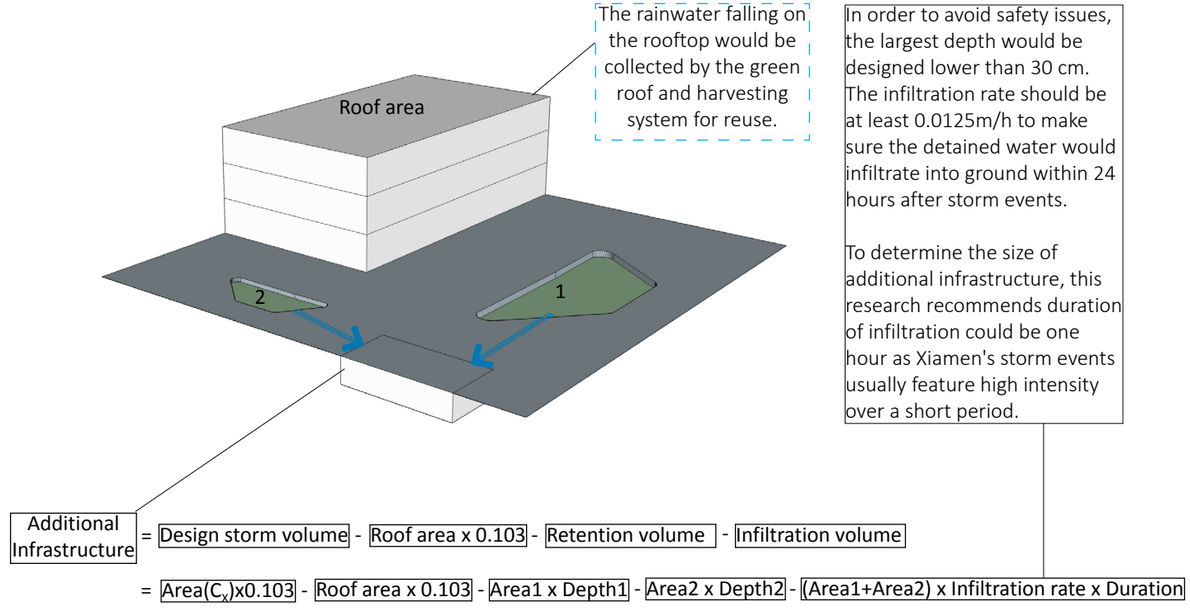


Figure 4.35 Guidance for sizing determination

4.3.2 Design Illustrations of GI at Three Scales

This section demonstrates design interventions at three scales (as seen in Figure 4.36), regarding how the proposed green facilities and techniques are designed and integrated to achieve sustainable stormwater management, provide accessible green space and amenities for social congregation and recreation, and in the meantime enlighten people the ecological functions of green stormwater infrastructure.

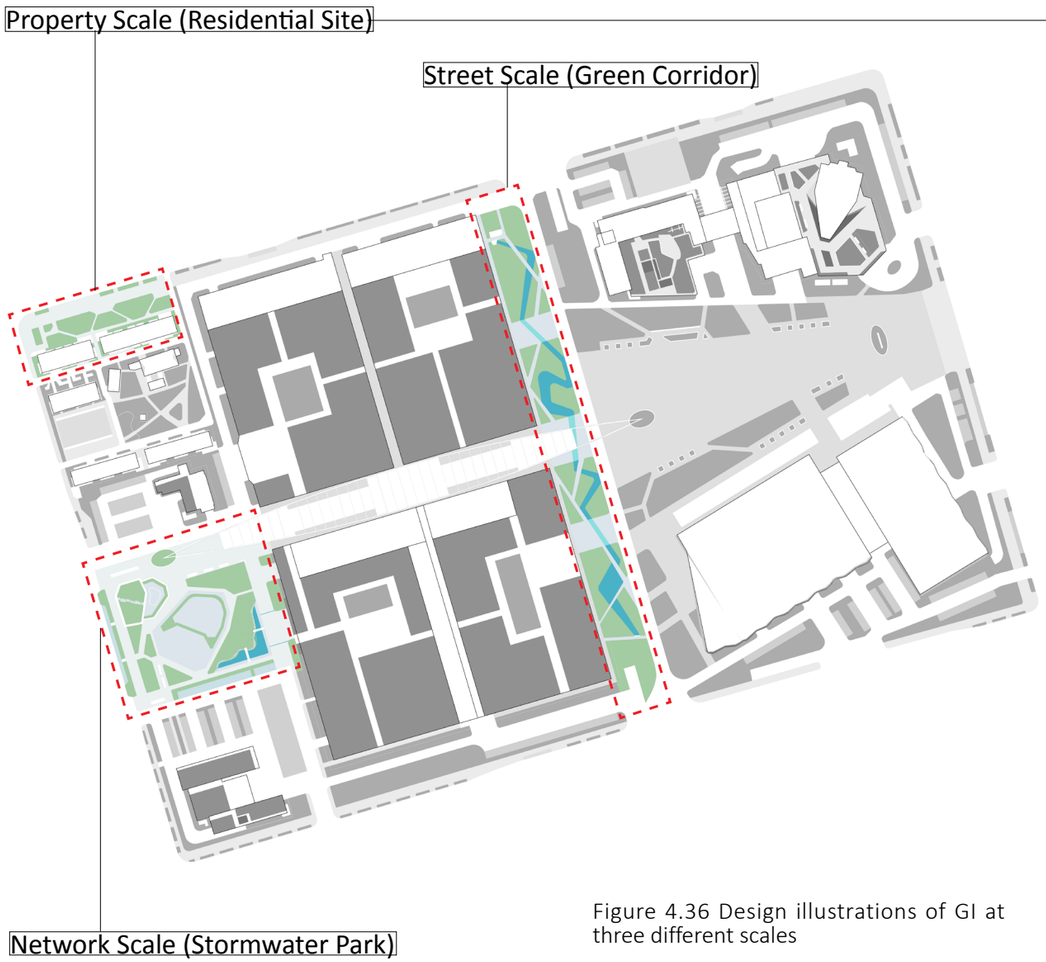


Figure 4.36 Design illustrations of GI at three different scales

4.3.2.1 Property Scale (Residential Site)



Figure 4.37 Existing condition of the residential site (C1)

The photo shows existing condition of the residential site at the northwest corner of the study block, which features an inaccessible green space planted with a cluster of trees and shrubs underneath. The following diagram contrasts existing condition of the site with the proposed green space.

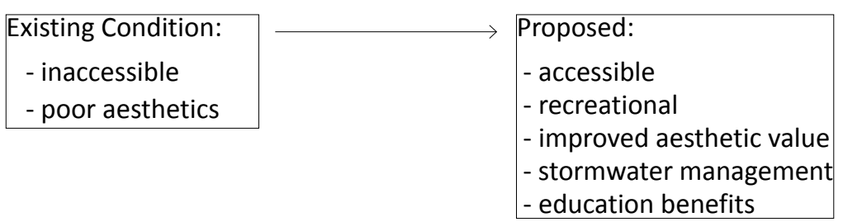
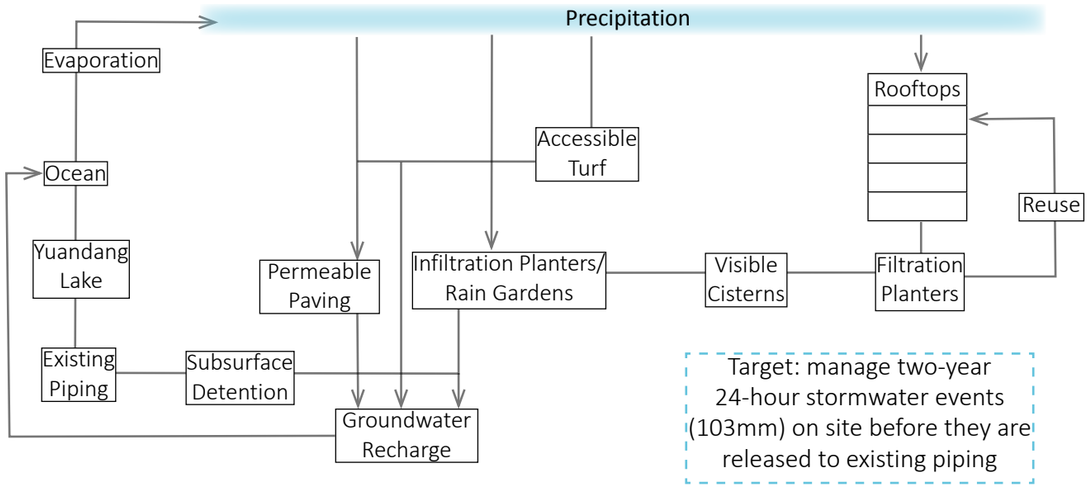




Figure 4.38 Proposed GI layers



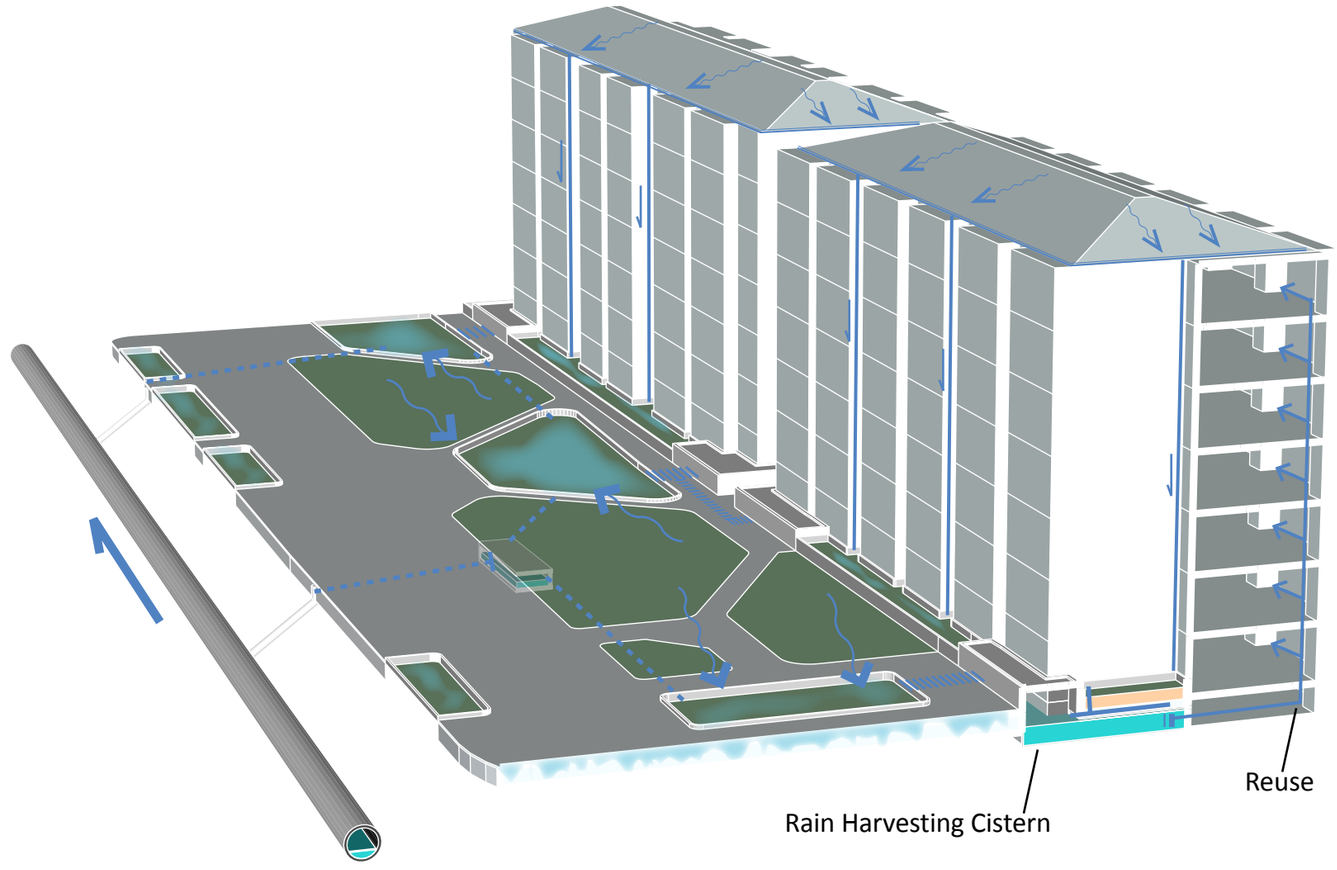
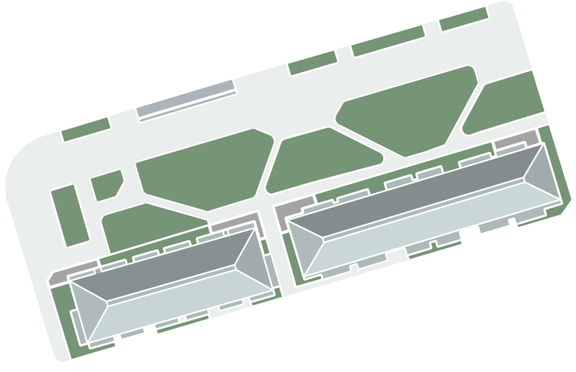


Figure 4.39 Water flow of the residential site

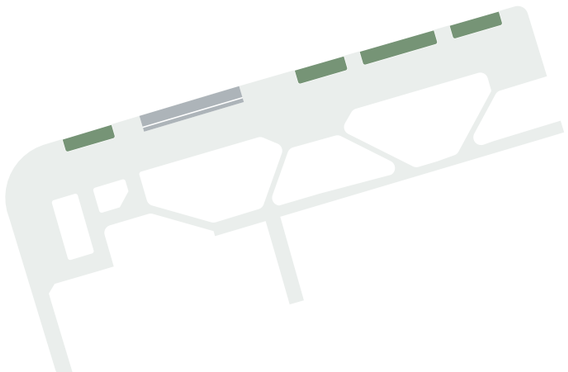
Sizing Determination (Design Storm: 103mm)



Area: 4201m^2

The volume of rainwater falling on the property block

= 4201m^2 x 0.103m
= 432.703m^3

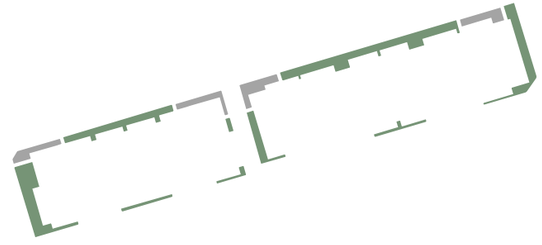


Area: 1796m^2

The volume of rainwater falling on the permeable pavement and sidewalk stormwater planters

= 1796m^2 x 0.103m
= 185m^3

Figure 4.40 Sizing determination of the residential site

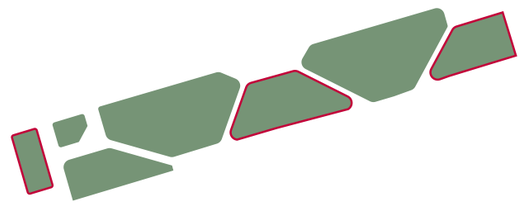


Area(including rooftops): 1299m^2

The volume of rainwater falling on the rooftops, adjacent filtration planters and rainwater cisterns

= 1299m^2 x 0.103m
= 133.8m^3

These water would be treated by the filtration planters and collected by the rainwater cisterns. During heavy storms, overflows would be conveyed to the three rain garden planters as needed.



Total green area: 1106m^2
Rain garden area: 361m^2

The volume of rainwater falling on the green areas

= 1106m^2 x 0.103m
= 113.9m^3

To collect water runoff (runoff value= 0.25) from entire green areas. The minimum depth of the rain garden

= [(1106m^2 - 361m^2) x 0.103mm x 0.25 + 361m^2 x 0.103mm - 361m^2 x 0.0125m/hour x 1 hour]/361m^2
= 0.144m (14.4cm)

This is lower than the **maximum depth 30cm** as discussed. Thus additional infrastructure would be not nessessary if the practice intends to manage only one-year 24-hour storm events.

① Bus stop brings visitors closer to innovative stormwater management site

② Social congregation space adjacent to the rain garden within the shading provided by the tree canopies

③ Stormwater planter along the curb of sidewalk to collect stormwater runoff from Xianyue Road

④ Accessible green space for people to stay, play and rest

⑤ Educational signage to inform people about the site plan and the natural functions for stormwater management

⑥ Accessible pedestrian path integrated with green space and rainwater cisterns to facilitate social engagement with stormwater management

⑦ Permeable paving for the sidewalk to promote water infiltration and storage

⑧ Stormwater planter to collect the stormwater runoff from the rooftop and adjacent area of the property

⑨ Visible rain harvesting cistern to inform people of the importance of water reuse

⑩ Stormwater Planter integrated with rainwater harvesting systems for water reuse

⑪ Sheltering trees provide wind protection, shade, biodiversity and wildlife habit. They are irrigated by rainwater and increase transpiration (evaporation) on site.

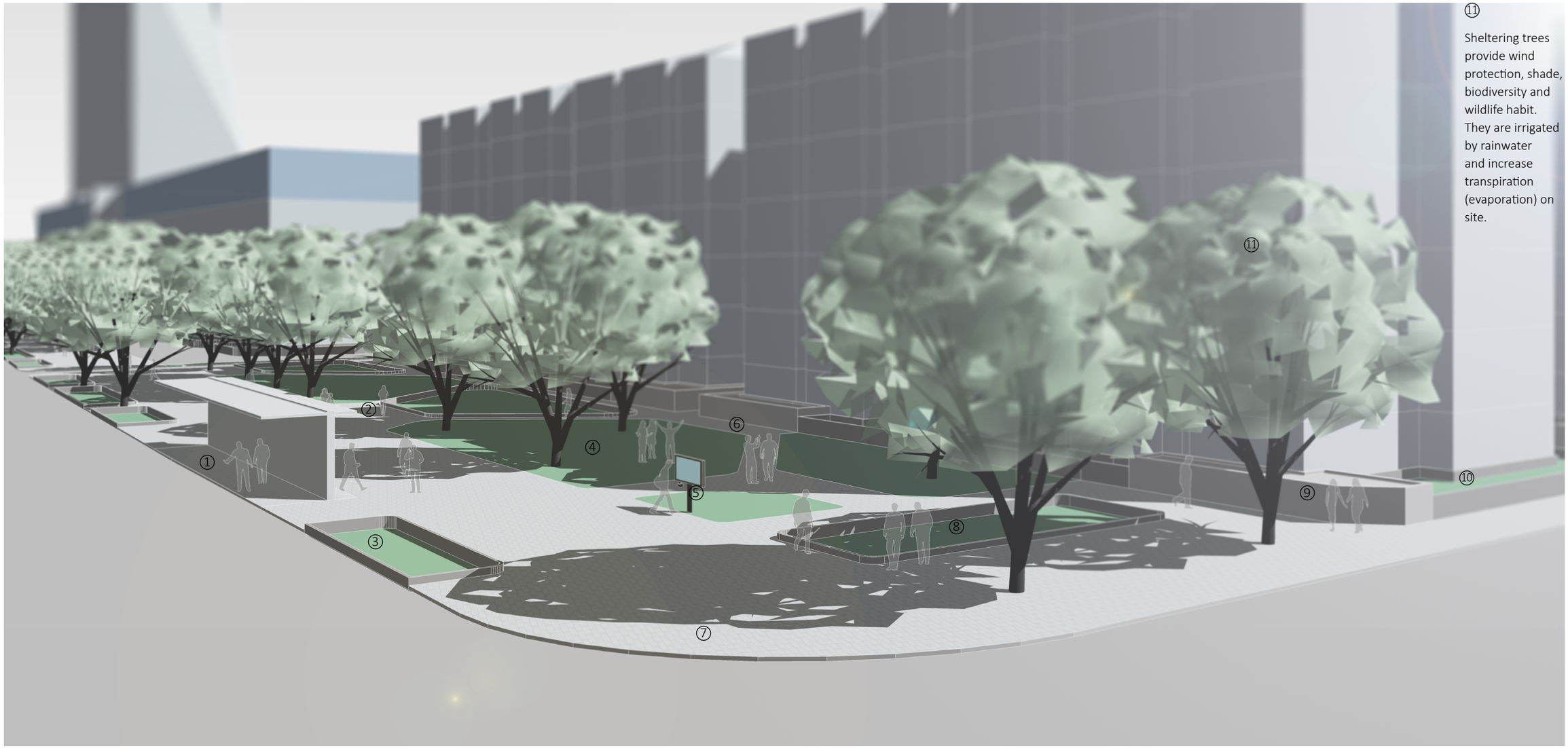
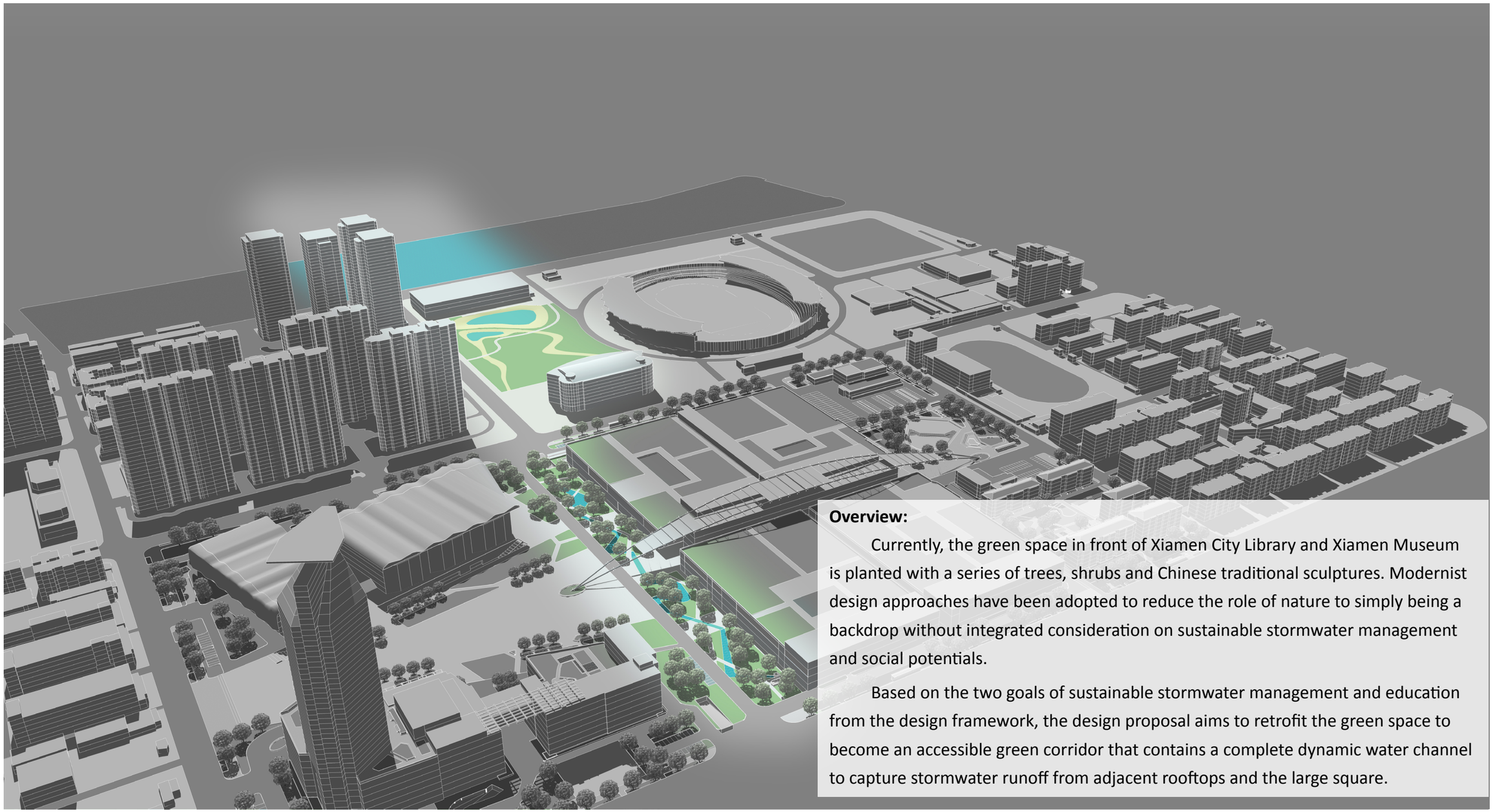


Figure 4.41 Perspective of the residential site

4.3.2.2 Street Scale (Green Corridor)



Overview:

Currently, the green space in front of Xiamen City Library and Xiamen Museum is planted with a series of trees, shrubs and Chinese traditional sculptures. Modernist design approaches have been adopted to reduce the role of nature to simply being a backdrop without integrated consideration on sustainable stormwater management and social potentials.

Based on the two goals of sustainable stormwater management and education from the design framework, the design proposal aims to retrofit the green space to become an accessible green corridor that contains a complete dynamic water channel to capture stormwater runoff from adjacent rooftops and the large square.

Figure 4.42 Proposed green corridor

Stormwater Flow Analysis of Catchment Area (C9)

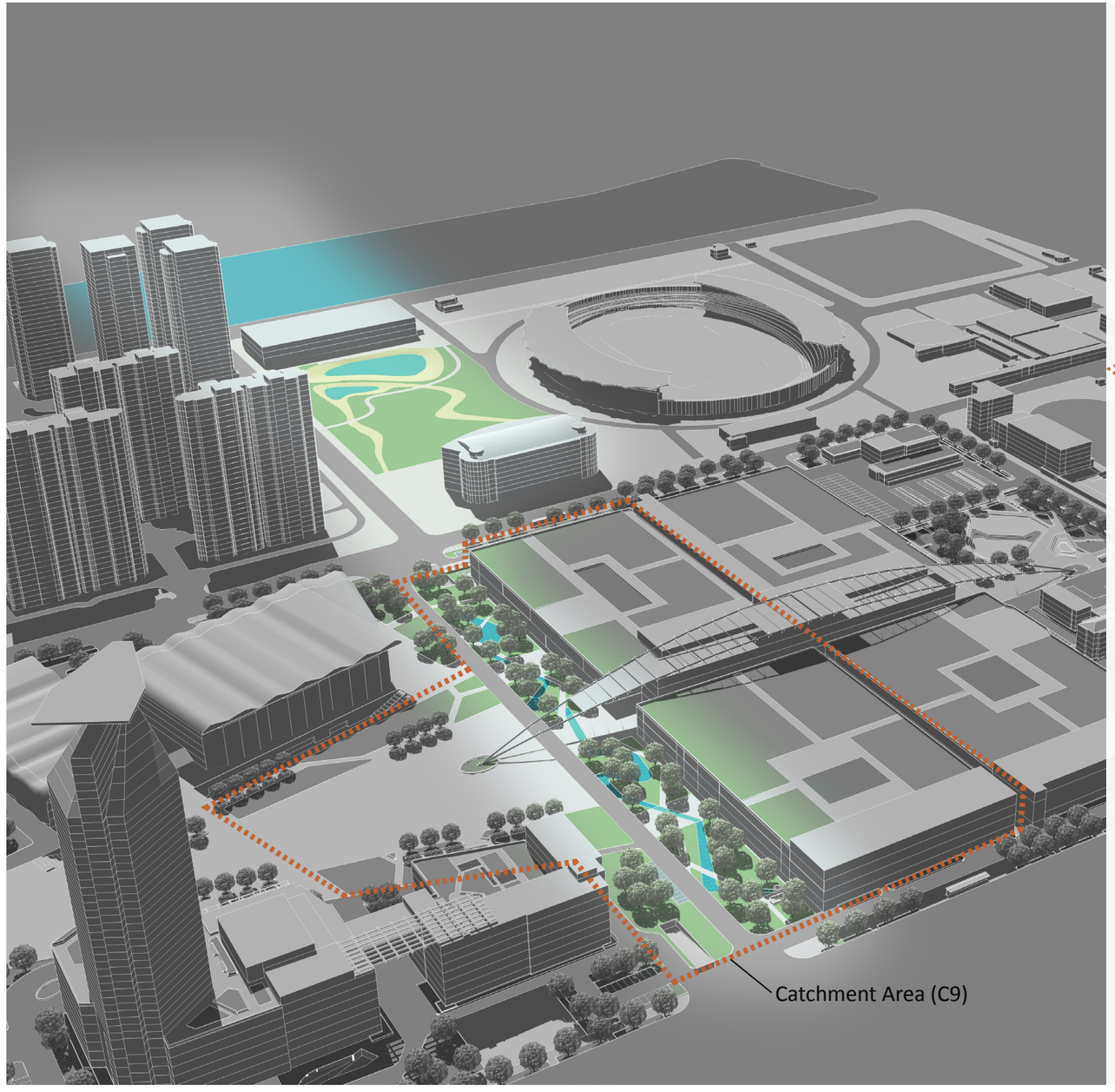


Figure 4.43 Proposed catchment area (C9)

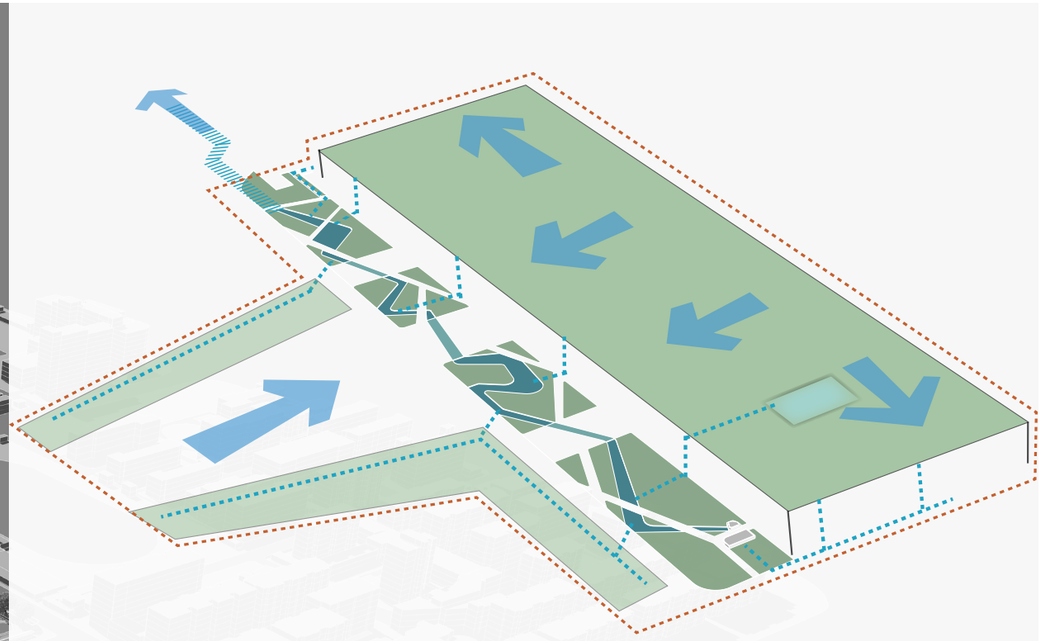
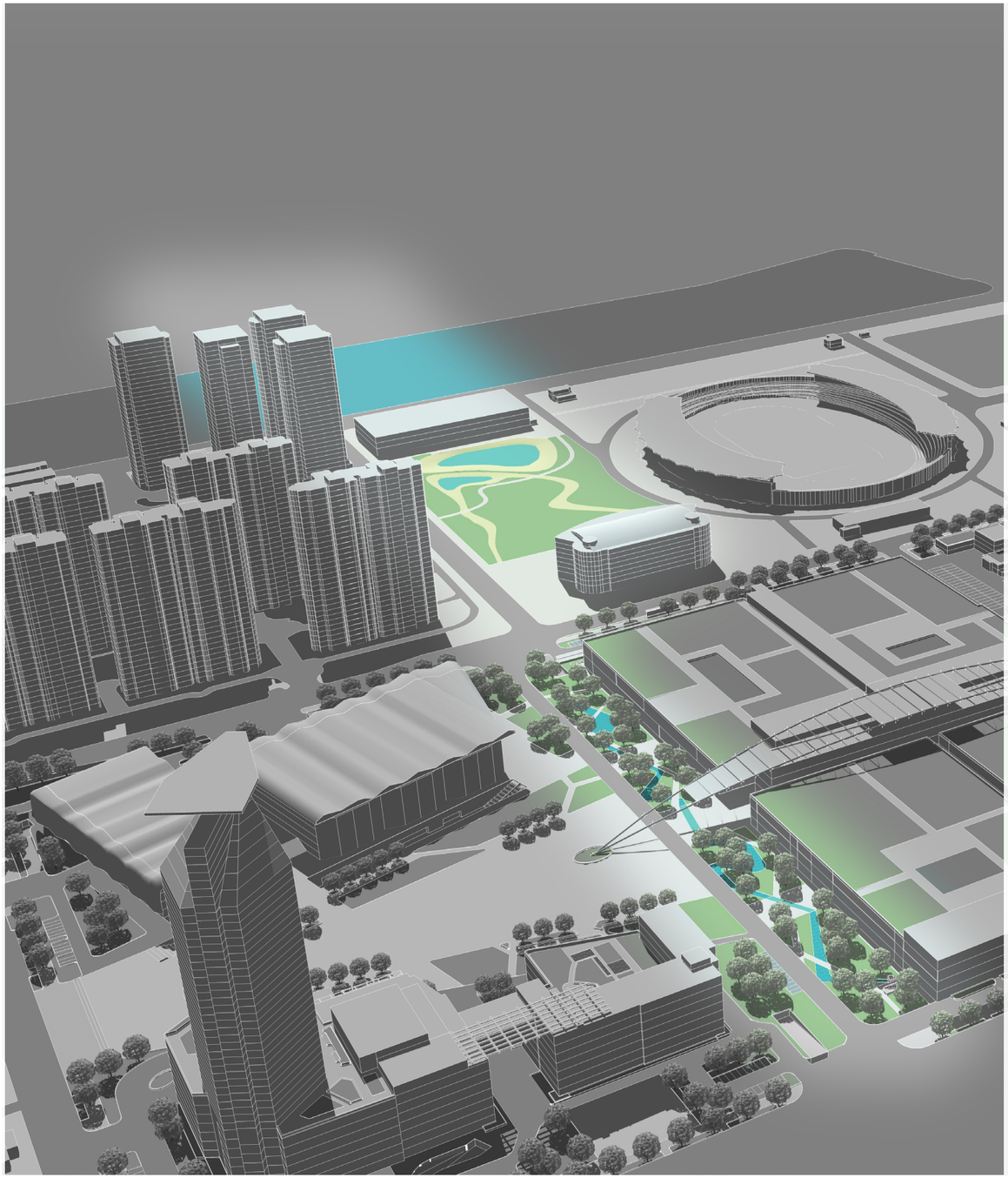


Figure 4.44 Stormwater flow analysis (C9)

The proposed green corridor collects stormwater runoff from adjacent rooftops and the large public square. As this area was constructed with underground parking and shopping mall, deep water infiltration is not appropriate in this area. However, rainwater harvesting cisterns could be installed to pursue water reuse as needed if space permits. During heavy storms, stormwater overflows would be conveyed through the connection piping to the next water receiving body (retention pond as shown in Figure 4.43)



Green Infrastructure Layers

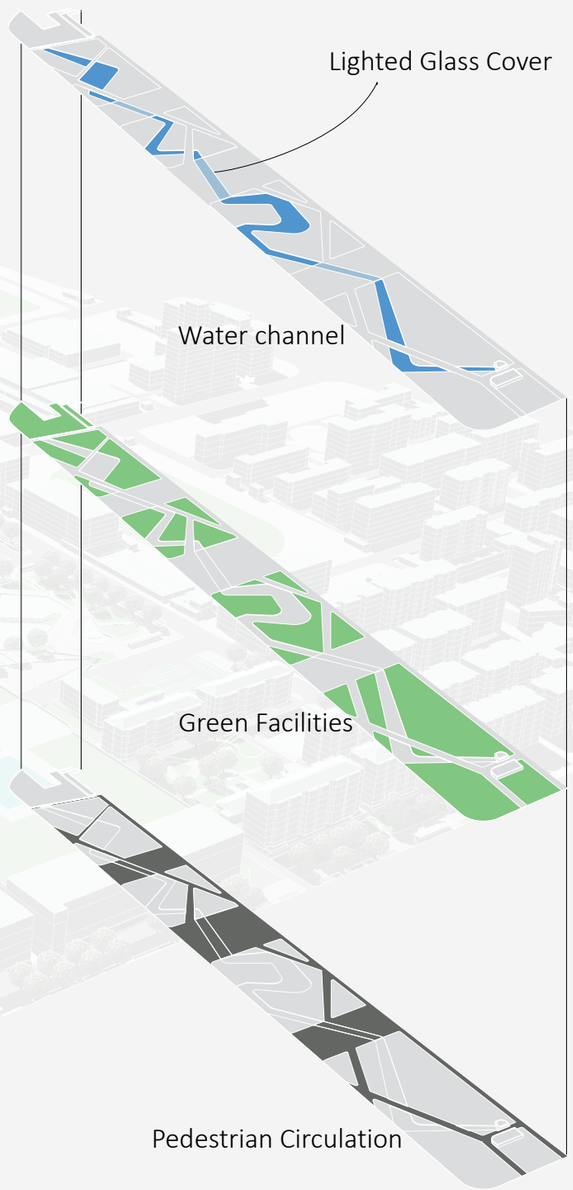


Figure 4.45 GI layers of the proposed green corridor

Design Strategies

1. Collect stormwater from two large-footprint buildings, and adjacent water runoff from the impervious public square.
2. Make the channel visible and accessible for recreational activities.
3. Install lighted glass covers on the water channeal that go through three small plazas to increase aesthetic value and provide bearing capacity for pedestrian.
4. Construct depressed green facilities and vegetative buffers for water treatment before entering into the channel and being conveyed to the next receiving drainage system.
5. Provide accessible green space and other amenities (seating/ picnic tables) for human activities.
6. Integrate pedestrian paths with green and blue patterns to allow for social interaction with the water features.
7. Apply education signage and other means to enlighten citizens regarding how the stormwater is sustainably managed on site and where is the next receiving drainage system during heavy storms.

① Stormwater planter integrated with rainwater harvesting systems for water reuse

② Accessible green space for recreation

③ Seating area under the tree canopy and tree planter for water detention

④ Retention pond (receiving water body) proposed in the abondoned golf park

⑤ Water channel along the pedestrian corridor to locate water feature closer to human activities

⑥ Lighted glass cover which is visible and aesthetically pleasing to convey water overflows

⑦ Mounded green area for water detention and treatment

⑧ Bridge over the water channel to encourage social egagement with the water features

⑨ Extensive green roof with a cistern to improve water detention capacity

⑩ Visible rainwater harvesting system with seating area and the source of the water channel

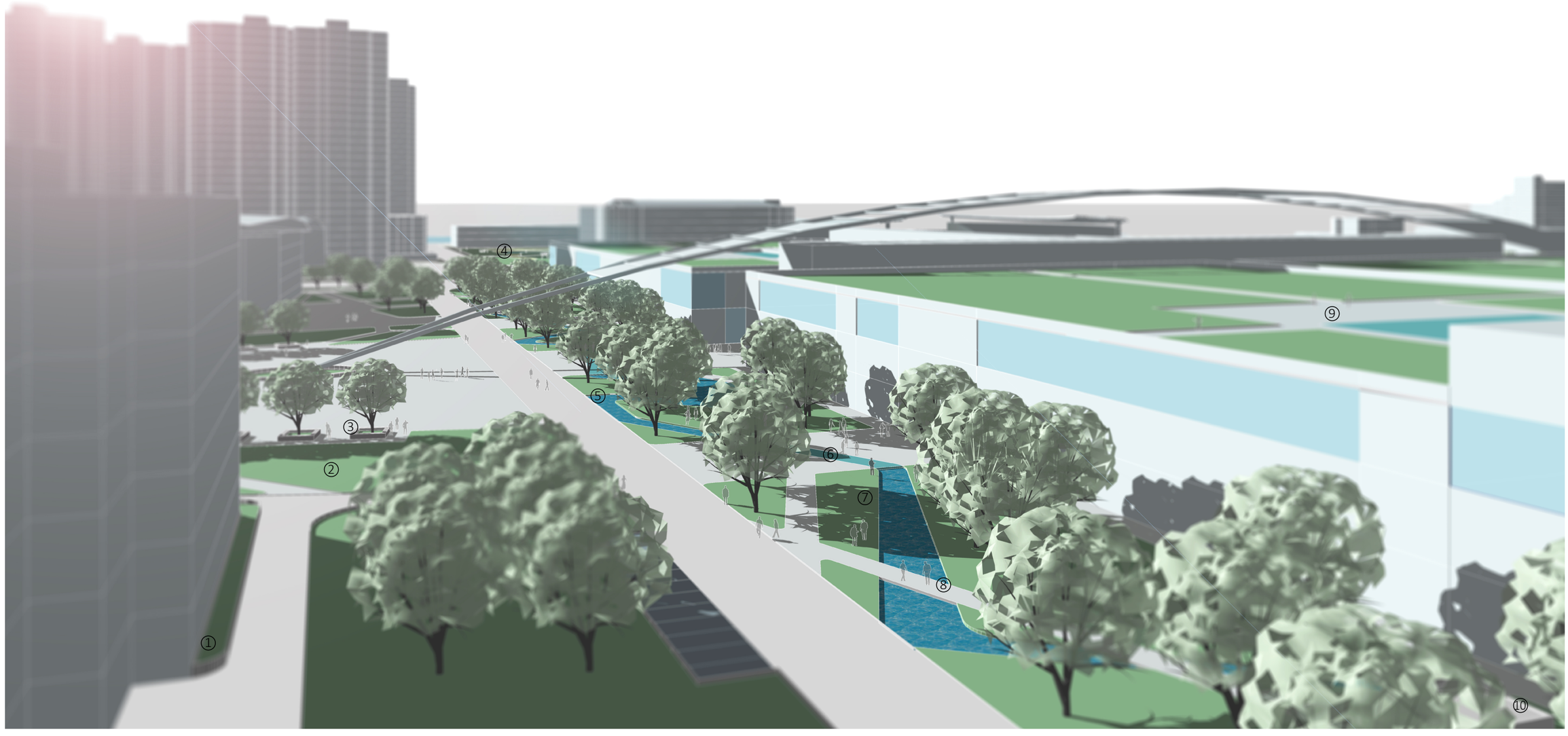


Figure 4.46 Perspective of the green corridor

4.3.2.3 Network Scale (Stormwater Park)

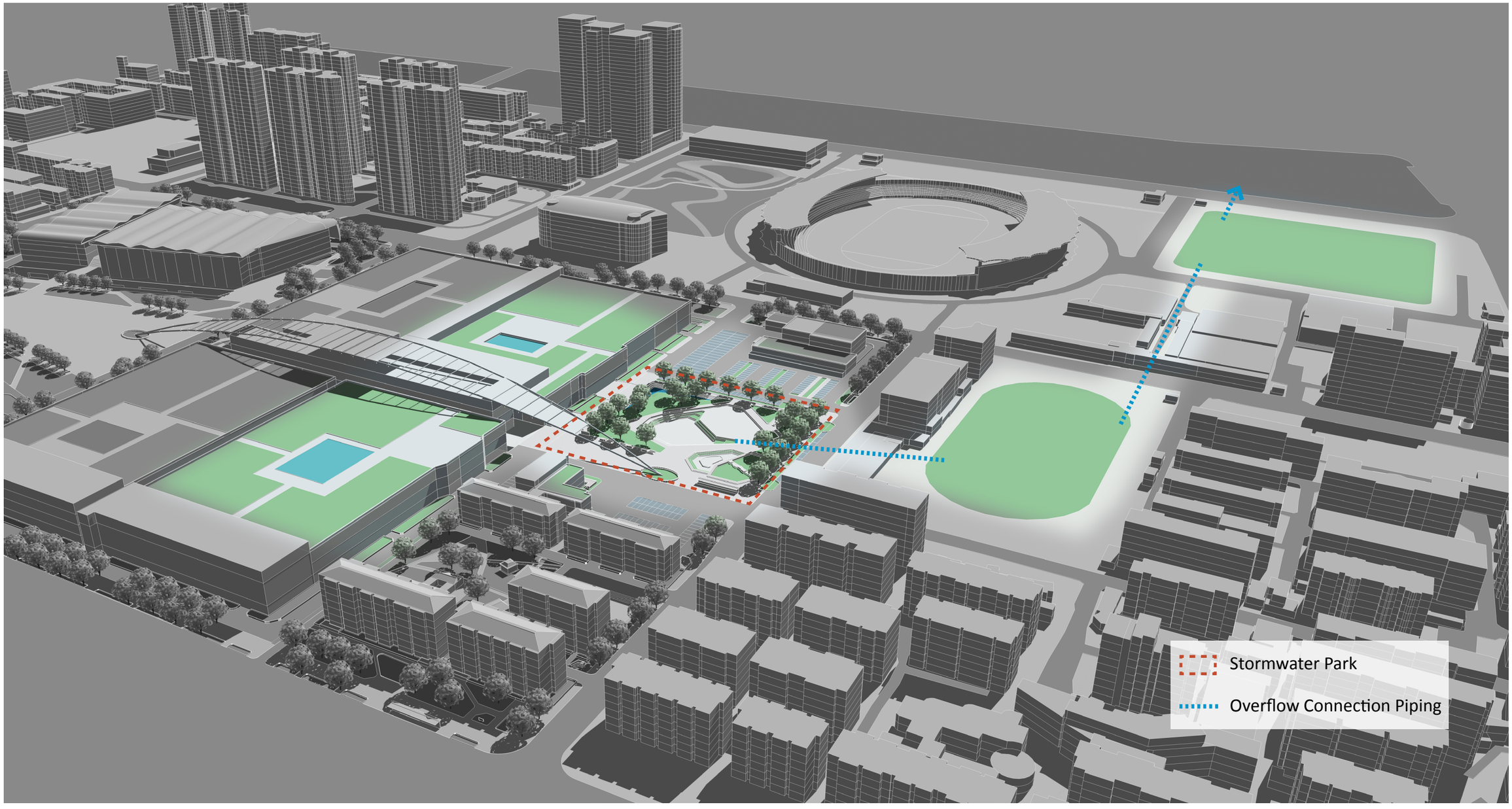


Figure 4.47 Proposed stormwater park and watershed subdivision

Stormwater Park (C4)

Catchment Area 4 is designed as a stormwater park that not only performs sustainable stormwater management, but also provides recreational use for social congregation. The digram as below identifies pedestrian and cyclist circulations, and indicates the spaces for social interactions. The pervious pavement between the storwater park and Xiamen Art Gallery would be used for pedestrians and cyclists under normal condition and allowed for emergent uses of fire truck and ambulance.

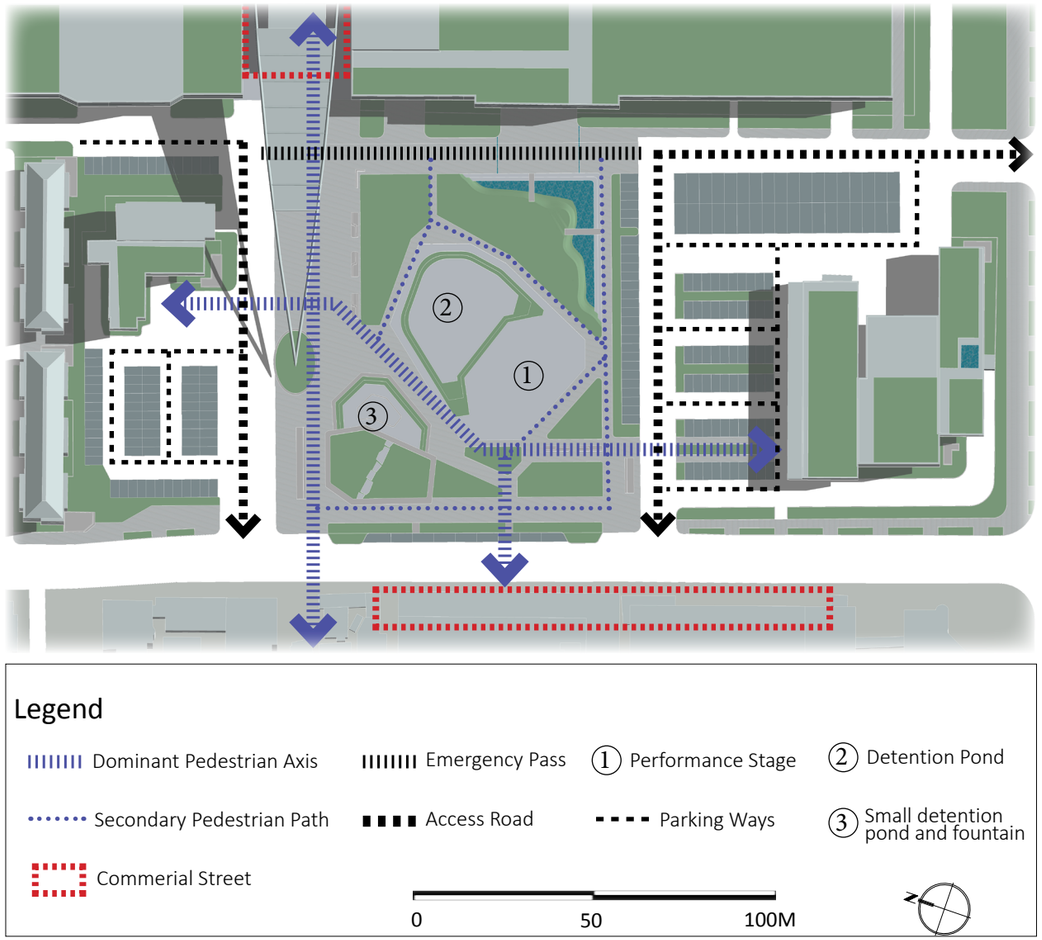


Figure 4.48 Circulation analysis of the proposed stormwater park

Green Infrastructure Layers

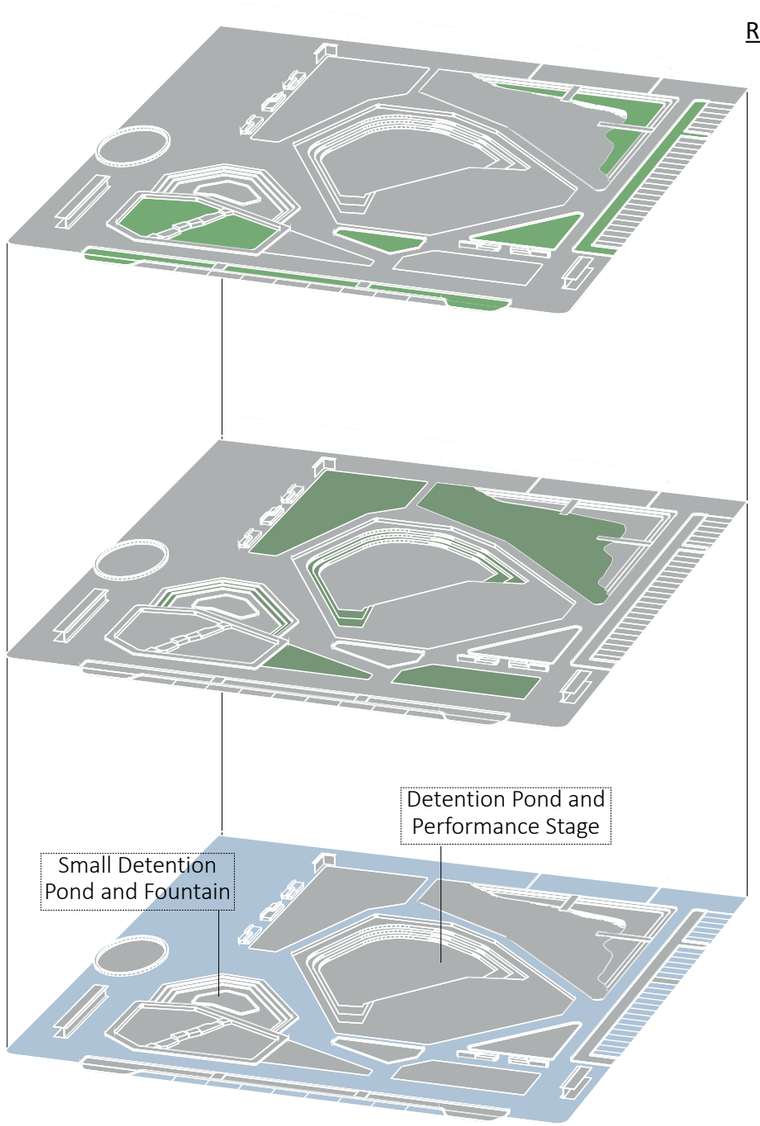


Figure 4.49 GI layers of the proposed stormwater park

Storm Events at Different Precipitation Scales

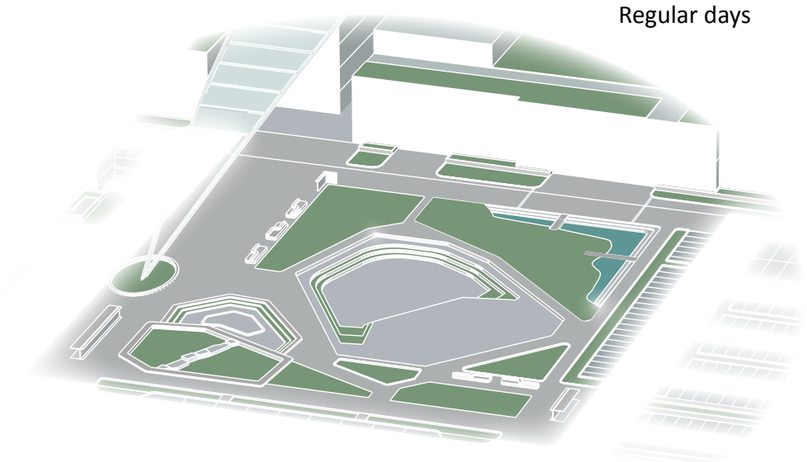


Figure 4.50 Scenarios of the stormwater park at different precipitation scales

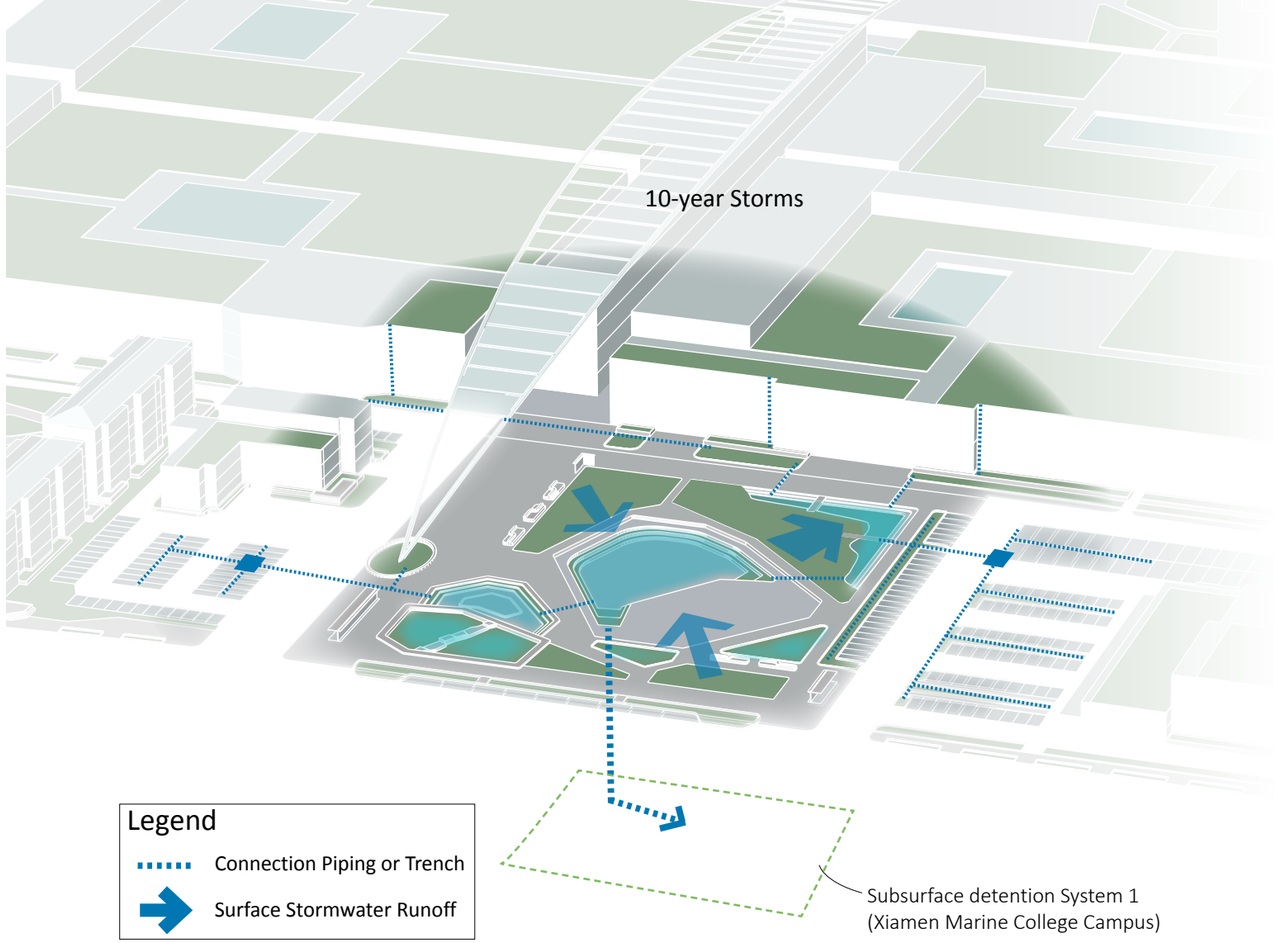


Figure 4.51 Stormwater flow analysis of the proposed stormwater park

In regular days between storm events, people of different age groups are able to enhance their knowledge and awareness of sustainability through engaging with a variety of green facilities, including stormwater planters, rain gardens, a wet pond, and permeable pavements constructed for both pedestrians and parking lots. The small detention pond with a fountain facility and the large pond with a performance stage work as a focus point for the general public, while during storm events, they turn to collect stormwater runoff generated from its own site and adjacent rooftops, parking lots, driveways as well. During 10-year or larger storm events, overflows from this park would be conveyed to next receiving drainage system (SD1) proposed on the campus of Xiamen Marine College.

① Extensive green roof with a cistern to improve water detention capacity

② Stormwater planter integrated with rainwater harvesting systems for water reuse

③ Seating under the tree canopy encourages social interaction with the stromwater park features

④ Retention pond with seating steps and bridges to encourage social acitivities close to water features

⑤ Detention pond at the core of the stormwater park to collect water runoff from adjacent areas

⑥ Seating steps with grass surrounding the detention pond and integrated with stormwater inlet and outlet

⑦ Fountain in the small detention pond to improve aesthetics of the stormwater park and bring social activities close to water features

⑧ Performance stage to provide a large space for social congregation and important events such as evening concerts

⑨ Bridge over the rain garden to encourage social egagement with the water features and provide step-seating for recreation

⑩ Bicycle parking space integrated with education signage to enlighten people on the site plan and the natural function for stormwater management

⑪ Permeable paving for the sidewalk to promote water infiltration and storage

⑫ Stormwater planter along the curb of sidewalk to collect stormwater runoff from the road and parking lots

⑬ Permeable parking lots with bioswale for water treatment, infiltration and conveyance

⑭ Retention pond (receiving water body) located in the abandoned golf park

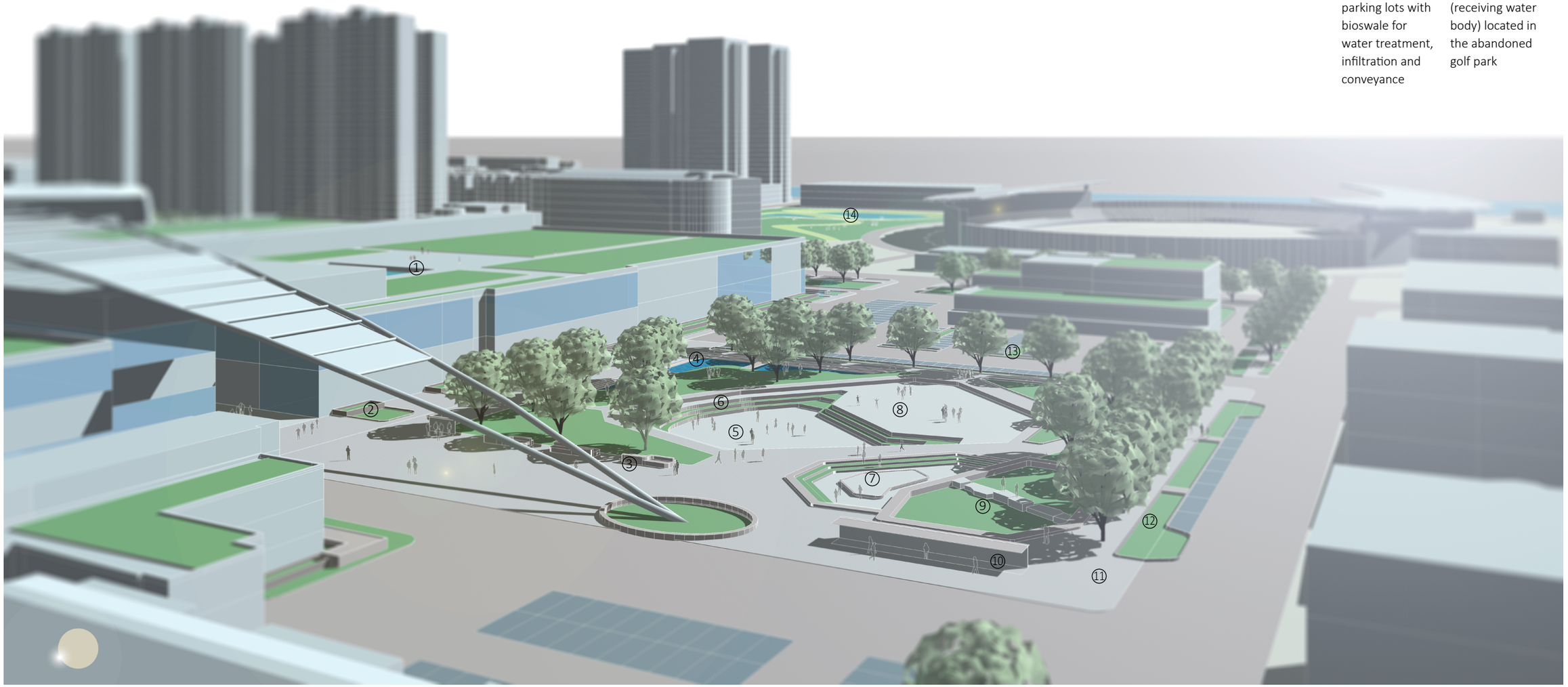


Figure 4.52: Perspective of the stormwater park

4.3.3 Green Tour Analysis

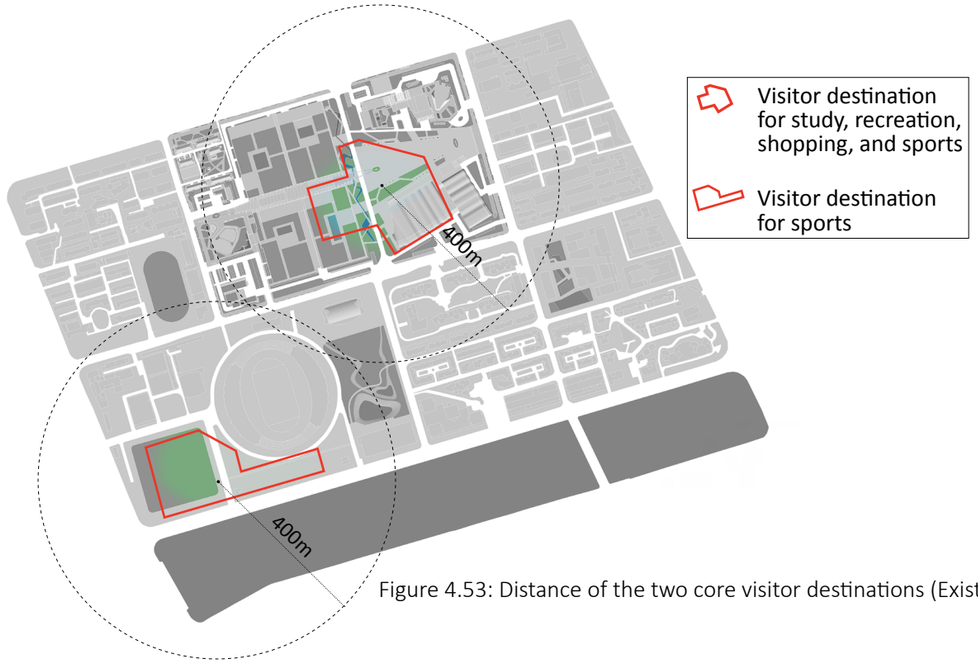


Figure 4.53: Distance of the two core visitor destinations (Existing)

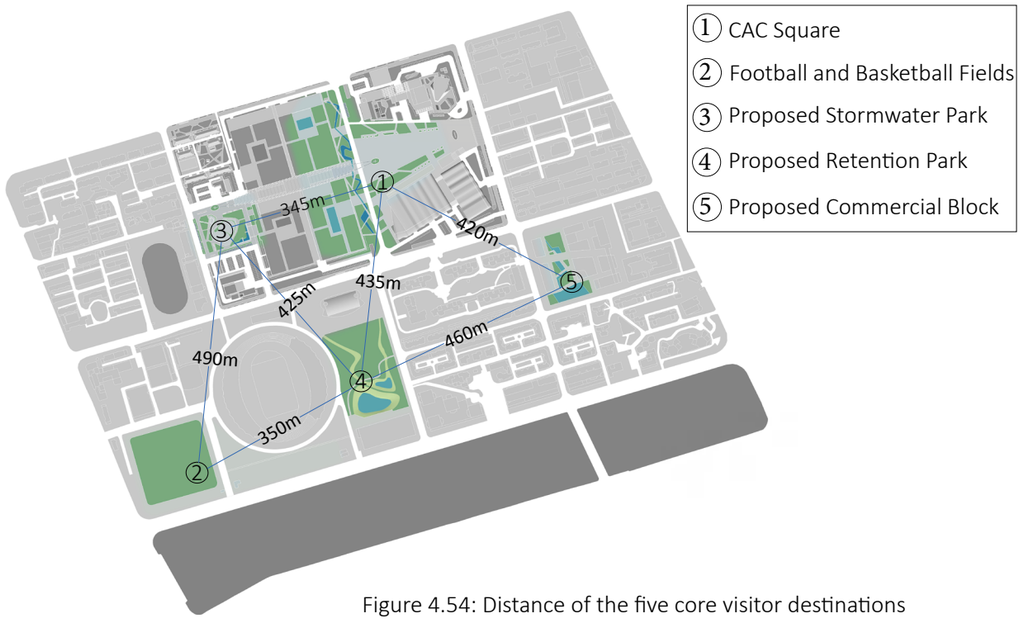


Figure 4.54: Distance of the five core visitor destinations

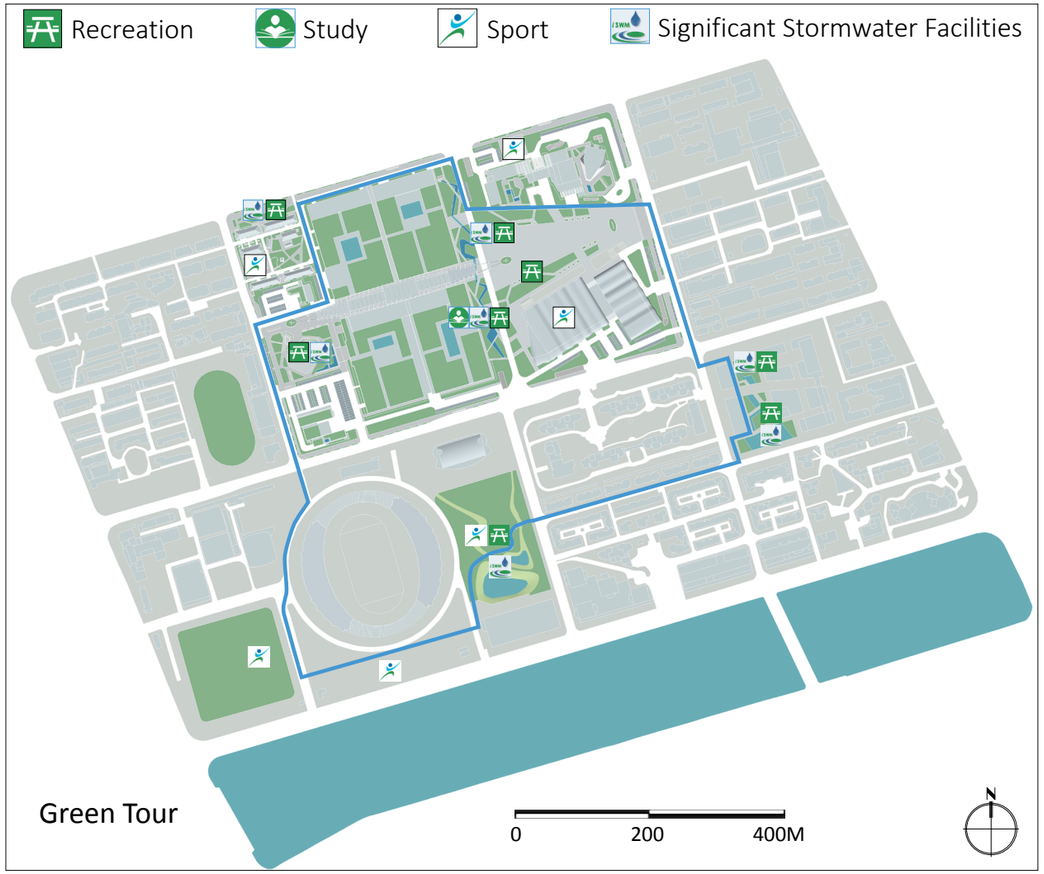


Figure 4.55: Proposed green tour

As shown in Figure 4.53, the distance of the two existing core visitor destinations is more than 700 meters, beyond the desirable walking distance (400 meters) of the general public. Also, there is a lack of walkable environment between the two destinations to encourage social dynamic and interactions. Figure 4.54 identifies existing visitor destinations and proposed visitor destinations. The average linear distance among them can be seen as a bit more but close to 400 meters. To further stimulate the continuity of these public nodes and deliver multi-function awareness of green stormwater infrastructure, a proposed green tour with dedicated lanes and routes for pedestrians and cyclists has been highlighted in Figure 4.55, indicating significant areas for recreation, study, sport, and stormwater management.

4.3.4 Post-design Indicators (the CAC block)



Figure 4.56: Post-design indicators (the CAC block)

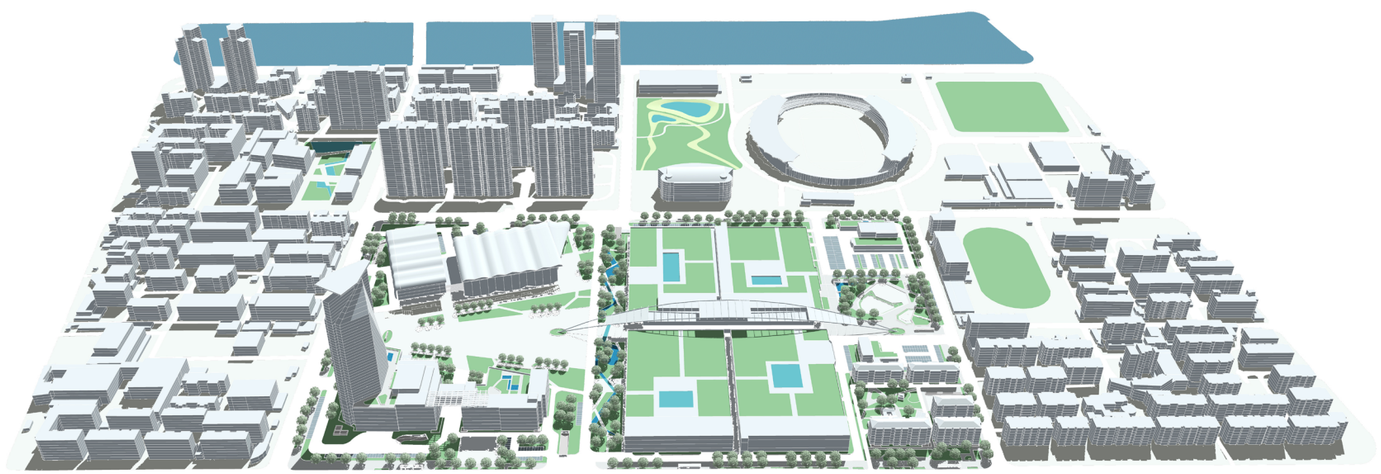


Figure 4.57: Aerial view of the CAC neighbourhood

Water Sensitivity:	
Decentralized	■■■
Detention	■■■
Infiltration	■■□
Cleaning	■■□
Evaporation	■■■
Others:	
Education	■■■
Aesthetics	■■■
Accessibility	■■■
Recreation	■■■
Usability	■■■
Experiences of nature	■■■

Table 4.2 Effectiveness assessment for the design proposal for the CAC neighbourhood

The design proposal attempts to provide a series of decentralized strategies, employing innovative green infrastructure of various types and at different scales for sustainable stormwater management. The retrofit of the CAC area is intended to detain a high volume of stormwater runoff as indicated in Figure 4.56. As seen in Table 4.2, this proposal aims to be highly multi-functional, facilitating social engagement and informing users about Low Impact Development principles and their application.

4.4 Conclusion

This research set out a proposal for reftrofitting the selected study block (Culture and Art Centre) and its adjacent areas. The design framework (see Figure 4.31) was developed based on two major goals: sustainable stormwater management and education/demonstration. The framework matrix was informed by the literature review, precedent studies and a logical analysis of the existing site and regional context to support and direct further design interventions. This design framework could also be adjusted and applied in other projects according to local context. In this proposed retrofit, three design concepts were developed and closely incorporated to achieve the two major goals. First, the author divided the study block into 14 basic catchment subdivisions to address stormwater runoff close to its source. Second, the entire water flow train from the study block to Yuandang Lake would perform through three watershed systems as shown in Figure 4.33. Third, the proposed green tour aimed to prioritize the rights of way for pedestrians and cyclists, meet the need for continuity to connect different visitor destinations, provide spaces for recreation, study and sports, and where to find opportunities to engage with innovative and sustainable stormwater management features.

The design proposal is an ambitious rethinking of how urban development should combine multi-functional aspects. The retrofitting project at the large scale allows for more opportunities and areas to consider, to address the challenges of stormwater management in a highly urbanized context. The study block (CAC) is a recently developed site with a large area of underground infrastructure, which would call for major and costly changes to implement such a neighborhood-wide retrofitting project. Considering the increasing precipitation experienced in Xiamen, the current overwhelming of existing infrastructure, huge sunk costs of engineered piping and the uncertainty of climate change, the proposed improvements tend to bring additional benefits that the traditional drainage systems do not. By contrast, the engineered piping address quantity of stormwater runoff, while LID approaches account for quantity, quality and aesthetics (Olsson, 2011). In addition, this research considered social aspects to encourage more human activities closer to green space and the water features.

Previously, Olsson (2011) conducted a case study of sustainable stormwater management in the Xiamen urban context. His research considered locations on the south side of Yuandang Lake, while the current research addresses a large area on the north side of the lake. While Olsson (2011) illustrates and evaluates various examples of LID techniques respectively, I have provided what an integration of SUDs techniques on one large site could look like. Olsson (2011) applied a 10-year 24-hour precipitation for evaluating each technique, while I suggest applying a 2-year 24-hour rainfall event at first before considering and calculating the water flow equilibrium of the retention/ detention ponds. I am critical that the application of a 10-year 24-hour precipitation would be beyond the capacity of small scale green facilities such as stormwater planters and rain gardens when located at such a highly urbanized site within the Xiamen central area. Olsson's research was more focused on the evaluation of a general urbanized area, applying the precipitation data of the city of Xiamen, instead of giving greater consideration to the physical conditions of the specific site context. He conducted quantitative and qualitative analysis in separate chapters, which could result in significant bias when having to consider the existing conditions on an actual site. For example, Olsson (2011) applied 0.6 as the runoff coefficient and 10 hectares as the water catchment area of a pond for the evaluation of water ponds located in the urbanized area, which tends to be too general when his study was focused on a specific urbanized area. Olsson (2011) could have determined a more precise solution for evaluation if he considered the potentials of green roofs, rain gardens, bioswales, rain harvesting systems in advance, which are all parts of the entire flow train system processing from property sites to Yuandang Lake. The elevation of a specific site has significant influence on the determination of runoff coefficient and water catchment area as well, which should have been taken into account to identify a feasible location and area for proposed water ponds.

The design proposal of the current research provides an overall concept to communicate the implications of what is needed in a full retrofit. This coneptual proposal is developed by a planner; the scope, focus and rigour would be different if undertaken by a landscape architect, civil engineer, hydrologist etc. This type of work really requires

an interdisciplinary team to develop a complete concept. The author advocates improving the role of urban planners and landscape architects in the sustainable stormwater management, which remains in many places to be dominanted by civil engineers from traditional piping perspective employed to address stormwater issues. The design proposal is intended to be a stimulus to advance discussion by politicians, policy makers, planners, developers, other professional experts and stakeholders in the City of Xiamen to advance future sustainable stormwater management.

Chapter 5 Conclusion

In order to mitigate the flooding issues in Xiamen through innovative and sustainable stormwater management, this research identified Low Impact Development best practices in North America and sought illuminations from the initiatives and experiences of certain precedent cities and built-projects to inform the retrofit design practice on the selected study block (Culture and Art Centre). The author of this research attempts to submit this report to Xiamen Urban Planning and Design Institute and other authorities as needed to advance LID principles and strategies in the Xiamen urbanized areas as a green stormwater infrastructure planning and design reference.

This chapter summarizes the findings and lessons from literature review, precedent documentation, and design application, and provides recommendations for the green infrastructure planning and implementation in the City of Xiamen. This research conducted an interview with a planner at the Urban Planning and Design Institute of China to inquire comments on the document of precedent city studies and recommendations in Chapter 3. Perspectives informed by the feedback interview with the Chinese practitioner Li (2015) are included in this chapter to support recommendations. After responding to the research questions, seven recommendations were developed from long-term perspectives for the City of Xiamen to take actions for Low Impact Development. Limitations were composed at the end to explain the shortage of this research, which should be carefully pondered to provide more feasible and effective solutions in future research.

5.1 Responding to Research Questions

This practicum project was directed by six research questions in four themes to achieve the research objectives. Below is a general response to each question, interpreting how these questions were addressed in this research. Recommendations for the City of Xiamen are also summarized regarding both policy-based and design-oriented aspects.

5.1.1 Concerning Low Impact Development Principles and Strategies

1a. What are Low Impact Development (LID) best practices and where are informative precedents of their application?

As a result of urban development, the increase of impermeable surfaces contributes to a large volume of stormwater runoff, causing flooding issues during heavy storms. Low Impact Development can be interpreted as applying green infrastructure and taking advantages of natural function for stormwater management. There is a variety of green facilities and techniques at property scale, street scale, and network scale. These infrastructure should be collectively implemented to provide efficient sustainable stormwater management. Besides innovative stormwater management, LID contributes to multi-function benefits, including environmental, economic and social aspects (see Section 2.4.1). In the early 1990's, the United States began to advance LID to address stormwater issues. Nowadays LID principles and strategies have been widely applied in many other regions over the world. Water Sensitive Urban Design (WSUD) is the term used in Australia, while the United Kingdom uses Sustainable Stormwater Management. In this research, these terms have been used interchangeably with Low Impact Development.

Literature review identified a wide range of green stormwater infrastructure at different types and scales, exploring their design considerations, benefits and limitations respectively (see Section 2.4.3). The author has inquired green roofs, rain gardens, permeable pavements, and rain harvesting systems at the property scale; stormwater planters and bioswales at the street scale; and retention/detention ponds at the network scale. These facilities and their features were summarized in Appendix D (Overview of green infrastructure at different scales) for the sake of convenient reference for design interventions.

The research found Portland and Seattle have great initiatives and performance in Low Impact Development. Last year, the author conducted a one-week field trip to Portland and Seattle, interviewing three practitioners with regards to their insights and recommendations on sustainable stormwater management. Precedent documentation analyzed these interviews and provided recommendations for the City of Xiamen (see Section 3.1). The research identified and engaged with several built projects and three (Shoemaker Green, Tanner Springs Park, and the Olympic Village in Vancouver) were typically analyzed and demonstrated (see Section 3.2) to inform design interventions.

5.1.2 Inquiring Current Situation of Stormwater Management in Xiamen

2a. What is the current condition of urban stormwater drainage in Xiamen?

2b. What role does urban landscape play in Xiamen currently?

The literature review identified conventional drainage system, including combined sewer and separated sewer. Combined sewers collect both stormwater and sanitary sewage in the same pipes, while separated sewers convey stormwater and sanitary sewage by different pipes. In comparison with combined sewers, separated sewers are more expensive but reduce combined sewer overflows and mitigate negative impacts on water quality. Since 1981 when the City of Xiamen was designated as one of the four special economic zones , Xiamen municipality has constructed combined sewers. More recent development has implemented separated sewer systems. Thus, many old areas on the Xiamen Island still manage stormwater with combined sewers. Yuandang Lake is the receiving water body for a stormwater catchment area of approximately 35 km^2 on the Xiamen Island. Yuandang Lake has suffered from severe degradation of water quality influenced by combined sewer overflows in recent decades. The water quality of Yuandang Lake did not improve significantly until the City of Xiamen was aware of the problem and took actions to remedy the situation in the last decade or so. Recently built properties, including the selected study block on the north of Yuandang Lake were constructed with separated sewers. During heavy storms, a large volume of stormwater runoff would be released to Yuandang Lake directly, leading to flooding issues. This research has gathered evidences of flooding events occurred on the Xiamen Island in the summer of 2013 (see Appendix C).

In terms of the urban landscape in Xiamen, the city has tended to adopt modernist design approaches to improve aesthetic values but having less consideration for stormwater management. Although small projects such as permeable paving with

grass were constructed on certain parking lots, individual green facilities would not be sufficient and effective to address stormwater issues, unless a wide range of green stormwater infrastructure at different scales can be implemented and integrated to have the maximum effect. Due to inappropriate maintenance, those permeable pavements with grass have almost lost the function for stormwater management and even influence the aesthetic quality of the properties. The research documentation during field trips summarized landscape features in the study block as being artificial, inaccessible and having little regard to stormwater management. Several water cisterns were identified in front of Xiamen Museum and used for recreational use rather than stormwater management.

5.1.3 Facilitating Sustainable Stormwater Management (Policy-based)

3a. What are effective ways to stimulate the implementation and proliferation of LID in Xiamen urban area?

Precedent documentation explored and analyzed the ways and means that have been applied by Portland and Seattle to accelerate green infrastructure planning and implementation. Informed by the three preliminary interviews, the author ascribed the common successful initiatives and managerial experiences of Portland and Seattle to four aspects: continuing educational programs for the general public, rational policies and specific regulations to request LID principles and techniques in development, clear sources of financing and incentives for the planning and implementation of green infrastructure, and an integrated and complete administration system. Contrasting with the situation in Xiamen, this research discussed and identified lessons that could be applicable to the City of Xiamen (see Section 3.1.5). These lessons have been mostly confirmed by the feedback interview (Li, key informant-interview, 2015). Significant information and insights provided by Li are explained in the following.

Currently, green infrastructure have not been well known and not widely implemented in the city of Xiamen, even though there are a range of LID programs and projects in other cities in China that merit consideration. This situation could be

attributed to the lack of awareness regarding sustainable stormwater management (Li, key informant-interview, 2015). Li (2015) believed local governments have ignored the ecological benefits of green infrastructure and tended to facilitate economic development to manifest political achievements. Green infrastructure could have been extensively and successfully constructed with consistent support of the national government. Li (2015) informed the author of the concept of "sponge city" (interchangeable term with LID) and the guideline the national government issued in early 2015. This guideline could accelerate the implementation of green stormwater infrastructure if relevant funding can be sustained to support provincial and local governments to take immediate actions. Local governments should incorporate the national guidelines and strategies into the city comprehensive plans and establish specific regulations according to local climate conditions (Li, key informant-interview, 2015).

5.1.4 Facilitating Sustainable Stormwater Management (Design-oriented)

4a. How to apply Low Impact Development (LID) strategies into the study block, to achieve more sustainable urban stormwater management?

4b. In what ways can the implementation of Low Impact Development (LID) strategies make the block more inviting and aesthetically pleasing?

This research provides conceptual solutions and design interventions for the CAC block and area as a demonstration pilot project for future development in the City of Xiamen. The design proposal was informed by the literature review and the precedent documentation. Principles (1-4) were derived from the literature review to address stormwater issues, while principles (5-8) were identified from the precedent project study to inform the conceptual design that integrates strategeis and achieves the educational purposes.

Principle 1: Enable water reuse for domestic demands, landscape irrigation and others
Principle 2: Implement a complete and integrated flow train system
Principle 3: Reduce impermeable paving
Principle 4: Collectively construct green infrastructure at a variety of types and scales

Principle 5: Make stormwater flow visible
Principle 6: Integrate green infrastructure with human amenities
Principle 7: Encourage social interaction with water features
Principle 8: Expose principles of sustainable stormwater management

As informed by preliminary interviews, education initiatives play a key role in enhancing public awareness of LID benefits to advance proactive participation in LID practices. Green infrastructure constructed with little attention to stormwater being evident would not efficiently provide educational benefits from long-term perspectives. The design proposal demonstrates an integrated solution, showing how green infrastructure can be designed and constructed at different scales and types to reduce stormwater impacts, and to enhance public awareness regarding human relationships with natural systems. Integrating the 8 principles with site and context inquiry, the design framework has been applied as a foundation for guiding retrofit in the study block (see Section 4.2). This design framework could also be adjusted as needed to be applied in other urban areas in Xiamen according to the local conditions.

5.2 Recommendations for Green Infrastructure Planning and Implementation in the City of Xiamen

This research summarized seven recommendations to inform Xiamen of how the city could commence and move forward in the long term, in response to the call of the national government under the banner of constructing a "Sponge City". These recommendations are based on the synthesis of the literature review, key-informant interviews, precedent project studies, and the retrofit design proposal. If applied, these recommendations could be a catalyst to stimulate green stormwater planning and implementation in Xiamen urban context for years to come.

5.2.1 Conduct a variety of education programs for different stakeholders in the City of Xiamen

As informed by key-informant interviews, Portland and Seattle would not have been successful in Low Impact Development without strong education initiatives and campaigns. The findings of this research recommend the City of Xiamen early on conduct a range of education and training programs for relevant authorities, professionals, developers, property owners, the general public, etc. Programs at different levels should be developed for different stakeholders according to their specific knowledge, background and education purposes. Demonstration pilot projects could be conducted at major sites such as the CAC block to enhance public awareness and encourage wider implementation. If applied, the retrofit proposed in this research would be a significant demonstration of integrated design that incorporates Principles (5-8) for design interventions of green infrastructure.

5.2.2 Incorporate LID principles and strategies into the urban comprehensive plan of Xiamen

As the highest level of statutory plans, the Xiamen Urban Comprehensive Plan plays a key role in guiding general urban growth and development in the City of Xiamen. It is necessary to incorporate LID principles and strategies into the comprehensive plan, indicating how the city would take actions in response to the national guideline of "Sponge City". The City of Xiamen could work out a green infrastructure master plan based on existing piping and previous drainage plans. Integrating green infrastructure planning with other planning concepts and strategies, such as compact city form, active transportation, smart growth, nature first planning and more would provide integrated solutions for the entire urban fabric to deliver more sustainable urbanism. It is necessary to strengthen the role of the Xiamen Urban Comprehensive Plan in guiding the land use for green infrastructure with a complete legal system and amendment procedures.

5.2.3 Review and update regulatory plans in alignment with the guidance and requirements in the comprehensive plan revision

The Regulatory Plan is the secondary level of statutory plans applied as an implementing tool to meet the goals and regulatory provisions in the Xiamen Urban Comprehensive Plan. As discussed in Section 3.1.5, current regulatory plans in Xiamen include a range of mandatory indexes mostly applied to regulate architecture forms,

site plan and the relationship between buildings and other urban settings. Regarding landscape aspects, regulatory plans merely involve the percentage for green space. There are three recommendations that could be considered by the City of Xiamen to update existing regulatory plans or request future plans to promote landscape functions for sustainable stormwater management. Informed by the literature review and precedent documentation, there are a series of green stormwater infrastructure of different types and scales. Regulatory plans could assign the percentage index to more types of green infrastructure according to site conditions and adjacent environment. Second, it is recommended to apply form-based index for landscape regulations, which provides flexible and multiple options of scales, types and forms for green facility determinations. This allows planners, architects and landscape designers to propose an integrated plan for the general urban context and watershed system. Last, it is important for the planners to review and adjust other indexes and requirements as needed such as street sections, setbacks, and rooftops to accommodate proposed green facilities.

5.2.4 Compile a sustainable stormwater manual for the Xiamen urban context

Green Infrastructure includes a wide range of types, scales and techniques. This research has explored typical ones at the property scale, street scale and network scale, identifying their design considerations, benefits, and limitations respectively. It is important for the City of Xiamen to conduct a thorough study, identifying more types and techniques of green facilities and compile a specific sustainable stormwater manual according to the Xiamen urban context. Planners should cooperate with relevant authorities and experts to address potential conflicts with existing design guidelines and regulations for drainage systems. In addition to the components that this research has addressed in the literature review, the stormwater manual should also include guidelines and regulations for plant selection and maintenance based on local conditions, including climate, precipitation, soil permeability, elevation, hydrology, etc. The long-term success of sustainable stormwater management significantly relies on a higher level of maintenance, as green infrastructure requires variable measures and frequencies of maintenance for different types and scales. The City of Xiamen could

address this concern, as suggested by Olsson (2011), to conduct training programs for the street cleaners as a part of the maintenance, as there is a labor force available to clean and maintain the streets on a daily basis. If these workers are well educated in how to maintain different facilities and devices, the green infrastructure would perform effectively for stormwater management (Olsson, 2011).

5.2.5 Set up a clear and rational financing system

As discussed in the precedent documentation section, regulating new development for green infrastructure implementation would not be efficient to facilitate sustainable stormwater management from long-term perspectives as most areas on the Xiamen Island have been developed at a high density. It is necessary to encourage retrofit projects in developed areas as well. However, it would be a long-term process to shift the mindset of developers and property owners to voluntarily participate in constructing green infrastructure. As informed by the interviews with key informants, both Portland and Seattle applied financing and incentives as a catalyst to stimulate LID practices. This research recommends the City of Xiamen to set up a clear and rational financing system, which are transparent, informative and applicable for the general public. The planning exhibition hall located at the ground floor of Xiamen Planning Institute, Xiamen City Library, schools and the Xiamen planning website would be considerable spaces to convey financing information.

5.2.6 Consider the adoption of stormwater rate in the City of Xiamen

If the City of Xiamen initiates charging a stormwater rate on properties for stormwater treatment, a stormwater rate discount could be applied as an indirect subsidy to speed up the implementation process. However, the tax system in the United States is quite different from that in China regarding the transparency of how the city manages and allocates taxes on different public infrastructure and services. Without strong education initiatives, the stormwater rate would likely not gain public acceptance, as the citizens of Xiamen could dismiss this requirement, suspecting that the government aims to promote revenue by utilizing the stormwater rate. This research

recommends the City of Xiamen to embark on education programs in advance and to conduct a feasibility study for the adoption of stormwater rate when the general public have improved their awareness regarding their relationships with green infrastructure for sustainable stormwater management.

5.2.7 Establish a dedicated stormwater solution group

As discussed in the precedent documentation, the City of Xiamen has multiple government agencies involved in the water management such that decision making becomes a challenge as a result of decentralized responsibility. This research recommends the City of Xiamen to found a stormwater solution group dedicated to green stormwater planning and implementation. This group would be made up of multidisciplinary professionals, including planners, architects, landscape designers, engineers, ecologists, sociologists, etc. The stormwater solution group could be set up in either the Xiamen Planning Institute or the Environmental Protection Bureau of Xiamen, being authorized to coordinate with relevant government agencies for data retrieval, document review and update, and temporary transfer of experts as needed. Moreover, the City of Xiamen should launch a cross-bureau stormwater committee to further support communication and collaboration among the stormwater solution group and other relevant departments. Informed by the key informant interviews, it is highly recommended that the City of Xiamen appoints management personnel who are comfortable with change and can manage change. The appointed officials need to recognize that while there are risks involved in undertaking new strategies for more sustainable stormwater management, the innovative approaches such are outlined here are needed to effectively address pressing problems to improve the present situation.

5.3 Assessment of the Research Methodology

The research methodology of this practicum combines theoretical analysis with empirical analysis, employing literature review, precedent documentation and design application to provide constructive recommendations for sustainable stormwater management in the City of Xiamen. This section identifies potential biases and limitations as a result of the research methodology, which could be promoted in future research or LID practices to improve the rigor and applicability of outcomes.

The literature review explored a wide range of green infrastructure at the property scale, street scale and network scale, identifying their design considerations, benefits and limitations, which were summarized in an overview table (see Appendix D).
This proved to be a basic design reference for the following precedent study and design interventions. However, this overview would be insufficient to support future planning and implementation for the City of Xiamen from long-term perspectives. The planners in Xiamen could conduct a more throughout study of green infrastructure and compile specific design guidelines based on the Xiamen urban context. The literature review of this research provides a good starting point regarding typical LID best practices in North America as an inspiration to work out a practical version for the City of Xiamen.

The precedent documentation is based on key informant interviews and the precedent project study. Interviews were conducted with key informants regarding sustainable stormwater management and built projects in two of the cities. The interviews involved three practitioners, one in Portland and the other two in Seattle. Potential biases could exist as all participants are all professionals in LID best practices. Insights and recommendations informed by these practitioners are not intended to be fully reflective of other stakeholders relevant to sustainable stormwater management. Future research could involve more experts, politicians and other stakeholders as needed. Focus group could be an efficient research method in addition to semi-structure interviews employed in this research.

Regarding the proposed design interventions, a limitation would be the method applied for the water subdivision. Figure 4.33 provides a general concept of the water catchment areas where stormwater runoff from each area could be managed on site before conveyance to the next receiving water bodies. Figure 4.34 aims to demonstrate, in an ideal condition, how much stormwater would be involved for each catchment area for sizing determination of the proposed green infrastructure. Regarding the actual volumes of water in catchment areas, the situation is dynamic, as not all the volume

occurs at the same time. The intensity is different along the system due to elevations, slopes and material (green roofs) etc., which should be carefully considered in future development to provide more rigorous, practical and effective solutions. This would require a multidisciplinary team to work out an integrated proposal.

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Appendix A: Interview Schedule

The interviews were organized in two stages, including key informant interviews and feedback interviews. The key informant interviews aimed to inform the research regarding green infrastructure planning and implemenation derived from the precedent cities (Portland and Seattle), inspiring recommendations for the City of Xiamen. The intention of feedback interviews was to gather reflections and comments on the draft recommendations for Xiamen with the purpose to make the outcomes more applicable and feasible

Questions for Preliminary Interviews (Participants from Portland and Seattle)

a) About Precedent Cities

1. To what degree do you think the implementation of Low Impact Development (LID) benefits the urban environment and humans in this city?

2. What do you consider to be the most significant challenges of implementing LID, and what steps could be taken to overcome these challenges?

3. What techniques are useful in educating the public on the principles and process of LID?

4. What tactics are effective to shift social mindsets to be more considerate of LID?

5. What role do planners play in facilitating the implementation of LID?

b) About Precedent Projects

1. In what ways does this project (project name) apply LID principles and techniques?

2. What role do planners play in the implementation of this project?

3. What do you consider to be the most significant challenges of implementing this project?

Questions for Feedback Interviews (Participants from China)

1. How were you knowledgeable about Low Impact Development (LID) before this survey? How would you rate the potential of green infrastructure in improving conventional urban drainage?

2. What is the current situation of applying green stormwater infrastructure (LID practices) in China? In what ways do you feel the national government has guided more sustainable stormwater management?

3. What do you consider are the greatest challenges to implement green stormwater infrastructure in new developments, existing areas and on public streets?

4. What do you think would be the challenges to introduce indexes of green stormwater infrastructure into regulatory plans as mentioned in the precedent city case study?

5. Do you feel any of the recommendations mentioned in the case study are not appropriate to take into practice, and why?

6. What recommendations in the case study do you think would be most effective and why?

7. In general, do you have any other suggestions for policies, programs or projects to reduce stormwater impacts?

Appendix B: Email Script for Initial Contact with Potential Interviewees

Salutation,

I am Keke Wang, a student in the Master of City Planning program at the University of Manitoba, Canada. Currently, I am conducting my Major Degree Project research, which is titled "Retrofitting Green Infrastructure for Urban Stormwater Treatment: A Case Study in Xiamen Urban Context".

Key Informant Interview is an important research method applied to further inform my research. I would be thankful if you would agree to participate in the interview, sharing your knowledge and experience related to my project. You will find in the attached file, the questions intended for the interview. The interview is expected to require up to one hour. The specific schedule for the time and place will be depending on your choosing.

If you would like more information on this research and interview, please contact me by email at wangk345@myumanitoba.ca or by phone at 1(204)-294-8835.

Thanks a lot for your time and consideration.

Best Regards,
Keke

Principal Researcher and contact information:
Keke Wang
Email: wangk345@myumanitoba.ca

Research Supervisor and contact information:
Dr. David van Vliet
Email: David.VanVliet@ad.umanitoba.ca
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UNIVERSITY OF MANITOBA | Research Ethics and Compliance
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APPROVAL CERTIFICATE

August 19, 2014

TO: **Keke Wang** (Advisor D. van Vliet)
Principal Investigator

FROM: **Susan Frohlick, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2014:111**
"Retrofitting Green Infrastructure for Urban Stormwater Treatment: A Case Study in Xiamen Urban Context"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans.*

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

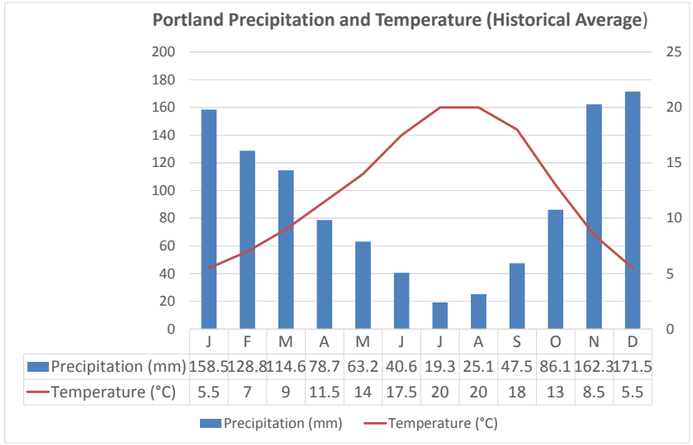
Appendix C: Flooding Events (2013) in Xiamen

Storm Events	**5/16/2013**			**7/19/2013**
Precipitation	- More than 200mm in 12 hours - More 185mm in the first 6 hours in some areas of Xiamen island			- More than 150mm in 17 hours - The highest rainfall (232.8mm) occurs in the area of Gulangyu
Impacts/issues	- Lead to traffic congestions - Flooding occured in certain traffic tunnels - Flooding occured in underground parking of certain residential areas - A number of vehicles broke on the way - Lead to soil erosion and landslide in certain areas - Land subsidence frequently occured after the storm event - Sewer leaking due to aging pipes - An estimated cost of approximately $15 million for merely piping inspection, which can not be conducted with only $200,000 budget appropriated by the city for piping maintenance			- Electricity service collapsed in some residential areas due to flooding - Certain elevator wells were filled by stormwater - Flooding occured in the University of Xiamen - Stormwater leaked into underground floor of the libary at the University of Xiamen - Line One of BRT had to stop operating because of flooding - Landslide occured at Dongping Mountain - All traffic tunnels were closed for ten days because of flooding - Lead to traffic congestions - A number of vehicles broke on the way - Land subsidence occured nearby the music square of Huandao Road
Photos of evidents				
Sources: Xiamen Night Newspaper, May 16,2013				Sources: Xiamen Night Newspaper, July 19,2013

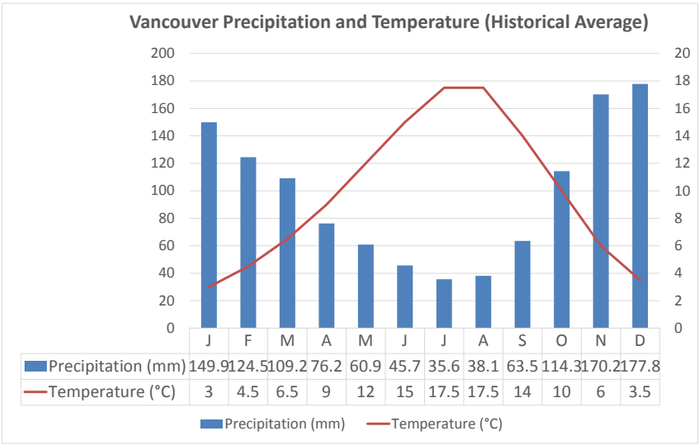
Appendix D: Overview of green infrastructure at different scales

Green Infrastructure				
Types		**Main features**	**Area served**	**More information**
Property scale	Intensive green roofs	- Accessible and recreational - More capable for stormwater management than extensive roofs - Allow for shrubs, trees and lawn - Irrigation usually necessary - More costly than extensive eco-roofs	Rooftops (with limited load-bearing capacity)	See page.13
	Extensive green roofs	- Often inaccessible to the public - Less stormwater retention benefits - Allow for sedums, moss and perennials - Low water requirement - Less costly than intensive eco-roofs	Rooftops (with competent load-bearing capacity)	See page.13
	Rain gardens	- Vegetated shallow depression - Includes amended soil for rainwater percolation - Applicable on flat or slightly sloping areas (less than 12%)	Property yard; public square	See page.19
	Permeable paving	- Applicable in low-traffic areas - Allow stormwater flow through voids in hard surface to underlying soil - Rainwater can be stored in the gravel reservoir for the purpose of detention	Pedestrian paths; driveways (with small traffic volume); parking lots	See page.26
	Rainwater harvesting	- Applicable in most land use types (residential/commercial/industrial) - water reuse and reduce demands on municipal water supply - Detain water during heavy storms	Underneath buildings; adjacent to building	See page.31
Street scale	Stormwater planters	- Long and narrow landscaped facilities with level bottom - Applicable in limited space - Provide water detention and purification through vegetation	Edge of sidewalk paving; adjacent to buildings	See page.38
	Bioswales	- Provide water treatment and infiltration during stormwater conveyance - Longitudinal slope range from 1 to 6 percentage, while optimal slope is between 1 to 2 percentage - Check dam can be applied to prolong residence time of rainwater as needed	Edge of driveways; parking space; green space	See page.34
Network scale	Retention/ detention ponds	- Applicable to capture stormwater runoff from a large drainage area - Improve water quality through biological uptake of vegetation - Provide recreational use and nature experience for the general public - Provide wildlife habitats and increase biodiversity	Large public square/park	See page.41

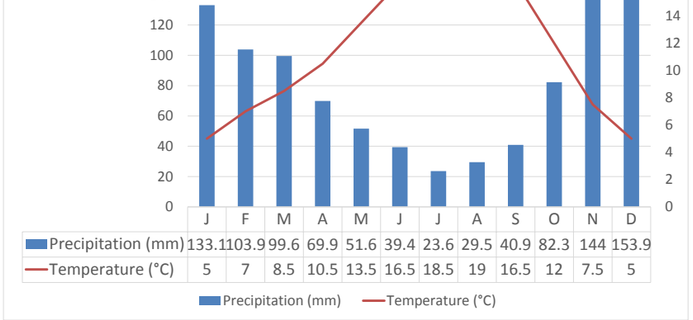
Appendix E: Climate diagrams of Precedent Cities and Xiamen



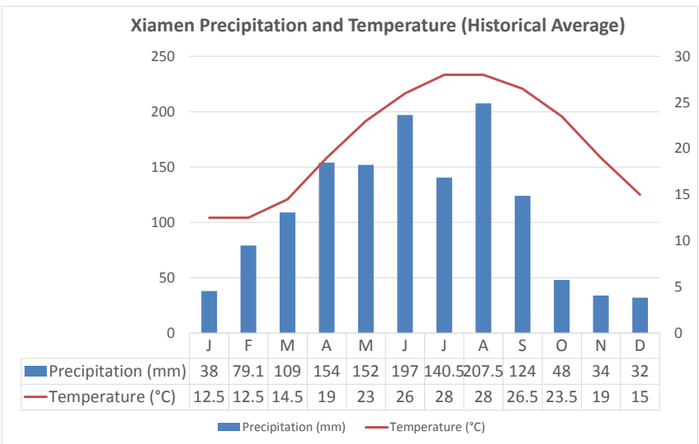
Av. Annual Rainfall
1096mm



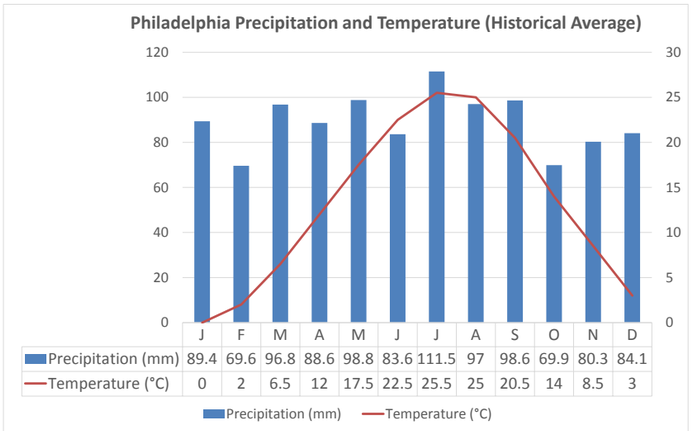
Av. Annual Rainfall
1166mm



Av. Annual Rainfall
972mm



Av. Annual Rainfall
1315mm



Av. Annual Rainfall
1068mm

Observation on data:

Xiamen has dominant precipitation during the spring summer period, and rainfall is greater than other three cities. Seattle and Portland cities have low precipitation in Summer, when temp are high. Philladelphia has fairly even precipitation through the year.

Appendix F: News Brochure"Environmental Services by the Numbers"

SPRING 2014

RiverViews

your Wastewater and Stormwater System

2,500 miles of it lies underground. Some of its biggest pipes are **150 feet below** the surface. **Millions of gallons** of wastewater and stormwater flow through it every day—most on the way to **one place.** And a major part of the system **relies on plants to do the dirty work.**

150 Years of Wastewater and Stormwater

Portland built its first sewer pipe in 1864. Today the city has 2,500 miles of pipes underground that carry millions of gallons of sewage every day. And hundreds of green street planters and other facilities on the surface manage stormwater runoff.

We've assembled some facts and figures about your wastewater and stormwater system. **Let's take a look at the system by the numbers.**

Protecting Water Quality

People, fish and wildlife depend on clean water. Environmental Services works to protect water quality in Portland's rivers and streams.



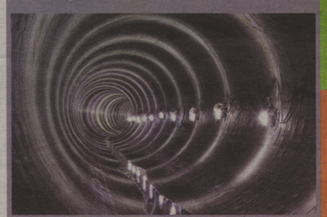
Finding Green Solutions

Green street planters, ecoroofs, rain gardens, trees, natural areas and open space are all part of Portland's system to manage stormwater and keep it out of sewers. Green infrastructure makes sewers work more efficiently and saves ratepayers money by reducing sewer construction costs.



Pipes! Pipes! Pipes!

One third of Portland's 2,500 miles of sewer pipes are more than 80 years old. And every year more pipes reach that 80-year milestone. An on-going repair and replacement program keeps the system operating efficiently.





It's the law!

Environmental Services projects and programs help Portland meet the requirements of the Clean Water Act, the Safe Drinking Water Act, the Endangered Species Act and the Superfund Act. To comply with those rules, Environmental Services enforces city codes that regulate connections to the public sewer and stormwater system, commercial discharges to the system, and stormwater management.

Sewers in Time–A History

Starting with that first sewer in 1864, the system has grown with Portland and its ever-changing needs. The complex system now includes thousands of miles of pipes, nearly 100 sewage pump stations and two wastewater treatment plants.

ENVIRONMENTAL SERVICES
CITY OF PORTLAND

The Bureau of Environmental Services works with Portland residents and businesses to protect water quality, public health, and the environment through wastewater collection and treatment, sewer construction and maintenance, stormwater management, and stream and watershed restoration.

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers

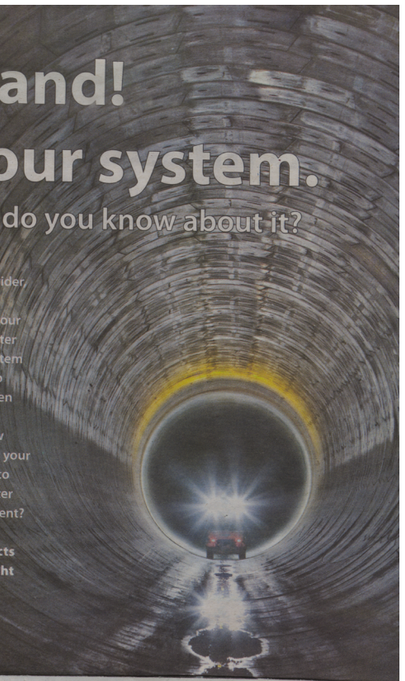
Nick Fish, Commissioner
Dean Marriott, Director

Portland! It's your system.

How much do you know about it?

As your wastewater and stormwater services provider, Environmental Services maintains and operates your wastewater and stormwater system. It's a complex system with miles of pipes, pump stations, hundreds of green street facilities, and two treatment plants. But how much do you know about your system and how it works to protect public health, water quality and our environment?

We've gathered some facts and figures that just might astonish you!



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CITY OF PORTLAND
1120 SW Fifth Avenue, Room 1000
Portland Oregon, 97204-1912

Nick Fish, Commissioner
Dean Marriott, Director

RiverViews is a newsletter from the City of Portland's Bureau of Environmental Services, which provides city residents with programs to protect water quality and public health, including wastewater collection and treatment, sewer construction and maintenance, stormwater management, and stream and watershed restoration.

The City of Portland complies with all non-discrimination laws including Title VI (Civil Rights) and Title II (ADA). To request a translation, accommodation or additional information, please call 503-823-7740, or use City TTY 503-823-6868, or Oregon Relay Service: 711.

**********ECRWSS
RESIDENTIAL CUSTOMER

ENTER TO WIN A TOUR and see your wastewater and stormwater system in action. Look inside for more details!

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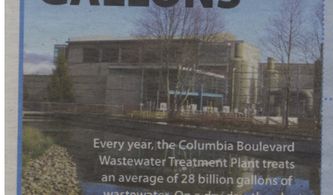
Appendix F (Con'): News Brochure"Environmental Services by the Numbers"

Environmental Services by the Numbers

With an estimated replacement value of $12.5 billion, Portland's complex wastewater and stormwater system is impressive. The numbers prove it. Here are some interesting – and surprising – facts about the system you rely on every day.

Protecting Water Quality

28 billion GALLONS



Every year, the Columbia Boulevard Wastewater Treatment Plant treats an average of 28 billion gallons of wastewater. On a dry day, the plant treats an average of **70 million gallons** and on rainy days that number can reach **450 million gallons.** Wastewater treatment starts at the headworks, pictured here.

FROM 50 TO 4 SEWAGE OVERFLOWS

Portland's combined sewers used to discharge raw sewage to the Willamette River about 50 times a year during heavy rainstorms. Since 2011 when Environmental Services finished a 20-year sewer overflow control program, **overflow events have dropped** to no more than 4 per winter and one every third summer.

15%

Percentage of Oregonians who rely on Portland's wastewater and stormwater system.

29,600 FEET

of Portland stream banks restored with native plants in 2013 to prevent erosion, filter stormwater and protect water quality.

Sewers in Time–A History

$1,000 COST OF PORTLAND'S FIRST SEWER PIPE

The city spent $1,000 in 1864 to construct Portland's first sewer. It was made of wood and ran under SW Montgomery Street from SW 4th Avenue to the Willamette River.

1873

The year Portland installed its first clay sewer pipe in SW Stark from SW 6th Avenue to the river. Over the years, Portland has used a variety of materials in its public sewer construction including wood, clay, brick, concrete and plastic.



1952 Columbia Blvd Wastewater Treatment Plant opened.

Before the city opened its first treatment plant in 1952 (dedication pictured above), all of Portland's raw sewage drained directly into the Willamette River and Columbia Slough **with no treatment.**

Pipes! Pipes! Pipes!

5 OPERATORS

Sewer pipes carry most of Portland's sewage to the Columbia Boulevard Wastewater Treatment Plant, a facility that never stops working. Even at 3:00 a.m., **five operators run the plant and six technicians are on call** to respond to emergencies. During the day, the plant has up to 21 operators on duty.



47,779

MANHOLES IN THE CITY

Also known as **sewer access structures**, these are large structures under the street that provide access to the sewer system. They generally range in size from **48 to 60 inches** across but **some are up to 144 inches in diameter.**



Did you know?

The estimated replacement value of the Columbia Boulevard Wastewater Treatment Plant is more than **$1 billion,** making it one of the city's most valuable assets.

96,000 ACRES

Your sewage and stormwater system serves an area that covers 96,000 acres. That's about 150 square miles.

Did you know?

With an inside diameter of 22 feet, the largest sewer pipe in Portland's sewer system is the East Side Big Pipe, which captures combined sewage that once overflowed to the Willamette River. The smallest pipes in the system are just 6-inches in diameter.

22 FEET

Did you know?

More than 800 miles of Portland's 2,500 miles of sewer pipes are as old as or older than the cars in this 1930s photograph. Each year, more pipes turn 80 years old.

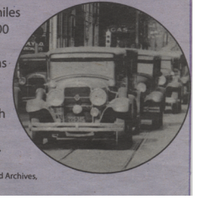


Photo from City of Portland Archives, Oregon, A1999-004.256

Finding Green Solutions

TABOR to the RIVER

partnerships for sewer, green stormwater, and watershed improvements

$63 million

Portland started work in 2008 on the Tabor to the River Program to solve problems caused by aging sewers. The program would have cost an estimated $144 million using only pipe solutions. Combining green street facilities and rain gardens with sewer improvements added watershed health benefits and reduced the estimated cost to $81 million, saving sewer ratepayers about $63 million.

The average mature tree catches nearly 600 gallons of rain every year to reduce stormwater runoff volume. Because every tree planted in Portland contributes to clean rivers and healthy watersheds, you can earn a sewer bill credit for trees you plant on your property. Get more information about the Treebate Program at **www.portlandoregon.gov/bes/Treebates**.

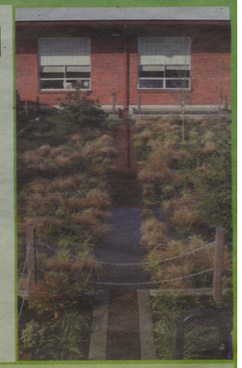
NEARLY **600** GALLONS

2.3 BILLION

Number of gallons of stormwater runoff Portland's green infrastructure captures and filters annually

The stormwater management system includes more than 22 acres of ecoroofs, 1,500 green street facilities, 260,000 street trees and 34,480 single family homes with disconnected downspouts.

Partnerships with residents and business owners around the city are responsible for much of Portland's green infrastructure.





Adopt a green street today!

Green streets are landscaped planters that capture stormwater runoff from streets and allow it to soak into the ground as soil and vegetation filter pollutants. They keep stormwater out of sewers and local streams, replenish groundwater supplies, and create urban green spaces. Green Street Stewards are volunteers who help care for green streets in their neighborhoods and keep them functioning properly. Go to **www.portlandoregon.gov/bes/GreenStreetSteward** and learn how to join more than 100 other green street stewards taking care of more than 200 green street facilities.

It's the law!

Did you know?

The **Clean Water Act**, passed in 1972, regulates the discharge of pollutants to waterways. Environmental Services is the city bureau responsible for ensuring that Portland complies with Clean Water Act mandates.

1,667 SPILL COMPLAINTS

Environmental Services Spill Protection and Citizen Response investigates pollution going to, threatening, or leaving Portland's sewer system. Investigators responded to more than 1,660 complaints in 2013. Someone washing paint down a storm drain, a strange looking discharge coming from a pipe on the river, or sewage coming out of a manhole are all things Spill Protection and Citizen Response investigates. **If you see pollution, call the Spill Response Hotline at 503-823-7180.**



53,345 water and soil sample analyses last year

Portland's Water Pollution Control Laboratory analyzes samples from treated wastewater, industrial waste discharges, stormwater, rivers and streams, and soil excavated during construction projects to help ensure that Environmental Services meets its regulatory requirements.

6.4 million

pounds of grease and food waste removed from sewers since 2012

Since 2012, Portland restaurants and other food service businesses have helped reduce sewage overflows by removing more than 6.4 million pounds of grease and food waste from the Portland sewer system.



Did you know?

Grease isn't the only thing that can cause sewer maintenance problems. Sometimes other things enter the sewer system that don't belong there and can cause costly maintenance problems, both in residential plumbing and in public sewers. Go to **www.portlandoregon.gov/bes/WhatNotToFlush** to learn more.



Enter to Win!

Want to see your wastewater and stormwater system in action?

The Columbia Boulevard Wastewater Treatment Plant, the Swan Island Pump Station and the Water Pollution Control Laboratory are key parts of the system.

Enter your name in a drawing to win a guided tour of one of these important facilities this summer. To enter, send your name, phone number and which facility you would like to visit: Columbia Blvd Wastewater Treatment Plant, Swan Island Pump Station or Water Pollution Control Laboratory. Please pick one.

BY MAIL
City of Portland Environmental Services
Attn: RiverViews Tour
1120 SW 5th Avenue, Room 1000
Portland, OR 97204

ON THE WEB
www.portlandoregon.gov/bes/tour

BY EMAIL
tour@portlandoregon.gov

Entries will be accepted until May 30, 2014.

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers