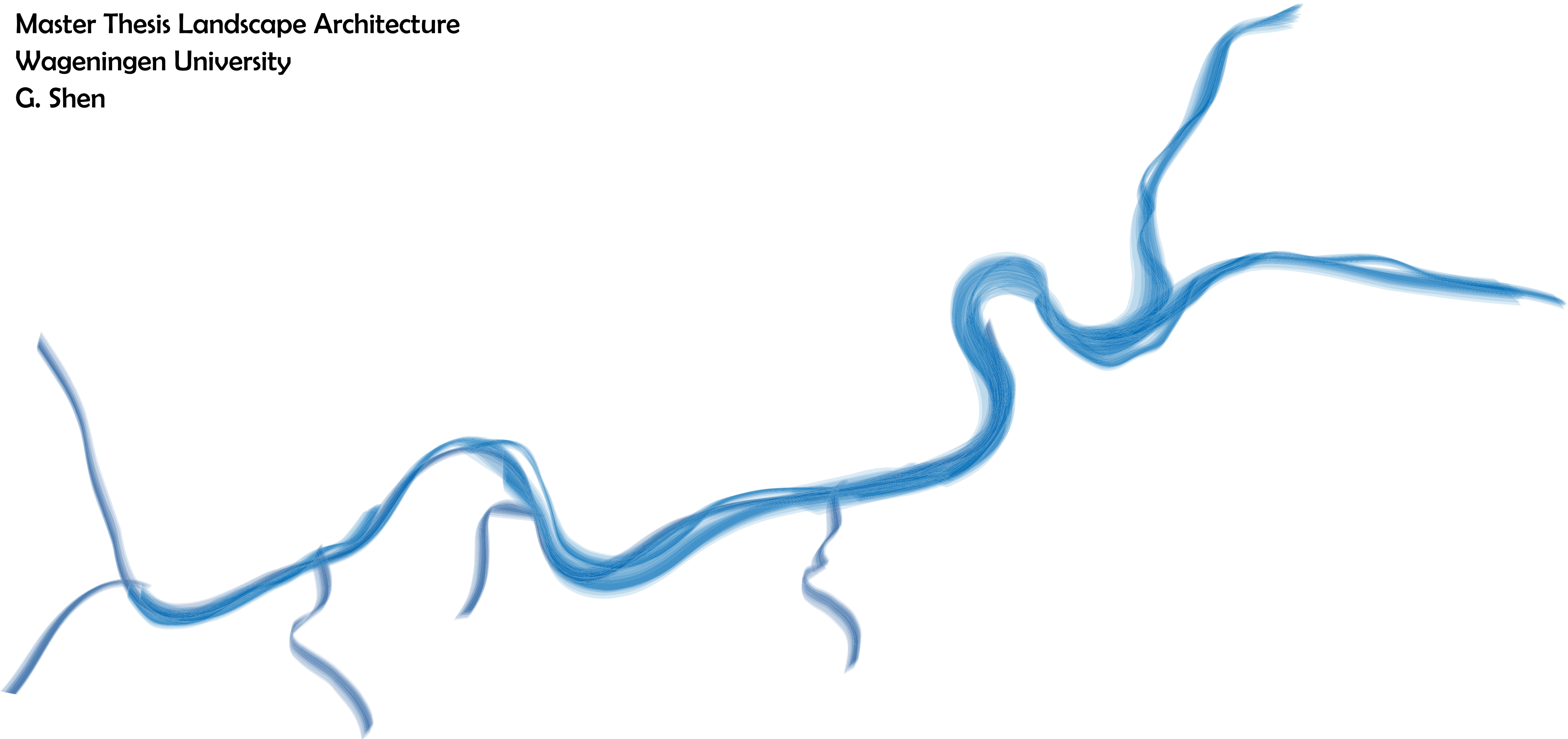
Designing the Shangbu Watershed

An Exemplary Landscape Design for Stormwater Management in Hangzhou, China

Master Thesis Landscape Architecture
Wageningen University
G. Shen



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For quality of life

Preface

This master thesis is a result of a year of research and design process on stormwater management in Hangzhou, a typical Chinese urbanized and populous city which faces urban flooding and water pollution issues. In the past year, I have researched how the Sustainable urban drainage system (SUDS) and the Best Management Practices (BMPs) deal with water quantity and quality issues, respectively. I studied the landscape, the hydrologic process and how they influence our life economically, socially and environmentally. The result of this thesis project is a landscape-based combined approach which combines SUDS and BMPs for managing stormwater in the Shangbu Watershed, a representative research case in Hangzhou. The generated design strategies and design principles can also be applied in other Chinese cities with similar landscapes to the Shangbu Watershed.

I would like to thank in particular my supervisor Sanda Lenzholzer from Wageningen University for guiding me from the very beginning till the end of the thesis. Her criticism, professional knowledge and patience inspired and motivated me to think critically and strategically, and helped me build up strong argumentations in the thesis.

Furthermore, I would like to thank Xiaoming Shao, the professorate senior engineer from Hangzhou Urban Planning Bureau, and Zhe Wang from Liuxia local government. They spared a lot of time with me through internet meetings and provided me with a lot of important materials which helped me have a deeper understanding of Hangzhou and the Shangbu Watershed.

Lastly, I would like to thank my colleague students, friends and family for their positive support and critical comments during discussions.

Abstract

This master thesis elaborates how landscape architects can combine their professional skills with hydrologic skills to address urban water issues differently. The urban flooding and water pollution issues are the two common water-related problems in Chinese urbanized and populous citie, and they bring severe consequences to the society. The generated approach in this research combines the Sustainable Urban Drainage Systems (SUDS) and the Best Management Practices (BMPs), which make it possible to address those two major water issues at the same time while creating high quality environment for people. The combined approach is translated into four design strategies to solve water problems in the Shangbu Watershed. Shangbu is a typical watershed which has similar landscape characteristics to Hangzhou, and it suffers the two mentioned water problems. In order to see how those strategies can be applied in detailed sites, designs are made for three exemplary sites in the watershed. And detailed design principles and impressions are made for those three sites based on their site-specific constrains and opportunities. Designs aim to show the potential of integrating the combined approach into existing landscapes in order to reduce stormwater quantity and improve water quality at a site scale.

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"Just as water is the foundation of life it must be the foundation of design in the built environment."

--- Betsy Damon

Figure 0.1 Urban flooding and people's living environment
Source: Waggonner & Ball Architects, 2013

1. Problem Introduction

Figure 1.1 Urban floods happen in Hangzhou. Source: http://zjnews.zjol.

Figure 1.2 Water pollution in Hangzhou (bottom). Source: info.water.com.

1.1 Research Issue

Water is essential in all aspects of our human life - in our living environment, in our productions, and in our economies, etc.. Water has a central place in the economic, environmental and social development (Renato, 2003). On the contrary, human activities, particularly urbanization has affected our hydrologic system negatively, resulting in several water-related issues (U.S.Geological Survey, 2014). Urban flooding and water pollution have been identified as two major water problems which most Chinese urban cities are experiencing (Xinhua, 2013)(Figure 1.1). The conventional drainage approach in most Chinese cities is the pipe-bounded drainage system, which has limited discharge capacity, can easily get overflowed, and does not consider about the water pollution issue (Zhang et al., 2012) (Figure 1.3). Therefore, searching a new sustainable approach that can solve the urban flooding and water pollution issues in China is called for in this thesis research.

1.2 Research Object

The initial research objects are most urbanized and populated cities in China (population more than 5 million) which face urban flooding and water pollution issues, because urban floods take place in those cities will normally cause more intense and costly damages than other less urbanized or populated cities (Jha et al., 2014). Those problematic cities are all across the country, with diverse landscape characteristics. It would be useful if solutions can be made for all those problematic cities, but within the limited thesis time span, the research and design can only be done on one city. In this thesis, the city of Hangzhou is selected as the case city to represent other 4 highly urbanized and populated cities which are Ningbo, Xiamen, Guangzhou and Foshan (Figure 1.4).

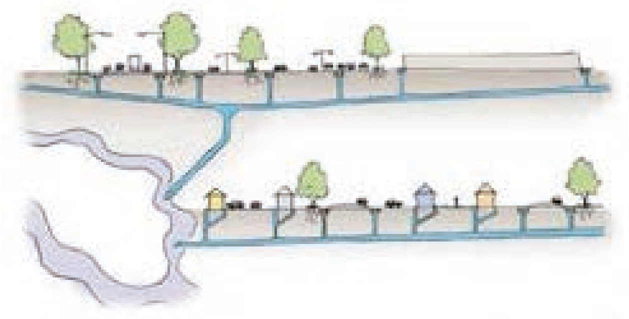


Figure 1.3 Conventional drainage sytem depends on pipe-bounded systems to drain water away. Source: http://www.asla.org.

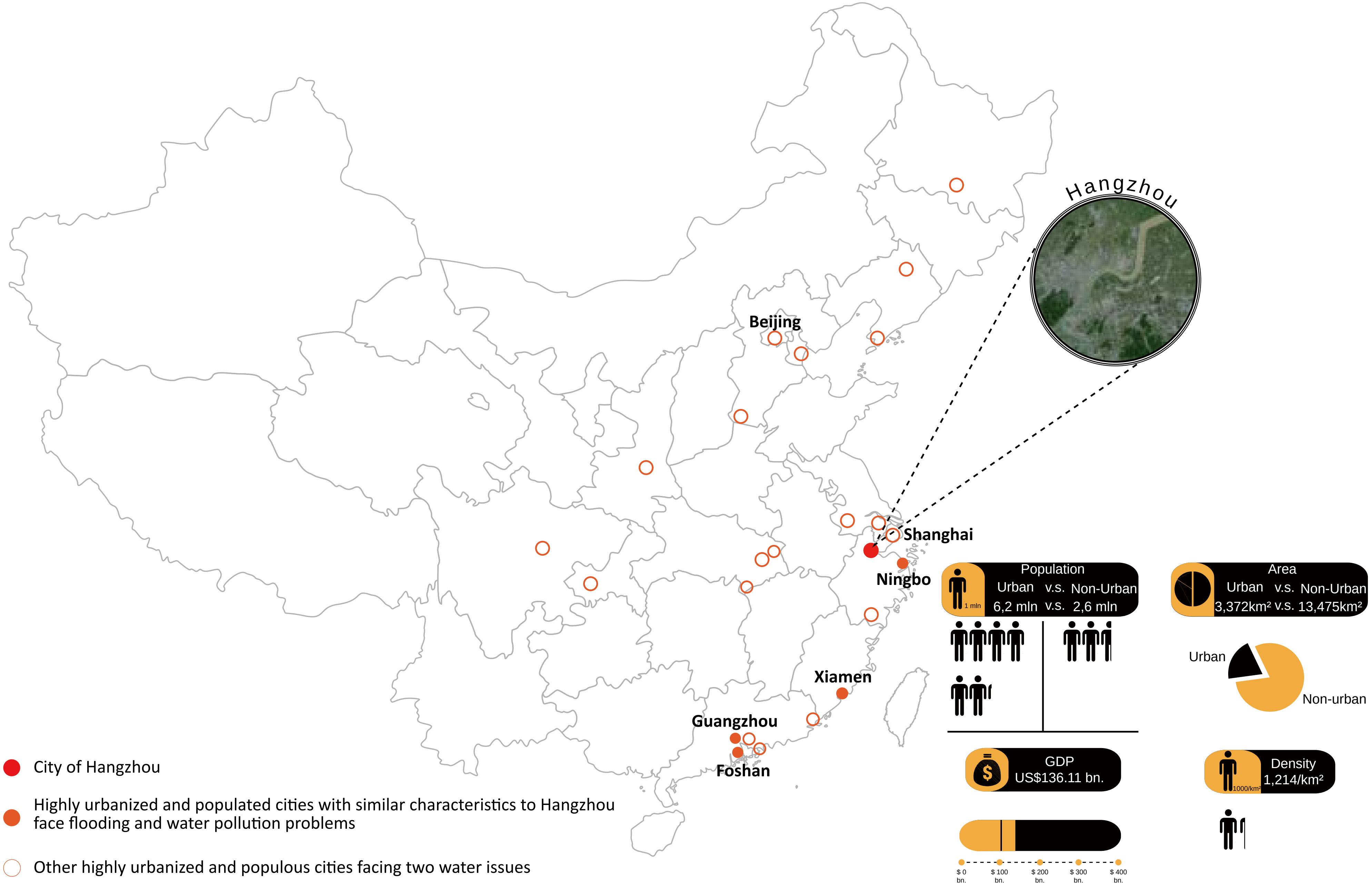


Figure 1.4 Highly urbanized and populated Chinese cities (with population more than 5 million people) face severe urban flooding and water pollution issues.

Hangzhou is selected because: firstly, Hangzhou mainly contains loam and rice paddy soils which are also common in other 4 problematic cities (Figure 1.5), and details of soil types as well as their drainage characters will be discussed in the chapter 2; secondly, all the five cities have similar topographic conditions, as they have hilly terrain in high land, broad flat terrain in the middle land and low-lying flat terrain in the low land (1.6-1.11). Besides those reasons, Hangzhou Municipality has been concerned about the urban flooding and water pollution problems and has expressed the necessity for innovative stormwater management approaches to address the city's current water problems (Zhang, 2013). Therefore, the city of Hangzhou is a suitable and representative case city in this thesis research.

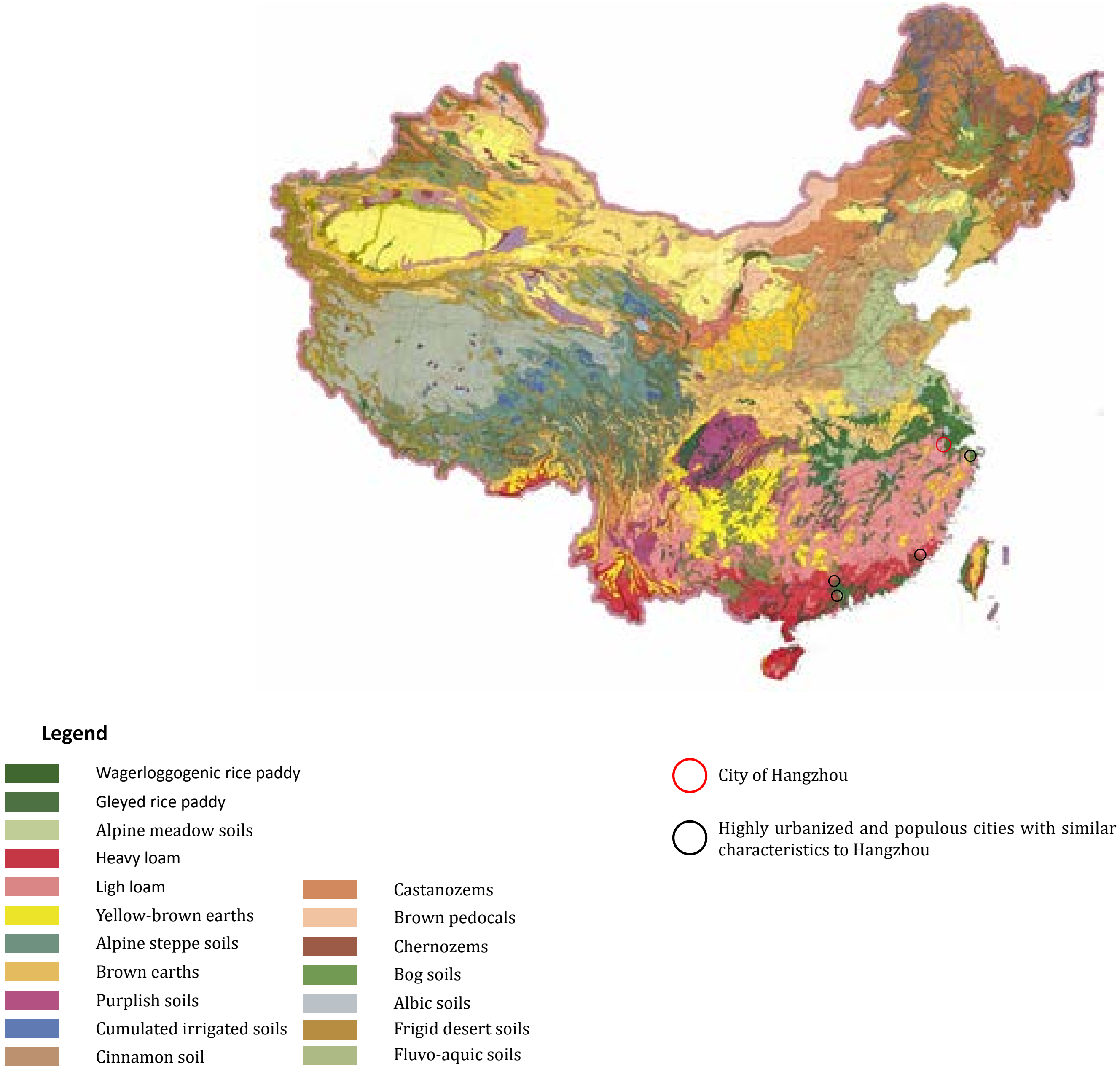
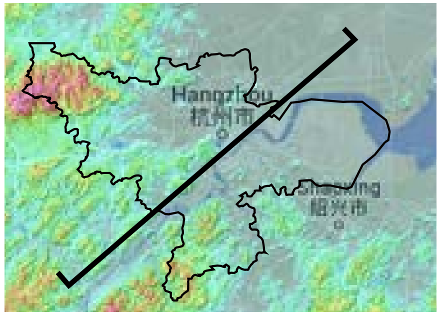


Figure 1.5 The soil map of China shows major soils that are commonly seen in the five object cities are loam and rice paddy soils. Source: http://zrdl.snnu.edu.cn/.



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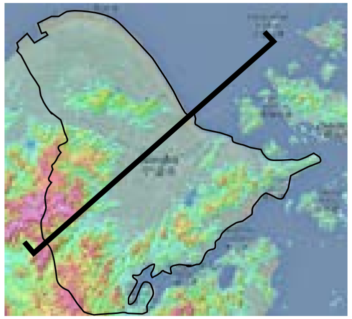

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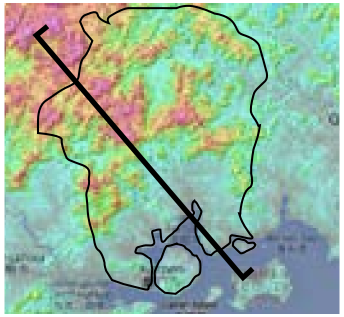


Figure 1.8 Topography map of Xiamen. Source: http://en-gb.topographic-map.com/.

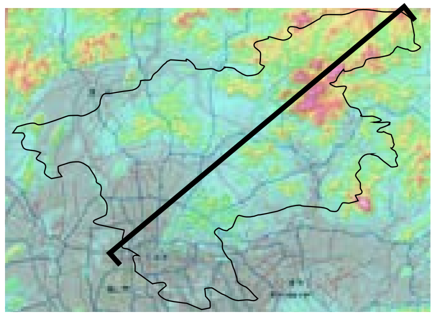


Figure 1.9 Topography map of Guangzhou. Source: http://en-gb.topographic-map.com/.

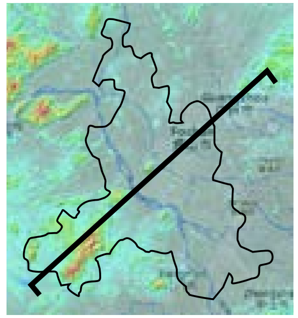
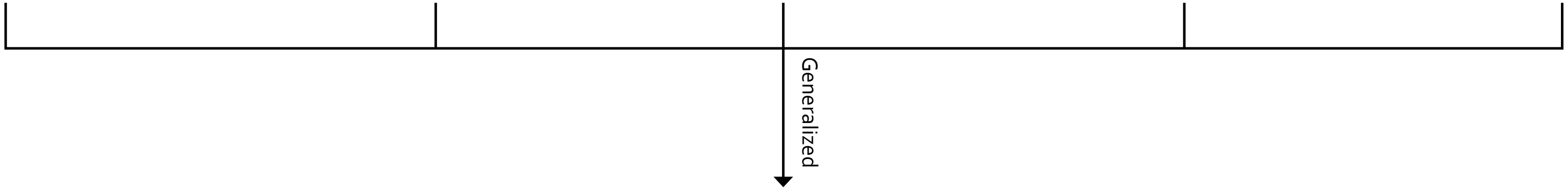


Figure 1.10 Topography map of Foshan. Source: http://en-gb.topographic-map.com/.



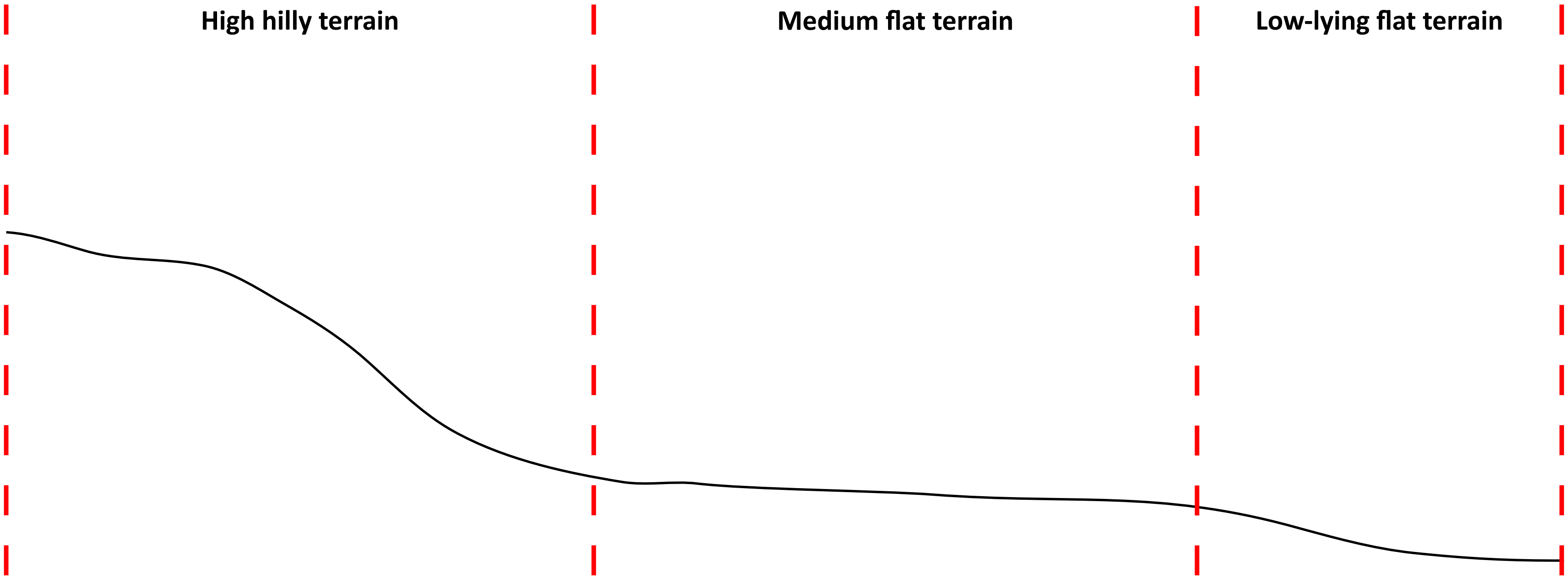


Figure 1.11 A generalized topographic profile of the five object cities. Generally, they have hilly terrains on high lands, broad flat terrains on medium height lands, and flat terrains on low lands.

1.3 Urbanization - the Fundamental Cause of Urban Flooding and Water Pollution

1.3.1 The shifting urban hydrology and drainage infrastructure

The recent urban development in Hangzhou started in 1949, and before that, Hangzhou residents and urban properties mainly inhabited the city's medium height flat terrain. While the low terrain is featured with rural characteristics such as fish ponds, agriculture fields and wetlands. During the process of urbanization in Hangzhou, the city expanded the size of its urban areas significantly, mainly towards the lower terrain, converting large portions of natural and agricultural features into paved surfaces. See Figure 1.12, Figure 1.13 and Figure 1.14.

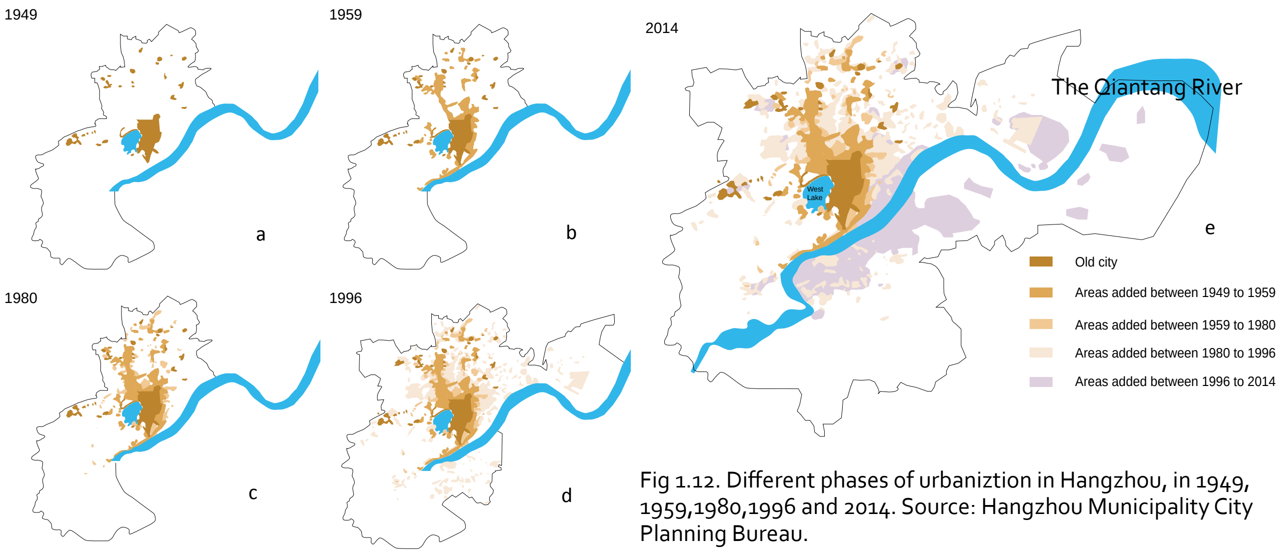


Fig 1.12. Different phases of urbaniztion in Hangzhou, in 1949, 1959,1980,1996 and 2014. Source: Hangzhou Municipality City Planning Bureau.

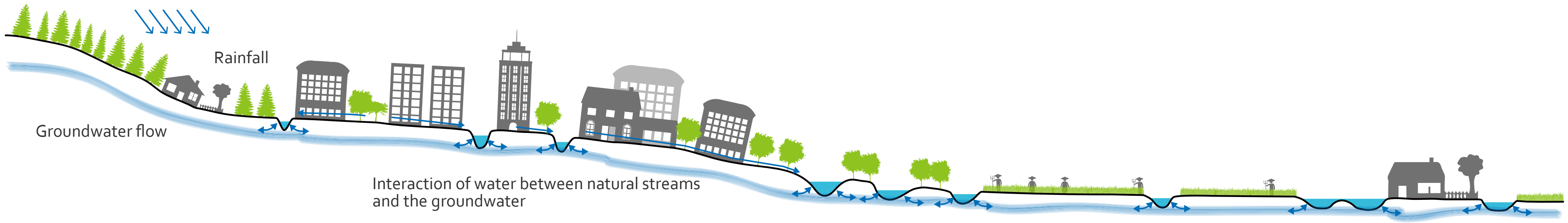


Fig 1.13. Before the modern urbanization process in Hangzhou in 1949, urban areas are mainly situated on the medium height flat terrain of the city, while rural and natural areas such as agricultural fields, and wetlands occupy the low-lying terrain.

Fig 1.14. During the urbanization, low-lying natural and rural areas are converted into urban areas, paved surfaces prevent create more surface runoff, while streams are either buried or canalized.

Figure 1.15 A typical pitch of rural area in the low-lying terrain of Hangzhou before 2003 consisted of fish ponds and agricultural fields (top), while the same area is consformed into a urban residential area now (bottom). Source: Google earth.

The process of urbanization has changed the city's landscape, which results in a negative impact on its urban hydrologic cycle. For instance, agricultural lands and forests in rural areas in Hangzhou which used to infiltrate or store water were replaced by concrete grounds where residential areas, schools and other infrastructures are built, resulting in more vulnerability of urban floods (Silveira, 2002, Fang et al., 1997) (Figure 1.15). All those transformations of the landscape lead to an increased amount of surface runoff in urban areas. Instead of infiltrating into ground to recharge groundwater, the stormwater created on paved surfaces flows into the urban drainage system and is transported into nearby rivers or water bodies directly. Figure 1.16 shows that the volume of surface runoff created in the urban area is much greater than the volume created in natural surface areas.

Urbanization not only affects the land surface, but also natural waterways across the city. Before Hangzhou started its urbanization there were hundreds of streams and creeks traversing inside the city, forming an interconnected network to help hold or drain off water to other places. However, when the urbanization proceeded, many waterways gave way to the expansion of the city and its industrial development. Some of them were gradually filled up and replaced by underground pipe-bound drainage system, while some were canalized (Figure 1.17).

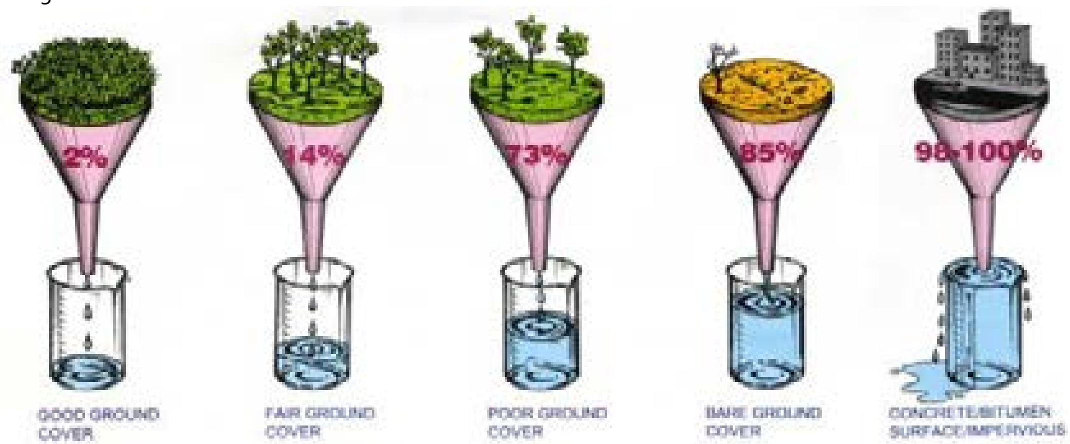


Figure 1.16 Natural surfaces allow water to infiltrate into the ground, less surface runoff is created. While the percentages of paved surfaces occur in the urban area, the groundwater recharge process is prevented, resulting in more runoff. Source: Upper Parramatta River Catchment Trust, 2001.

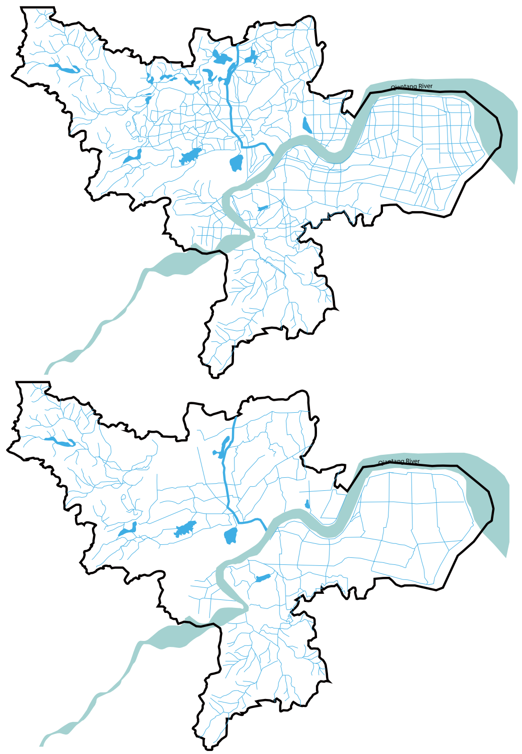


Figure 1.17 Old surface streams before 1949 (top) and current surface streams (bottom). Source: Hangzhou Municipality City Planning Bureau and local Chronicles Office.

Currently, the city mainly relies on the conventional pipe-bounded drainage system to drain stormwater created within the city out of it as fast as possible. Two types of drainage systems are found in Hangzhou, the separated system and the combined sewer system (Figure 1.18). The separated sewer system is used in the most of urbanized areas, and it consists of two pipes for different purposes. One pipe collects stormwater and transports it to nearby watercourses, while the other pipe drains the sewage to water treatment plants. In rural areas, the combined sewer system is applied which transports both sewage and stormwater together to water treatment plants. They are more likely to get overwhelmed by water during intense rainfall events as water treatment capacities in those water treatment plants are limited and cannot afford too much water during that extreme situations. So the overflowed water which consists of stormwater and untreated wastewater is discharged into nearby water bodies directly, causing water pollution.

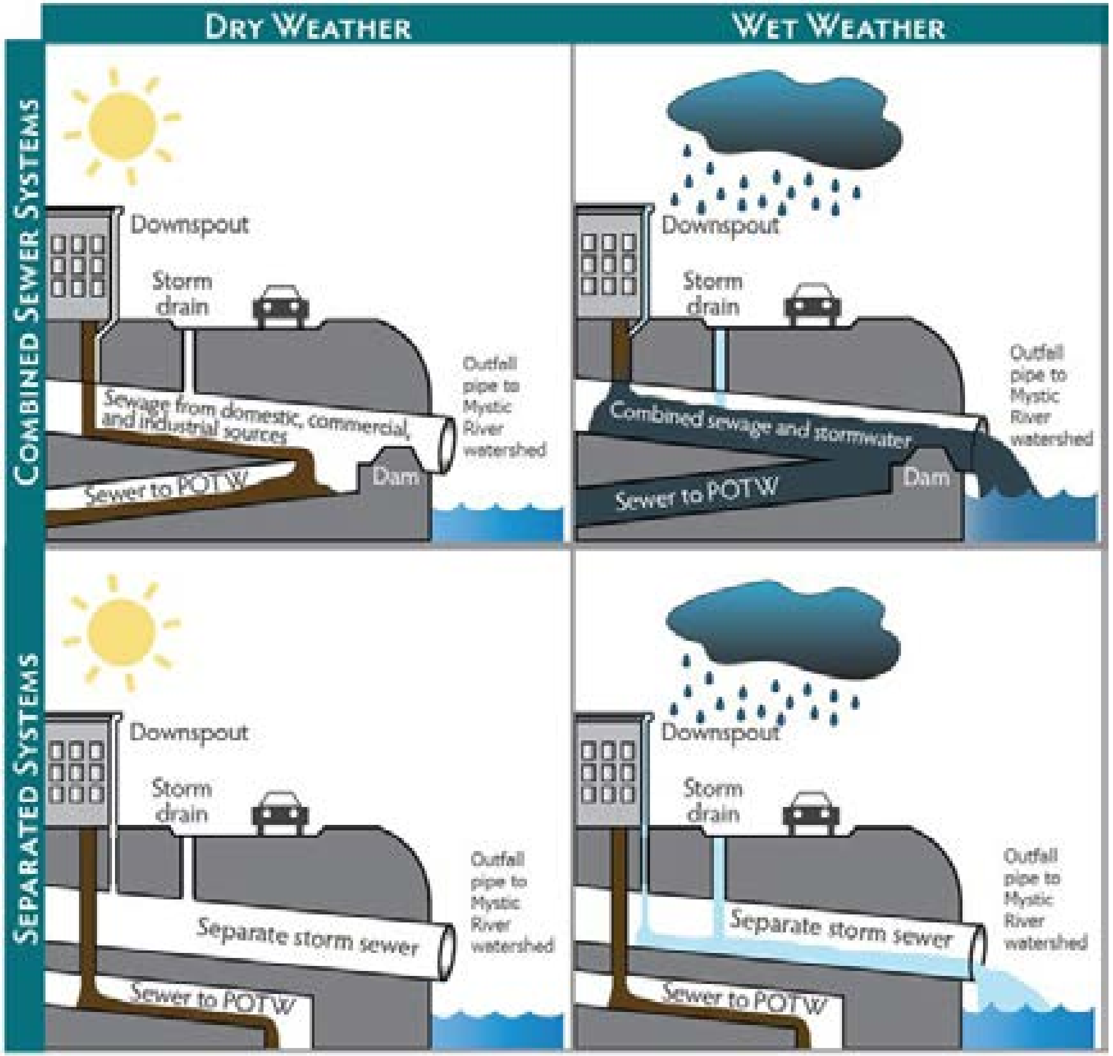


Figure 1.18 The working process of two common urban drainage systems: CSO and SSO during dry and wet conditions. Source: http://mysticriver.org/csos/.

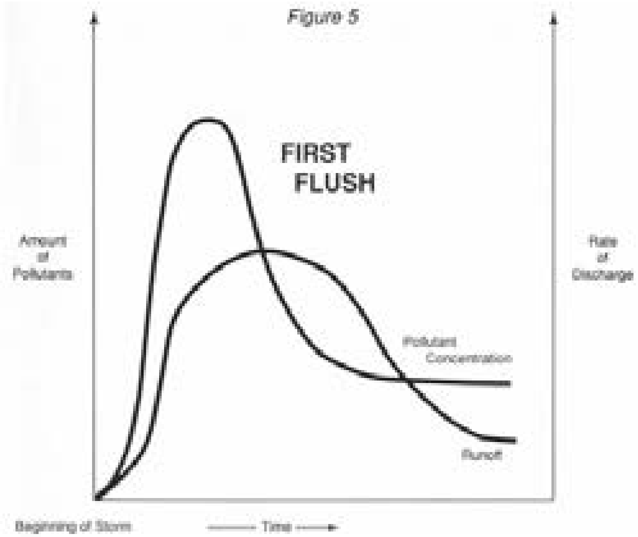


Figure 1.19 Amounts of pollutants in the first flush. Source: 1991, cited from Verbon, 2012.

1.3.2 Water pollution

Urbanization changes the land uses which affect the water quality directly (USPEA, 2012). Dry seasons create a long period of time for pollutants to build up on the urban surface, and the first flush washes those pollutants away into nearby waterways, causing water pollution such as eutrophication. The concentrated pollutants carried by the first flush of runoff are times higher than later flush (Deletic, 1998)(Figure 1.19). Researchers have found out that the amount of pollutants carried by the stormwater runoff in urbanized areas in Hangzhou is the highest in the first 5-20 minutes (Li et al., 2012). Table 1.1 elaborates on pollutants which are normally detected in the stormwater runoff in most Chinese cities.

Stormwater is the major source of pollutants to Hangzhou's lakes, waterways, and other water bodies (Li et al., 2012). Many watercourses have been detected being polluted due to the direct discharge of stormwater. Those polluted stormwater come from roads, industrial and commercial lands, and sediments have been recognized as the major pollutant in Hangzhou (Li et al., 2012).

Hangzhou is situated near the estuary, which has high productive and dynamic marine systems. If pollutants, sediments in particular, are drained to the sea consistently, the types of organisms living in the estuary would be altered, and this would disrupt the essential nursery area for a diverse habitats. In addition to the environmental impact, water pollution has economic impacts as well. For instance, excess deposits of sediments can clog water transport ways, and Hangzhou government has spend millions of dollars to dredge and maintain those transport channels (Zhejiang Municipality, 2004).

Table 1.1 Elaboration on pollutants which are normally detected in the surface runoff in most Chinese cities. Source: Li et al., 2012; ICMI, 2014 .

Pollutants	Main Source	Main Impacts
Suspended particles	Soil erosion, precipitation, vehicles, construction as well as other urban activities	They clog waterways, smother bottom living aquatic organisms and increases turbidity
Nitrogen and phosphorus	Precipitation, fertilizer	They can cause unwanted and uncontrolled growth of algae and aquatic weeds like hydrilla or hyacinths
Heavy metals (Zn, Pb, Fe, Cu,Cr, Ni)	Oil, vehicles, road materials, garbages contain heavy materials	disrupt the reproduc tion of fish and hellfish and accumulate infish tissues
Cyanide	Chemicals contained in the deicer	They are toxic to people and widelife at very low concentrations (5.0mg/L) in terms of delayed mortality, pathology, susceptibility to predation and so on
Oil and Grease	Vehicular exhaust, petroleum leak, asphalt road	They are toxic to many aquatic organisms
Sulfate	Subgrade, fuel, deicer (a kind of heater that removes ice or frost), and low Dissolved oxygen levels in water	They are are quite soluble in water and are toxic to both humans (as drinking water) and fish. When sulfate is more than 0.5 mg/L, algal growth will increase

1.4 Projected Flood Risks from Climate Change

Meanwhile, the urban flooding risk is getting higher as more intense and frequent extreme weather events are projected over the next few decades and Hangzhou is expected to experience that climate change (Nicholls, 2011, Prudhomme et al., 2010, China Weather Center, 2012) (Figure 1.21).

The rapidly increased flushing stormwater can not only pose higher risks of flooding to Hangzhou, but also increase erosion to all land. Consequently, bringing severer pollution issues to the city. To conclude, the need to use a better solution to solve water quantity and quality issues in Hangzhou is urgent.

Figure 1.20 More rainfall-induced flooding events are projected to happen in Hangzhou due to climate change. Similar situations shown in images are expected to happen more frequently if futher no protection is done. Source: http://www.china.org.cn/.

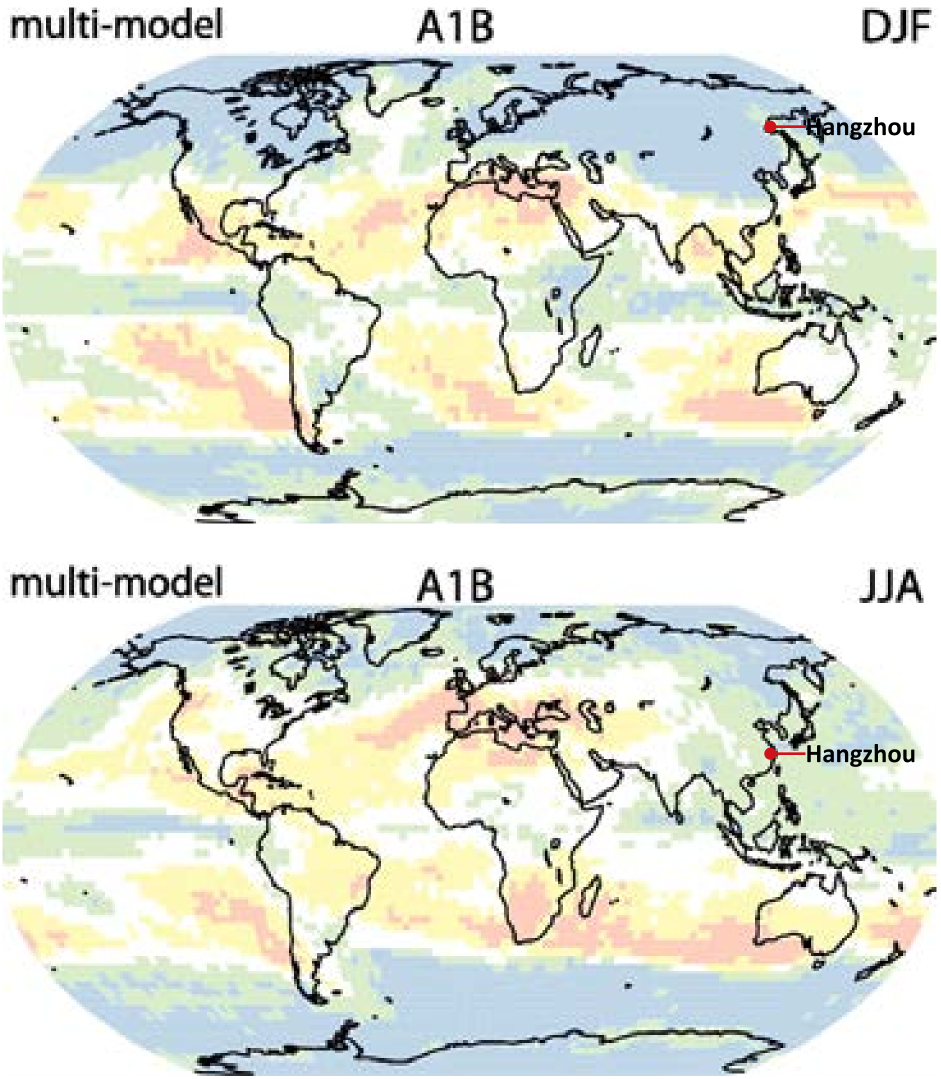


Figure 1.21 The top panel shows projections for the period covering December, January and February, while the bottom panel shows projections for the period covering June, July and August. China is in the precipitation increase zone according to the projection. Source: www.ipcc.ch/.

2. Hangzhou Context

2.1 Topography, Soils and Groundwater Levels

2.2 Plum Rain Seasons and Intense Rainfalls

2.3 Urban Watersheds and Urban Water Systems

2.1 Topography, Soils and Groundwater Levels

The west and south part of Hangzhou is in the high zone (mountainous areas define the west and south boundaries of Hangzhou city), while the area in north and east part is located in lower lands. Because the surface areas in the high flat terrain are small, so the city has to expand its urban areas down to the low-lying flat terrain, which makes those low-lying urban areas prone to urban flooding (Figure 2.1).

The major soils are loam and rice paddy. Loam soil is widely distributed in high lands, while rice paddy soil is commonly seen in lower lands. What needs to be mentioned is rice paddy soil is a type of soil widely used in China for agriculture. It is an artificial soil which has a low infiltration rate and high water storing capacity (China Soil Data Base, 2000). The distribution of soil types in Hangzhou is shown Figure 2.2.

The groundwater in Hangzhou is mainly pore water while karst water is distributed in mountain areas in the south-west part of Hangzhou. In general, the groundwater flows from high south-west part to the low north-east part of the city. The groundwater level in high loam lands stays deeper than 1.2 meters below the ground, and the groundwater level in low-lying rice paddy land is normally less than 1 meter below the ground (Hangzhou Municipality, 2003) (Figure 2.5).

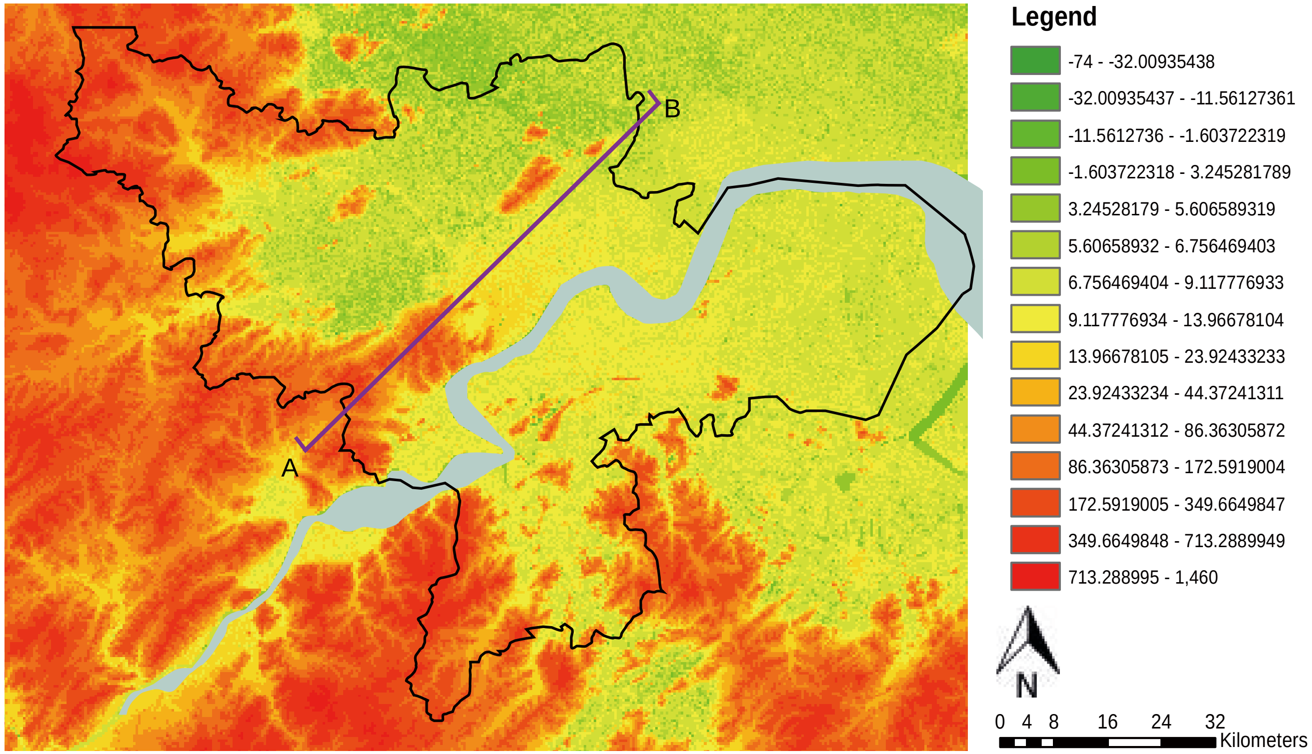


Figure 2.1 Topographic condition in Hangzhou. Source: GIS data.

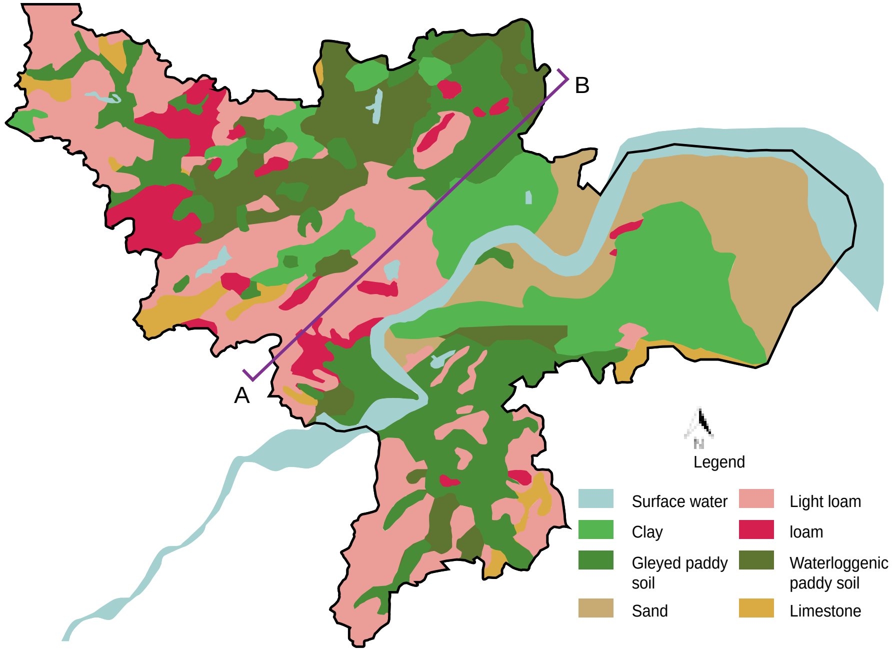


Figure 2.2 Different soil types in Hangzhou. Source: Hangzhou Municipality Land and Resources Bureau.

Figure 2.3 Loam soil is the mixture of sand, silt and clay, which makes it a moderate soil type for infiltration. Source: adapted from http://www.coorgblog.orangecounty.in/.

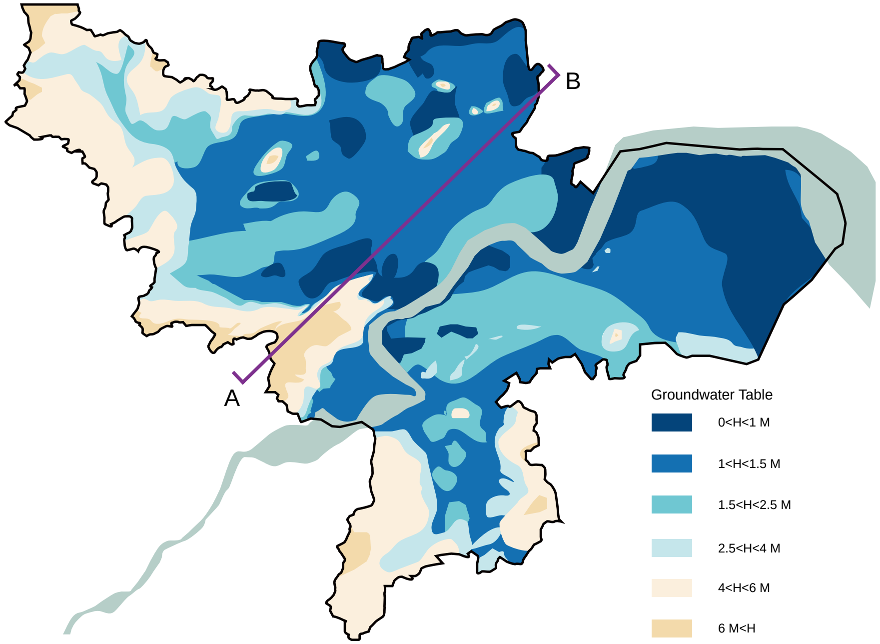


Figure 2.5 Current groundwater level in different parts of Hangzhou. Source: Hangzhou Water Resource Communique, 2007.

Figure 2.4 Rice paddy is a typical farm soil in the southern China, which has small particles and a low infiltration rate. Source: adapted from http://www.isric.org/.

The potential for the stormwater infiltration varies in accordance with site-specific landscape characteristics. The south-west part of Hangzhou locates on the higher land which is featured by permeable loam and the deep groundwater level, stormwater can find its way to infiltrate into ground and recharge the aquifer. The terrain height decreases towards the north-east part of the city, the infiltration is not feasible in areas consist of impermeable rice paddy soil, in those landscapes stormwater cannot be soaked into the ground. The infiltration may also be limited to areas which feature steep slopes or contaminated soils. In those areas where infiltration is not feasible, different storwmater management strategies need to be implemented.

Figure 2.6 illuminates the typical landscape profile of Hangzhou, and the suggested water movement.

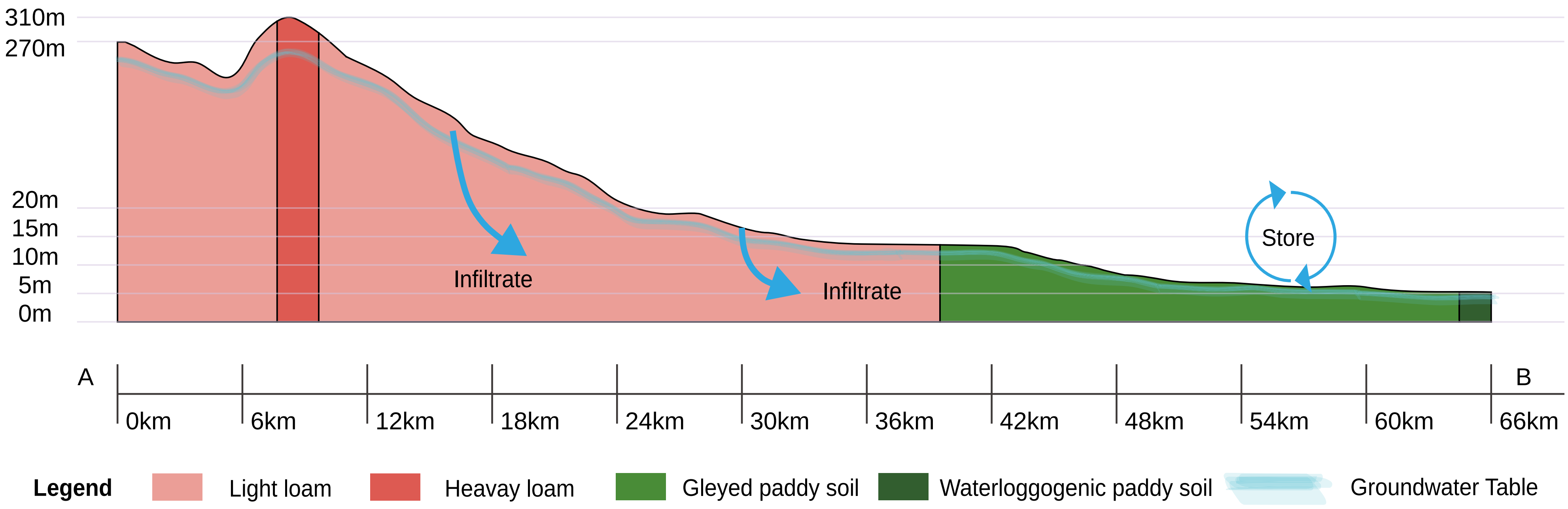


Figure 2.6 Typical landscape profile in Hangzhou.

2.2 Plum Rain Seasons and Intense Rainfalls

Hangzhou is one of the wettest cities in China, receiving average 1438 mm rainfall every year (Figure 2.7). As the city has a subtropical climate, Stratiform precipitation dominates the precipitation events in Hangzhou, resulting in the plum rain season (from April to June). The plum rain season, also known as Meiyu, is a precipitation period when gentle rainfalls last for months. The plum rain season is a main period to recharge groundwater in Hangzhou.

In summer months, typhoons and thunderstorms are common, which bring intense rainfalls to the city. Sometimes the city receives as much as 30 to 40 mm in one single hour, posing heavy stresses on urban drainage systems.

2.3 Urban Watersheds and Urban Water Systems

Hangzhou can be roughly divided into two major drainages: the northern and southern basins. And based on topographic and hydrological conditions, those two major basins are consisted of eight sub-basins containing a diverse urban settings of residential, commercial and industrial land uses, open space and natural lands (Figure 2.8).

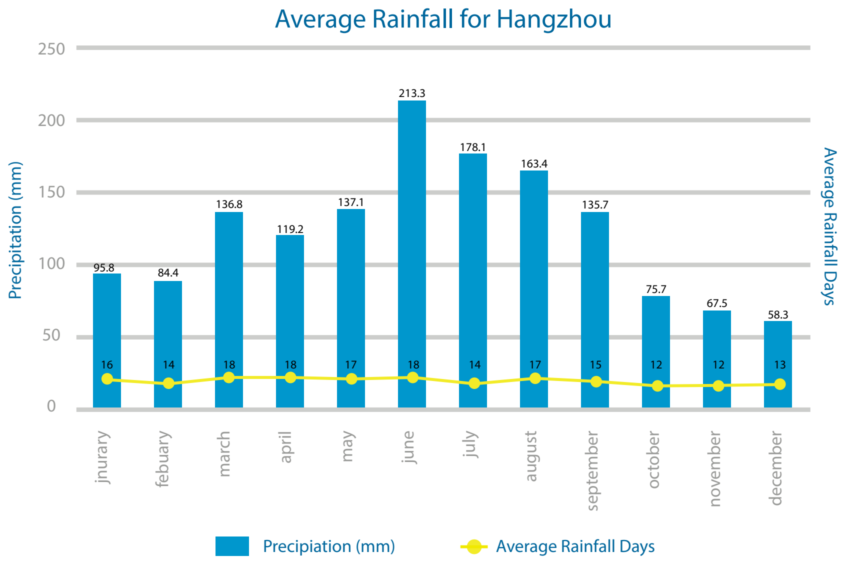


Figure 2.7 Anual precipitation (mm) in Hangzhou and the average rainning days. Source: http:// www. worldweatheronline.com.

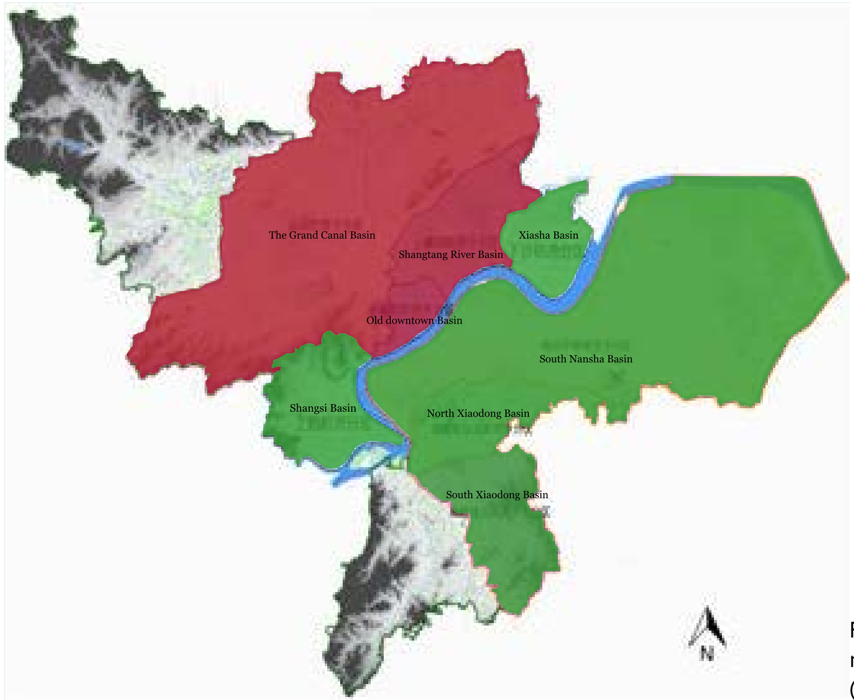


Figure 2.8 Hangzhou's topography divides the northern basin (red) from the southern basin (green). Source: Hangzhou Planning Bureau.

The Grand Canal, Tiaoxi River and Shangtang River are the largest waterways in Hangzhou and together with other small waterways, form the major urban water system in Hangzhou. Those three rivers discharge most of the water in the northern part of the city to the Taihu Lake Basin downstream (to the north) (Figure 2.9). Several pump states are built along the Qiantang River in order to drain water from urban waterways into the Qiantang River.

Throughout the city, the current urban water system entirely relies on the pipe-bounded drainage system to collect and transport stormwater to canals which then discharge water downstream to the Taihu lake or to the Qiantang River by pumping (Figure 2.10).

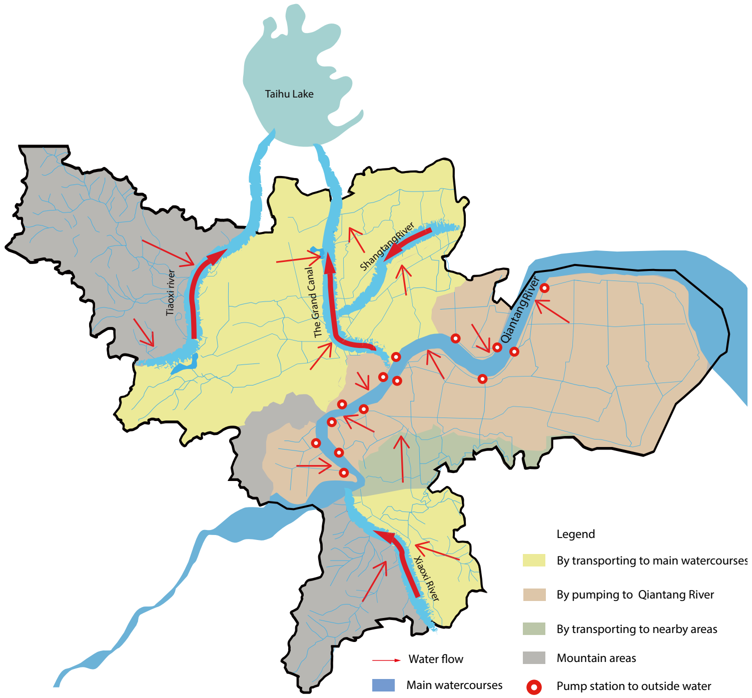


Figure 2.9 Current water systems in Hangzhou. Source: Hangzhou Water Plan 2014.

Figure 2.11 The Qiantang River is the biggest river in the region, connecting inland cities with the East China Sea. Source: http://www.panoramio.com.

Figure 2.12 The Tiaoxi River. Source: http://www.tba.gov.cn/.

Figure 2.13 The Grand Canal which flows through the northern basin of Hangzhou. Source: http://www.lsphoto.org/.

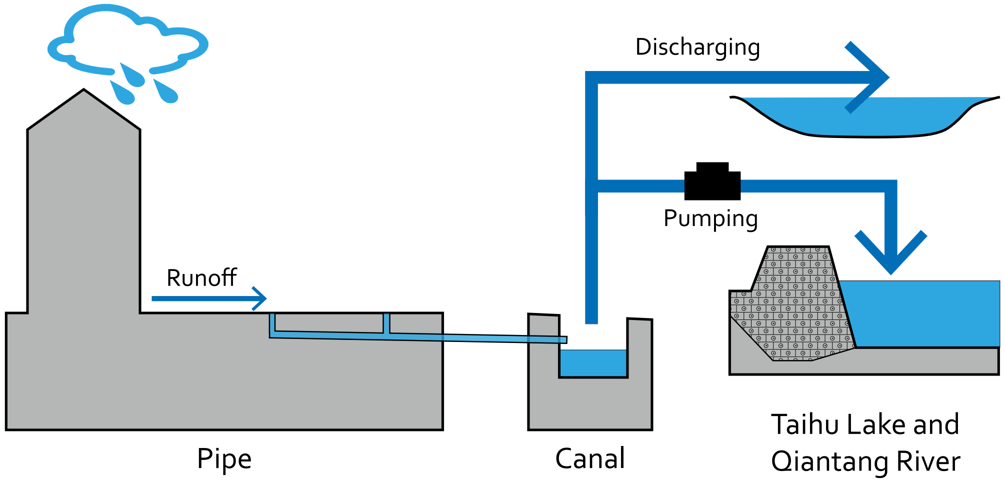


Figure 2.10The existing urban water drainage process in Hangzhou.

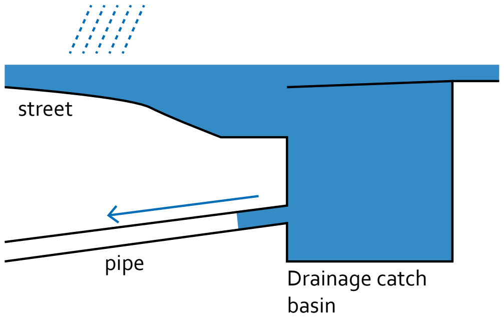


Figure 2.14 When the drainage catch basin gets clogged or the outflow pipe is undersized, it will cause water backs up. Source: adapted from Waggonner & Ball Architects, 2013.

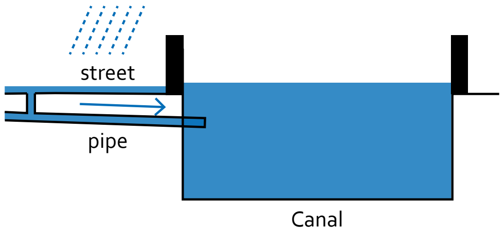


Figure 2.15 High water levels in the canal is also a major reason for localized flooding as pipes cannot transport runoff into high water level canals.

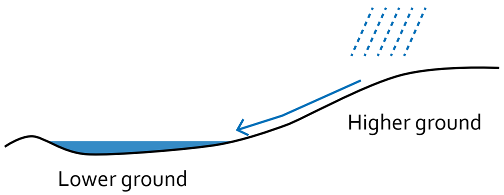


Figure 2.16 Surface runoff that cannot be drained away through pipes from higher grounds flows to lower grounds, causing severer flooding.

During an intense storm event, large quantities of stormwater flowing into the drainage system. Those large volumes of stormwater is not only caused due to the intensity of the rainfall, but also because of the high percentages of paved surfaces in the city. The existing pipe-bound drainage system can only afford the quantity of stormwater created in a 0.5 year-rainfall event, which cannot satisfy the current precipitation, leading to the drainage system get overwhelmed by water (Figure 2.14). This is a common reason for local flooding, no matter whether the site is situated on the high or low grounds of the city.

Besides, the quantity of stormwater enters the drainage system within a short period of time, and can easily overwhelm canals which receive all urban water from pipes. Consequently, when canals are overwhelmed, the drainage capacity of the urban drainage system is restricted, since the water level is at the same height or even higher than underground pipes. This directly leads to the site inundation in the affected area (Figure 2.15). Moreover, when runoff from the higher land cannot enter pipes, it will flow to lower areas which typically cause worst flooding situation (Figure 2.16).

Hangzhou Municipality made a flooding risk map of Hangzhou, showing the different degrees of vulnerability Hangzhou faces (Figure 2.17). This flooding risk map has an influence in selecting the design location in the Chapter 7.

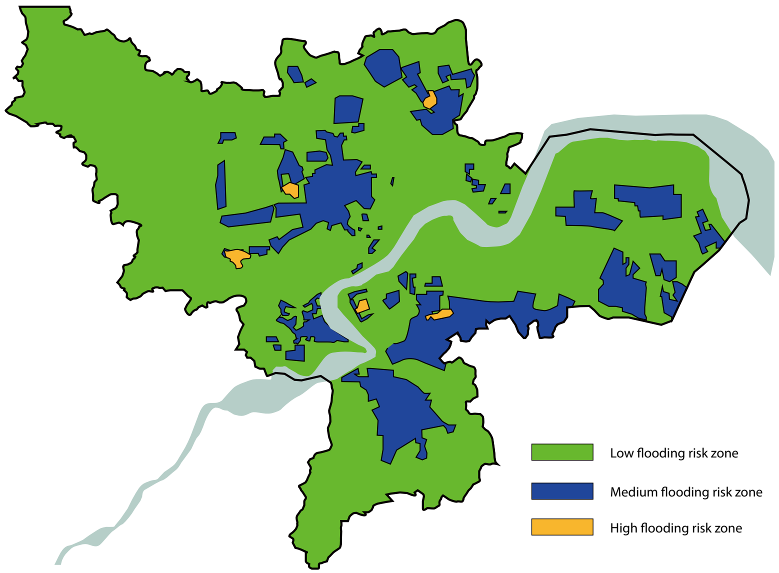


Figure 2.17 Flooding risk places map in Hangzhou. Source: Hangzhou Water Plan 2014.

3. Theoretical Background

3.1 Converting from the Current Approach to New Approaches

3.1.1 SUDS management train

3.1.2 BMPs treatment train

3.2 Knowledge Gap

3.1 Converting from the Current Approach to New Approaches

From previous chapters, urban flooding and water pollution have been identified as two prominent water-related problems in Hangzhou. The principle of current water management in the city is to rely on the pipe-bounded drainage system, canals and pump stations to discharge water out of the city as fast as possible. This results in a paved city landscape that prevents the natural drainage and groundwater recharge process, and creates excessive quantities of stormwater runoff that enters the pipe-bounded drainage system. This obsolete way to deal with water puts huge economic costs on the city and its citizens, mainly in the form of flooding across the city. Moreover, this approach neglects and wastes the value of water assets (Figure3.1 and Figure 3.2).

In this thesis, new and sustainable stormwater approaches are sought in order to solve the two mentioned water-related problems while celebrating the value of water.

There are many approaches that deals with different water aspects based on specific goals (Fletcher et al., 2014). Within which I selected two approaches to help me achieve my research goal of solve flooding and water pollution problems in Hangzhou. First approach is the Sustainable urban drainage systems (SUDS) which focuses on water quantity control, and the other approach is the Best management practices (BMPs) which deals with water quality control.

Figure 3.1 In the present society, water is usually regarded as a nuisance which disturbs people' life and causes economic damages. Source: http://gb.cri.cn/.

Figure 3.2 The current principle of "drain the water out the city as fast as possible" neglects the value of water assets which can enhance the livability of the neiborhood and the environment. Source: http://www.hinews.cn/.

3.1.1 SUDS management train

SUDS aims to mimic some altered process of the natural hydrological cycle due to urbanization and manage rainwater close to where it falls (CIRIA, 2007). It focuses on reducing water quantity by directing stormwater flow through a management train which consists of a series of stormwater facilities: harvesting (e.g., water cisterns and barrels), infiltration (e.g., permeable pavement, soakaways), detention (e.g., detention ponds, wetlands), and they are connected with each other by conveyance (e.g., swales, ditches) (Woods-Ballard et al., 2007). The water quantity can be reduced after the management train before the storwmater is finally released into the nearby watercourses (Poleto and Tassi, 2012, Charlesworth et al., 2003).

The SUDS management train starts with prevention (preventing the creation of stormwater in the individual premises), then progresses stormwater to local source controls and larger downstream site controls until it finally reaches the regional controls (CIRIA, 2007) (Figure 3.3). What has to be noticed is that stormwater does not have to flow through the four mentioned control stages. For instance, the stormwater can go directly to the site control without passing through the source control. One thing is essential in terms of efficient stormwater quantity control: to manage it locally, returning the water back to nature as close to the source as possible (CIRIA, 2007). Stormwater is treated within different small "sub-catchments" with specific strategies based on site-specific landscape characteristics and land use types. This does not only reduce water quantity with more efficiency, but also reduces the need to transport stormwater to downstream places.

The SUDS management train has two benefits in terms of water quantity control. First, the series of different facilities slows down the velocity of stormwater, thereby providing more time for efficient infiltration and other kinds of treatment. Secondly, the interconnected facilities which are located downstream can act as overflow storages,

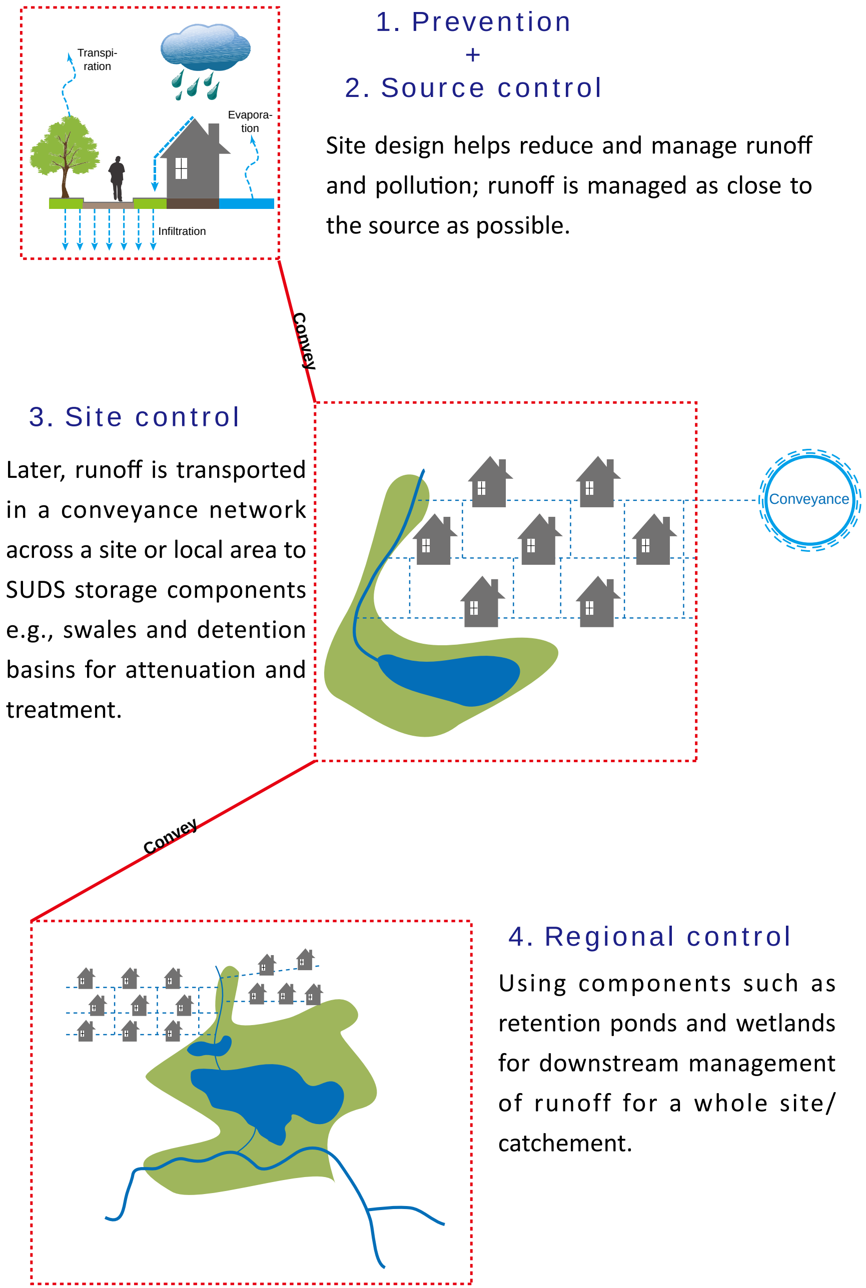


Figure 3.3 The SUDS management train. Source: adapted from Dickie et al., 2011.

thus avoiding the risk that SUDS facilities are being flooded (Fryd et al., 2012). However, the big disadvantage of SUDS is that detentions would take up too much space in the region. So different ways to be explored to seek the possibilities to apply the SUDS in places where available space is limited to ensure the sufficiency capacity of water storages.

3.1.2 BMPs treatment train

The BMPs is an ecological approach mainly towards water quality improvement (DENR, 2007). It provides diverse treatment facilities which can remove different pollutants of concern (Figure 3.4). As single BMP facility cannot treat the entire range of pollutants in the water adequately, especially in large areas with several land uses. Considered about that, several BMPs are recommend to be combined together in a sequence (BMPs treatment train) to treat all pollutants on a given site (Commission, 2009).

BMPs advocates the usage of ecological materials such as vegetations and plants to purify dirty stormwater runoff. Major pollutants such as nutrients, metals can be removed through uptake by plants, but the removal of sediments needs to be taken care of in particular as they cannot be eliminated by plants. To a certain degree, sediments are a naturally important component of all water bodies, as they help shaping streams and developing streams' biotic communities (Missouri Department of Natural Resources, 2012). However, human activities (urbanization and agricultural activities) changed natural landscape surfaces, resulting in increased amounts of rapid flushing stormwater which exaggerates erosions to lands. Those increased eroded sediments are transported into receiving water bodies where they eventually get concentrated enough to disrupt aquatic ecosystems (Lehner, 2001, CWEP, 2012). The dangerous consequence of

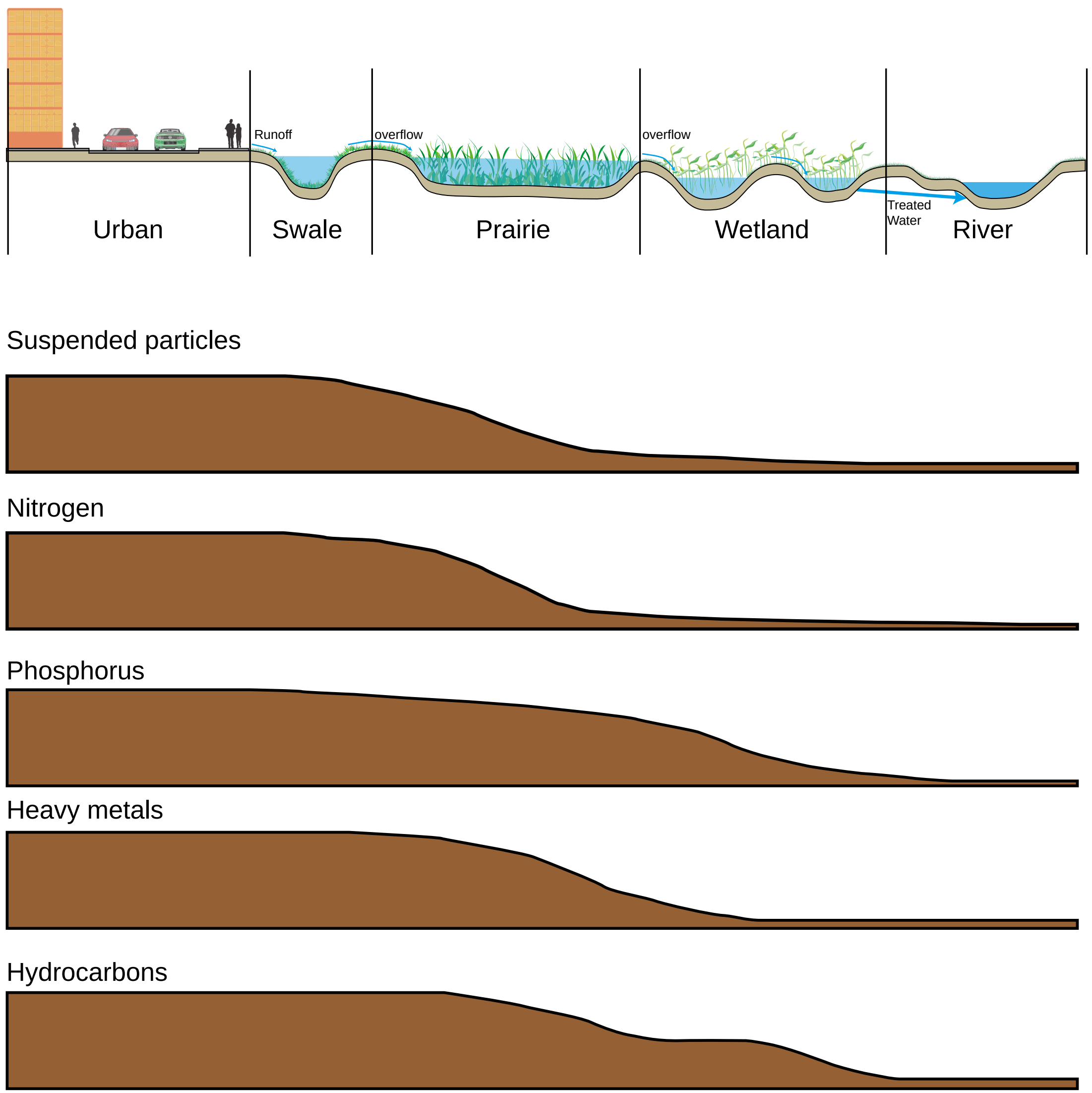


Figure 3.4 The BMPs treatment train. Source: adapted from Applied Ecological Services, inc, 2013.

Table 3.1 Performances of different techniques on removing pollutants, adpated from Commission, 2009.

		Metals	Sediments	Trash	Oil & Grease	Bacteria	Organics	Nutrients
Infiltration	Dry Well	High			High	High	High	High
	Infiltration Basin	High	Low p	Low p	High	High	High	High
	Infiltration Trench	High	Low p	Low p	High	High	High	High
	Permeable Paving	Moderate	High p	Low p	Low	Moderate	Moderate	High
Detention	Constructed Wetland	High	High p	Low p	High	High	High	Moderate
	Detention Basin	Moderate	Moderate p	Low p	Moderate	Moderate	Moderate	Low
	Detention Vault	Low	Moderate	Low	Moderate	Low	Low	Low
	Wet Pond	High	High p	Low p	High	High	High	Moderate
Bioretention	Flow-through Planter	High	High p	Low p	High	High	High	Moderate
	Rain Garden	High	High p	High p	High	High	High	High
Biofiltration	Vegetated Buffer Strip	High	High	Moderate	Moderate	Low	Moderate	Low
	Vegetated Swale	Moderate	Moderate	Low	Moderate	Low	Moderate	Low
	Media Filter	High	High p	High p	High	High	High	High
	Sand Filter	High	High	High	High	High	Moderate	Moderate
	Vegetated Rock Filter	Moderate	High p	Low p	High	Moderate	High	High
	Silt trap	Low	High	High	Moderate	Low	Low	Low
	Water Quality Inlet	Low	Moderate	Moderate	Moderate	Low	Low	Low
	Drain Insert	Moderate	Moderate	High	Moderate	Low	Low	Low
Rainwater Harvesting	Rainter Harvesting*							

High   Moderate   Low   p Requires Pre-treatment

* Rainter Harvesting does not provide stormwater treatment. However, it prevents polluted stormwater from reaching receiving water bodies.

having overloaded sediments in natural water bodies is the dangerous risk they may pose to aquatic life (e.g., invertebrate and fish species), wildlife habitat impairments, and even human environments (MPCA, 2015). Besides, too many amounts of sediments can also negatively affect water quality treatment performances of stormwater facilities, mainly by causing clogging and poor aesthetics in big water storages such as bioretention basins (Commission, 2009). In order to protect the natural environment and ensure the long-term treatment efficiency of water quantity and quality as well as their maintenances, BMPs recommends to use pretreatment facilities to ensure the removal of sediments before they flow into big stormwater facilities (Table 3.1) (Commission, 2009). For example, the vegetated swale is regarded as an important pretreatment facility since it can reduce pollutants in the water while transporting the water to other facilities such as a detention basin (Sayre et al., 2006, Minnesota Pollution Control Agency, 2013).

There are many stormwater facilities widely used in the field of sustainable stormwater management to deal with water quantity and quality. The appendix A illuminates some of the facilities which are commonly used at local level.

3.2 Knowledge Gap

From the literature study, it can be seen that the combination of above two sustainable stormwater management approaches can solve Hangzhou's urban flooding and water pollution issues best. The advantage of those approches is that they do not only care about water issues but also try to improve amenity between human and their environment (Figure 3.5). But there is an uncertainty about the combined approach of SUDS and BMPs:

At present there is no literature talking about how those two approaches can be combined to treat water quantity and quality issues, particularlly for urbanized and populous cities with loam and rice paddy soils in China.

Therefore, a knowledge gap exists concerning about the application of the combined solution of SUDS and BMPs to solve both water quantity and water quality issues at the same time.

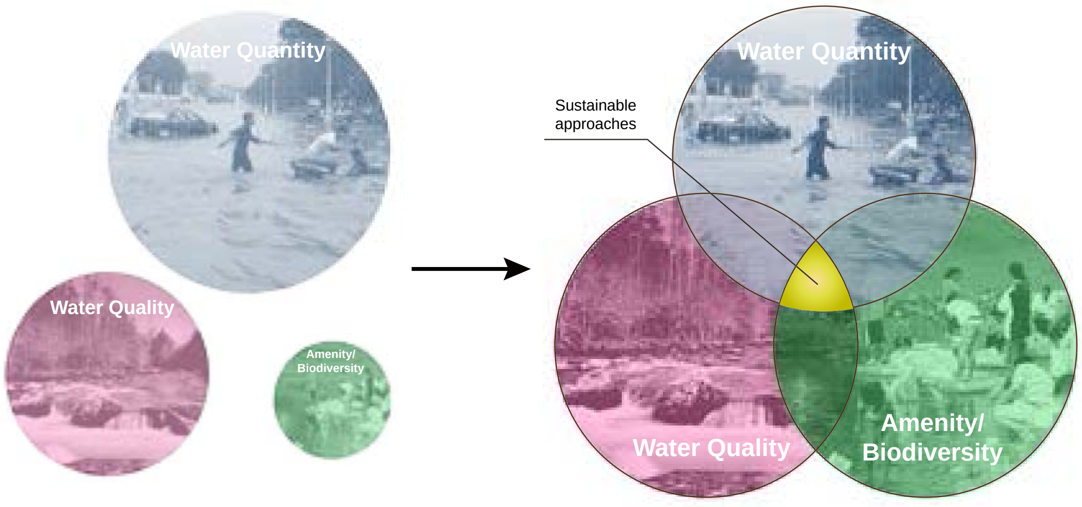


Figure 3.5 Benefits of sustainable stormwater approaches. Source: adapted from Woods-Ballard et al., 2007.

4. Landscape Architecture Perspective

4.1 Vision

4.2 A Pragmatic World View

4.1 Vision

Sustainable development is defined as a condition of stability in physical and social systems achieved by accommodating the present needs without compromising the ability of future generations to meet their needs (Bruntland, 1987). Sustainability at the landscape scale is a challenging goal, and can be achieved by landscape architects' knowledge of natural and social science combined with artistic creativity to create a well-conceived landscape (Gazvoda, 2002, Ahern, 1991).

The environmental problems analyzed in this research are mostly induced by the influence of human activities (Vitousek et al., 1997, Assessment, 2005), the land cover has been changed a lot since the urbanization (Antrop, 2004, Carlson and Traci Arthur, 2000). As Steiner (2008) said, the landscape is related to land use and the land is always related to human activities(Steiner, 2008), the relation between landscape and human activities should be taken care if we want to solve the tension between them.

The knowledge of natural and social science is necessary in order to proceed the research, it requires me to use a systematic, scientific and analytical method to understand the specific issue and the landscape around it. At the same time, creative arts can help carry out innovative solutions. The integration of natural and social science, and the creative arts form the landscape based approach which I have learnt from Wageningen University.

4.2 A Pragmatic World View

Creswell (2013) describes "research" as a systematic activity to generate new valid and reliable knowledge or insights. He outlined four knowledge claims in research theory: (post) positivist, constructivist, advocacy/participatory and pragmatic knowledge claims. Each of the knowledge claims relates to different aims, methods and value systems.

My research combines two existing working systems (positivist world view) to solve the practical social, environment and economic issues (constructivist world view), therefore, I will choose the pragmatic world view as the basis for this research project. Researchers within the pragmatic knowledge claim focus on practical problems and integrate all methods available to understand and solve the problems (Creswell, 2013). In the research, the constructivist research will inspire me to generate new design principles with creative ideas and insights based on the combination of two working systems, while the positivistic research would help to verify and evaluate whether the research outcomes function well and meet the expectations.

Lenzholzer et al.(2013) outlined that research through designing, in the pragmatic research, focuses on finding solutions to problems within the specific site. The public space in the city of Hangzhou will act as the experiment and test case for the research. Through the circle of designing-reflection-redesigning, research problems are reframed and the situation will be better understood, I can come up with new ideas and test them just on the spot. The new design principles can be verified by scientific evidence, and then the verified ones can be used as recommendations in cities which have similar landscape characteristics to Hangzhou.

Concerning the fact that in this research I am dealing with urban stormwater management, therefore I need to take many factors into consideration, such as urbanization, human activities, etc. Working in the pragmatic world view enables me to choose any kinds of research methods and produce what I need to solve the problems. Besides that, the social constructivist view allows me to generate new ideas based on my subjective understanding of the phenomena (Creswell, 2013).

5. Research Framework

5.1 Research Objective

5.2 Hypothesis

5.3 Research Questions

5.4 Research Methods and Process

5.1 Research Objective

The objective of the research and design thesis is ***"to create sustainable urban water systems for Hangzhou by generating a set of landscape design principles which combine SUDS and BMPs to manage the urban flooding and water pollution issues".***

The thesis tries to explore the combination of SUDS and BMPs which is capable of dealing with the water quantity and quality problems at the same time. Eventually, landscape design principles of the combined approach of SUDS and BMPs are generated, and they are not only suitable to Hangzhou, but also to other cities with similar landscape characteristics to Hangzhou.

5.2 Hypothesis

The SUDS approach combined with the BMPs approach will generate design principles which can prevent urban flooding and improve water quality at the same time.

Design principles are generated based on site-specific landscape conditions, so they are applicable and replicable to those areas which share similar landscape characteristics. In this research, the city of Hangzhou will be used as an "showcase" to generate those design principles and solve its water quantity and quality problems.

5.3 Research Questions

To explore the hypothesis and achieve the research objective, the main research question is formed as:

How can the SUDS and BMPs be combined to solve both the water quantity and quality problems at the same time in Hangzhou?

Two sub-questions are formed in order to answer the main research question:

How to manage excess stormwater runoff and poor water quality on lots, streets and open spaces levels in accordance with the SUDS and BMPs?

How can design principles be generated by integrating SUDS and BMPs into Hangzhou on its lots, streets and open spaces levels?

5.4 Research Methods and Process

The thesis is divided into three steps: identifying research problems, generating the solution in responding to identified problems, and integrating and testing the solution in selected sites.

The first step is to identify major water problems of Hangzhou - urban flooding and water pollution, and their fundamental causes based on the literature study. A desk study is done on literature and maps to help me get a deep understanding of the city's landscape and its most vulnerable places. Furthermore, two sustainable stormwater management approaches, namely the Sustainable Urban Drainage System (SUDS) and the Best Management Practices (BMPs) are selected as the most suitable theoretical background in order to address the research objects.

SUDS and BMPs can solve water quantity and quality with best efficiency, respectively, but there is no literature showing that they can be integrated together to solve water problems, especially in a Chinese urban city. So the second step is to combine those two approach and to solve the two water problems at the same time. Through designing, different combinations are explored on three different levels - the lots level, the streets level and the open spaces level. The outcome is the combined approach of SUDS and BMPs, which can address excess stormwater runoff and poor water quality on lots, streets and open spaces levels. They will function as guidelines for designs in later phases.

The last step is to integrate the combined approach into the city and test their performances in terms of water quantity and water quality issues. One watershed: the Shangbu Watershed is selected as an exemplary case based on the flood risk map and the consultation with the water specialist in Hangzhou Municipality.

By studying the watershed from its topography, soils, groundwater and land uses, reasons that cause water problems in the watershed have been found. Consequently, conceptual design strategies are made for four typical landscapes in the watershed to address their water problems based on the combined approach.

Three exemplary sites are chosen to integrate the combined approach. They are representative in terms of landscape characteristics and land uses, and they can set up examples for near-term development projects in the watershed. The results are design principles and design impressions showing how the landscape looks like after the implementation of the combined approach. After each exemplary site designs, a general evaluation will be conducted mainly to see if the two design objectives of the thesis (water quantity and water quality) have been achieved.

At the end, the conclusions will be made by reflecting the whole research and design process of the thesis. And take-away knowledge, namely a tool box of design principles will be generated for the community of landscape architects or other professionals who are interested in dealing with stormwater quantity and quality issues in Hangzhou or other areas with similar landscapes.

The research process is shown in figure 3.1.

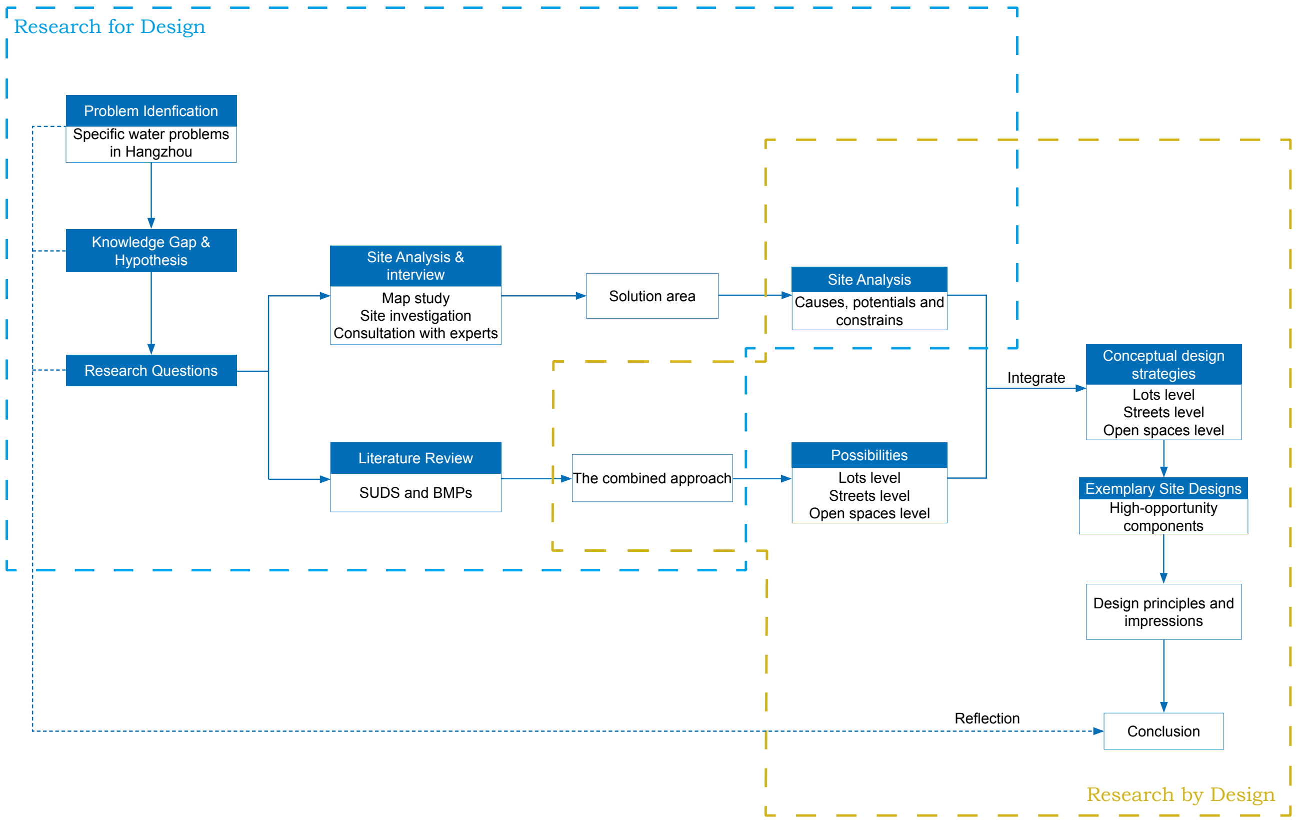


Figure 5.1 The research and design process in the thesis.

6. The Combined Approach

6. The Combined Approach

As discussed in the previous chapters, the current water systems in Hangzhou do not function well, which lead to two prominent water-related consequences: urban flooding and water pollution. In response to those identified water problems, two suitable stormwater management approaches are proposed. And it is expected that the combination of them can solve Hangzhou's existing water problems best.

In this chapter, the main goal is to explore possibilities of combining SUDS and BMPs together through designing, so that water quantity and quality problems can be solved at the same time. The process will be elaborated in the following paragraphs.

6.1 SUDS on the Lots Level

SUDS stresses the importance of prevention stormwater in the first place, and to manage stormwater close to the source (CIRIA, 2007). At the first stage, the stormwater treatment focuses on the lots level, which consists of the individual building and the area within its property line (Figure 6.1).

Through designing, I found out that there are a lot of potentials to prevent and treat stormwater on this level. For instance, green roofs, green walls can help reduce and slow rainwater that drops on the building. And an underground water cistern can be used to harvest water for non-portable reuses such as toilet flushing or irrigation (Figure 6.2). This way, buildings can be designed as facilities which help recharge and harvest water. While in its surrounding areas within the same property line, stormwater facilities such as infiltration trenches, rain gardens and swales can be implemented to constitute an ecological stormwater treatment landscape other than just a decorative one. And different forms can be explored by combining those stormwater facilities together to manage stormwater within a property area (Figure 6.3).

Figure 6.1 Areas within the property line (shown in red) are the design target on the lots level. Source: http://ecode360.com/.

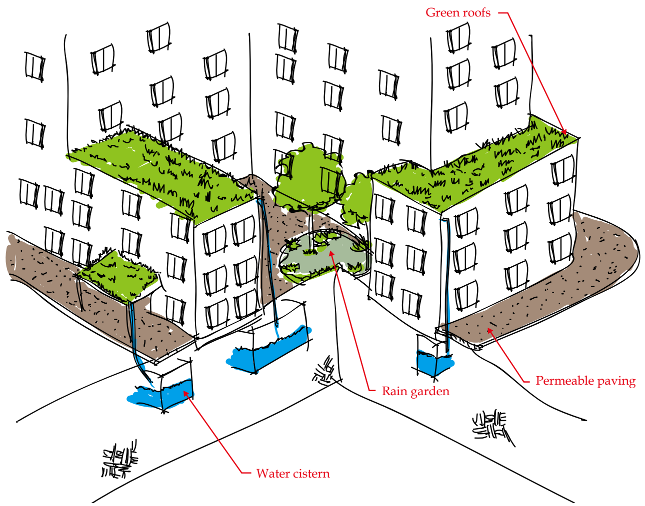


Figure 6.2 One example shows how stormwater facilities can be integrated on the lots level.

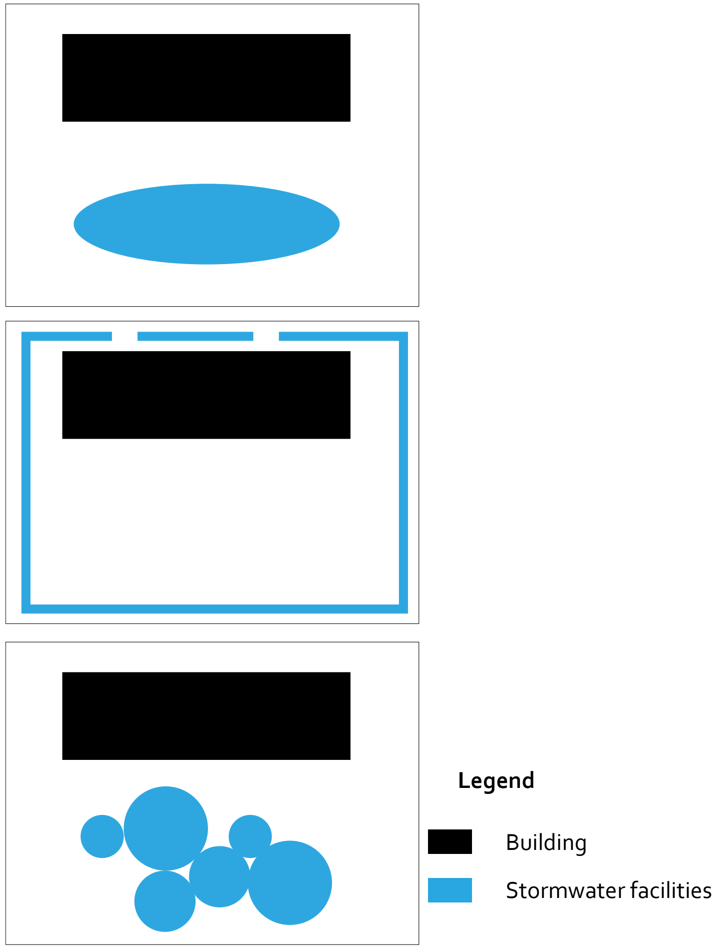


Figure 6.3 Different forms of stormwater facilities can be explored witin the available property area, blue represent facilities such as rain gardens and swales.

6.2 SUDS on the Streets Level

Besides buildings and their property areas, streets are another major component which create large amounts of stormwater and pollutants. But there are also great opportunities to integrate stormwater facilities into streets to manage stormwater and improve amenity aesthetics and other values of streets.

Depending on street typologies, different stormwater facilities can be integrated into streets to reduce stormwater quantity and improve its quality on site. For example, through designing, I figured out that existing conventional landscape medians in the arterial road are the most suitable component to apply vegetated swales. Being long and continuous, they can purify and convey dirty stormwater runoff collected from the street (Figure 6.5). In the permeable soil region, those swales can reduce water quantity through infiltration on site.

The following schematic images show another two typical major street typologies in Hangzhou based on the classification of urban roads (BMEDI, 1991) (Figure 6.6-6.9). They reduce stormwater runoff on site and link individual parts of facilities together to convey water . However, when space is limited, some pipework may still be required.

Figure 6.4 The existing arterial road. Source: photo by the author.

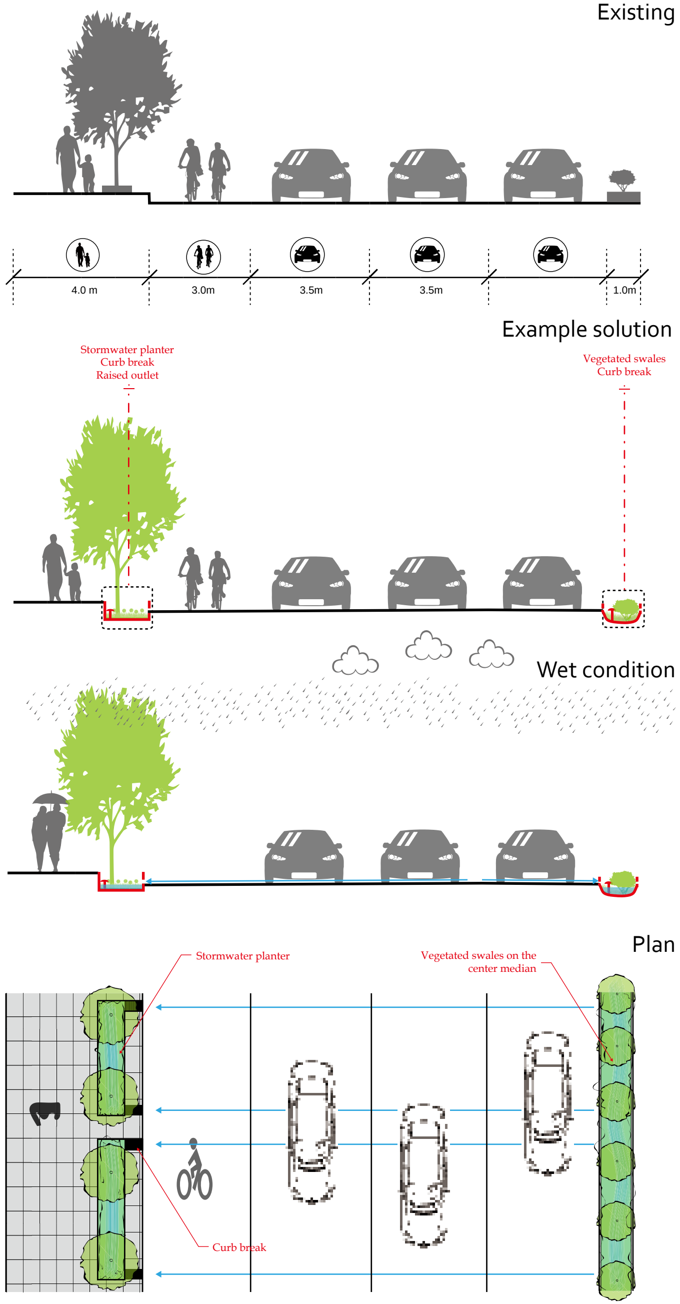
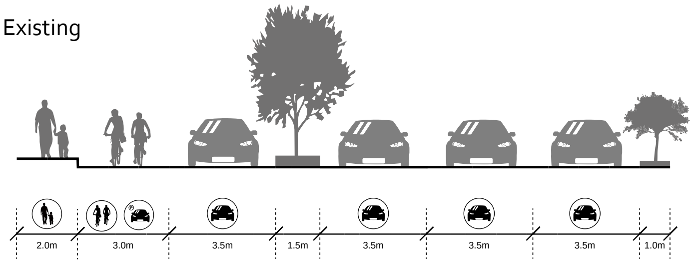


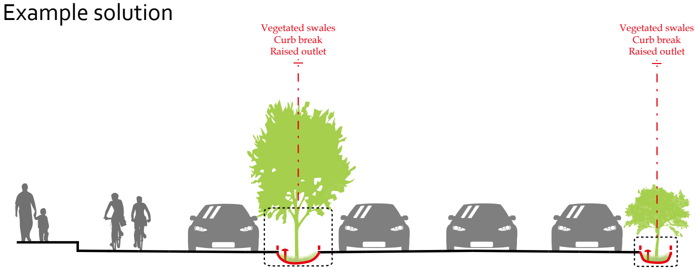
Figure 6.5 Representative stormwater design solution on the current arterial road.


Figure 6.6 The existing urban expressway. Source: Baidu Maps

Existing



Example solution



Plan

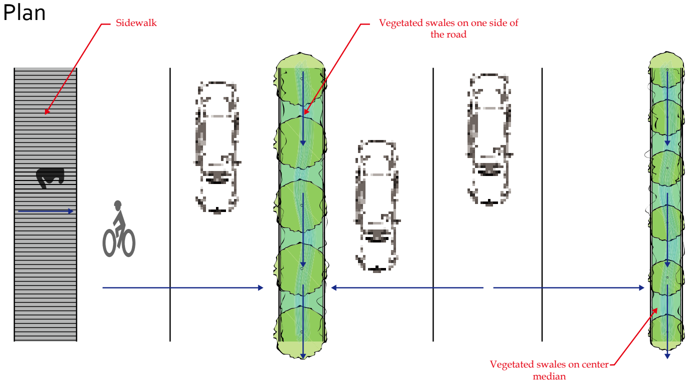
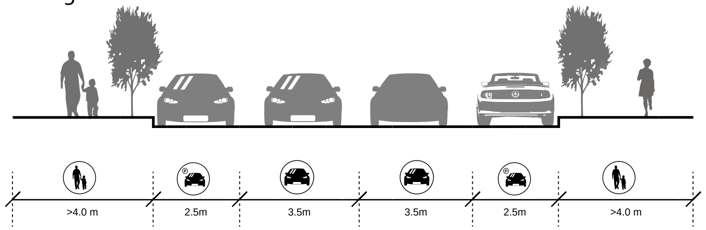


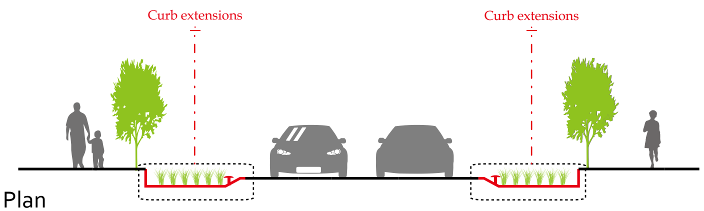
Figure 6.7 Representative stormwater design solution on the current urban expressway.


Figure 6.8 The existing branch road. Source: Baidu Maps

Existing



Example solution



Plan

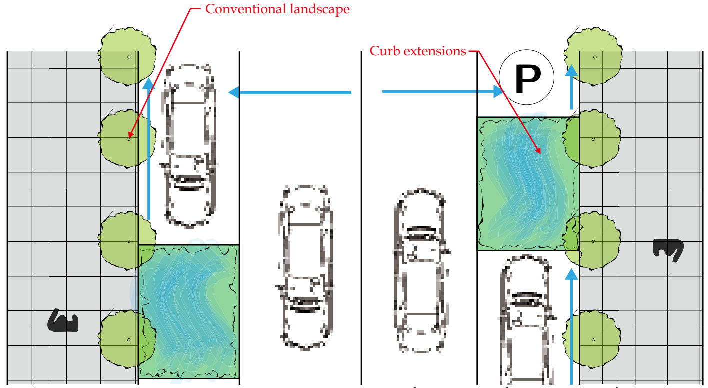


Figure 6.9 Representative stormwater design solution on the current branch road.

6.3 SUDS on the Open Spaces Level

Normally, the open space has less restrictions to build stormwater facilities and has more spaces available for big water storages. Excess water from lots and roads will be transported to the local open space, where the quantity and quality of stormwater can be further managed. The local open space can be a square, a playground, green areas, etc, which are located within the same site boundary of those lots. When the amount of water exceeds local storages capacities, overflows can be conveyed through streets to bigger public open spaces at the same drainage catchment. Bigger open spaces refer to larger green areas, lakes, wetlands and canals, they receive water from one or several sites, so they act as regional water storages and treatment places. Figure 6.10 to 6.12 indicate two possible water storage locations in the urban plaza and the public green space.

Although open spaces have bigger capacities to store or treat the stormwater, it is recommended to manage it on site rather than transporting all the water to regional water storages for concentrated treatment, as on-site treatment is the most cost-effective way to deal with water (Woods-Ballard et al., 2007). In principle, only if the stormwater cannot be managed on site, then it is allowed to be conveyed to regional open spaces downstream.

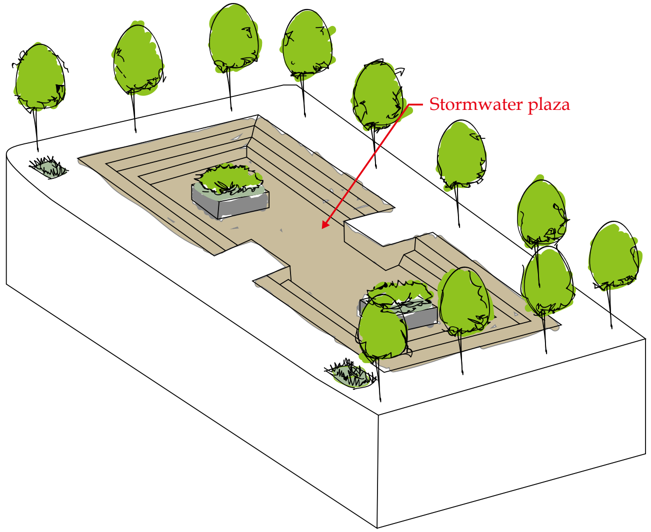


Figure 6.10 Urban public square can be converted into stormwater plaza, in the dry condition plenty of activities can be held there.

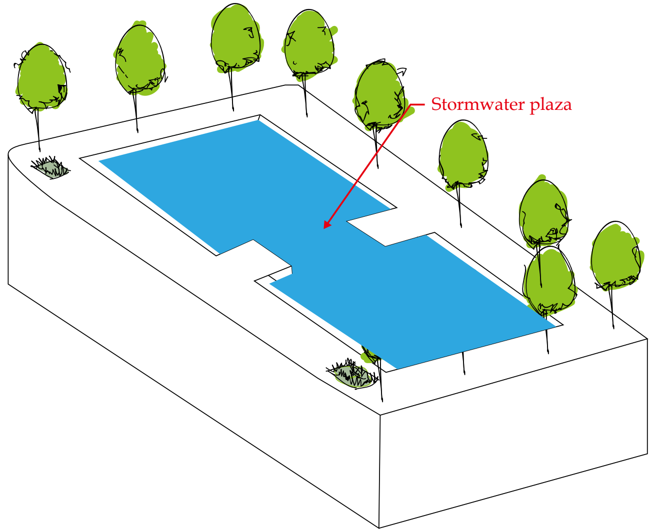


Figure 6.11 In the rainfall, the plaza can contemporarily store water, relieving drainage burdens on other places.

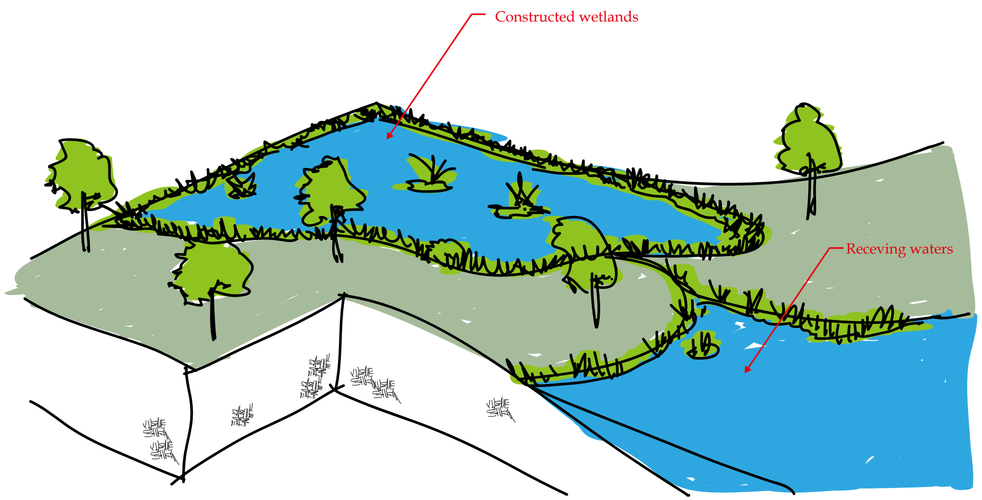


Figure 6.12 Big public green spaces have more opportunities to apply bigger BMPs treatment facilities to store and treat water. Green spaces also offer opportunity to attract people.

6.4 Pretreatment BMPs

Treatment BMPs facilities provide a variety of potentials to manage stormwater in terms of both quantity and quality. But as discussed in Chapter 3, too large amounts of sediments can negatively affect their treatment efficiency, particularly for infiltration facilities. Hence, pretreatment facilities need to be implemented to remove sediments on different levels: the lots level, the streets level or the open spaces level. Pretreatment facilities implemented on the lots and streets level are essential as they are located in small-scale areas and collect "first flush" in the first place. Those pretreatment facilities trap some sediments before they flow into treatment BMPs implemented on the same level. They can reduce the risk that those treatment BMPs are clogged or vegetations are killed, due to too many sediments. But when the rainfall becomes intense, the sediments removal level of pretreatment facilities will decrease when there is increasing volumes of stormwater flowing through them at a rapid speed (Pittner and Allerton, 2009). Consequently, most sediments will flee from being "pre-removed" and flow towards open spaces with flashing stormwater. Therefore, bigger pretreatment facilities are required to be implemented as parts of treatment BMPs in open spaces to capture the "fled" sediments before they are discharged into receiving water bodies.

Through designing, I found out that there are different approaches to pre-treat runoff depending on different situations:

1) if the stormwater enters into the water storage in the form of concentrated flows, then forebays are probably the most efficient method to pre-treat it. A big depressed basin is created to reduce water velocity and offer an area for sedimentation to take place. The form of the forebay is flexible, it can be a dry basin or a wet basin, depending on the soil type on site. A pile of gravels is settled at the entrance to prevent erosion. Only treated water can flow to the clean water storage through a designed flow-out way. An additional advantage of applying forebays to be pretreatment facilities is that forebays can provide extra space for temporary water storage (Figure 6.13).

In order to improve the efficiency of trapping sediments and also reduce regular maintenance burdens, I suggest to transport stormwater from different lots and streets to concentrated deployed forebays, and after being pre-treated, water can flow to open spaces for further quantity and quality treatments (Figure 6.14). In this way, maintenance staffs only need to go to those concentrated deployed forebays to clean up the trapped sediments during regular maintenance.

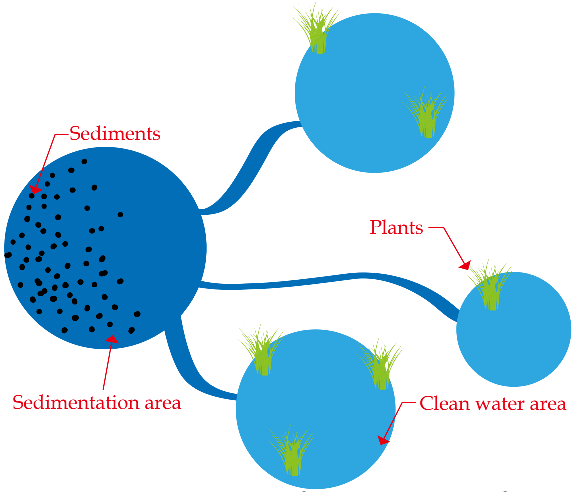


Figure 6.14 Big pretreatment facility is created to filter out sediments before it releases cleaned water to other BMPs treatment for further treatment.

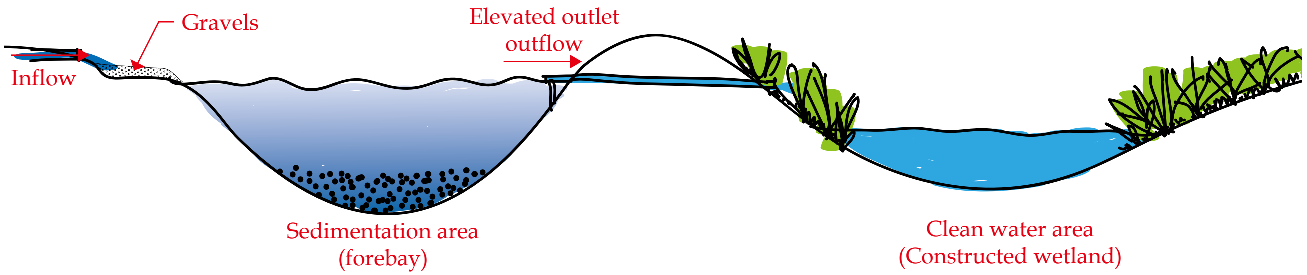


Figure 6.13 One exemplary combination of forebay and constructed wetlands. Sediments settle down in the forebay, while cleaned water flows to the constructed wetland through the elevated outlet, other pollutants will be removed by plants take up or other process.

2) if the stormwater enters the water storage in the form of a sheet flow, for example, from roads and parking lots, then vegetated filter strips are the most effective method for the pretreatment (Committee, 2005). They can slow down runoff speed, and allow sediments to settle or be trapped by vegetations (Figure 6.15).

3) vegetated swales are another common pretreatment facility that can be integrated into streets with wide space (at least 1.2 m wide). Sediments can either be trapped by the vegetation along the swale or settle when the water within the swale is still. In principle, the longer the swale is, the higher the sediment removal efficiency it can provide.

In terms of maintenance, periodic removal of accumulated sediments and debris in those pretreatment facilities is still needed. Regular maintenance ensures the high level of pollutants removal in other treatment BMPs (Committee, 2005).

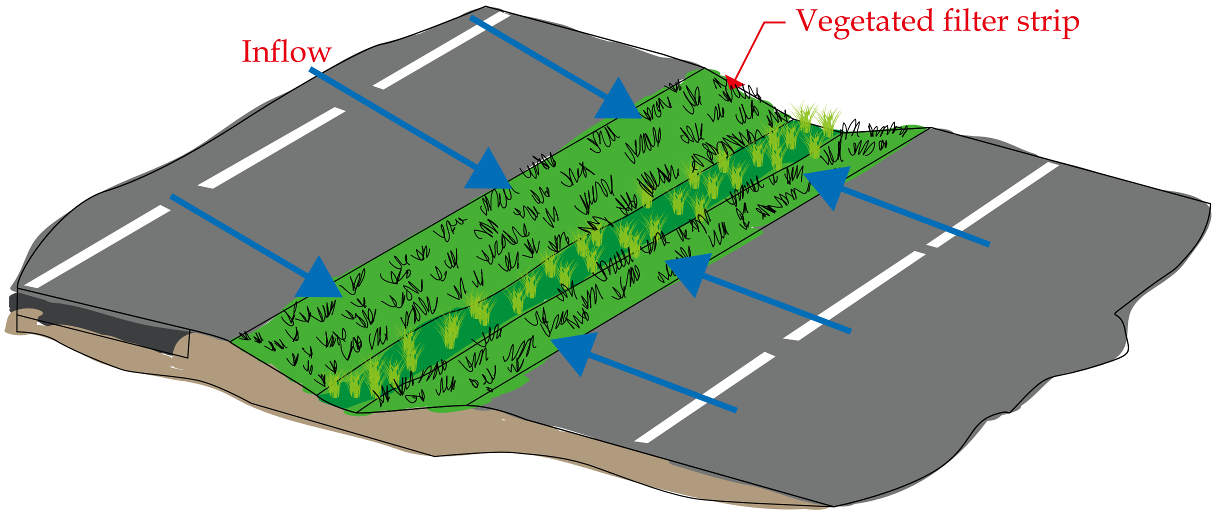


Figure 6.15 Vegetated filter strip is most suitable to collect stormwater runoff coming in the form of "sheet flow". This example shows runoff from roads flows directly into the curbless ditch via vegetated filter strip. Sediments and trash can be trapped by this pretreatment facility.

6.5 The Combined Approach of SUDS and BMPs

Finally, the research through designing process resulted in a combined approach of SUDS and BMPs (CIRIA, 2007, DENR, 2007). The combined approach indicates the stormwater is managed on 3 levels: **1) the lots level; 2) the streets level; and 3) the open spaces level**. In addition, pretreatment facilities are required to be put before stormwater enters treatment BMPs on all levels to ensure the high level of pollutants removal in treatment BMPs to protect environment in receiving water bodies (Figure 6.16).

When implemented on the regional scale, the combined approach provides four main process (slow, recharge, store and reuse) to reduce the risk of flooding, improve water quality and create an aesthetically pleasing environment for citizens. For example, on lots and streets levels, by using green roofs, underground water cistern and swales, rainwater can be caught where it falls and water is allowed to infiltrate into the ground. Large size of detention and retention facilities can be integrated into open spaces that can provide additional water storage capacity. The stored and treated water can be reused for other purposes such as irrigation and entertainment later. However, the new water system does not disconnected with the existing drainage system. When the volume of stormwater exceeds the total storage capacity of the new water system (on lots, streets and open spaces levels), excessive water is drained to canals, which further transport water to downstream areas or pump stations (Figure7.17).

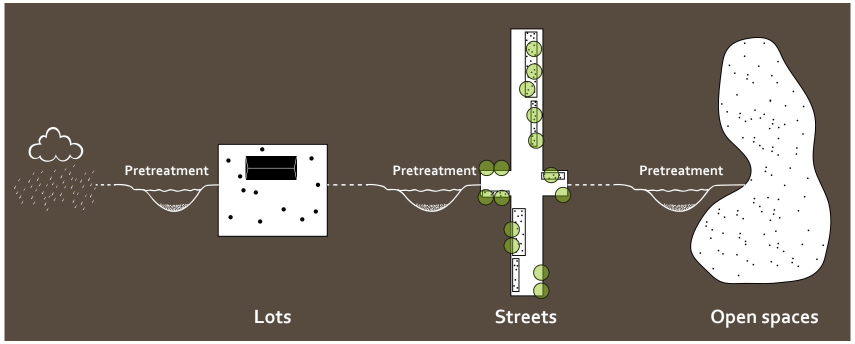


Figure 6.16 The combined approach of SUDS and BMPs.

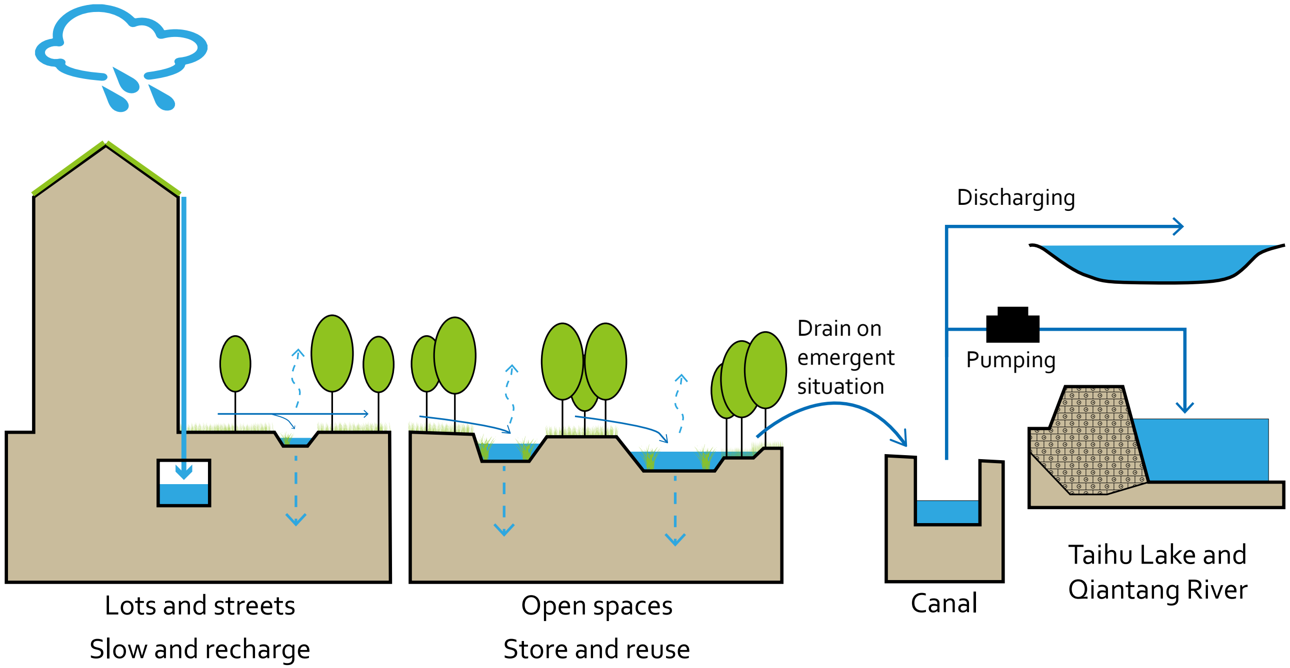


Figure 6.17 The working process of the new water system when the combined approach is integrated on a regional level. The combined approach relies on the process of slow, recharge, store and reuse water to prevent flooding, and improve water quality.

Water storage facilities are consisted of temporary storages and permanent storages. No matter it is on lots levels, streets levels or the open spaces level, as long as the water storage is used to store peak flow contemporarily, the drain-down time (time for the storage from full to empty) should be considered. In this thesis, the utmost drain-down time for contemporary water storages is set to be 48 hours, in order to leave enough space for the subsequent rainfall (Woods-Ballard et al., 2007). Therefore, perforated underdrains are needed to be built beneath contemporary water storages to facilitate the drain-down process (Figure 6.18). And stormwater facilities, for instance, vegetated swales, which mainly function as conveyance tools need to be designed with an appropriate slope degree so that there will be no standing water in them. Overland flow routes are also needed to be planned for stormwater facilities on all three levels in case of unexpected extreme rainfall events (Figure 6.19).

The combined approach provides multiple benefits beyond stormwater management. It provides economic benefits, for example, the treated stormwater can be used for irrigation; it provides environmental benefits, as the natural hydrologic cycle is kept or restored when stormwater facilities are applied. It also offers social benefits, for instance, the "green-blue" open spaces and streets can improve the area's livability.

Figure 6.18 One example of the underdrained system consists of perforated pipes and gravel beds. Source: http://www.septicplus.com.

Figure 6.19 One example of the raised water outlet. Source: http://webpages.uidaho.edu.

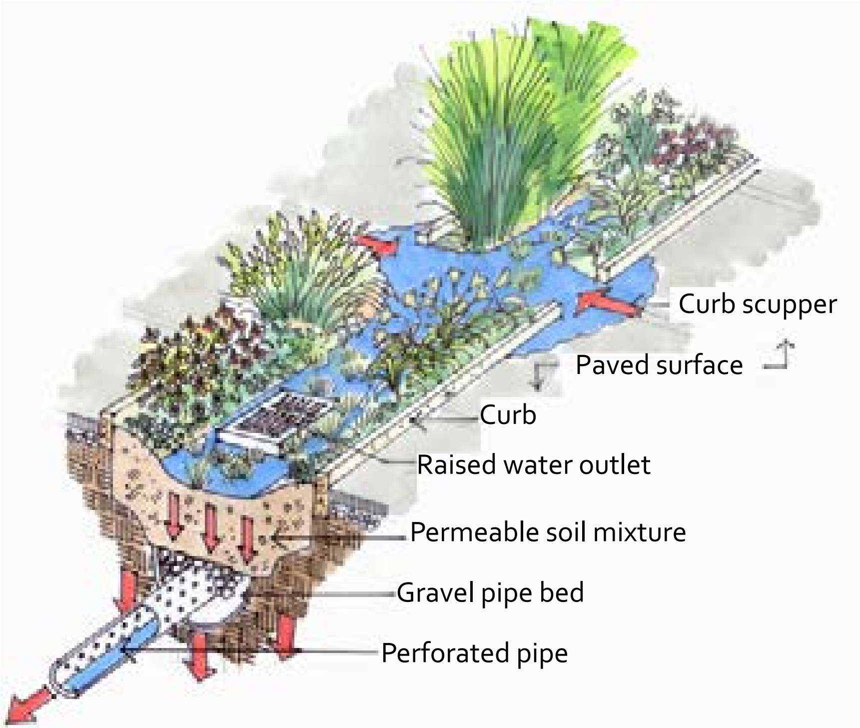


Figure 6.20 Indicative picture shows one type of combination of the underdrain system and raised water outlet implemented along the street. Source: http://bladesandgoven.com.

7. Implementation of the Combined Approach

7.1 Design Site Selection

Based on the previous study in Chapter 2, the Liuxia area is located in one of the five high flood risk zones in Hangzhou (Figure 7.1). After discussing with water specialists in the Hangzhou municipality, it is apparent that the Liuxia area has been recognized by the municipality as one of flooded places which suffers the severest social and economic consequences, as it is a urbanized area with high population density around 4000 people/km^2 (National Bureau of Statistics of China, 2012). At present, Liuxia is on the top of five most flooding vulnerable places in Hangzhou, its average stormwater depth during flooding is 0.8 meter (Zhang, 2013)(Figure 7.3). With its population projected to continue growing, it is of great importance to protect the area from flooding (Figure 7.4).

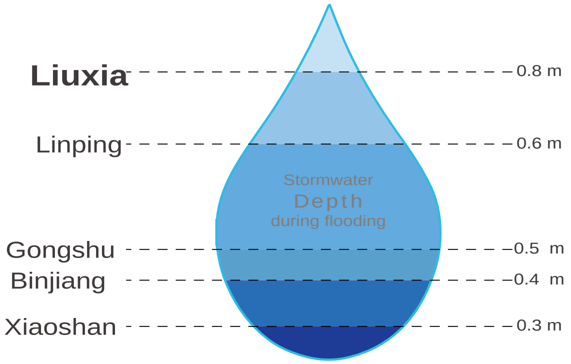


Figure 7.3 The average stormwater depth in Liuxia tops the list of five most flooding vulnerable places in Hangzhou. Source: made by the author, adapted from Zhang, 2013.

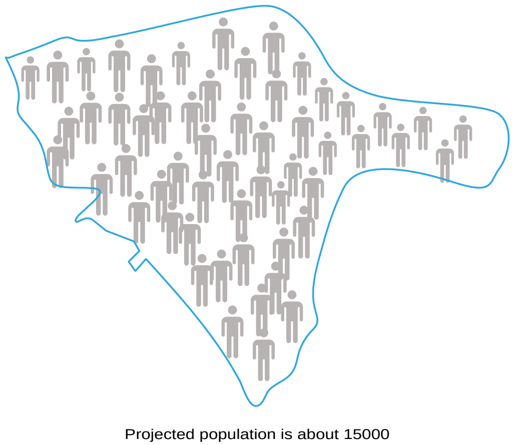


Figure 7.4 Population in Liuxia is projected to grow from current 12000 (top) to 15000 in 2016 (bottom). Source: made by the author, adapted from National Bureau of Statistics of China, 2012.

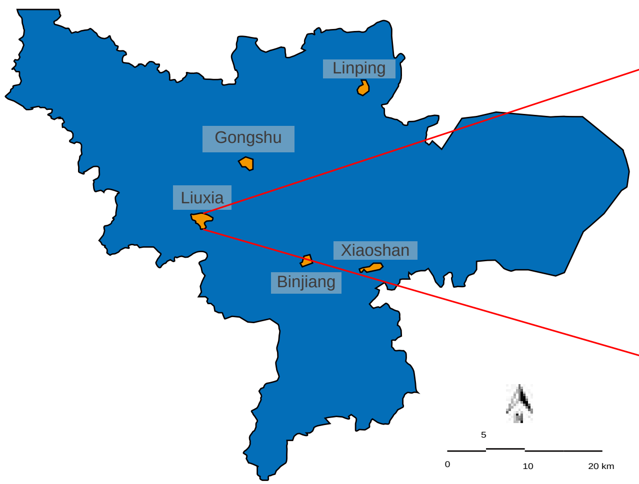


Figure 7.1 Location of Liuxia in Hangzhou.

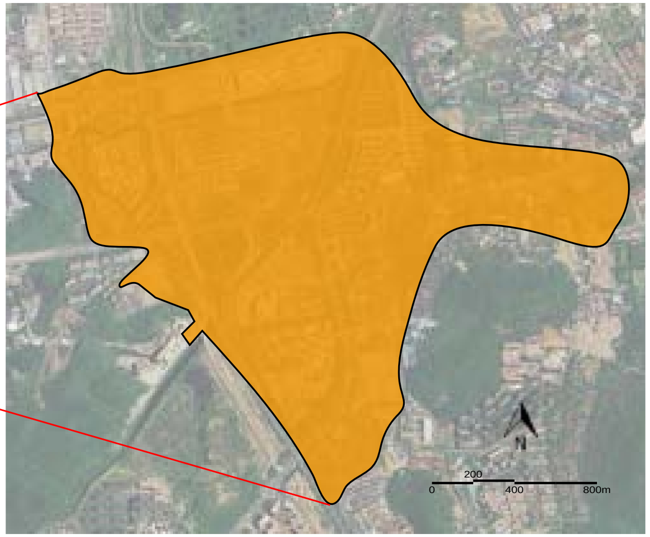


Figure 7.2 The current flooded area in Liuxia. Source: Google Earth.

The Shangbu Watershed is the watershed where the Liuxia area is situated, all the water within the watershed is transported to Liuxia, resulting in frequent flooding events there (Figure 7.5).

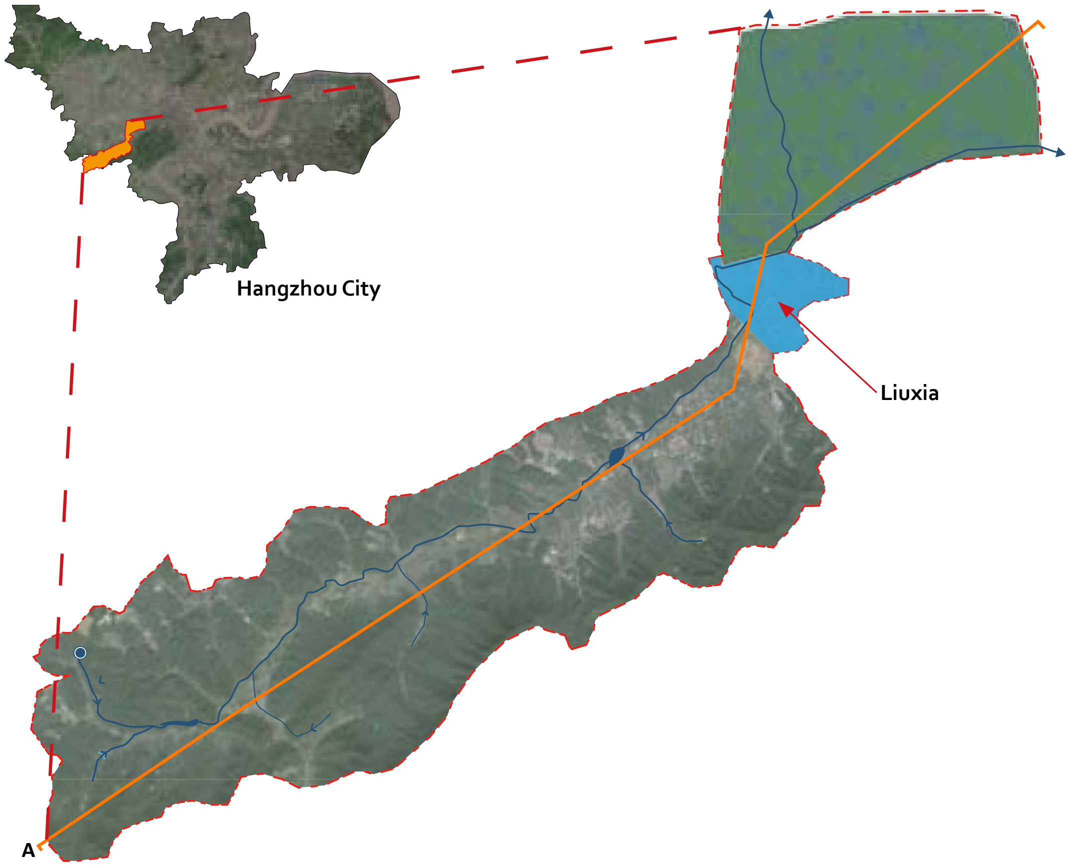


Figure 7.5 The location of the Shangbu Watershed in Hangzhou (shown in the oringe), and the blue area represents the Liuxia's location in the watershed. Source: made by the author, adapted from Google Earth.

Figure 7.6 - 7.8 Current urban flooding events in Liuxia disturb people normal life. Source: Chinanews.com.

The Shangbu Watershed is about 31.5 km^2 with loam and rice paddy soils, respectively, beneath the watershed. It has similar landscape characteristics to Hangzhou and other similar cities, so it can serve as an exemplary study case for the application of the combined approach in this thesis (Figure 7.9). The results, namely design principles are replicable to similar cities or areas with similar landscape characteristics.

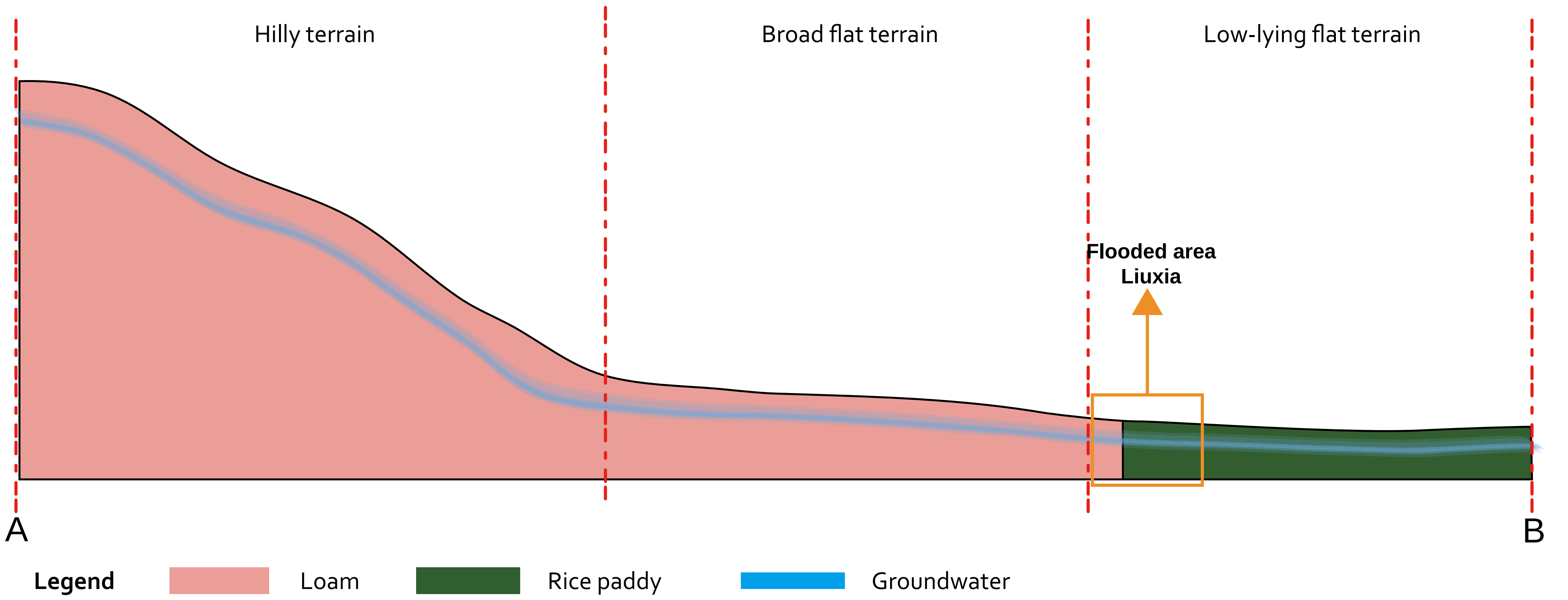


Figure 7.9 The long-cross profile of the Shangbu Watershed, showing that is has similar landscape characteristics to Hangzhou.

7.2 Current Flooding and Water Pollution problems in the Shangbu Watershed

Flooding in the watershed is caused by two reasons: flash stormwater in the development area and several tributaries from surrounding mountains.

Urban development in the flat plain of the watershed changed the natural landscape and increased the amounts of impermeable surfaces, resulting in high volumes of and rapid stormwater runoff during rainfall events. The lack of open spaces on the flat plain prevents natural water infiltration process. Those increased amounts of stormwater find their way into the stormwater drainage system (Figure 7.10). Small reservoirs and lakes have been built at foothills to collect excess water coming from steep mountains during the time when loam soils stop absorbing water in the plum rain season or intense rainfall events (Figure 7.11). But in some places at foothills, human activities such as development and agricultural operations changed the previous forestry landscape, and reduced the landscape's ability to absorb water. Consequently, flash stormwater is more likely to occur at foothills, and it runs down through tributaries, joining the Shangbu River on the flat plain. Combined with rapid stormwater coming from the stormwater drainage system, the inflow rates into the Shangtang river exceeds its discharge rate, leading high water levels in the river (Zhang, 2013).

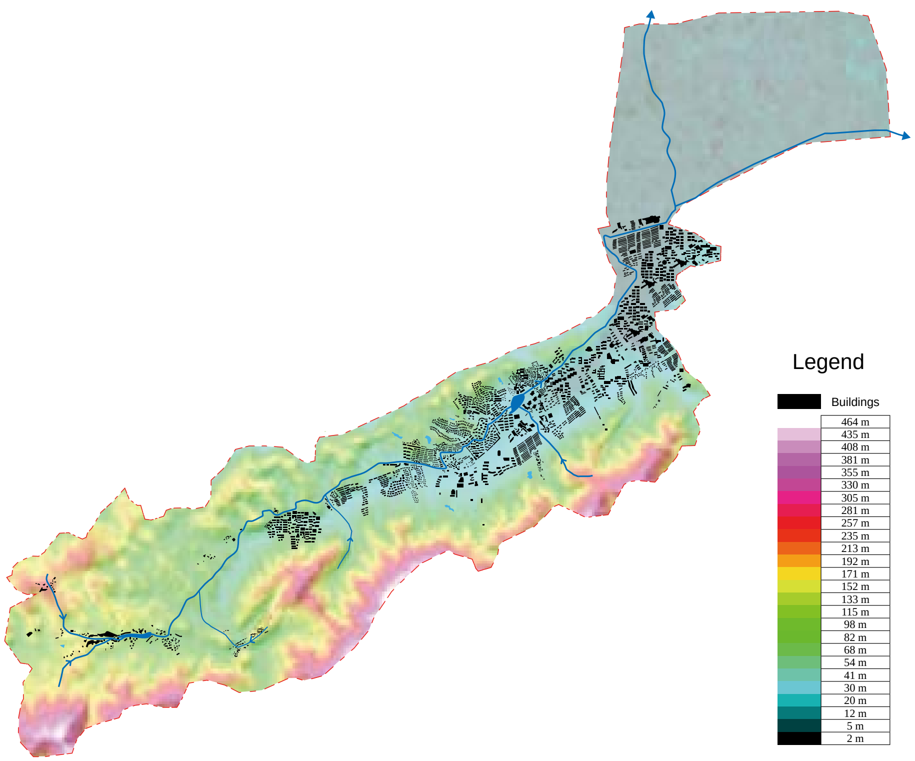


Figure 7.10 High levels of buildings occupy most flat plain in the watershed. Source: GIS.

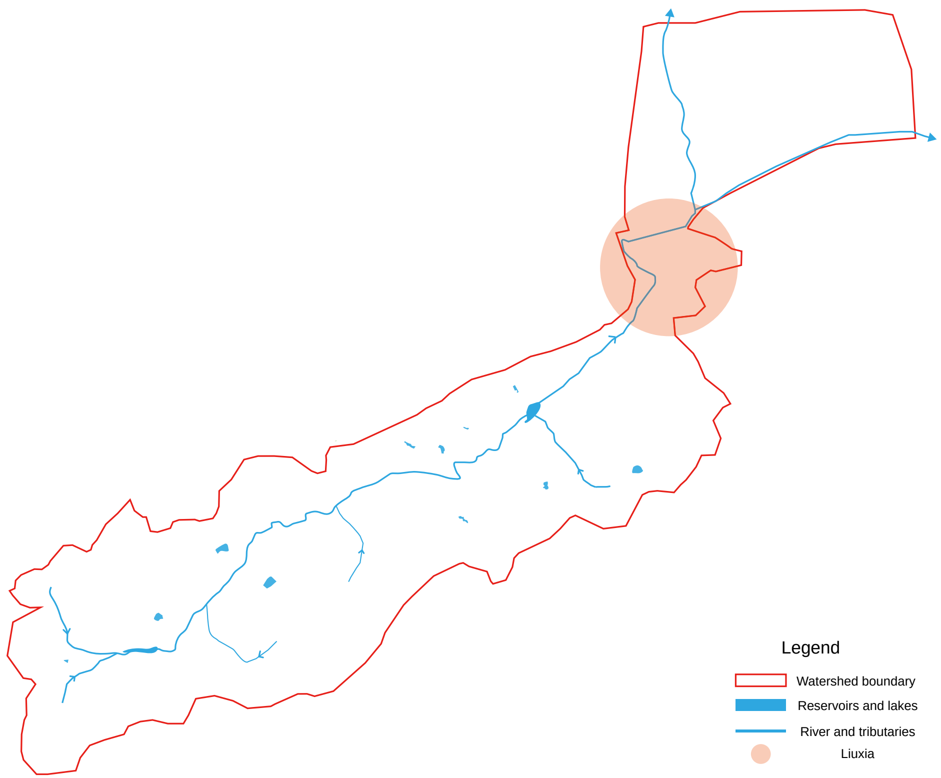


Figure 7.11 Shangbu River, lakes, reservoirs and tributaries in the watershed.

The drainage capacity of the existing stormwater drainage system in Liuxia cannot stand the amounts of stormwater during intense rainfalls, adding up the risk of water inundation in Liuxia.

The wetlands park which is located at the end of Shangbu Watershed suffers from the water pollution issue, the polluted water coming from its surrounding waterways and the development area within the wetlands park (Dong et al., 2013) (Figure 7.12). As a major waterway connecting the wetlands, the Shangbu River travels across several land uses, and receives stormwater from areas in the whole watershed. And it has been recognized as one major source discharging pollutants into the wetlands (Chen et al., 2009).

Excessive amounts of fertilizers and pesticides are used to help crops and plants grow in agricultural fields in the rural areas upstream as local farmers lack the knowledge of their damages to the environment. Fertilizers are made of nutrients and organic chemicals like nitrogen and phosphorus. Too many fertilizers in water bodies may cause algae to grow, ending up in low oxygen left in the water. In addition to excessive usage of fertilizers, large proportions of previous forests in the rural area were plowed to grow agricultural crops, so that the surface soils are loosened and become vulnerable to erosion. So during rainfall events, sediments, nutrients and organic chemicals are carried by stormwater runoff and flushed directly into the Shangbu River.

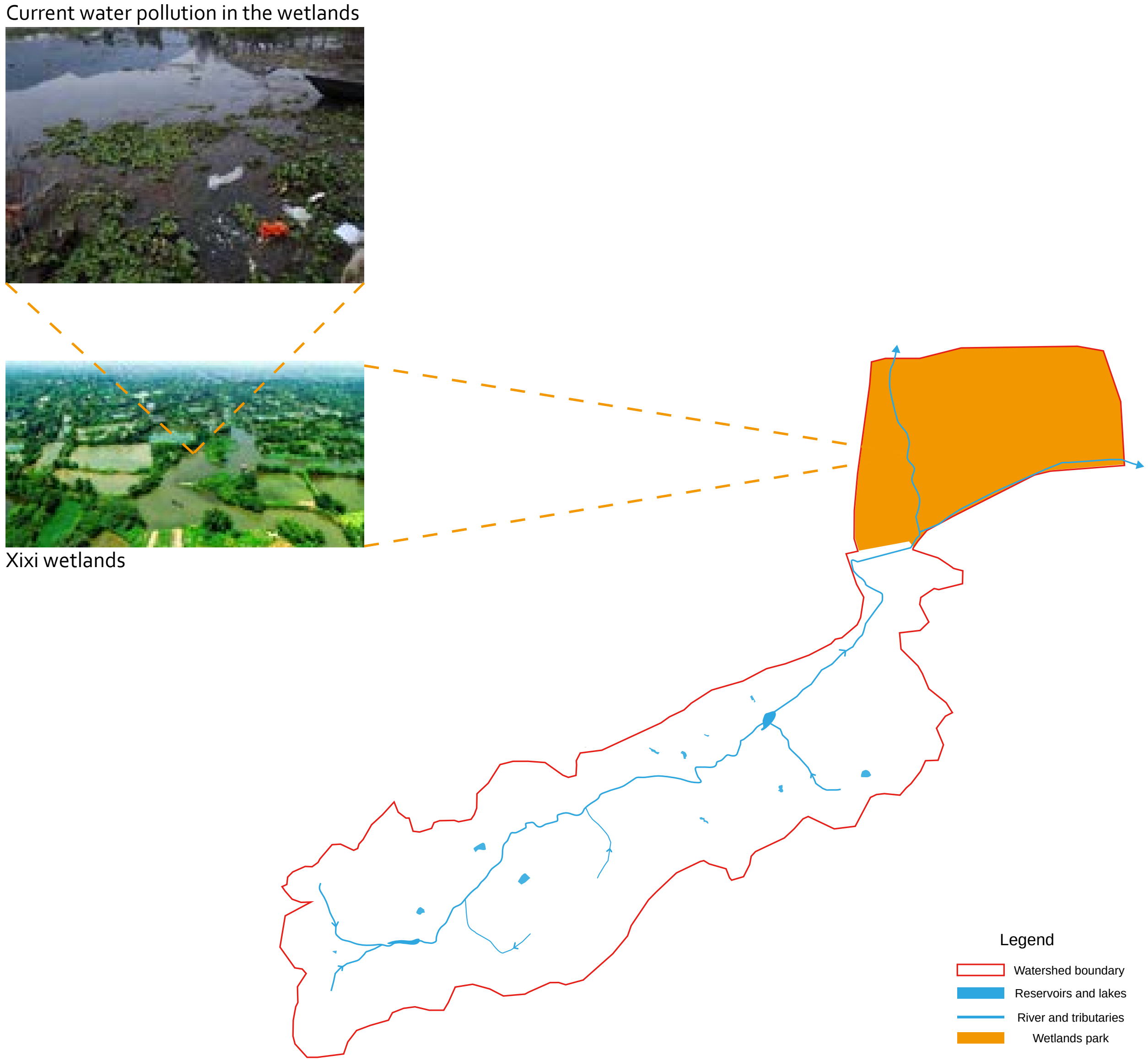


Figure 7.12 Location of the wetlands park in the watershed and its pollution problems.

Development areas in the middle-stream area and the downstream area (including the wetlands park) also contribute significant amounts of pollutants to the Shangbu River. High proportions of impervious paved surfaces prevent water from infiltrating into the ground, so pollutants created on paved surfaces are more easier to be carried into nearby stormwater drainage systems. Common pollutants that are identified in different development land uses in Hangzhou are shown in Table 7.1.

Table 7.1 Event mean concentration of surface runoff in different land use areas of Hangzhou. Source: Li el al., 2012.

Land Use	SS ($mg \cdot L^{-1}$)	COD ($mg \cdot L^{-1}$)	TP ($mg \cdot L^{-1}$)	NH_3 - N ($mg \cdot L^{-1}$)
Road	509.46	348.98	1.07	2.33
Commercial	339.54	224.43	1.15	3.11
Residential	285.06	108.38	0.57	1.63
Industrial	455.96	239.80	0.79	1.36
Preferred levels	200.00	40.00	0.40	2.00

7.3 Stormwater Storage Goal

The amounts of precipitation of the 220mm -24 hour 20 year (24h20y) rainfall event is set as the stormwater assignment (Hangzhou Water Conservancy Academy of Planning and Design, 2012).

Due to data limitation, only a rough calculation can be conducted based on the water assignment to form the basis of designs in this thesis. The 24h25y rainfall event is used to dimension the maximum size of stormwater facilities in extreme rainfall situations, in order to ensure the water storage and quality treatment efficiency of each stormwater facility during that period.

The water storage goal will be used in detailed designs to help dimension stormwater facilities as discussed before, and set the quantitative criteria for final evaluation.

7.4 General Design Strategies for the Watershed Scale

Shangbu Watershed has been divided into four main regions: the rural loam soil region, the urban area loam soil region, the urban rice paddy soil region and the wetlands park with rice paddy soil (Figure 7.13). The division is based on landscape characteristics and land use types.The main water system, namely the Shangbu River, travelling across all those four main regions and convey water within the whole watershed to the wetlands, and later it is transported to other primary waterways in Hangzhou.

The landscape characteristics of four regions, as well as land use types vary from each other, so that design strategies to be followed are different as well. This section provides conceptual design strategies for those four areas in consistent with their own site constrains and potentials identified.

Design strategies focus on foothills and flat plains where human activities changed the natural landscape and cause flooding and water pollution problems. The aim of those strategies are to reduce stormwater quantity and improve water quality in four main regions of the watershed.

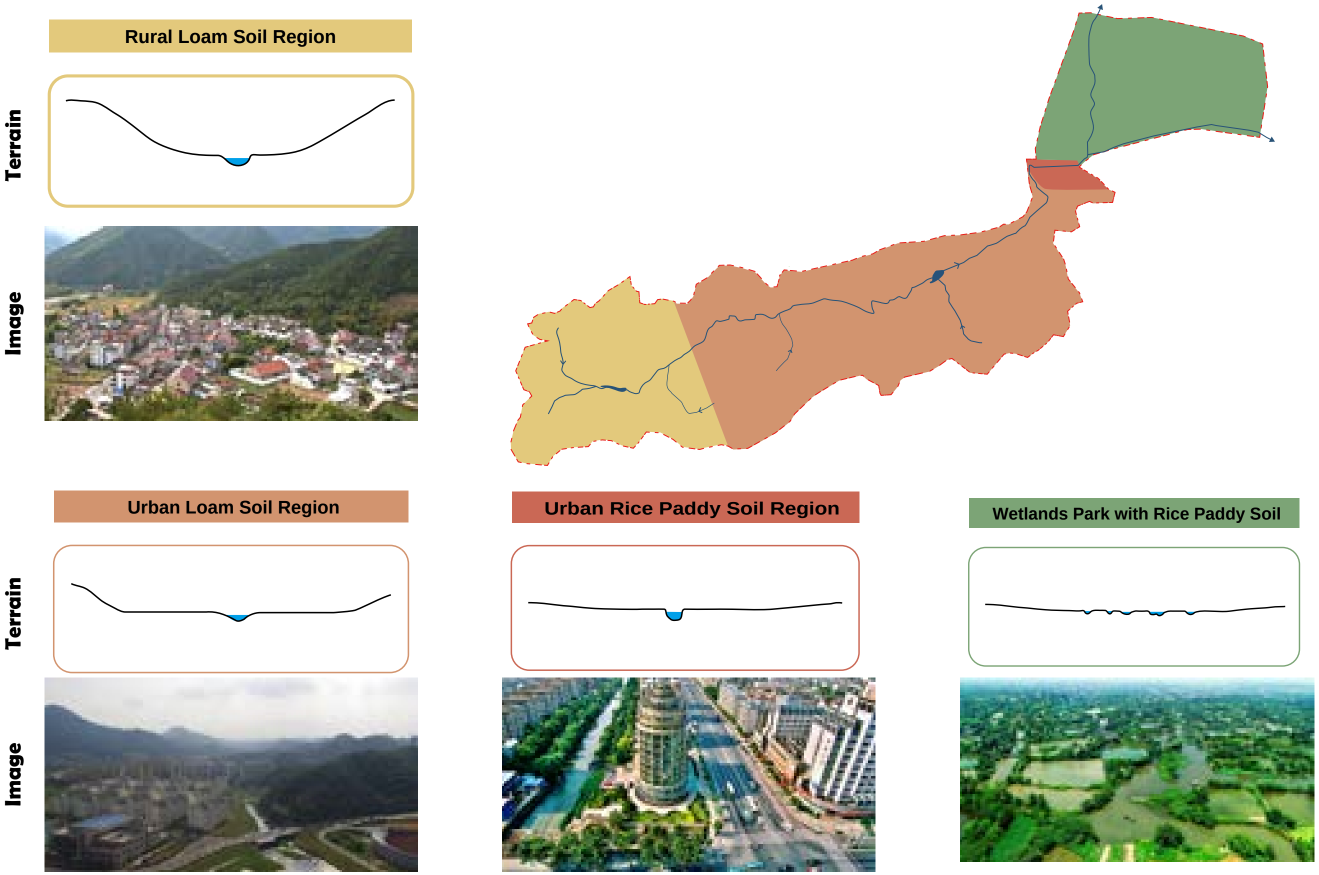


Figure 7.13 Four typical landscape regions in the watershed.

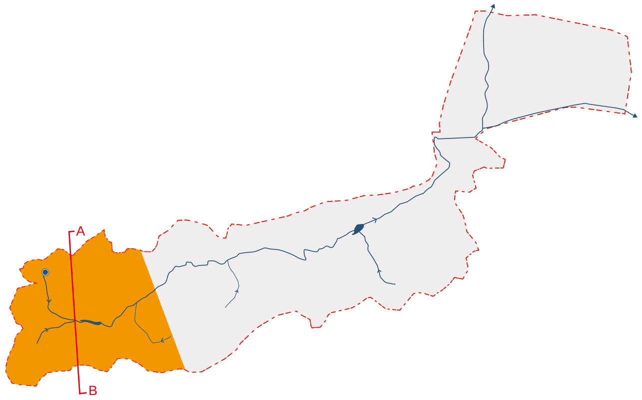


Figure 7.14 Location of the rural area in the watershed.

7.4.1 The rural loam soil region

The rural region occupies the upstream area in the watershed, which consists of many villages and agricultural fields, and they are located mainly on the foothill and the flat plain. The primary problem is its big contribution to water pollution problems in the watershed. Nutrients, organic chemicals and sediments have been identified in the previous section as main water pollutants produced from this area mainly due to the agricultural work.

The area is located on the loam soil region with groundwater deeper than 4 meters below the ground, which make it a perfect site for implementing infiltration (Figure 7.15).

Based on the contour map, general stormwater flow in this region can be identified. Stormwater starts from foothills, flows across agricultural lands and the village area and finally enters the Shangbu River (Figure 7.16 to 7.18).

Agricultural lands make up a significant portion of the whole landscape, but those places cannot be used for water storages, as they produce crops and vegetables which are major incomes for local farmers. On the other hand, those agricultural lands are big water consumers, currently, farmers depend on local wells to fetch water from the ground. The high percentage of green areas and public activity squares provides a great opprtunity to manage stormwater on site, and most of them are situated at a relative low position.

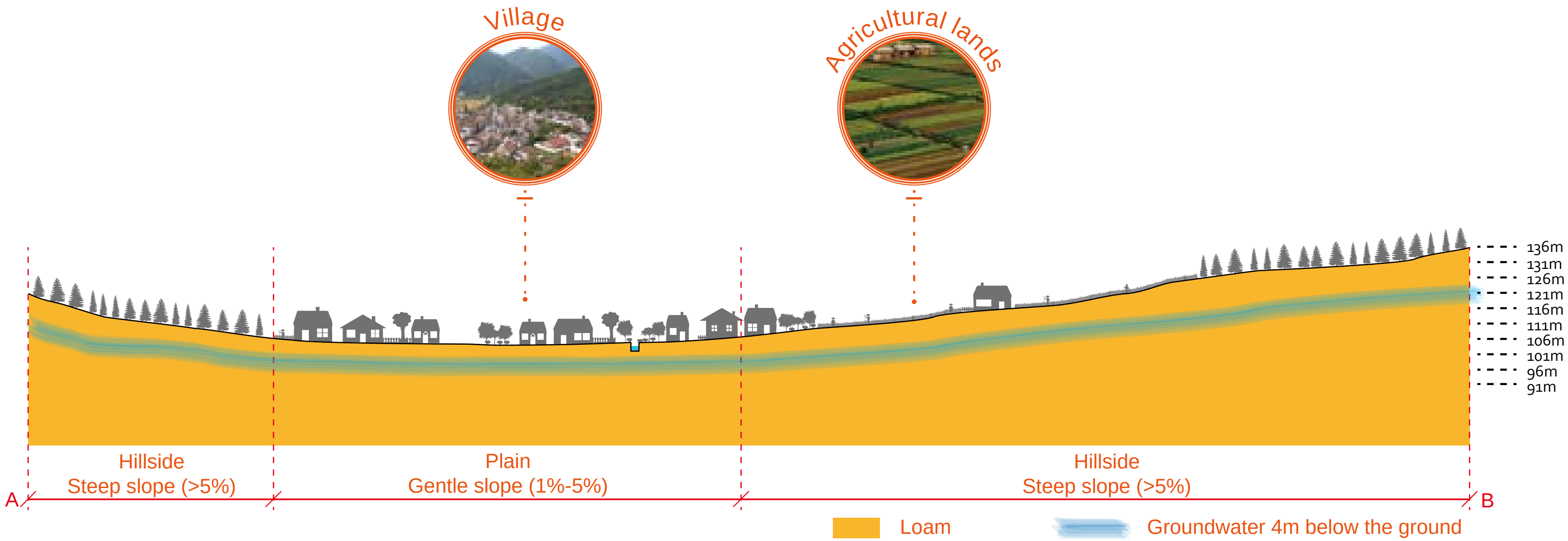


Figure 7.15 Typical landscape profile of the rural region.

Figure 7.16 Height differences (interval=5m).

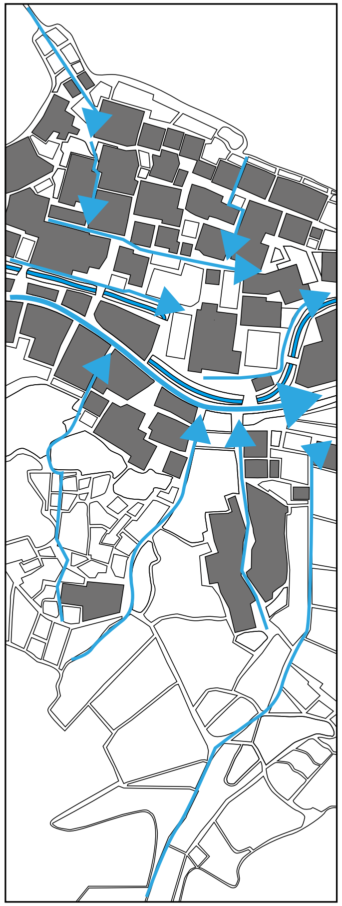


Figure 7.17 General stormwater runoff direction.

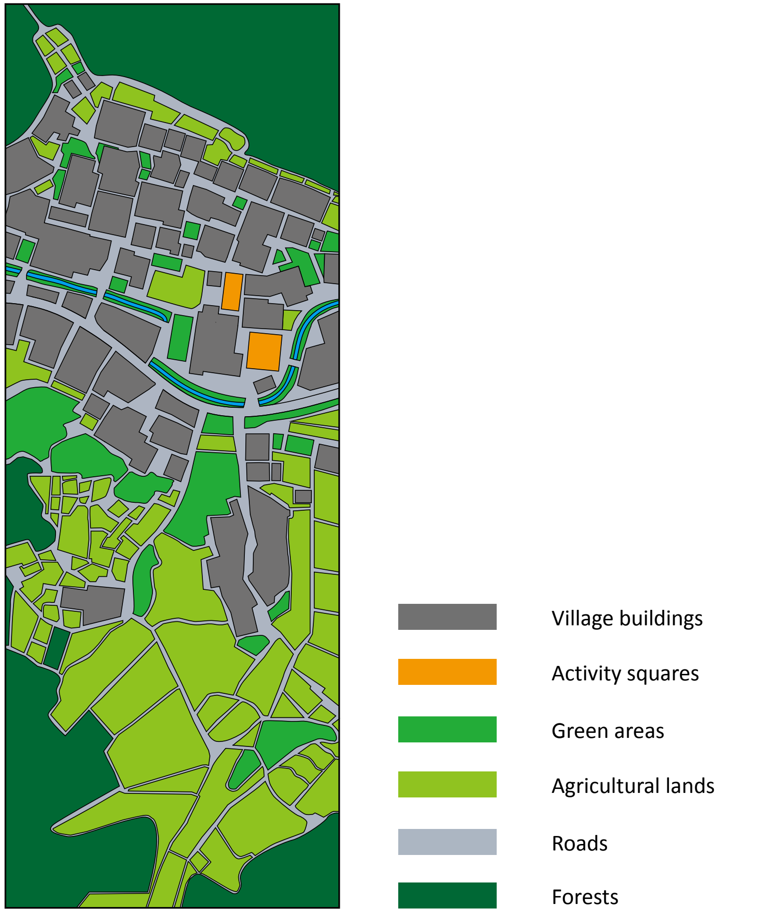


Figure 7.18 Land uses .

The strategy for the upstream rural area focuses on detaining stormwater, and removing pollutants mainly from the agricultural lands before it enters the Shangbu River. Detained and treated water can also be used as irrigation water for agricultural fields that are situated on the foothill. Typical 3-story high private-owned individual buildings show an good opportunity to install water harvesting facilities, while green areas and squares offer spaces for storing and treating water from agricultural lands and streets (Figure 7.19). The cleaned water can be either infiltrated into the ground to recharge the groundwater or discharged into the river.

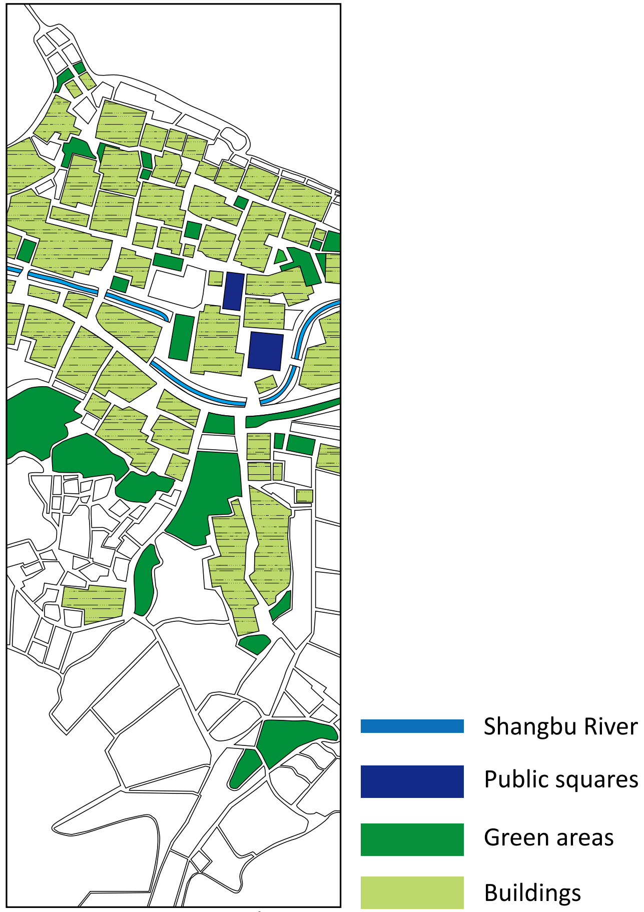


Figure 7.19 Potential water storage locations.

7.4.2 The urban loam soil region

Development in this urban region was started quickly from 2006, at the time when Liuxia decided to expand its development area to attract more people from other cities to boost its local economy. Currently, land uses in the region consist of several residential communities and three university campuses. University campuses are mainly situated on the flat terrain while some low-density residential communities built their properties on foothills with slopes greater than 5%. The urban loam soil region is located on loam soil with groundwater deeper than 2.5 meters below the ground, so infiltration process is still the most suitable mechanism for stormwater management (Figure 7.21 and 7.22).

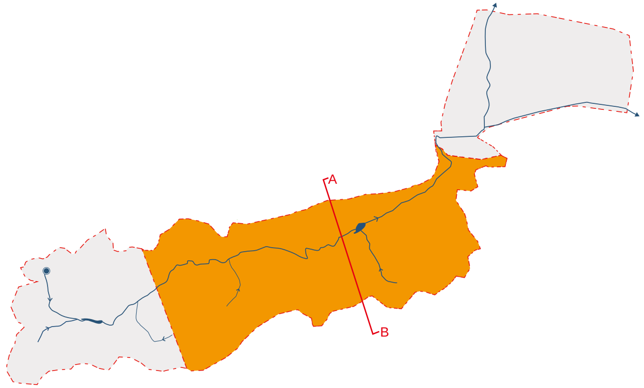


Figure 7.20 Location of the urban loam soil region in the watershed.

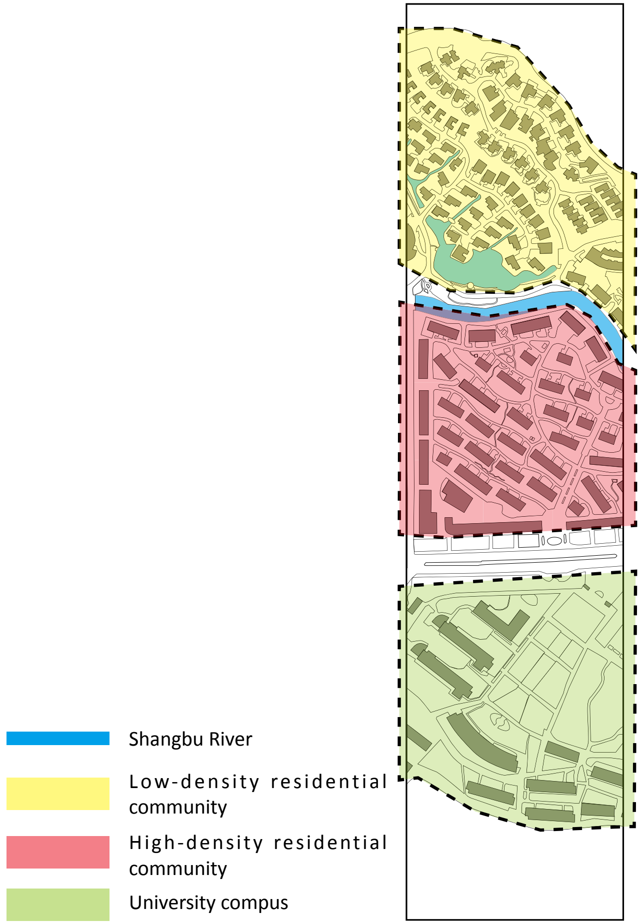


Figure 7.22 Land use types in the urban loam soil region.

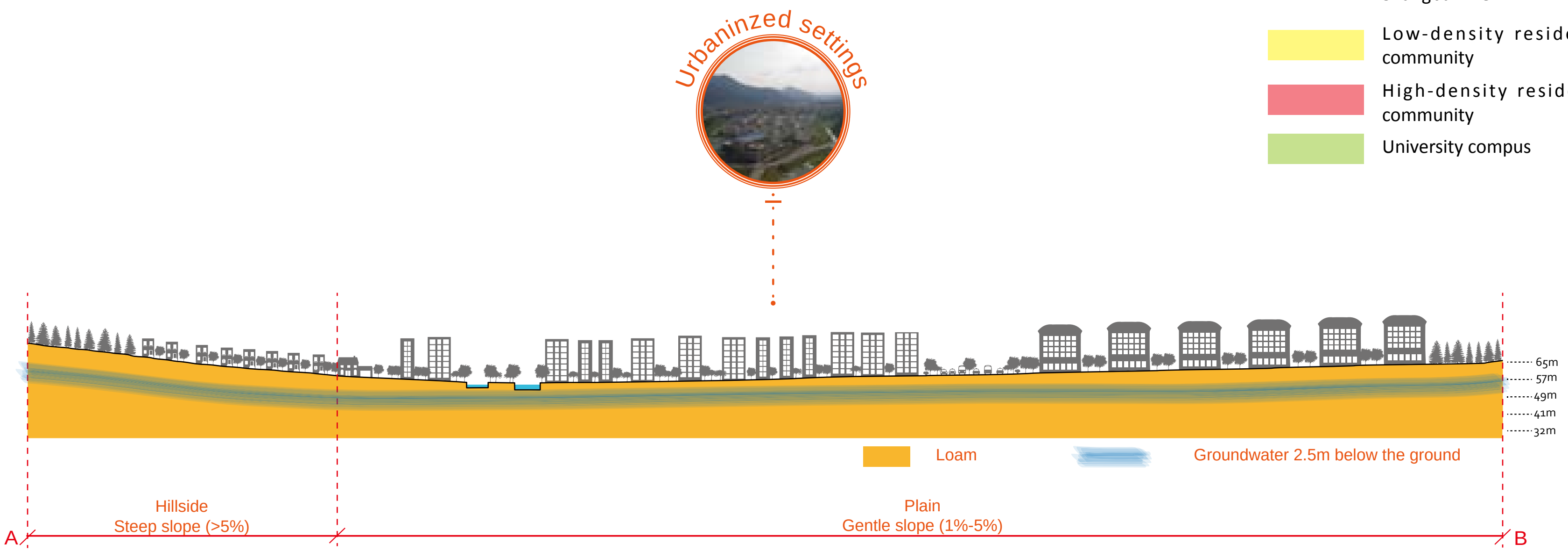


Figure 7.21 Typical landscape profile of the urban loam soil region.

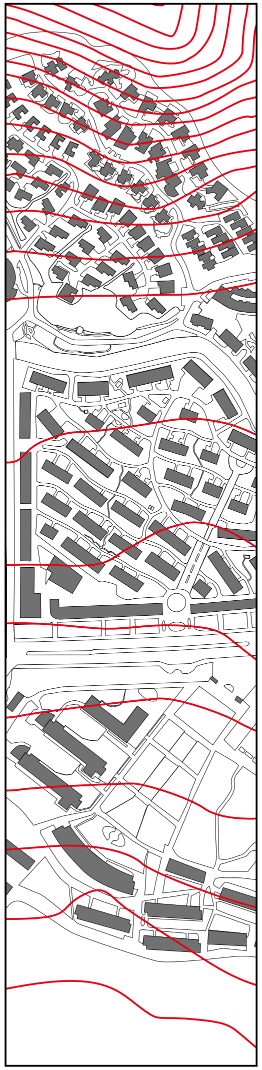


Figure 7.23 Height differences (interval=2m).

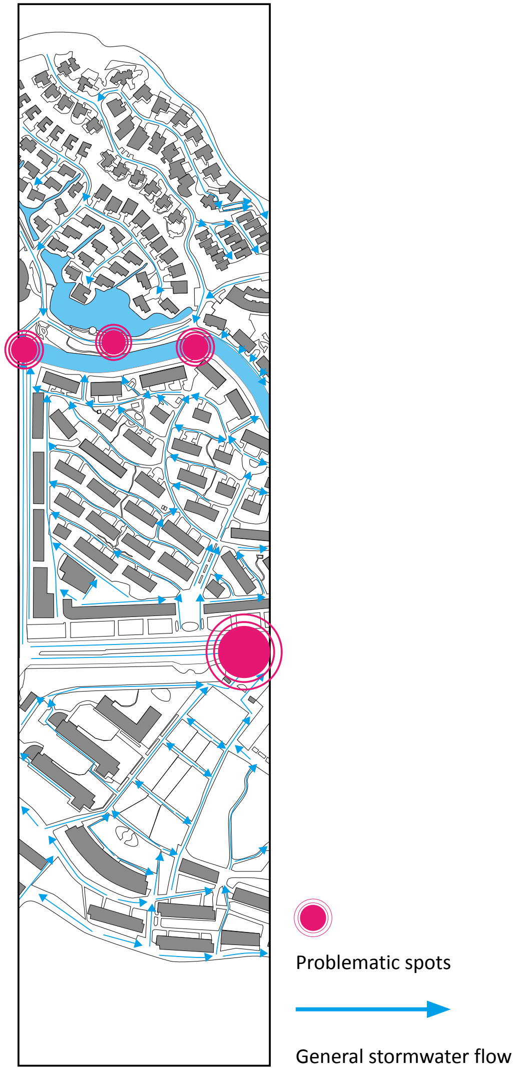


Figure 7.24 General stormwater flow directions.

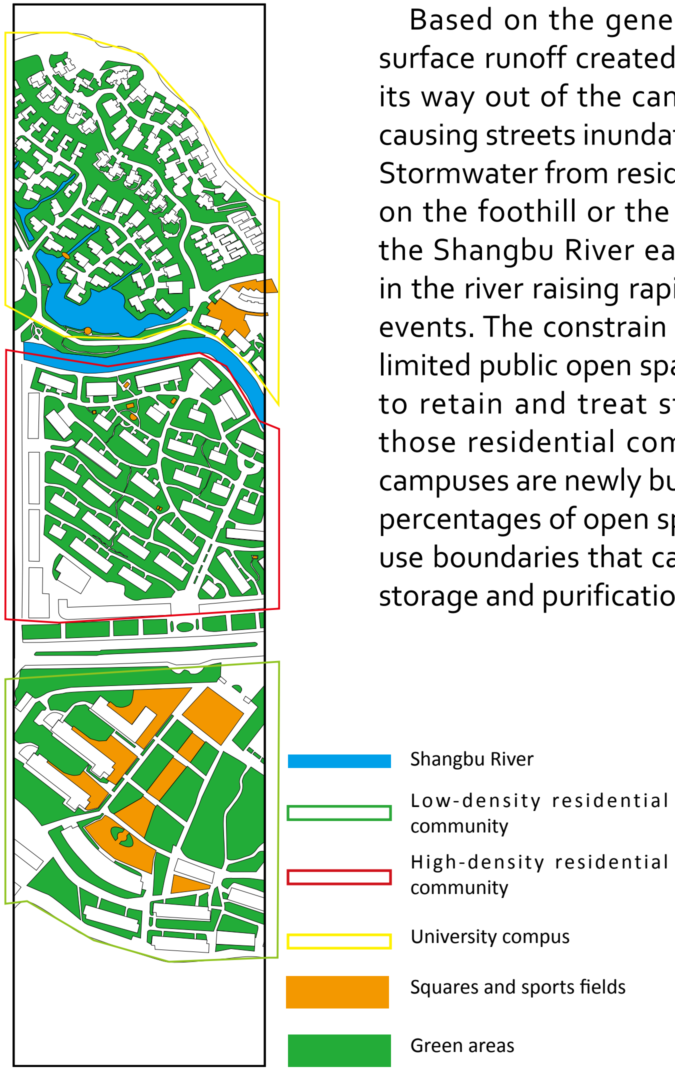


Figure 7.25 High percentage of public spaces within each land use boundary.

Based on the general stormwater flow, the surface runoff created in the university can find its way out of the campus and stay on streets, causing streets inundation (Figure 7.23 and 7.24). Stormwater from residential communities either on the foothill or the flat terrain can flow into the Shangbu River easily, causing water levels in the river raising rapidly during intense rainfall events. The constrain there is that there is very limited public open space available in this region to retain and treat stormwater. However, as those residential communities and university campuses are newly built, they have relative high percentages of open space within their own land use boundaries that can be used for stormwater storage and purification (Figure 7.25).

The strategy for this urban area calls for water detention facilities and treatment facilities within each land use boundaries where plenty of open spaces such as green areas and sports fields can infiltrate and store water. Streets are one important component to treat stormwater: on one hand, they are one main source for creating pollutants in the urban area; on the other hand, they can collect water on surfaces and link stormwater facilities with each other. Buildings are encouraged to be applied with harvesting facilities to harvest water and reduce the amounts of stormwater runoff at the first place (Figure 7.26).

Figure 7.26 Potential water storage locations.

7.4.3 The urban rice paddy soil Region

The urban rice paddy soil region consists of a variety of living and other environments such as residential communities, big shopping malls, and primary schools. This is where the largest portion of the Liuxia area is situated (Figure 7.28 and 7.29).

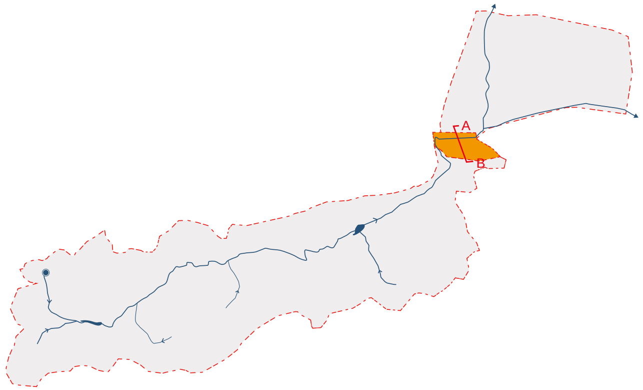


Figure 7.27 Location of the urban rice paddy soil region in the watershed.

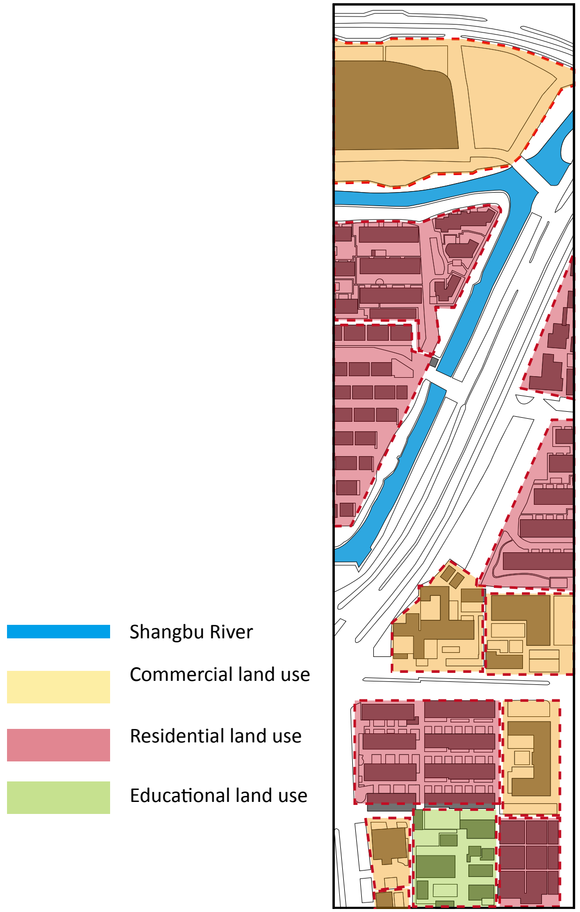


Figure 7.29 Land use types in the urban rice paddy soil region.

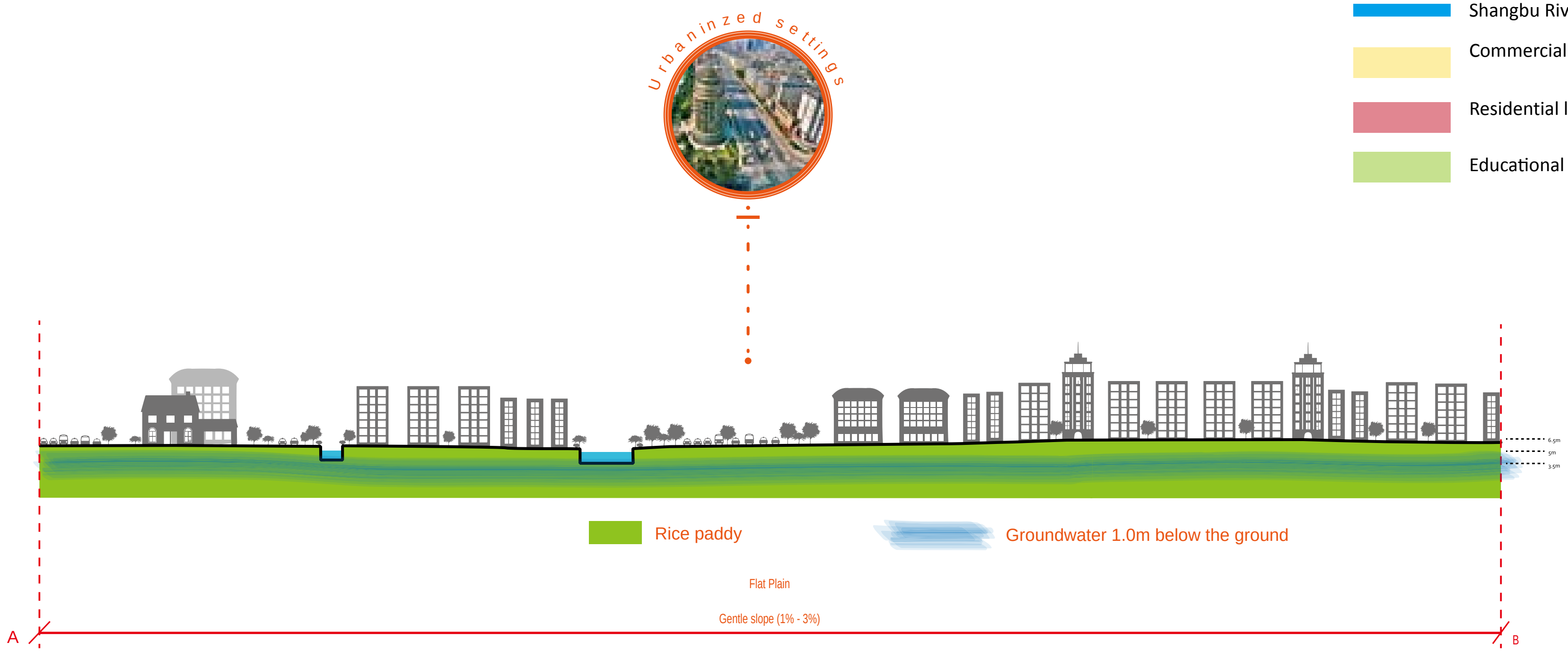


Figure 7.28 Typical landscape profile of the urban rice paddy soil region.

Stormwater runoff created from different land uses stagnates mainly on streets and residential communities, affecting people's daily life (Figure 7.30 and 7.31).

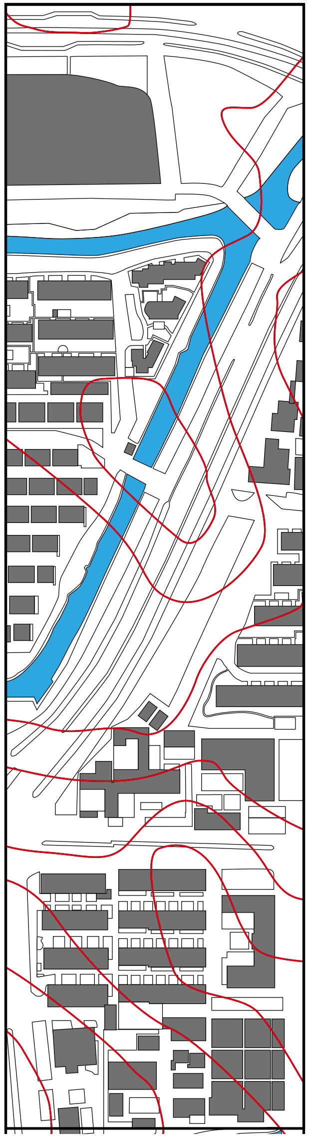


Figure 7.30 Height differences (interval=2m).

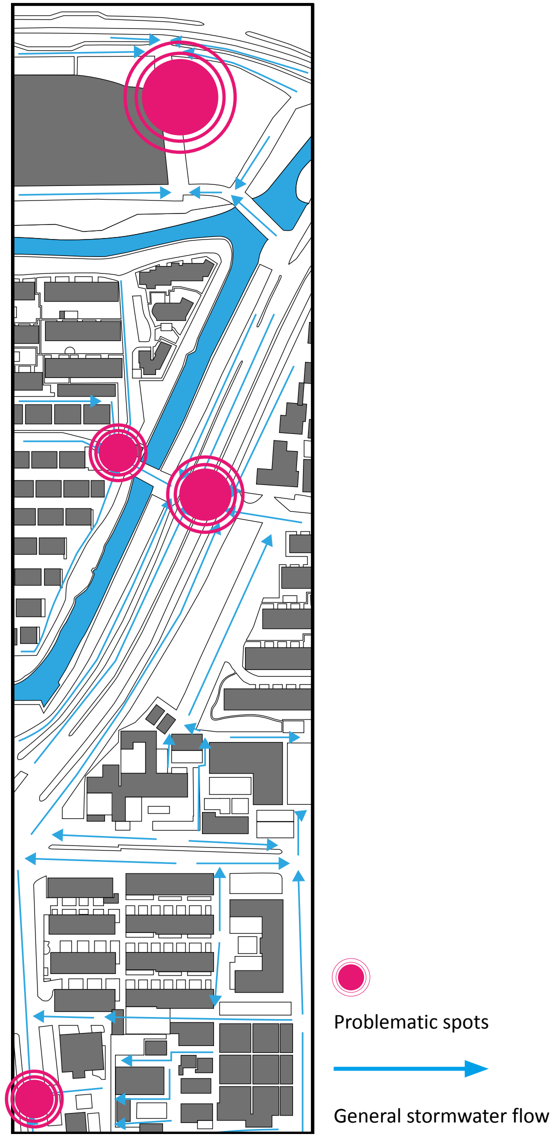


Figure 7.31 General stormwater flow directions.

The strategy focuses on two parts: the individual land use and riparian riverfront. In the individual land use, harvesting facilities are strongly encouraged to be implemented as they are the biggest potential water storages on site. Green spaces in the residential communities provide potential to control stormwater quantity. Parking lots are a major component in commercial land uses, underground space within those places should also be explored in order to create extra space for water retention. Underdrain systems are recommended to be built underneath those water storage facilities in the rice paddy region in order to fulfill the 24 hours drain-down time target (Figure 7.32).

As the region is located downstream of the watershed, receiving water from up and middle-streams, its river drainage capacities should be expanded in order to handle large amounts of water during intense rainfall events. The existing riparian recreational area provides the possibility to expand the river's surface area to further store and treat water (Figure 7.33)

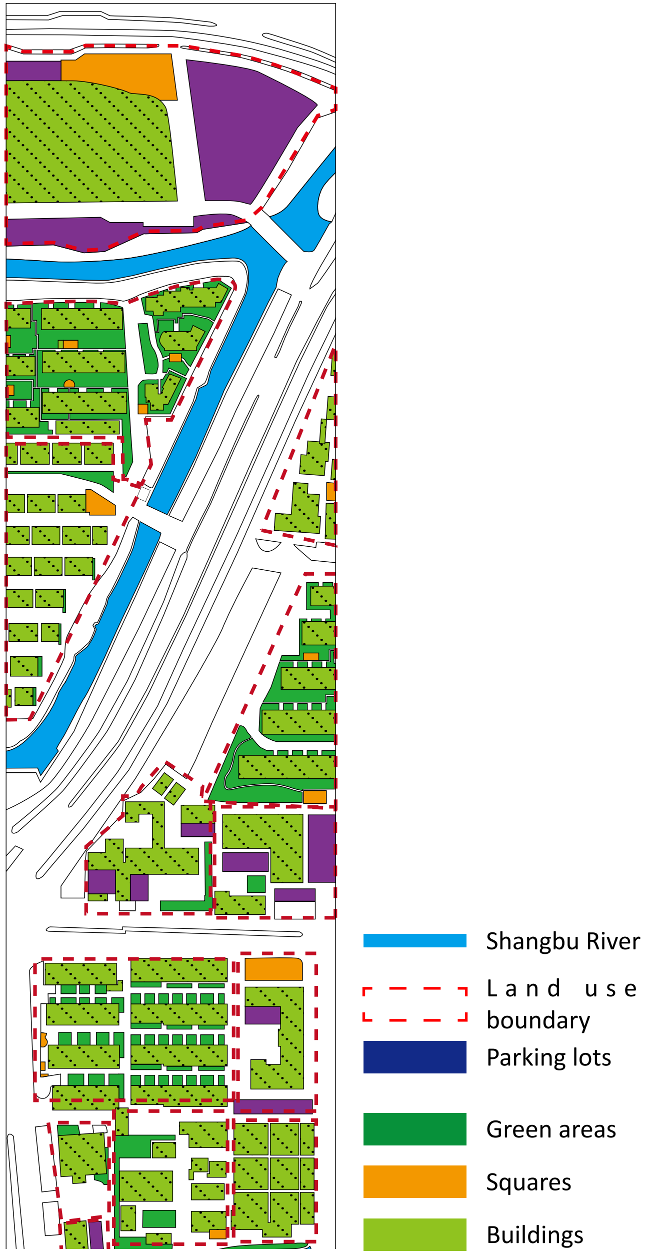


Figure 7.32 Water storage potentials within individual land uses.

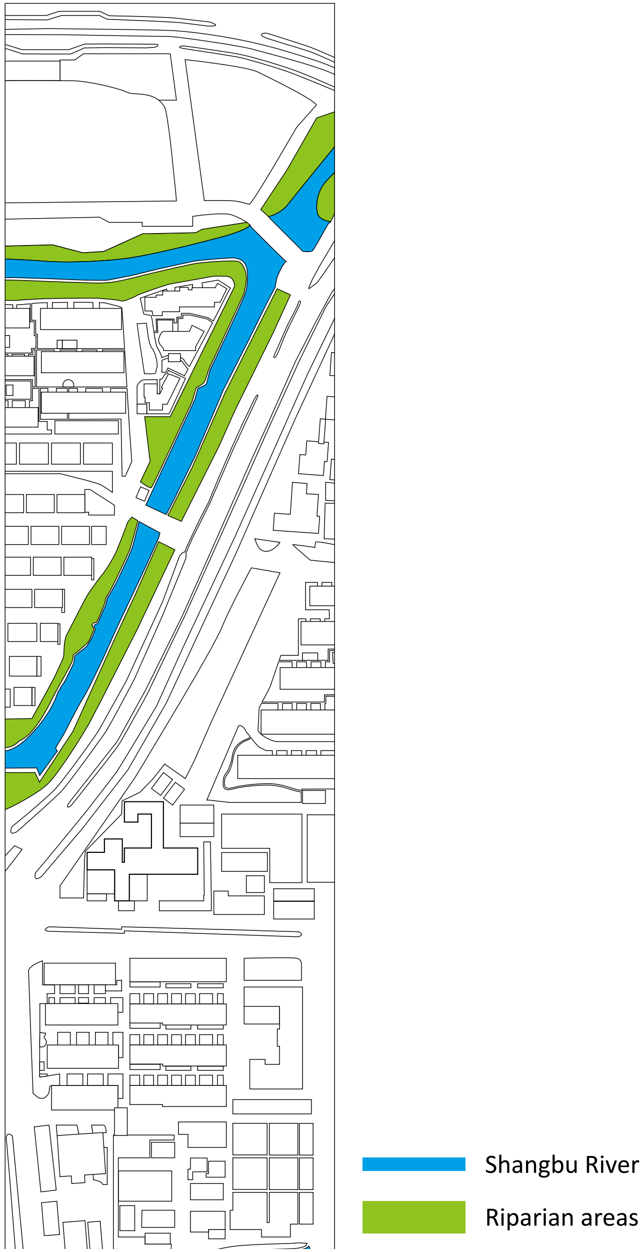


Figure 7.33 Potential intervention locations of riparian areas.

7.4.4 The wetlands park with rice paddy soil

From the rural area, the Shangbu River continues travelling across the middle-stream urban area and downstream Liuxia area until it ends in the wetlands park. The wetlands park is made of lakes, ponds and rivers, all located on low permeable rice paddy soils(Figure 7.34 and 7.35). The landscape in the wetlands park in the downstream area is influenced by urban development as well. More parking lots and streets (both driving and pedestrian streets) have been built in the development area in the wetlands park which produce pollutants to the wetlands directly, combined with polluted water coming from the Shangbu River, the water quality in the wetlands has been degraded significantly (Chen et al., 2009, Dong et al., 2013).

The wetlands park itself is a natural place for water quality treatment as well as flood control, but sediments and pollutants such as oil and grease can harm and even kill the vegetation and micro-organisms that treat other pollutants (FDER, 1991). Although water quality should already be improved when the water reaches the wetlands park, stormwater facilities can be applied to the upstream areas of the Shangbu Watershed. At places where water is conveyed into the wetlands park from upstreams, pretreatment should be done to intercept and remove sediments, oil and grease, in order to capture pollutants that is not removed from previous stages. (Figure 7.36).

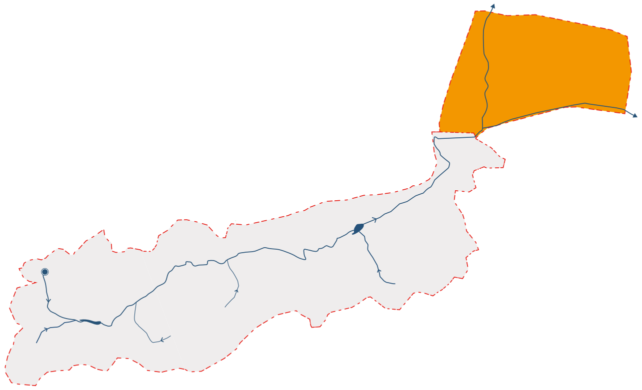


Figure 7.34 Location of the wetlands park in the watershed.

Figure 7.35 The overview of the Xixi wetlands park. Source: http://yeetravel.com.cn.

Figure 7.36 Pretreatment interventions locations.

Streets and parking lots within the wetlands park have been recognized as the major sources of water pollutants (Dong et al., 2013). Therefore, the strategy also focuses on retaining and treating stormwater that is created on those two areas. As the wetlands park is made of rice paddy soils, underdrain systems made of coarse materials such as gravels need to be built beneath water storage facilities to increase the stormwater facility's water storage capacity. High percentages of green areas in the wetlands park offers chances for water storages, excess water from streets and parking lots can be conveyed to green areas for treatment and storage during rainfall events. And the cleaned water can be released slowly to lakes, ponds or rivers after rainfalls (Figure 7.37 to 7.39).

Figure 7.37 The existing pedestrian street. Source: http://www.shidi.org/.

Figure 7.38 The existing traffic street. Source: Baidu Maps.

Figure 7.39 The existing parking lots. Source: http://www.shidi.org/.

7.5 Design Principles and Impressions

In the previous sub-chapter, design strategies is made to provide insights to manage stormwater quantity and improve its quality in the Shangbu Watershed. However, designs may vary from site to site as each one has its unique landscape characteristics in soils, topography, etc., which requires site-specific solutions. From the watershed-scale landscape analysis, it is clear that individual land uses have greater potentials to manage stormwater quantity and quality problems, meanwhile, they are also recognized as the most cost-effective locations to treat stormwater (Woods-Ballard et al., 2007). Therefore, design solutions are focused on individual land uses, which make up the majority of landscapes in the watershed.

By consulting experts from Hangzhou Planning Department, we first identified nine potential sites which were typical land uses distributed in Shangbu Watershed. The selection criteria is based on land use types, landscape characteristics (topography, soil types and groundwater levels). This list was later narrowed down to three exemplary design projects which can set examples for three identified near-term redevelopment projects in the watershed (Figure 7.40). Three exemplary design projects include a rural village in the rural region, a residential community in the urban loam soil region, and a parking lot as well as two streets within the wetlands park. Design solutions and principles are proposed to them, and impressions are made to show how the landscape would look like when the combined approach is applied into those places.

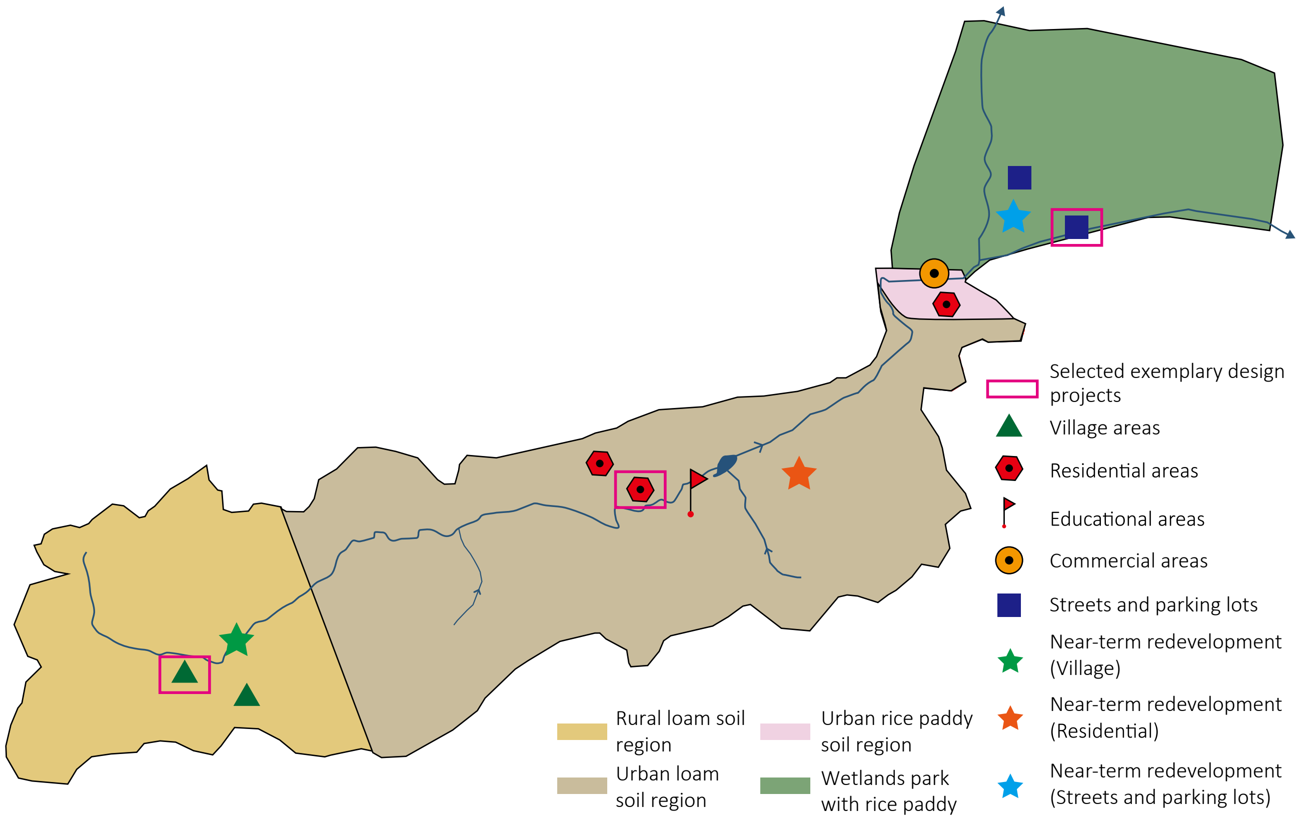


Figure 7.40 The selection of pilot projects in the watershed.

7.5.1 Yunxi village

The Yunxi village is composed of the moderate permeable loam soil with deep groundwater. The first step is to find out opportunities for stormwater interventions within the local context, so the current site plan is overlapped with the contour map and the relative height map of open spaces (Figure 7.42 to 7.44). Green areas are the most suitable for large water storage and treatment, while the big limitation for applying stormwater facilities in this area is the steep slope at foothills, which accelerates stormwater velocities, so techniques should be explored to reduce its speed and make infiltration feasible at foothills (Figure 7.45).

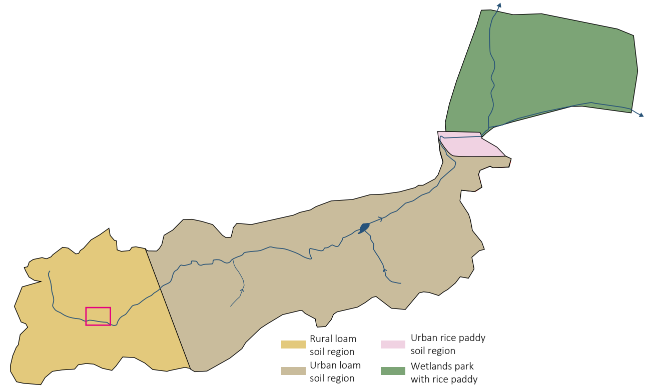


Figure 7.41 Location of Yunxi village.

Figure 7.42 Height differences (interval=5m).

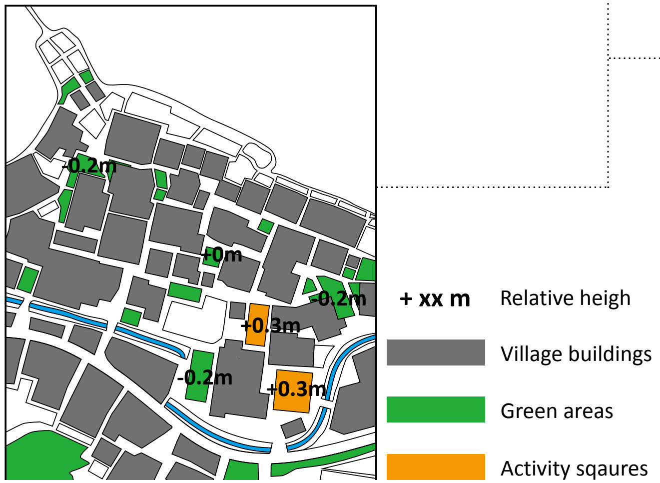


Figure 7.43 Land uses with relative height.

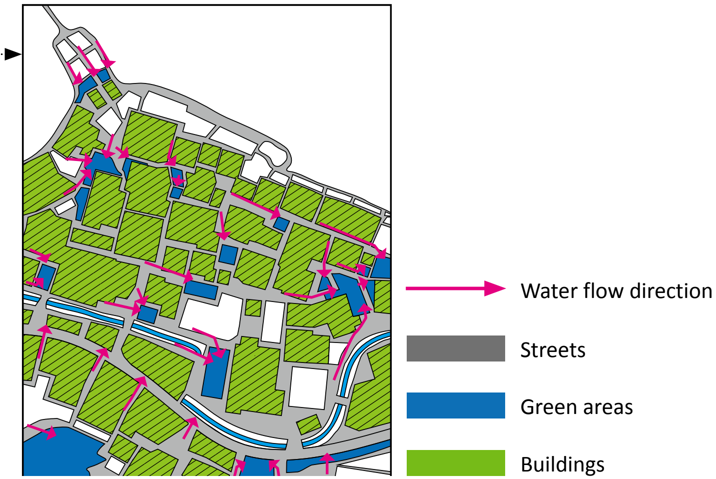


Figure 7.44 Potential components and proposed water flow directions.

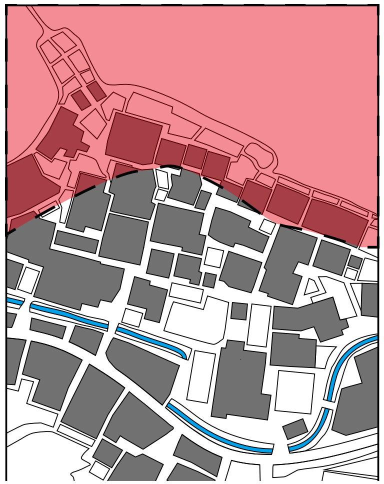


Figure 7.45 The light red indicates foothill areas with steep topography.

The Lots Level

The next step is to apply the combined approach on different levels. On the lots level, private-owned individual village buildings and their backyards are recommended to implement rainwater barrels and rain gardens to make contribution to reducing stormwater on site (Figure 7.47). And this intervention may also benefit local villagers to reduce costs for water, as the collected water from rainwater barrels can be used for irrigation or toilet-flushing.

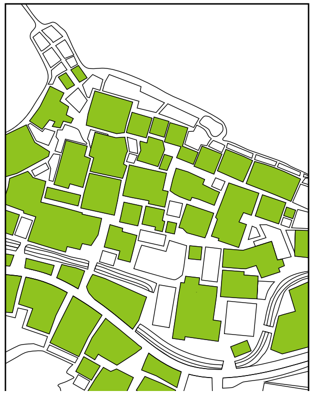


Figure 7.46 Locations of private buildings and backyards.

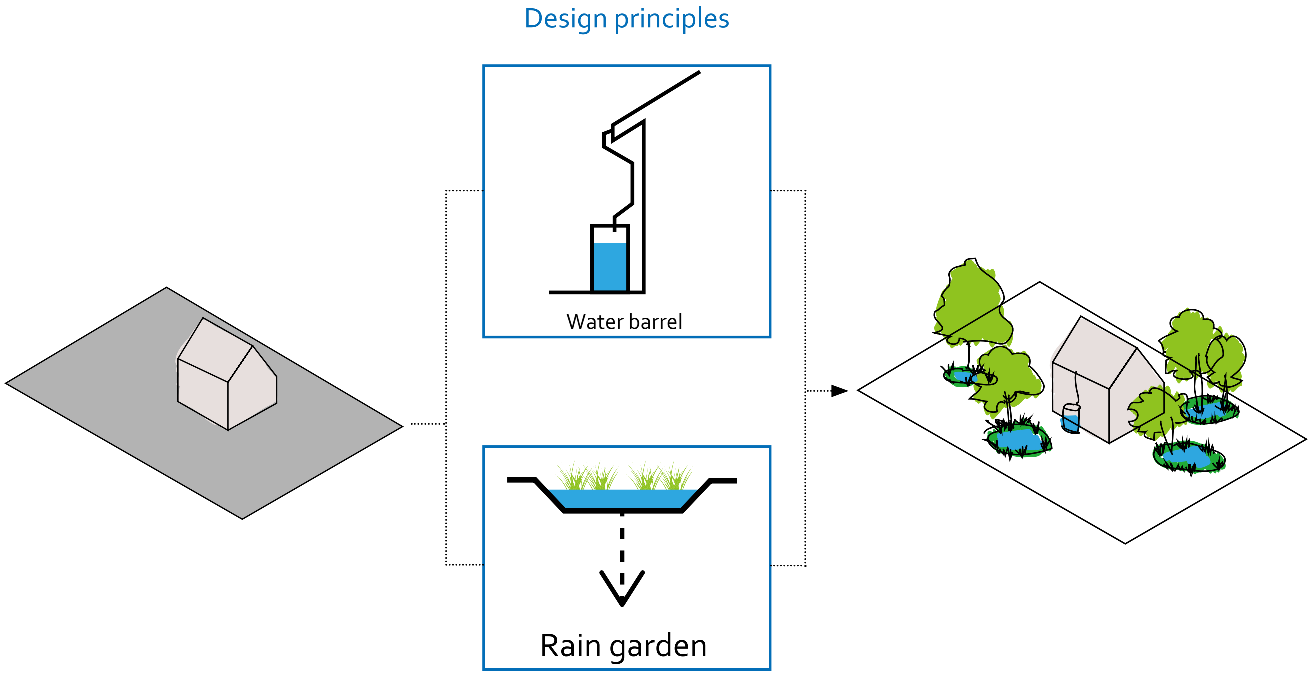


Figure 7.47 Design principles on private buildings and backyards.

On the streets level, vegetated swales and green gutters should be applied on streets, via which the first flush can be collected and constrained within them. Weirs can be applied on steep slopes, so water velocities can be reduced, and sediments as well as other heavy matters can settle down before entering other BMPs facilities (Figure 7.50 and 7.51).

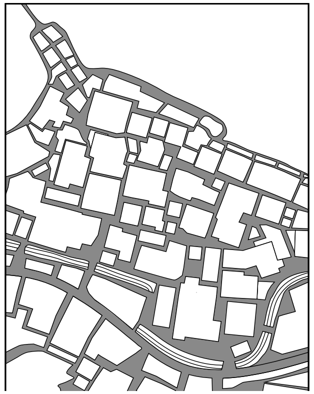


Figure 7.48 Locations of rural streets.


Figure 7.49 Existing situation of steep street in the village. Source: photo by the author.

The Streets Level

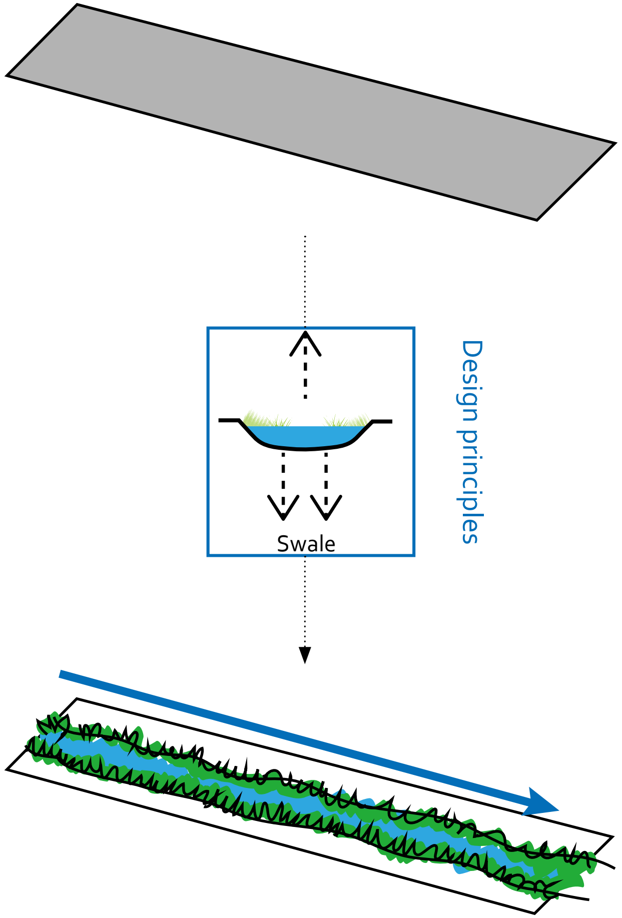


Figure 7.50 Vegetated swale is applied into streets on the flat plain.

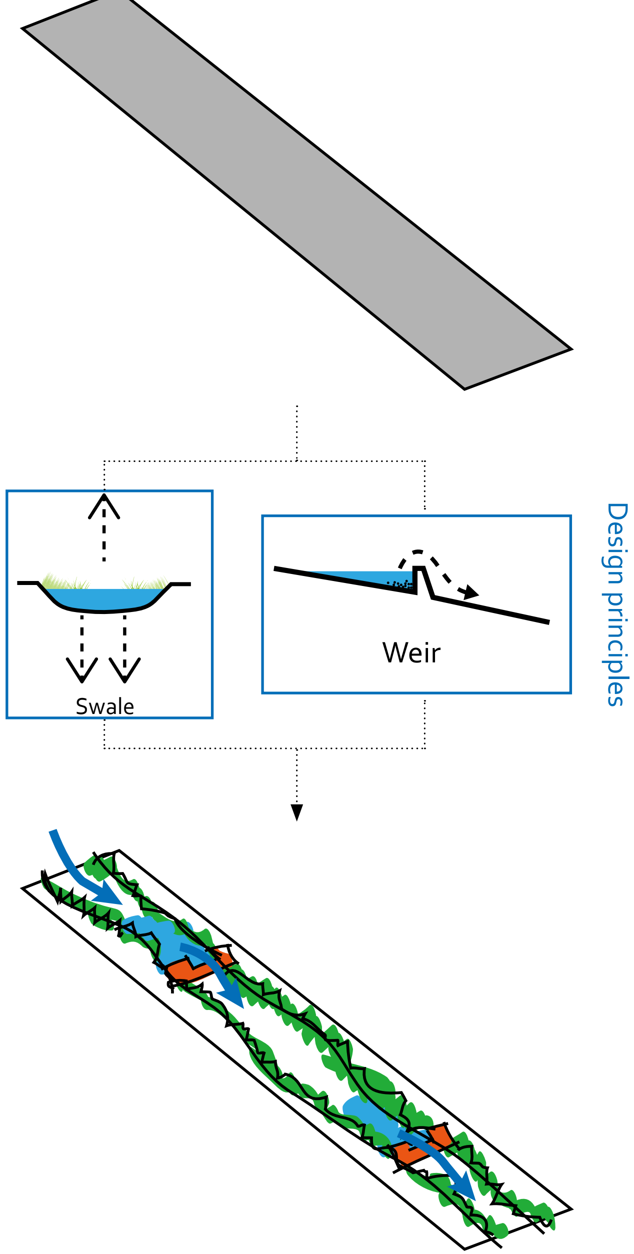


Figure 7.51 Dams are built in swales to reduce water velocities and store it contemporarily.

The Streets Level

The major road which is situated at the low position in the village also has great potential to collect water. As it is the only way connecting the village with outsides, traffic volumes on this road is heavy, consequently, it is also a major pollutants creator (Figure 7.52).

Besides water problems this road is concerned, it is not safe for village people to walk on it either. As shoulders along the road is too narrow, and there is no barricade between traffic lane and the road shoulders (Figure 7.53). The potential of this road is that the existing driving lanes are actually over-sized. So if the width of the driving lanes as well as one side of the shoulder is decreased, enough space could be created on the other side of the road where sidewalk and green gutters can be implemented. The 2 meters wide sidewalk is covered with permeable pavement which allows water infiltrating into the ground. As the road can

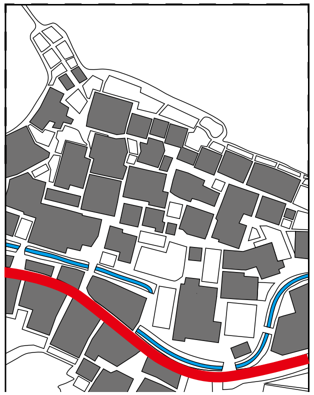


Figure 7.52 Location of rural major street.

Figure 7.53 Existing situation of the major street in the village. Source: photo by the author.

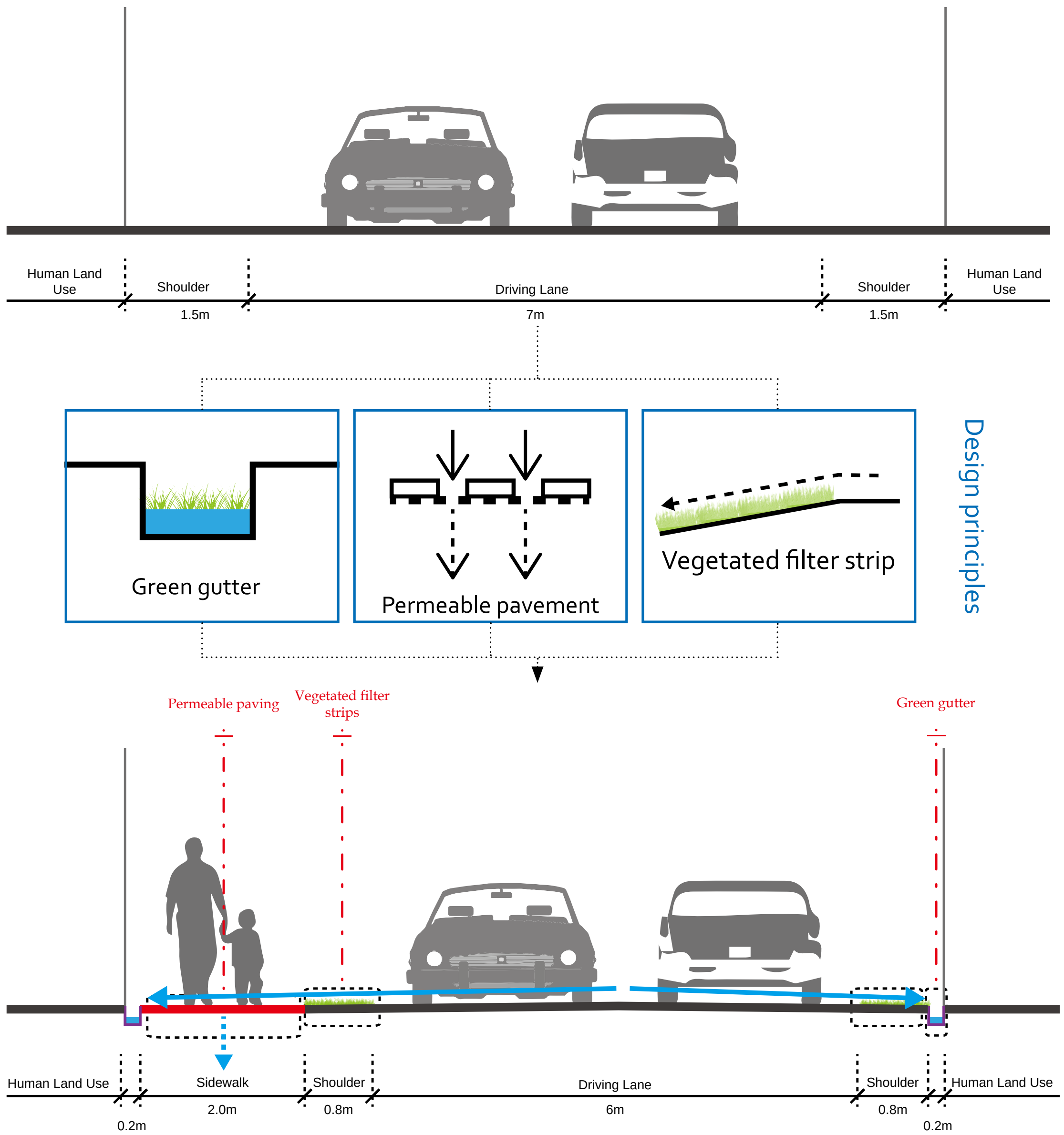


Figure 7.54 Design principles on the major street.

produce many pollutants, particularly sediments, pretreatment is required before the runoff flows to the sidewalk. In this case, filter strips are implemented here. In one way, they can trap sediments, so that only pre-treated water can infiltrate through the permeable pavement; in another way, they act like a barricade separating sidewalk from the heavy traffic (Figure 7.54).

Figure 7.55 Existing situation of the major street in the village. Source: photo by the author.

Impression A in the dry condition

Figure 7.56 Impression A showing the vegetated filter strips and permeable sidewalk provide safety to pedestrians.

And street lights can also be installed in filter strips, which provide more safety for both pedestrians and traffics during nights (Figure 7.57).

Impression B during a rainfall event

Figure 7.57 Impression B showing new designed street with street lights in a raining evening.

On the open spaces level, all water is conveyed to green areas in the same catchment (Figure 7.58). On the steep terrain (greater than 5%), the terrain can be terraced so that detention basins can be created to hold and infiltrate water. The first detention basin is used as pretreatment pond, together with filter strips, they are used as areas for sedimentation. Raised outlet is installed to let clean water flow to next basins (Figure 7.60).

Figure 7.58 Existing locations of steep green areas in the rual area.

Figure 7.59 Existing situation of the steep green area. Source: photo by the author.

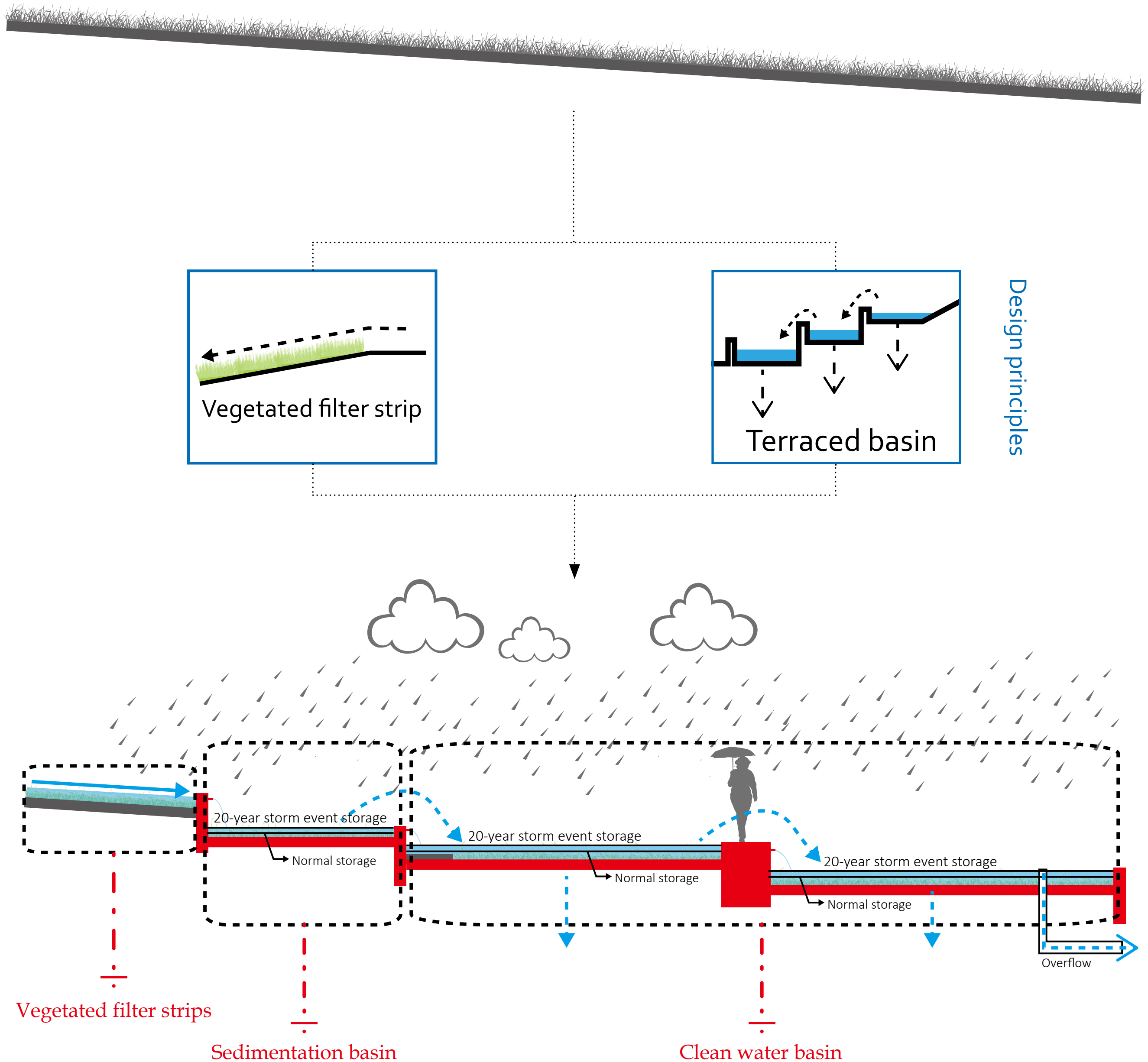


Figure 7.60 Design principles on the steep green area.

While on the flat terrain (between 1%-5%), the plain surface can be re-graded to create depressed basins to hold more water. Water is transported into the basin via swales on the street, so A forebay is created as the first part of the basin to remove sediments mixed with incoming water. Plants which can tolerant long-time inundation are planted in the clean water pond so that they can take up pollutants such as nitrogen to improve water quality. Furthermore, as green areas are close to agricultural fields, cleaned water can also be used for irrigation (Figure 7.63)

Figure 7.61 Existing locations of flat green areas in the rual area.

Figure 7.62 Existing situation of the flat green area. Source: photo by the author.

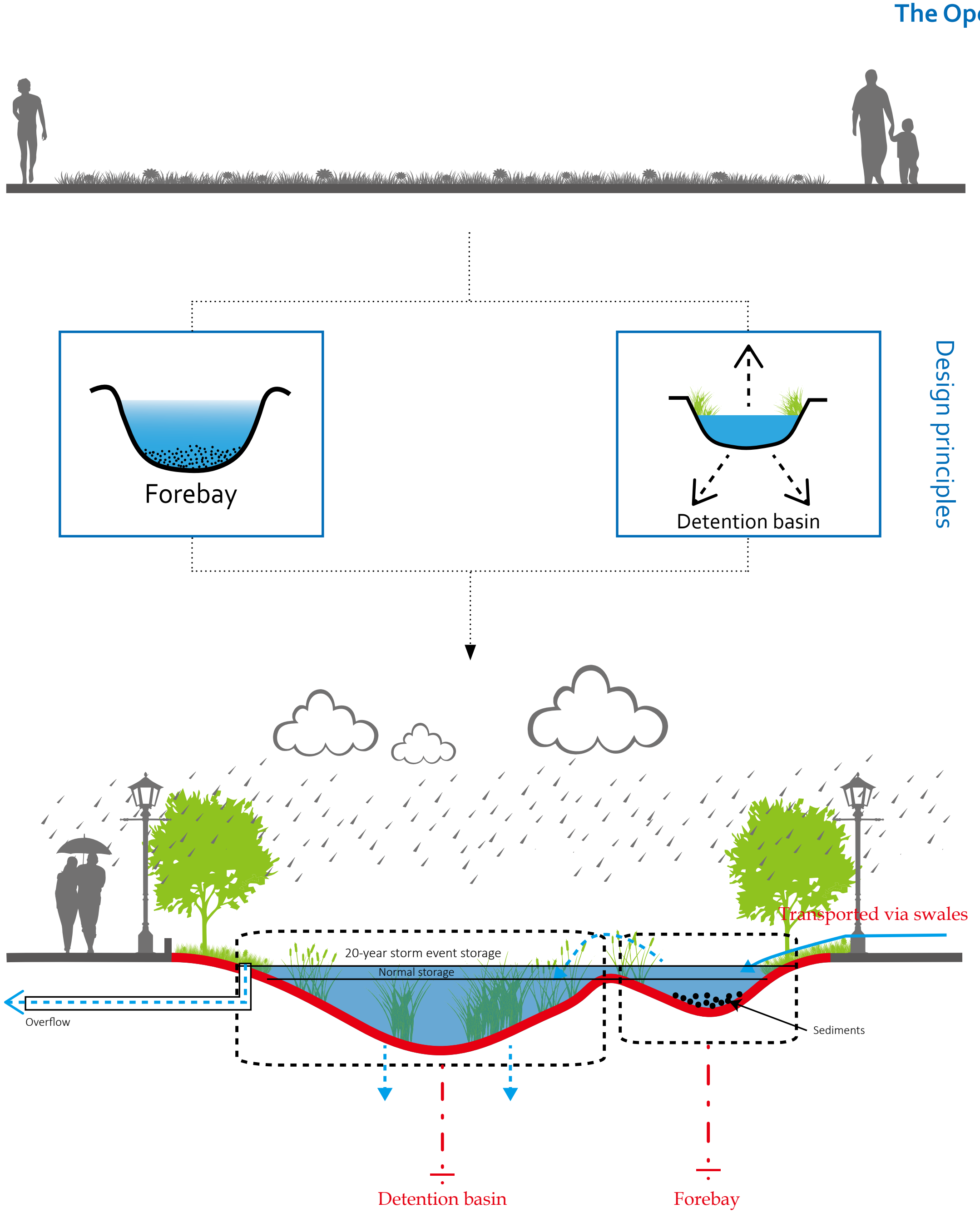


Figure 7.63 Design principles on the flat green area.

Figure 7.64 Existing situation of the flat green area. Source: photo by the author.

Impression A in the dry condition

Figure 7.65 Impression A showing the detention basin can provide activity places for local residents in dry situations.

Impression B during a normal rainfall event

Figure 7.66 Impression B showing the detention basin and forebay can store water during the average rain event.

Impression C during an extreme rainfall event

Figure 7.67 Impression C showing the full storage capacity during the extreme rainfall event.

Impression D after the rainfall event

Figure 7.68 Impression D showing the situation after the rainfall.

At last, a rough calculation of the water storage capacity is conducted in order to examine whether the design can fulfill its water storage goal on site.

To make the calculation easier, it is presumed that water barrels and rain gardens implemented in individual buildings and backyards can handle the rainwater on their site, then the required water storage volume in the village comes from 4 parts: streets, green areas, squares and agricultural lands.

4 parts of surface areas: 18,000 m^2 (total area)-10,875 m^2(buildings and backyards)=7,125 m^2

Total runoff: 7,125 m^2 * 0.22 m (24h20y rain event) =1,568 m^3

As discussed in the chapter 6, in order to leave enough water storage space for the sequent rainfall event, water in storage facilities has to be drained out within 48 hours. Green areas are located in the loam soil region with the infiltration rate of 1.3 cm/hour (Food and Agriculture Organization of United Nations, 2008), which makes the maximum height of forebays and detention basins in the green areas to be 0.624 m.

So the total water storage capacity of green areas is: 2,360 m^2 (total green area)* 0.624 m (maximum height) = 1,473 m^3

This calculation result shows that almost 94% of stormwater runoff created from streets, agricultural lands, squares and green areas can be stored in forebays and detention areas. And the stored water can be drain-out within 48 hours, making it possible to prepare storage capacities for the next rain event. The Table 7.2 shows the evaluations of the design based on design criteria.

Figure 7.69 The example area in the village for the rough water storage calculation. Source: Google Earth.

Table 7.2 Evaluation of the water storage facilities in the village.

	Criteria	Evaluation
Water storage goal	The total capacity of water storage facilities should be sufficient to handle the amount of surface runoff created in a 24hr 20year rain event	1,473 m^3 Accomplished 94% of total storage capacity
Water quality improvement	- Improve water quality before it is discharged into receiving waters - Apply pretreatment facilities to capture and remove sediments and other heavy matters before water enters treatment BMPs	- Treatment BMPs are implemented on design components at three levels - All treatment BMPs are integrated with pretreatment facilities ahead of them

7.5.2 Hanmo residential community

The Hanmo residential community is a high-density community which is situated in an area of loam soil on a flat plain (Figure 7.70).

After site analysis, in the Hanmo residential community, besides buildings, the surrounding green areas make up the majority of the land surfaces in the community. Other open spaces such as playgrounds and sports fields are not suitable as they are higher than their surrounding and their surface areas are small (Figure 7.71 to 7.73).

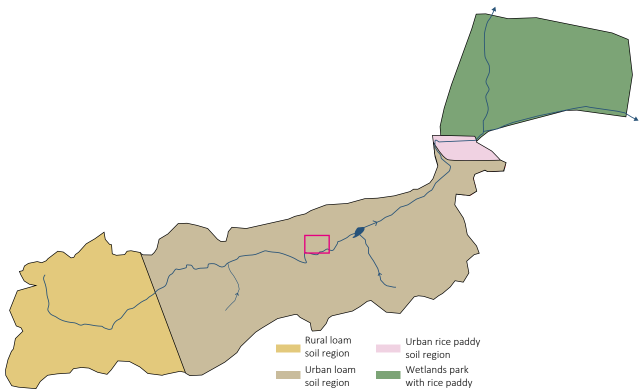


Figure 7.70 Location of Hanmo residential community.

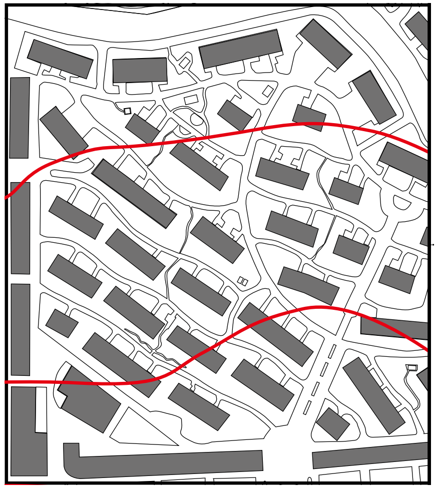


Figure 7.71 Height differences (interval=2m).

Figure 7.72 Land uses with relative height.

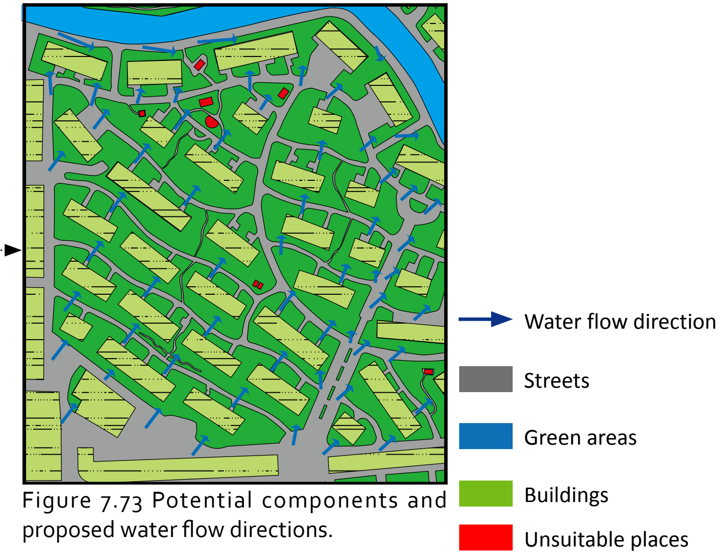


Figure 7.73 Potential components and proposed water flow directions.

On the lots level, 5 to 11-story buildings consist the high-density residential community, in this urban context, green roofs are recommended to help filtrate rainwater drops on roofs. While space underneath the building is possible to be explored, and dry wells can be connected with downspouts to collect water from green roofs. Water contemporarily stored in the dry well can recharge the groundwater after the rainfall (Figure 7.76).


Figure 7.74 Location of buildings.


Figure 7.75 Existing situation of buildings. Source: photo by the author.

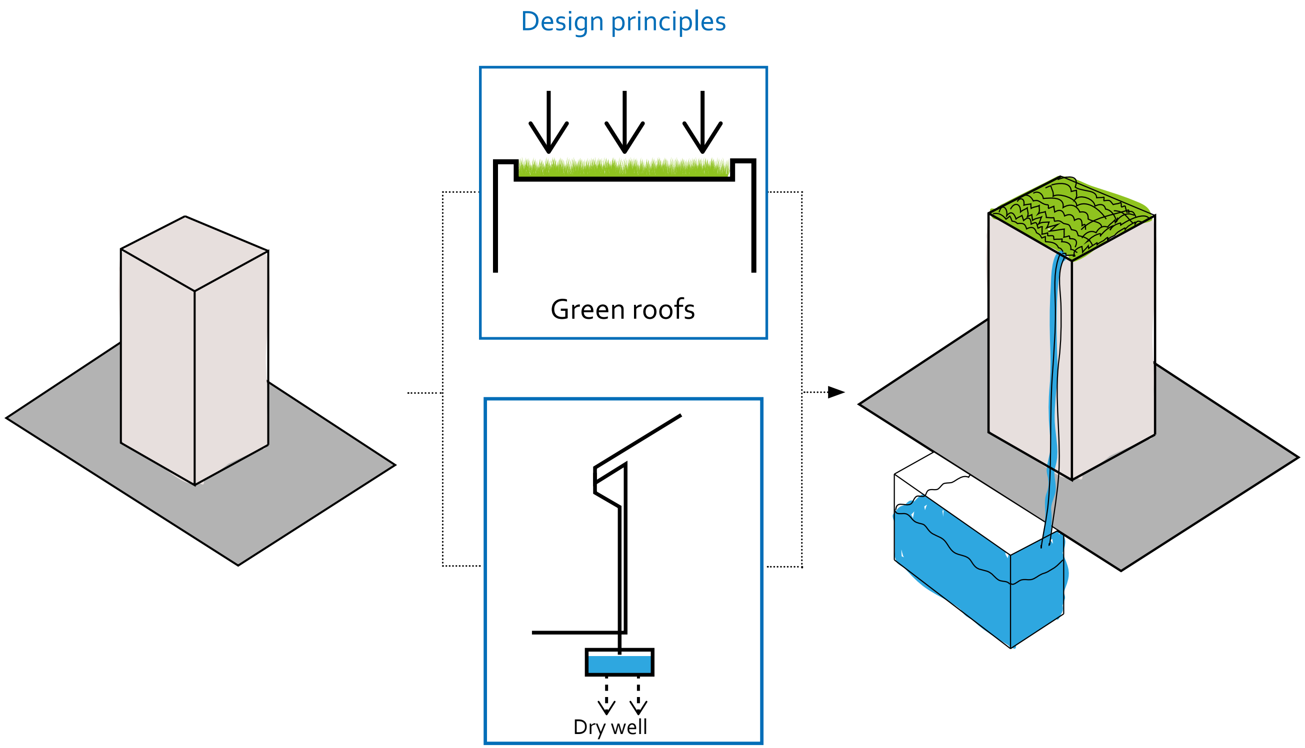


Figure 7.76 Design principles on residential buildings.

Streets within the residential community provide on-street parking, the parking space, and can be provided with permeable pavement to enable the water infiltration proces (Figure 7.79).

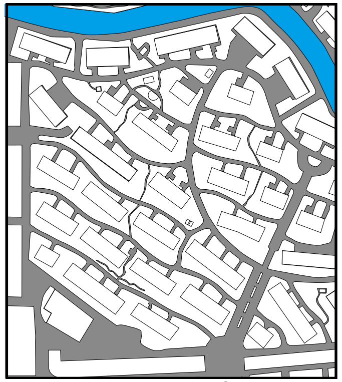


Figure 7.77 Location of streets.

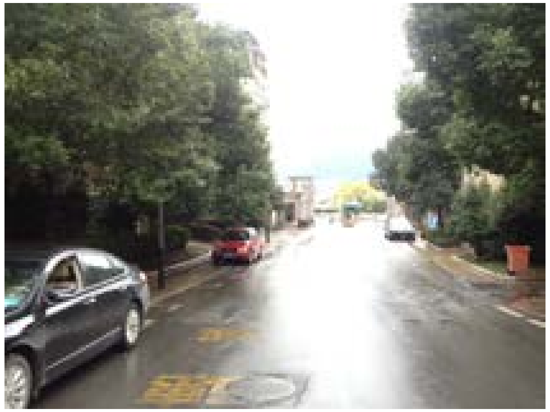


Figure 7.78 Existing situation of streets. Source: photo by the author.

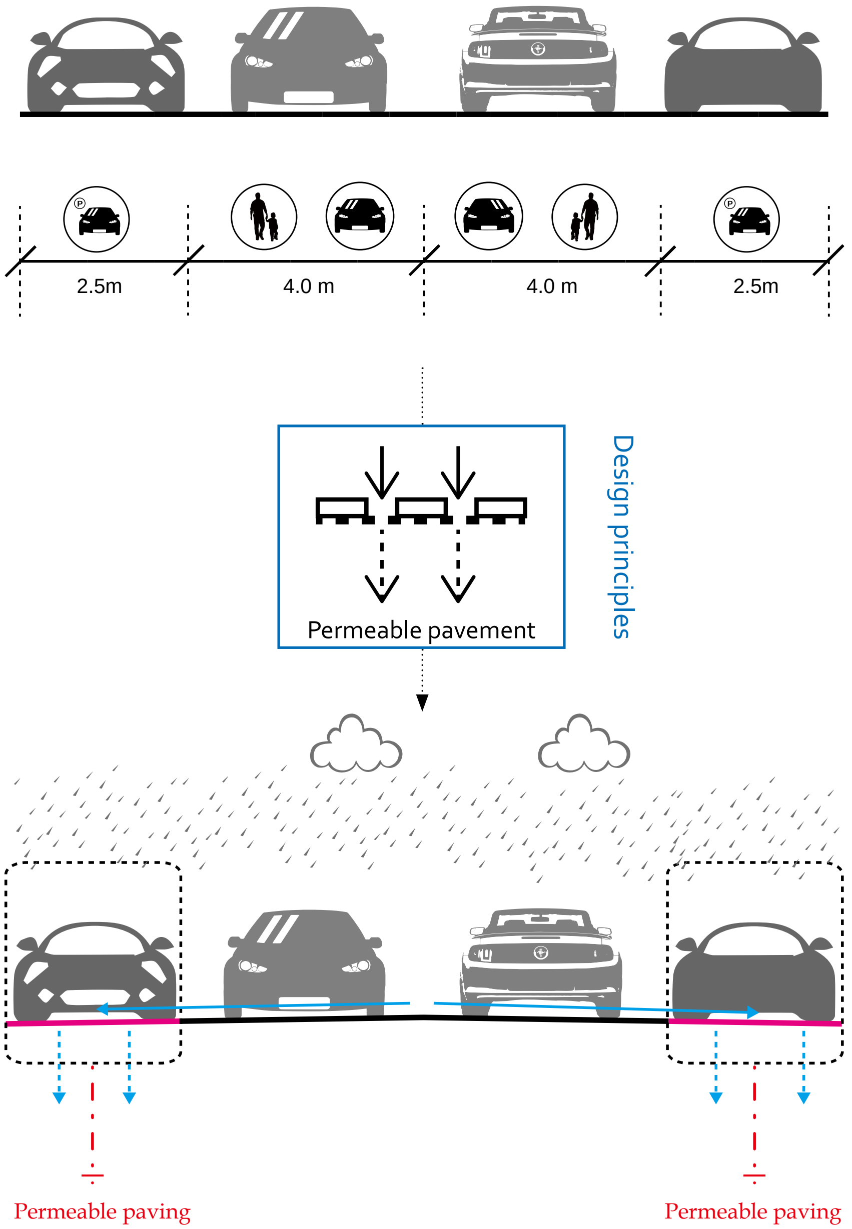


Figure 7.79 Design principles on residential streets.

Green areas provide the greatest opportunity to store and treat stormwater on site as it occupies most of the surface area in the community (Figure 7.80). Rain gardens can be designed to store, infiltrate and treat water. Pretreatment is required here to remove sediments before water flows into rain gardens in order to ensure its high level of treatment. Also long and continuous green areas offer opportunities to implement vegetated swale to treat stormwater runoff. As the green area is also adjacent to the street, swales can also collect excess stormwater from streets. Check dams can be along the swale so that more water can be held, providing more time for infiltration and purification in the vegetated swale. Sediments which are not trapped by the swale will settle down due to the reduced water velocity (Figure 7.82).

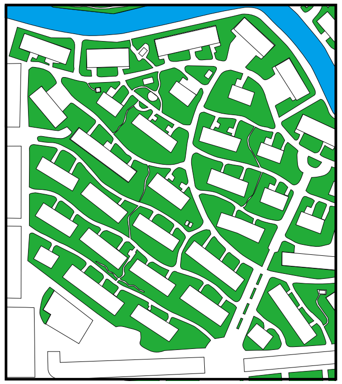


Figure 7.80 Location of green areas.

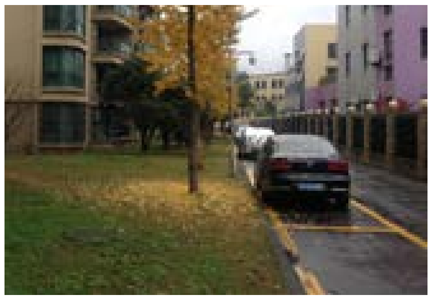


Figure 7.81 Existing situation of streets and green areas. Source: photo by the author.

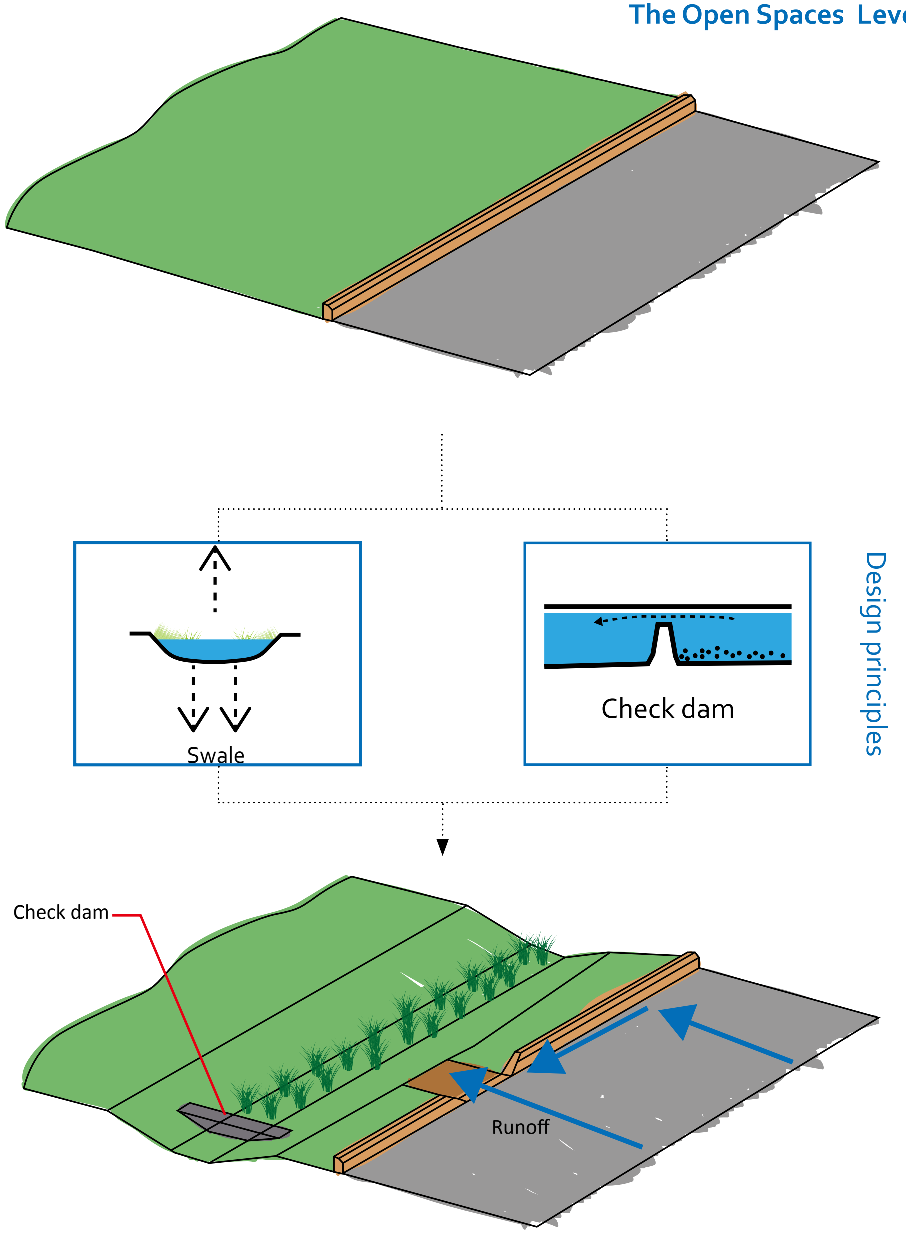


Figure 7.82 Design principles showing how swales and check dams can treat stormwater from streets.

The swale is connected with the rain garden, where pre-treated water can be further treated. In case of extreme rainfalls, extra areas are depressed with certain degrees at far edges of rain gardens, so that they can hold overflows during heavy rainfall situation (Figure 7.83).

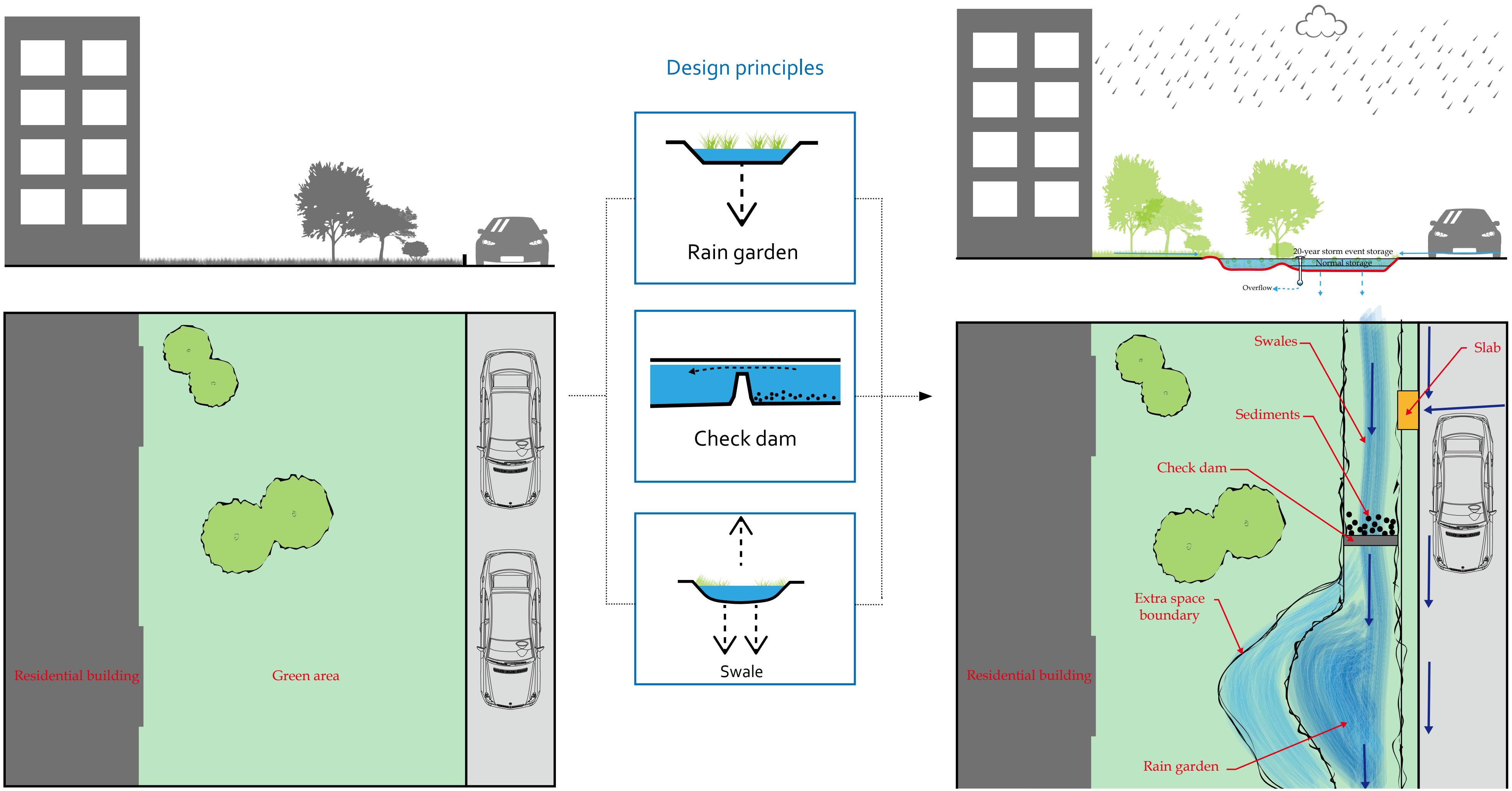


Figure 7.83 Design principles on green areas surround buildings.

The impressions show how the design can manage stormwater under different rainfall situations (Figure 7.85 to 7.87).

Figure 7.84 Existing situation of the green area surrounds residential buildings. Source: photo by the author

Impression A in the dry condition

Figure 7.85 Impression A showing the rain garden and swale can provide aesthetic beauty in dry situations.

Impression B during a normal rainfall event

Figure 7.86 Impression B showing the rain garden is coverd with water in the normal rainfall event.

Impression C during an extreme rainfall event

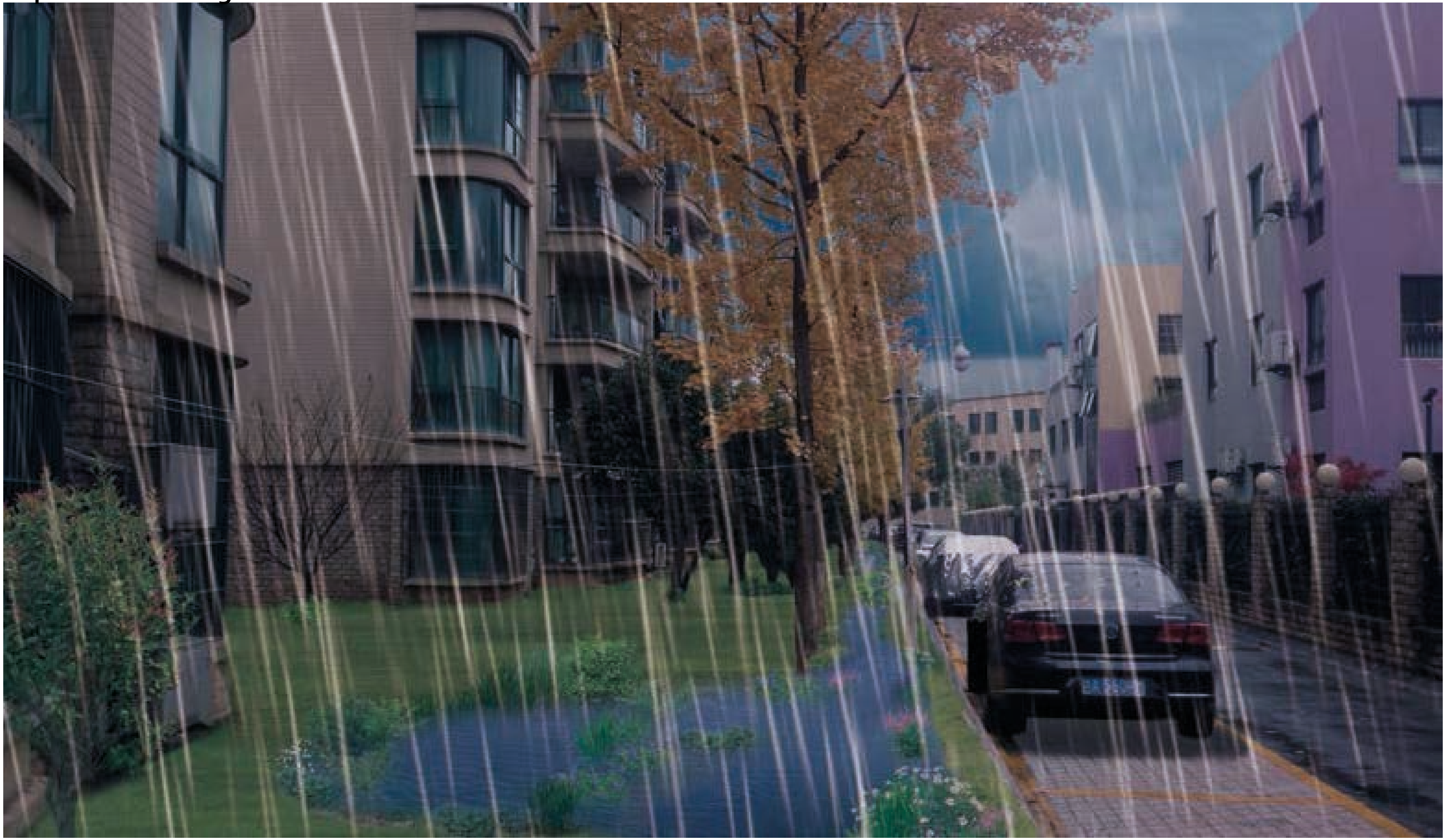


Figure 7.87 Impression C showing the rain garden and the extra space is filled with water during the extreme rainfall event.

Green areas and buildings are two major stormwater components that control the water quantity. Green areas receive surface runoff coming from streets, squares and playground. It is presumed that green roofs and underground dry wells implement on buildings can handle the amount of rainwater drops on them.

Stormwater runoff created surface area: 100,500 m^2 (total area)-18,510 m^2(buildings and backyards)=81,990 m^2

Total runoff: 81,990 m^2 * 0.22 m (24h20y rain event) =18,038 m^3

The total green areas surface: 42.875 m^2

However, in this situation, apparently not all green areas will be used for rain gardens as they also need to be provided with swales. So needed green area surface is: 18,038m^3 (total runoff) / 0.624 m (maximum height for 48 drain-out time) = 28,907 m^2. The required green area surface is smaller than the total green area surface, so the water storage goal can be fully achieved.

The Table 7.3 shows the evaluations of the design based on design criteria.

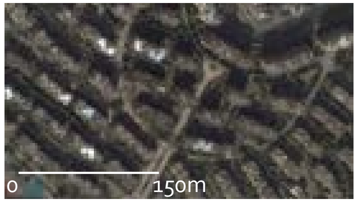


Figure 7.88 Example site for a rough water storage calculation. Source: Google Earth

Table 7.3 Evaluation of the water storage facilities in the residential community

	Criteria	Evaluation
Water storage goal	The total capacity of water storage facilities should be sufficient to handle the amount of surface runoff created in a 24hr20year rain event	100% of the total runoff storage requirement can be achieved
Water quality improvement	- Improve water quality before it is discharged into receiving waters - Apply pretreatment facilities to capture and remove sediments and other heavy matters before water enters treatment BMPs	- Treatment BMPs are implemented on design components at three levels - All treatment BMPs are integrated with pretreatment facilities ahead of them

7.5.3 Parking lots and streets within Xixi wetlands park

Xixi wetlands park is a popular tourism destination for people to experience wild life and natural scenery in the city. To help accommodating high visitation to the park, more parking lots and streets are being built since 2012. However, as parking lots and streets in the development area in the wetlands park have been recognized as major sources of pollutants in the wetland park (Dong et al., 2013), the more of them means the higher risks of exposing the wetlands to more pollutants. One parking lot, one main traffic road and one pedestrian street are selected to set examples of managing stormwater runoff for the rest of the wetlands park.

Stakeholders of the wetlands park noticed the negative impact from parking lots, so they put a conventional landscape median between existing parking spaces to reduce the paved surface area (Figure 7.92). In order to fully utilize the potential in those landscape median, vegetated swales are implemented in the long landscape strip, collecting stormwater from the parking lot. As the width of the current landscape median is not wide enough to implement swales, green gutters will be implemented instead. It functions as a pretreatment facility, removing sediments while transporting stormwater to rain gardens at the landscape island. Check dams are implemented along the green gutter to help reduce water velocities, so that sediments can

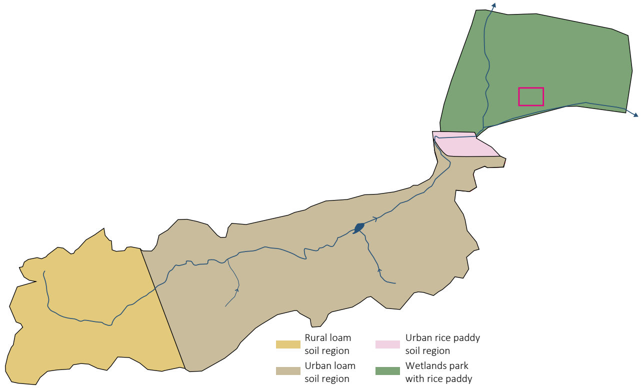


Figure 7.89 Location of the wetlands park.

Figure 7.90 Location of the parking lots in the wetlands park. Source: Google Earth.

Figure 7.91 Existing situation of the parking lots. Source: photo by the author.

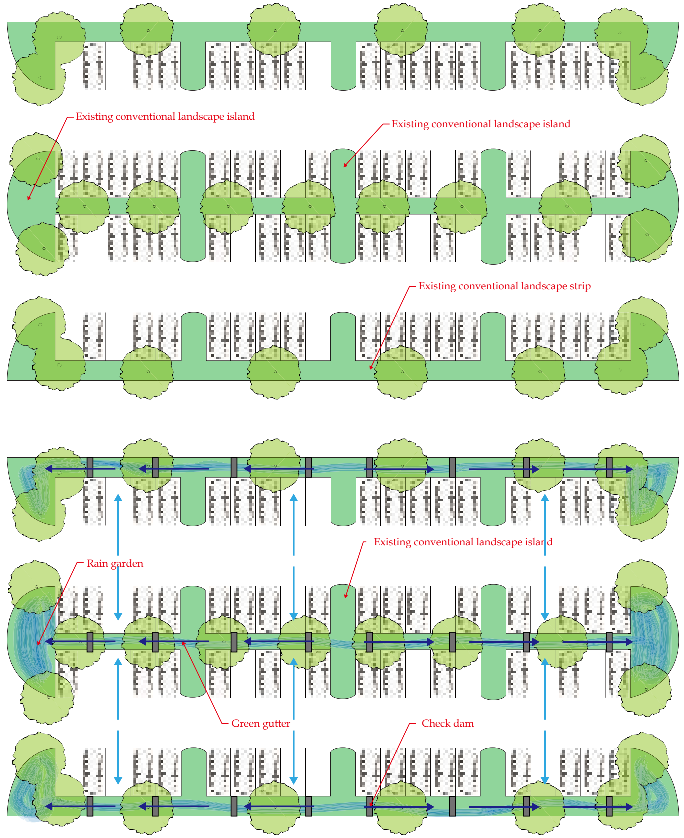
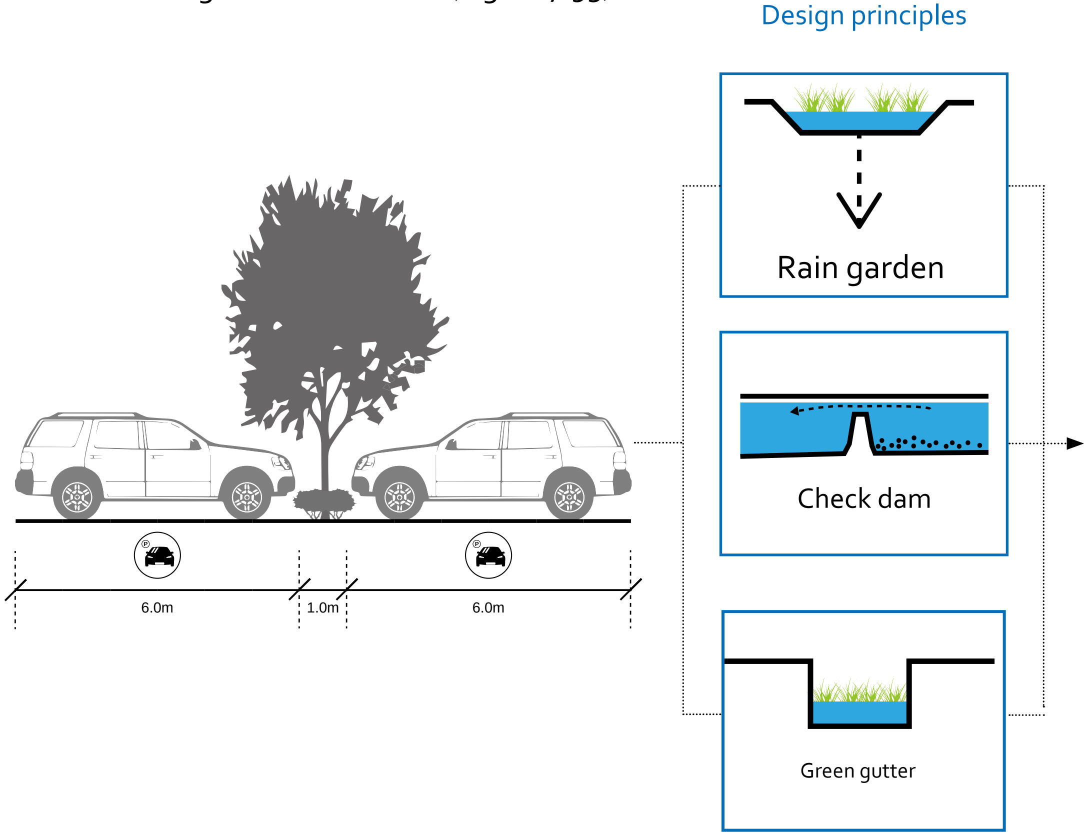


Figure 7.92 Existing conventional landscape areas are converted to stormwater facilities.

settle down before the water finally enters the rain garden. As the parking lot is situated on the low permeable rice paddy soil, perforated underdrain and amended soil mix are put underneath swales and rain gardens in order to increase the soil's water storage capacity. Raised outlet are put in rain gardens to drain out overflows during extreme rainfalls (Figure 7.93).

The Streets Level



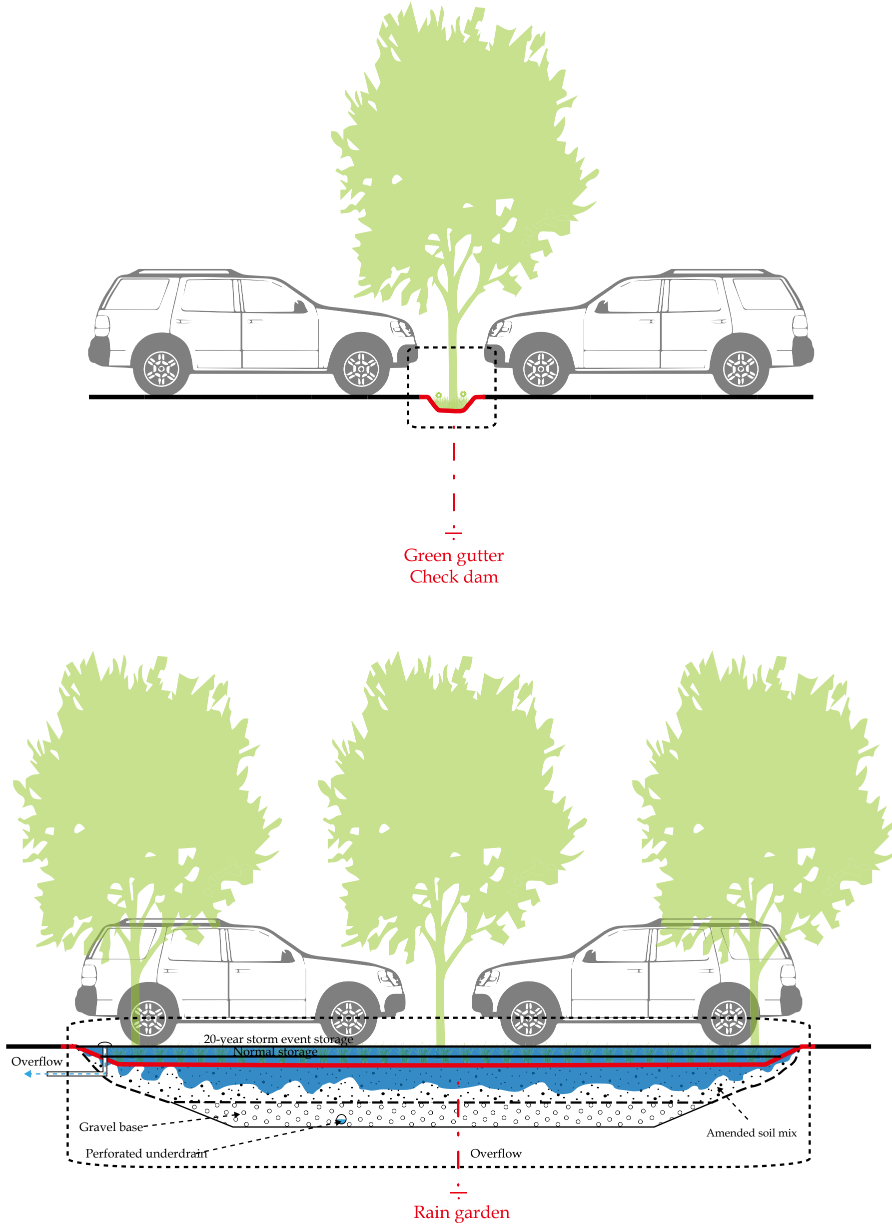


Figure 7.93 Design principles for the parking lots.

The current sidewalks in major traffic streets are wide, but as the wetlands park experience many visitors, it is not recommended to occupy too much space of sidewalks (Figure 7.93). In order to save space, green gutters are built on both sides of the street to collect stormwater and pollutants from the street. They are pretreatment facilities conveying and purifying water to curb extensions which are located at certain points of the street, e.g. street corners. Curb extensions are designed to store stormwater and provide further quality treatment, on the other hand, they help calm the traffic, creating safer streets for pedestrians. Like the rain garden in the parking lot, perforated underdrains and an amended soil mix are put under curb extensions in order to increase the soil's water storage capacity. Overflow outlets are designed in curb extensions, when the overflow occurs, it will be transported to depressed basins designed at riparian areas of wetlands.

Figure 7.94 Location of the major traffic street in the wetlands park. Source: Google Earth.

Figure 7.95 Existing situation of the major traffic street. Source: Baidu Maps.

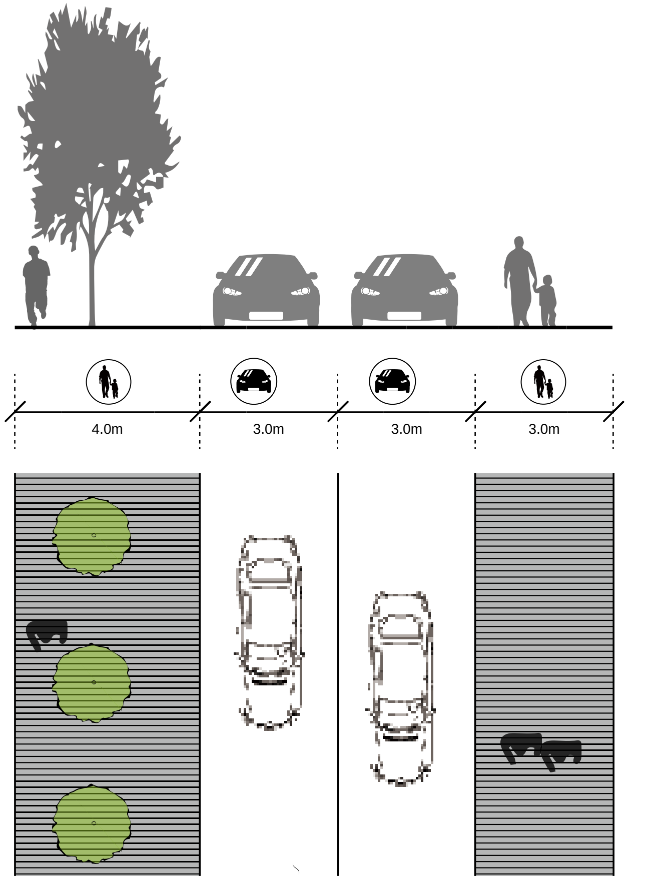
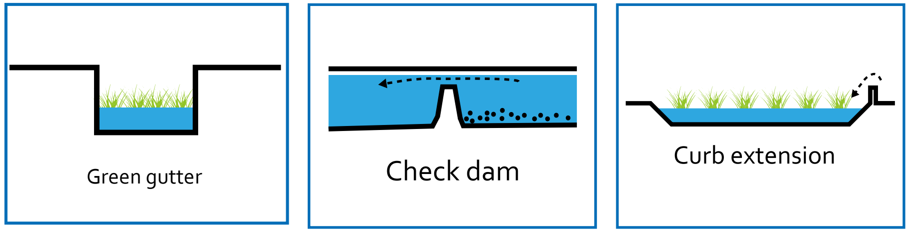


Figure 7.96 Existing major street typology.

Design principles



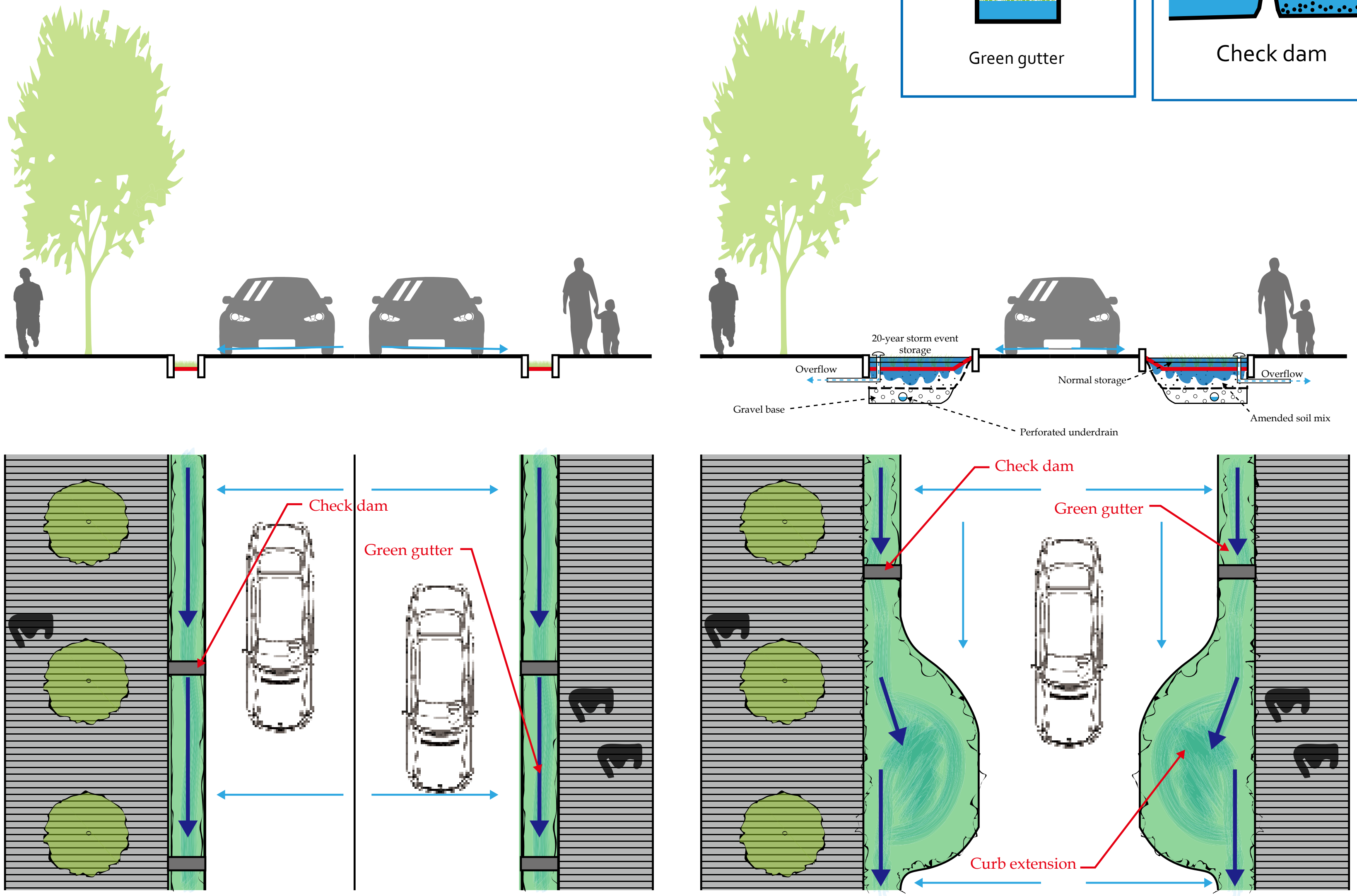


Figure 7.97 Design principles for the major traffic street.

Figure 7.98 Existing situation of the major traffic street in the wetlands park. Source: Baidu Maps.

Impression A in the dry condition

Figure 7.99 Impression A showing the curb extentions and green gutters create a natural feeling in the park.

Pedestrian streets connect major traffic streets to tourist places inside development area in the wetlands park. The width of each street is normally wide (around 6 meters), enough for the implementation of stormwater facilities without compromising pedestrians' walking experience (Figure 7.101). Considered that pedestrian streets usually are less exposed to sediments, so the pretreatment process is not very necessary in this situation in order to be cost-effective. Stormwater planters are chosen as the most suitable facility to treat stormwater because their appearances are fitted into the development area. Street benches can also be installed along the stormwater planter to offer sitting areas for people. Due to the low impermeability of rice paddy soils, perforated underdrains and amended soil mix are required to be put below stormwater planters to facilitate their drainage process. The raised water outlet is installed to deal with overflows (Figure 7.103).

Figure 7.100 Location of pedestrian street in the wetlands park. Source: Google Earth.

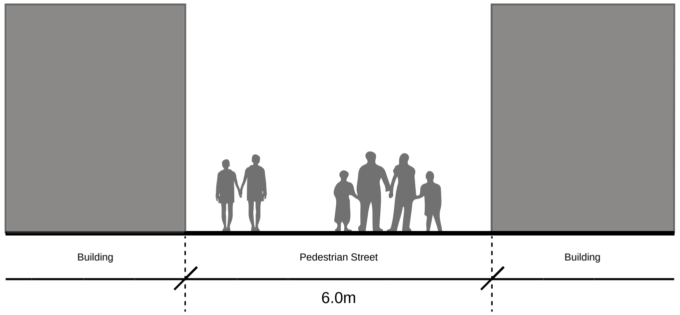


Figure 7.101 Existing situation of the pedestrian street. Source: http://www.shidi.org/.

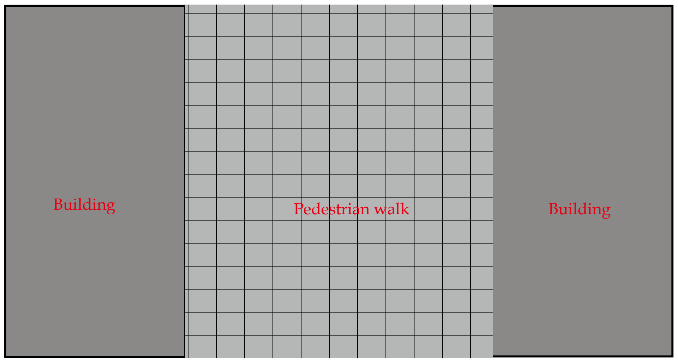
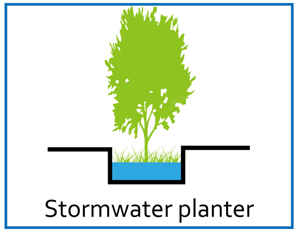
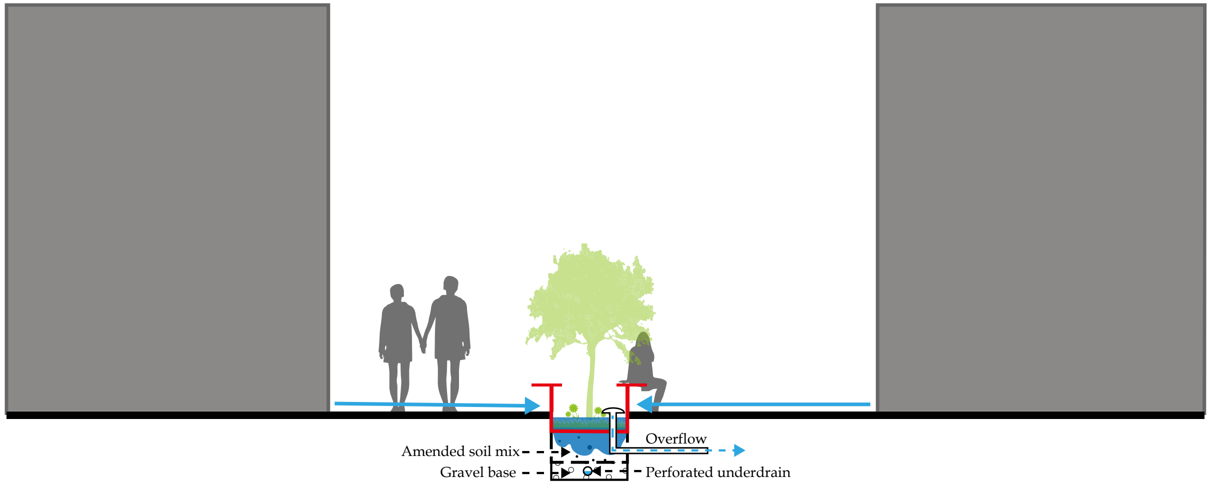


Figure 7.102 Existing pedestrian street typology.

Design principles





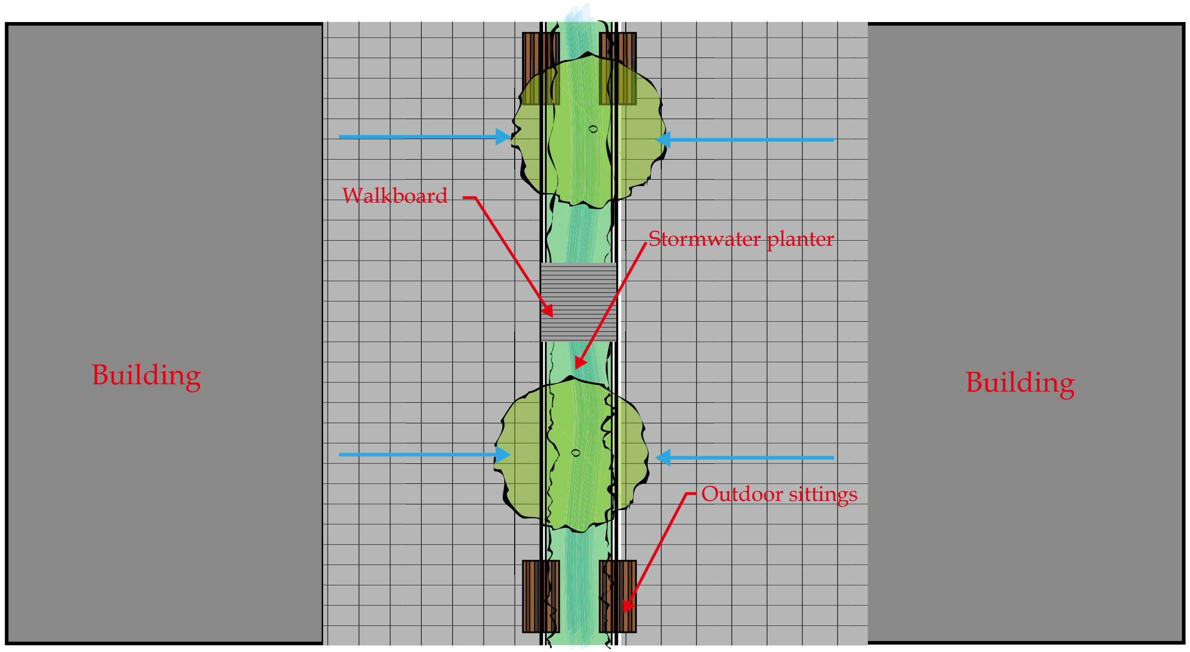


Figure 7.103 Design principles on the pedestrian street.

Figure 7.104 Existing situation of the pedestrian street.
Source: http://www.shidi.org/.

Impression A in the dry condition

Figure 7.105 Impression A showing the stormwater planters and outdoor sitting implemented on the pedestrian street offer both aesthetic beauty and comfort to visitors.

A rough calculation of the water storage capacity is conducted on the parking lots, pedestrian streets and traffic streets to examine the reliability of the stormwater design.

1) on the parking lots

Total surface area: 3,750 m^2

Total volume of the stormwater created during the 24 hr 20 year rain event: 3,750 * 0.22 = 825 m^3

The storage capacity of rain gardens: 287 m^2 (total rain garden surface area) * 0.624 m (maximum height) = 179.1 m^3

Figure 7.106 The example site of parking lots for the rough calculation of the water storage capacity. Source: Google Earth.

2) on the major traffic street

Total surface area: 446 m (length of the traffic street) * 14 m (width of the street) =6,244 m^2

Total volume of the stormwater created during the 24 hr 20 year rain event: 6,244 * 0.22 = 1,374 m^3

The storage capacity of curb extensions: 840 m^2 (total curb extensions surface area) * 0.624 m (maximum height) = 524.2 m^3

Figure 7.107 The example of traffic road for the rough calculation of the water storage capacity. Source: Google Earth.

3) on the pedestrian streets

Total surface area: 718 m (length of pedestrian streets) * 6 m (width of the street) =4,308 m^2

Total volume of the stormwater created during the 24 hr 20 year rain event: 4,308 * 0.22 = 947.8 m^3

The storage capacity of curb extensions: 718 m (length of pedestrian streets) * 1 m (width of stormwater planters) * 0.624 m (maximum height) = 448 m^3

Figure 7.108 The example of pedestrian streets for the rough calculation of the water storage capacity. Source: Google Earth.

It is clear that the volume of rain gardens implemented in the parking lots can only fulfill around 21 % of the total stormwater storage goal. While curb extensions and stormwater planters can achieve 38.1 % and 47.3 % of the water storage assignments, respectively. The water quantity control performances on parking lots, streets in the wetlands park are sufficient to handle the amount of stormwater created during the 24 hr 20 year rain event, but this is still ok as the water drainage burden has been reduced compared with previous condition. More importantly, the focus stormwater designs on the wetlands park is to reduce pollutants that flows into the wetlands. By applying a combination of pretreatment and major treatment facilities, the key pollutant, namely sediments is expected to be captured and removed from the water.

The Table 7.4 shows the evaluations of the design based on design criteria.

Table 7.4 Evaluation of the water storage facilities in the wetlands park.

	Criteria	Evaluation
Water storage goal	The total capacity of water storage facilities should be sufficient to handle the amount of surface runoff created in a 24hr20year rain event	- 21% of the total runoff storage requirement can be achieved on parking lots - 38.1 % of the total runoff storage requirement can be achieved on major traffic street -47.3 % of the total runoff storage requirement can be achieved on pedestrian streets
Water quality improvement	- Improve water quality before it is discharged into receiving waters - Apply pretreatment facilities to capture and remove sediments and other heavy matters before water enters treatment BMPs	- Treatment BMPs are on along streets and parking lots - All treatment BMPs are integrated with pretreatment facilities

8. Reflection, Discussion and Conclusions

8.1 Reflection and Discussion

8.2 Conclusions

8.1 Reflection and Discussion

In this thesis research, the combined approach of SUDS and BMPs was implemented in three different land uses (a village, an urban residential community, and the wetlands park) in the Shangbu Watershed. Designs were proposed on three levels (the lots level, the streets level and the open spaces level) in each land use to deal with stormwater quantity and water quality problems.

Designs of the rural village and the urban residential community at the open spaces level show that they have a great potential to solve large quantities of stormwater in each site by transforming current underutilized green areas into water storage facilities such as retention basins and detention basins. They can store more than 90% of the total amount of water created in a 24hour-20year storm event. Pretreatment BMPs can be integrated with other treatment BMPs to ensure the high level of pollutants removal in stormwater.

The potential to solve excessive amounts of stormwater and poor water quality also exists on the steep topography. In the design proposal for green areas on the steep foothill, a series of terraced basins are made to decrease water velocity, store it temporarily, and let it infiltrate into the soil. This design proposal also prevents the soil erosion which may happen on steep slopes.

Besides dealing with stormwater quantity and quality, the combined approach also shows the potential to improve biodiversity when it is implemented on a larger scale in the city. This is because the combined approach relies largely on green materials such as tree canopies which are implemented on roofs, streets and open spaces.

However, design proposals show that there is less potential to store water on the streets level. In rural and urban areas, traffic lanes occupy the majority of road surfaces. Potential to apply stormwater facilities can only be sought on narrow pedestrian sidewalks and existing landscape medians. Compared to rural and urban areas, potential on the streets level is higher in the wetlands park as wide sidewalks (wider than 3m) are a common street component there. In addition, the design proposal also indicates it is possible to store more water on streets by creating curb extensions on roads, which can also calm the traffic and provide safety for pedestrians. But the stormwater design on the streets level in the wetlands can only fulfill less than 40% of the total water storage goal.

In the designing phase, some uncertainties have been identified that need to be further discussed.

In all three design proposals, stormwater designs focus on surfaces, however, space beneath the ground is also worth being explored to create extra "room" for water storage. For instance, underground water cistern can be implemented underneath squares, so that they can be used for storing cleaned water from other places. And the water here can either be used for irrigation or recharging the groundwater (Figure 8.1).But the space underground may be full of utilities such as underground power lines, gas lines and water lines, which conflict with underground stormwater facilities. Due to the lack of necessary data, the underground space is not researched in the thesis, but it can be a valuable component in the city, particularly in urban places where there is very limited surface area.

Secondly, the possibility of co-existence between long time water retention and the prevention of mosquito breeding has not been researched during the thesis. For instance, water storages near high water-demanding places (agricultural fields), are designed to stay dry on normal days as they are situated on loam soils with deep groundwater level. If they can keep water within them for a long period, especially in summer days, they can provide water for irrigating those farm lands. But too much surface water may increase the risk of mosquito breeding, which further can pose health threats to local people. Therefore, how to balance these two issues needs future research.

Lastly, rough calculations were carried out in each exemplary design site to examine how the combined approach can achieve the stormwater storage goal. However, the result might not be very accurate as the calculation method used is based on the ***Total water storage of all available water storage basins in the example site*** divided by ***Total volume of stormwater created in the same site***. Because each water storage basin receives different amounts of water, which means the basin situated on the higher ground may receive less stormwater while the one located on the lower ground will receive more water. Therefore, more detailed data and calculation will be required in order to make the water storage capacity evaluation more accurate.

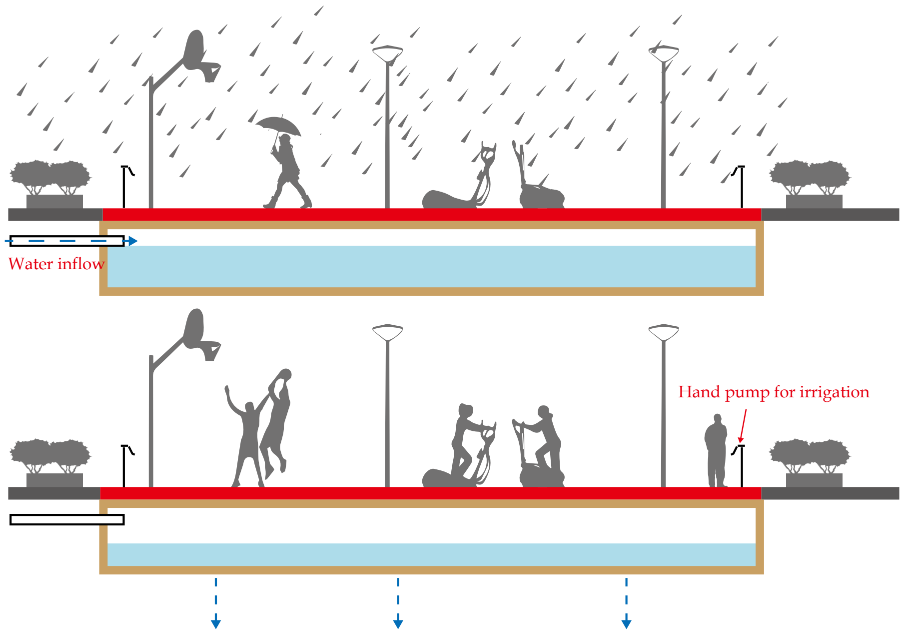


Figure 8.1 The possible solution of the underground water cistern used for places that are not suitable for surface water storages.

8.2 Conclusions

This master thesis starts from the fascination of urban flooding and water pollution, two most prominent water issues in China, especially in those urbanized and populous cities. The issues are urgent and responding solutions are of great importance to those urbanized cities since it became clear that the altered landscape surface and water system have significantly influenced those cities and their people in a negative way.

The city of Hangzhou, a highly urbanized and populated city in China was selected as a research case in this thesis. The aim was to use Hangzhou as a representative to provide representative solutions for other four flood- and pollution-troubled cities, namely Ningbo, Guangzhou and Xiamen, which have similar landscape characteristics to Hangzhou.

Two leading stormwater management approaches: the Sustainable Urban Drainage System (SUDS) and the Best Management Practices (BMPs) approach were chosen as the best ways to solve the water problems Hangzhou is facing.

My main research question was that: ***"How can the SUDS and BMPs be combined to solve both the water quantity and quality problems at the same time in Hangzhou?"***

Two sub-questions were formed based on the main question. And the main research question can be responded by answering the two sub-questions which are presented below:

1. How to manage excess stormwater runoff and poor water quality on lots, streets and open spaces levels in accordance with the SUDS and BMPs?

In chapter 6, potentials on lots, streets and open spaces levels were explored to control water quantity as well as to improve quality. In order to ensure a high level of pollutants removal process in stormwater facilities, three forms of the pretreatment process had also been researched in accordance with the way how the pretreatment facility receives the water. The result was the combined approach, which included pretreatment and other stormwater facilities to remove sediments and other heavy matters before the water is treated on the three mentioned levels. The combined approach can be integrated on a larger scale to form a new water system which relies on the processes of slow, recharge, and store and reuse to prevent water flooding and improve water quality (Figure8.2).

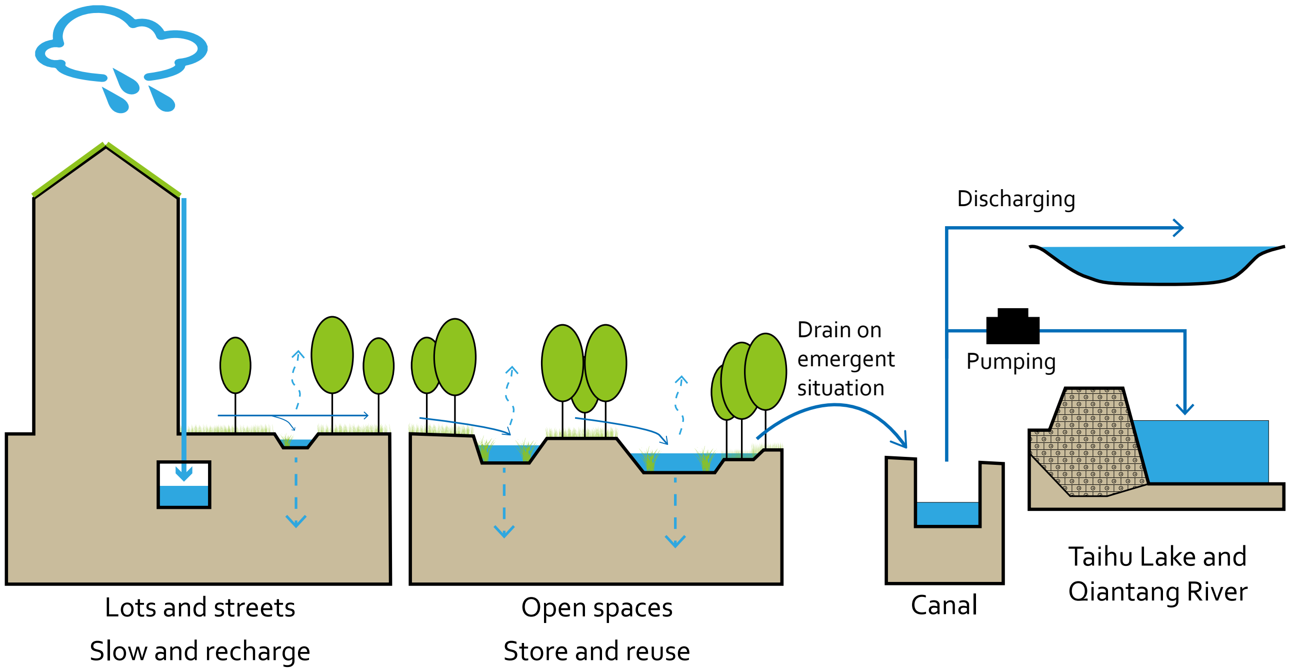


Figure 8.2 The combined approach relies on the process of slow, recharge, store and reuse water to prevent flooding, and improve water quality on a regional level.

2. How can design principles be generated by integrating SUDS and BMPs into Hangzhou on its lots, streets and open spaces levels?

To answer the second research question, I chose the Shangbu Watershed, which has similar landscape characteristics in soils, topography and groundwater to Hangzhou. And it served as an exemplary study case to show how the combined approach can be integrated to address flooding and water pollution issues in Liuxia, a densely populated urban area at the end of the watershed. Four watershed-scale strategies were made for the four distinctive landscapes in the watershed, namely the rural loam soil region, the urban loam soil region, the urban rice paddy soil region and the wetlands park with rice paddy soil. Each strategy provided potential landscape components that can be used for water storage and treatment based on site analysis.

Later, three sites: Yunxi village, Hanmo residential community and one development area in Xixi wetlands park in the watershed, were selected as exemplary design projects to demonstrate the application of the combined approach into site-specific sites. Designs were proposed for each exemplary design site on lots, streets and open spaces levels, aiming to solve the flooding and water pollution problems occuring within each site.

The research and design in the three exemplary design projects resulted in several design principles which were implemented on the lots level, the streets level and the open spaces level. And they are listed in the Figure 8.3.

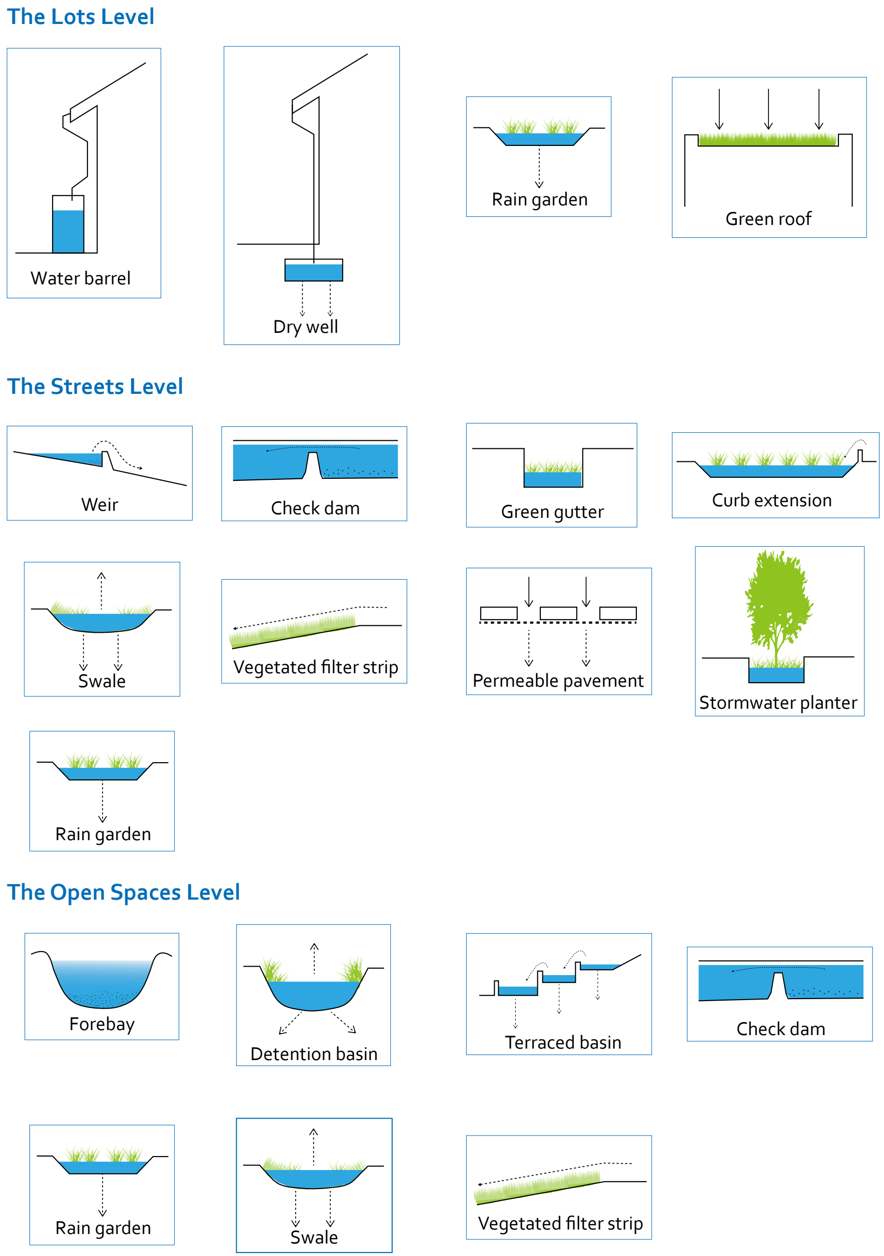


Figure 8.3 Design principles generated for the lots level, the streets level and the open spaces level.

Furthermore, the research and design resulted in six common BMPs treatment train configurations on the mentioned three levels that can improve water quality with high level of treatment and long-term efficiency by integrating pretreatment facilities into the treatment train (Figure 8.4)

Techniques such as check dams were integrated with facilities such as swales on the street level to help reduce water velocity and hold water within the facility longer for better treatment such as infiltration and plants taking up process.

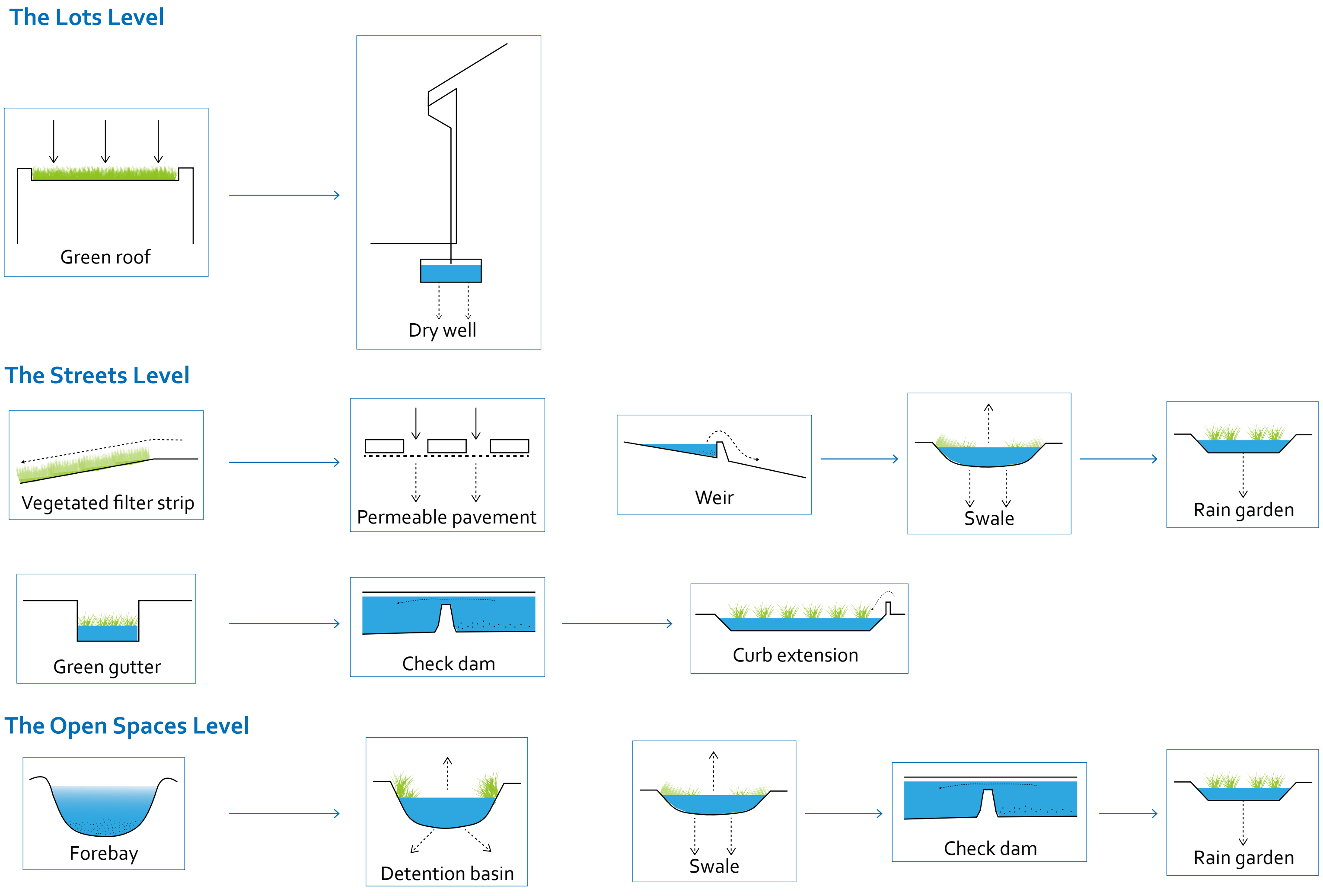


Figure 8.4 Common BMPs treatment train configurations for the lots level, the streets level and the open spaces level.

In general, green areas were the major component among all design components on the three levels (lots, streets and open spaces). They can easily be re-graded to create space for water quantity control and quality improvement. But there are still distinctions when apply the combined approach to the green area in the three different land uses due to their unique spatial settings.

In the rural village, green areas are independent patches which receive water coming from streets. Those green areas can be used as forebays, detention basins or the combination of the two. Water flows along the street and enters green areas in a "linear" form (Figure 8.5). Normally, they can have bigger storage volumes by increasing the height of detention basins.

In the urban residential community, green areas enclose residential buildings. As green areas here also are adjacent to residential street which has little space for implementing conveyance facilities, green areas take the responsibility of being a water quantity and quality control, and the water transporting system. Water from the street enters the green area in a "sheet-flow" form. The combination of swales and check dams aim to pre-remove sediments and other heavy matters before the water flows into the rain garden - the major water quantity and quality control facility. Unlike detention basins in the rural village, rain gardens have shallow depth which restrict their storage capacities. Thus, extra space surround rain gardens are created in the preparation of extreme precipitation events (Figure 8.6).

While in the wetlands park, large proportion of green areas are arrayed along streets and parking lots. Street and parking lots already have a lot of potentials to implement stormwater facilities as sidewalks on streets are wide and parking lots have many landscape islands and strips presented on site (Chapter 7.5.3). Therefore, storwmater can be transported, treated and contemporarily stored on the street, while overflows can flow into green areas for further storage (Figure 8.7).

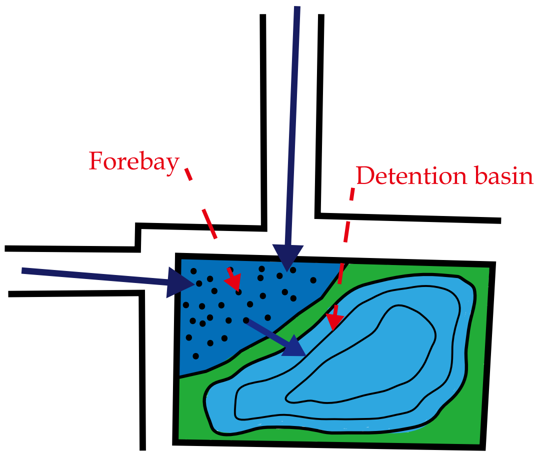


Figure 8.5 Typical design interventions on green areas in the village.

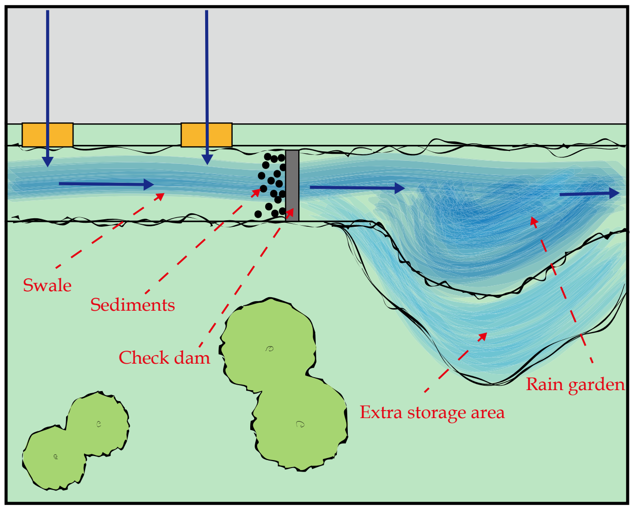


Figure 8.6 Typical design interventions on green areas in the urban residential community.

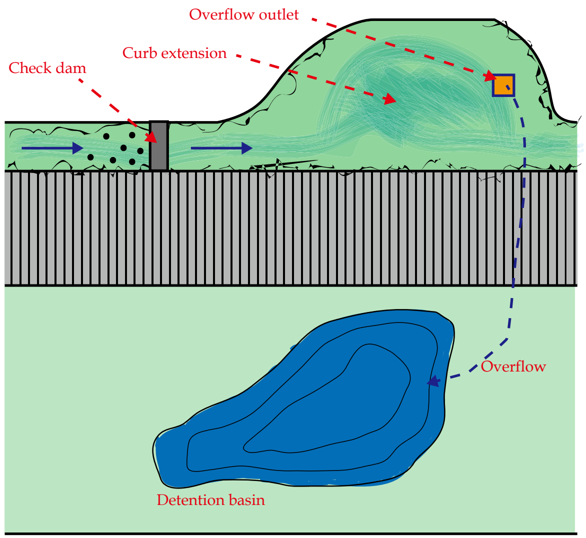


Figure 8.7 Typical design interventions on green areas and streets in the wetlands park.

In conclusion, general strategies had been proposed to four different landscapes in the Shangbu watershed, and design principles made for three exemplary land uses were inspiring and replicable to similar land uses with similar landscape characteristics in soils, topography and groundwater. But the work of solving flooding and water pollution issues is not complete as only three land use types had been given design solutions and principles. Therefore, more researches are need to be done on other land uses such as educational land uses and commercial land uses in order to provide solutions and design principles that are replicable in other areas in Hangzhou and other cities with similar landscape characteristics.

9. Glossary

Watershed
A watershed is an area where all of the water which drains off of it flows into the same place (United States Environmental Protection Agency, 2012).

Hydrology
Hydrology is the science that studies the occurrence, distribution, movement and properties of all kinds of water on earth and their relationship with the environment (USGS, 2014b).

First flush
It refers to the initial runoff from a rain event (Coastal Watershed Council, 2014).

Weir
A type of low wall or dam which is built across a linear water body to raise the water level or to change its flowing direction (Merriam-Webster, 2015).

Infiltration
Infiltration means the process of water on the ground surface enters the soil (USGS, 2014a).

Detention
It is the process of holding of stormwater in facilities such as a swale, a detention basin, or other features temporarily (United States Environmental Protection Agency, 2014a).

Retention
Contrary to the detention basin, the retention means the process holding of stormwater in a basin, or a pond permanently (united States Environmental Protection Agency, 2014b).

Stormwater harvesting
It is the process of collection, accumulation, purification, and storage of stormwater and reuse it (GDRC, 2015).

Sedimentation
It is the process by which solids are removed from the water column by settling (Gulliver et al., 2010).

Stormwater runoff
It is the flow of water that occurs when excess stormwater, meltwater, or other sources flows over the earth's surface (Sayre et al., 2006).

Water quality
It is a measure of the condition of water, based on its chemical, physical, and biological characteristics, normally it is used to determine whether the water is suitable for certain purposes such as drinking or swimming (National Ocean Service, 2011)

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Figure 7.495: photo by the author

Figure 7.53: photo by the author

Figure 7.55: photo by the author

Figure 7.55: photo by the author

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Figure 7.95: Baidu Maps

Figure 7.95: Baidu Maps

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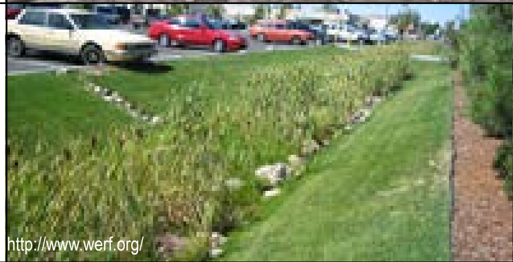
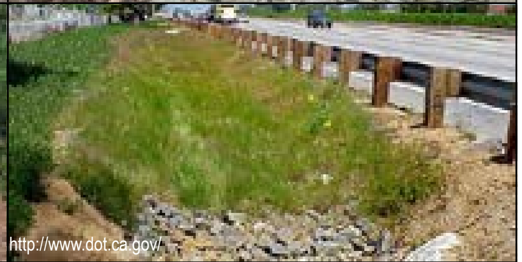
12. Apendix

Appendix A: Common Stormwater Facilities Used in Permeable Soil Regions

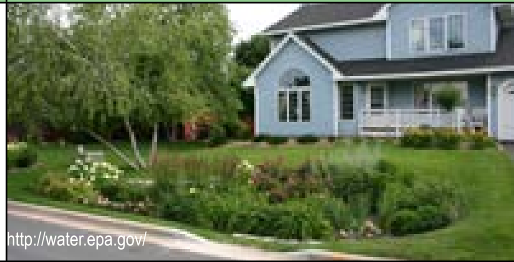
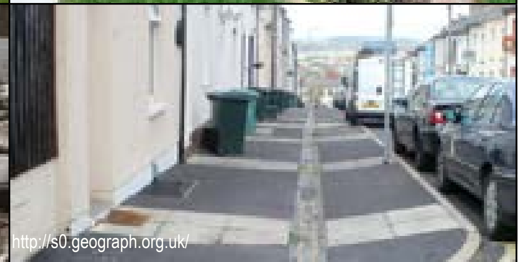
Appendix B: Common Stormwater Facilities Used in Impermeable Soil Regions

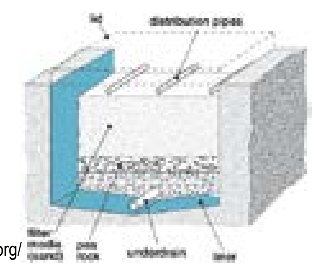
Appendix C: Common Stormwater Facilities Used in Water Bodies

Appendix A: Common Stormwater Facilities Used in Permeable Soil Regions

Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images
Permeable pavement is designed to allow percolation or infiltration of stormwater through the surface into the soil below where the water is naturally filtered and pollutants are removed.	Infiltration Treatment Detention (if aggressive base is provided underneath the pavement)	1. preferred to be used in a region of permeable soils; when used in low permeable soils, a base composed of clean washed stone with 25-35%voids is required as temporary storage for stormwater; 2. to be implemented in low traffic areas; 3. at least 1.2 meters above bedrock or the seasonally high groundwater table. 4. cannot be implemented in areas with slopes geater than 10 percent.	●●●	●●●	 
Infiltration trench is an excavation filled with porous material, which collects run-off. Stormwater infiltrates from the walls and base of the trench into the surrounding soil, while particulate and some dissolved pollutants are retained in the porous material.	Infiltration Treatment	1. permeable soils; 2. the bottom of the infiltration trench should be at least 1 meter higher than the seasonally high groundwater table; 3. cannot be implemented in areas with slopes geater than 15 percent;	●●●	●●●	 
Vegetated swales are shallow, broad and conveyance channels planted with vegatation that help slow srunoff facilitate infiltration, filter pollutants from runoff and recharge groundwater.	Infiltration Detention Treatment Conveyance	1. cannot be implemented in areas with slopes geater than 5 percent; 2. the width requires at least 2.1 meter; 3. works on permeable and impermeable soil.	●●●	●●●	 
Geocellulars are odular plastic systems that can be used to create infiltration and storage tank underground.	Infiltration Detention Retention	1. if infiltration is the target, the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table; 2. needs pretreatment device near the water entranes to avoid blocks inside the facility.	●●●	●	 

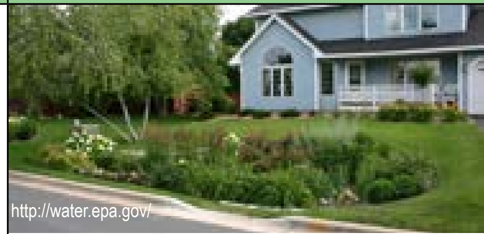
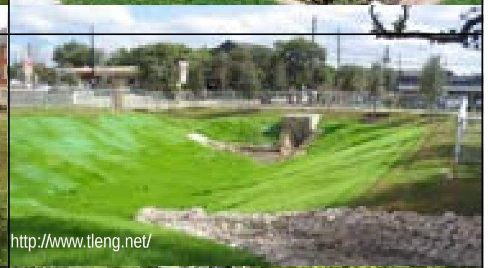
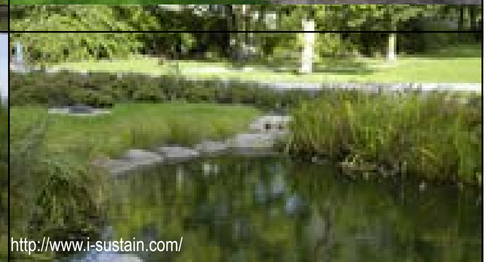
Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images
Green gutters are narrow, vegetated systems along street frontages that capture and slow stomrwater flow.	Infiltration Treatment Conveyance	1. needs long and continuous space to function effectively.	●	●●●	 
Vegetated filter strips are vegetated areas of gently sloping ground designed to drain water evenly off impermeable surfaces and filter out silt and other materials, while infiltrating some stormwater into the ground.	Infiltration Treatment	1. be implemented on slopes between 2 to 6 percent; 2. should not be implemented on soils with impermeability; 3. should be separated from the groundwater by at least 0.6 meter; 4. infiltration can only be achieved when the soil is permeable.	●●	●●●	 
Stormwater planters Stormwater planters are small landscaped stormwater devices that can be placed above or below ground to treat stormwater by infiltration, or filtration.	Infiltration Detention Treatment Conveyance	Depends on the soil types, there are two types of stormwater planters: infiltration (permeable soils)and flow-through stormwater planters (impermeable soils).	●●●	●●●	 
Curb extensions are vegetated curb extension that protrudes into the street either mid-block or at an intersection to enhance pedestrian safety. Stormwater can be stored, infiltrated and treated in the facility.	Infiltration Detention Treatment Conveyance	1. works on permeable and impermeable soil.	●●●	●●●	 

Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images	
Rain gardens Vegetated areas into which runoff is drained, attenuated and stored. Water can either infiltrate into the ground or be taken up by plants.	Infiltration Detention Treatment	1. the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table; 2. permeable soils.	●●●	●●●	 http://water.epa.gov/	 http://www.esf.edu/
Street gutters are depressions running parallel to a road designed to collect rainwater flowing along the street. Street gutters usually transport stormwater into detention ponds for treatment or into a body of water.	Conveyance		●	●	 http://australianclimatemadness.files.wordpress.com/	 http://s0.geograph.org.uk/
Underground water tank accomplishes the capture and storage of stormwater collected from surrounding impervious areas.Stored water is then released directly through an outlet pipe back into natural waters, it also allows water to infiltrate into the ground if the soil is permeable.	Infiltration Detention Retention	1. if infiltration is the target, the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table;	●●●	●	 http://www.kubatequipment.com/	 http://etraintoday.com/
Inlet protect devices are flow-through structures with a settling or separation unit to remove pollutants from stormwater.	Treatment	1. works in regions with permeable or impermeable soils.	●	●●●	 http://www.deltatsolutions.com/	 http://langeindustries.com/

Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images	
Sand and organic filters direct stormwater runoff through a sand bed to remove metals, and other pollutants. They are typically used as a component of a treatment train to remove pollution from stormwater before discharge to receiving waters, to groundwater, or for collection and reuse.	Infiltration Treatment	1. the bottom of the facility should be at least 0.6 meter higher than the seasonally high groundwater table; 2. works in regions with permeable or impermeable soils.	●	●●●	http://www.susdrain.org/ 	

Good contribution ●●● Medium contribution ●● Low contribution ●

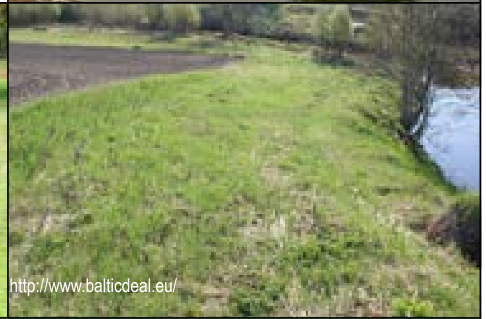
Appendix B: Common Stormwater Facilities Used in Impermeable Soil Regions

Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images	
Rain gardens Vegetated areas into which runoff is drained, attenuated and stored. Water can either infiltrate into the ground or be taken up by plants.	Infiltration Detention Treatment	1. the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table; 2. permeable soils.	●●●	●●●	 http://water.epa.gov/	 http://www.esf.edu/
Detention basins are shallow vegetated depressions to control the amount and rate of runoff and some water quality improvement by infiltration. In most cases, they are dry until periods of heavy rainfll events.	Infiltration Detention Treatment	1. the slope of the facility should be no greater than 15 percent; 2. if infiltration is the target, the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table;	●●●	●●	 http://www.susdrain.org/	 http://www.tleng.net/
Retention ponds are ponds with an open water area and marginal wetland around the edge. By incorporating filtration devices at the inlet, improved water quality can be used for other usages.	Infiltration Retention Treatment	1. if infiltration is the target, the bottom of the facility should be at least 1 meter higher than the seasonally high groundwater table;	●●●	●●●	 http://www.susdrain.org/	 http://www.i-sustain.com/
Wetland are retention ponds with more emergent aquatic vegetation and a smaller open water area.	Infiltration Detention Retention Treatment	1. works in regions with permeable or impermeable soils.	●●●	●●●	 http://www.wycokck.org/	 http://www.business-services.upenn.edu/

Description	Possible functions	Mechanisms	Flood prevention benifits	Water quality benefits	Example images
Vegetated swales are shallow, broad and conveyance channels planted with vegatation that help slow srunoff facilitate infiltration, filter pollutants from runoff and recharge groundwater.	Infiltration Treatment Conveyance	1. cannot be implemented in areas with slopes geater than 5 percent; 2. the width requires at least 2.1 meter	●●●	●●●	 

Good contribution ●●● Medium contribution ●● Low contribution ●

Appendix C: Common Stormwater Facilities Used in Water Bodies

Description	Possible functions	Siting restrictions	Flood prevention benifits	Water quality benefits	Example images	
Floating treatment wetlands are designed to substantially reduce nutrients levels and other pollutants such as suspended solids in the water.	Treatment	1. a minimum water depth of 1.0 m should be maintained to prevent the macrophyte roots from attaching to the benthic substrate.	●	●●●	 http://www.rbg.vic.gov.a	 http://ichef.bbci.co.uk/
Vegetated filter strips are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. They were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. They can be used as an alternative when there is limited space for implementing riparian buffers.	Infiltration Treatment	1. the infiltration can only be achieved when the soil is permeable; 2. should be separated from the groundwater by at least 0.6 meter; 3. the width should be at least 5 meters; 4. should be designed on slopes between 2 and 6 percent.	●●	●●●	 http://web.benesch.com/	 http://www.balticdeal.eu/
Riparian buffers are the strips of grass, shrubs, and trees and shrubs along the banks of rivers and streams. They improve water quaity in a significant way, also they provide others functions such as bank stabilizers and wildlife habitats.	Infiltration Treatment	1. the infiltration can only be achieved when the soil is permeable; 2. the width should be at least 30 meters;	●	●●●	 http://www.ent.iastate.edu/	 http://upload.wikimedia.org/

Good contribution ●●● Medium contribution ●● Low contribution ●

"The true eye of the earth is water. In our eyes it is water that dreams."
---Gaston Bachelard

Figure source: http://landscapevoice.com/jamison-square/