Study on Ideal Way of Water Environment Improvement by China's Sponge City Construction

(中国の「海綿都市建設計画」に見る水環境のあり方に関する研究)

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1.1 Urbanization and Its Impacts in China

1.1.1 Rapid Urbanization in China

Evidently, China has shown a trend focusing on the infrastructure construction since 2000 due to restriction by limited resources, before then resources were mainly poured on the industrial development. The *13th Five-Year Plan for National Economic and Social Development of China (2016~2020)* is China's supreme guideline which encompasses national social, economic, and political goals. According to it, the *National Environmental Protection Tax* is scheduled to be collected since 2016. Evidently, China's ecological deterioration had not been virtually reversed presently. Meanwhile, the Central Committee of the Communist Party of China and the State Council enacted the *National New Urbanization Plan (2014~2020)*, which is the first official detailed plan on urbanization. Following the international experience of urbanization pattern, China is and will be still in the rapid urbanizing range because of both latest rate of 53.7% and 2020's goal of 60% lie between 30%~70% (Figure 1-1). This plan predicted that the China's urbanization rate would reach to 60% by 2020. Under this condition, previous urbanization mode which highlighted construction speed and scale are converting to a balanced development mode considering quality together with quantity.

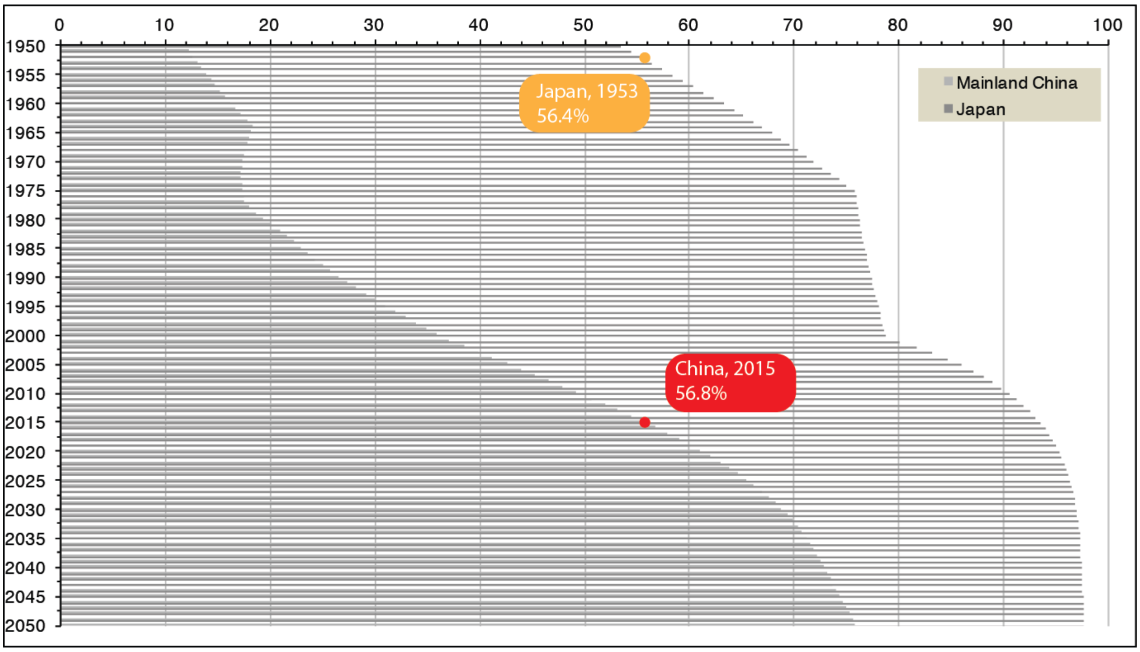

Figure 1-1 Urbanization Rate of China and Japan

Data from database: World Development Indicators, Last Updated: 05/02/2016

Urban population refers to people living in urban areas as defined by national statistical offices. It is calculated using World Bank population estimates and urban ratios from the United Nations World Urbanization Prospects.

1.1.2 Impacts of Urbanization in China

Urbanization would generally lead to an increasing area of the impermeable surface (Table 1-1). Impermeable surface often mean rainwater outflowed without utilization, increased the volume of stormwater drainage and insufficient groundwater recharge. Thus, urban land development always accompanies with water problems such as water scarcity, runoff pollution, and water disasters. Besides, concentrated people at urban areas generally consume more water resources, produce more pollutants. Anyway, water cycle of urbanized area would be affected by human activities and be significantly different from natural conditions (Figure 1-2).

Table 1-1 Composition of Urban Development Land

Land Use	Percentage (%)
Residential	25.0 ~ 40.0
Administration and public service	5.0 ~ 8.0
Industrial, manufacturing	15.0 ~ 30.0
Road, street, and transportation	10.0 ~ 25.0
Green space and square	10.0 ~ 15.0

Source: Ministry of Housing and Urban-Rural Development. Code for classification of urban land use and planning standards of development land (GB 50137-2011).

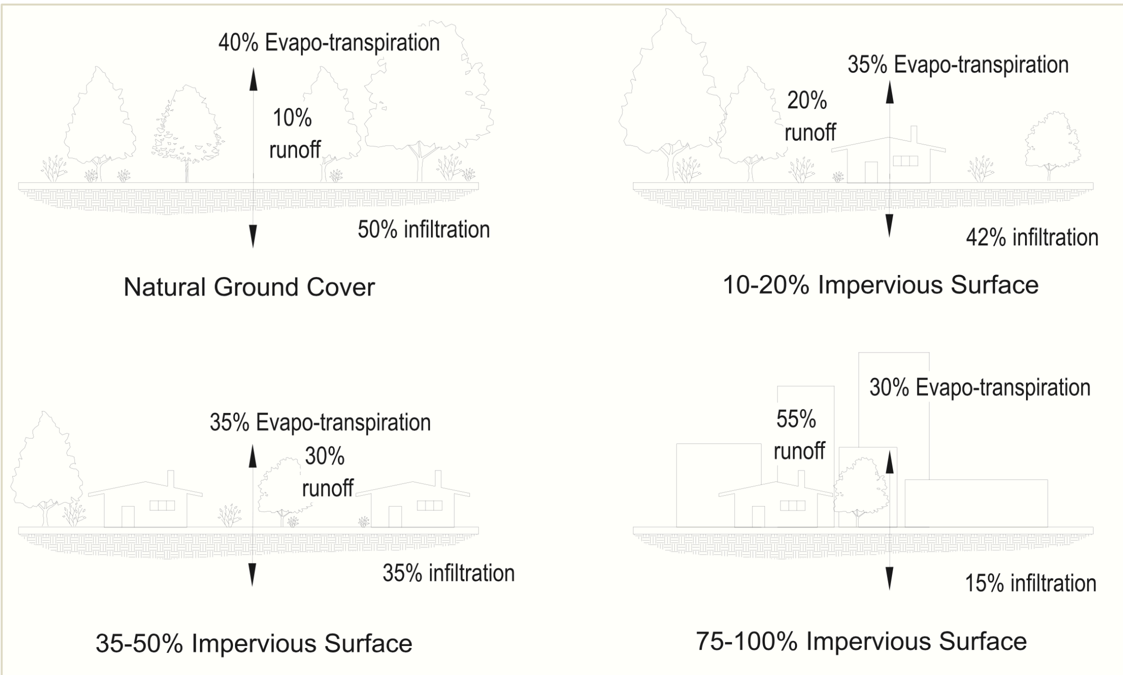

Figure 1-2 Impervious Surface Changes due to Urbanization

Source: Wynkoop, S. E. (1999). Low-Impact Development Design Strategies: An Integrated Design Approach. M. Prince George's Country.

Evidently, China has shown a trend focusing on the infrastructure construction since 2000, because of restriction by limited resources, which mainly poured on the industrial construction before. ZHANG (2015) pointed out that the China's rapid urbanization impact the urban water system and water cycle in the following ways.

(1) The risk of flooding and waterlogging arises and losses expands. Table 1-2 shows the types of flooding problems occurred in China. According to a survey of 351 cities conducted by Ministry of Housing and Urban-Rural Development, from 2008 to 2010, 62% cities had the different degree of waterlogging; 137 cities had waterlogging disasters more than 3 times; 57 cities had suffered waterlogging more than 12 hours.

Table 1-2 Types of Flooding Problems in China

Type	Main causes				Typical location
	Inundation from rivers and/or lakes	Local stormwater runoff, poor drainage	Flash flood	Storm, High tide	
Urban flooding	●	●			Urban areas
Rural flooding	●	●			Rural areas
Flash flooding			●		Remote mountainous areas
Coastal flooding				●	Coastal areas
-	●				Flood detention areas

Source: Kobayashi, Y., & Porter, J. W. (2012). Flood Risk Management in the People's Republic of China: Learning to Live with Flood Risk: Asian Development Bank.

(2) Rainwater pollution aggravates. The erosion of ground sediment is the main cause of urban surface runoff pollution source, which is the second largest source of pollution following the agricultural area. The drainage system in most China's cities is combined system, in a style of mixing rainwater and wastewater. Some separate drainage system also has some serious problems like wrong and disorder connection, sewage overflow problems, leading a lot of rainwater running into the sewer, thus increasing the load and cost of sewage treatment plant.

(3) Water scarcity frequently occurs. Among 660 cities nationwide, 400 cities suffer insufficient water supply, more than 110 cities are in acute shortage. Water shortage reaches 6.0 billion m^3 yearly, resulting in a serious impact on economy and society. Nowadays, there are many problems such as land subsidence caused by over-exploitation of groundwater in many cities.

1.2 Literature Review

Overall, the management level of urban flooding, water logging, stormwater in China lags developed countries. For example, the lag of the concept, planning, design, and engineering; lack of policies and regulations; citizens' weak consciousness of environmental protection and other issues. In this context, China's government has been actively promoting a policy called *Sponge City Construction* nationwide recently. Researches including journal articles and proceedings about sponge city construction have been booming since 2011. Noteworthy is that ARGENT, ROLLEY *et al.* (2008) had published an article titled with "The sponge city hypothesis: does it hold water", which describe the conception of sponge city as some regional centers 'soak up' population and business from a 'pool' of surrounding areas. This conception differs radically from the China's, which refers to an urban development mode that such built cities function like a sponge which can absorb, store, infiltrate, purify and release water, to pursue a low impact to the former natural environment, typically in harmony with local ecosystem and water cycle system.

To carry out innovative exploration based on previous studies on sponge cities, we have made a comprehensive review of previous literatures. We use "sponge city" as the key word in Cnki, Vip, Cinii, Web of Science and other technology index to conduct the precise and detailed indexing and screening. Our results showed that there are 1, 1, 0, 2, 454 articles about "Sponge City" in each year from 2011 to 2015, and 958 papers published in 2016 (as of November 1, 2016). DONG and HAN (2011) proposed an approach of the rainwater utilization based on the conception of eco-sponge city and provided the optimal construction as well as an evaluation index system. MO and YU (2012) explored a new way of stormwater utilization through landscape architecture, structuring the urban green sponge, with green space and water system as the main body. Its purpose is to solve the coexisting conflict of waterlogging and water shortage by integrating the latest concept of ecological stormwater management into urban planning process, and changing the tradition reliance on large-scale engineering facilities and pipeline construction. WANG, LI *et al.* (2014) analyzed the conception and approaches to realize sponge city and summed up the implementation strategies for low impact development at urban space. ZHANG and PANG (2014) pointed out that the water conservancy administrations should took the chance to lead the sponge city construction with other sectors.

We also screened 14 thesis with the sponge city as the research object, of which 3 in 2015, 11 in 2016. All of them are the master's thesis of profession of landscape architecture, architecture, and municipal drainage. ZHANG (2016) had studied the effect of runoff at the mountainous city with the low impact development mode under sponge city construction. WANG (2016b) had studied on the technologies of rainwater storage and utilization of real estate development project based on sponge city construction. JING (2016) proposed a way of model design of low impact development system for residential area under sponge city target. YUAN (2016) studied on the sponge city construction based on city waterlogging prevention. PENG (2016) studied on the planning and design of parks and green spaces under the goal of sponge city. BIAN (2016) proposed a planning and design method of rainwater collecting botanical garden under the view of sponge city. WANG (2016a) had discussed on park planning method based on sponge city concept. LIU (2016) had studied on applying the concept of sponge city in widening urban roads. ZAHNG (2016) had studied on design of rainwater utilization for urban parks. SONG (2016) researched on planning and design of rainwater collection for mountainous parks. YU (2016) had researched on the application of pervious concrete in sponge city construction. WANG (2015) had conducted a simulation and evaluation of planning scheme of urban stormwater system based on the concept of sponge city. SUN (2015) researched on systematic design of urban road based on sponge city. GONG (2015) had taken a community in Xi'an as an example to study on construction and practice of the sponge city.

a. General Theory

QIU (2015) had introduced the conception, proposed 3 methods and 5 prospects of sponge city construction. YU, LI *et al.* (2015) had summarized the background, development, conception and methodology of sponge city. Also, they pointed out that the key to sponge city construction is to build multiscale water ecological infrastructures, which refers to naturally functioning water ecosystems that deliver valuable services to people. XU (2015) had provided an application strategy of pilot demonstration of sponge city and suggestions on capacity improvement. He also summarized concerned policies of sponge city construction, urban stormwater drainage, waterlogging prevention and water saving. CHE, ZHAO *et al.* (2015) LI, WANG *et al.* (2015, WANG, LI *et al.* (2015) had explained the technical guide of sponge city construction by describing the basic conceptions and comprehensive goals, regional division for total rainfall runoff volume capture target, planning index for urban total runoff volume capture. CHE, XIE *et al.* (2015) had studied on the development and provided constructive approaches for theories and technologies of sponge city system. LI, ZHANG *et al.* (2016b) conducted a study on exploration and expectation of smart sponge city. WANG, ZHANG *et al.* (2016) analyzed the importance and measures of conservation and ecological restoration of lakes and rivers during sponge city construction. KUROZUMI (2016) provided a proposal of international matching towards China's progress with sponge city construction. YANG, KUROYANAGI *et al.* (2016a) had simply investigated the general situation of utilization of water resources, as well as related policies, concrete measures, practices and latest scheme of stormwater utilization and management in Tokyo. YANG, KUROYANAGI *et al.* (2016b) had summarized the background, technical routine, current situation of pilot projects, progress of rainwater harvesting in Japan, and finally with some recommendations.

b. Case Studies

WANG and WU (2015) had introduced the practices and thinking of planning Xiamen sponge city construction project. ZOU, XU *et al.* (2015) had conducted the research on sponge city construction in the southern rainy hilly area - a case study of Ningxiang County in Hunan Province. HU, LI *et al.* (2015) had a discussion on important points about sponge city construction including urban policy, public participation, and financial support, etc. Typically, Jian Hu, director of Zhenjiang drainage Management division, responds from the governmental perspective, explaining local difficulties in Sponge city implementation and sharing Zhenjiang's experience and lessons in their practices. ZHAO (2015) had conducted a case study of Zhenjiang on urban waterlogging control under Sponge City Construction. YANG, KUROYANAGI *et al.* (2016a) had outlined the current situation of sponge city construction in Zhenjiang and summarized 7 problems, following their countermeasures. FANG and LIAO (2016) evaluated the effect of sponge city construction on river water quality and quantity, taking Chongguang lakeside park in Chongqing as a case study.

c. Simulations

Herath, Musiake *et al.* (2003) had conducted a simulation study of infiltration facility impact on the water cycle of an urban catchment. ZHANG, GU *et al.* (2015) had applied the Low Impact Design (LID) Module of SWMM Model to simulate the effect of LID facilities at old city areas of Quzhou and Zhenjiang.

d. Facilities

Luo, CHE *et al.* (2008) introduced functions, classification, design calculation, vegetation selection principles, maintenance and management measures of rainwater garden on China Water and Wastewater, and forecasted its application prospect. Su, WANG *et al.* (2014) had use water balance method to determine the design parameters of sunken greenbelt, based on *Code for Design of Stormwater Management and Harvest Engineering for Beijing*. The authors also briefly introduced the method of optimum design of grading, landscaping, and plant waterlogging time.

e. Hydrological Process

WANG, LV *et al.* (2009) had used remote sensing and geographic information systems to analyze the impacts of land use changes on hydrological processes in an urbanized basin, with a case study in the Qinghuai river basin. They also applied a distributed hydrological model (Soil and Water Assessment Tool, SWAT) to simulate the great changes of runoff yield caused by land use changes.

f. Stormwater Management

LI, ZHANG *et al.* (2016a) had discussed the concept and connotation of sponge city construction and urban stormwater management. They also studied on differences between LID and GI - the former focuses on source control, while the latter values both source control as well as process control and terminal control measures. The conception of green infrastructure comprises the LID measures and other detention facilities such as green corridors, wetlands, multifunctional detention ponds, water amenities and so on. They believed that the conception of sponge city construction is more equivalent to the conception of green infrastructure.

1.3 Original Contributions

Current researches about sponge city construction are enormous. However, most of them deal with the concept of sponge city construction, or case study of the single pilot city, or outline of functions of facilities for stormwater utilization and management, etc. Therefore, this paper aims to grab the whole image of sponge city construction and conduct an evaluation through a comparative examination of the implementation status of 30 pilot cities.

- Firstly, we summarized the conception of sponge city and investigated the implementation status of 30 pilot cities to grasp problems and propose resolutions.
- Secondly, by comparing 30 cities' objectives of sponge city construction, classify construction contents, as well as analyzing its natural, economic and social conditions, the character and experience of each pilot city are summarized.
- Furthermore, based on the above two studies, refine the sponge city theory further regarding rainwater measures in Japan and overseas.

1.4 Methodology

One of the biggest challenges for us to proceed our study is collecting enormous data. (Table 1-3).

Table 1-3 Methods for Collecting Data

Survey Type	Items for Present Situation
Literature Research	Laws, Regulations, Policies, Guidelines, Plans, Research Report Map, Aero photo, Statistical data (Climate, Precipitation, geography, etc.) Infrastructure (Water supply, Sewer, Waters, etc.) Location, Shape, Size/ Area, Elevation, Vegetation Specific cases, Photographs, Sketches/blueprint, Design data The surrounding area, Landscape, Transportation, People Flow.
Fieldwork	Data which cannot get from Literature Research
Fact-finding Survey through Interview, Questionnaire, Observation	
Awareness Survey	People's opinions, requirements, etc.

By pre-study of sponge city construction, we made our investigation plan and decided the investigation areas (Figure 1-3).

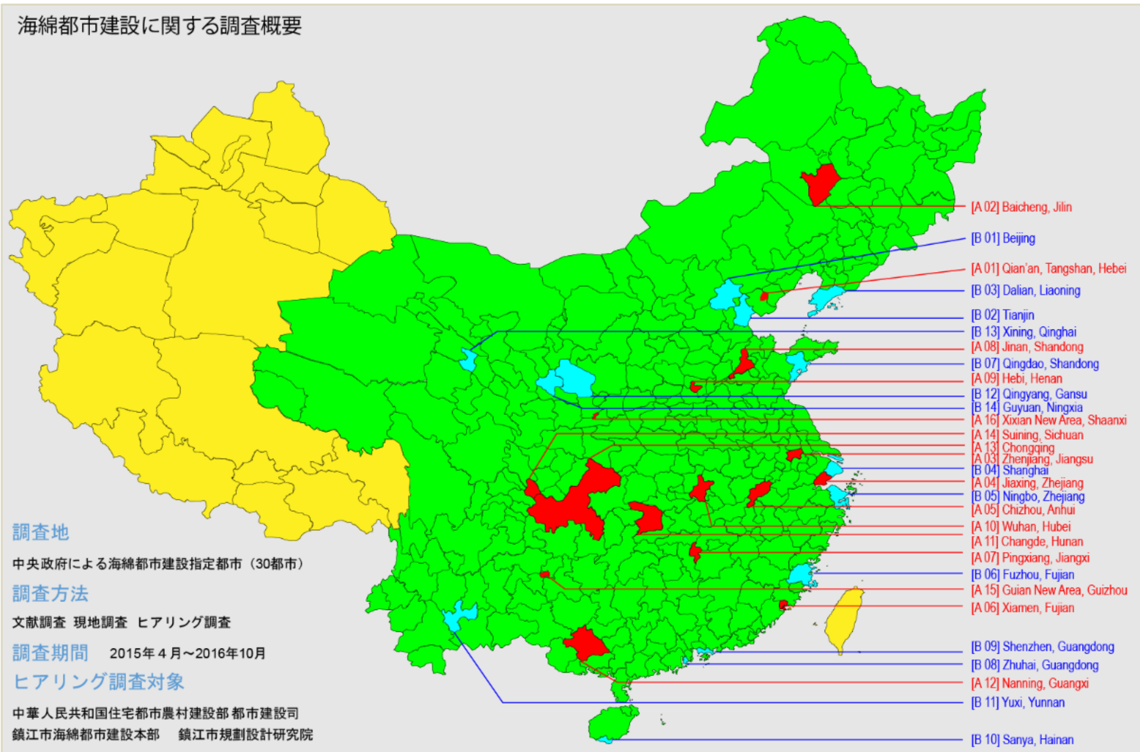

Figure 1-3 Investigation Schedules about Sponge City Construction

This thesis has 6 chapters, as shown in Figure 1-4. Chapter 1 is the introduction which consists of a section on analyzing urbanization and its impacts in China, a literature review on sponge city construction, the purpose of research, and our methodology. Chapter 2 is the review of mainstream theories for urban stormwater management as well as the progress of urban stormwater management in the United States, Japan, and China. Chapter 3 focus on the current conditions of flood control in China, historical of China's ecological water conservancy, the urban environment in China, and the sponge city construction with above background. Chapter 4 elaborate the conception and measures of sponge city construction. Chapter 5 is the analysis on current situation and problems of implementing sponge city construction. Finally, the last chapter is the conclusion.

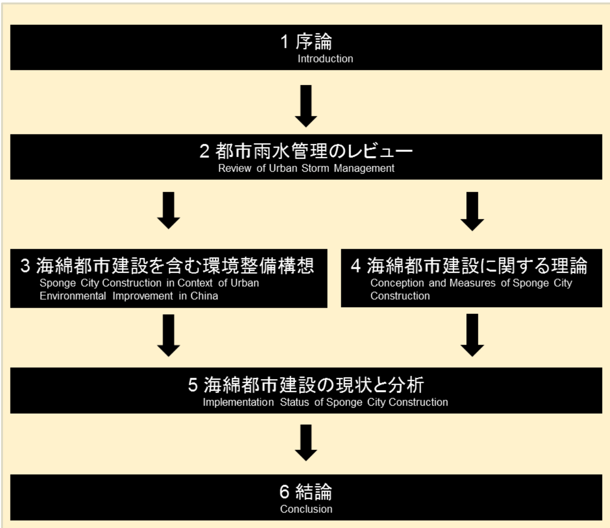

Figure 1-4 Research Flow

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2 Review of Urban Stormwater Management

With the accelerating of China's urbanization process, not only the speed but also the quality and efficiency have been valued. The currently dominated strategy for most cities in China is enlarging the ability of drainage network to drainage out as soon as possible, hardly considering the storm water management.

2.1 Mainstream Theories for Urban Stormwater Management

Urban drainage is a very old field, dating back to at least 3000 BC, with a primary focus on the conveyance of water away from urban areas (Burian and Edwards (2002)). Fletcher, Shuster *et al.* (2015) had examined the history, scope, application and underlying principles of terms used in urban drainage and provides recommendations for clear communication of these principles. There has been rapid growth in the use of terms such as LID, SUDS, WSUD, BMPs and alternative techniques. So only four of above terms were included in the original Urban Drainage Multilingual Glossary (Ellis, Chocat *et al.* (2006)).

ZHANG (2015) had reviewed the concepts and models of modern urban stormwater management. At present, typical sustainable stormwater management systems are mainly including: Best Management Practices (BMP) since 1970 s in North American; Low Impact Development (LID) since 1990 s in United States; Sustainable Urban Drainage System since 1990 s in United Kingdom; Water Sensitive Urban Design at Melbourne, Australia; Low Impact Urban Design and Development in New Zealand, etc.

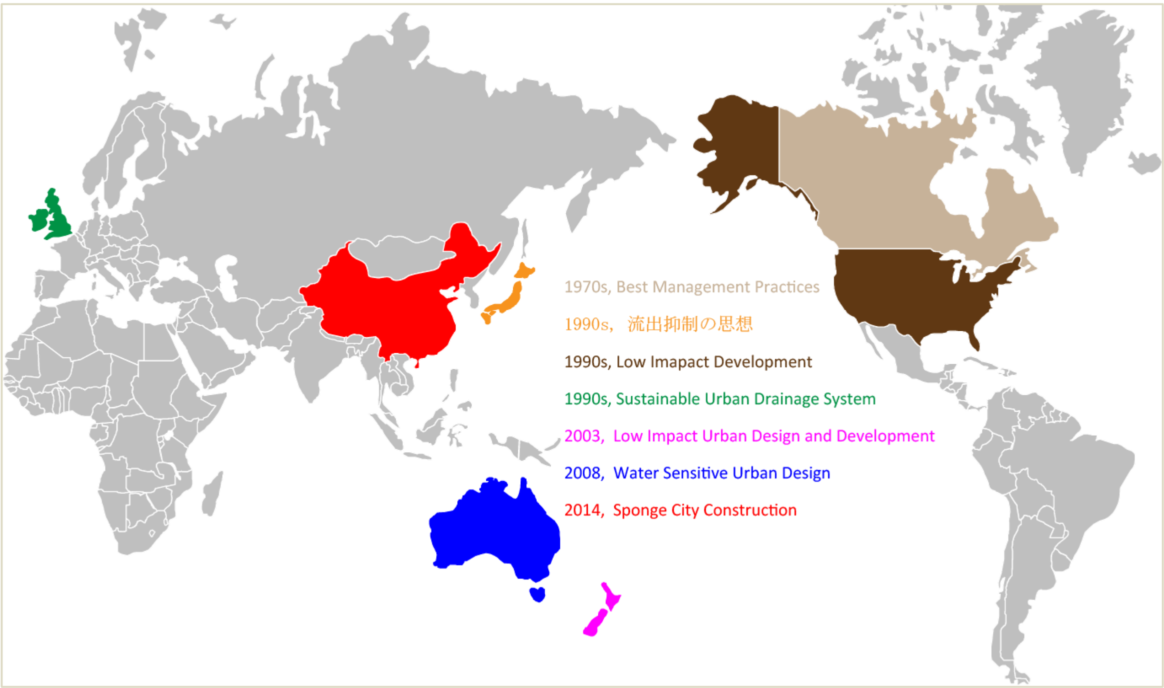

Figure 2-1 Mainstream Theories of Urban Stormwater Management

Figure 2-2 shows the perspectives of urban drainage management is broadening over time, engaging by such as architects, landscape architects, planners, ecologists and social scientists (Fletcher, Shuster *et al.* (2015)).

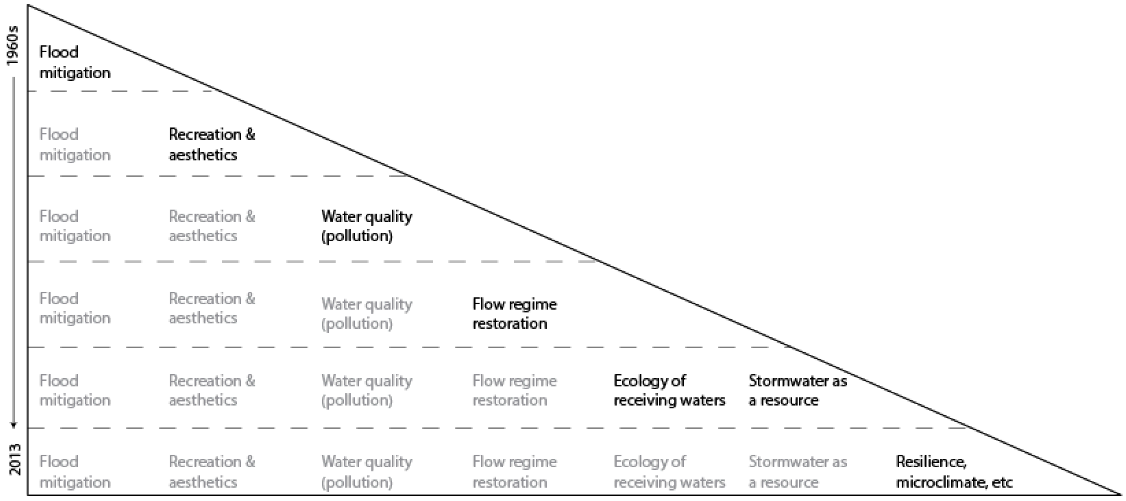

Figure 2-2 Increasing Integration and Sophistication of Urban Drainage Management Over Time

Adapted from Fletcher, Shuster *et al.* (2015)

2.1.1 Best Management Practices (BMPs)

The United States Environmental Protection Agency (USEPA) defines stormwater BMPs as techniques, measures, or structural controls that are used for a given set of conditions to manage the quantity and/or improve the quality of stormwater runoff in the most cost-effective manner (Sayre, Devinny *et al.* (2006)). Two classes of BMPs are often distinguished. Structural BMPs are systems that are engineered and constructed, whereas nonstructural BMPs consist of pollution techniques designed to stop pollutants from entering an urban runoff. The conception of Best Management Practices (BMPs) is firstly raised in the amendment of the Federal Water Pollution Control Act (subsequently referred to as the Clean Water Act) in 1972 (COUNCIL (2008)). This amendment required control of discharges of pollutants to waters from point sources.

Initial efforts to improve water quality primarily focused on reducing pollutants from industrial process wastewater and municipal sewage discharges. Later the *Clean Water Act amendment of 1987* and *Wet Weather Quality Act*, measures of BMPs were firstly taken to control non-point source pollution, manage stormwater drainage and sewage overflow, dealing with rainwater through evaporation, infiltration, interception, filtration, biochemical reaction etc. Over the past three decades, urban runoff has been identified as a critical source of pollution in the United States. The runoff is now regulated under the *Clean Water Act* through *National Pollutant Discharge Elimination System* permitting, with pollution limits defined as total maximum daily loads. The *United States Environmental Protection Agency (USEPA)* ranks urban runoff and storm drain discharges as the second most significant source of water quality impairment to US estuaries, and the fourth most significant source of impairment to US lakes. Stormwater pollution prevention and treatment is an important regulatory issue in the United States. The poor quality of stormwater runoff arises mainly from two human alterations of the environment: the conversion of soils and other pervious surfaces to concrete, asphalt, buildings, and other impervious surfaces, and the release of pollutants from residential neighborhoods and industrial areas.

Since 1992, cities of different scales, certain industries, and construction sites have developed and implemented stormwater plans under Phase I of the *National Pollutant Discharge Elimination System (NPDES)* stormwater regulations. BMPs have become a common means for controlling runoff quality since then and their effectiveness has been evaluated through studies conducted in the United States, Europe, and other parts of the world (Roesner, Bledsoe *et al.* (2001)). The following subsections distinguish four groups of BMPs which are classified based on the type of intervention or location in the hydrologic cycle where modifications are made (Table 2-1).

Table 2-1 Groups of BMPs Classification and Technologies

Classification	Technologies
Runoff Capture at Source	Porous Pavements Green Roofs Rain Barrels, Cisterns Dry Wells
Detention and Retention of Peak Flow	Detention Ponds Extended Detention Ponds Retention Basins
Treatment of Captured Flow	Constructed Wetlands Filtration Filtration Basins Underground Filters Sand Filters Grassed Swales Vegetated Strips Water Quality Flotation Inlets Stormceptors Continuous Deflection Separation
Runoff Infiltration and Groundwater Recharge	Infiltration Basins Infiltration Trenches/ Ditches Bio-retention Areas

2.1.2 Low Impact Development (LID)

LID emphasizes conservation and use of on-site natural features to protect water quality. This approach implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source (Coffman (1999)).

LID emerged at the time which 'urban sprawl' was prevalent, but nowadays in some existing urban areas the trend of densification has been emerging, so the definition of LID will keep evolving from now on (Fletcher, Shuster *et al.* (2015)). The term LID has been most commonly used in North America and New Zealand. It appears to have been firstly used by Barlow et al. (1977) in a report on land use planning in Vermont, USA. The original intent of LID was to achieve a 'natural' hydrology by use of site layout and integrated control measures. LID discouraged the then common practice of large end-of-catchment solutions, because of their inability to meet this catchment-wide hydrologic restoration.

LID involves a series of innovative concepts, parameters, and methods, and its goals significantly differ with the conventional drainage system. It was used to distinguish the site-design and catchment-wide approach from the common stormwater management approach at that time, which typically involved conveyance to large end-of-pipe detention systems. In contrast, LID was characterized by smaller scale stormwater treatment devices such as bio-retention system, green roofs, and swales, located at or near the source of runoff. By the end of the 1990s and due to the influence of the design community, the interpretation of LID had strayed from its original meaning to encompass any set of practices that treated stormwater (typically in small catchments of 1 ha or less). The LID manuals reestablish hydrologic targets for both retrofit and new urban developments and provide design options to meet and sustain these objectives (North Carolina State University (2009)). Washington (2012) defined LID as a stormwater and land use management strategy that strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation and transpiration by emphasizing conservation, use of on-site natural features, site planning, and distributed stormwater management practices that are integrated into a project design.

The most influential early use of the term was in Prince George's County, Maryland, USA in the early 1990s (Coffman (1999)) . Compared with conventional stormwater control measures, it can high reduce the impact on the natural hydrological regime. For instance, a conventional rainwater pond can only improve water quality, but cannot improve the habitat structure or hydrological regime of biological communities, while a LID pond can provide high quality as well as the protection of aquatic species groups.

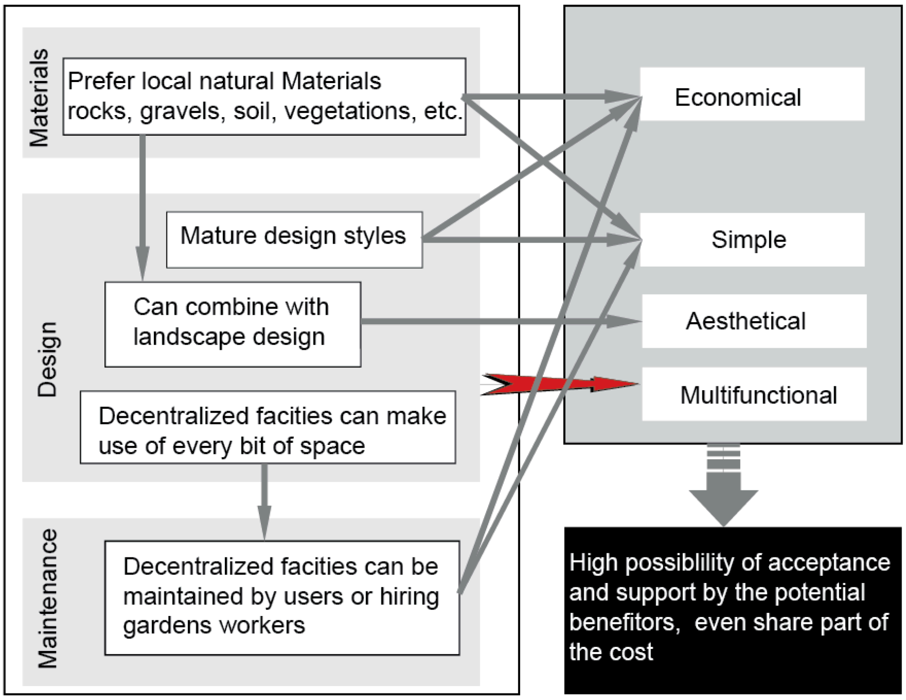

Figure 2-3 Benefits of Low Impact Design

Table 2-2 shows the major differences between LID, BMPs, and conventional stormwater drainage network. The objective of conventional approaches, BMPs and LID differs. Conventional approaches consist of pump stations, stormwater management ponds, pipes, inlet structures, curb, gutter infrastructure, etc. Its main goal is to discharge rainwater flow from the site as soon as possible. But the main purpose of BMPs is to reduce peak flow at the site's down land, and for LID is to remain the hydrological characteristics of site. The cost of constructing them also differs. For example, LID is more economical than conventional approaches due to a fewer pipe and below-ground infrastructure requirements. Typically, in the case of retrofitting urban drainage, the cost is quite lower. Besides, the former two need specific maintenance, however, part of the last can be maintenance as general landscape. Conventional approach can reduce the risk of flooding, but decreases groundwater recharge and changes the natural hydrologic regime of the site due to high runoff conveyance capacity and efficiency. But it is prone to cause water quality degradation, stream channel erosion and adverse effects on aquatic and riparian biota. However, LID strategy can retain stormwater runoff onsite and promotes infiltration (therefore reduced flooding) and groundwater recharge through reduction of impervious surfaces and natural drainage features.

Table 2-2 Major Differences between LID, BMPs, and Conventional Stormwater Drainage Network

Items	Conventional	BMPs	LID
Control Style or Location	Directly discharge into pipeline	Part is at site end	At site source
Disturbance to Natural Hydrological Regime	High	Moderate	Low
Effect of Flow Control	No	Good	Great
Effect of Water Quality Improvement	No	Have	Have
Effect of Natural Resources Conservation	No	Moderate	High
Distribution of Constructional Measures	Decentralized	Centralized	Decentralized
Scale of Facilities	large	large	small
Space Requirements	Small	Large	Middle
Disturbance to the Ground	Strong / middle	Middle / Weak	Weak / No
Combination with Landscape	No	Low	High
Ease of Implementation	Easy	Moderate	Difficult
Cost	High	Moderate	Low

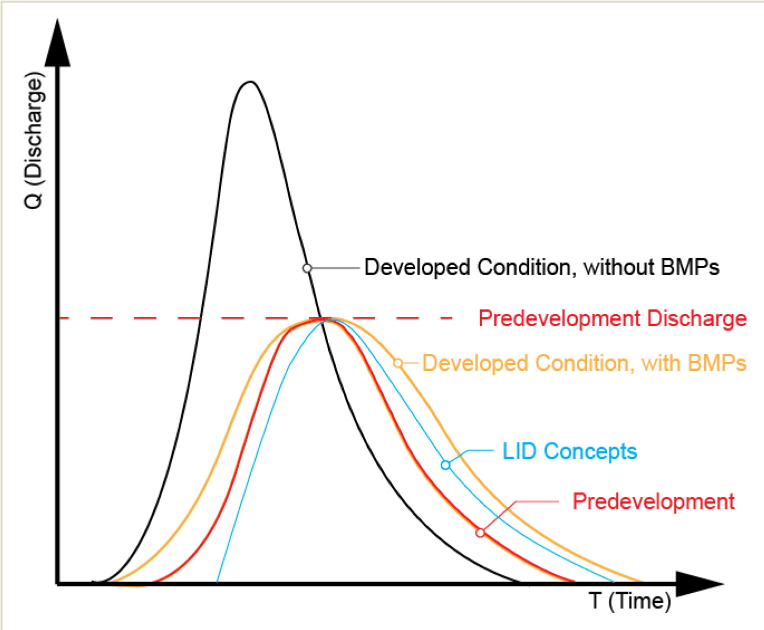

Figure 2-4 Comparison of Hydrologic Response of Conventional Approach, BMPs, and LID

Figure courtesy of Larry Coffman (1999). Low-Impact Development Design Strategies: An Integrated Design Approach. M. Prince George's Country.

Table 2-3 summarizes how conventional stormwater management and LID technology alter the hydrologic regime for on-site and off-site conditions (Coffman (1999)).

Table 2-3 Comparison of Conventional and LID Stormwater Management Technologies

Hydrologic Parameter	Conventional	LID
On-site		
Impervious Cover	Encouraged to achieve effective drainage	Minimized to reduce impacts
Vegetation/Natural Cover	Reduced to improve efficient site drainage	Maximized to maintain predevelopment hydrology
Time of Concentration	Shortened, reduced as a by-product of drainage efficiency	Maximized and increased to approximate predevelopment conditions
Runoff Volume	Large increases in runoff volume, not controlled	Controlled to predevelopment conditions
Peak Discharge	Controlled to predevelopment design storm	Controlled to predevelopment conditions for all storms
Runoff Frequency	Greatly increased, especially for small, frequent storms	Controlled to predevelopment conditions for all storms
Runoff Duration	Increased for all storms, because volume is not controlled	Controlled to predevelopment conditions
Groundwater Recharge	Reduction in recharge	Maintained to predevelopment conditions
Off-site		
Water Quality	Reduction in pollutant loadings but limited control for storm events that are less than design discharge	Improved pollutant loading reductions, full control for storm events that are less than design discharge
Receiving Streams	Channel erosion and degradation Sediment deposition Reduced base flow Habitat suitability decreased, or eliminated	Stream ecology maintained to predevelopment
Downstream Flooding	Peak discharge control reduces flooding immediately below control structure but can increase flooding downstream through cumulative impacts and super positioning of hydrographs	Controlled to predevelopment conditions

2.1.3 Sustainable Urban Drainage System (SuDS)

To cope with the high flood risk at downstream under the conditions of quick urban drainage, together with river channel construction impact on stream corridors' habitat, the United Kingdom developed Sustainable Urban Drainage System (SuDs) based on BMPs Structural measures. The idea is to imitate the onsite discharge conditions of predevelopment and to process to remove pollutants from stormwater runoff. Compared to LID, to prevent runoff generation and pollutant emissions, it emphasizes on-site design and management measures taken by household and communities (Figure 2-5). For example, minimize impervious pavement, frequently clean the ground of parking lots, properly dispose of garbage. In 2014, the British Parliament passed the Flood and Water Management Act (2010), defined that all new construction projects must apply SuDs (Group (2004), Woods-Ballard, Kellagher *et al.* (2015)).

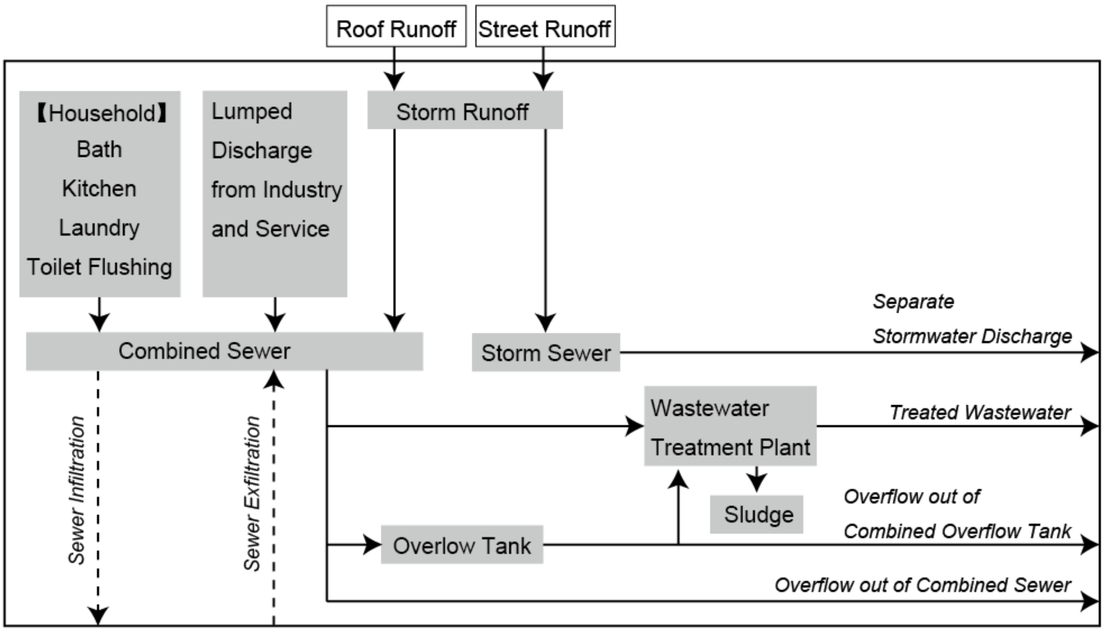

Figure 2-5 Operation Process and Framework of Sustainable Urban Drainage System

Note: Adapted from CHE, Shengquan, Bingqin YU and Wei YAN (2015). Research and Practices for Sponge City - Taking Examples of Shanghai Urban and Rural Green Space. Shanghai, Shanghai Jiao Tong University Press. Page 18.

2.1.4 Water Sensitive Urban Design (WSUD)

Fletcher, Shuster *et al.* (2015) pointed out that the term Water Sensitive Urban Design (WSUD) began to be used in the 1990s in Australia, which stresses on maintaining the natural flow of water cycle during the urban development. Stormwater management is a subset of WSUD directed at providing flood control, flow management, water quality improvements and opportunities to harvest stormwater to supplement main water for non-potable uses.

Parts of its objectives are listed as below:

- Manage the water balance (considering groundwater and streamflow, along with flood damage and waterway erosion);
- Maintain and where possible enhance water quality (including sediment, protection of riparian vegetation, and minimize the export of pollutants to surface and groundwater);
- Improve the self-sufficiency of water resources within the city, such as optimize water utilization

(using water saving appliances, rainwater, and recycled water), minimize stormwater on urban design, lessen the inflows and outflows of domestic water and wastewater, etc.

- Improve the city's aesthetic and recreational amenity.
- Use vegetation and replenish groundwater to offset urban heat island effect.

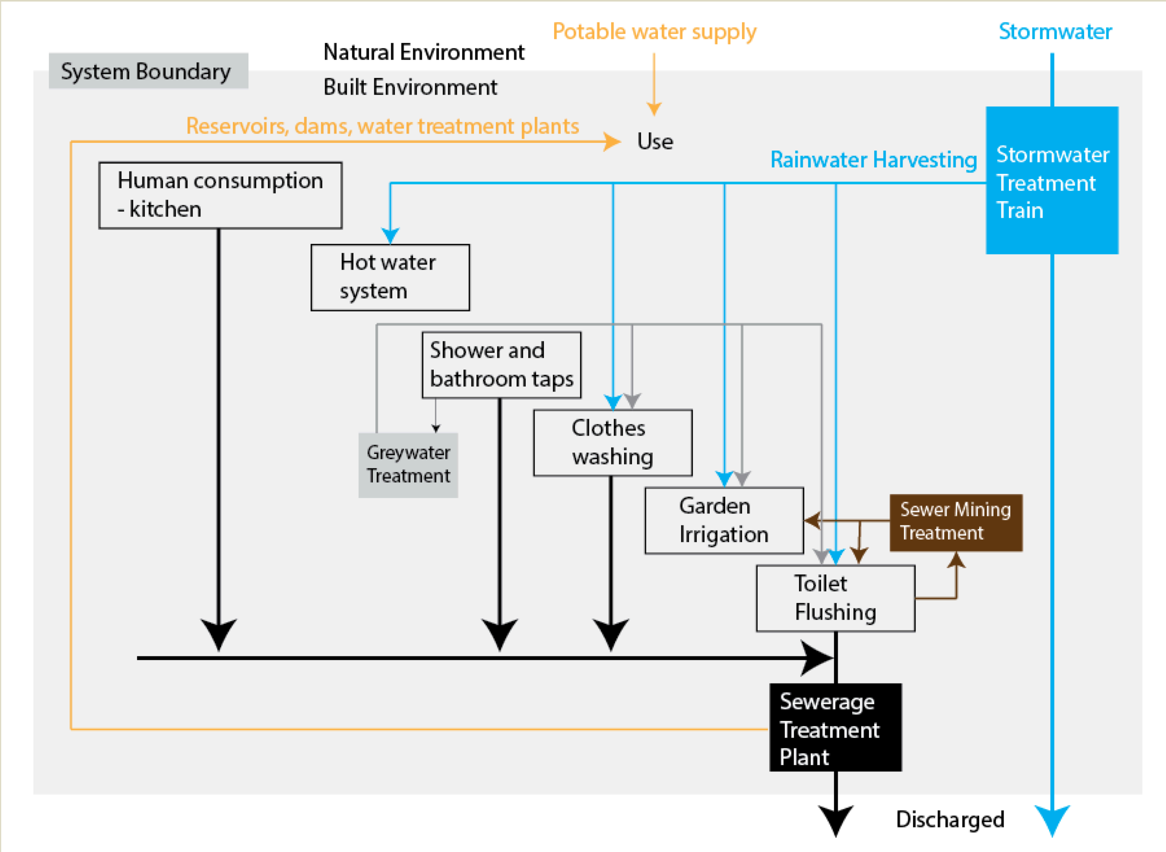

Figure 2-6 Integrated Water Cycle Systems Approach of WSUD for the City of Melbourne

Source: Melbourne Water. The City of Melbourne WSUD Guidelines. 45pp. 2008

Table 2-4 Elements, Fact Sheet and Key Selection Characteristics of Water Sensitive Urban Design

	Fact Sheet	Stormwater		Wastewater	Aesthetic Value
		Quality	Retention		
Household	Household rainwater tanks	√	√	-	–
	Porous paving	√	√	×	×
	Site layout and landscaping	√	√	×	×
Developers, Council planners, architects, engineers	Waterway Rehabilitation	√	×	×	√
	Rainwater tanks	√	×	×	√
	Gross pollutant trap	√	√	×	●
	Sedimentation (settling)	√	√	●	√
	Ponds and lakes	√	√	-	
	Vegetated swales and buffer strips	√	×	×	√
	Raingardens	√	×	×	√
	Raingarden tree pit	√	×	×	√
	Surface Wetlands	√	√	●	√
	Subsurface flow wetlands	●	●	●	√
	Suspended growth biological processes	×	×	√	×
	Fixed growth biological processes	×	×	√	×
	Recirculating media filter	×	×	√	×
	Sand and depth filtration	×	×	√	×
	Membrane filtration	×	×	√	×
	Disinfection	×	-	√	×

√ Primary Purpose; ● Some impact but not primary purpose; × Does not contribute; - not applicable

Source: Melbourne Water. The City of Melbourne WSUD Guidelines. 2008

2.2 Progress of Urban Stormwater Management

2.2.1 Progress of Urban Stormwater Management in the United States

The source of contamination in stormwater runoff is a principal contributor to water quality impairment of waterbodies nationwide in the United States. COUNCIL (2008) pointed out that stormwater runoff from the built environment remains one of the great challenges of modern water pollution control. We concluded that the major driving force of generation and development of water quality control in the United States is the strict norms, standards, laws and regulations systems, which constantly, gradually be perfected (Table 2-5).

Table 2-5 Trending of Stormwater Management in the United States

1950s	Hygiene (Public Health)	• Most cities had established good drainage infrastructures.
1960s		• Diversion Drainage of Rainwater from Sewage Pattern is widely used.
1970s	Water Quantity	• Started and widened the application of the site retention method [a)]. • In 1977, the Amendment of *Clean Water Act* firstly proposed the conception of BMPs to regulate the industrial wastewater.
1980s	Water Quality	• Overall planning of storm flood management became heated. • After successfully controlled the point source pollution in the mid and late 1980s, began to virtually deal with non-point source pollution. In 1987, the *Water Quality Act* enhanced the regulation on poisonous pollutants and non-point pollution, and firstly put the stormwater drainage into the *National Pollutant Discharge Elimination System* (NPDES), and required local governments to control water quality with BMPs measures.
1990s	Ecology	• In 1990, Environmental Protection Agency released the *Biological Criteria: National Program Guidance for Surface Waters*, which introduced the ecological standard into the assessment of stormwater management.
Present		• All 51 states have implemented stormwater management mode based on BMPs and LID, directed by manuals, guidelines etc. made by the federal government and states.

[a)] Site retention method is used to postpone the surface runoff flowing into drainage networks and receiving water bodies, usually in a way of using natural or artificial ponds, low-lying areas and other constructional measures. It can well control the stormwater runoff, but without a larger scale or an overall planning of catchment, it may cause the downstream receiver water bodies in high water level for long, as well as flooding, erosion of stream channels etc.

2.2.2 Progress of Urban Stormwater Management in Japan

Many researchers in Japan has studied on the stormwater management early since the 1980s. YAMAGUCHI, YOSHIKAWA *et al.* (1981) had given a systematic method to clarify and analyze the flood problems to make a flood control plan for an urbanized watershed. KOYAMA and FUJITA (1984) had written a book, proposing a new method to plan and design a type of sewer system which can reduce the outflow of stormwater runoff. KADOYA (1985) had reviewed the runoff changes due to urbanization. KUMAGAI and HARADA (1986) had given a method of planning and designing rainwater storage facility which can meanwhile reduce the rainwater runoff in residential complexes. FUJITA (1986) had proposed the experimental sewer system (ESS) to reduce urban storm runoff, by combining unit processes of infiltration and storage with the conventional sewer system. He also confirmed the quantitative effects of ESS by practical measurements taken in Tokyo and used a simulation model to evaluated the total efficiency within a catchment. ICHIKAWA and Maksimović (1988) published a book which elaborated the significance of stormwater runoff reduction, experimental zones in Japan, measurement technologies, the establishment of implementation system, the unit process of facilities, etc. WADA (1990) had given an outlook of urban rainwater management in the 21st Century. MATSUI (2007) had published a technical manual for the small-scale system of rainwater retention, infiltration, and drainage piping. MATSUSHITA, OZAKI *et al.* (2001) studied on rainwater drainage management for urban development based on public-private partnership. He pointed out that Japan's Urban Development Corporation (UDC) has developed rainwater infiltration technology since 1975. This technology is very effective to reduce stormwater runoff at newly built towns. In 2001, UDC also developed the "Rainwater Recycle Sewer System", which is applicable to both urban construction and redevelopment. This new system is supported by Rainwater Storage and Infiltration Technology (RSIT). It has two parts - RSIT components based on Public-Private Partnership (PPP) and a stormwater drainage system. Herein, the private sector is responsible for the main part of RSIT, and the public sector is responsible for the stormwater drainage from the development area. Thus, the capacity of public facilities, such as rainwater sewers and stormwater reservoirs, can decrease effectively. In parallel, the initial/running cost of public facilities is expected to be reduced.

Chitresh, Pankaj *et al.* (2016) has assessed the stormwater runoff management practices and governance under climate change and urbanization and analyzed the case of Bangkok, Hanoi, and Tokyo. He pointed out that Tokyo suffered from serious flood problems led by stormwater runoff and thus has been taking both structural and non-structural measures for stormwater runoff control. Tokyo has constructed underground infrastructure, using five silos and through-tunnel channels to transport water out of the city, namely the Metropolitan Area Outer Underground Discharge Channel or G-Cans Project. This project is the largest underground flood water diversion facility in the world Bobylev (2007). In addition, many cities in Japan has been applying the artificial infiltration stormwater system. It is evident that many Non-profit organizations (NPO) join the process and functions well.

The Japan Government also released a series of policies and standards about stormwater management and rainwater use since 1991. For example, PUBDIS and Ministry of Land (1991) released the *Standard of Planning and Commentary on Drainage Reuse and Rainwater Utilization System (1991 Edition)*, which established a technical standard of water quality, structure, construction and maintenance for the system installed at government facilities. On April 1st, 2016, it was abolished and replaced by the *Standard of Planning Equipment of Rainwater Utilization and Drainage Reuse* (Ministry of Land (2016)). Technology (2013) published the *Proposal of Technological Guideline for Plastic Facilities of Underground Rainwater Storages (Reformulated Edition)*.

Noteworthy is that there are a lot of studies on urban flooding or waterlogging in Japan nowadays. For example, MORI (2016) conducted a numerical study on the inundation properties in urban space due to serious storm surge and river flooding.

Table 2-6 Historical Trends of Urban Stormwater Management in Japan

1960s	• In 1963, began to construct reservoirs for stormwater detention and storage.
1970s	• Began to implement comprehensive water control measures. Kept using conventional methods to control the river. Meanwhile, developed rainwater infiltration measures to adapt to local conditions, and formed corresponding industry. • In 1977, the conception of basin management was put forward in the *3rd National Comprehensive Development Plan*.
1980s	• In 1980, the Ministry of Land, Infrastructure, Transport, and Tourism promoted the idea of "Outflow Suppression" in the "Rainwater Storage and Infiltration Plan". • In 1988, Association for Rainwater Storage and Infiltration Technology was established, which executes investigation, research, and development related to the technology to store and infiltrate rainwater, aiming to disseminate comprehensive mitigation measures against flood damage. Its members consist of 71 companies.
1990s	• In 1992, the Tokyo Bureau of Sewerage promulgated the *Master Plan for Second Generation Sewer*, in which regulates that a plan for stormwater infiltration facilities and permeable surface should be included in the master plan. For example, the new-built and reconstructed large public complexes should install underground rainwater infiltration facilities; the newly developed urban areas should set up subsidiary rainwater retention facilities, of which 1 hectare land with 500 m^3 capacity.
2000s	• In 2000, the *Quick Plan for Rainwater Construction* was formulated as the emergent prior rainwater measures by the Tokyo Bureau of Sewerage. • In 2001, the Tokyo Bureau of Sewerage formulated the *Quick Plan for Improving Combined Sewerage,* aim at keeping waterfronts beautiful even on rainy days. • In 2004, The Tokyo Bureau of Sewerage amended the *Quick Plan for Rainwater Construction*, and the *Quick Plan for Improving Combined Sewerage.*
2010s	• On April 2nd, 2014, the House of Representatives promulgated the *Water Circulation Basic Act*, which is the first comprehensive law on water. • On April 2nd, 2014, the *Rainwater Act* was also Promulgated. It stipulates details that all the newly constructed buildings owned by governments and administrative units should, in principle, set up rainwater storage and utilization facilities in the basement; for those private buildings, which had established related facilities, governments should take tax relief, grants or other forms to encourage the promotion. • In 2015, both the *National Land Development Plan* and the *Social Capital Development Priority Plan* initially put the *Green Infrastructure* into concerned articles.

This part shows Japan's efforts on rainwater harvesting. By the end of 2013, Japan has 1, 937 public facilities and offices performing Rainwater Utilization Facilities (Ministry of Land). The total amount of utilizing storm water in 2013 is about 7.92 billion m^3, shares about 0.01% of water consumption in Japan, mainly used for toilet flushing, spray, firewater, cleaning, historic preservation, refrigeration, car washing, washing, cooler etc.

Japan early started a rainwater storage project at Akishima Tsutsujigaoka Heights in March 1981. And in 1983 the government founded Rainwater Storage and Infiltration Project, focusing on the rainwater storage and infiltration in small watersheds. And finally, the Rainwater Act was promulgated on May 5th, 2014. Then the Act to Advance the Utilization of Rainwater was made on March 10, 2015. Based on that, in newly constructed buildings by the state government or incorporated administrative agencies, all should install the rainwater harvesting systems. The success of Japan's rainwater harvesting is not only pushed by laws and policies but also because of efforts made by many institutions and associations, for instance, Association for Rainwater Storage and Infiltration Technology (ARSIT), Environmental Engineering Committee of Architectural Institute of Japan (AIJES), etc. Some proposals, guidelines, and standards are published by them to instruct concerned issues (Table 2-7).

Table 2-7 Some Published Instructions for Rainwater Utilization in Japan

Publications	Year	ARSIT	AIJES
Handbook of Products for Rainwater Storage and Infiltration Facilities	2005	●	
Installation Manual for Rainwater Storage and Infiltration Facilities in Single-family Houses	2006	●	
Proposal of Technical Guidelines for Rainwater Infiltration Facilities – Research and Planning (Supplement and Reformulated Edition)	2006	●	
Proposal of Technical Guidelines for Rainwater Infiltration Facilities –Structure, Construction, and Maintenance (Supplement and Reformulated Edition)	2007	●	
Guideline for Rainwater Harvesting Architecture (AIJES-W0002-2011)	2011		●
Technical Standards for Rainwater Harvesting (AIJES-W0003-2016)	2016		●

Note: ARSIT (Association for Rainwater Storage and Infiltration Technology), AIJES (Environmental Engineering Committee of Architectural Institute of Japan)

2.2.3 Progress of Urban Stormwater Management in China

Frequent urban waterlogging in most cities of China is caused by the low waterlogging prevention, as well as low drainage standard. Conventional drainage approach of pipeline networks is widely used in most China's urban areas for the time being.

The design standards for drainage of cities in Europe and United States are higher than China's. According to *Drain and Sewer Systems Outside Buildings*. (EN) and *Standard Guidelines for the Design, Installation, and Operation and Maintenance of Urban Subsurface Drainage* (Engineers (2013)) , the return period of drainage design for general areas is 2~5 years, for important areas is 5~10 years, for some large cities is even higher. For example, New York for 10 years, Berlin for 25 years.

However, China's "Outdoor Drainage Design Code" (GB 50014-2011) provides that the design return period of urban drainage facilities in general areas is 1~3 years, the important areas of 3~5 years. Furthermore, most cities in China takes the lower limit, more than 70% of urban drainage system design rainstorm return period is less than 1 year, 90% of the old city's key areas even lower than the lower specification limit. Therefore, China's drainage system needs to be improved and perfected.

At present, rainwater utilization in China is mainly limited to rural households, agriculture and water conservancy projects (ZHANG (2015)). Urban stormwater management and rainwater utilization in China began from the 1990s. In 1989, the Water Quality Standard for Living Miscellaneous Water (CJ25.1-1989) was formulated. In 1996, the first national rainwater utilization symposium was held in Lanzhou, but the rainwater utilization practice was slow. In 2001, the Ministry of Water Resources released “storage and utilization of engineering technical specifications", marks the initial maturity of the technology.

Researches or practices of rainwater utilization have been recently carried out in many cities such as Beijing, Tianjin, Qingdao, Shanghai, Dalian, Nanjing, Wuhan, Harbin, Xi'an, Kunming, etc. In 2000, Beijing government officially launched the *Urban Rainwater Control and Utilization Project*. In 2003, it also promulgated the *Interim Provisions on Strengthening the Utilization of Rainwater Resources in Construction Projects*, requiring construction projects to collect, infiltrate, store and use rainwater onsite. Once the construction is completed, both stormwater peak runoff and the total volume of outflow should not increase. Shenzhen is also actively promoting the comprehensive utilization of rainwater. In 2006, Shenzhen issued the *Research on Rainwater Utilization Planning at Shenzhen*, on which proposed to collect, infiltrate and treat rainwater, then use it as municipal water and landscape water, meanwhile to alleviate the flood control pressure. In 2011, Shenzhen promulgated the *Specification Rainwater Utilization Engineering*, which stipulated that construction land should not increase the peak discharge of rainwater. The concentration of COD, SS and TP should be lower than the stipulated value, and the rainwater should be collected and reused.

2.3 Summary

This chapter has reviewed the mainstream theories for urban stormwater management including the Best Management Practices (BMPs), Low Impact Development/Design (LID), Sustainable Urban Drainage System (SuDs), and Water Sensitive Urban Design (WSUD). We have summarized their ideas, measures, and made a comparison. Generally, there is significant overlap between various terms (Figure 2-7). Indeed, all terms are generally underpinned by two broad principles: (i) mitigation of changes to hydrology and evolution towards flow regime as much as feasible towards natural levels or local environmental objectives, (ii) improvement of water quality and a reduction of pollutants.

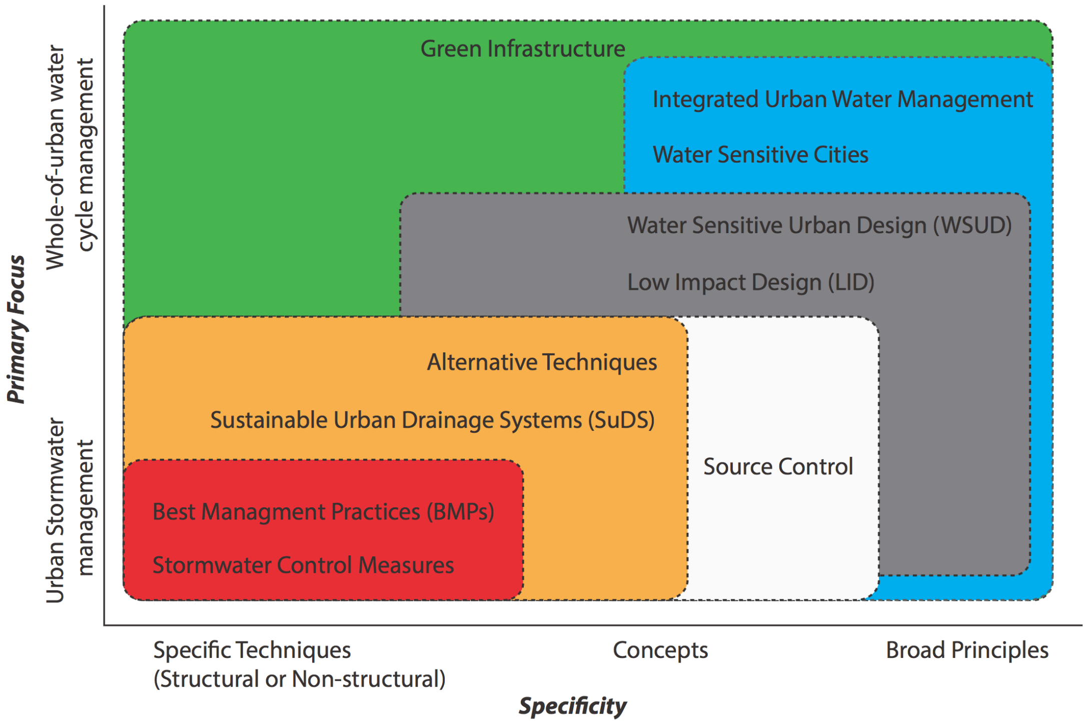

Figure 2-7 Classification of Urban Drainage Terminology

Note: Adapted from Tim D Fletcher, William Shuster, William F Hunt, Richard Ashley, David Butler, Scott Arthur, Sam Trowsdale, Sylvie Barraud, Annette Semadeni-Davies and Jean-Luc Bertrand-Krajewski (2015). "SUDS, LID, BMPs, WSUD and more–The evolution and application of terminology surrounding urban drainage." Urban Water Journal 12(7): 525-542.

Also, we analyzed the current progress of urban stormwater management of the United States, Japan, and China. It can be concluded that the concept and technologies of China's urban stormwater management including utilization is relatively backward. Presently, only a few cities have carried out some preliminary policies, but most cities in China do not have any practices on rainwater management especially the utilization.

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3 China's Sponge City Construction in Current Conditions

3.1 Current Situation of Flood Control in China

YANG, KUROYANAGI *et al.* (2016) has conducted a pre-study on river environmental improvement based on human water harmony by using PEST analysis of flood control situation in Mainland China. We summarized that river environment improvement activities have commonly been unfolded in Japan during its nature-oriented river management for decades. To evaluate their prospects in mainland China, grasping the current situation of flood control should always be the first place. We achieved by a comprehensive overview survey based on past detailed data and research findings of related domains, within the framework of Political, Economic, Social and Technological dimensions (PEST Analysis). Our results showed that evolutionary progression had continued obviously in every dimension during the period of 2004 to 2013. However, flood control expenditure's proportion to the whole water conservancy investment showed a downward trend despite both amounts kept increasing, since a focus shifting to water resource projects. It suggests that not until accomplishing those water resources projects in next dozen years will the river environment improvement activities be virtually promoted under the conception of human water harmony.

For half a century at least, but especially recently, mainland China has been confronting critical water crisis hazards mainly consisting of floods, water scarcity, pollution and turbidity (WU (2005)). This is largely due to the harsh geographic climate conditions, for instance, about 10% of the land area are below the flood control level of water bodies nearby, covering 44% of the whole population, 35% of cultivated land and 70% of gross product; those problems also result from rapid population growth along with enormous economic activities, and even be further aggravated by climate change (Qian and Zhu (2001)).

Water conservancy refers to all processes and aspects that relate to the safety and sustainability of water utilization such as the policies, strategies and activities of water bodies regulation, flood control and waterlogging control, irrigation, water supply and water resources protection, hydropower utilization, etc. Similar to the process of Japan, China's efforts to water conservancy has shifted 3 times since 1949, firstly on floods, next on water resources, finally on environmental problems (Wang and Hu (2011)).

According to developed countries' evolution of water conservancy during the urbanization and industrialization, more attention is believed to be paid to China's environmental treatment. Indeed, in terms of river environmental improvement, a tendency emphasizing on human water harmony is observed presently, mainly propelled by the growing demand of water amenities for populous Chinese.

Naturally, this progress could only be achieved beyond the society' content with the safeness, good quality, and beauty of water. Take Japan for example, where river environment improvement activities have been unfolded since the 1970s without overlooking flood control via both structural and nonstructural measures, but flood damages still occurred frequently (Japan (2014)). Therefore, in any case, not only occasions of constructing water conservancy projects but also implementing river environment creation activities, safeness should be firstly and constantly considered particularly in the form of flood control.

As a pre-study on river environmental improvement in China, the current situation of flood control should be hence comprehensively analyzed with detailed statistics. However, most researches were on certain branch issues either independently or insufficiently. Thus, this paper aims to provide such a satellite view by the PEST analysis. Besides, in this paper *flood* is defined as waterlogging occurred on flat or low-lying areas, either by floodwater overflowed from water bodies or just a heavy precipitation; and *flood control* refers to all methods including the arts and techniques used to prevent the occurrence of floods or to reduce its detrimental effects near water areas.

PEST analysis, referring to four dimensions, namely political, economic, social and technical analysis, describes a framework of macro environmental factors which are used to effectively identify the principle factors among many parameters around a project, so strategic management can be achieved. It has a quite vague history, the first traceable mention is regarded by Francis J Auilar in his book *Scanning the Business Environment* in 1967, first called as ETPS and finally adopted the acronym PEST instead. Since then it is widely used in many fields such as scanning and evaluating a market or a business.

The conventional usage of PEST method is mostly to analyze either the position of an object or the viability of general solutions within a particular environment Peng and Nunes (2007). There are already many cases using this method until now, for example, evaluating the current state of e-Government in Singapore and its preparedness HA and COGHILL (2008), proposal of transportation planning KATO, SHIROYAMA *et al.* (2006), researching on the environment of Chinese Agricultural E-commerce DU and LU (2009), software industry analysis MCMANUS, LI *et al.* (2007), etc. However, none of them is related to the research of flood control. Our task has three steps: firstly, filter sub items of each dimension; secondly, examine them one by one; finally, discuss the relations of each detention.

The data sources are from: the series of *Statistic Bulletin on China Water Activities* from 2007 to 2013; the series of *Bulletin of Flood and Drought Disaster in China* from 2006 to 2013; data issued on the website of National Bureau of Statistics of the People's Republic of China. Note that the data did not cover Hong Kong, Macau, and Taiwan.

Data Source:

Statistical Bulletin on China Water Activities, yearly compiled by Ministry of Water Resources, PRC since 2007. And published next year by China Water & Power Press, Beijing China. So far available until 2013, a total of 7.

Bulletin of Flood and Drought Disaster in China, yearly compiled by the State Flood Control and Drought Relief Headquarters, Ministry of Water Resources, P. R. China since 2006. And published next year by China Water & Power Press, Beijing China. So far available until 2013, a total of 8.

National Bureau of Statistics of PRC (09/15/2015 updated) GDP data page. <http://data.stats.gov.cn/easyquery.htm?cn=C01&zb=A0201&sj=2013>, 09/15/2015 referred.

3.1.1 Political Analysis

a. Administrative System

The State Flood Control and Drought Relief Headquarters (SFCDRH) is in charge of nationwide flood control affairs. Its supervisor is the vice premier in the State Council who governs water resources; other members are always the vice heads of each governmental department and agency in the State Council, as well as vice leaders of The People's Liberation Army and Chinese People's Armed Police Force, China Railway Administration. This headquarters is a virtual mechanism for negotiating. An office set at the

Ministry of Water Resources is virtually taking care of this business, which has many branch offices at both basin administrations and provincial level, county level and city level (Figure 3-1). The affiliations of their members are similar to the SFCDRH.

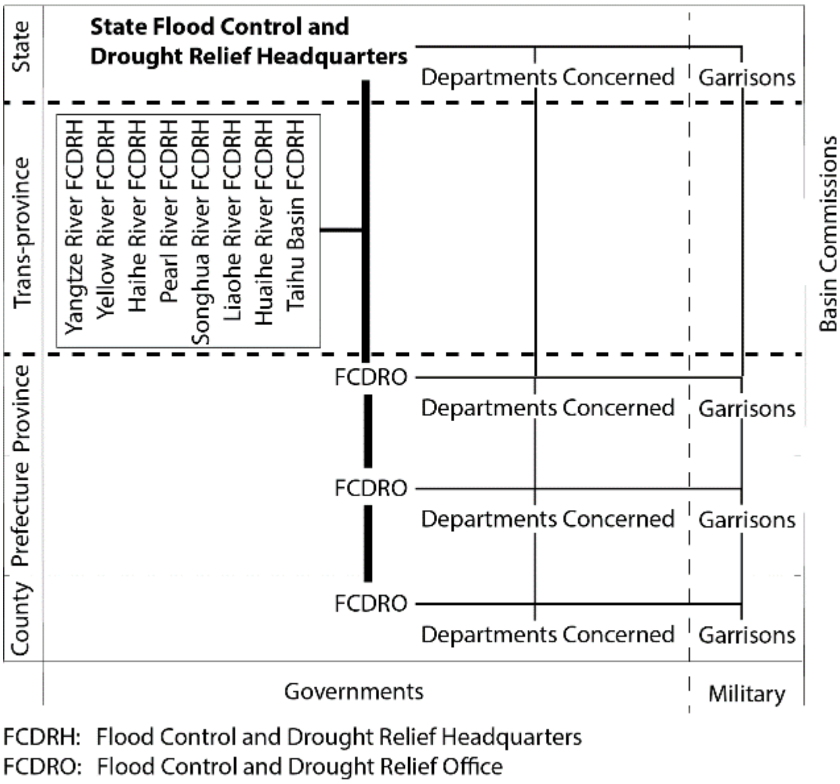

Figure 3-1 Administrative System of Flood Control

b. Legislation

Waters in China is state-owned according to The *Constitution of PRC*. China's prime legislation concerning flood control is summarized below, namely 2 national laws issued by Standing Committee of the National People's Congress, and 4 regulations by the State Council (Table 3-1). Hundreds of decrees formulated by local government are omitted since they are based on these listed laws and regulations. Additionally, these lawmaking activities always comply with the Legislation Law of the PRC. It can be seen that the enactment of law and regulations peaked around 1990 and 2000. The enactment of the *Water Law* is a significant milestone because since then the legalization involving flood control activities had been accelerated. The word *flood* appears 28 times in it, on which is the first time clearly written on a national law. And *the Flood Control Law*, as a specialized law, generally states principles, basic procedures, constructions, planning implementation management system, administration system, the obligation of governments and responsibilities of units and individuals, etc. Besides, *The Flood Control Regulation* is a derivative of the *Water Law*, focusing on the specific affairs and activities of flood fighting.

Table 3-1 Laws and Regulations for Flood Control

Titles	Law	Regulation	Effective Date	Revised Date
River Channel Management Regulation		○	Jun. 20, 1988	Jan. 8, 2011
Water Law	●		Jul. 7, 1988	Oct. 1, 2002
Reservoir and Dam Safety Regulation		○	Mar. 22, 1991	Jan. 8, 2011
Flood Control Regulation		○	Jan. 2, 1991	Jul. 15, 2005 Jan. 8, 2011
Flood Control Law	●		Jan. 1, 1998	Aug. 27, 2009 Apr. 24, 2015
Compensation Regulation for Operation of Flood Storage and Detention Areas		○	May. 27, 2000	None

c. Public Policies

Currently, three most important public policies concerning flood control are followed in chronological order:

- State Emergency Plan for flood prevention and Drought Relief, issued on January 11, 2006;
- Decision of the Central Committee of Communist Party of China and the State Council on Accelerating the Water Conservancy Reform and Development, issued on December 31, 2010;
- the Water Conservancy Development Plan for 2011 to 2015, issued on June 6, 2012.

The first one is mainly for the prevention and urgent disposal of nationwide sudden damage caused by floods; while the latter two put construction of flood control after irrigation, ranks 2 of 5 for overall water conservancy treatment, and both of them set an objective that an elementary relief system for flood control and disaster should be established by 2020.

3.1.2 Economic Analysis

This section calculated, compared and analyzed the crucial economic indicators of flood control. Figure 3-2 shows the yearly direct economic loss by floods, Gross Domestic Product (GDP) and their ratio from 2004 to 2013. The yearly loss is average 175.11 billion Chinese Yuan (CNY), takes an average 0.51% of the yearly GDP.

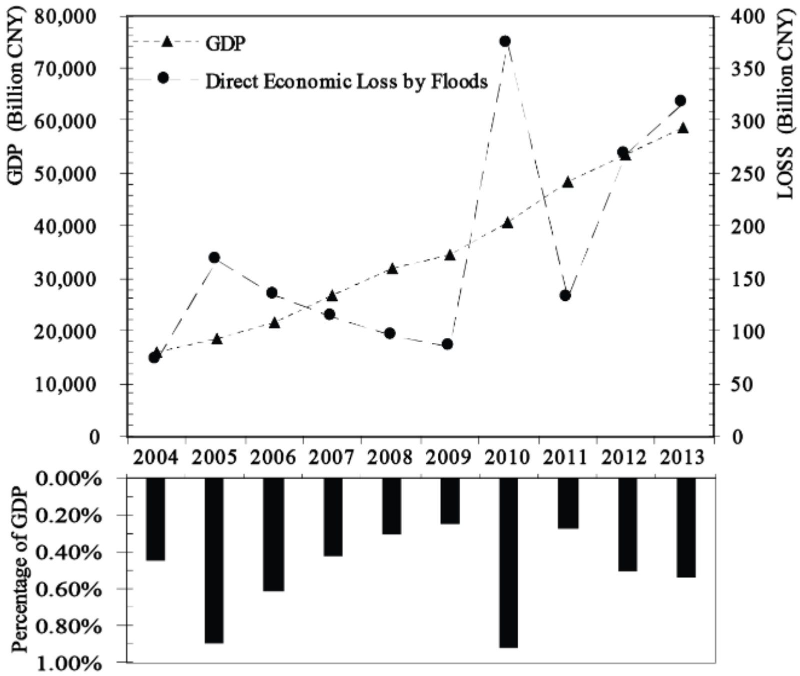

Figure 3-2 Direct Economic Loss by Floods and GDP from 2004 to 2013

Figure 3-3 shows the investment in flood control, GDP and their ratio from 2004 to 2013. It indicates that investments had almost maintained around 30 billion CNY from 2004 to 2008, and been on increase from 2009 to 2012, finally up to 134 billion CNY in 2013, averagely 0.18% of the GDP.

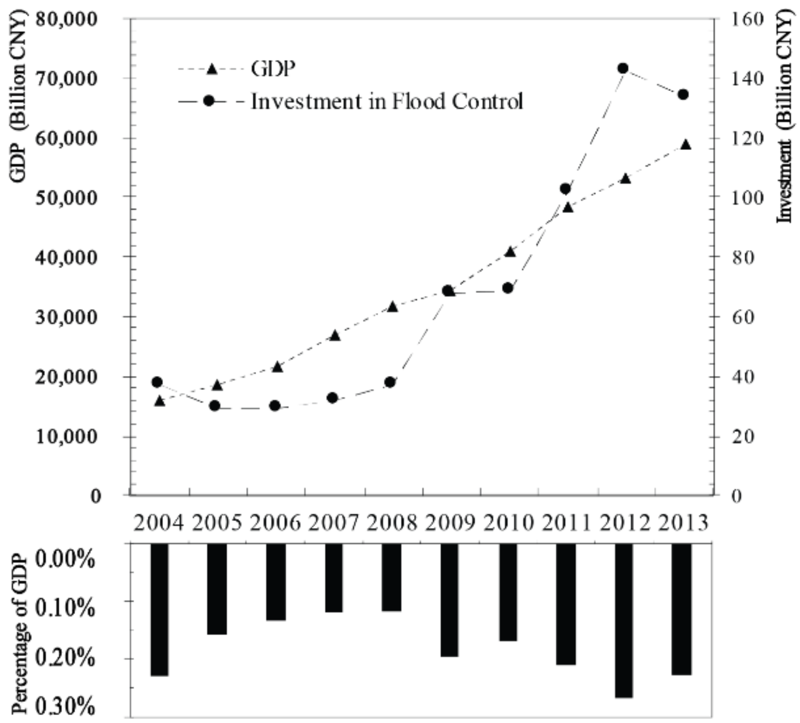

Figure 3-3 Investment in Flood Control and GDP from 2004 to 2013

Figure 3-4 shows the investment in flood control, fiscal expenditure and their ratio from 2004 to 2013. It shows that both the investment and fiscal expenditure had grown several times from 2004 to 2013, and their ratio just kept steadily on an average of 0.88%.

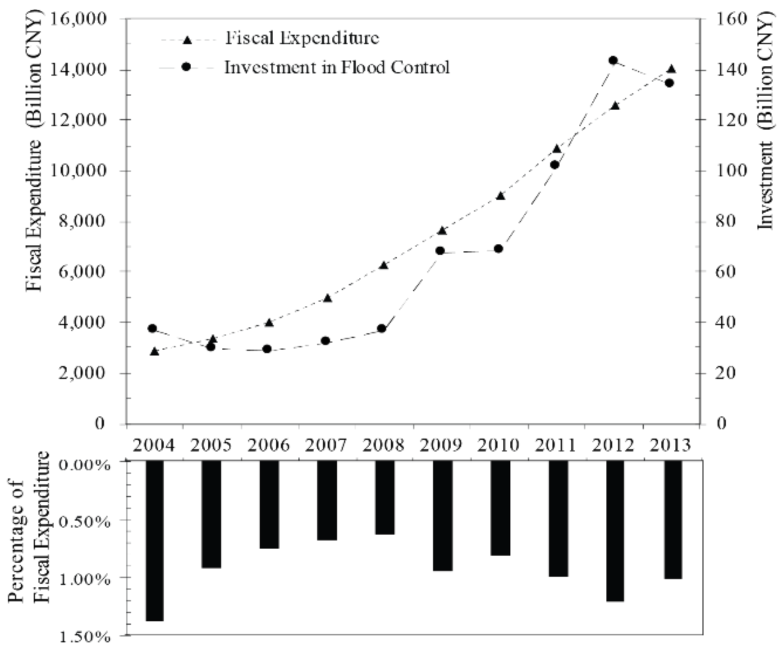

Figure 3-4 Investment in Flood Control and Fiscal Expenditure from 2004 to 2013

Figure 3-5 shows the framework of incomings and expenditure of water conservancy. The main incomings are from the central and local government, shared 89.3% in 2013. There is no direct tax for flood control, however, there is always flood prevention charge by the local governments, usually a certain proportion of enterprises' sales income. The ratio varies different areas.

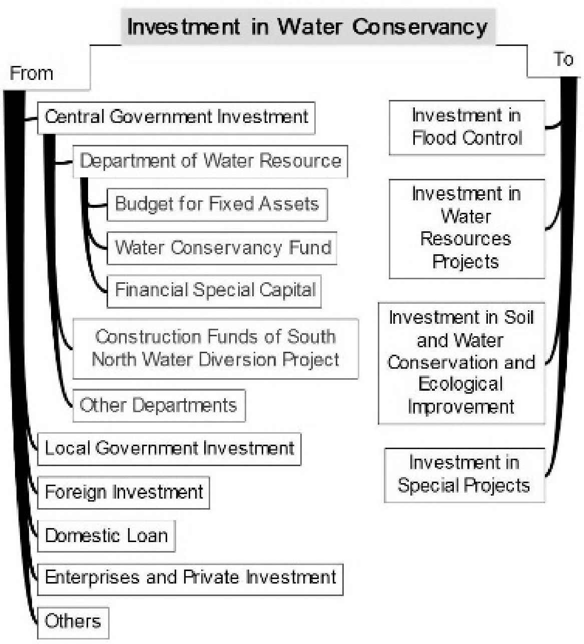

Figure 3-5 Categories of Incomings and Expenditures on Water Conservancy

Figure 3-6 shows the investment in flood control and water conservancy and their ratio from 2004 to 2013. It shows that both investments in flood control and water conservancy had been kept growing, nevertheless, the ratio tended to decline because other investments had taken precedence gradually such as water resources projects, which has grown rapidly and exceeded it since 2006. It should be also noted that the average yearly investment in improving the water conservancy capacity also kept about 2.7 billion CNY, aiming at the improvement of communication facilities, hydrological networks, scientific researches and educational sectors etc.

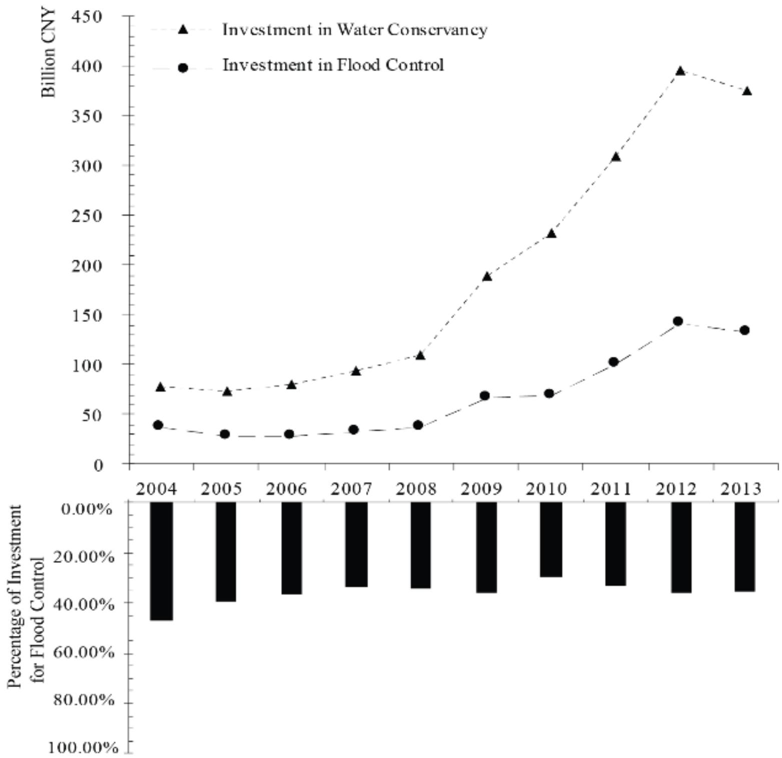

Figure 3-6 Investment in Flood Control and Water Conservancy from 2004 to 2013

3.1.3 Social Analysis

The population growth rate of China is as low as 0.49% (Year 2013), while the domestic migration and urbanization are fierce. And according to the Flood Control Law and Flood Control Regulation, every drainage basin and province-level, county-level governments should make a flood control planning and submit to the related department for approval. Most basin-level governments had put it into effective in 2007~2009, therefore except the striking case in 2010, the deaths, missing and affected persons as well as collapsed houses has a downtrend (Table 3-2 Populations and Houses Loss by Floods from 2004 to 2013).

Table 3-2 Populations and Houses Loss by Floods from 2004 to 2013

Year	Persons			Houses Collapsed(×10^3)
	Dead	Missing	Affected (×10^9)	
2004	1282	none	None	933.1
2005	1660	none	200.3	1532.9
2006	2276	none	138.8	1058.2
2007	1230	none	177.0	1029.7
2008	633	none	140.5	447.0
2009	538	none	111.0	555.9
2010	3222	1003	210.8	2271.0
2011	519	121	89.4	693.0
2012	673	159	123.7	586.0
2013	775	374	119.7	533.6

On the other hand, to deliver warning message, news and common sense of flood to the public, the media is extensively utilized under the leadership of SFCDRH (Figure 3-7). The two critical systems are the press spokesman system (established in 2010) and the live broadcast system with China Central Television (established in 2012), led by the SFCDRH office. Nearly every mainstream media and part of local media have launched news, special programs, columns, etc. For example, television programs such as the XINWEN LIANBO and LIVE NEWS of CCTV, newspapers such as People's Daily, Guangming Daily, radio programs such as Central People's Broadcasting Station, China Radio International, and websites such as people.cn, Guangming Online etc. Besides, flood advertisements can be seen on TV occasionally.

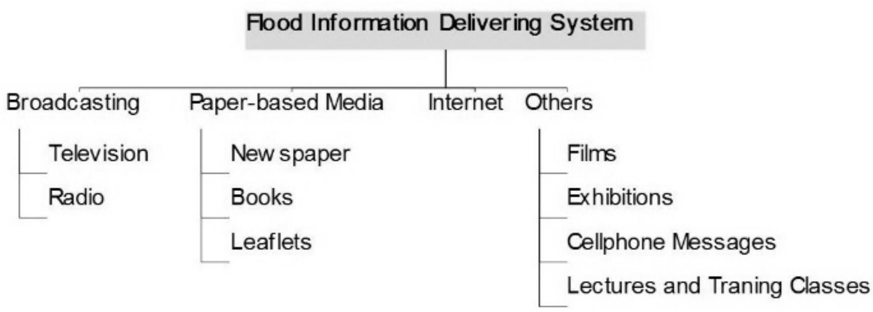

Figure 3-7 Diagram of Flood Information Delivering System

3.1.4 Technical Analysis

Academic researches and technical development are booming these years. To study on the technical dimension of flood control development, the best way is to evaluate its maturity of technology and associated technologies, calculate its research findings, global communications, innovation potentials, etc. However, we only selected the related technical standards as our criterion to briefly analyze this dimension. The reasons are not only because they represent the current mature practicable directions from the government, but they are also able to reflect the development of technology level in various periods. Additionally, in contrast to political, economic and social dimensions, its development relies more on the former and be more tractable.

Standard means authoritative directives and instructions established by the government about the best way to do something, often as a rule for the measure of quantity, extent, value, or quality. Our research showed that more standards had been made for flood prevention and control recently, including integrated technique, planning, geological survey, design, construction, qualities, management, and machinery etc.

They consist of national standards (GB) and professional standards for the Ministry of Water Resources of PRC (SL), of some are compulsory, others are voluntary. These standards cover: flood fighting standards for rivers, lakes, reservoirs, dykes, embankments, lifesaving high platform; structural measures standards for floodwater storage, discharge, detention, diversion, and waterlogged area drainage; nonstructural measures standards for flood early warning, forecast, operation, river channel obstacles-clean up; technical standards of dredging of river channels, lakes and reservoirs etc.

This research has investigated flood control situation of China in 2004~2013, which can be shortly summarized as below: (1) politically: administrative system became rigorous; legislation became relatively systematic; public policies fairly supported; (2) economically: investment for flood control up trended, while its ratio to the whole water conservancy investment tended to drop; (3) socially: impact slightly decreased, and flood information delivering system had been basically established; (4) technically: a trend towards standardization.

Particularly considerable effort can be observed in recent decades. Generally, the strategy for flood fighting in China has gradually changed from control to management since the 1998 floods (CHENG (2006)), not only directly and simply focusing on flood itself such as floodwater storage, discharge, detention, but also enhances efficient utilization of existing projects and regulating the development of highly risky flooded areas. As nonstructural flood control measures, have been advocated to collaborate with structural measures, it has become more efficient than before.

Our findings revealed that the government leading flood control in China has consistently progressed, while its centric role of whole water conservancy had been replaced by water resources projects recently. Thus, we believe that it would not be too long before the next focus on the river environment creations based on human water harmony, and it would expand rapidly within a dozen years. This view is in substantial agreement with those of Wang Yahua and Hu Angang, who concluded that the construction of water amenities in China was launched from 1998 to 2010, then spreads during the period of 2011 to 2020, finally, proliferates from 2021 to 2030 (Wang and Hu (2011)).

Reference to the experience of water conservancy in Japan and other developed countries, actions regarding environment improvement would only boom after contenting with safeness. Via our study, peers are able to grasp the development level of China in this field, and it would contribute to developing nature-oriented river improvement in the future. Yet, our results lack clarifying how those indicators were filtered among mass dynamic external factors of flood control, besides an analysis on flood itself were ignored completely. Therefore, a further research should combine both of them.

3.2 Historical Transition of China's Ecological Water Conservancy

YANG, SUGAHARA *et al.* (2016) concluded that hat environment protection actions at Chinese central government level virtually began from 1972, conservation and restoration activities regarding riverside ecosystem have been booming in China since 2001. They had investigated the transition of China's concerned national policies as well as briefly summarized related constructing projects.

Japan has combined river control with the creation of habitats and landscape design since 1990 (DOZONO (2015)). Cities in China also took some similar projects at the same time, but water bodies in urban areas have been still seriously harmed due to the rapid urbanization these years. Therefore, in 2001, the Chinese central government put the conception of "Ecological Conservancy" into the "10th Five-Year-Plan (2001~2005)". This conception basically focuses on restoring and maintaining the basin's ecosystem and environment to achieve a harmony coexistence of people and nature. From then, more and more river restoration projects were implemented national wide based on that concept (HAGIWARA and HAGIWARA (2010)). HAGIWARA, HAGIWARA *et al.* (2008) had outlined the basic concept, characteristics, and problems of China's waterside improvement. But in this section, we summarized the historical trends of river improvement based on considering conserving nature and ecosystem.

Ecological conservation is the upper concept of ecological water conservancy, which covers conservation of forests, meadows, wetlands, rivers, lakes, seas and oceans etc., aiming at sustainable development. China's Central government formulated the 1st Five-Year-Plan in 1953. In most cases, a Five-Year-Plan would be released every 5 years since then (Table 3-3).

Table 3-3 Historical Transition of Policies in Five-Year-Plans

Five-Year-Plan	Period	Times of "Ecology"	Whether approved by National People's Congress	Aims of Plan
1st	1953~1957	0	◯	• Industrialization centered for economic development; • Not emphasized on social development such as improving living conditions or protect the environment.
2nd	1958~1962	0	×	
3rd	1966~1970	0	×	
4th	1971~1975	0	×	
5th	1976~1980	0	×	
6th	1981~1985	1	◯	• Harmony between economic development and social development
7th	1986~1990	3	◯	
9th	1991~1995	5	◯	
9th	1996~2000	7	◯	• Focus on sustainable social development
10th	2001~2005	28	◯	
11th	2006~2010	66	◯	
12th	2011~2015	52	◯	

By analyzing the detailed policies on ecological conservation of Five-Year-Plans, we found that the 6th Five-Year-Plan (1981~1985) started to value the balance of economy development and society development, typically determined to control and improve the worsening situation of ecosystem and environment such as desertification and deterioration; then, from the 10th Five-Year-Plan (2001~2015), the conservation and restoration of forests and watersides began (Table 3-4).

Table 3-4 Policy Changes on Ecological Conservation of Five-Year-Plans

	Five-Year-Plan						
	6th	7th	8th	9th	10th	11th	12th
Policy	Preventing deterioration of ecosystem and environment						
				Emphasize on ecological protection			
					Utilize the ecosystem's self-healing ability		
						Ecosystem conservation	
							Construct ecosystem network
Research and Financial Support			Science and technology support				
					Strengthen basic research		
					Financial support of migration for ecosystem protection		
						Utilize information science	
						Strengthen research to improve water ecosystem and environment	
						Legislate ecological protection	
Concrete Measures	Afforestation for controlling desertification expansion						
		Strengthen water source protection				Strengthen water source protection	
			Protect and restore ecosystem of grasslands		Protect and restore ecosystem of grasslands		
			Designate and maintain nature reserves		Designate and maintain nature reserves		
					Protect biodiversity		
					Suppress soil erosion		
					Suppress cultivated land use		
					Protect forest resources		
					Inhibit rock desertification		
						Construct ecosystem network of Qingzang Plateau	
Focused Measures			Promote agriculture considering ecosystem and environment protection			Promote agriculture considering ecosystem and environment protection	
					Reduce environmental deterioration in mining		
					Emphasize protecting ecosystem in urban development		
							Develop tourism with ecosystem and
Conserve Water Ecosystem					Protect environment of fishery watershed		
					Water environment improvement		
					Reduce dam's impact on ecosystem		
					Conserve ecosystem of wetlands		
						Protect ecosystem of marines	
						Protect ecosystem of rivers and lakes	

Until the 1980s, China’s river improvement activities valued the space development based on the conception of “Water Conservancy Engineering”, which prioritized economic efficiency and land use, neglected the ecosystem and environment. Until the 6th Five-Year Plan (1981~1985), the central government began to implement policies aimed at returning arable land and pasture to grassland. According to the 10th Five-Year Plan (2001~2005), protection and improvement of the waterside ecosystem and environment had been enhanced. Ever since, creating aquatic habitats, securing its biodiversity, etc. became major purposes of waterside environment improvement (Table 3-5).

Table 3-5 Policy Changes on Ecological Conservancy about Waters of Five-Year-Plans

Five-Year-Plan	Period	Policy on ecological water use
10th	2001~2005	【Clarified the importance of protecting and improving waterside ecosystem】 • Improve water environment to create aquatic habitat space by protecting water sources and wetlands; • Balance of domestic water, industrial water, and water for ecosystem; • Focus on protecting biodiversity; • Construct water ecosystem and environment at urban areas.
11th	2006~2010	【Concrete policy study on protecting and improving waterside ecosystem】 • Build ecology compensation mechanism; • Develop ecosystem-friendly hydroelectric power generation; • Prevent of alien species damage to indigenous species.
12th	2011~2015	【Fundamental restraint against deterioration of ecosystem and environment】 • Protect ecosystem and environment of Important lakes, reservoirs and large rivers by building ecological safety barriers; • Develop waterside ecosystem as tourism resources.

Since 2005, Ministry of Water Conservancy, China, had conducted the "National Water Ecosystem Protection and Restoration Experiment" based on 10th Five-Year-Plan (2001~2005); then, conducted the "Ecological and Clean Improvement Experiment of Small Basins" in 2006; moreover, conducted the "Construction Experiment of National Water Ecology Civilization City" from 2013 (Table 3-6).

Table 3-6 Experimental Efforts Based on Ecological Water Conservancy by Ministry of Water Conservancy

Five-Year-Plan	Start Year	Experiment name and place of implementation
10th	2005	" National Water Ecosystem Protection and Restoration Experiment " 【12 cities】 Wuxi, Wuhan, Guilin, Lanzhou, Lishui, Xinbin County, Fenghuang County, Songyuan, Xingtai, Xi'an, Hefei, Harbin
11th	2006	" Ecological and Clean Improvement Experiment of Small Basins" 【335 counties (By 2014)】
12th	2013	"Construction Experiment of National Water Ecology Civilization City" 【104 cities (2013: 45 cities, 2014: 59 cities)】

LIU (2004) pointed out that the recovery of catchment ecosystem would experience four phases:

Phase 1: Water Quality Improvement;

Phase 2: Recovery of Small Aquatic Organisms;

Phase 3: Recovery of Large Aquatic Organisms;

Phase 4: Whole Basins Presenting the recovery of the ecosystem;

For China, it is at the 2nd phase, as financial resources limited, recovery projects are mainly implemented in urban areas, not deployed throughout China. Both the central and local governments of China have been promoting measures based on the conception of ecological water conservancy to prevent flooding and pollution, to manage water resources, etc. However, there is no national river restoration project like Japan's *Nature-oriented River Improvement Project* being promoted in China. In fact, on the budget side, most cities carried out projects respectively. Therefore, except for experimental efforts in urban rivers, conservation of river ecosystems can be said to be a short-term and local business. For example, in Beijing, measures to restore and maintain river ecosystems are not sufficiently implemented, and they have been developing businesses that emphasize landscape formation such as lighting up of river space and greening.

3.2.1 Overview of Redevelopment at Xinjiangwancheng Town, Shanghai

Here we took Xinjiangwancheng Town, Shanghai as a case study of river improvement under the concept of ecological water conservancy in China (Figure 3-8). We summarized the background, efforts, and achievements by its redevelopment as below.

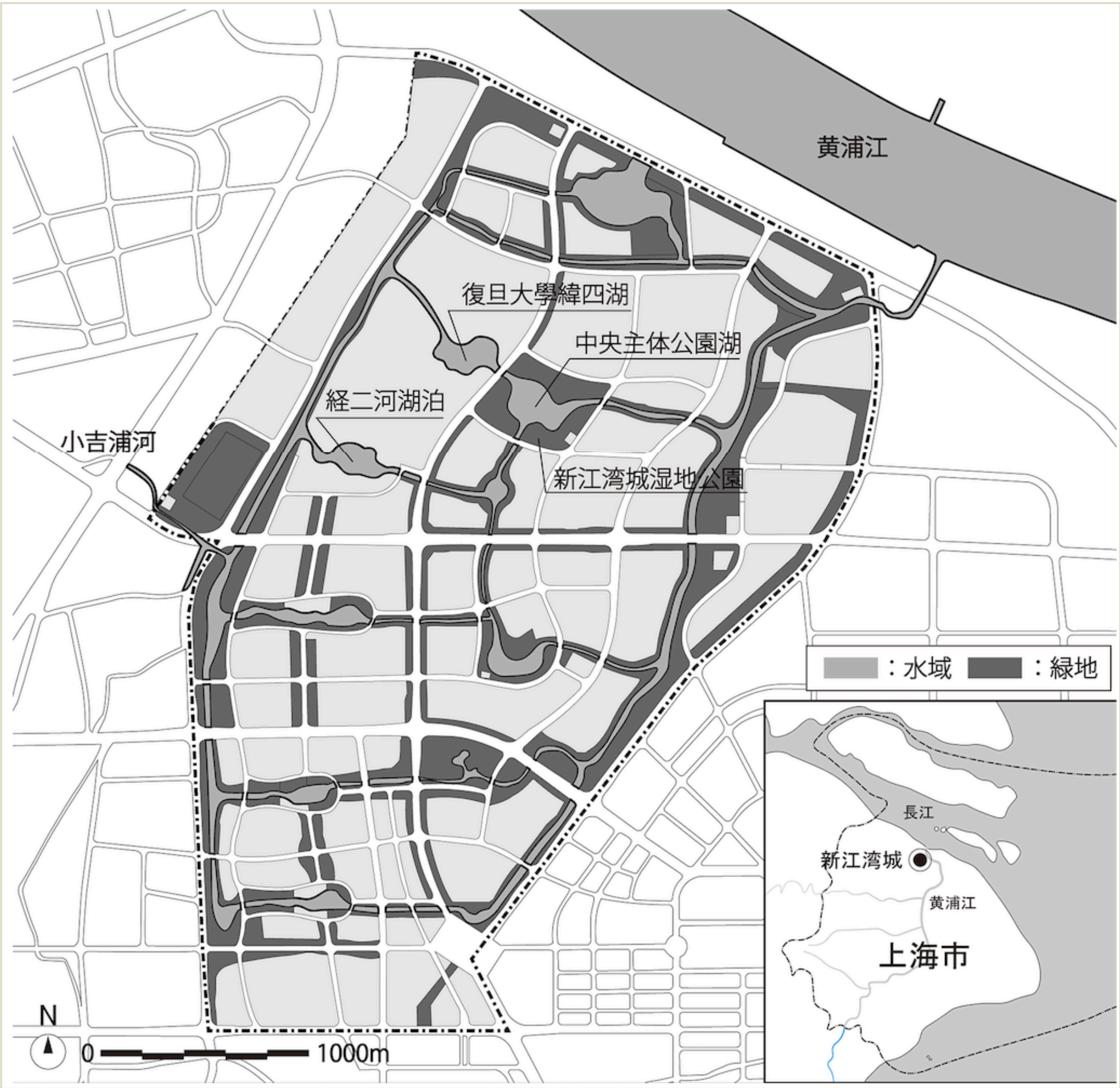

Figure 3-8 Map of Xinjiangwancheng Town, Shanghai, China

(1) Background

Xinjiangwancheng Town is located at the confluence of the Pujiang River and the Yangtze River, in the plain areas along the coast. It has a population of about 43,000 and an area of about 9.45 km^2. The altitude is between 3.10 m to 4.50 m.

About 90 years ago, most areas of Xinjiangwancheng Town had been farmlands and wildlands. In 1937, it received the takeover by the Japanese army and was transformed into an air force base. Until 1989 the base use was stopped, the grasslands, wetlands etc. began recovery. In 1997, it was designated as Shanghai Model Residential Areas by Shanghai Municipal Government, planned to be reconstructed as a residential district. In the same year, the land ownership was shifted to Shanghai Municipal Government from the Chinese People's Liberation Army Force. In 2001, the development goal of A 21st Century Intelligent Ecotype Garden City was set, determined its land use goal as that the green space rate by more than 20%, and the area of water surface by more than 20% of the district. Its construction was started in 2003 and completed in 2011, including infrastructure such as water supply networks, sewers, roads, etc., together with environment improvement such as green space and waterways.

(2) Development policy

The development conception of Xinjiangwancheng Town is to form a nature network composed of waters and greens. River channels in this area were reconstructed, and sluices were set to enable the function of exchange its water with the nearby Huangpu River and Xiaojipuhe Stream. Besides, reservoirs, embankments, revetments and other structures were constructed to realize other objectives like the sufficient water resources supply, forming landscape, flood control, drainage exclusion, etc.

(3) Development Items

After the urban renewal at Xinjiangwancheng Town, the water surface had been extended to 8.14% of the whole region, with an area of about 0.8 km^2 which can store 1.6 million m^3. Now there are 10 stream channels at Xinjiangwancheng Town, of which 7 in the east-west direction, 3 in the north-south direction. Besides, 10 reservoirs/lakes were constructed based on the original waters, mainly placed at confluences. In case of water scarcity and water quality deterioration occur in Xinjiangwancheng Town, an amount of water can be adjusted into this district for mitigation.

(Ⅰ) Measures for Flood Control and Rainwater Drainage

Its planning standards for flood control and stormwater drainage is to surmount heavy rain of 20-year frequency. The highest water level of the waterway is 3.50 m. The storage capacity is 700,000 m^3. The discharge capacity of the adjustment facility at the confluence of the Huangpu River is 28 m^3/s.

(Ⅱ) Water resource use

Rainwater is utilized for irrigation for the green areas and road cleaning by about 5 million m3 yearly. Moreover, it also discharges the tide of the Huangpu River to supplement the water supply whenever water shortage occurs in Xinjiangwancheng Town.

(Ⅲ) Water quality improvement

In Xinjiangwancheng Town, the rainwater runoff is made to flow through the purification filter or the like to improve its water quality, then flows into waterways and reservoirs. Also, the domestic wastewater is drainage to the sewage treatment plant outside Xinjiangwancheng Town through the sewer system.

(Ⅳ) Waterside landscape formation

Figure 3-9 shows the green space improvement along the waterway. To achieve the landscape formation of waterfront space of Xinjiangwancheng Town, the Xinjiangwancheng Wetland Park was established, lawns and plantings are also constructed on the both sides of the waterways.

Figure 3-9 Scenery of Reservoir After Construction

(V) Protection and restoration of riparian ecosystems

① Forming rivers paths in consideration of the ecosystem

The pattern and the cross-section of the waterway is to be shaped close to a natural stream. The riverbed is also constructed with riffles and pools, etc. aiming to conserve the biological growth-nurturing environment. In addition, making the gradient to a gentle slope to ensure the continuity of ecosystem along the riverbeds, watersides, and lands, as well as creating a habitat for the waterside ecosystem.

② Revetment form in consideration of the ecosystem

Figure 3-10, Figure 3-11 shows the revetment after the improvement in consideration of the ecological system. Basically, vegetation banks are constructed. For the confluences of the waterways, vegetation revetment using the natural stone and high-density Prescient resin are also constructed. Besides, wooden stakes were implanted at some points of the revetment to prevent the erosion due to flowing water.

③ Creation of ecosystem habitats

Figure 3-12 shows the aquatic organisms found along the waterways. In consideration of the habitats of aquatic organisms, wetlands were constructed in Xinjiangwancheng Town such as the Xinjiangwancheng Wetland Park, etc. together with other forms of space development such as ecological revetment. By doing those, the original waterside aquatic organisms are likely to habitat and breed again.

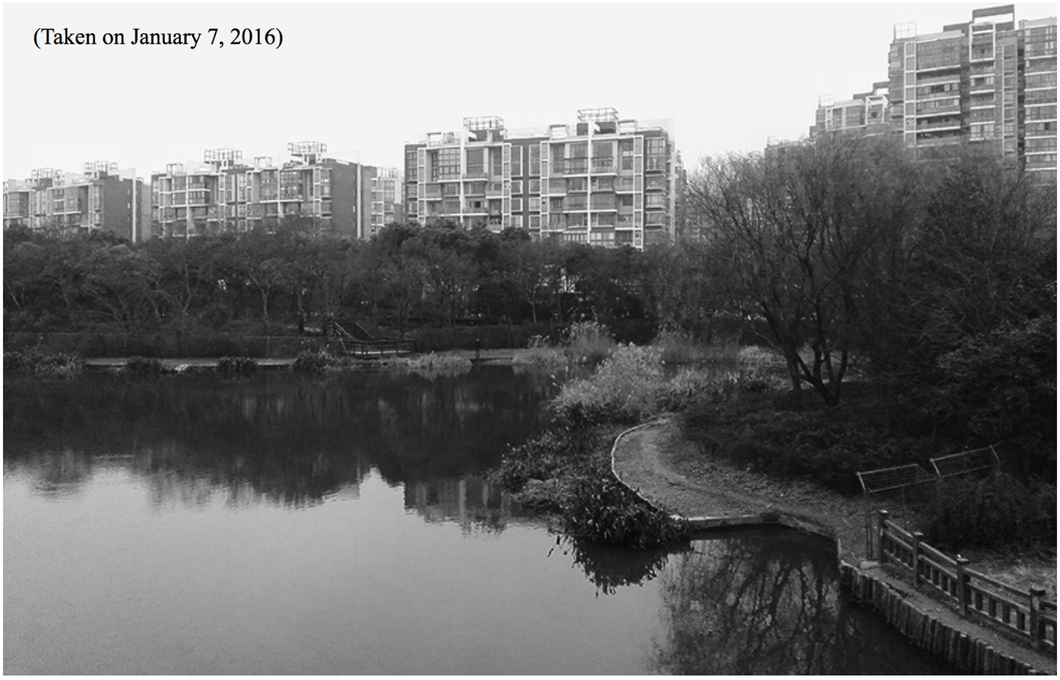

Figure 3-10 Landscaping of the Green Area Along the Waterway

Figure 3-11 Revetment Constructed Along the Waterway

Figure 3-12 Aquatic Plants Found Along Waterways

3.3 Sponge City Construction Under Urban Environmental Improvement in China

High-speed urbanization in China always accompanies with water logging as well as flooding. The concept of Sponge City Construction has recently been proposed to mitigate them in urban areas. To successfully implement it, its relation to environmental improvement activities in the process of urbanization must be explored. It is achieved by carefully analyzing concerned information with three steps. Our results showed that by 2020, China would continue a rapid speed of urbanization, more attention on environment improvement has been paid during this process, and sponge city construction could be integrated into the background of China’s National New Urbanization.

Sponge city construction policy has been actively promoted since 2015, aiming to lessen the risk of water logging and flooding in urban areas, as well as to effectively utilize rainwater. Its concept and theories are rapidly enriched these days, however, its correlation with environmental improvement during urbanization has not been examined yet. The former targets on disposal of rainwater, while the latter performs a wide range of activities, increasing the difficulty to combine and compare them. This paper defines urban environment as the sum of natural and built environment with high population density, such as atmosphere, hydrosphere, biosphere, geosphere, and the society. And the urban environmental improvement accordingly refers to all kinds of activities involving with conserving, recovering, and creating interactions, for example, afforestation etc.

Architectural Institute of Japan (1962) initiated a research on architectural environment improvement, the first study on urban environment construction in Japan. Since then, concerned topics are studied in chronological order as follows: land development, residential conditions, economics, construction standards, assessment methods, aging of population, planning, role of developing groups, effects, planning, transportation, soundscape, administrations, health, infrastructure, policies, water amenities, administrations, vegetation, the disables, culture, waste management, parenting, sub-replacement fertility, universal design, barrier-free, etc.

Japan is well developed and advanced on urban construction, however, China has some advantages due to its later urbanization, thus new conceptions, technologies, and other experiences are possible being absorbed. Many close attentions had been paid on this issue in China while in Japan almost few papers studied on it except a small amount of news. Therefore, this paper aims to simplify Sponge City Construction Policy and outline its current situation with a systematically concerned research as a reference to Japan.

Until now, neither projects nor guidelines have been made nationwide to improve the urban environment. However, many local governments have taken actions and been written into own environment conservation plans. Typically, various urban environment assessment system both at nation level and local level have been introduced, taking an important role. (Jin, Z. et al, 2011). We can have concluded that most of them are dominated by the Ministry of Housing and Urban-Rural Development (MOHURD), focusing on air quality, water quality, solid wastes, greening, noise etc. Noteworthy is that the National ecological garden city had taken it into consideration that the proportion of permeable area to roads and squares in built-up areas, the extent of urban heat island effect, and the public satisfaction for the environment.

Table 3-7 Policies on China's National New-type Urbanization

Year	Phase	Policies
2014	Generalize replicable experiences	**National new urbanization planning (2014~2020)**
2015		**Notice on pilot programs of the National new urbanization planning** [1st batch of pilot projects: Jiangsu and Anhui provinces, Ningbo and other 60 cities, 2 towns]
		National Development and Reform Commission on expanding the pilot scope of National new urbanization
		Key points of 2nd batch of pilot programs for National new urbanization planning [2nd batch of pilot projects: Fangshan District of Beijing and other 58 cities/towns]
2016		N/A
2017		
2018	Promote nation widely	
2019		
2020		

Sponge city construction (SCC) is impossible to avoid the occurrence of urban waterlogging. Strictly speaking, the sponge city is not a rigorous scientific concept, but a popular image of the argument. SCC can be understood as a sustainable management of urban water system, which centers on stormwater and urban waters. Its objectives include the sustainable management of regional water resources, water environment, water ecology and water security. Taking SCC can significantly reduce the risk and loss of flood and waterlogging, as well as to delay the peak time, but it cannot avoid the occurrence of urban waterlogging because the infrastructure for flood control and drainage is designed based on a certain standard. Just considering the huge cost of municipal infrastructure, flood control and drainage facilities design capability are impossible increased limitlessly.

Measures concerning urban environment are summarized in Figure 3-13, mainly consist of pollution prevention and reduction, infrastructures improvement, culture-oriented construction, ecological construction and efficient utilization of resources. Essentially, the major purpose of introducing sponge city construction is to reduce runoff and better utilize the rainwater, thereby less water consumption and pollution. It involves in infiltration, storage, retarding, purification, utilization and drainage of rain water. It is apparent that measures of sponge city construction are embraced in measures of urban environmental construction. In short, the National new urbanization covers the concept of sponge city construction.

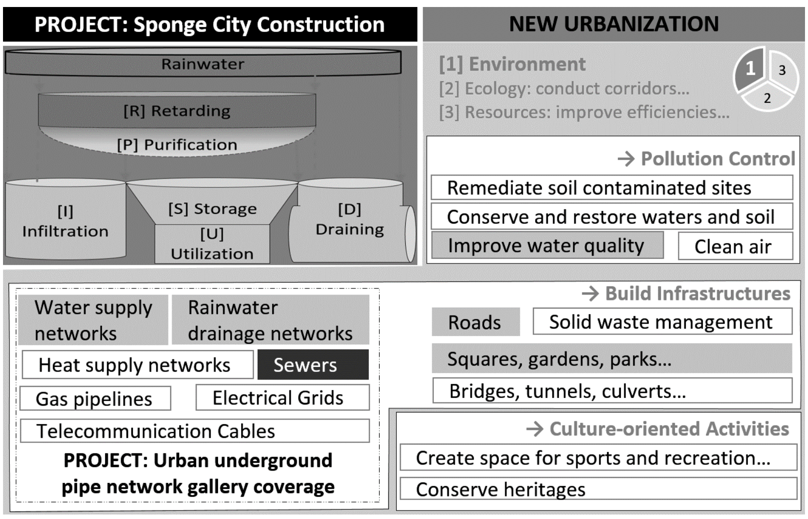

Figure 3-13 Relation of Sponge City Construction and New-type Urbanization of China

3.4 Summary

This chapter has investigated the background of sponge city construction by analyzing the current situation of China's flood control management, historical transition of China's ecological water conservancy, and the urban environmental improvement. Obviously, an integrated framework to sustain environment-friendly urbanization is needed under the direction of a national unified real-time online environmental monitoring system and the regional collaborative governance and multi-sectoral collaboration. Regulatory and fiscal mechanisms should also be established and reinforced to incentivize efficient resource consumption and environment construction. In fact, they are handicapped by the absence of clear holistic guidelines from the central government to provincial and municipal governments. Furthermore, policy coherence, public participation, and performance assessment system should be improved in the future.

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4 Conception and Approaches of Sponge City Construction

4.1 Sponge City Construction and LID Stormwater System

The core routine of Sponge City Construction is to solve water scarcity, waterlogging and floods, water pollution as well, basically by efficient utilization, retention and pollution control of rainwater (Figure 4-1). Through a stormwater management, mainly by rainwater harvesting, collected storm water can be used for irrigating the green, cleaning, etc. thus reducing the intensity of water supply system; besides, less surface runoff production, more evaporation and recharging to groundwater, lead a more natural, balanced and stable runoff process, finally cause less waterlogging and floods in urban areas. Meanwhile, it also enhances on improving the water ecology and environment through controlling runoff pollution and ecology conservation.

Technological Guide for Sponge City Construction - Storm Water System Construction Under Low Impact Development (Interim) aims to promote and combine LID mode during the New-Type Urbanization in China, with main contents as following:

A. Basic principles of constructing SCC and LID Stormwater System.
   - Planning Leading
   - Prioritizing Ecology
   - Safety First
   - Considering Local Conditions
   - Constructing Collaboratively

B. Division, fulfilling methods of control objectives for planning.

C. Tasks, requirements and methods for each phase of urban planning, design, construction, maintenance and management.

D. Practical examples in China.

Approaches to achieve SCC:

A. Conserve Original Ecosystem.
   - Protect the original rivers, lakes, wetlands, pits, trenches and other aquatic ecological sensitive areas;
   - Keep enough forest land, grassland, lakes, wetlands etc. for water conservation, as well as defense of intensive rainfall;
   - Preserve the pre-construction hydrological features to the maximum extent.

B. Restore Damaged Water Bodies and Harmed Ecosystem.

C. LID Mode.
   - LID Stormwater System: To control quantity and quality of stormwater, peak discharge.
   - Stormwater Drainage System: To collect, transfer and drain stormwater.
   - Drainage System for Over Standard Stormwater:

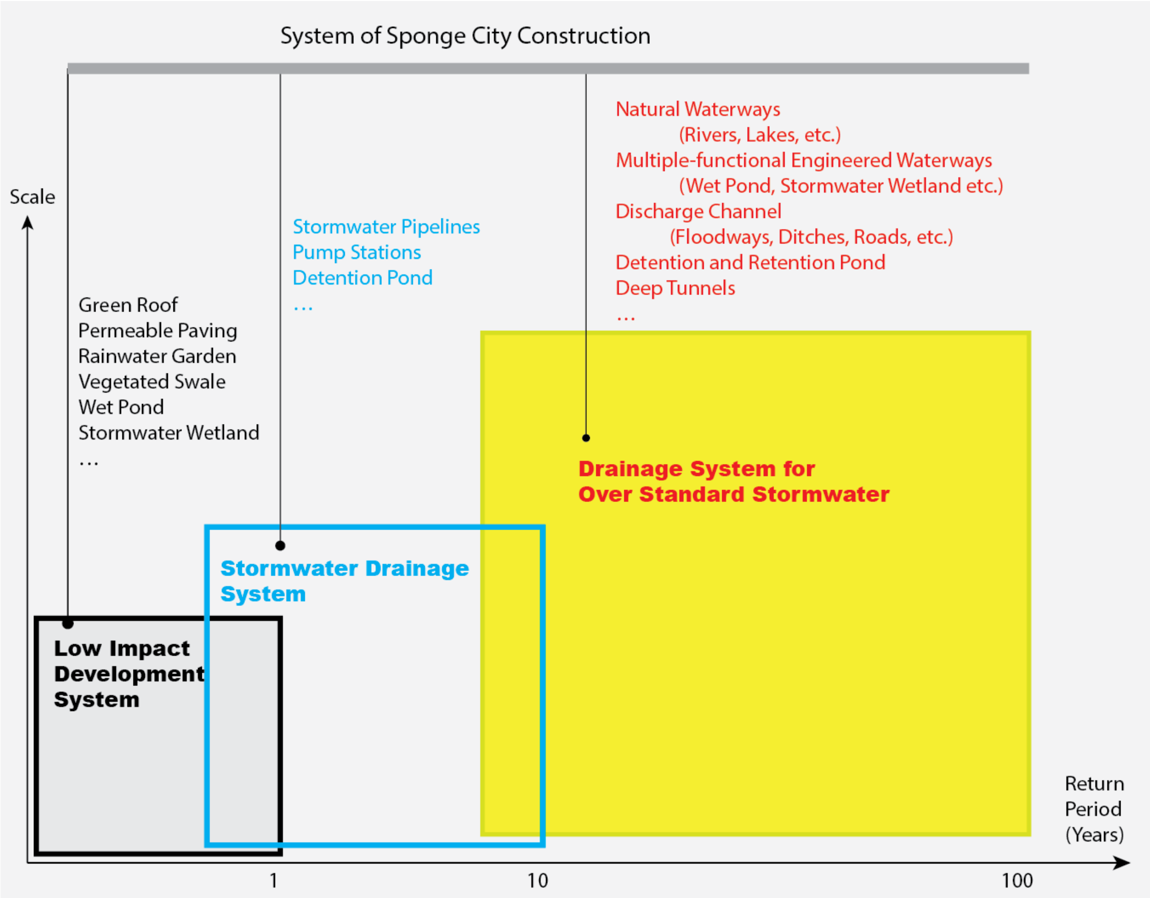

Figure 4-1 Elements of Sponge City Construction

Compared with China, most developed countries have a low population density and land use intensity, and with higher greening rate. Thus, sufficient space is available to use at the construction site to deal with the increasing runoff volume after developing. However, most cities in China are impossible to keep the total stormwater runoff and peak flows remain unchanged only by those source control measures, because their land use intensity are generally high. Therefore, end measures and other comprehensive measures should be introduced to realize the purpose to let the hydrological characteristics after the development close to before the development (Table 4-1, Figure 4-2).

Table 4-1 Major Differences between Sponge City Construction and Low Impact Development

	Sponge City Construction	Low Impact Development
Priorities	Ecology>Environment>Security>Resource	Environment>Resource>Ecology>Security
Approach	Based on mountains, forests, fields, waterways, lakes, etc., artificial constructions as a supplement	Site source control measures such as permeable paving, swales, rainwater gardens etc.
Scales	Large (Whole city)	Small (Residential districts, streets, etc.)

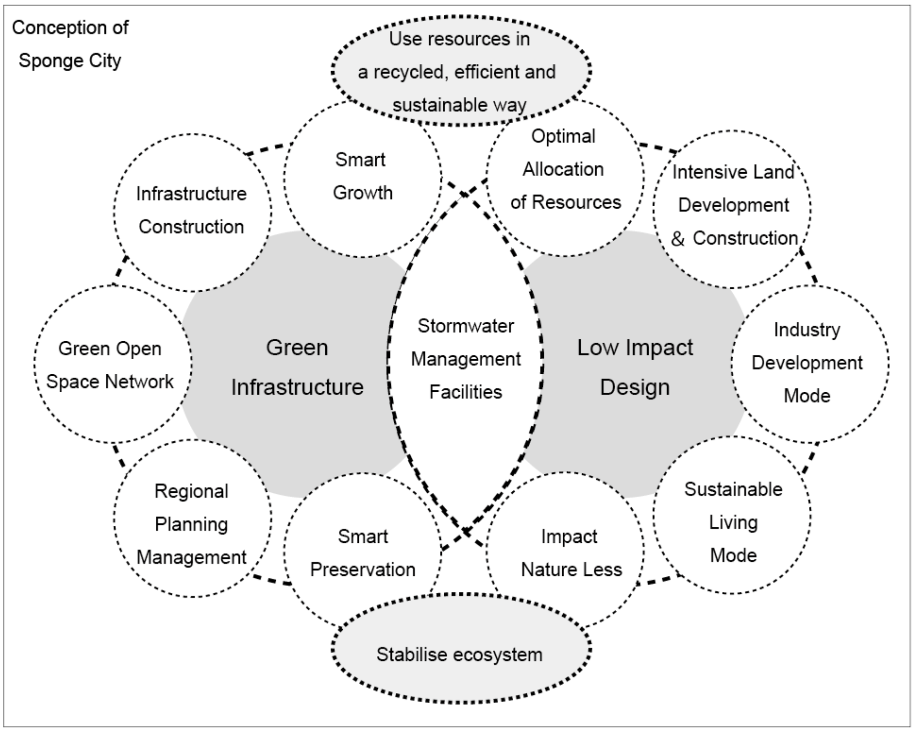

Figure 4-2 Conception of Sponge City Based on Green Infrastructure and Low Impact Design

Note: CHE, Shengquan, Bingqin YU and Wei YAN (2015). Research and Practices for Sponge City - Taking Examples of Shanghai Urban and Rural Green Space. Shanghai, Shanghai Jiao Tong University Press. Page 2.

4.2 Related Codes of Practice and Guidelines

At present flood control standards of city in China have been improving, but still in a low level. In response to this problem, a series of polices have been released. And as countermeasures for waterlogging etc. problems, the Sponge City Construction was proposed by the central government in China (Table 4-2, Table 4-3).

- In Apr. 2012, the conception of Sponge City Construction was firstly proposed on *2012 Low-Carbon Forum of Urban and Regional Development*.
- In Dec. 2013, on *Central Government Meeting on Urbanization*, President Xi Jinping pointed out the Sponge City Mode should be carried out as to build cities which can naturally store, infiltrate and clean stormwater.
- Since Oct. 22, 2014, the central government of China has promulgated a series of policies concerning sponge cities construction, which revolve around its technical guideline, financial support system, applying system of experimental projects, the evaluation system etc.

And the Instructions for Promoting Sponge City Construction stipulates that more than 70% of precipitations should be utilized locally and not be drained out, more than 20% of urban areas should meet the standards of Sponge City Construction by 2020, and to 2030 this would be 80%.

Table 4-2 National Policies Concerning Sponge City Construction

Title	Promulgation Date	Promulgation Agencies		
		MOHURD	MWR	MOF
Technological Guide for SCC - Storm Water System Construction under LID (Interim)	Oct. 22, 2014	●	×	×
Notice on Central Government's Financial Support for Pilot Projects of SCC (2015)	Dec. 31, 2014	●	●	●
Application Guidelines for Pilot Projects of SCC (2015)	Jan. 1, 2015	●	●	●
Performance Evaluation and Assessment Method for SCC (Interim)	Jul. 10, 2015	●	×	×
Instructions for Promoting SCC	Oct. 11, 2015	State Council		
Systematical Design of National Standards of Building for SCC	Jan. 22, 2016	●	×	×
Notice on Central Government's Financial Support for Pilot Projects of SCC (2016) (Attached with 2016 Application Guidelines for Pilot Projects of Sponge City Construction)	Feb. 25, 2016	●	●	●
Interim Provisions of Planning for SCC	Mar. 11, 2016	●	×	×

Note: MOHURD (Ministry of Housing and Urban-Rural Development), MWR (Ministry of Water Resources), MOF (Ministry of Finance).

In 2014, The State Council also ordered all cities to make preparation of *Comprehensive Plan of Urban Stormwater Drainage and Waterlogging Control*. However, as of August 16, 2016, there are still some areas have not yet prepared the relevant planning. It is estimated that the investment of SCC costs 0.1 ~ 0.15 billion RMB per square kilometers. The monitory sources of pilot cities are consisted of three parts, subsidy by the central government, local government revenue and financial funds collected by PPP mode. For the subsidy, from 2015 to 2017, Direct-controlled municipalities (Beijing, Tianjin, Shanghai, Chongqing) obtain 0.6 billion annually, capitals of subdivisions of China get 0.5 billion, other cities get 0.4 billion. Besides, for those cities whose PPP mode achieve certain proportions, another bonus of 10% would be given.

Table 4-3 National Codes and Standards Concerning Design of Sponge City Construction

Code	Title
GB/T 50805-2012	Code for Design of Urban Flood Control Project <城市防洪工程设计规范>
GB 50318-2000	Code of Urban Wastewater Engineering Planning <城市排水工程规划规范>
GB 50400-2006	Engineering technical code of Rainwater Utilization in Building and Sub-District <建筑与小区雨水利用工程技术规范>
GB 50014-2006	Code for Design of Outdoor Wastewater Engineering <室外排水设计规范>
GB 50268-2008	Code for Construction and Acceptance of Water and Sewerage Pipeline Works <给水排水管道工程施工及验收>
HJ 2005-2010	Technical Specification of Constructed Wetlands for Wastewater Treatment Engineering <人工湿地污水处理工程技术规范>
CJJ 37-2012	Code for Design of Urban Road Engineering <城市道路工程设计规范>
GB/T 50378-2014	Assessment Standard for Green Building <绿色建筑评价标准>
CJJ 48-92	Code for Designs of Parks <公园设计规范>

4.3 Administrative System Concerning Sponge City Construction

Several government agencies in China have jurisdiction over urban waters. Figure 4-3 shows the implementation system of sponge city construction. Even for the Department of Housing and Urban-Rural Development, its composition is also complicated in different cities, for instance, Table 4-4 shows the branch offices of Jiangsu provincial department of housing and urban-rural development.

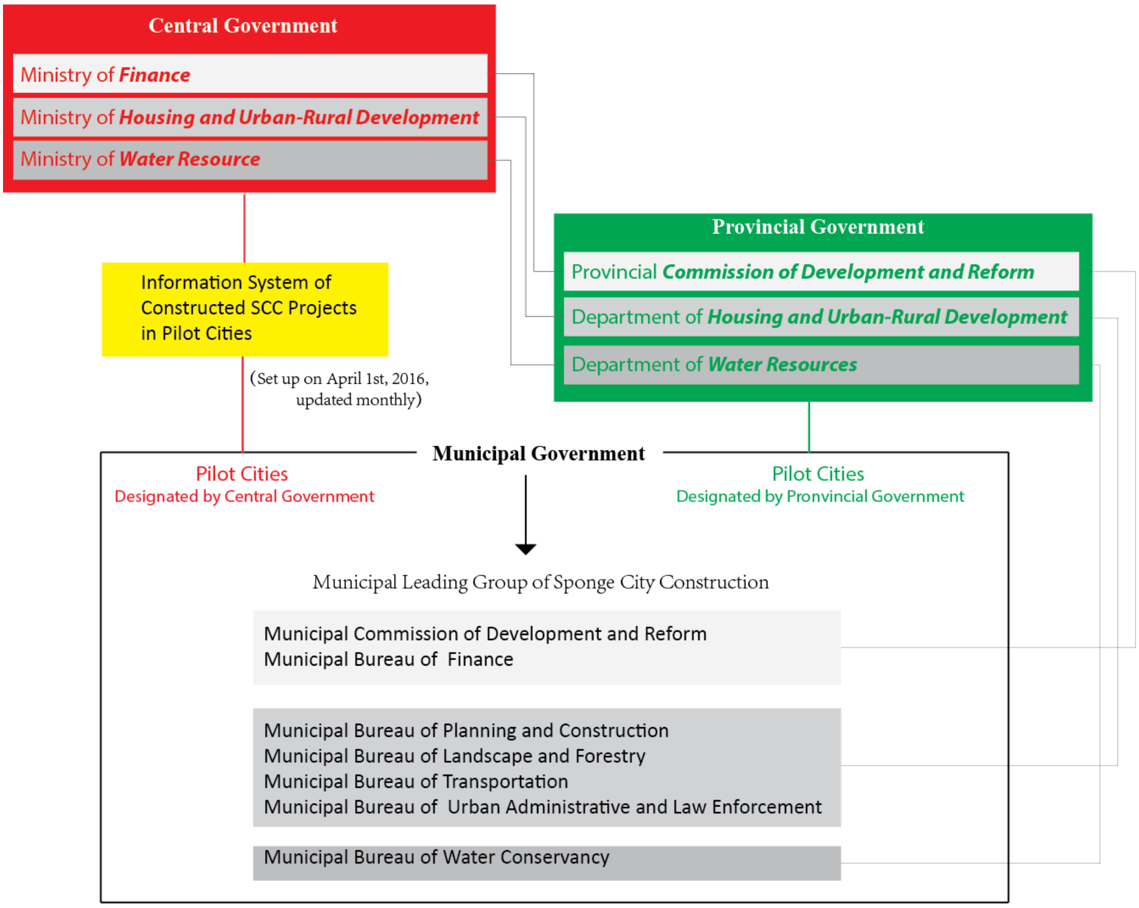

Figure 4-3 Implementation System of Sponge City Construction

Table 4-4 Branch Offices of Jiangsu Provincial Department of Housing and Urban-Rural Development

<table>
<tr><th rowspan="2">City</th><th colspan="5">Municipal Bureaus at Each City</th></tr>
<tr><th>Planning</th><th>Urban Administrative and Law Enforement</th><th>Housing Indemnification and Management</th><th>Urban-Rural Development</th><th>Afforestation</th></tr>
<tr><td>Nanjing</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Wuxi</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Xuzhou</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
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<tr><td>Yangzhou</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Zhenjiang</td><td>●</td><td>●</td><td colspan="2">●</td><td>●</td></tr>
<tr><td>Taizhou</td><td>●</td><td>●</td><td colspan="2">●</td><td>×</td></tr>
<tr><td>Suqian</td><td>●</td><td>●</td><td colspan="3">●</td></tr>
</table>

4.4 Planning and Design of Sponge City Construction

LID Stormwater System takes following control goals:

① **Runoff Volume Control**: The natural landform is often considered in accordance with the green land. Under normal circumstances, the total annual runoff rate of green land is 15% -20% (equivalent to the annual rainfall runoff coefficient of 0.15 ~ 0.20), therefore volume capture ratio of annual rainfall is about 0.80 ~ 0.85. However, in practice, this value should be determined with a wide range of factors considered: site's runoff coefficient before construction, local water resources, rainfall patterns, development intensity, utilization efficiency of LID facilities, economic development level and other factors.

② **Peak Runoff Control**: The peak reduction effect of LID facilities is affected by factors such as rainfall frequency and rainfall type, construction and maintenance management conditions, etc. Generally, cases of medium and small rainfall event have better effect.

③ **Runoff Pollution Control**: To control stormwater runoff pollution, it is necessary to regulate the total amount of pollutants of a separate sewer system, but also to control the frequency of overflow or the total amount of contaminants of a combined sewer system. Based on the conditions of city's water environment such as pollution type and the quality requirements, control objectives can be determining by an integrated index of runoff pollution. Pollutant index may be Suspended Solids (SS), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP) and the like. SS always have some correlation with other indicators of urban runoff pollutants, so in general, it can be used as the runoff pollutant control targets. The annual SS removal rate of LID Stormwater System can reach 40% -60%. Considering the randomness and complexity of runoff pollutants changes, runoff pollution control targets can be generally estimated by the total amount of runoff volume control, and the average concentration of stormwater runoff, pollutants removal rate of LID facilities.

④ **Rainwater Utilization**: This goal is not compulsory for water supply connections of cities differs.

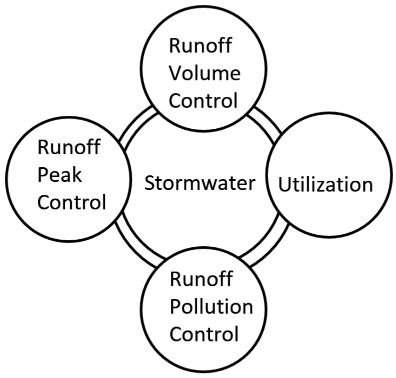

Figure 4-4 Control Objectives of Sponge City Construction

At each region, the control objectives should be determined according to the local conditions, including rainfall characteristic, hydrogeological conditions, runoff pollution conditions, waterlogging risk construction standard, demanding intensity for rainwater converting into water resources, etc. Meanwhile, it should also take other factors into considerations, like prominent problems concerning water environment, economical rationality and so on.

Master Plan as well as subzone planning should not only give out greening rate, water surface ratio, but also define volume capture ratio of annual rainfall etc. Specific Plans have four parts:

a. Specific Plan of Urban Water System

Urban water system is one of the most important part of urban environment and ecosystem. Besides, it can also function as the green infrastructure, for example, the river channels can drain stormwater, the lakes can store them, ponds can serve as retention space, wetlands can clean the water.

For Planning of Urban Water System, firstly it should designate the urban waters, shorelines and waterfronts, and clarify their conservation zones, the city master plan abided. Secondly, maintain the integrity of urban water system structure, optimize the layout of urban river and lake system, to achieve natural, orderly discharge and storage of stormwater. Thirdly, optimize the layout of green space around water area, shoreline, waterfront; clarify LID control index of water system and surrounding areas.

b. Specific Plan of Urban Drainage System

Firstly, to clarify capture ratio of runoff volume and to decompose it into indicators such as unit control volume and the like.

Secondly, to determine control objectives of runoff pollution control, then to select LID facilities.

Thirdly, to determine the goals and approaches of rainwater utilization by specifying the total amount of rainwater utilization, usages, facilities and so on.

c. Specific Plan of Urban Green Space System

Urban green space is an important space to construct sponge city. Planning of urban green space system should clarify control objectives. Based on the premise of realizing basic functions such as ecology, landscape, recreation and the like, a reasonable space should be reserved or created to infiltrate, regulate, store, purify the rainwater runoff yielded onsite or surrounding impermeable surfaces. Besides, it should be able to well connect with drainage pipe system and excessive stormwater runoff drainage system.

d. Specific Plan of Urban Transportation System

Urban roads are main area to yield runoff, and the main source of pollutants into stormwater runoff. Therefore, this specific plan should endeavor to reduce its yield runoff and carried pollutants.

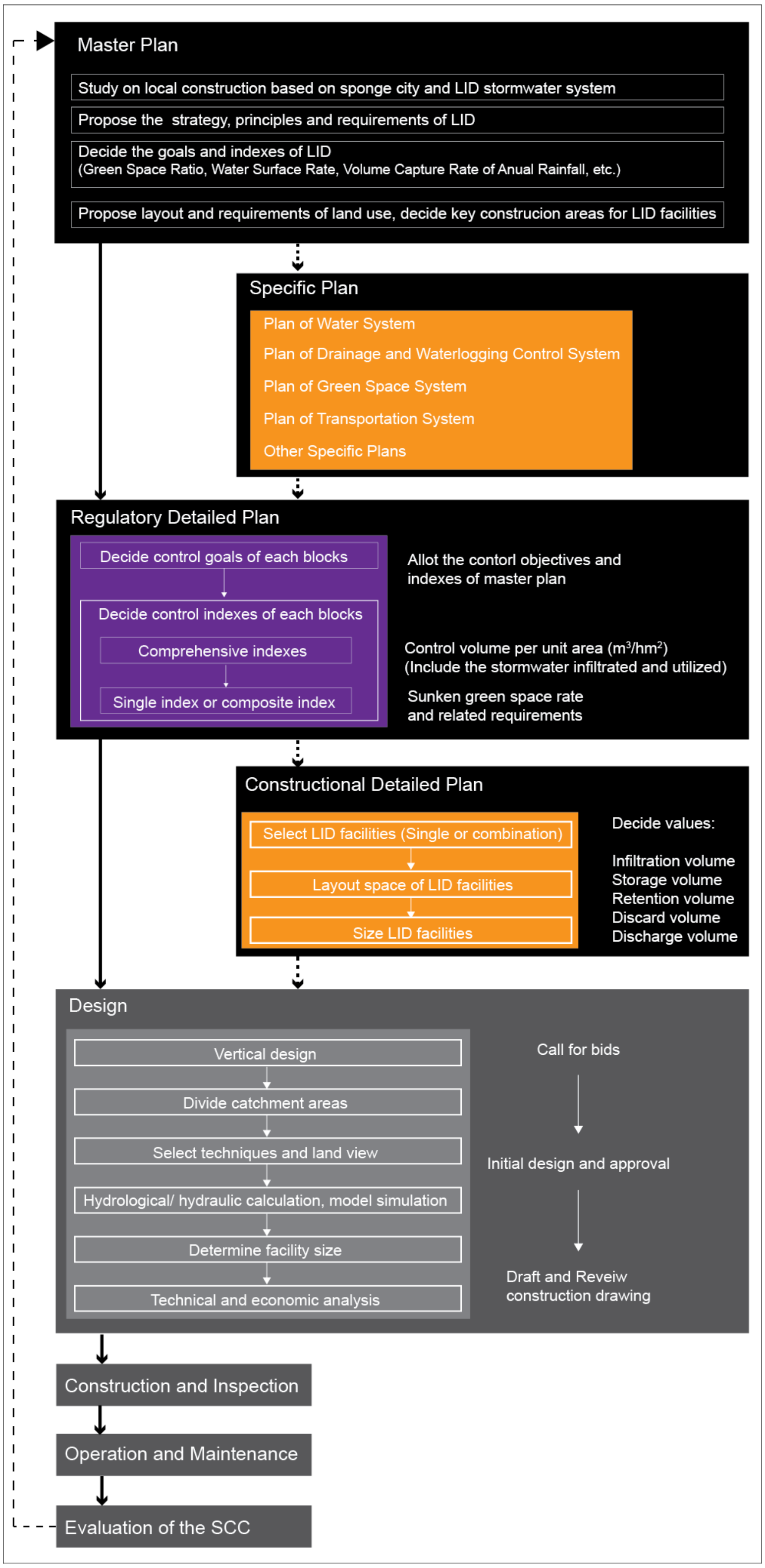

Figure 4-5 Workflow of Constructing LID Stormwater System

We have summarized the typical diagrams of sponge city design for architectures and neighborhoods, urban roads, greenbelts and squares, urban water system (Figure 4-6, Figure 4-7, Figure 4-8, Figure 4-9).

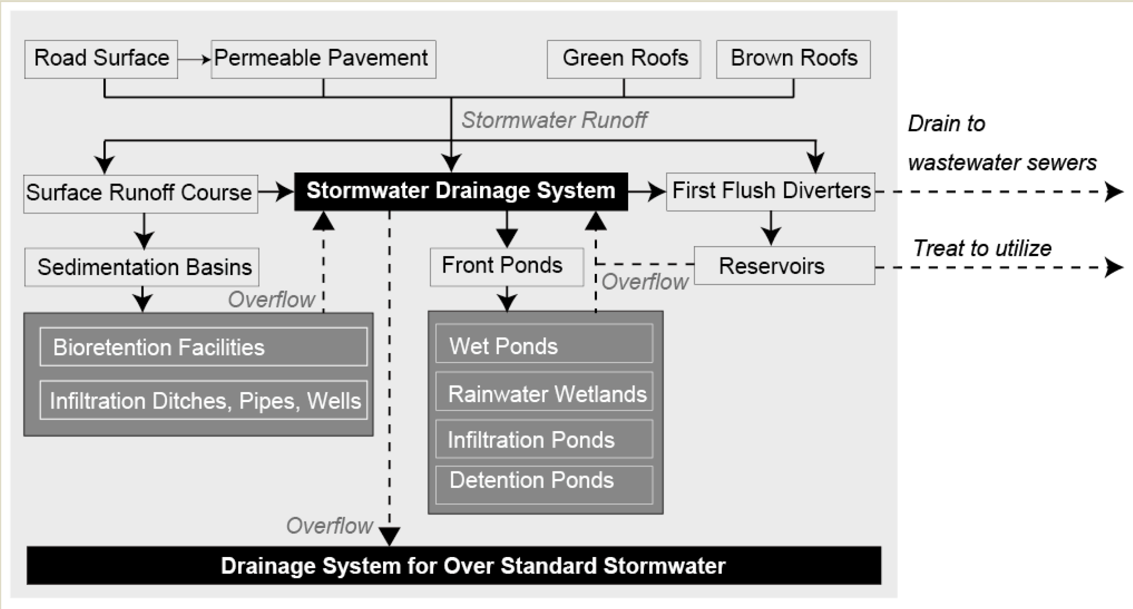

Figure 4-6 Typical Process of Sponge City Design for Architectures and Neighborhoods

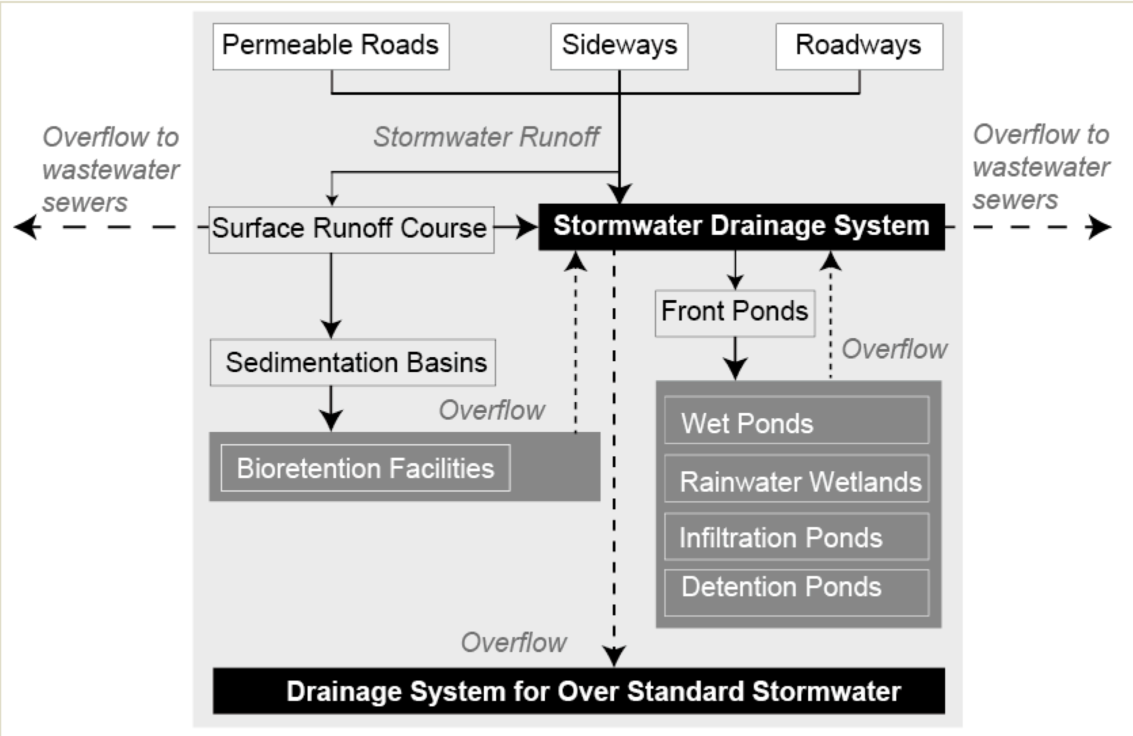

Figure 4-7 Typical Process of Sponge City Design for Urban Roads

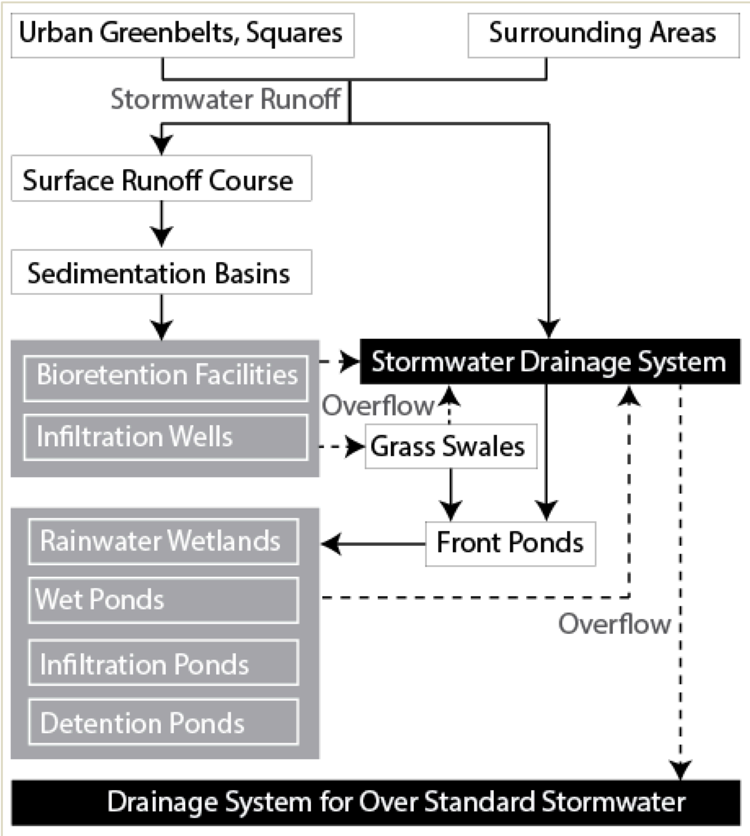

Figure 4-8 Typical Process of Sponge City Design for Greenbelts and Squares

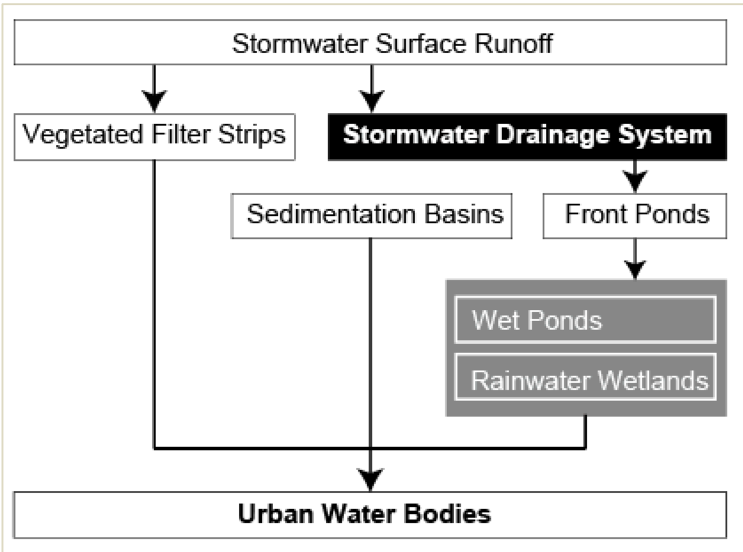

Figure 4-9 Typical Process of Sponge City Design for Urban Water System

Above used LID techniques can be categorized into 5 types – infiltration, storage, detention, transport, and purification, including: Permeable paving, green roofs, sunken greenbelt, bio-retention facility, infiltration basin, dry well, wet pond, stormwater wetland, reservoir, stormwater barrel, retention basin, detention pond, grass Swale, infiltration pipe/ trench, vegetative filter strip, first flush device etc. (Coffman (1999)).

Table 4-5 Relations of LID Facilities and Pretreatment Facility for Stormwater Runoff

No.	LID facility	Whether Need facility to pretreat stormwater before inflowing
1	Permeable Paving	NO
2	Planted Roof	NO
3	Sunken Greenbelt	Only in serious polluted areas
4	Bio-retention facility	Only in serious polluted areas
5	Infiltration Basin	YES
6	Dry Well	YES
7	Wet Pond	YES
8	Stormwater Wetland	YES
9	Reservoir	Only in serious polluted areas
10	Stormwater Barrel	NO
11	Retention Basin	YES
12	Detention Pond	NO
13	Grassed Swales	NO
14	Infiltration Pipe/ Trench	YES
15	Vegetative Filter Strip	Belongs treatment Facility
16	Fist Flush Device	Belongs treatment Facility
17	Artificial Soil Infiltration	Only in serious polluted areas

Construction and operation mode of SCC projects can be classified into two types. One is integrated mode, namely the construction and operation are conducted by one unit, the other is nonintegrated mode. For units operates certain SCC project, major sources for their revenue or profit can be provided by government's purchasing cost or subsidies, or users' payment.

4.5 Summary

This chapter focused on the conception and approaches of sponge city construction. Firstly, we introduced the SCC with LID stormwater system; then, related codes of practice and guidelines concerning SCC was summarized; also, the administrative system for SCC was confirmed by our investigation; finally, the planning and design method of SCC is combed.

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5 Characteristics Analysis of Pilot Cities Designated for Sponge City Construction

5.1 General Information of 30 Pilot Cities

Japan and other western countries have developed low impact development to mitigate the waterlogging since 1990s, while China started Sponge City Construction recently, which is based on those theories and practical experiences from those developed countries. Studies about Sponge City Construction are booming these years, but few of them focus on concrete problems occurred during its implementation process. Thus, this paper aims to summarize those challenges from a case study – Zhenjiang, by literature review, site investigation and hearing research to officers and designers.

Since 2015 the Chinese government has been actively promoting a policy called Sponge City Construction nationwide, which refers to an urban development mode that such built cities function like a sponge which are able to absorb, store, infiltrate, purify and release water, so as to pursue a low impact to the former more natural environment, typically in harmony with local ecosystem and water cycle system. Evidently, China has showed a trend focusing on the infrastructure construction since 2000, as a result of restriction by limited resources which were mainly poured on the industrial construction before. Till now, 30 pilot cities have been designated by the central government of China and some provinces are carrying out similar improvement projects at a provincial level as well.

There are 34 provincial level divisions in China, of which situation of SCC is listed in Table 5-1. Among them, 4 divisions which has 2 designated cities - Fujian Province, Guangdong Province, Shandong Province, Zhejiang Province; 22 divisions each has 1 designated city; 8 divisions have no designated city – Heilongjiang Province, Inner Mongolia Autonomous Region, Shanxi Province, Xinjiang Uyghur Autonomous Region, Taiwan Province, Tibet Autonomous Region, Hong Kong Special Administrative Region and Macao Special Administrative Region. Though the above 8 divisions have no designated city by central government, but except Tibet, Hong Kong and Macao, each of other 5 provinces has provincial policy to request all subordinate cities act the SCC.

Table 5-1 Sponge City Construction by Each Provincial Level Division by 2016

No.	Provincial Level Divisions	Subordinate Cites Designated by Central Government		No.	Provincial Level Divisions	Subordinate Cites Designated by Central Government	
1	Fujian	A 06 - Xiamen	B 06 - Fuzhou	18	Jiangsu	A 03 - Zhenjiang	
2	Guangdong		B 08 - Zhuhai B 09 - Shenzhen	19	Jiangxi	A 07 - Pingxiang	
3	Shandong	A 08 - Jinan	B 07 - Qingdao	20	Jilin	A 02 - Baicheng	
4	Zhejiang	A 04 - Jiaxing	B 05 – Ningbo	21	Liaoning		B 03 - Dalian
5	Beijing		B 01-Beijing	22	Ningxia		B 14 - Guyuan
6	Shanghai		B 04-Shanghai	23	Qinghai		B 13 - Xining
7	Tianjin		B 02-Tianjin	24	Shaanxi	A 16 - Xixian New Area	
8	Chongqing	A 13-Chongqing		25	Sichuan	A 14 - Suining	
9	Anhui	A 05 - Chizhou		26	Yunnan		B 11 - Yuxi
10	Gansu		B 12 - Qingyang	27	Heilongjiang		
11	Guangxi	A 12 - Nanning		28	Inner Mongolia		
12	Guizhou	A 15 - Guian New Area		29	Shanxi		
13	Hainan		B 10 - Sanya	30	Xinjiang		
14	Hebei	A 01 - Qian’an		31	Taiwan		
15	Henan	A 09 - Hebi		32	Tibet		
16	Hubei	A 10 - Wuhan		33	Hong Kong		
17	Hunan	A 11 - Changde		34	Macao		

Note: No. 5,6,7,8 are Direct-Controlled Municipalities.

At present, China has 658 urban built-up areas. By 2016, a total of 30 cities have been approved by Chinese central government to implement experimental projects of SCC (Table 5-2).

Table 5-2 List of 30 Pilot Cities Designated for SCC by Chinese Central Government in 2015&2016

Year		Pilot Cities	Total Area (km^2)	County-level City	Prefecture-level City	Municipality Directly under the Central Government
Total of 2015&2016		30	337,518	3	23	4
Sum of 2015		16	186,884	3	12	1
Sum of 2016		14	150,697	0	11	3
No.	Code	A: Cities Designated on April 2th, 2015; B: Cities Designated on 2016-04-25 Code: Administrative division codes of the PRC (Latest version issued on 2014-10-31)				
A 01	130283	Qian'an	1,208	●	Tangshan	Hebei
A 02	220800	Baicheng	25,683	×	●	Jilin
A 03	321100	Zhenjiang	3,799	×	●	Jiangsu
A 04	330400	Jiaxing	4,009	×	●	Zhejiang
A 05	341700	Chizhou	9,423	×	●	Anhui
A 06	350200	Xiamen	1,699	×	●	Fujian
A 07	360300	Pingxiang	3,824	×	●	Jiangxi
A 08	370100	Jinan	8,177	×	●	Shandong
A 09	410600	Hebi	5,326	×	●	Henan
A 10	420100	Wuhan	8,494	×	●	Hubei
A 11	430700	Changde	2,749	×	●	Hunan
A 12	450100	Nanning	22,190	×	●	Guangxi
A 13	500000	Chongqing	82,300	×	×	●
A 14	510900	Suining	5,326	×	●	Sichuan
A 15	×	Guian New Area	1,795	●	×	Guizhou
A 16	×	Xixian New Area	882	●	×	Shaanxi
B 01	110000	Beijing	16,410	×	×	●
B 02	120000	Tianjin	11,760	×	×	●
B 03	210200	Dalian	13,240	×	●	Liaoning
B 04	310000	Shanghai	6,341	×	×	●
B 05	330200	Ningbo	9,816	×	●	Zhejiang
B 06	350100	Fuzhou	12,180	×	●	Fujian
B 07	370200	Qingdao	11,067	×	●	Shandong
B 08	440400	Zhuhai	1,724	×	●	Guangdong
B 09	440300	Shenzhen	2,050	×	●	Guangdong
B 10	460200	Sanya	1,920	×	●	Hainan
B 11	530400	Yuxi	15,285	×	●	Yunnan
B 12	621000	Qingyang	27,119	×	●	Gansu
B 13	630100	Xining	7,372	×	●	Qinghai
B 14	640400	Guyuan	14,413	×	●	Ningxia

Procedures and requirements for applying as a pilot city is summarized in Table 5-3 and Table 5-4.

Table 5-3 Application Procedures for Pilot Project of Sponge City Construction (2015)

Step	Notes
Recommendation	Each determined provincial government recommend single city to the MOF&MOHURD&MWR by submitting two materials: ① Application Document. ② Implementation Plan for Sponge City Construction.
Qualification Review	The MOF&MOHURD&MWR verifies list of competent cities for next assessment from above recommended cities.
Competitive Assessment	The MOF&MOHURD&MWR organizes experts to assess whether each candidate is qualified after a presentation, and then confirm lists of pilot cities.

Table 5-4 Requirements for Qualification Review

<table>
<tr><th></th><th>2015 Qualification review</th><th>2016 Qualification review</th></tr>
<tr><td>Instructive Group</td><td colspan="2">The Municipal government has established a leading group for sponge city construction.</td></tr>
<tr><td>Plan</td><td colspan="2">A plan of sponge city construction has been well finished per concerned policies. Besides, it is in harmony with other urban plans.</td></tr>
<tr><td rowspan="4">Experimental Area</td><td colspan="2">Its area is no less than 15 km^2.</td></tr>
<tr><td colspan="2">Its local annual rainfall is no less than 400 mm.</td></tr>
<tr><td>-</td><td>Concentrated and contiguous areas</td></tr>
<tr><td>-</td><td>Including a certain percentage of old urban areas</td></tr>
<tr><td>Cities favorable</td><td>Reconstruction projects prioritized Cities, where the urban development is urgent to improve the infrastructure for drainage and waterlogging control, as well as intensive demand for stormwater management and Emergency Management.</td><td>In the urban built-up area, at least one catchment area can meet the general requirements of the sponge city construction.
Preliminary results have been achieved in a way that in the light rain does not water, heavy rain does not waterlog, water is not black and foul, heat island has been alleviated.</td></tr>
</table>

For competitive assessment, the requirements are more detailed and stringent. The implementation Plan should embody following principles: planning leading, prioritizing ecology, safety first, considering local conditions, constructing collaboratively, progress harmoniously and technically advanced. For example, the plan should well clarify following facts:

- The municipal government and provincial government have established a multi-sectoral collaboration mechanism.
- Have comprehensively assessed the capability and risks to drain storm and prevent flood.
- Has conducted the feasibility study of planned projects.
- Has proposed an innovative investment and finance mode, showing it has an economical and reasonable investment, clearly accounted cost of construction and management, an objective evaluation of local government's financial burden, an effectively application of Public-Private Partnership Mode for construction and operation …

5.2 Natural Conditions Analysis of 30 Pilot Cities

5.2.1 Climate Characteristics Analysis

All the 30 pilot cities are located in monsoon climate zone, which can be classified into 7 types by climatic conditions(Table 5-5). We can concluded that:

Most cities locate in subtropical zone (17 of 30 cities);

Most cities locate in humid area (18 of 30 cities).

Most cities locate in continental climate zone (16 of 30 cities).

Most cities of 2015 belong to subtropical humid zone (11 of 16 cities);

Most cities of 2015 belong to continental zone (11 of 16 cities);

Half cities of 2016 belong to warm temperate zone (7 of 14 cities);

Most cities of 2016 belong to oceanic zone (8 of 14 cities).

Compared cities of 2016 with cities of 2015 from the view of climatic conditions, we found that two batch of pilot cities show following transitions:

Subtropical → Warm temperate; Humid → subhumid and semi-arid; Continental → Oceanic.

Table 5-5 Climatic Conditions of 30 Pilot Cities

No.	City
A09	Hebi
A16	Xixian New Area
B12	Qingyang
B13	Xining
B14	Guyuan
A01	Qian'an
A02	Baicheng
A08	Jinan
B01	Beijing
B02	Tianjin
B03	Dalian
B07	Qingdao
A03	Zhenjiang
A10	Wuhan
A11	Changde
A13	Chongqing
A14	Suining
A15	Guian New Area
A04	Jiaxing
A05	Chizhou
A06	Xiamen
A07	Pingxiang
A12	Nanning
B04	Shanghai
B05	Ningbo
B06	Fuzhou
B08	Zhuhai
B09	Shenzhen
B11	Yuxi
B10	Sanya

The annual temperature and evaporation of 30 pilot cities is shown in Table 5-6. The annual temperatures of 30 pilot cities range from 4.9 ℃(Baicheng) to 25.5 ℃(Sanya). Average annual temperature of these cities is 15.4 ℃, which mainly decided by the latitude, altitude and the distance from the ocean. The annual evaporations range from 467.0 mm (Beijing) to 2360.7 mm (Sanya), and the average is 1350.2 mm. The evaporation also shows positive correlation with the annual temperature of the city.

Table 5-6 Annual Temperature, Rainfall, and Evaporation of 30 Pilot Cities

No.	City	Annual Temperature (℃)	Annual Rainfall (mm)	Annual Evaporation (mm)
A01	Qian'an	11.5	655.0	1849.0
A02	Baicheng	4.9	407.9	1200.0
A03	Zhenjiang	15.4	1063.1	1276.7
A04	Jiaxing	15.9	1168.6	1313.0
A05	Chizhou	16.7	1638.8	757.5
A06	Xiamen	21.0	1530.0	1651.3
A07	Pingxiang	17.2	1603.0	1268.0
A08	Jinan	14.7	672.7	1420.7
A09	Hebi	14.6	664.9	2069.5
A10	Wuhan	16.6	1304.3	949.8
A11	Changde	16.7	1323.0	1132.7
A12	Nanning	21.6	1304.2	1736.6
A13	Chongqing	18.0	1063.6	1106.6
A14	Suining	17.4	900.0	1019.5
A15	Guian New Area	15.3	1325.5	1201.1
A16	Xixian New Area	13.4	641.6	738.3
B01	Beijing	12.9	584.7	467.0
B02	Tianjin	14.0	511.0	1639.1
B03	Dalian	9.1	736.0	1551.0
B04	Shanghai	15.7	1173.4	1324.0
B05	Ningbo	16.5	1455.4	1458.4
B06	Fuzhou	20.4	1360.0	967.2
B07	Qingdao	12.2	775.6	1410.0
B08	Zhuhai	22.2	2294.0	1469.0
B09	Shenzhen	23.0	1933.3	1755.4
B10	Sanya	25.5	1392.2	2360.7
B11	Yuxi	16.0	909.0	1801.0
B12	Qingyang	8.9	539.0	506.0
B13	Xining	7.6	380.0	1363.6
B14	Guyuan	6.1	492.2	1753.2
	Average	15.4	1060.1	1350.5

Note: Most following data are of the end of 2015, but a few are of the end of 2014.

From the above table, we can also see that average annual rainfall is 1060.1 mm. The maximum value of annual rainfall is Zhuhai's (2294.0 mm), and the minimum is Baicheng's (407.9 mm).

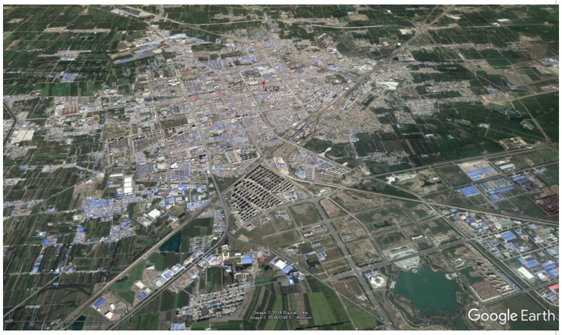
5.2.2 Landform Characteristics Analysis

Table 5-7 shows landforms of 30 pilot cities. Among them, 10 cities are plain, 9 cities are hill, 5 Cities are plateau, 4 cities are mountain, 1 city is table land, 1 city is basin; Besides, 10 cities belong to coastal city.

Table 5-7 Landforms of 30 Pilot Cities

No.	City	Plateau	Mountain	Hill	Table Land	Basin	Plain	Coastal
A01	Qian'an			●				
A02	Baicheng						●	
A03	Zhenjiang			●				
A04	Jiaxing						●	
A05	Chizhou		●					
A06	Xiamen				●			△
A07	Pingxiang			●				
A08	Jinan					●		
A09	Hebi						●	
A10	Wuhan						●	
A11	Changde						●	
A12	Nanning						●	
A13	Chongqing		●					
A14	Suining			●				
A15	Guian New Area	●						
A16	Xixian New Area						●	
B01	Beijing		●					
B02	Tianjin						●	△
B03	Dalian			●				△
B04	Shanghai						●	△
B05	Ningbo						●	△
B06	Fuzhou			●				△
B07	Qingdao			●				△
B08	Zhuhai			●				△
B09	Shenzhen			●				△
B10	Sanya		●					△
B11	Yuxi	●						
B12	Qingyang	●						
B13	Xining	●						
B14	Guyuan	●						
Sum		5	4	9	1	1	10	10

Qian’an



Baicheng

Zhenjiang

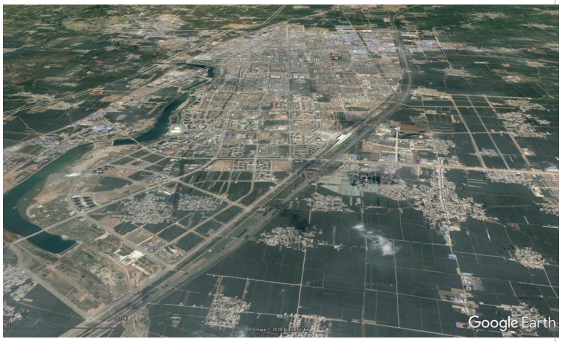
Jiaxing

Chizhou

Xiamen

Pingxiang

Jinan



Hebi

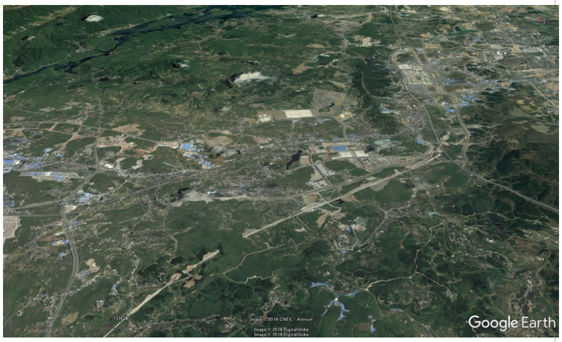
Wuhan

Changde

Nanning

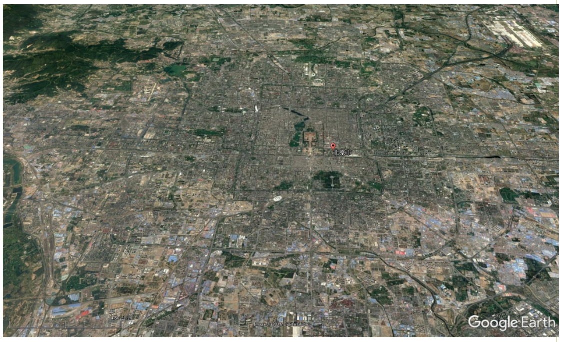
Chongqing

Suining



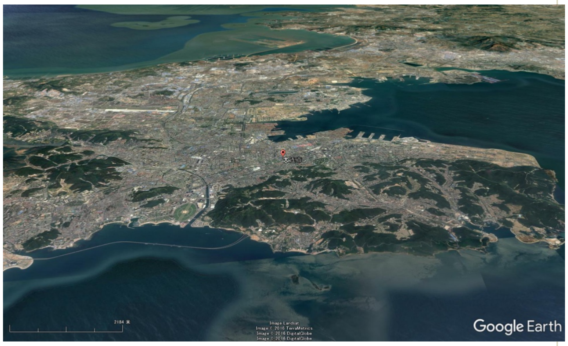
Guian New Area

Xixian New Area



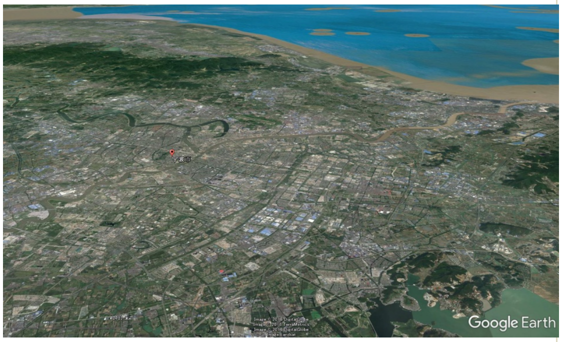
Beijing

Tianjin



Dalian

Shanghai



Ningbo

Fuzhou

Qingdao

Zhuhai

Shenzhen

Sanya

Yuxi

Qingyang

Xining

Guyuan

5.2.3 Water Resources Analysis

China has been facing increasingly severe water scarcity, especially in the northern part of the country. China's water scarcity is characterized by insufficient local water resources as well as reduced water quality due to increasing pollution, both of which have caused serious impacts on society and the environment. Three factors contribute to China's water scarcity: uneven spatial distribution of water resources, rapid economic development and urbanization with a large and growing population; and poor water resource management (JIANG (2009)).

To indicate the water scarcity of 30 pilot cities, "Falkenmark Index" (FI) is used in this paper, which is a standard measure of per capita water availability and widely adopted due to its simplicity (Table 5-8) JIANG (2009, Perveen and James (2011)).

Table 5-8 Thresholds for Falkenmark Index (standards measuring social water scarcity)

Falkenmark indicator (m^3/capita/yr.)	Water stress implication	Consequences
<1700	Water stress	Disruptive water shortage can frequently occur.
<1000	Chronic water scarcity	Severe water shortage can occur threatening food production and economic development.
<500	Beyond the water barrier [a]	Absolute water scarcity would result.

[a] Water barrier: the maximum level that an advanced, irrigation-dependent country can sustain. e of water stress and scarcity indicators.

China's water resources are spatially distributed with temporal dynamics, per capita water resources of 2010 is only 2, 100 m^3, which equals the 28% of world's, ranked 125th in the world (WANG (2014)). Only 3 pilot cities' average annual renewable water resources are over 2, 100 m^3 - Chizhou (A 05), Ningbo (B 05) and Changde (A 11) (Table 5-9).

Table 5-9 Average Annual Renewable Water Resources and per capita Water Resources

No.	City	Average annual renewable water resources (Billion m³)	Per capita water resources of 2015 (m³)
A05	Chizhou	7.06	4918.5
B05	Ningbo	7.53	3960.1
A11	Changde	15.30	2618.1
A12	Nanning	14.02	2007.3
B10	Sanya	1.44	1943.7
A07	Pingxiang	3.57	1896.8
A13	Chongqing	56.77	1882.1
B11	Yuxi	4.34	1837.0
B06	Fuzhou	10.18	1358.6
A02	Baicheng	2.27	1155.1
B08	Zhuhai	1.76	1104.8
A15	Guian New Area	N/A	1093 [a]
B03	Dalian	3.19	1060.1
B13	Xining	1.31	568.6
A04	Jiaxing	2.55	525.6
A01	Qian'an	0.37	502.7
B14	Guyuan	0.57	470.4
A10	Wuhan	4.62	435.8
B12	Qingyang	1.04	392.5
A03	Zhenjiang	0.95	298.1
A14	Suining	N/A	293.0
A06	Xiamen	1.23	290.4
A08	Jinan	1.75	247.4
B07	Qingdao	2.21	242.9
A09	Hebi	0.33	203.7
B09	Shenzhen	2.05	186.5
A16	Xixian New Area	0.18	178.6
B01	Beijing	3.74	172.3
B02	Tianjin	1.57	101.4
B04	Shanghai	1.92	79.4

Water Stress		
	Beyond the water barrier (m³)	<500
	Chronic water scarcity (m³)	<1000
	Water stress (m³)	<1700
	China's average per capita water resources (m³)	2100

[a] Per capita water resources of Guian New Area in 2015 is replaced by the data of Anshun City of 2013.

Note: Water resource data are from Water Resources Bulletin of each city, government homepages or state-owned websites.

We think that if the water resources of a city's itself or the city's plus other economically available sources cannot meet the water demand, then this kind of city should be classified into water scarcity city. The so-called economically available sources refer to cost of using rainwater harvesting system, water transferring projects, sea water desalination projects or other means is within the acceptable range. Based on this standard, the water shortage situation in 30 pilot cities was analyzed in Table 5-10.

Table 5-10 Water Scarcity Analysis of 30 Pilot Cities

No.	City	Impacts			Can be Mitigated by Improving Water Supply Capability
		Shallow Groundwater Over-exploitation	Over-exploitation of Deep Groundwater	Insufficiency for Ecology and Environment	
A01	Qian'an	○		○	○
A02	Baicheng		○		○
A03	Zhenjiang		○		○
A04	Jiaxing		○		○
A05	Chizhou				○
A06	Xiamen				○
A07	Pingxiang				○
A08	Jinan	○		○	○
A09	Hebi	○		○	○
A10	Wuhan				○
A11	Changde				○
A12	Nanning				○
A13	Chongqing				○
A14	Suining				○
A15	Guian New Area				○
A16	Xixian New Area	○	○	○	
B01	Beijing	○		○	○
B02	Tianjin		○	○	○
B03	Dalian			○	○
B04	Shanghai		○		○
B05	Ningbo				○
B06	Fuzhou				○
B07	Qingdao	○		○	
B08	Zhuhai				○
B09	Shenzhen				○
B10	Sanya				○
B11	Yuxi				○
B12	Qingyang			○	
B13	Xining				○
B14	Guyuan				○

Table 5-11 lists the water supply sources of pilot city, showing that most cities basically rely on surface runoff. The water supply other than surface and aquifer water is quite low presently. So, the rainwater utilization system should be built in the future.

Table 5-11 Source of Water Supply

No.	City	Water Supply (%, Year)		
		Surface	Aquifer	Others
A01	Qian'an	□ 15.60%, 2003	84.4%, 2003	0
A02	Baicheng	85.50%, 2013	□ 14.50%, 2013	0
A03	Zhenjiang	99.95%, 2013	□ 0.05%, 2013	0
A04	Jiaxing	99.99%, 2014&2015	□ 0.01%, 2014&2015	0
A05	Chizhou	99.5%, 2014	□ 0.50%, 2014	0
A06	Xiamen	93.79%, 2014; 94.09%, 2015	□ 5.15%, 2014; 4.85%, 2015	1.06%, 2014& 2015
A07	Pingxiang	91.53%, 2014	□ 7.60%, 2014	0.87%, 2014
A08	Jinan	56.64%, 2013	□ 38.95%, 2013	4.41%, 2013
A09	Hebi	□27.76%, average of 2005~2013	72.24%, average of 2005~2013	0
A10	Wuhan	99%,2014; 99.1%, 2015	□ 1.00%, 2014; 0.90%, 2015	0
A11	Changde	93.80%, 2005	□ 6.20%, 2005	0
A12	Nanning	95.35,2014; 95.27,2015	□ 4.60%, 2014; 4.68%, 2015	0.05%, 2014&2015
A13	Chongqing	98.01%, 2014; 98.02%, 2015	□ 1.86%, 2014 1.79%, 2015	0.13%, 2014; 0.19%, 2015
A14	Suining	94.50%, 2005	□ 5.50%, 2005	0
A15	Guian New Area	95.70%, 2014	□ 3.90%, 2014	0.40%, 2014
A16	Xixian New Area	□ 43.22%	56.78%, 2010	0
B01	Beijing	□ 23.00%, 2014	52.00%, 2014	25.00%, 2014 (Reclaimed water: 23%; South–North Water Transfer Project: 2%)
B02	Tianjin	69.50%, 2015	□ 19.20%%, 2015	11.30%, 2015
B03	Dalian	70.5%, 2014; 65.7%, 2015	□ 18.30%, 2014; 23%, 2015	11.20%, 2014 (Reclaimed water, stormwater, desalination); 11.30%, 2015 (Reclaimed water, stormwater, desalination)
B04	Shanghai	99.93%, 2011	□ 0.07%, 2011	0
B05	Ningbo	98.40%, 2014; 98.30%, 2015	□ 0.20%, 2014; 0.2%, 2015	1.40%, 2014 (Reclaimed water, stormwater); 1.50%, 2015 (Reclaimed water, stormwater)
B06	Fuzhou	98.80%, 2013	□ 1.20%, 2013	0
B07	Qingdao	64.84%, 2015	□ 27.85%, 2015	7.31%, 2015
B08	Zhuhai	97.80%, 2011	□ 0.20%,2011	2.00%, 2011
B09	Shenzhen	94.12%, 2015	□ 0.34%%, 2015	5.54%, 2015 (Reclaimed water: 4.6%; stormwater: 0.94%)
B10	Sanya	97.00%, 2013	□ 3.00%, 2013	0
B11	Yuxi	97.88%, 2007	□ 1.99%, 2007	0.12%, 2007
B12	Qingyang	64.89%, 2014	□ 29.79%, 2014	5.32%, 2014 (Reclaimed water: 0.05%; stormwater: 5.27%)
B13	Xining	72.00%, 2014	□ 27.73%, 2014	0.27%, 2014
B14	Guyuan	61.96%, 2014; 59.57%, 2015	□ 37.28%, 2014; 39.39%, 2015	0.76%, 2014 (Reclaimed water); 1.04%, 2015 (Reclaimed water)

5.2.4 Analysis of Drainage Density and Water Surface Ratio

The rapid urbanization is damaging the China's river network system in recent decades. A large number of rivers were buried and disappearing, which changed the hydrological process of the basin. WANG Yuefeng (2016). Change of land use and increasing of impervious areas are the main direct reasons of weakening of river networks, such as blocking the connectivity, decreasing of regulation capability. Therefore, both the risk and loss of flooding and waterlogging rise, as well as intensify the worsening of water environment and water ecosystem, etc.

A successful construction of sponge city should carefully consider the regulation capacity of river networks as it is an important factor for flood disaster mitigation. Calculating its value is complicated but it has close relationship with the structure of river networks, so we simply estimate the regulation capacity by analyzing the river networks structure instead. Wang Yuefen has established an equation of regulation capability of river networks with stream structure indexes (Equation 5-1, Equation 5-2), based on the concept of Representative elementary watershed model and Hurst index of water level WANG Yuefeng (2016).

Equation 5-1

$$\frac{d}{dt}M = aR_d + b{R_d}^{1/2}W_p^2$$

M: storage amount of water in stream channels (m^3).

a, *b*: coefficients. Can be calculated by the Hurst index.

R_d: Drainage density (km/km^2). $R_d=L_R/A$. (L_R : total length of streams; A: total area of the region.)

W_p: Water surface ratio (%). $W_p=(A_W/A)$ *100%. (A_W: total area of streams on average annual water level; A: total area of region.)

Equation 5-2

$$\frac{d}{dt}M = aR_d + b{R_d}^{2(D/4-1)}$$

M, a, b, R_d: definitions same with above equation.

D: box dimension. A bigger value of box dimension means the more complex of spatial distribution of streams. Its calculation method can refer to WANG Yuefeng (2016).

In this section, we only conducted an analysis of the stream structure by indexes of drainage density and water surface ratio (Table 5-12).

Table 5-12 Drainage Density and Water Surface Ratio

No.	City	Drainage Density (km/km^2)		Water surface ratio of 2015 (%)	Water surface ratio of planning year (%)	Appropriate value of Water surface ratio (%) [a]		
						△ (2~5)	□ (3~8)	○ (8~12)
A01	Qian'an	0.26		N/A	N/A		□	
A02	Baicheng	0.03		11.4	N/A		□	
A03	Zhenjiang	0.18		13.7	N/A			○
A04	Jiaxing	3.44		8.9	N/A			○
A05	Chizhou	0.07		N/A	11.0(2017)			○*
A06	Xiamen	0.08		6.6	N/A			○
A07	Pingxiang	N/A	N/A	N/A	N/A			○
A08	Jinan	0.03		2.6	N/A		□	
A09	Hebi	0.07		N/A	N/A		□	
A10	Wuhan	0.26		25.0	N/A			○
A11	Changde	2.47		1.5	N/A			○
A12	Nanning	0.21		N/A	11.2(2013 planning goal for downtown); 12.5(2020)			○
A13	Chongqing	0.44		N/A	N/A			○*
A14	Suining	0.70		2.3	N/A			○
A15	Guian New Area	0.25		4.8	9.0(2017)		□	
A16	Xixian New Area	N/A	N/A	N/A	N/A			○
B01	Beijing	0.39		2.9	N/A		□*	
B02	Tianjin	0.51		N/A	N/A		□	
B03	Dalian	0.07		15.5	N/A		□	
B04	Shanghai	3.41		9.8(2011)	10.10(2020)			○
B05	Ningbo	1.11		5.2(2012)	N/A			○
B06	Fuzhou	0.07		7.0	8.0(2020); 10.0(2030)			○
B07	Qingdao	0.28		1.4	1.6(2016); 1.8(2017); 2.0(2018)		□	
B08	Zhuhai	0.08		10.0	N/A			○
B09	Shenzhen	0.65		4.6(2013)	N/A			○
B10	Sanya	0.16		N/A	16.0 (Downtown area)			○*
B11	Yuxi	N/A	N/A	N/A	3.5(2016); 3.6(2017); 3.7(2018)			○*
B12	Qingyang	N/A	N/A	0.4	N/A		□*	
B13	Xining	0.09		N/A	N/A	△*		
B14	Guyuan	N/A	N/A	N/A	N/A		□*	

[a] Ministry of Housing and Urban-Rural Development, General Administration of Quality Supervision, Inspection and Quarantine. Code for plan of urban water system. 2009.

* Mountainous cities and highland cities may lower this value appropriately.

Source: Ministry of Environmental Protection of the People's Republic of China. 2014 National Eco-Environmental Quality Report. 2015. p. 15.

Table 5-13 Standard for Evaluating Drainage Density

Rate	Drainage Density (km/km^2)
Poor	(0.00, 0.10]
Fair	(0.10, 0.30]
Good	(0.30, 1.00]
Excellent	(1.00, 3.50]

5.3 Social-Economic Analysis of Pilot Cities

China’s urbanization has made great achievements in the past decades, with obvious growth in the size of cities. Table 5-14 shows the latest standard for categorizing city sizes in China, based on a city’s population.

Table 5-14 China’s City Classification by Permanent Resident Population

City Size	Permanent Resident Population (million)
Small-sized city	< 0.5
Medium-sized city	[0.5，1]
Large-sized city	[1，5]
Very large-sized city	[5，10]
Super large-sized city	≥10

Source: State Council (2014.10.29). Notice of the State Council on Adjusting the Standards for Categorizing City Sizes. <http://www.gov.cn/zhengce/content/2014-11/20/content_9225.htm>

By above standard, 30 pilot cities can be classified into 4 sizes (Table 5-15).

Table 5-15 Populations of 30 Pilot Cities and Their Sizes

No.	City	City size				Permanent resident population at end of 2015 (million)	Permanent resident population density (persons/km²)
		○ Medium-sized	△ Large	□ Mega	☆ Super		
A01	Qian'an	○				0.76	613
A02	Baicheng		△			1.97	77
A03	Zhenjiang		△			3.18	836
A04	Jiaxing		△			4.86	1211
A05	Chizhou		△			1.44	152
A06	Xiamen		△			4.25	2702
A07	Pingxiang		△			1.88	492
A08	Jinan			□		7.07	864
A09	Hebi		△			1.63	306
A10	Wuhan				☆	10.61	1249
A11	Changde			□		5.84	321
A12	Nanning			□		6.99	315
A13	Chongqing				☆	30.17	367
A14	Suining		△			3.29	618
A15	Guian New Area	○				0.73	407
A16	Xixian New Area	○				0.98	1111
B01	Beijing				☆	21.71	1323
B02	Tianjin				☆	15.47	1315
B03	Dalian		△			3.01	227
B04	Shanghai				☆	24.15	3809
B05	Ningbo		△			1.90	194
B06	Fuzhou			□		7.49	615
B07	Qingdao			□		9.10	822
B08	Zhuhai		△			1.59	922
B09	Shenzhen				☆	11.00	5366
B10	Sanya	○				0.74	386
B11	Yuxi		△			2.36	155
B12	Qingyang		△			2.65	98
B13	Xining		△			2.31	313
B14	Guyuan		△			1.21	84

5.3.1 Industry Structure

There is a strong positive correlation between urbanism and tertiary industry. HATTORI (1969) From below Figure, we can conclude that the 2015 pilot cities are less developed than the 2016 batch (Figure 5-1).

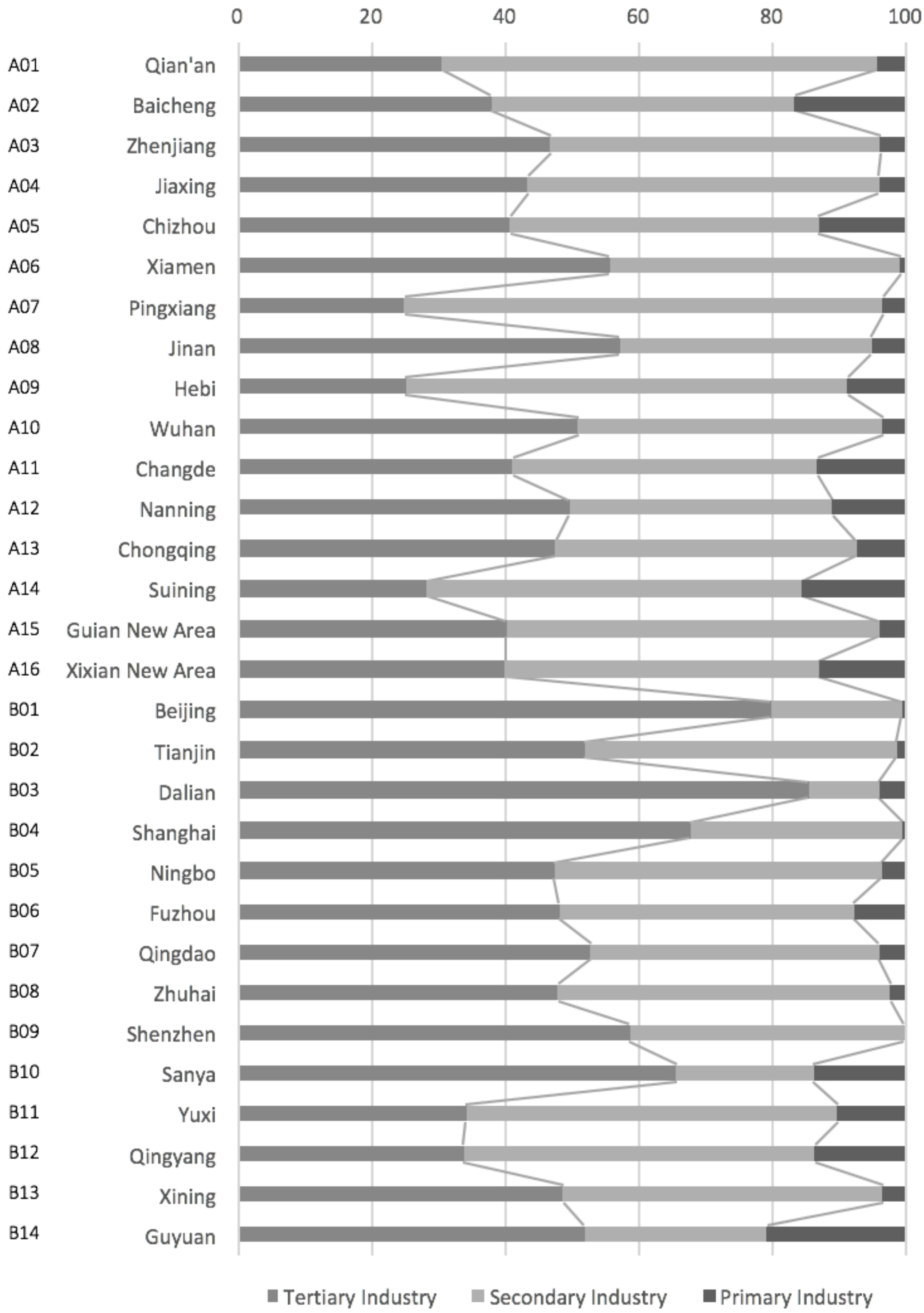


Figure 5-1 Composition of Gross Regional Product of 30 Pilot Cities

5.3.2 GDP and Government Revenue

GDP and Government Revenue of 30 Pilot Cities is shown in Table 5-16.

Table 5-16 GDP and Government Revenue of 30 Pilot Cities

No.	City	Total GDP (Billion RMB)	GDP Per Capita (RMB)	Government Revenue (Billion RMB)
B09	Shenzhen	1750.3	157985	272.7
A01	Qian'an	99.4	130922	6.2
B08	Zhuhai	202.5	124700	27.0
B03	Dalian	773.2	110673	58.0
A03	Zhenjiang	350.2	110351	71.2
B02	Tianjin	1653.8	106907	266.7
B01	Beijing	2296.9	106284	472.4
A10	Wuhan	1090.6	104132	223.2
B04	Shanghai	2496.5	103100	552.0
B07	Qingdao	930.0	102519	271.4
B05	Ningbo	801.2	102475	207.3
A06	Xiamen	346.6	90378	100.2
A08	Jinan	610.0	85919	61.4
A04	Jiaxing	351.7	76834	63.9
B06	Fuzhou	561.8	75259	84.8
B10	Sanya	43.5	58361	8.9
B11	Yuxi	124.6	52887	50.6
A13	Chongqing	1572.0	52330	215.5
B13	Xining	113.2	49200	32.7
A12	Nanning	341.0	49066	57.2
A07	Pingxiang	91.2	48531	13.0
A11	Changde	270.9	46408	21.1
A09	Hebi	71.3	44629	5.3
A16	Xixian New Area	43.2	44092	1.6
A05	Chizhou	54.5	38014	9.6
A02	Baicheng	71.5	36370	4.0
A14	Suining	91.6	27836	9.8
B12	Qingyang	60.9	27366	14.8
A15	Guian New Area	17.1	23370	1.7
B14	Guyuan	21.7	17910	1.6

5.3.3 Urbanization Rate

City illness refers to prominent problems which can harm citizens' living standard and city's sustainability. It often appears gradually during the urbanization process. Current urban problems in China include: Population congestion, traffic congestion, environmental pollution, housing difficulties, the loss of the sense of well-being of urban residents, etc. (Table 5-17). Chuankai Yang has summarized the development process of city illness can be divided into four stages, showing with the non-symmetrical inverted U. YANG and LI (2014))

Table 5-17 Urbanization and City Illness

Stage	Urbanization Rate (%)	Major symptoms
Incubation period	(0, 30]	Poverty, disease, famine, natural disasters, etc.;
Onset period	(30, 50]	Population congestion, traffic congestion, inadequate infrastructure, resource shortage, environmental pollution, housing difficulties, slums, crimes, etc.
Burst period	(50, 70]	Problems above worsen, along with the loss of the sense of well-being of urban residents.
Recovery period	(70, 100]	By taking countermeasures, the degree of city illness is decreasing.

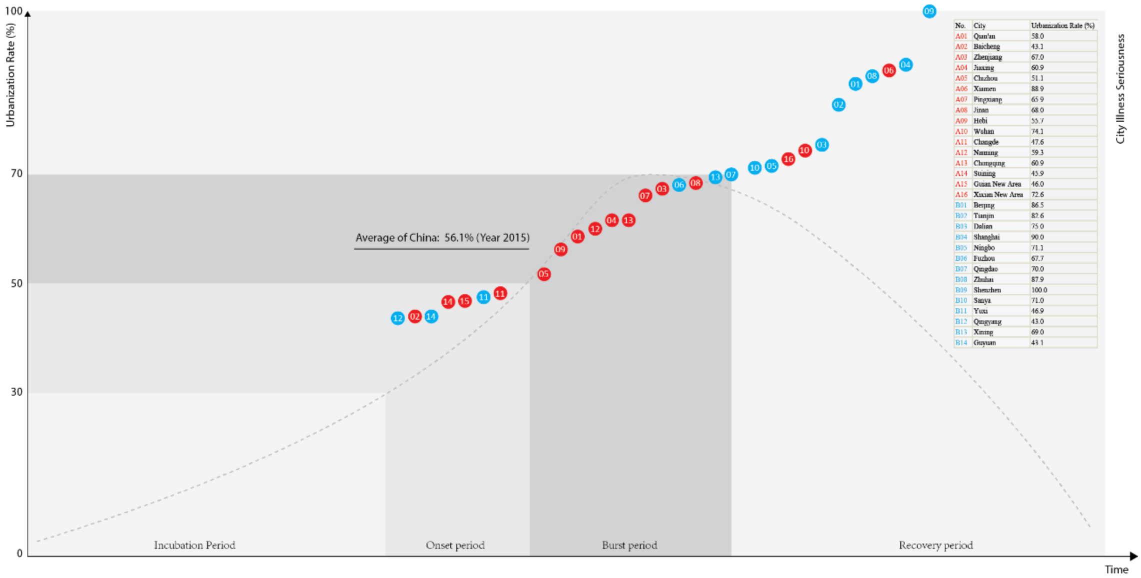


Figure 5-2 Urbanization Rate of Pilot Cities

5.3.4 Water Security Analysis

Flood control project must meet the requirements of the overall urban planning because it is a type of urban infrastructure. Meanwhile, urban flood control project is the focus of flood control planning of the basin, besides, some city must rely on basin's flood control projects outside the city to ensure its water security, therefore, the urban flood control planning must be determined based on the city's own situation as well as the basin overall planning.

Figure 5-3 shows the diagram of structural measures of urban flood and waterlogging control system. The planning of urban flood control and drainage system mainly relate to urban flood control standard, urban waterlogging control standard and urban drainage network design standards. The urban flood control standard refers to the size of the flood that the flood channel can withstand in the city (Table 5-18). The flood not only includes the runoff generated by heavy rainfall in the region, but also the "passenger water" generated in the upper reaches of the river and in the periphery of the city. It is mainly used in the planning and design of urban flood channels, embankments, dams, etc. The standard of urban drainage design mainly refers to the flood control standard of internal water (runoff caused by heavy rainfall in the region). Mainly used in the city does not have the flood control function of rivers, lakes, ponds and other planning and design. It is mainly used in new construction, expansion and reconstruction of the old city, industrial areas and residential areas, not submerged city roads as the standard, the drainage pipe network system and pumping station planning and design.

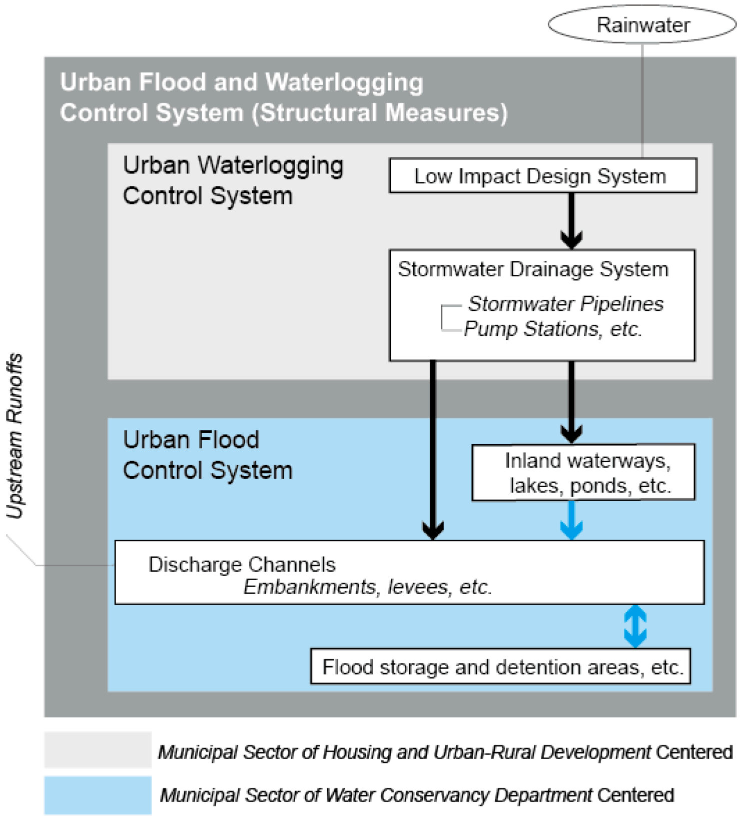


Figure 5-3 Diagram of Structural Measures of Urban Flood and Waterlogging Control System

Table 5-18 Flood Control Standard for Urban Protection Areas

Permanent Resident Population (Million)	Flood Control Standard
< 0.20	20-year ~ 50-year
[0.20, 0.50)	50-year ~ 100-year
[0.50, 1.50)	100-year ~ 200-year
≥1.50	≥ 200-year

Source: Ministry of Housing and Urban-Rural Development, General Administration of Quality Supervision, Inspection and Quarantine. (2014). Standard for flood control, China Planning Press. GB50201-2014.

Table 5-19 Flood Control Goal of Pilot Cities

No.	City	Flood Control Goal (A: Goal of 2017; B: Goal of 2018)				Whether the goal meet the Flood Control Standard's
		☆ 200-year	□ 100-year	△ 50-year	○ 20-year	
A01	Qian'an			△		×
A02	Baicheng					?
A03	Zhenjiang		□			×
A04	Jiaxing		□			×
A05	Chizhou		□			√
A06	Xiamen			△		×
A07	Pingxiang			△ Main channel of Pingshui River	○ Tributaries	×
A08	Jinan		□	△		×
A09	Hebi		□			×
A10	Wuhan		□			×
A11	Changde					?
A12	Nanning	☆ Yijiang River at Naning Downtown reaches		△ Other rivers and lakes		√
A13	Chongqing		□			×
A14	Suining			△ Fujiang River	○ (Other rivers)	×
A15	Guian New Area		□			√
A16	Xixian New Area		□			√
B01	Beijing	☆ Downtown regions		△ New-built regions		√
B02	Tianjin	☆ Jiefangnanlu Street		△ Sino-Singapore Eco-Town		?
B03	Dalian			△		×
B04	Shanghai		□			×
B05	Ningbo	☆ General regions	□ Cicheng New District			√
B06	Fuzhou		□			×
B07	Qingdao			△		×
B08	Zhuhai		□			×
B09	Shenzhen			△		×
B10	Sanya		□			√
B11	Yuxi		□			×
B12	Qingyang		□			×
B13	Xining		□			×
B14	Guyuan					?

Table 5-20 Waterlogging Control Goal of Pilot Cities

No.	City	Planning Goals of Waterlogging Prevention (A: Goal of 2017; B: Goal of 2018)				Return Period of Waterloggging Prevention Standard			Whether meet the requrements of Waterlogging Prevention Standard
		○ 20-year	◎ 30-year	△ 50-year	□ 100-year	20-year ~ 30-year	30-year ~ 50-year	50-year ~ 100-year	
A01	Qian'an					●			N/A
A02	Baicheng						●		N/A
A03	Zhenjiang	○					●		×
A04	Jiaxing	○					●		×
A05	Chizhou		◎				●		√
A06	Xiamen			△			●		√
A07	Pingxiang		◎				●		√
A08	Jinan			△				●	√
A09	Hebi		◎				●		√
A10	Wuhan			△				●	√
A11	Changde		◎					●	×
A12	Nanning	○						●	×
A13	Chongqing			△				●	√
A14	Suining		◎				●		√
A15	Guian New Area		◎			●			√
A16	Xixian New Area					●			N/A
B01	Beijing			△				●	√
B02	Tianjin			△				●	√
B03	Dalian	○					●		×
B04	Shanghai				□			●	√
B05	Ningbo			△			●		√
B06	Fuzhou			△				●	√
B07	Qingdao			△				●	√
B08	Zhuhai		◎				●		√
B09	Shenzhen			△				●	√
B10	Sanya		◎			●			√
B11	Yuxi		◎				●		√
B12	Qingyang		◎				●		√
B13	Xining			△			●		√
B14	Guyuan						●		N/A

Table 5-21 Waterlogging Prevention Standard for Downtowns

Size	Return Period of Waterlogging Prevention Standard	Major Requirements
Small City	20-year ~ 30-year	Bottoms of residential and commercial buildings are not waterlogged; Accumulated rainwater depth of lanes is no more than 15 cm.
Medium-sized City		
Large City	30-year ~ 50-year	
Megacity	50-year ~ 100-year	
Super city		

Source: Ministry of Housing and Urban-Rural Development, General Administration of Quality Supervision, Inspection and Quarantine (2016). Code for design outdoor wastewater engineering (2016 Edition). GB 50014-2006.

Table 5-22 Water Security Design Standard for Rainwater Networks

No.	City	Design Standard for Rainwater Networks (A: Goal of 2017; B: Goal of 2018)
A01	Qian'an	
A02	Baicheng	
A03	Zhenjiang	
A04	Jiaxing	
A05	Chizhou	1-year
A06	Xiamen	
A07	Pingxiang	
A08	Jinan	3-year
A09	Hebi	2-year ~ 3-year (General regions); 3-year ~ 5-year (Important regions); 10-year ~ 20-year (Underground crossings and sunken squares)
A10	Wuhan	
A11	Changde	2-year
A12	Nanning	3-year (General regions); 5-year (Important regions); 10-year (Crucial regions)
A13	Chongqing	3-year ~ 5-year
A14	Suining	2-year ~ 5-year (General regions); 5-year ~ 10-year (Important regions)
A15	Guian New Area	
A16	Xixian New Area	
B01	Beijing	3-year
B02	Tianjin	Jiefangnanlu Street: 3-year (New-built pipelines); 3-year ~ 5-year (Important regions); Sino-Singapore Eco-Town: 3-year (New-built pipelines); 5-year (Important regions)
B03	Dalian	2-year ~ 10-year
B04	Shanghai	3-year ~ 5-year
B05	Ningbo	3-year (General regions); 10-year (Important regions)
B06	Fuzhou	1-year ~ 2-year
B07	Qingdao	2-year ~ 5-year
B08	Zhuhai	3-year ~ 5-year
B09	Shenzhen	1-year
B10	Sanya	2-year ~ 3-year (New-built pipelines); 3-year ~ 5-year (Important regions)
B11	Yuxi	3-year ~ 5-year
B12	Qingyang	2-year
B13	Xining	
B14	Guyuan	

Table 5-23 Design Return Period of Stormwater Drainage Networks

<table>
<tr><th>Size</th><th>Non-downtown</th><th>Downtown</th><th>Important areas at downtown</th><th>Underground crossings and sunken squares, etc. at downtown</th></tr>
<tr><td>Small city</td><td rowspan="5">2~3</td><td rowspan="2">2~3</td><td rowspan="2">3~5</td><td rowspan="2">10~20</td></tr>
<tr><td>Medium-sized city</td></tr>
<tr><td>Large city</td><td>2~5</td><td rowspan="3">5~10</td><td>20~30</td></tr>
<tr><td>Megacity</td><td rowspan="2">3~5</td><td rowspan="2">30~50</td></tr>
<tr><td>Super city</td></tr>
</table>

Source: Ministry of Housing and Urban-Rural Development, General Administration of Quality Supervision, Inspection and Quarantine (2016). Code for design outdoor wastewater engineering (2016 Edition). GB 50014-2006.

5.4 Analysis of Current Construction Conditions of SCC

5.4.1 Investment and Number of Projects of 30 Pilot Cities

The sources of investment for sponge city construction are: Funds collected by construction unit; government; social capitals and others.

Table 5-24 Areas, Investment, and Project Amounts of 30 Pilot Cities

No.	City	Area of Built Districts (km^2)	Area of Experimental Zone (km^2)	Planned Investment (Billion RMB)
A01	Qian'an	42.0	21.5	3.40
A02	Baicheng	38.0	22.0	4.35
A03	Zhenjiang	52.3	22.0	3.06
A04	Jiaxing	95.8	18.4	5.10
A05	Chizhou	37.0	18.5	4.45
A06	Xiamen	324.0	35.4	5.68
A07	Pingxiang	50.9	33.0	6.30
A08	Jinan	390.0	39.0	7.93
A09	Hebi	50.0	29.8	3.29
A10	Wuhan	408.0	38.5	15.00
A11	Changde	79.0	36.1	17.40
A12	Nanning	143.0	54.6	8.77
A13	Chongqing	278.0	27.1	5.20
A14	Suining	52.0	25.8	5.83
A15	Guian New Area	N/A	19.1	4.67
A16	Xixian New Area	N/A	22.5	2.71
B01	Beijing	1268.0	19.4	N/A
B02	Tianjin	605.0	39.5	7.50
B03	Dalian	37.0	21.8	2.90
B04	Shanghai	1563.0	79.0	8.01
B05	Ningbo	321.9	31.0	6.04
B06	Fuzhou	177.0	57.0	7.80
B07	Qingdao	464.9	25.2	4.88
B08	Zhuhai	57.4	52.0	10.66
B09	Shenzhen	900.0	24.7	4.09
B10	Sanya	40.1	20.3	4.04
B11	Yuxi	50.9	20.9	4.87
B12	Qingyang	40.0	29.6	4.74
B13	Xining	71.6	21.6	5.79
B14	Guyuan	52.3	23.0	3.65
Average		274.6	30.9	6.14

The number of SCC projects in 30 pilot cities changes due to practical considerations, but we have investigated this data for reference. Our results showed that the average number of projects implemented in pilot cities is 233 (Table 5-23). Types of projects includes: Architectures and Neighborhoods, Roads and Squares, Parks and Greenbelts, Flood and Waterlogging Control, Pipe Network Construction, Rainwater Collection and Utilization, Water System Improvement and Ecosystem Restoration, Monitoring and Regulation Construction, Water Supply and Sewage Treatment Projects, etc.

Table 5-25 Number of SCC Projects of 30 Pilot Cities

Period	City	Sum of Projects	Architectures & Neighborhoods	Roads & Squares	Parks & Green Spaces	Water System Improvement & Ecosystem Restoration	Flood & Waterlogging Control	Pipe Network Construction	Monitoring & Regulation Construction	Water Supply & Sewage Treatment Works
2015~2017	Qian'an	214	-	-	-	-	-	-	-	-
	Baicheng	317	-	-	-	-	-	-	-	-
	Zhenjiang	495	-	-	-	-	-	-	-	-
	Jiaxing	488	-	-	-	-	-	-	-	-
	Chizhou	117	-	-	-	-	-	-	-	-
	Xiamen	244	-	-	-	-	-	-	-	-
	Pingxiang	159	-	-	-	-	-	-	-	-
	Jinan	137	-	-	-	-	-	-	-	-
	Hebi	317	12	11	24	10	5	-	-	6
	Wuhan	389	-	-	-	-	-	-	-	-
	Changde	148	-	-	-	-	-	-	-	-
	Nanning	494	-	-	-	-	-	-	-	-
	Chongqing	67	-	-	-	-	-	-	-	-
	Suining	346	204	64	48	7	21	0	1	1
	Guian New Area	67	-	-	-	-	-	-	-	-
	Xixian New Area	58	15	25	6	7	0	0	5	0
2016~2018	Beijing	51	-	-	-	-	-	-	-	-
	Tianjin	114	52	24	22	8	0	4	2	2
	Dalian	54	25	13	5	1		5	5	
	Shanghai	N/A	-	-	-	-	-	-	-	-
	Ningbo	171	77	34	22	27	4	0	7	0
	Fuzhou	267	107	48	15	16	10	8	-	-
	Qingdao	269	177	21	14	3	5	48	1	-
	Zhuhai	447	214	63	77	9	17	61	2	4
	Shenzhen	54	15	15	6	4	4	2	0	8
	Sanya	68	21	12	21	3	5	4	0	2
	Yuxi	199	98	37	23	4	5	31	1	-
	Qingyang	256	-	-	-	-	-	-	-	-
	Xining	313	184	12	7	3	-	-	-	4
	Guyuan	430	221	151	49	1	6	0	1	1
Average		212	-	-	-	-	-	-	-	-

Note: By December 5th, 2016

We have also conducted an incomplete statistic on the progresses of SCC projects in 30 pilot cities by the end of December, 2016 (Table 5-26).

Table 5-26 Progresses of SCC Projects in 30 Pilot Cities

Period	City	Number of Projects begin construction	Percentage of City's Projects	Number of Projects be completed	Percentage of City's Projects	City's Projects
2015~2017	Qian'an	N/A	Most projects	N/A	N/A	214
	Baicheng	56	18%	34	11%	317
	Zhenjiang	299	60%	20	4%	495
	Jiaxing	99	20%	N/A	N/A	488
	Chizhou	35	30%	49	42%	117
	Xiamen	117	48%	68	28%	244
	Pingxiang	26	16%	15	9%	159
	Jinan	57	42%	N/A	N/A	137
	Hebi	104	33%	27	9%	317
	Wuhan	N/A	N/A	50	13%	389
	Changde	N/A	N/A	60	41%	148
	Nanning	295	60%	68	14%	494
	Chongqing	21	31%	N/A	N/A	67
	Suining	56	16%	34	10%	346
	Guian New Area	25	37%	6	9%	67
	Xixian New Area	N/A	N/A	1	2%	58
2016~2018	Beijing	24	47%	N/A	N/A	51
	Tianjin	N/A	Most projects	N/A	N/A	114
	Dalian	N/A	N/A	1	2%	54
	Shanghai	1	N/A	N/A	N/A	N/A
	Ningbo	31	18%	N/A	N/A	171
	Fuzhou	70	26%	27	10%	267
	Qingdao	52	19%	N/A	N/A	269
	Zhuhai	15	3%	N/A	N/A	447
	Shenzhen	18	33%	16	30%	54
	Sanya	N/A	N/A	1	1%	68
	Yuxi	4	2%	N/A	N/A	199
	Qingyang	26	10%	20	8%	256
	Xining	16	5%	N/A	N/A	313
	Guyuan	80	19%	N/A	N/A	430

By end of December, 2016.

The above table shows that：

Generally, the first batch of 16 pilot cities (A01 ~ A16) are progressing well: ① numbers of projects started and finished in Wuhan, Changde and Xi Xian New District are not available; ② most projects in Qian'an have been started; ③ For other 12 cities, 16% ~ 60% of SCC projects have begun construction, and 2% ~ 42% of projects have been completed.

The current situations of the second batch of 14 pilot cities (B01 ~B14) are as following: ① most SCC projects in Tianjin has been started, the number of projects completed is not available; ② Shanghai has started 1 SCC project and not finished; ③ Dalian and Sanya each finished 1 SCC project, but the numbers of projects started are not available; ④ For other 10 cities, 2% ~ 47% of SCC projects have been started; ⑤ 2% ~ 30% of SCC projects in Dalian, Fuzhou, Shenzhen, Qingyang had been finished, and the remaining 8 cities have no clear data.

In addition, according to the investigation results conducted by Ministry of Housing and Urban-Rural Development, most projects of 30 pilot cities have been completed as per schedule. However, to some extent, they were small size, scattered, and fragmented, thus is not conducive to play the overall effect of SCC. Meanwhile, after this round of investment, those completed projects may face the lack of sustained funding to maintain. In addition, in many cases, designing took a long time but the result was rough and mechanically due to designers' lack of skills, experiences and raw data (2016).

5.4.2 Volume Capture Ratio of Annual Rainfall and Design Rainfall

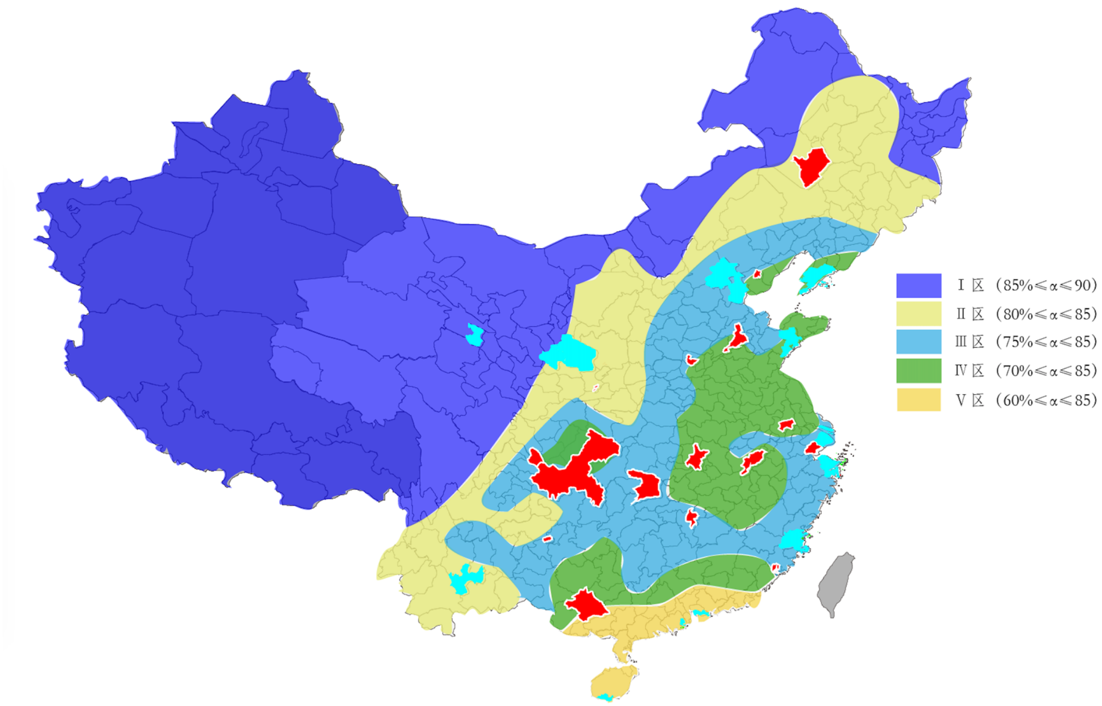


Figure 5-4 Design Value of Volume Capture Ratio of Annual Rainfall

Source: Technological Guide for Sponge City Construction – Storm Water System Construction under Low Impact Development

Design rainfall depth of most cities are among 20 ~ 30 mm/24h, only a few of cities are over 30 mm/24h (Table 5-27).

Table 5-27 Runoff Coefficient, Volume Capture Ratio of Annual Rainfall, and Design Rainfall Depth

No.	City	Volume Capture Ratio of Annual Rainfall (%)	Design Rainfall Depth (mm/24h)	Average Runoff Coefficient
A01	Qian'an	76	29.3	0.22
A02	Baicheng	85	N/A	0.12
A03	Zhenjiang	75	25.5	0.19
A04	Jiaxing	78	22	0.38
A05	Chizhou	80	32.5	0.50
A06	Xiamen	75	24.1	0.50
A07	Pingxiang	80	27.1	0.58
A08	Jinan	75	27.7	0.21
A09	Hebi	70	22.2	0.10
A10	Wuhan	75	29.2	0.39
A11	Changde	80	24.8	0.55
A12	Nanning	75	26	0.48
A13	Chongqing	80	25.5	0.52
A14	Suining	75	25.7	-
A15	Guian New Area	85	33.9	-
A16	Xixian New Area	80	15.9	-
B01	Beijing	80	30	0.18
B02	Tianjin	80	30.4	0.17
B03	Dalian	75	29	-
B04	Shanghai	80	26.7	0.34
B05	Ningbo	80	24.7	0.57
B06	Fuzhou	75	N/A	0.62
B07	Qingdao	75	27.4	0.61
B08	Zhuhai	70	28.5	0.56
B09	Shenzhen	70	31.3	0.53
B10	Sanya	70	35.4	-
B11	Yuxi	82	23.9	-
B12	Qingyang	90	27.5	0.74
B13	Xining	88	N/A	0.40
B14	Guyuan	85	N/A	0.11

As data, not all can be accessed, we also took a rough study by:

Leakage rates of public water supply network of 30 pilot cities are high. For example, Shenzhen of 8.0%, Tianjin and Dalian of 10.0%, Qingdao, Zhuhai and Yuxi of 12.0%. Therefore, this aspect should be improved in the near future to mitigate water scarcity.

As for green roof rate, not all the pilot cities have a definite limit on this value. But for Ningbo, it requires 14.6%; Sanya requires 10%.

As for sewerage reuse rate, Xiamen targets 20% by 2020; For goal of 2017, Jinan targets by 30%, Dalian targets by 25%; Qingdao, Sanya and Yuxi target by 20%; Zhuhai targets by 15%.

As for the goals for rainwater utilization, Fuzhou set a goal of utilization rate by 2%, Chizhou by 3%, Sanya by 5%, Qingdao by 6%, Zhuhai and Yuxi by 10%, Pingxiang by 12%, Jinan by 25%. Xiamen set a goal of using rainwater replacing tap water by 1.5%.

As for annual runoff pollutants reduction (by SS), Fuzhou by 45%, Dalian and Zhuhai by 50%, Qingdao by 65%, Yuxi by 50%, Qingyang by 60%.

As for permeable pavement rate, most cities require that in redeveloped areas, it should be more than 20%, but the concrete value differs much by conditions. For example, Jinan requires the permeable pavement rate for roads and squares should not less than 70%; Ningbo requires the experimental area not less than 26.9, Zhuhai by 25%, Sanya by 20%. Besides, for new-built areas, this value is often larger, for example, Zhuhai by 30%, Sanya by 50%.

Drainage system can be classified into two types by whether stormwater is directly drained into a sewer system, and the two types both have advantages and disadvantages.

A combined drainage system is simple - only a set of drainage pipe network. It can also collect the initial rainwater, access to sewage treatment plant for treatment. However, the diameter of pipes is much greater, and the total amount of water collected in rainy days and sunny days differs much, leading the operation of sewage treatment plants being difficult. Moreover, whenever the stormwater collected is over the sewage treatment plant's capacity, the mixed rainwater and sewerage will be discharged directly into the river, resulting in pollution. For example, when the stormwater runoff in storm days is 2.5 times more than a sunny day in Shanghai, the overpassed part of stormwater will be discharged into the natural water without any treatment.

In contrast, a separate drainage system can ensure at any weather conditions, all the sewerage will be sent to the sewage treat, besides the sewage treatment plants can be much smaller scale because the amount of sewage treatment is generally fixed and will not increase significantly during rainy days. Typically, in areas with dense water networks, rainwater can be drained into nearby water bodies by a very short rainwater pipeline, resulting in low construction costs and the pipe diameter of confluence pipes becomes smaller. This type is particularly suitable for areas where have a long rain season. During the rainy season, the initial rainwater pollutants contains more pollutants, but after a period of rain erosion, pollutants in stormwater runoff become quite little. However, the drainage system needs two sets of pipe network, the initial rain will flow straight into water bodies nearby.

They both have advantages and disadvantages. Therefore, it should be carefully discussed before reconstruction according to the actual situation of each city, such as the urgency of environmental pollution control, the actual situation of the existing pipe network, the strength of urban investment in the city, the level of urban development, etc.

Anyway, we can find a trend that some cities are promoting the separate draining system for rainwater and sewerage. For example, Sanya requires the redeveloped area by 90%, new-built area by 100%. And some cities do not set a definite goal for SCC.

5.5 Quantification Analysis of Pilot Cities for Sponge City Construction

5.5.1 Concise Introduction of Theories

Quantification Theory III Analysis is a method of finding out several latent variables from several observation variables. Its sample score can be used to check the similarity of each sample by calculating the score of each sample in the latent variables, and its category score can be used to check the similarity of observation variables by using their weight in the relational expression that finds the latent variable.

Cluster Analysis is a method used to classify the obtained data into several groups. It can be divided into hierarchical method and nonhierarchical method.

Correspondence Analysis is a multivariate statistical technique which uses the distance in a scatter diagram to express the correlation strength of each option from a cross tabulation table.

In this section, we used the excel statistic 2015 as the calculation tool (Figure 5-5).

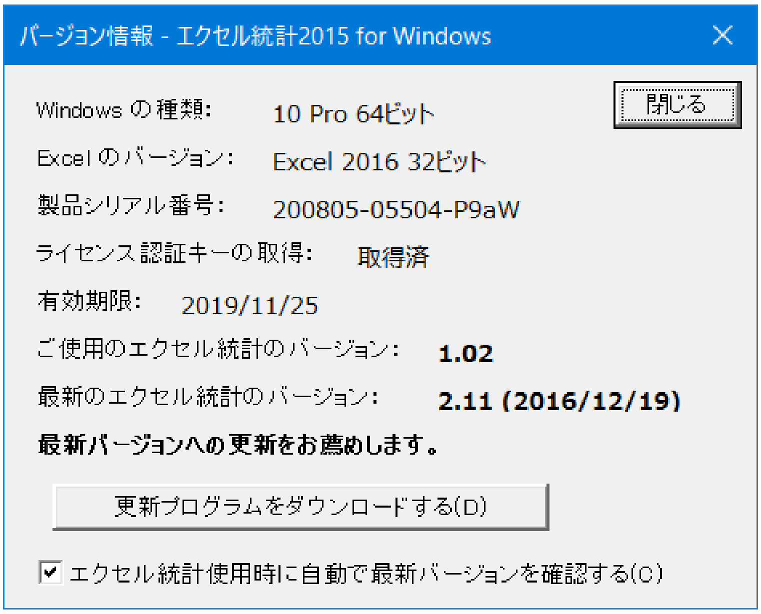


Figure 5-5 Version Information of Soft Used for Quantification Theory III Analysis, Cluster Analysis, and Correspondence Analysis

5.5.2 Data Selection for Quantification Theory Ⅲ Analysis

【Step 1】Quantification Theory Ⅲ Analysis (Extract the following table from the analyses in above sections)

Table 5-28 Raw Data for Quantification Theory Ⅲ Analysis of Pilot Sponge Cities

Designation Year	City	Water Security Goals for SCC			Landform					Waters					City Size			Urbanization			Dominant Industry
		Meet the Flood Control Standard	Meet the Waterlogging Prevention Standard	Meet the Drainage System Design Standard	Plateau	Mountain	Hill	Plain	Coastal	Poor Drainage Density	Fair Drainage Density	Good Drainage Density	Excellent Drainage Density	Appropriate Water Surface Ratio	Large	Mega	Super	Onset Period	Burst Period	Recovery Period	Tertiary
2015	Chizhou	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0
	Hebi	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0
	Nanning	1	0	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1	0	1
	Chongqing	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1
	Suining	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0
2016	Beijing	1	1	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	1
	Dalian	0	0	1	0	0	1	0	1	1	0	0	0	1	1	0	0	0	0	1	1
	Shanghai	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0	1	0	0	1	1
	Ningbo	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0
	Fuzhou	0	1	0	0	0	1	0	1	1	0	0	0	1	0	1	0	0	1	0	1
	Qingdao	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1	0	1
	Zhuhai	0	1	1	0	0	1	0	1	1	0	0	0	1	1	0	0	0	0	1	0
	Shenzhen	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0	1	0	0	1	1
	Yuxi	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
	Qingyang	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0

5.5.3 Quantification Theory Ⅲ Analysis

We inputted the above data into the excel statistic 2015, and set as following table.

Table 5-29 Setting contents of Quantification Theory Ⅲ Analysis

Data content	Individual classification
Distance calculation	Euclidean distance
Distance calculation after merger	Ward's method

Then, we got following result.

Table 5-30 Summary of Cases

Case	Number	%
Effective case	15	100.00%
Unknown case	0	0.00%
Overall	15	100.00%

Table 5-31 Eigenvalue, Contribution Rate, and Correlation Coefficient

Axis	Eigenvalue	Contribution rate	Cumulative contribution rate	Correlation coefficient
1	0.4700	0.271592635	0.271592635	0.6855
2	0.2907	0.168022707	0.439615342	0.5392
3	0.2435	0.140696018	0.580311359	0.4934
4	0.2304	0.133122565	0.713433924	0.4800
5	0.2061	0.119128084	0.832562009	0.4540
6	0.0925	0.053440384	0.886002392	0.3041
7	0.0647	0.03738003	0.923382422	0.2543
8	0.0558	0.032239922	0.955622344	0.2362
9	0.0329	0.019012552	0.974634896	0.1814
10	0.0218	0.012605163	0.987240059	0.1477
11	0.0123	0.007109913	0.994349972	0.1109
12	0.0082	0.004761665	0.999111637	0.0908
13	0.0015	0.000888363	1	0.0392
14	0.0000	3.97448E-17	1	0.0000
15	0.0000	1.0422E-17	1	0.0000
16	0.0000	1.13975E-18	1	0.0000
17	0.0000	1.47729E-17	1	0.0000
18	0.0000	3.07468E-17	1	0.0000
19	0.0000	3.34574E-17	1	0.0000

Table 5-32 Cross Tabulation Table

	Meet the Flood Control Standard	Meet the Waterlogging Prevention	Meet the Drainage System Design	Plateau	Mountain	Hill	Plain	Coastal	Poor Drainage Density	Fair Drainage Density	Good Drainage Density	Excellent Drainage Density	Appropriate Water Surface Ratio	Large	Mega	Super	Onset Period	Burst Period	Recovery Period	Tertiary
Meet the Flood Control Standard	4	3	3	0	2	0	2	1	1	1	1	1	3	2	1	1	0	2	2	2
Meet the Waterlogging Prevention Standard	3	13	9	2	3	5	3	6	4	1	6	2	5	7	2	4	3	5	5	6
Meet the Drainage System Design Standard	3	9	11	2	2	3	4	4	3	1	5	2	5	7	1	3	3	3	5	5
Plateau	0	2	2	2	0	0	0	0	0	0	2	0	0	2	0	0	2	0	0	0
Mountain	2	3	2	0	3	0	0	0	1	0	2	0	2	1	0	2	0	2	1	2
Hill	0	5	3	0	0	6	0	5	3	1	2	0	3	3	2	1	1	2	3	4
Plain	2	3	4	0	0	0	4	2	1	1	0	2	2	2	1	1	0	2	2	2
Coastal	1	6	4	0	0	5	2	7	3	1	1	2	4	3	2	2	0	2	5	5
Poor Drainage Density	1	4	3	0	1	3	1	3	5	0	0	0	4	4	1	0	0	3	2	2
Fair Drainage Density	1	1	1	0	0	1	1	1	0	2	0	0	1	0	2	0	0	2	0	2
Good Drainage Density	1	6	5	2	2	2	0	1	0	0	6	0	1	3	0	3	3	1	2	3
Excellent Drainage Density	1	2	2	0	0	0	2	2	0	0	0	2	1	1	0	1	0	0	2	1
Appropriate Water Surface Ratio	3	5	5	0	2	3	2	4	4	1	1	1	7	3	2	2	0	3	4	5
Large	2	7	7	2	1	3	2	3	4	0	3	1	3	8	0	0	3	2	3	1
Mega	1	2	1	0	0	2	1	2	1	2	0	0	2	0	3	0	0	3	0	3
Super	1	4	3	0	2	1	1	2	0	0	3	1	2	0	0	4	0	1	3	4
Onset Period	0	3	3	2	0	1	0	0	0	0	3	0	0	3	0	0	3	0	0	0
Burst Period	2	5	3	0	2	2	2	2	3	2	1	0	3	2	3	1	0	6	0	4
Recovery Period	2	5	5	0	1	3	2	5	2	0	2	2	4	3	0	3	0	0	6	4
Tertiary	2	6	5	0	2	4	2	5	2	2	3	1	5	1	3	4	0	4	4	8

Table 5-33 Category Score of Quantification Theory Ⅲ Analysis

Category	Axis 1st	Category	Axis 2nd
Fair Drainage Density	1.6665	Excellent Drainage Density	2.5908
Mega	1.5524	Super	1.7543
Burst Period	0.8548	Recovery Period	1.6236
Tertiary	0.7400	Mountain	0.9099
Appropriate Water Surface Ratio	0.7052	Plain	0.5515
Plain	0.6863	Meet the Flood Control Standard	0.4850
Coastal	0.6713	Coastal	0.3033
Meet the Flood Control Standard	0.6334	Meet the Drainage System Design Standard	0.2133
Poor Drainage Density	0.5110	Appropriate Water Surface Ratio	0.1951
Excellent Drainage Density	0.4821	Good Drainage Density	0.0942
Recovery Period	0.3038	Meet the Waterlogging Prevention Standard	0.0070
Hill	0.2680	Tertiary	-0.0664
Super	0.1994	Large	-0.0978
Mountain	0.1574	Poor Drainage Density	-0.2914
Meet the Waterlogging Prevention Standard	-0.3237	Hill	-0.6714
Meet the Drainage System Design Standard	-0.5123	Onset Period	-1.2370
Large	-0.9395	Burst Period	-1.3107
Good Drainage Density	-1.4856	Plateau	-1.3706
Onset Period	-3.0043	Mega	-2.6894
Plateau	-3.4430	Fair Drainage Density	-3.0617

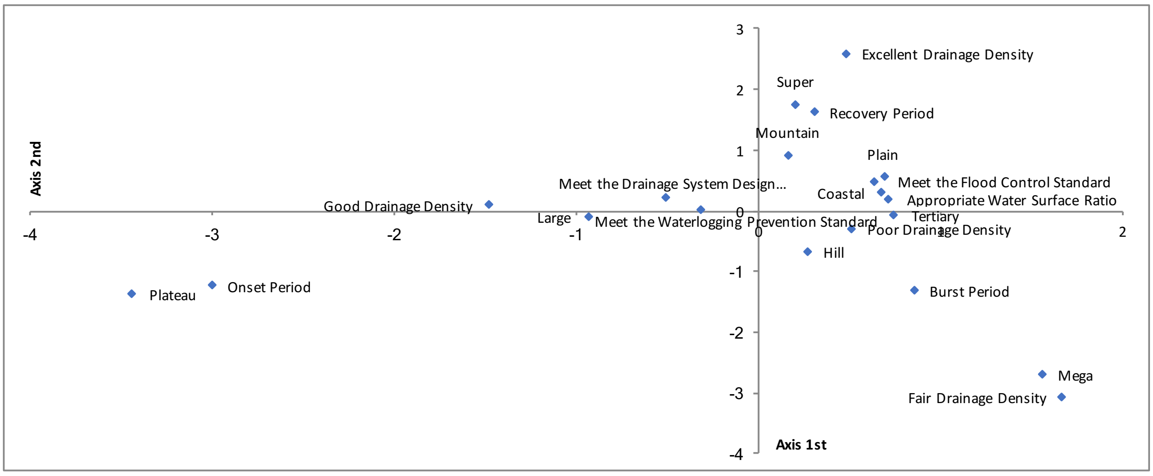


Figure 5-6 Scatter Diagram of Category Score of Quantification Theory Ⅲ Analysis

We found the latent variables from above figure by naming the two axes (Figure 5-7).

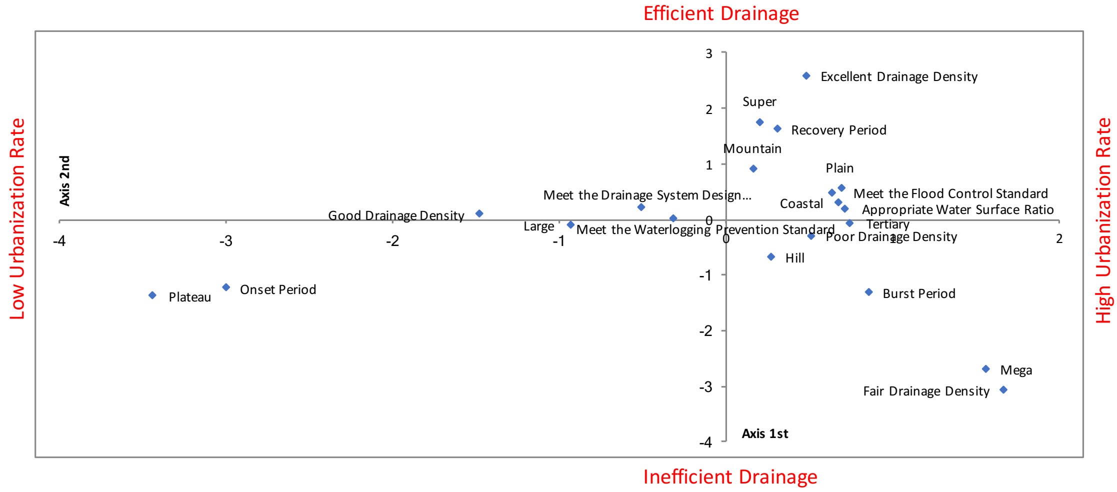


Figure 5-7 Naming Two Axes of Scatter Diagram of Category Score of Quantification Theory Ⅲ Analysis

Table 5-34 Sample Score of Quantification Theory Ⅲ Analysis

No.	City	Axis 1st	Axis 2nd
1	Chizhou	0.3331	-0.0273
2	Hebi	0.0672	-0.2869
3	Nanning	1.1535	-1.3175
4	Chongqing	-0.0771	0.4243
5	Suining	-1.4581	-0.5229
6	Beijing	0.0677	1.0748
7	Dalian	0.3186	0.2801
8	Shanghai	0.4785	1.4780
9	Ningbo	0.1826	1.3160
10	Fuzhou	0.9078	-1.0487
11	Qingdao	1.1314	-1.9842
12	Zhuhai	0.1247	0.2971
13	Shenzhen	0.0778	0.8066
14	Yuxi	-2.3603	-0.7390
15	Qingyang	-2.3603	-0.7390

We used the cluster analysis to group the above 15 cities with their sample scores (Figure 5-8).

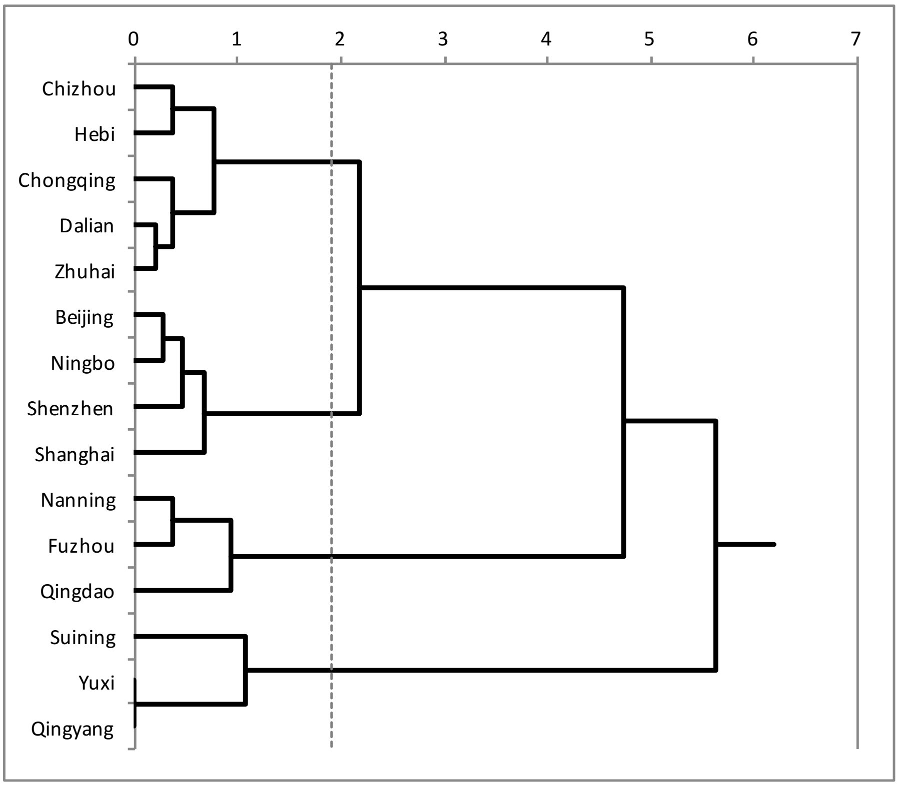


Figure 5-8 Tree Diagram Made by Cluster Analysis of Sample Score of Quantification Theory Ⅲ Analysis

According to above figure, we grouped the 15 pilot cities into 4 (Figure 5-9).

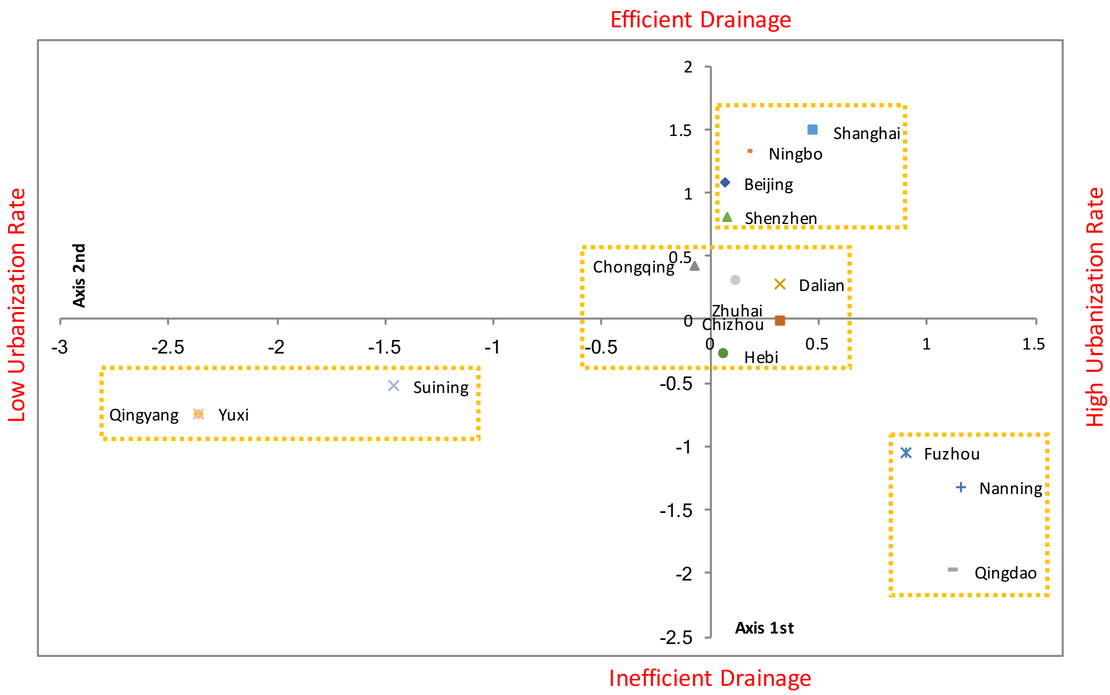


Figure 5-9 Scatter Diagram of Sample Score of Quantification Theory Ⅲ Analysis

To analyze the characteristics of each group, the progress of sponge city construction and type of projects in each city are listed in Table 5-35.

Table 5-35 Progresses and Types of Projects of Sponge City Construction in Each City by 4 Groups

Group	Classification	Cities	Designation Year		Sum of Projects	Progress				Type of Projects							
			2015	2016		Number of Projects begin construction	Percentage of Sum of Projects	Number of Projects be completed	Percentage of Sum of Projects	Architectures & Communities	Roads & Squares	Parks & Green Spaces	Water System Improvement & Ecosystem Restoration	Flood & Waterlogging Control	Pipe Network Construction	Monitoring & Regulation Construction	Water Supply & Sewage Treatment Works
i	Developed cities with efficient drainage	Shanghai		○	-	1	-	-	-	-	-	-	-	-	-	-	-
		Ningbo		○	171	31	18%	-	-	77	34	22	27	4	0	7	0
		Beijing		○	51	24	47%	-	-	-	-	-	-	-	-	-	-
		Shenzhen		○	54	18	33%	16	30%	15	15	6	4	4	2	0	8
ii	Average cities	Chongqing	○		67	21	31%	-	-	-	-	-	-	-	-	-	-
		Zhuhai		○	447	15	3%	-	-	214	63	77	9	17	61	2	4
		Dalian		○	54	-	-	1	2%	25	13	5	1		5	5	
		Chizhou	○		117	35	30%	49	42%	-	-	-	-	-	-	-	-
		Hebi	○		317	104	33%	27	9%	12	11	24	10	5	-	-	6
iii	Developed cities with inefficient drainage	Fuzhou		○	267	70	26%	27	10%	107	48	15	16	10	8	-	-
		Nanning	○		494	295	60%	68	14%	-	-	-	-	-	-	-	-
		Qingdao		○	269	52	19%	-	-	177	21	14	3	5	48	1	-
iv	Developing cities with ineffcient drainage	Suining	○		346	56	16%	34	10%	204	64	48	7	21	0	1	1
		Yuxi		○	199	4	2%	-	-	98	37	23	4	5	31	1	-
		Qingyang		○	256	26	10%	20	8%	-	-	-	-	-	-	-	-

Our conclusion is summarized in following table by analyzing above table.

Table 5-36 Characteristics and Causes Analysis of 4 Groups of Pilot Cities

Group	Classification	Characteristics	Analysis of Causes
i	Developed cities with efficient drainage	All cities of Groups i were designated in 2016 and their total numbers of projects are small. All the cities have started the project, but the number of projects completed other than Shenzhen is unknown. The largest types of SCC projects are the architectures & community, and roads & squares.	The first batch of pilot cities were cities with ordinary conditions, which are distributed through China, then the second batch of pilot cities expanded to cities with poor or unbalanced conditions. Meanwhile, the total number of projects in cities with better conditions is generally less than other cities.
ii	Average cities	Most cities of Group ii were designated in 2015 and the total number of projects in each city is less. The largest types of SCC projects are the architectures & communities, and parks and green spaces.	By analyzing the progresses of 4 groups, compared with the Group iv, the first three groups were more successful in implementation for less difficulty. One of the main reason is the cities of Group iv are prone to suffer lacking detailed, reliable, measured data.
iii	Developed cities with inefficient drainage	Most cities of Group iii were designated in 2016 and their sum of projects are averagely bigger than other groups. The largest type of SCC projects is the architectures & communities.	The largest type of projects implemented in 15 pilot cities is the developing and redeveloping architectures & communities. In addition, the Group i also attached importance to roads and squares, while the group ii also valued parks and green spaces.
iv	Developing cities with inefficient drainage	Most cities of Group iv were designated in 2016, the total number of projects in each city is relatively big. The largest type of SCC projects is the architectures & communities.	

5.5.4 Correspondence Analysis

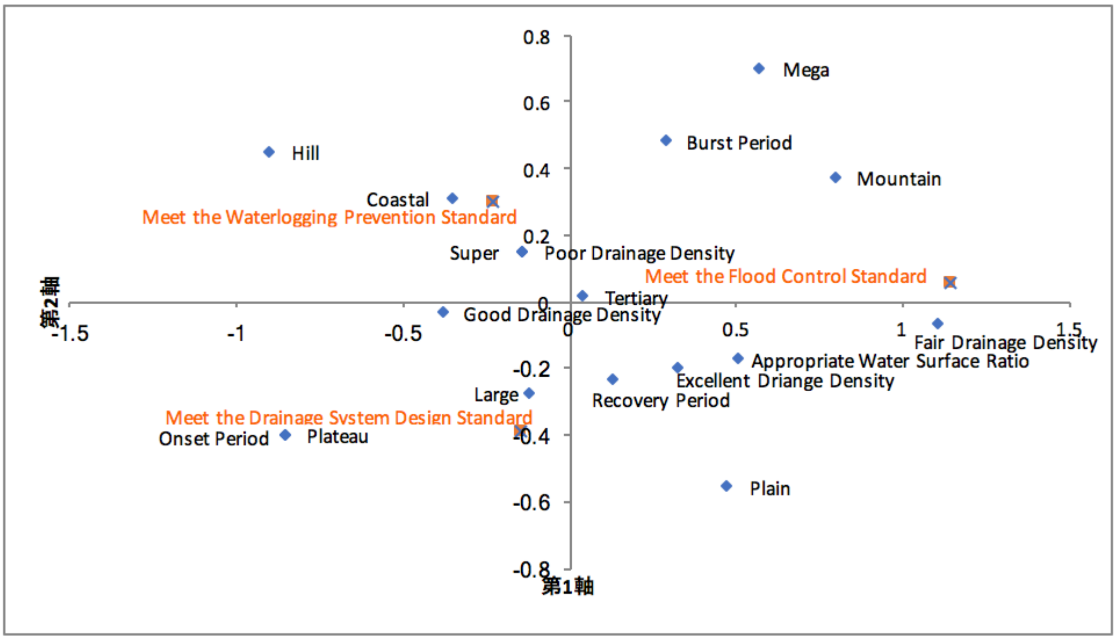


Figure 5-10 Plot of Correspondence Analysis of Pilot Cities for Sponge City Construction

From the above plot, we can see that the fact that Meet the Waterlogging Prevention Standard point is close to the Coastal point, the fact that Meet the Flood Control Standard point is close to the Fair Drainage Density point, and the fact Meet the Drainage System Standard is close to the Large point. The plot shows that:

The coastal cities tend to meet the waterlogging prevention standard. This may be interpreted by these cities have better infrastructures as they are more developed.

The cities where the drainage density is fair tend to meet the flood control standard. One reason maybe that these cities can better drain their stormwater runoff as well as the upstream runoff to the downstream area.

The large cities (With a permanent population by 0.50 ~ 1.0 million) tend to meet the drainage system standard. Possible explanations are there area and population is small, thus the drainage system itself can be made relatively simpler; on the other hand, they have lower speed of urban development, so their slower population concentration would have smaller pressure on the drainage system.

5.6 Problems of Implementing SCC and Countermeasures

This section takes Zhenjiang, Jiangsu Province as a case study to find out the problems faced in the process of implementation and gives some counter measurements. The followed Table 1 shows our research method and schedule. The head office is situated at the Municipal Bureau of Housing and Urban-Rural Development, as showed in Photo 1, namely Zhenjiang Command Center for Sponge City Construction.

Zhenjiang has largely been improving its ability against waterlogging and diffused pollution since 2007, mainly by enlarging drainage networks and building reservoirs. The location of Zhenjiang is showed in *Figure* 1. Zhenjiang was designated as pilot city by the central government in April 2nd, 2015, from which gets annual subsidy of 0.4 billion from 2015 to 2017. *Tables* below shows Its basic information.

Table 5-37 Investigation Schedule for Zhenjiang

Method	**Schedule (In 2016)**
Literature Review	June 1st ~ Sep.30th
Site Investigation	Sep. 29th ~ Sep. 30th
Hearing Research to Officers and Designers	Sep. 29th

Figure 5-11 Zhenjiang Command Center for Sponge City Construction

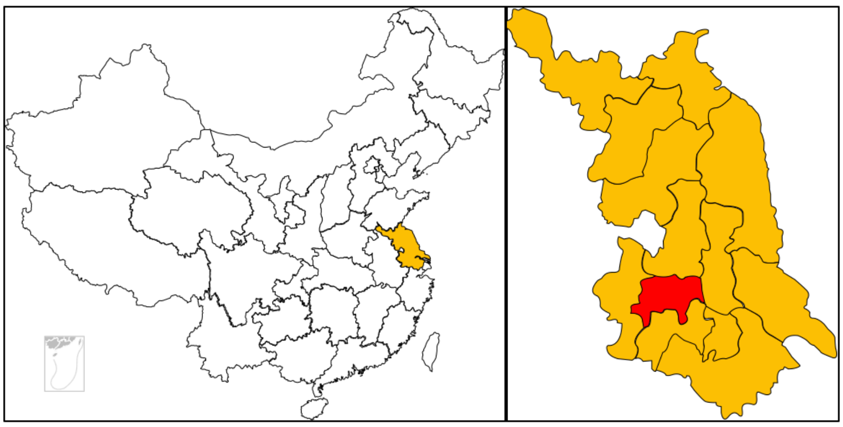


Figure 5-12 Site Map of Zhenjiang, Jiangsu Province, China

Table 5-38 Basic Information about Sponge City Construction in Zhenjiang

Experimental Area (km^2)		22
Total Investment (billion RMB)		2.585
Number of Projects		396
Objectives	Volume Capture Ratio of Annual Rainfall	75%
	Overcome Storm	30-year
	Reduce Diffused Pollutants	60%

By summarizing the results of literature review, our hearing research and site investigation (XIA and WANG (2012, YANG and ZHAO (2013, ZHU, ZHAO *et al.* (2014, HU, LI *et al.* (2015, ZHAO (2015)), we concluded some practical factors against successful implementation as following:

No direct experience could be simply and soon applied in Zhenjiang as their natural, social and other conditions differs among those pilot cities or foreign cities, thus the chance of making ill-considered decision is inevitable and high.

The construction itself is a systematical solution. So, every part should be well considered and the total should be balanced. For instance, only valuing the Low Impact Facilities is not enough, the enhancement of drainage system is also important, and every site should be maintained in good condition, otherwise, risk of immersing the low-lying areas would rise high.

Implementation involves multiple municipal bureaus. The procedures of construction include: project establishment, feasibility study, bidding, contract reporting, safety supervision, etc. Involved sectors include: Transportation and Traffic Administration, Police Office, Water Supply Company, Power Supply Company, Industry Associations, etc. Besides, the bid winning company is an endemic enterprise, thus lacks the strength to deal with local connections smoothly. Therefore, their cooperation and communication need be improved. Typically, the present Promotion Committee of Sponge City Construction consists of leaders from each bureau, thus a sort of loose. So, different bureaus should share more real-time information together and enhance their collaboration from now on.

The most difficult type of projects is renewing old communities with Low Impact Facilities, compared with transforming streets, green belts, squares and waters. The interest of residents is complicated and difficult to balance. For instance, residents prefer their parking area without green for worrying attracting insects and venomous insect such as centipede.

As residents oppose or other reasons, planning and designs always must be changed frequently, resulting the project delayed or not reach the expected effect. Therefore, the demand survey of residents should be well taken previously.

After the transformation, most residents think the effect is positive and wonderful, but few quantitative studies support those opinion as the lack of a long series of measured data about rainwater and drainage system. At present, only mathematical models are being used to simulate and evaluate the effect.

Most residents lack the awareness of importance of rainwater utilization. For instance, 100 rainwater tanks will be set up in those communities this year, however most residents think there is no need to use rainwater and the tanks look disharmonious.

In conclusion, this study indicates that implementation of sponge city construction in Zhenjiang faces many challenges and their solutions will take a very good enlightenment significance for other similar cities.

In the summer of 2016, 19 cities suffered waterlogging (*Table 5-39*). Therefore we should consider following questions carefully soon.

- Whether established a preservation and management system for urban rivers and lakes?
- Whether established a construction and management system for Low Impact Development and Stormwater Regulation, Storage and Utilization?
- Whether established a sufficient, efficient and sustainable investment mechanism?
- Whether made proper construction standards?
- Whether established an effective Storm water overflow Monitoring & Alarm System.
- Whether improved the Emergency Response Mechanism and Emergency Preplan for drainage, waterlogging and flood Prevention?
- Whether enhanced implementation system by training personnel, improving emergency rescue, etc.?

Table 5-39 Whether Water logging Happened in the Summer of 2016

No.	City	Waterlogged or not	No.	City	Waterlogged or not
A01	Qian'an	No	B01	Beijing	Yes
A02	Baicheng	Yes	B02	Tianjin	Yes
A03	Zhenjiang	Yes	B03	Dalian	Yes
A04	Jaxing	Yes	B04	Shanghai	No
A05	Chizhou	Yes	B05	Ningbo	No
A06	Xiamen	No	B06	Fuzhou	Yes
A07	Pingxiang	Yes	B07	Qingdao	No
A08	Jnan	Yes	B08	Zhuhai	Yes
A09	Hebi	No	B09	Shenzhen	Yes
A10	Wuhan	Yes	B10	Sanya	No
A11	Changde	Yes	B11	Yuxi	Yes
A12	Nanning	Yes	B12	Qingyang	Yes
A13	Chongqing	Yes	B13	Xining	Yes
A14	Suining	No	B14	Guyuan	No
A15	Guian New Area	No			
A16	Xixian New Area	No			

5.7 Summary

In this chapter, we conducted a characteristic analysis of 30 pilot cities designated for sponge city construction. Firstly, we analyzed their natural conditions by climate, landforms, water sources, drainage density as well as water surface ratio. Secondly, from the perspective of social-economic aspect, we analyzed the populations, industry structure, GDP, government revenue, urbanization rate, and water security. Thirdly, we investigated the current construction conditions by analyzing the investment, number of projects, control goals for SCC. Fourthly, based on above analyses, we also conducted a quantification analysis of 15 pilot cities by quantification theory 3rd type analysis, cluster analysis, and correspondence analysis. At last, we summarized practical problems of implementing by a case study of Zhenjiang and proposed some countermeasures.

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6 Conclusion

6.1 Summaries by Chapters

Chapter 2 has reviewed the mainstream theories for urban stormwater management including the Best Management Practices (BMPs), Low Impact Development/Design (LID), Sustainable Urban Drainage System (SuDs), and Water Sensitive Urban Design (WSUD). We have summarized their ideas, measures, and made a comparison. Generally, there is significant overlap between various terms (Figure 2-7). Indeed, all terms are generally underpinned by two broad principles: (i) mitigation of changes to hydrology and evolution towards flow regime as much as feasible towards natural levels or local environmental objectives, (ii) improvement of water quality and a reduction of pollutants. Also, we analyzed the current progress of urban stormwater management of the United States, Japan, and China. It can be concluded that the concept and technologies of China's urban stormwater management including utilization is relatively backward. Presently, only a few cities have carried out some preliminary policies, but most cities in China do not have any practices on rainwater management especially the utilization.

Chapter 3 has investigated the background of sponge city construction by analyzing the current situation of China's flood control management, historical transition of China's ecological water conservancy, and the urban environmental improvement. Obviously, an integrated framework to sustain environment-friendly urbanization is needed under the direction of a national unified real-time online environmental monitoring system and the regional collaborative governance and multi-sectoral collaboration. Regulatory and fiscal mechanisms should also be established and reinforced to incentivize efficient resource consumption and environment construction. In fact, they are handicapped by the absence of clear holistic guidelines from the central government to provincial and municipal governments. Furthermore, policy coherence, public participation, and performance assessment system should be improved in the future.

Chapter 4 focused on the conception and approaches of sponge city construction. Firstly, we introduced the SCC with LID stormwater system; then, related codes of practice and guidelines concerning SCC was summarized; also, the administrative system for SCC was confirmed by our investigation; finally, the planning and design method of SCC is combed.

In Chapter 5, we conducted a characteristic analysis of 30 pilot cities designated for sponge city construction. Firstly, we analyzed their natural conditions by climate, landforms, water sources, drainage density as well as water surface ratio. Secondly, from the perspective of social-economic aspect, we analyzed the populations, industry structure, GDP, government revenue, urbanization rate, and water security. Thirdly, we investigated the current construction conditions by analyzing the investment, number of projects, control goals for SCC. Fourthly, based on above analyses, we also conducted a quantification analysis of 15 pilot cities by quantification theory 3rd type analysis, cluster analysis, and correspondence analysis. At last, we summarized practical problems of implementing by a case study of Zhenjiang and proposed some countermeasures.

6.2 Problems and Prospect

For 2015 pilot cities, the main practical problems during sponge city construction include:

- **Weak preliminary work**: most cities currently suffer insufficient gray facility such as lack supportive drainage planning or even without drainage plans;
- **Unreasonable construction targets**: most cities' targets were set too high even impossible to pass the examination, for example, the volume capture ratio, indicators for waterlogging and flood control etc.
- **Low feasibility of implementation**: inadequate refinement of program, for example, shortage of quantitative indicators, unsuitable with local conditions;
- **Lacking supporting measures**: imperfect coordination, supervision and evaluation mechanism and so on;
- **Unpractical Investment and financing mode**: carelessly considering characteristics of different projects.

We concluded that the primary motive for Chinese Government to promote sponge city construction is to minimize the risk of waterlogging and flood in urban areas with less cost, rather than merely strengthen drainage system. However, since drainage networks and retention basins are undoubtedly stronger in most developed countries, China should not neglect reinforcing them in the future.

Firstly, to solve urban water problems like overflow of combined sewerage, waterlogging control and flood control, most China's cities must enhance their drainage capability first by enhancing grey infrastructures rather than simply developed low impact development, especially at high density urban areas. The reason is that China's stormwater management is backward, including water quantity control, water quality improvement, water ecosystem protection, rainwater harvesting, etc. The modern flood and waterlogging control in developed countries are developed based on stronger drainage systems, but China's planning and construction lags a lot. Therefore, China must combine the sponge city construction with the conventional drainage constructions.

Secondly, governments at each level should strengthen legislation and policy support by referring to success of developed countries, for example, the drainage permit management, drainage discharge fee system, market incentive mechanism etc. As we concluded, the achievements of controlling urban water problems all have benefited from strong regulations derived from and guided by laws and policies.

Thirdly, basic researches and technical guidance should be improved and strengthened. Governments at each level should make plenary criteria for stormwater management. As we said above, the strategy for stormwater management should seriously consider the regional conditions, so it would be better for the local governments to formulate own suited construction mode. Guidelines, norms, manuals should be made to effectively promote stormwater management. There is an urgent need to further develop and systematically promote rainwater management by expanding the quantitative study, for example, install more water measurement devices and make the data more accessible to researchers and the public. At present, many cities face data problems of poor accuracy and outdated, or unopen due to confidentiality.

Fourthly, it is necessary to strengthen water management by more efficient coordination and cooperation or even integration of sectors which manage water. Typically, urban waterlogging and flood control are centered respectively by municipal sector and water conservancy sector, they also involved in environmental protection sector, etc. Also, the promoting mechanism should be well established with which participants includes scholars, architects, landscape designers, municipal engineers, developers, maintainers, the public and so on, because the stormwater management is a huge and complex engineering and involving many disciplines (Figure 6-1). For example, some experts on water conservancy believe that sponge city construction should be not only considered on a city scale but also from the basin scale to truly solve the urban water problems. Future exploration of solution should absorb more opinions form other sectors and the public. In addition, we should advocate the combination of grey infrastructure with green infrastructures, source control measures and end control measures, ground facilities and underground facilities.

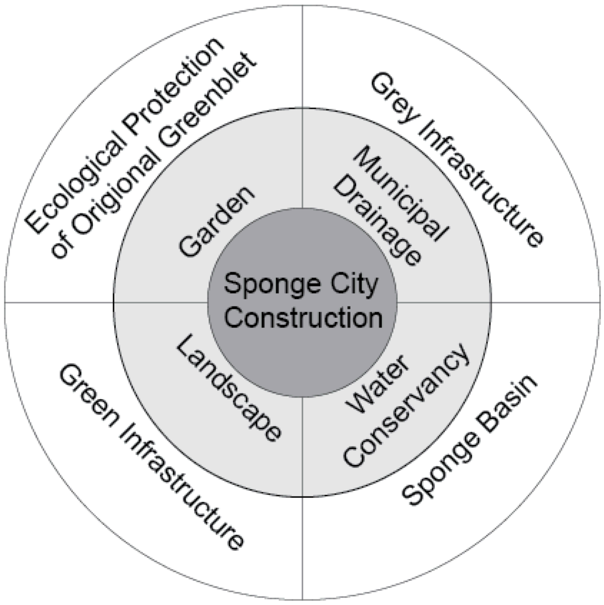

Figure 6-1 Combination of Different Disciplines' Bias of Sponge City Construction

Fifthly, Regarding Japan's urban construction and maintenance experience, other challenges for China' Sponge City Construction remain: expand the scales and explore the varies sources of capital and finance; raising public awareness and interest; developing more stable technologies with less cost, etc. Moreover, with the conception shifting from draining rainwater as quickly as possible to constraining outflow as much as possible, developing these technologies concerning rainwater utilization of architecture will become one of the top-priority issue, as buildings share more area compared with roads and waters in urban areas, which means it is a key point for reducing cities drainage intensity.

Appendix: Glossary

Refer to: Group, N. S. W. (2004). Interim code of practice for sustainable drainage systems. Londres: National SUDS Working Group.

Attenuation

Reduction of peak flow and increased duration of a flow event.

Biodegradation

Decomposition of organic matter by micro-organisms and other living things.

Bio retention area

A depressed landscaping area that can collect runoff so it percolates through the soil below the area into an underdrain, thereby promoting pollutant removal.

Catchment

The area contributing surface water flow to a point on a drainage or river system. Can be divided into sub-catchments.

Combined sewer

A sewer designed to carry foul sewage and surface water in the same pipe.

Detention basin

A vegetated depression, normally is dry except after storm events, constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground.

Diffuse pollution

Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment, or sub-catchment, and do not arise as a process effluent, municipal sewage effluent, or an effluent discharge from farm buildings.

Evapotranspiration

The process by which the Earth's surface or soil loses moisture by evaporation of water and by uptake and then transpiration from plants.

Extended detention basin

A detention basin in which the runoff is stored beyond the time normally required for attenuation. This provides extra time for natural processes to remove some of the pollutants in the water.

Filter drain

A linear drain consisting of a trench filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage, to store and conduct water, but may also be designed to permit infiltration.

Filter strip

A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and to filter out silt and other particulates.

Filtration

The act of removing sediment or other particles from a fluid by passing it through a filter.

First flush

The initial runoff from a site or catchment following the start of a rainfall event. As runoff travels over a catchment it will collect or dissolve pollutants, and the "first flush" portion of the flow may be the most contaminated thus. This is especially the case for intense storms and in small or more uniform catchments. In larger or more complex catchments pollution wash-off may contaminate runoff throughout a rainfall event.

Flood plain

Land adjacent to a watercourse that would be subject to repeated flooding under natural conditions.

Flood routing

Design and consideration of above-ground areas that act as pathways permitting water to run safely over land to minimize the adverse effect of flooding. This is required when the design capacity of the drainage system has been exceeded.

Flow control device

A device used to manage the movement of surface water into and out of an attenuation facility, e.g. a weir.

Greenfield runoff

This is the surface water runoff regime from a site before development, or the existing site conditions for brownfield redevelopment sites.

Green roof

A roof with plants growing on its surface, which contributes to local biodiversity. The vegetated surface provides a degree of retention, attenuation and treatment of rainwater, and promotes evapotranspiration.

Impermeable surface

An artificial non- porous surface that generates a surface water runoff after rainfall.

Infiltration (to a sewer)

The entry of groundwater to a sewer.

Infiltration (to the ground)

The passage of surface water into the ground.

Infiltration basin

A dry basin designed to promote infiltration of surface water to the ground.

Infiltration device

A device specifically designed to aid infiltration of surface water into the ground.

Infiltration trench

A trench, usually filled with permeable granular material, designed to promote infiltration of surface water to the ground.

Lagoon

A pond designed for the settlement of suspended solids.

Pavement

Technical name for the road or car park surface and underlying structure, usually asphalt, concrete or block paving.

Permeability

A measure of the ease with which a fluid can flow through a porous medium. It depends on the physical properties of the medium, for example grain size, porosity and pore shape.

Permeable surface

A surface formed of material that is itself impervious to water but, by voids formed through the surface, allows infiltration of water to the sub-base through the pattern of voids, for example concrete block paving.

Pervious surface

A surface that allows inflow of rainwater into the underlying construction or soil.

Piped system

Conduits generally located below ground to conduct water to a suitable location for treatment and/or disposal.

Pond

Permanently wet basin designed to retain stormwater and permit settlement of suspended solids and biological removal of pollutants.

Porous surface

A surface that infiltrates water to the sub-base across the entire surface of the material forming the surface, for example grass and gravel surfaces, porous concrete and porous asphalt.

Proper outfall

An outfall to a watercourse, public sewer and in some instances an adopted highway drain. Under current legislation and case law, the existence of a proper outfall is a prerequisite in defining a sewer.

Public sewer

A sewer that is vested in and maintained by a sewerage undertaker.

Rainwater harvesting or Rainwater use system

A system that collects rainwater from where it falls rather than allowing it to drain away. It includes water that is collected within the boundaries of a property, from roofs and surrounding surfaces.

Retention basin

A pond where runoff is detained for a sufficient time to allow settlement and possibly biological treatment of some pollutants.

Sewer

A pipe or channel taking domestic foul and/or surface water from buildings and associated paths and hard standings from two or more curtilages and having a proper outfall.

Sewerage undertaker

This is a collective term relating to the statutory undertaking of water companies that are responsible for sewerage and sewage disposal including surface water from roofs and yards of premises.

Soak away

A subsurface structure into which surface water is conveyed to allow infiltration into the ground.

Source control

The control of runoff at or near its source.

Sustainable Urban Drainage Systems

A sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques.

Surface water management train

The management of runoff in stages as it drains from a site.

Suspended solids

Undissolved particles in a liquid.

Swale

A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration; the vegetation filters particulate matter.

Watercourse

A term including all rivers, streams, ditches, drains, cuts, culverts, dykes, sluices and passages through which water flows.

Wet Detention Pond

A pond designed to attenuate flows by storing runoff during the peak flow and releasing it at a controlled rate during and after the peak flow has passed. The pond always contains water.

Green Infrastructure

Green Infrastructure encompasses approaches and technologies to infiltrate, evapotranspiration, capture and reuse stormwater to maintain or restore natural hydrology. It is one of the sustainable environmental planning and design approaches.