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Storm Water Management and Flood Control in Sponge City Construction of Beijing

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Abstract: To solve the problems of increasing local flooding, water shortage, and water pollution caused by the traditional model of urban development, the Chinese government proposed a new model of urban development—the Sponge City. In Beijing, the capital of China, research on storm water management in urban areas has been carried out since 1989 and has put forward the concept of urban storm water harvesting and flood control. The further research and demonstration application started in 2000. So far, a series of policies and technology standards on storm water management have been formulated, which promote the application of technologies on comprehensive urban storm water harvesting and flood control. A significant number of storm water harvesting and flood control projects have been built in Beijing, which are now playing important roles in runoff reduction, local flood control, non-point source pollution reduction, and storm water utilization. However, it does not solve the above problem completely. Storm water management and flood control needs to be further strengthened. The "Sponge City" is based on natural and ecological laws, which allows storm water to be managed with natural infiltration, natural retention and detention, and natural cleaning facilities. Through in-depth analysis of the connotation, characteristics, and construction path of "Sponge City", this paper summarizes the status quo of urban rainwater flooding, flood control technology development and application, and Beijing policy and engineering to introduce the overall ideas and methods of Sponge City construction. All the above will provide a reference for cities with similar problems in the construction of sponge cities.

Keywords: Sponge City; water ecology; storm water management; flood control; resilience

1. Introduction

With global warming, rainstorms and other extreme weather events are occurring frequently, leading to flood and non-point source pollution [1]. In order to solve this problem, in the late 1990s, the state of Maryland in the United States developed Low Impact Development (LID) technology to achieve runoff and pollution control caused by heavy rain, mainly through decentralized, small-scale source control. After nearly 20 years of development, it has become the urban green rainwater infrastructure (GSI) technology most commonly used in the United States and many developed countries [2]. Similarly, Australia's Water Sensitive Urban Design (WSUD) [3], New Zealand's Low Impact Urban Design and Development (LIUDD) [4], and the UK's Sustainable Urban Drainage System (SUDS) [5], are like-minded technologies. The concepts and related measures of storm water harvesting and storm water management in Japan and rainwater storage infiltration in Japan are also offer important precedents for different countries to deal with urban flooding and runoff pollution. Since 1949, China's management of urban rainwater runoff has generally experienced three stages, namely the direct rain stage (1949~2000), the combined use stage (2000~2013), and the system management stage (2013~present). In 2013, General Secretary Xi Jinping proposed the construction of "Sponge City", which indicates that China's urban rainwater management has entered the stage of system's management. Beijing has conducted research and applied rainwater utilization since 1989. It is the earliest city in China and has achieved good results. It has played an important role in reducing and controlling urban rainfall runoff, reducing non-point source pollution and preventing urban infighting. Therefore, studying the current situation of sponge cities in Beijing, especially in the management of storms and floods, will help to provide experience and reference for the international defense construction of cities affected by floods [6].

2. The Connotation of Sponge City

2.1. Concept

General Secretary, Xi Jinping put forward the construction of a "sponge city" with natural accumulation, natural infiltration, and natural purification at the Central Working Conference on Urbanization in December 2013. At an important speech on the protection of water safety in March 2014, General Secretary Xi reiterated that urban planning and construction must consciously reduce the intensity of development, retain, and restore an appropriate proportion of ecological space, and build a "sponge home" and a "sponge city". In November 2014, the Ministry of Housing and Urban-Rural Development issued a technical guide for the construction of sponge cities—the construction of rainwater systems with low impact development (Trial), pointing out that sponge cities, like sponges, had good "elasticity" in adaptation to environmental changes and response to natural disasters [7]. When it rains, the city will absorb, store, infiltrate, and purify water, if necessary, the storage water will be released and utilized. As the Guidance of the Ministry of Water Resources on promoting the water conservancy work in Sponge City construction defines it, the sponge city is based on the low-impact development and construction model, and is supported by the flood control system, giving full play to the natural accumulation, penetration, purification and relaxation of green space, soil, rivers, and lakes. The release of runoff effect has achieved source reduction, decentralized retention, sustained release, and rational utilization. Urban storm water runoff enables cities to mitigate or reduce the impact of natural disasters and environmental changes, and to protect and improve the ecological environment as sponges. As the Guidance of General Office of the State Council on promoting the water conservancy work in Sponge City construction defines (No. 75 [2015] issued by General Office of the State Council), Sponge City is a city development model with natural accumulation, infiltration, and purification. By strengthening urban planning and construction management, it effectively controls rainwater runoff and gives full play to the construction, roads, green spaces, water systems and other ecosystems on absorption, storage-infiltration and slow release effect to rain. In this paper, we take the concept of Sponge City proposed by the State Council of China's highest government agency as the research object, and further put forward our own understanding.

Therefore, sponge city should have at least the following three aspects of meaning: first and foremost, from the perspective of water resources utilization, urban planning and construction must conform to the laws of nature. By constructing water-saving urban underlying surfaces, the urban rainfall can be accumulated, purified, reused, or recharged to groundwater. Second, from the perspective of flood control and disaster reduction, the city can live in harmony with rain and flood. Measures will be taken to minimize the risk of floods, reduce disaster losses, and recover production and life rapidly. Third, from the perspective of ecological environment, the city should be placed in nature, establish scientific development, and make residents "clear and lush". In other words, "Sponge City" should be able to cope with different return periods of rainfall to prevent flood disasters, rationally use rainwater, and maintain a good hydrological and ecological environment. Sponge city construction should adopt corresponding engineering and non-engineering measures according to the rainfall return periods at residential, regional and basin levels, so as to realize scientific management and use of different scales of rainwater. Since sponge city mainly deals with rainfall in different return periods, the technical framework is shown in Figure 1.

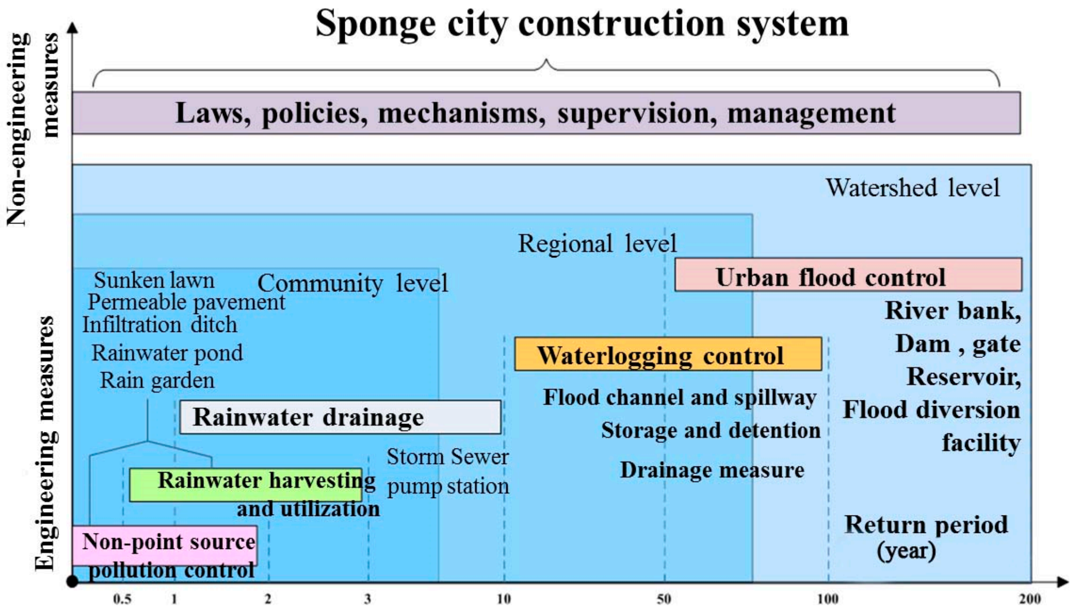

Figure 1. Diagram of sponge city construction system.

2.2. Characteristics of Sponge City Construction

In sponge city construction, water cycle regulation is the foundation and the framework gives full play to the function of storage, diversion and regulating of urban rainwater pipe network and river system. The work should be carried out according to local hydrological, geological, geographic, economic, and social conditions. Therefore, the sponge city construction has the following characteristics:

(1) Multi-scales. The sponge city construction needs to be carried out on community scale, drainage scale, city scale and watershed scale so that urban rainfall and flood can be dealt with from multi-scales, and urban water cycle is regulated well.
(2) Wide rainfall reappearing period. Sponge city construction needs to deal with the rainfall and flood in rainfall return period from small to large, including the rainfall and flood events that exceed the standard of the project [8].
(3) Versatility. Sponge city construction has the function of preventing urban floods and relieving urban flood disaster, and also has the function of reducing rainfall and runoff pollution and improving water ecological environment. It also has the function of increasing the available water resources by direct or indirect use [9].
(4) Systematisms. Sponge city construction is a systematic project involving water conservancy, architecture, gardens, landscapes, municipalities, and planning, etc. The project requires professional and technical personnel to plan, design, construct, operate, and maintain the engineering facilities, as well as to supervise, organize and coordinate the various departments.
(5) Long-term nature. Sponge city is a beautiful vision not built overnight. It needs more than ten years or even decades of continuous construction and management.

2.3. Path of Sponge City Construction

As a systematic project, sponge city construction has the following procedures:

First, protect the city's original ecosystem. In the process of urban construction and development, maximize the protection of the original rivers, lakes, wetlands, ponds, ditches and other "sponges".

Leave enough water and maintain the natural hydrological characteristics of forest, grassland, lakes and wetlands in the process of an urban development faced with intensive precipitation [10].

Second, do ecological restoration and repair work. For damaged waters and other natural environments, use ecological means to recover and repair, maintain a certain proportion of ecological space, and then build a water ecological infrastructure through systematic scientific methods.

Third, implement the concept of low impact development. According to the development and construction concept of the minimum impact on the urban ecological environment, control the intensity of development reasonably to minimize destruction of the original urban water ecological environment, such as retaining sufficient ecological land and controlling the proportion of urban impermeable surface areas. According to the needs, we should properly excavate rivers, lakes, and ditches, increase the water area, promote the accumulation of rainwater, infiltrate and purify, and improve the size and quality of the urban "sponge".

Fourth, strengthen the comprehensive utilization and management of urban rain and flood resources. Regulate comprehensively and manage the surface runoff generated by urban precipitation and rain flood in pipe networks and rivers. Under the premise of ensuring the safety, utilize rainwater and control pollution, establish a flood disaster risk management system as well as personal hedging and disaster prevention and mitigation for buildings and other adaptive measures system.

Since the core issue of sponge city construction is the management of urban rainwater and the prevention of floods, this article will specifically introduce the current situation of rainwater management and flood control in Beijing.

3. Rainwater Management and Flood Control in Beijing

3.1. Progress of Rainwater Management Research and Practice

The technical research and practice of urban rainwater in Beijing has experienced three stages, namely the direct discharge of rainwater, the combination of discharge and harvesting, and system's management (Figure 2) [11]. Before 2000, the urban rainwater in Beijing was directly discharged, and a rainwater drainage system was built, including community rainwater pipe networks, municipal rainwater pipe networks, and drainage channels. In the early 1990s, due to the severe situation of water shortage, Beijing launched the National Natural Science Fund project: "one of the key issues of water resources development and utilization in Beijing is rain flood utilization research". At this time the concept of urban rain and flood utilization was put forward. Research is now complete, but due to various conditions, there were no exemplary applications. At the beginning of the year 2000, with the support of the Sino-German International Cooperation Project and the Beijing Major Science and Technology Project, the project "Beijing Rainwater Flood Control and Utilization Research and Demonstration" was launched, and the first batch of urban rainwater control and utilization demonstration projects in China completed. Now, Beijing urban flood management has entered the stage of "combination of discharge and harvesting". As the first city in China to carry out research and application of urban rain flood utilization, the "combination of discharge and harvesting" of urban rainwater in Beijing has gone through four stages: exploration (1989–2000), research and demonstration (2000–2005), integration and initial promotion (2006–2012), and comprehensive promotion (2012–present). At the present stage of development, the main task is to improve the relevant policies and measures to further strengthen the mandatory use of urban rainwater. In the whole city's perspective, urban rainwater utilization will be comprehensively and profoundly promoted.

With the continuous improvement of the urban sewage treatment rate in Beijing, the problem of urban rainfall runoff pollution has become increasingly prominent. The effect of reducing and controlling the non-point source pollution of rain flood control and utilization measures is recognized and valued. In recent years, frequent urban rainstorms have led to waterlogging disasters, which have become the focus of attention of governments at all levels and the whole society in general. As an important measure for resource utilization and flood control, the effective use of urban rainwater is critical. Therefore, in order to solve the water resource problems faced by urban development, such as rainwater runoff pollution, urban floods, and water shortages, Beijing began to explore how to effectively reduce water pollution, floods etc., as well as the pattern in which the upstream and downstream and hydrological process was systematically managed. In other words, Beijing's rainwater management began to enter the "system management" phase, which is in line with the concept of "sponge city" construction.

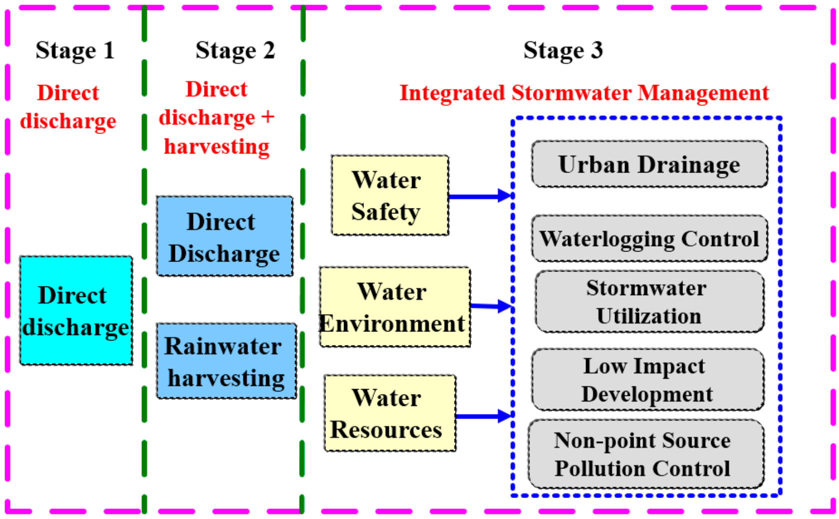

Figure 2. Diagram of Beijing urban rainwater management development.

The total amount of rainwater utilization in Beijing has been increasing steadily and the number of new projects each year increased from 129 in 2010 to about 169 in 2016. Comprehensive rainwater utilization capacity increased from 3300 million m^3 in 2010 to 4962 million m^3 in 2016. And the collection and utilization provided an important source of water for the lake and river environment, green land irrigation, car washing, and groundwater recharging etc. [12].

3.2. Status of Rainwater Management Technology

In addition to traditional drainage technology, rainwater management technology in Beijing is mainly embodied in rain flood control and utilization. After more than ten years of research, demonstration and application, Beijing has initially built a five-in-one roof green land-drainage-network and urban rainwater control system, which has been initially applied in residential, regional, and many other levels to reduce non-point source pollution and increase water infiltration [13]. Some technical measures have also been incorporated into the International Low Impact Development (LID) and have gradually become ecological and easy to use. Rain flood control and utilization at the residential level is organized into different blocks divided by urban roads. It includes mainly the basic measures for rainwater infiltration, collection and reuse, and discharge regulation [14]. Rainwater infiltration is a method allowing rainwater to penetrate underground through green spaces, permeable surfaces, and special infiltration facilities. Collect and reuse rainwater from roofs, roads, courtyards, plazas, and other undersides, irrigating green areas, flushing, car washing, landscape water supply, and road spraying, etc. Discharge regulations use storage facilities such as storage tanks, control facilities like flow control wells, and overflow weirs to keep rainwater in place in the pipeline and storage facilities in the appropriate position before rain is discharged from the area, then discharging rainwater to the downstream according to the flow controlled. In further research and application of urban flood control and utilization technologies, some new international ideas and technologies are gradually introduced and applied, such as best management practices (BMPs), low impact development (LID), and water-sensitive urban design (WSUD) and so on. A number of technologies that blend with the environment are formed, such as rain gardens, rain raised roof greening, road biological detention tank, dry pond, and wet pond, etc.

Rain flood control and utilization on a regional level is in municipal rainwater pipelines and river systems at all levels outside the city blocks. Since rainwater on the ground is discharged into municipal rainwater pipelines directly, runoff reduction and pollution control measures at the source of the residential rain flood control and utilization are often preferred, such as rainwater clean drainage and utilization technology in urban motor vehicle lanes. For rainwater in municipal pipelines and river systems, the following techniques can be adopted: separation and disposal of pollutants in municipal rainwater pipelines, rainwater storage technology in municipal pipelines, wetland regulation and purification technology before rainwater is discharged into river, regulation and utilization technology of rainwater in the public green lands along the river, rainwater infiltration increasing technology, utilization of sand and gravel pit to store and utilize rainwater in rivers, or real-time optimal operation and utilization of rainwater in urban rivers and lakes.

3.3. Status of Rainwater Management Policy

There are no special regulations on rainwater management in Beijing at present. Local regulations set by the operation of law can provide some guidance for urban rainwater management policies, such as "Water Resources Management Ordinance in Beijing", "Approach to Implement the Water Law of the People's Republic of China in Beijing", "Approach to Implement the Flood Prevention Law of the People's Republic of China in Beijing", "Approach to Save Water in Beijing", "Regulation of Drainage and Recycled Water Management in Beijing", and "Regulation of Soil and Water Conservation in Beijing". Particularly, "Regulation of Soil and Water Conservation in Beijing" issued by Beijing in 2015 put forward specific demands of rain control and utilization for all types of production and construction projects.

The Beijing Municipal Government has issued a series of official documents on the use of rainwater, such as the "Interim Provisions on Strengthening the Use of Rainwater Resources for Construction Lands" in March 2003; the "Beijing Water Conservation Measures" in October 2005; the "Key Points for Rainwater Control and Utilization of New and Reconstructed Projects (Temporary)" in August 2012; the "Notice on Printing and Distributing the Opinions on Further Strengthening Urban Rain and Flood Control and Utilization Opinions in August 2013, etc., which put forward the requirements for rainwater utilization or rain flood control and utilization, and promote urban rain flood management vigorously. In particular, a water impact assessment system of construction projects implemented in December 2013 made rainwater control and utilization indexes, which included layout and typical designs that corresponded to measures intended to uphold water and soil conservation schemes such as "Permeability rate of hardened ground", "Sunken rate of green lands", "storage modulus", "Permeability rate of hardened ground in pavements", and "permeable rate of side ditches". "The analysis and calculation of the influence of rainwater exclusion", "the analysis and calculation of waterlogging", "the evaluation of the rainwater exclusion influence" and "the evaluation of waterlogging influence" were listed in contents of reviewing flood impact assessments. Each contribute to the feasibility of sponge city construction.

From "The Comprehensive Planning of Water Resources Utilization in Capital in the Early 21st Century" approved by the State Council, Beijing has formulated the following documents: "Eleventh Five-Year Special Planning for Rain Flood Utilization of Beijing Water Affair Development Planning", "12th Five-Year Rainwater and Recycled Water Use Planning in Beijing" and four other municipal plans on urban rainwater utilization. There are also thirteen rainwater utilization planning documents for the district, county or regional level such as "Special Planning of Rain Flood Utilization on Beijing Economic and Technological Development Zone", "The Planning of Rainwater Utilization in the Central Area of the Olympic Park", "11th Five-Year Special Plan of Rainwater Utilization in Fengtai District", a series of local standards such as "Standard of Roof Greening (DB11/T281-2005)", "Content and Depth of Landscape Design Documents (DB11/T 335-2006)", "Technical Standard of

Urban Rainwater Utilization Engineering (DB11/T685-2009)", "Rules for Construction and Acceptance of Grounds with Permeable Bricks (DB11/T686-2009)", "Standard for Calculation of Storm Runoff on Urban Rainwater System Planning and Design (DB11/T969-2013)", "Design Code of Rainwater Control and Utilization Engineering (DB11/T685-2013)", and ten enterprise, industry or association standards such as "Sand Permeable Brick", and "Blocks with Silica Sand Well", and "Technical Rules for Silica Sand Rainwater Utilization Engineering".

3.4. Flood Preventive Measures

Beijing still lacks specialized prevention and control projects for urban waterlogging caused by the inadequate drainage capacity of storm sewers. However, the urban lakes in Beijing can retard and store the rain, which plays an important role in controlling waterlogging. Before liberation, there are many depressions and lakes that retard and store the rain in the urban water system of Beijing downtown, most of which are buried in the process of urban construction. According to statistics, the area of rivers and lakes buried reached 71.84 km^2. According to "Beijing Basic Data Handbook for Safe Flood Season" (2009), the area of urban rivers and lakes at present is 621.59 km^2. The total maximum capacity is 114.501 million m^3, and the total normal water storage capacity is 9,861,800 m^3, of which the effective water storage capacity is 1,677,300 m^3. At the same time, there are 355.8 kilometers of drainage rivers in the urban area. However, due to demolition and land acquisition, some rivers cannot be managed as planned.

3.4.1. Facilities for Drainage and Preventing Waterlogging

Drainage facilities includes sewage treatment plants (reclaimed water plants), network facilities, and pumping stations, etc. According to the results of the first water affair census in Beijing "Water Drainage Survey Results", there are 1108 sewage treatment plants in Beijing, of which 58 sewage treatment plants in the central urban area (including the new city) have a designed sewage treatment capacity of 3.735 million m^3/d. The total length of the public drainage network in Beijing is 11,619.88 kilometers. The rainwater pipe network is 4230.20 kilometers long, including 683.53 kilometers of integrated sewer network. Moreover, there are 167 drainage pump stations, including 133 public rain water pump stations.

3.4.2. Flood Prevention Projects

First of all, the city must have a system of flood prevention engineering for security. Beijing has a good system of flood prevention projects, including reservoirs, rivers, dikes, and flood detention areas, etc. There are 84 reservoirs in Beijing with a total capacity of 9.35 billion m^3, 210 locks on the river with the total water storage capacity of 80~100 million m^3, 256 small reservoirs with the total capacity of 8.3 million m^3, and 65 inflatable rubber dams with the total storage capacity of 70 million m^3. In the right bank of the Yongding River, a flood detention area—the Xiaoqing river flood diversion area—was built. Meanwhile, there are dikes of main rivers with the length of 429 km, the flood prevention standard is 20 to 50 years. The flood control standard of the Yongding River to the left bank of the Lugou Bridge is the maximum possible flood, which usually occurs during a perennial period.

3.4.3. Flood Hazard Mapping and Risk Management

The flood risk map is an important basis for "flood risk management". It is of great significance in regulating land use, formulating watershed or regional flood control plans, deploying non-engineering measures and engineering measures for flood control and disaster mitigation, and raising awareness of flood control and disaster mitigation among citizens. Therefore, the mapping of risk maps from "flood prevention" to "flood management" is an important basis and support for establishing risk management systems and developing flood risk management. At present, there are many studies on flood risk maps of basins in Beijing, but the flood hazard map system for an urban flood has not been fully established, especially for the waterlogging risk.

3.4.4. Non-Engineering Measures Based on Resilience

The non-engineering measures for flood control and disaster mitigation mainly include daily management and emergency response capabilities. For daily management, key measures mainly include strengthening public emergency management education, establishing an emergency response system that is led by the government, involving the whole society, public welfare and market-oriented enterprises; establishing a concept of flood coexistence and strengthening floods risk management concept; improving flood risk management processes, reducing the vulnerability of social and natural ecosystems, bearing risks, and standardizing and restricting the development, utilization and protection of flood risk zones based on flood disaster maps. Furthermore, it is also necessary to improve the ability of society to resist disasters and reduce disasters, strengthen social mobilization capacity, build with complementary strengths and positive interactions with social functions, give full play to the role of the market, society and citizens in flood control and disaster mitigation, adopt distributed data atlas, network communication, training and other measures to improve people's awareness of disaster prevention and mitigation, self-rescue ability, mutual assistance and crisis rational behavior.

In terms of emergency capacity building, it is essential to improve the real-time flood monitoring system, information sharing system, and flood disaster investigation and correction system, as well as dynamic early warning and forecasting, information release and dispatching systems to strengthen the collaboration and response speed between departments. In short, the timely release of waterlogging warning and emergency response information, in-depth and sustained emergency training and drills, attention to the particularity and operability of emergency drills, and specifying corresponding operational mechanisms before, during and after the event play effective guiding role in the emergency plan.

3.4.5. Emergency Response Mechanism

In 2013, Beijing established the "1 + 7 + 5 + 16" flood control system, namely the Beijing Municipal People's Government Flood Control and Drought Relief Headquarters, which established 7 special branches of propaganda, housing and construction, road traffic, urban underground pipelines, geological disasters, scenic spots and comprehensive support, 5 basin and 16 district-level flood control headquarters. During flood season, the command mechanism plays an important role and each sub-headquarters can perform respective tasks to effectively reduce the influence of rainstorm on social order and the production and life of residents [15].

The meteorological department monitors severe weather such as heavy rain, hail, strong winds, and thunder. The land department monitors areas threatened by geological disasters. The water department monitors the safe operation of flood control projects such as reservoirs, rivers, dams, and lakes, as well as precipitation data and hydrological information. Through the monitoring information, the city's flood control and drought relief headquarters, all branches, districts, counties, and units will conduct timely consultations to analyze the situation of flood, determine the possibility, scope, damage and impact of flood disasters, and then implement prevention measures and inform the relevant units of the results in a timely manner. According to the "Beijing Flood Control Emergency Plan (2014 Revision)", the Beijing flood warning response can be divided into three categories: rainstorm early warning response, geological hazard meteorological risk early warning, and flood early warning response. According to the severity and scope, it can be divided into IV, III, II, and I from low to high. After consultation with the municipal meteorological department, the land department, the hydrological department and the urban flood control office, the above-mentioned water level warnings are issued, changed, and deleted in blue, yellow, orange and red, respectively.

Above all, the core of sponge city construction is the scientific management of urban rainwater. When it rains, it can absorb water, store water, seepage water and clean water. When water is needed, the stored water can be "released" and used. At the same time, to ensure the safety of flood control in cities with large return period rainfall, and to minimize disasters when encountering super-standard storm floods. This part analyzes the construction of China's sponge city from the aspects of rainwater management research and practice progress, technology and policy status, and flood control measures. Although China has developed in areas such as policy, law, technology, human resources, industry, and investment mechanisms, it is still in the stage of germination and promotion, facing greater challenges. For example, the national norms and standards system is still not perfect; multiple departments fail to achieve unified and coordinated management, multi-disciplinary integration is difficult, and the talent team and industrial system gap is large.

4. The Vision of Sponge City Construction in Beijing

As the first city to adopt storm rain control and utilization measures, Beijing should innovate and lead the construction of sponge cities, breaking through the original ideas of urban rain flood control and utilization. The construction of sponge cities from multi-scale and multi-return period to manage rainfall runoff and prevent disasters has made Beijing a truly livable ecological sponge city with no fear of the storm, no flood, clear water, and green embankments. Therefore, the goal of the sponge city should be diversified and the measures should be more comprehensive and feasible.

There is a need to coordinate the relationship between sponge facilities, roads, green spaces, and water systems in the construction area, and formulate specific and feasible management measures. Therefore, in order to ensure the comprehensive benefits of the sponge city facilities, the sponge city construction requirements of the construction area, the new district, the park and the film district should be fully met. When the construction area of the newly built area exceeds 2000 square meters, the rainwater storage capacity in the hardened area shall not be less than 30 cubic meters per thousand square meters. There should be at least 50% sunken green space for stranding rain of green lands. The permeable pavement rate should be no less than 70% in buildings and residential areas, public parking lots, sidewalks, pedestrian streets, bike lanes and leisure squares, and outdoor courtyards. The old city should be combined with shanty towns, dilapidated buildings, and old districts to promote the city's overall management. For roads and squares, use permeable pavements in non-motorized vehicles roads and sidewalks of the newly built and converted roads should be incorporated. Permeable pavements are gradually promoted to use in squares and parking lots. Roads can make use of green belts to strand rainwater. Rain gardens, sunken green space, constructed wetlands or other ways can be used in parks and green lands to enhance the function of the sponge in the park and green land system, store rain in this and the surrounding region and purify rainwater quality. For the rivers and lakes system, strengthen the protection and restoration of natural forms such as ponds, rivers and lakes, and wetlands, maintain the connectivity of rivers and lakes natural water system, build a good urban water circulation system, and gradually improve the water quality and water environment. It is also necessary to recover deep pools, shoals and flood plains with ecological restoration to create a diverse living environment.

It is important to reflect upon and implement the concept of sponge city construction fully, and regard the volume capture ratio of annual rainfall as a rigid control index in compiling an overall plan, a regulatory detailed plan, and a municipal plan about roads, green lands, and water etc.

It is necessary to comprehensively consider the layout and space requirements of sponge facilities and scientifically delineate the urban blue line and urban watershed; sort out relevant urban construction standards and norms; propose and highlight the key content and technical requirements of sponge city construction; accelerate the preparation of Beijing sponge city construction plan, technical guide, and standard drawings.

One must establish a cooperation mechanism between government and social capital risk sharing and revenue sharing; encourage social capital to participate in the construction and operation management of a sponge city through business income rights, government procurement services, and financial subsidies, etc.; increase the investment in research and development of sponge city technology; support the innovation and application of new materials, new processes and new methods, the rational construction of sponge cities, and then provide scientific and technological support for the industrialization of sponge city construction and economic growth. At the same time, strengthen the construction of sponge city construction, create a good atmosphere for the construction of sponge cities, and then promote the broad support and active participation of the whole society.

5. Conclusions

Although in the construction of the sponge city Beijing made use of good theory and technology, engineering practices, management policies, technical standards and an industrial basis and has made some achievements, Beijing still has a long way to go to achieve its goal of building a harmonious and livable sponge capital. The main problems are as follows: Firstly, the urban flood hazard and water supply security situation are still grim; secondly, the contradiction between supply and demand of water resources is still very serious, and there is no fundamental solution to the problem of water shortage; thirdly, improving the water environment is more urgent; fourthly, the function of water ecological services is increasingly important. Therefore, we should establish a priority water-saving, space-balanced governance system, and comprehensively develop the construction of sponge cities. Under the background of the coordinated development of Beijing, Tianjin and Hebei, Beijing will become a world-class city with harmonious Chinese characteristics, ecology, and livability.

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