



Beijing:

Response to Urban Flood Disasters under Climate Change

Climate Risk and Resilience in China (CRR)



Project Overview

Name Climate Risk and Resilience in China

Commissioned by German Federal Ministry of Economic Cooperation and Development (BMZ)

The develoPPP project is jointly implemented by
GIZ and Swiss Re

Focus area

Climate Risk and Climate Resilience in urban centers and their rural surroundings in China

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Published by

Climate Risk and Resilience in China (CRR)

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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Introduction

Beijing, the capital of China and the largest city in the northern part of the country, is located in the northwest of the North China Plain and the east of the Yanshan Mountains, covering an area of 16410.54km². The permanent population of the city is 21.53 million, with an urbanization rate of 86.6%. Beijing has a typical warm temperate semi-humid continental monsoon climate, characterized by a multi-year average annual rainfall of about 626mm, among which 60% falls during the flood season (from June to September). In recent years, Beijing has suffered from severe floods caused by extreme rainstorms. Since 2013, Beijing has taken a series of measures in response to urban floods and has accumulated some successful experiences in the comprehensive response to urban floods. This case is a brief introduction about urban flood prevention under climate change in Beijing.

1. Extreme Rainfall and Flood Disasters in Beijing under Climate Change

1.1 Evolution of Rainfall in Beijing under Climate Change

Climate change has changed the global and regional water cycles. In some regions, the water cycle tends to accelerate, and the rainfall structure evolves and extreme rainfall becomes more frequent. In recent years, the rainfall characteristics in Beijing have changed significantly. Macroscopically, the rainfall in the flood season shows a downward trend, with a decline rate of about 8.2mm /10a^[1], while it does not mean the direct reduction of extreme rainstorms. The data analysis shows that the rainfall structure in Beijing has undergone major changes, which is mainly manifested by the increase of short-time heavy rainfall events, and the increase of rainfall uncertainty. In addition, the occasional occurrence of extraordinary rainstorms with the secondary rainfall of more than or close to 200mm has increased the catastrophic likelihood of urban rainstorms.

1.2 Flood Disasters Caused by Extreme Rainfall in Beijing

Over the past 20 years, heavy rains and floods have frequently occurred in Beijing during the flood season, some of which have brought about relatively greater impacts and losses. **Table 1** lists six typical flood disasters. From all the flood disasters with greater impacts, it can be found that, in addition to the heavy rainfall, the rainfall that causes severe

flood disasters is also characterized by a great rain intensity. Short-term strong rainfall makes it difficult for urban water to be removed in time. The main impact lies in the traffic disruption (**Figure 1**), which further affects the normal operation of urban economic and social life, and leads to direct or indirect socio-economic losses.



Figure 1a Scenes of Traffic Disruption Caused by Heavy Rains and Floods



Figure 1b Scenes of Traffic Disruption Caused by Heavy Rains and Floods

Table 1 Major Flood Disaster events in Beijing in the Past 20 Years^[2]

Date	Rainstorm Facts	Disaster Situation
July 10 th , 2004	The rainstorm happens once every 20 years, with a maximum rainfall of 22mm in 10 minutes and 90mm in 1 hour.	There were 41 road sections accumulating water severely, including 8 overpasses. Traffic disruption happened in the West Ring Road. Besides, water flew into over 90 places such as the underground shopping malls.
July 31 st , 2006	Rainfall in 1 hour in the Capital International Airport area got to 115mm.	The water under the Yingbin Overpass near the airport expressway reached 80cm, which cut the traffic of the airport expressway off for 3 hours.
August 1 st , 2007	Rainfall in 1 hour in the Anhuaqiao area of North Third Ring Road reached 91mm.	The deepest accumulated water in the urban area reached 2m, which interrupted the two-way traffic on the North Third Ring Road.
June 23 rd , 2011	The average and maximum rainfalls in the urban area were 73mm and 215mm respectively.	29 roads under the overpasses in the city broke off due to the water gathering. More than 800 cars were inundated.
July 21 st , 2012	The average rainfall in the city got to 170mm. In the urban area, the average and maximum rainfall were 215mm and 460mm respectively.	1.6 million people were affected, 63 roads were interrupted by water accumulation, 10,660 houses collapsed, causing a direct economic loss of 11.64 billion yuan.
July 20 th , 2016	The average rainfall in the whole city and the urban area were 210.7mm and 274mm respectively.	Measures such as unstopping at the stations, detouring, and pausing were taken on 164 bus routes; 212 flights of the Capital Airport were canceled.

2. Major Measures of Beijing in Response to Urban Flood Disasters

2.1 Response Idea and Principles

Response Idea: To minimize the damage to people's lives and property caused by flood disasters.

Basic Principles of:

- prevention-orientation and combining with disaster relief;
- combining daily disaster mitigation and emergency disaster relief;
- comprehensive planning, river basin integrated coordination, prominence to the key points and overall governance;
- attaching same weight on engineering and non-engineering measures;
- integrated planning of waterlogging prevention and disaster reduction, ecological civilization establishment and rainwater resource utilization.

2.2 Overall Response Plan

2.2.1 Overall Arrangement

The overall terrain of Beijing is high in the northwest and low in the southeast. There are four primary rivers passing through the central urban area, namely Qinghe, Bahe, Tonghuihe and Liangshuihe River. The main drainage channels of the central urban area of Beijing are based on those of the above four rivers. In combination with the western suburb rainwater storage project, urban underground drainage networks, rainwater pumping stations, storage tanks, and a deep tunnel drainage project, the plan is to form a drainage and waterlogging prevention system in the central urban area of Beijing, of which the western and eastern deep tunnels are part of the planning and demonstration process. The overall layout of the flood control and waterlogging drainage, which is said to be "drainage from the east to the west, flood diversion from the north to the south, and the deep stagnation of the two corridors," has been formed. In the above layout, combined with the reconstruction of key parts, such as overpasses, culverts, and waterlogging points, together with the construction of community sponge cities and the regulation and storage of green facilities, as well as the non-engineering measures such as urban flood forecasting and early warning measures, positive results of flood prevention and control in the central urban area of Beijing have been achieved^[3]. The overall project layout of flood control in the central urban area of Beijing is shown in **Figure 2**.

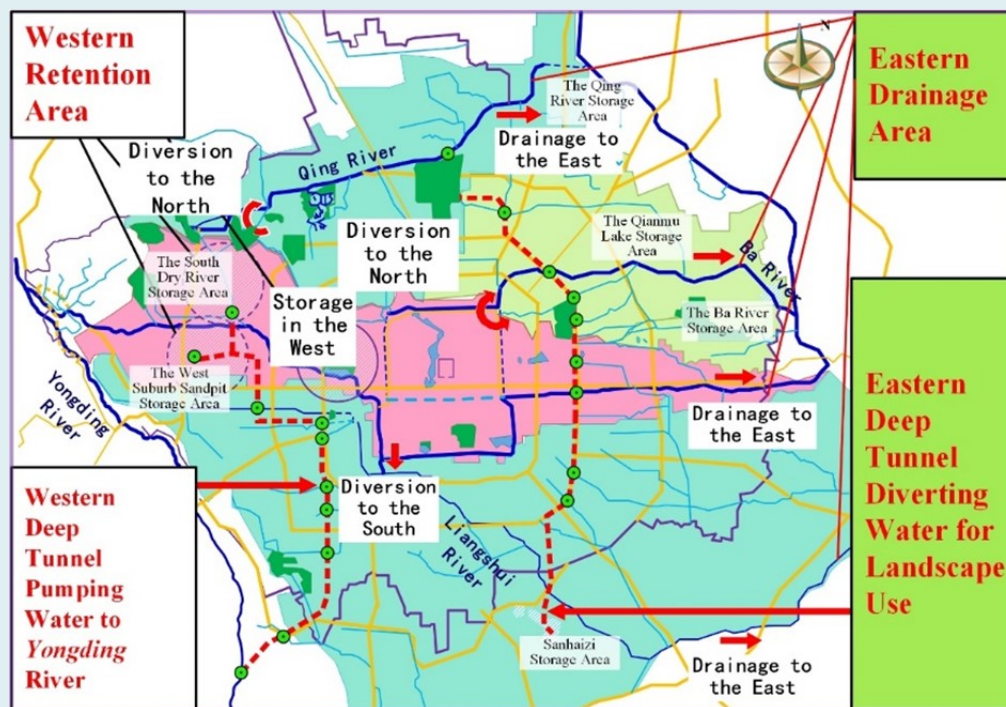


Figure 2 Overall Project Layout of Flood Control in the Central Urban Area of Beijing

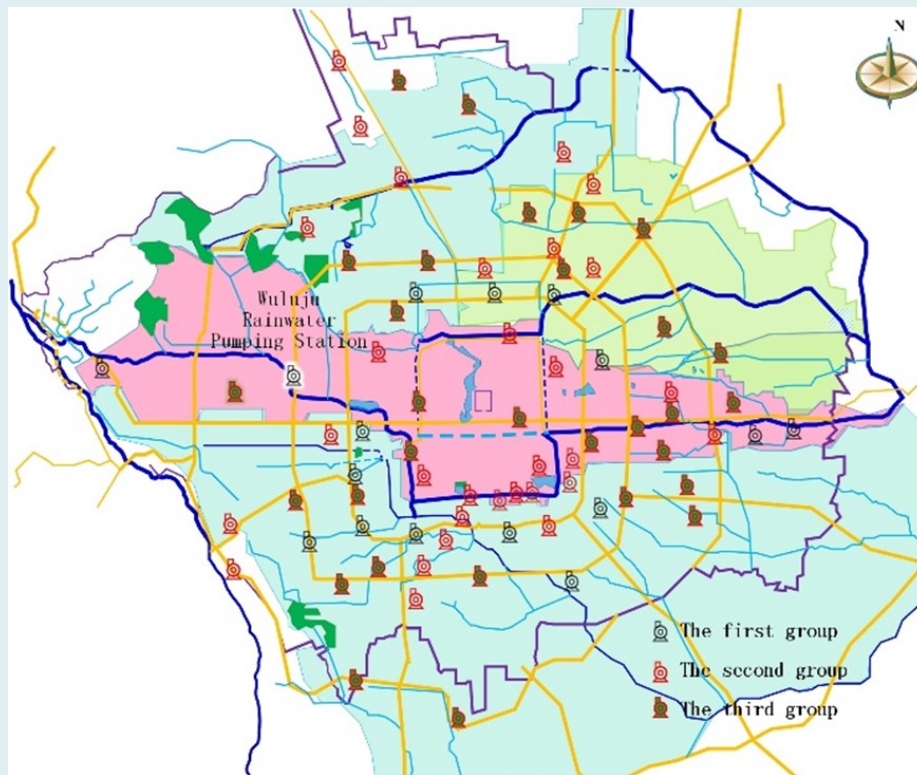


Figure 3 Schematic Diagram of Location of Rainwater Pumping Stations in Central Urban Area of Beijing

2.2.2 Upgrade and Reconstruction of Rainwater Pumping Station

According to Beijing's experience in flood prevention and control, low-lying roads, overpasses and road culverts are easy-to-flood points of urban floods, which can cause vehicle damage and casualties. The city mainly relies on pump station drainage and auxiliary storage tanks to store stagnant rainwater and relieve disasters. There are 192 rainwater pumping stations in Beijing with a total drainage capacity of 2.36 million m^3/h . Most of them were built in different periods together with the construction of roads or overpasses, whose design standards are different. There are 90 rainwater pumping stations in the central urban area, of which 4 of them (4%) are designed for rainfall only once a year, 81 of them (90%) are designed for rainfall once every 2 or 3 years, and 5 of them (6%) are designed for rainfall once every 5 years. However, in recent years, the frequency of heavy rains with an hourly rainfall of more than 70mm has increased, overwhelming most of the rainwater pumping stations. In addition, the runoff coefficient increases with the expansion of the hardened ground surface area. In the past ten years, the urban surface runoff coefficient has gone up from 0.55 to 0.63, an increase of 15%, which further increases the amount of

urban floodwater. In order to ensure the safety of the city, Beijing launched the "Three-year Action Plan for Renovation and Rainwater Collection of Rainwater Pumping Stations in the Central Urban Area of Beijing" in 2013. The plan aims to upgrade 77 overpass pumping stations that do not meet the requirements of the central urban area, including the transformation of the rainwater collection system, the expansion of pumping capacity of the water pump (total pumping capacity is expanded from 374,000 m^3/h to 718,000 m^3/h), the construction of 60 new storage tanks (new storage capacity of 210,000 m^3/h), and some drainage pipes. The goal of the implementation of the rainwater pumping station upgrade and reconstruction is to keep the main roads in the downtown area clear during the 10-year recurrence interval of rainstorms. In addition, supporting storage tanks have been built under greenbelts, parks, and parking lots. All the storage tanks mentioned above can collect rainwater for recycling^[3]. The schematic diagram of the location of the rainwater pumping stations in the central urban area of Beijing is shown in **Figure 3**.

2.2.3 Small and Medium Rivers Control Project

The whole area of Beijing (including the central urban area and suburbs) has a total of 425 small and medium-sized rivers with a length of 6,448km. These rivers are the “aorta” of drainage in Beijing. Once ruptured or blocked, it will cause flooding and inundating disaster on a larger scale. Small and medium-sized rivers without proper governance are usually polluted and destroyed and cannot be effectively drained. To solve this problem, Beijing released the “Beijing Water Conservancy Project Implementation and Construction Plan” in 2013, organizing to dredge and improve the channels extending to 1460km with a high flood risk, weak infrastructure, and large populations. The main measures include: dredging silt, removing illegal water-blocking structures, rationally connecting the rivers with the underground drainage pipes around them, and strengthening river embankments. After the implementation of the above measures, the flood control standards for small and medium-sized rivers have been raised from once in 5 years to once in 10 years or once in 20 years. There are four ways for small and medium-sized rivers to play the role of flood control and drainage: infiltration, storage, interception and drainage. The specific method to be applied depends on the local urban and rural layout, economic conditions and social environment. As for urban riverways, it is also necessary to deal with the relationship between sewage disposal and flood drainage^[3]. Runoff pollution from urban areas is taken away by rainfall erosion and waterlogging control. When it comes to the mountain rivers, it shall focus on the protection of villages and roads along the river, fully respect the local natural

landscape, and divert floods. Furthermore, river regulation also covers six tasks on the rivers themselves: (1) pollution control; (2) water connection; (3) South-to-North Water Diversion Project and groundwater recharge; (4) construction of flood storage and detention area; (5) water and soil conservation and afforestation in the plain area; and (6) green space construction and tourism development. **Figure 4** shows the comparison before and after the renovation of a section of a small and medium-sized river in Beijing.

2.2.4 Rainwater Regulation and Storage Project of Western Suburbs

A large part of the floods in the central urban area of Beijing originate from the mountainous regions in the west and flow into the central urban area. The general layout of flood control and drainage in Beijing proposes “storing in the west and draining in the east, and diverting from the north to the south”. Namely, before the flood flows into the urban area, a part of rainwater is stored in the west, some of which will be discharged to the south and north through the river channel, while the remaining part of the flood will enter the central urban area and be discharged to the downstream in the east through the four main river channels. In the above general layout, the specific measures to implement the “western storage” strategy is to build a rainwater regulation and storage project in the western suburbs. The rainwater storage project in the western suburbs is located on the north side of Shannan Road, Tiancun Village, Western Fifth Ring Road Area, Beijing, covering an area of about 165 acres. This site was previously a place for construction, sand, and gravel exploitation, which formed a gravel pit in the western suburbs since the sand mining was abandoned in the 90s and began to be a dumping area for construction dregs and domestic waste. Since the original sand gravel pit in the western suburbs was of the “sand-pit” structure, with good water permeability and low-lying terrain, Beijing planned to construct it as a rainwater storage project in 2014 and complete it in 2017. The finished water storage project in the western suburbs is able to accommodate 7 million m³ floods from a once-in-a-century rainfall of 27km² around the Yongyinqu Mountainous Area and the gravel pit of the western suburbs^{[3][4]}.

In addition to the function of rainstorm water storage, the rainwater storage project in the western suburbs is also featured with the controlled recharge of groundwater, ecological, sightseeing, and recreational functions, which has improved the ecological environment of the region. There are 8 lake regions, 6 terraced fields, and other sceneries in the project park. The green landscape accounts for 83% of the entire park area. More than 100,000 plants will create a scene of “florescent in three seasons and evergreen in four” in the park. In September 2019, the project park was officially opened to the public free of charge, creating a new model of opening up the water conservancy projects for the convenience of the people and sharing the ecological environment with citizens (**Figure 5**).



Figure 4a Comparison Before and After Renovation of A Section of A Small and Medium-Sized River in Beijing



Figure 4b Comparison Before and After Renovation of A Section of A Small and Medium-Sized River in Beijing



Figure 5 Comparison Before and After Construction of Rainwater Regulation and Storage Project in Western Suburbs

2.2.5 Early Warning and Emergency Control System for Urban Flood Disasters

In recent years, heavy rains have brought about huge human casualties and economic losses. In addition to the lack of engineering facilities, it also exposes some non-engineering issues such as weak flood control facilities, insufficient emergency equipment and reserves, lagging statistical reports, narrow warning coverage, imperfect command systems and poor knowledge among the public to the flood disasters. Summing up flood control experiences over many years, Beijing has established a "1 + 7 + 5 + 16" flood disaster warning and emergency control system^[3].

"1" is to strengthen the command effectiveness of flood control by establishing the Beijing Flood Control Headquarters. The entire flood control is set to be organized in a unified manner with the support of the Emergency Management Department while the deputy mayor works as the chief commander. Except for the necessary personnel and institutional improvement, the Flood Control Headquarters

has also established the Beijing Flood Control and Drainage Decision Support System which makes use of information technology to provide early warning and forecast of floods in Beijing, and provides such decision support services as solution deductions and flood simulations for flood control commands.

"7" refers to the establishment of seven branches in charge of specific areas such as housing construction, transportation, underground systems, geological disasters, tourist attractions, and information dissemination for flood prevention management and comprehensive support together with the coordinated response under the unified management of the Flood Control Headquarters. The Housing Construction Department is responsible for all structures, buildings under construction, and general underground facilities to safely survive the flood disasters; the Transportation Department takes on the duty to ensure the safety of roads and urban rails during heavy rain; the Underground System is tasked with the protection and emergency management of important power supply lines related to water, electricity, gas, and heating; the Geological Disaster Management department works for the flood prevention and control of geological disaster-prone and

mined-out areas; the Tourist Attraction Management Department is responsible for the flood prevention in the tourist attractions; the Information Service Department facilitates the raising of public awareness of urban flood disasters and improve education through media publicity.

"5" means to strengthen the protection and construction of the five relatively larger rivers outside the city. Beijing has established five sub-headquarters in the following river basins: Yongdinghe River, Chaobaihe River, North Canal, Qinghe River and Jihe River to organize the supervision of flood prevention and disaster relief.

"16" is to implement the administrative head responsibility system for flood control in 16 districts of Beijing. It is the Flood Control Headquarters at the district and county level that organizes and supervises all flood control and disaster relief work within the district and county.

Beijing has established a consultation system for the Meteorological Department and a press release system for flood seasons to standardize the issue of flood warnings during flood seasons. A basin collaboration system is established to help districts and counties in the same river basin unit jointly deal with flood disasters. As for key flood prevention targets, governments, industries, and operating units collaborate in planning, teamwork, safety measures, disaster relief, and the like.

Beijing has improved its supervision and accountability system. The officials who fail to perform their duties will be held accountable. The general principle is "command, dispatch and decide in a unified manner." Supervision shall be strengthened, and measures such as self-inspection and self-correction are to be taken. It is also of great significance to check the implementation of accountability, planning, teamwork, emergency supplies, safety measures, publicity, training, and drills. It is necessary to carry out flooding drills of different types and forms in various regions so as to strengthen emergency preparedness, accelerate the release of early warning information, and improve the operability of the flood control plan. Furthermore, the safety of emergency supplies and construction of necessary infrastructure should also be guaranteed.

Internet technology, Internet of Things, and smart water network technologies have also been applied in flood control and disaster relief in Beijing. A complete automated remote monitoring system for urban drainage infrastructure has been established. Strict hydrological monitoring of urban roads, blocks, lakes, and other water bodies are implemented. Furthermore, rainwater drainage pipes are also under supervision, which helps to provide knowledge about urban rainstorm and flood disasters in real-time. In addition, on the basis of monitoring facilities, a municipal flood control decision support system has been built to lay the foundation for emergency management and command and dispatch when a rainstorm occurs, which has greatly improved the efficiency and scientificity of dispatch and command.

2.3 Specific Cases of Typical Response Measures

Lianhuaqiao, located in Haidian District, is an overpass on the West Third Ring Road in Beijing. It is at the intersection of Lianhuachi West (East) Road and West Third Ring Road, which serves as an important passage to the Beijing West Railway Station. The total catchment area of the Lianhuaqiao area amounts to about 112,000m². The overpass was submerged in torrential rains in the flood seasons of 2004, 2007, 2011, and 2012. Among them, the deepest accumulated water in 2012 reached more than 2m, causing traffic interruption, which had a great impact on regional traffic. This situation is typical among all the waterlogging events happening on the Beijing overpasses.

The main reason for the water accumulation in the Lianhuaqiao area lies in the low-lying terrain. During the extreme rainstorms, all the rainwater in the surrounding area Lianhua Community and the northern part of the Lianhuaqiao flows into this area. However, the design pumping capacity of the pump station is only 4.1 m³/s, which means that the water accumulation speed as well as the amount of accumulated water far exceeds the pumping capacity of the pumping station, thus causing severe flooding and waterlogging. In the implementation of the "Three-year Action Plan for Renovation and Rainwater Collection of the Rainwater Pump Station in Beijing," the pumping station and its auxiliary drainage facilities in the Lianhuaqiao area were completely renovated to improve the flood response capacity of the area. The schematic diagrams of transformation are shown in **Figures 6 and 7**. The specific reform scheme is:

- a. Construct 4 new storage tanks in the green area on the south side of Lianhuaqiao overpass area. Storage Tank No.1 and No.2 are located in the green area in the southwest corner with an effective water depth of 4.6m, and an effective volume of 6079.3m³. Storage Tank No.3 and No.4 are situated in the green area in the southeast corner with an effective water depth of 3.0m and an effective volume of 5562.8m³. The total volume of the four storage tanks gets to 11642.1m³.
- b. Build a new drainage pump station with a flow of 26 m³/s. When the water level of the downstream river exceeds the flood elevation once every 20 years, and the water cannot be discharged by gravity, it is drained off into the Lianhuachi Pool through the drainage pump station.
- c. Improve the rainwater intake system of the main roads and auxiliary roads in the Lianhuaqiao Overpass area of the West Third Ring Road, change the rainwater inlet to a combined rainwater outlet, build a total of 601 rainwater outlets, and in the meanwhile, develop new rainwater outlet pipes, and raise the average diameter of nearby drainage pipes from 500mm to 1000mm.

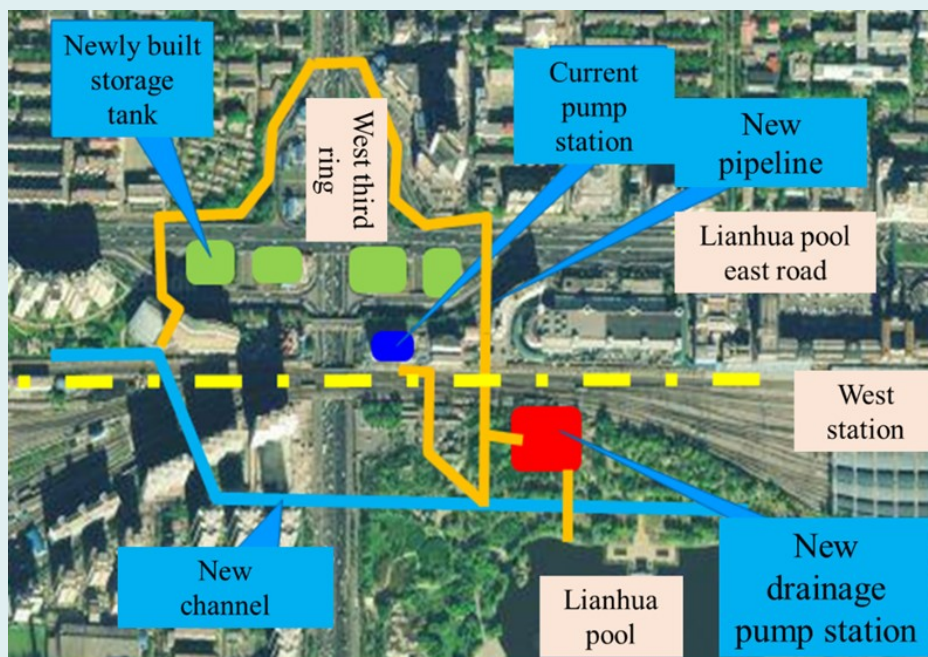


Figure 6 Schematic Diagram of Renovation of Drainage and Flood Control Layout in Lianhuaqiao Area

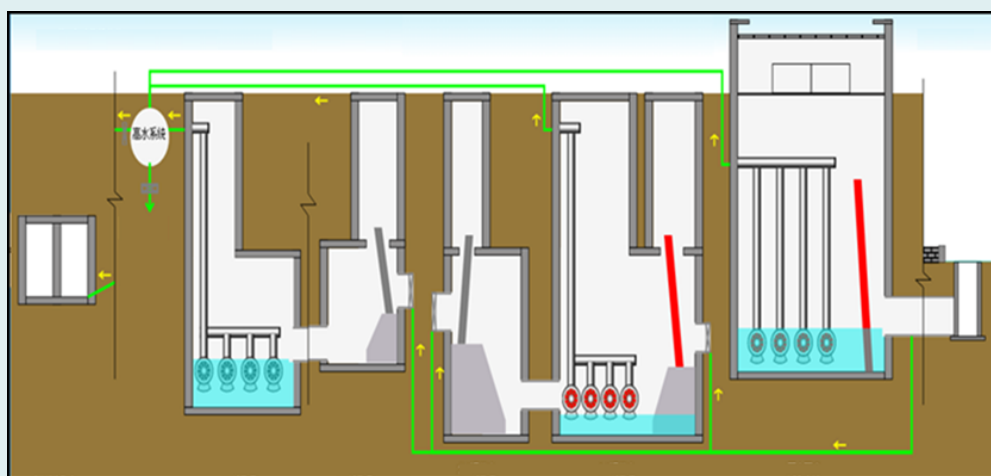


Figure 7 Schematic Diagram of Operation of "Pump Station + Storage Tank" System in Lianhuaqiao Area

On July 20, 2016, the rainfall monitored at the Lianhuaqiao Pump Station was 78.9mm. To avoid flooding and waterlogging, the "pump station + storage tank" system started operation. The cumulative pumping volume of the pump station and the water retention capacity of the storage tank amounted to 3,685.5m³ and 2,204.0m³ respectively. In total, the water discharge reached 5889.5m³. Data showed that the water storage capacity of 2,204m³ was equivalent to the accumulated water of 80cm depth in the Lianhuachi area,

which means that if water wasn't discharged from the pump station and stored in the storage tank, the rainfall probably would have caused waterlogging of 80cm depth on average, bringing about serious consequences such as traffic interruption. After the systematic transformation of the drainage system, road inundation in rainy seasons have been essentially eliminated in Beijing.

3. Investment and Financing Mechanism and Mode of Operation

3.1 Costs of Response Measures and Investment and Financing Mechanism

Due to the continuity and dynamic of the investment in flood control and drainage in the whole city, it is difficult to accurately estimate the cost. Below are the investment estimates of the comparison of the above-ground and underground schemes in the flood prevention and drainage planning of the central urban area as an example to roughly explain the relevant cost of response measures.

Urban flood control is a program for the public good to all the Chinese cities, which is funded by government revenue (**Table 2**). Taking Beijing as an example, the construction costs of flood control and drainage in Beijing are all borne by municipal finance, while 70% of the maintenance costs are borne by the municipal finance and 30% by the local government. It should be noted that in the past, part of the government's fiscal revenue was a "flood control fee" collected from the main market players (enterprises), but that particular revenue stream is no longer collected.

The maintenance of flood control and drainage facilities during the flood season is a professional matter. Beijing adopts the "government purchases service" method to purchase services from the "Beijing Urban Drainage Group Co., Ltd." (hereinafter referred to as Beijing Drainage Group) annually. The relevant costs are paid in full by government finance. Due to the big inter-annual changes in rainfall, the costs in different years may vary considerably. In actual payment, the Beijing Municipal Government will hire a third-party audit company to audit the rationality and details of the cost reported by Beijing Drainage Group to ensure that the purchased services of the government are economically cost-effective. At present, Beijing has not formulated a catastrophe insurance plan for flood disasters, or adopted multiple ways of financing, such as the PPP model.

3.2 Cooperation Mode of Stakeholders

In the investment, construction, and management of flood control and drainage, the stakeholders involved are mainly governments, enterprises, and individuals. As a facility investment and construction of public welfare, flood control and drainage construction usually do not have a clear direct beneficiary. The beneficiaries cover all stakeholders. The stakeholders of urban flood control and drainage construction are shown in **Table 3**.

3.3 Ways of Operation of Facility Maintenance

- a. **Implement unified dispatch and command of flood control and drainage.** The Beijing Municipal Water Affairs Bureau is bound to conduct the overall management for flood control and drainage projects. In response to flood disasters, the municipal government has established the Beijing Flood Control Headquarters, including several departments related to water affairs, urban construction, emergency response and meteorology. to achieve a unified command of flood response and exercise their functions of early warning release, flood control consultation, dispatch, and rescue.
- b. **Carry out "one river, one policy" for small and medium-sized rivers.** In the central urban area, corresponding management departments for Liangshuihe River, Bahe River, Tonghuihe River and Qinghe River have been set up, each of whom formulates their own response plan based on the characteristics of different rivers and implements the comprehensive management for the corresponding rivers with the authorization of the Beijing Water Affairs Bureau.

Table 2 Investment Budget Estimate for Flood Control and Drainage (Construction of Detention Storage Area) in Central Urban City of Beijing

Numbers of Detention Storage Area (places)	Volume of Detention Storage Water (in 10,000m ³)	Overground Storage Plan (in 100 million Yuan)			Underground Storage Plan (in 100 million Yuan)		
		Project Investment	Demolition and Occupation Fee	Total Investment	Project Investment	Demolition and Occupation Fee	Total Investment
41	1639.62	24.60	354.00	378.60	114.77	70.80	185.57

- c. **Put “one pump, one plan” for all drainage pump stations into practice.** Unified planning for the 192 “pump station + storage tank” systems in the urban area is implemented. Each “pump station + storage tank” system is a customized a plan for construction, management and dispatch individually, and each pump station is characterized by a scheduling plan for the rainstorms in different design recurrence intervals to ensure all pump stations to produce the best possible results.
- d. **Make use of information technology to support flood control decision-making. Beijing has established an urban flood warning and decision support system.** With the help of this system, the Beijing Flood Control Headquarters can respond to floods in Beijing in a unified manner, greatly improving the response efficiency, and the scientificity of decision-making.
- e. **Establish a professional enterprise for facility maintenance.** Beijing is mainly focused on supporting the development of the Beijing Drainage Group, a state-owned enterprise, which is a professional firm supported by the government and established in accordance with market

Table 3 Stakeholders of Urban Flood Control and Drainage Construction

Stakeholders	Specific Institutions/Individuals	Responsibilities or Duties
Government (Public Institutions)	Municipal Development and Reform Commission, Finance Bureau, Water Affairs Bureau, Urban-Rural Housing Construction Bureau, Meteorological Bureau, Planning and Natural Resources Commission, Municipal Landscaping Bureau, Ecology and Environment Bureau, Natural Resources Bureau, Civil Affairs Bureau, Information Office; People's Governments in all districts	Carry out planning and construction, engineering investment, emergency rescue, etc. related to flood control and drainage; direct the public's attention toward flood control and drainage affairs through publicity efforts, localized management and so on in daily life.
Enterprises (Legal Person)	Enterprises and institutions related to planning and design, project construction, investment and operation, construction materials, landscaping and gardening, water treatment, scientific research and the like; Beijing Urban Drainage Group Co., Ltd. and other franchise enterprises	With paying a certain "flood control fee", they can also participate in bidding competitions for project construction, project maintenance, equipment purchase, etc., making profits by providing services to the government.
Citizens	All residents of the city	The government takes part of their fiscal revenue from the taxes paid by individual citizens to work as the investment in flood control and drainage. In addition, citizens are also bound to comply with rainstorms and flood warnings in accordance with the law.

principles. Purchasing the services, the government realizes the routine maintenance and management in flood seasons of drainage infrastructure such as pump stations, dams, storage tanks, and pipe networks.

4. Main Effects and Benefits Achieved after Implementation of Measures

4.1 Main Effects: Event-Based Comparison

On July 21, 2012, Beijing had a sudden downpour whose average rainfall in the urban area reached 215mm, and the largest observed rainfall in the city amounted to 460mm. Rainfall in 1 hour was generally up to 40 to 80mm, and the duration reached 3 to 4 hours. This torrential rain caused such a large-scale disaster in the whole city that the traffic was almost paralyzed. Around 777,600 people were affected by the emergency; 95,900 people were transferred and resettled; 728 housing units collapsed, 44,000 seriously destroyed, and 121,900 generally damaged; 57,500 hm² of crops were affected, causing a direct economic loss of 11.64 billion yuan.

On July 19, 2016, there was another heavy rainfall incident in Beijing. The rainfall was characterized by a long duration, a heavy volume, and a wide geographical range. The total rainfall exceeded that of the July 2012 ("7·21" for short) storm. The average rainfall in the whole city and the urban area amounted to 210.7mm and 274mm respectively, and a total of 3.3 billion m³ of water was unleashed on the area. Although the total rainfall was greater than that of the "7·21" event, the heavy downpour did not cause as much loss, especially in terms of the overpass waterlogging. Due to the timely start of pump stations and storage tanks for rainwater regulation, there was no large area of water accumulating on the overpasses in the central urban area, and traffic wasn't interrupted for a long time. In the meanwhile, on account of the rich experience in response and accurate forecast of rainfall, a rigorous response plan was formulated before raining. This extreme storm and flood disaster did not cause casualties.

Through the comparison of the two extreme rainfall and flood disasters, it can be reasonably determined that after the implementation of the "Three-year Action Plan for Renovation and Rainwater Collection of the Rainwater Pump Station in Beijing" and the "Beijing Water Conservancy Project Implementation and Construction Plan" as well as the timely conclusion of the response experience related to urban flood disasters, great improvements and progress have been made, particularly in terms of response systems and mechanisms, flood prevention and drainage plans, personnel and material allocation, and water conservancy project scheduling. The urban flood disasters caused by extreme rainstorms are exerting a significantly weaker impact on the normal operation of the economy. The data clearly shows the disaster-hit area and the population affected are decreasing, and the floods bring about much less direct economic losses.

4.2 Benefits from Rainwater Utilization

Taking the rainfall on July 20, 2016 as an example, a total of 70 rainwater pump stations were operated by the Beijing Drainage Group. The total pump output and the overall storage capacity of the storage tanks reach 120,341,3m³ and 17,855m³ correspondingly. Most of the rainwater was used for ecology, river landscape, and municipal greening, among other things. According to preliminary estimates, the 192 pump stations and their storage tank facilities in the central urban area of Beijing have annual regulated storage of about 300,000m³ of rainwater in a normal year. This rainwater storage is used to shore up municipal water sources after being regulated and stored by the storage tanks. The raw water (untreated natural water) price is calculated at 0.5 yuan/m³. Therefore, the annual saving cost for replenishing water reaches 150,000 yuan or so.

4.3 Other Indirect and Comprehensive Benefits

The implementation of governance and management of the flood control and drainage project can also yield a variety of indirect and comprehensive benefits. Although they cannot be quantified one by one, they constitute an important part of the benefits which mainly covers the following:

- a. Reduced casualties and increased safety of urban residents;
- b. Reduced disturbance to social and economic activities and indirectly supported economic development;
- c. Stimulated market investment and increased economic development through engineering construction;
- d. Improved goodwill among urban residents to the government and maintained social harmony and stability;
- e. Improved the quality and increased the reputation of the city and promoted the attractiveness of tourism.

5. Highlights and Revelation of the Case

5.1 Beijing's Experience and Highlights in Response to Extreme Rainstorms and Floods

- a. **Plan as a whole in response to urban floods.** Urban flooding involves many aspects of the city, so it is necessary to make overall plans and arrange the urban flooding response layout based on the whole situation. In terms of spatial arrangement, Beijing has formulated the overall layout plan of flood control and drainage in the

light of its own topography and flood formation rules. That is to say, "drainage from the east to the west, flood diversion from the north to the south" which aims to disperse the floods and reduce the flood to "flow into the city" thus ensuring the safety of the central urban area. Regarding the response mechanism, Beijing relies on the Flood Control Headquarters and integrates the power of multiple administrative departments to achieve an all-round response to urban floods. Besides, it has formulated a strict plan, work program, and accountability system. All these practices make the response to urban floods no longer the business of a particular institution or department. Instead, a joint force has been formed to share the burden and realize the overall response to urban floods, which greatly enhances the city's own response capacity.

- b. **Develop personalized solutions to problems.** Urban floods have various patterns of manifestation in different domains. For example, the main problems of the riverways appear to be flood overtopping and dike breaching. As for overpasses, it is difficult to remove the accumulated water in time and, as a result, road interruptions are common. Therefore, on the basis of carefully sorting out the urban flood problems, Beijing has formulated personalized response plans for different types of problems. "One river and one policy" is implemented for small and medium-sized river floods, and corresponding management departments who have been authorized to carry out targeted management according to the actual situation are set up for the fore main river channels in the central urban area; with regard to the waterlogging and flooding of the overpasses, the strategy of "pump station + storage tank" is adopted, and the "one overpass, one plan" is formulated for different types of overpasses, which helps to implement the transformation, promotion, management and regulation pointedly. The above-mentioned targeted measures are problem-oriented and solve the urban flood problem one by one, which has achieved a very good effect.
- c. **Fully rely on science and technology to improve response capacity.** Urban flood responses, as a professional action, must depend on specialized knowledge to promote the urban flood response capacity, in which each step requires scientific and technical support. In terms of urban flood control planning, Beijing has formulated a scientific response strategy through scientific analysis of all storm and flood data; in urban flood forecasting and early warning, Beijing has carried out high-performance numerical forecasting for approaching rainfall. Furthermore, new technologies, such as the Big Data analysis, Internet of Things monitoring, have been applied to achieve a more scientific prediction of urban floods. With respect to urban flood dispatch and command, the Beijing Municipal decision-making support system for flood control and drainage has been built so as to achieve scientific decision-making on urban flood regulation with information technology.

5.2 Revelation of This Case to the Response to Extreme Storms and Floods

- a. **Respond to urban extreme storms and flood disasters in an all-round way.** The impact of floods caused by extreme rainstorms on society is comprehensive. Therefore, it requires integrating multiple forces to respond to extreme storms and floods in cities. At the same time, the response measures for urban flood disasters are also comprehensive and diversified. Both the engineering and non-engineering measures can be adopted. In the meantime, attention should also be paid to the comprehensive effect of the implementation of different measures. For example, the adoption of ecological measures to deal with floods can not only reduce the occurrence of flood disasters, but also protect the ecology and increase citizen's feeling of comfort, which plays a multi-faceted role.
- b. **Attach great importance to rainfall changes caused by climate change.** Global climate change and rising temperatures have changed the hydrological cycle, which has brought about significant changes in rainfall characteristics. Although in some areas it may appear that the total rainfall has decreased, there may be important changes in the rainfall structure, such as the increase in the frequency of extreme rainstorms in short durations, which may lead to more serious urban flood disasters. In addition, urbanization and urban construction itself may result in local, regional, and short-term climate variability. Superimposed with climate change in a larger background, it may make more complicated structural changes in rainfall. Therefore, the possible changes in rainfall caused by climate change should be fully paid attention to and studied in depth so as to take the initiative in urban flood response.
- c. **Raise the awareness of the whole society to deal with the urban flood risks.** Rainfall by its nature is uncertain, which makes the urban flood disasters unpredictable. Usually speaking, a huge investment does not necessarily bring huge profits. However, if the investment is insufficient, it may cause huge losses. In view of the uncertainty of flood disasters, the response concept needs to change from disaster loss mitigation to risk reduction, which means that great importance should be attached to reduce disaster risks by taking comprehensive preventive measures. Besides, the normal disaster alleviation needs to be taken as the basic work. It is essential to adhere to integrate the process of disaster prevention and relief, plan ahead and constantly work to enhance the society's ability to resist and respond to disasters.

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