Chapter 3
Urban Storm Flooding Management in Beijing

Jiahong Liu, Chaochen Fu, Chenyao Xiang, Hao Wang, and Chao Mei

Abstract Beijing is located in the piedmont plain of Taihang Mountains. It suffers from the floods formed in the Taihang Mountains as well as the local waterlogging. The precipitation in flood season (June to September) accounts for more than 80% of the annual precipitation, and it is often concentrated in late July to early August, which sometimes leads to serious urban flood disasters. For instance, in 1939 the precipitation in July and August was up to 1137 mm (recorded in Changping rain gauge); in August of 1963 the precipitation from 4th to 9th is more than 350 mm. Under the rapid urbanization in Beijing, the urban flood is becoming more serious, such as the pluvial disasters on 21st July of 2012. This chapter analysed the characteristics, evolution processes and main influencing factors of urban flood in Beijing based on the historical records. The four main measures of flood management in Beijing are summarized, which are: (1) upgrading and reconstruction of rainwater pumping stations; (2) improvement projects of small and medium rivers; (3) Sponge City construction; and (4) the West Suburb Storm-water Regulation Project. These measures have been put into use, and have played significant benefits on pluvial disaster mitigation in Beijing. On 20th July of 2016, the precipitation in urban area is 274 mm, which is more than that on 21st July of 2012, but there were no serious waterlogging events in urban area. In addition to early prevention measures, the flood warning and emergency management system has been established in Beijing.

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Beijing has also planned two deep tunnels to deliver overflowed rain water, which would greatly improve the defence standards of urban waterlogging in Beijing in the future. With the improvement of management and engineering measures, Beijing will be more resilient and safer under the heavy rains. The experiences of Beijing can also provide references for flood control in other cities.

Keywords Urban flood management · Extreme storm · Pluvial disaster mitigation · Beijing

3.1 Urban Storm Flood Events and the Causes in Beijing

Beijing is located on the northwest end of the North China Plain. The terrain inclines towards the northwest. It covers 16,400 km^2 in total, with the urban area of 1381 km^2 (approximately 8% of the total area). Five rivers flows through Beijing, namely the Juma River from the Qing River, the Yongding River, the North Canal, the Chaobai River and the Juhe River from the Jiyun River, all of which are parts of the Hai River Basin (Fig. 3.1).

In order to drain floods in the central urban districts of Beijing as quickly as possible, water bodies such as inner-city rivers or lakes are used for storage, and facilities such as water gates or dams are used for control (Xie 2014). The management

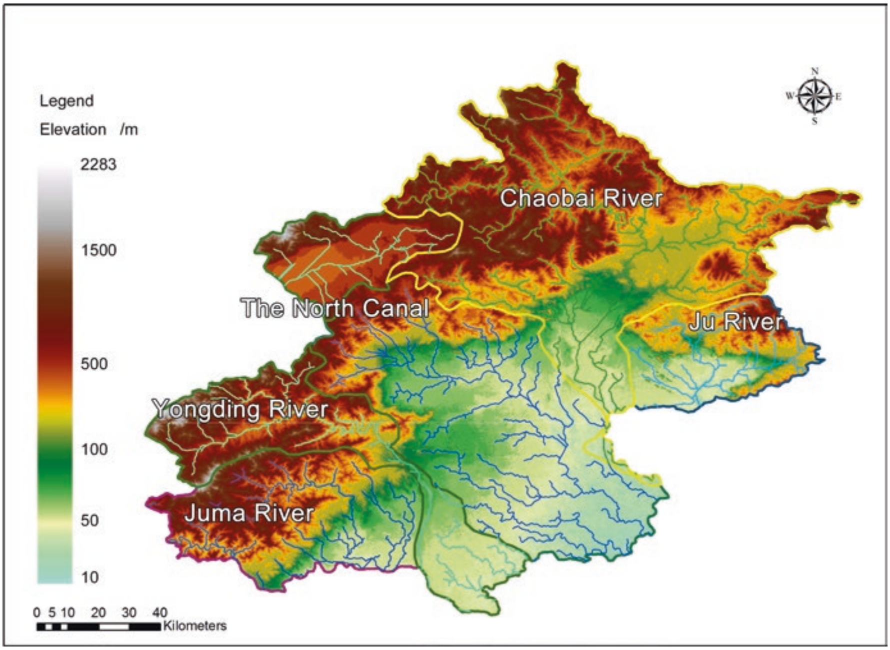

Fig. 3.1 Catchment division of Beijing

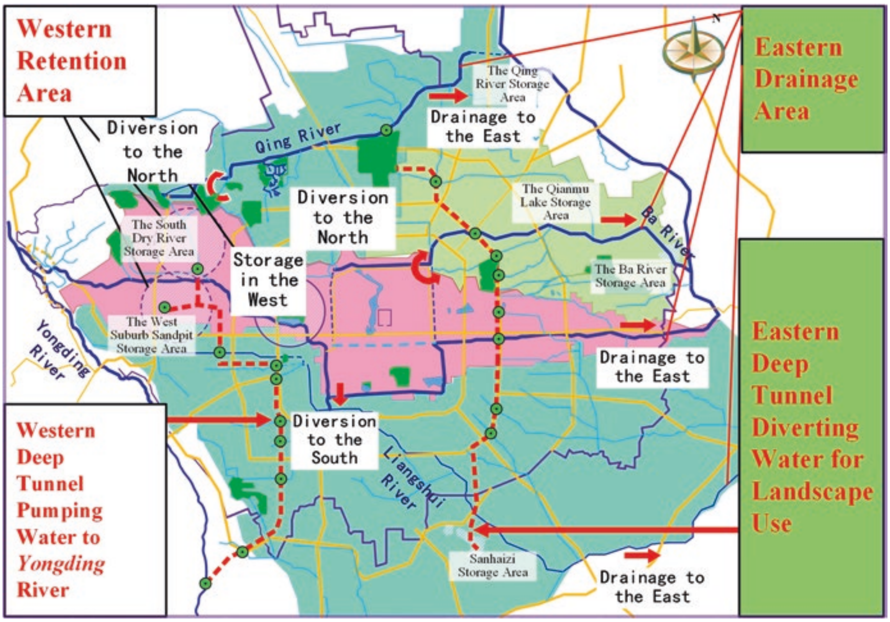

Fig. 3.2 The flood control configuration in the central districts of Beijing

protocol follows three principles: storage in the west, drainage to the east, and diversion in the north and the south. Storage in the west means that the flood waters from the upper region of the North Canal catchment are led to the creeks and lakes of the Yongding River in order to reduce the draining pressure on the midstream and downstream regions, and small floods in the Yongding River are retained by a reservoir before a barrage for recycling. Drainage to the east means that the flood from the upper and middle region of the city are led through creeks into the North Canal. Diversion to the south means that when the south moat is under full capacity, the rubber dam is filled and the sluice is opened so that the water flow is led via the Liangshui River to the North Canal. Diversion to the north means that when draining pressure is heavy in the northwest of the city, flood waters are diverted towards the northeast through three routes: (1) to the Qing River through three barrages; (2) to the Qing River through two creeks and one barrage, and (3) to the Ba River through one floodgate and one sluice (Fig. 3.2).

Beijing has a typical temperate continental monsoon climate, with uneven precipitation distribution. Precipitation in the wet season is over 80% of annual precipitation, and is usually brought by several storms between late July and early August. This climate is extremely likely to cause storm flood disasters, threatening economic and personal safety (Fig. 3.3).

The flood disasters brought by storms in Beijing can be classified into four types: (1) water logging disasters in urban areas, which includes fluvial floods, large scale water logging, traffic paralysis, old building collapse, water intake by underground

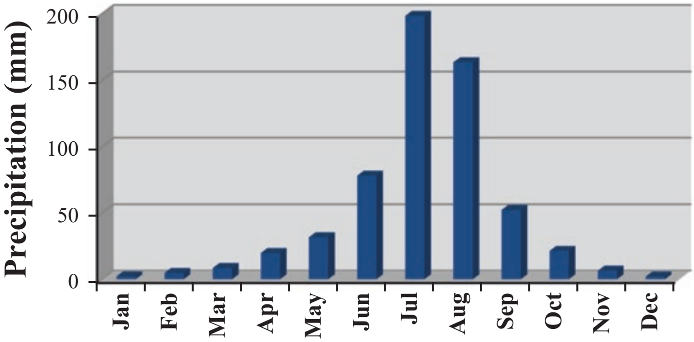

Fig. 3.3 Temporal distribution of the precipitation in Beijing

facilities, and related blackout and water cut-off; (2) flood disasters in reservoirs and big rivers, including piping, cracks, dam collapse, superflux, breach, inrush, river rise and other risks of important flood control facilities; (3) water logging in the outskirts and related secondary disasters, and (4) induced disasters in rural areas, including torrential floods, mudslide, landslide, ground collapse and so on.

3.1.1 The Extreme Storm Flood Events in Beijing

3.1.1.1 The Extreme Storm Flood Events in History

(1) 1939 Flood Event

The flood in 1939 is one of the greatest flood disasters in modern times in Beijing. The storm lasted for 30 days and severely flooded four inner-city rivers (namely, the Chaobai River, the North Canal, the Yongding River and the Qing River). On July 25th, the peak flow in the Yongding River reached 4665 m^3/s and several breaches were found downstream. The flood bent a railway bridge and surged over the Lugou Bridge, pushing down the stone handrail. On July 26th, the peak flow in Chaobai River reached 15,000 m^3/s. The flood ruined the railway bridge and roads, as well as the Suzhuang Watergate. All traffic was paralyzed. On July 27th, the North Canal, with a peak flow of 1670 m^3/s, was breached in the left dyke, and joined the Chaobai River. Based upon the analysis of peak flows, this storm led to an over-100-year flood in the Chaobai River, and 50-year floods in the Yongding River and the North Canal. This flood disaster was caused by three storms. The first was induced by two inverted troughs between July 10th and July 13th, falling mainly on the windward areas of the Tai-hang Mountains and west of Yan Mountain. The second, lasting from July 24th to July 29th, was induced by a typhoon landing on the Shandong Peninsula on July 24th and moved northwards. This storm mainly affected the Chaobai River, the Yongding River, the North Canal and the Qing River, and centered at the upstream of the North Canal and the valley area of the Yongding River. The last storm was induced by a low-pressure trough in the westerlies between August 10th and August 13th, mainly falling on the northwest region of Beijing. The total precipitation in July and August recorded was 1137.2 mm, which is the highest observed record in northwest Beijing.

(2) 1963 Flood Event

In the early days of August 1963, affected by a low vortex flow in the southwest, the Tai-hang Mountains in Hebei Province faced an extraordinary rainstorm. Between August 8th and August 7th, the precipitation in Xingtai reached 2051 mm (in which 1457 mm occurred in the last 3 days). Sicang of Baoding city received 704.3 mm of rainfall on August 7th alone, and the event is called "the 63.8 Storm". Beijing, which is encircled by Hebei Province, also suffered from a storm between August 4th and August 9th. The suburb area received over 300 mm of precipitation. There are five storm centers where daily precipitation was over 100 mm. This storm lasted a long time and was distributed unevenly, for example, between August 8th and 9th one storm center received 401 mm of precipitation in 24 h.

The 63.8 Storm raised the question of what could occur if a storm's center was in Beijing city center or upstream of the city, and how this could be handled. To better respond to flood disasters in Beijing's urban areas, Beijing Municipal Government raised the standards utilized in the 1964 Beijing Urban Flood Control Plan based upon investigations into the 1963 storm event. The Plan requires that designs for constructions relating to urban riverways must be able to withstand a 100-year flood event, and the drainage system a 20-year flood event, meaning that a 20-year flood event in the river should be lower than the tops of the inner main rain drainage outfalls to allow normal drainage. This standard still applies in the planning and regulations of constructions on the main rivers in Beijing.

3.1.1.2 Extreme Storm Flood Events in Recent Years

Since 2000, Beijing has suffered from several extreme storm events (Jisong et al. 2015). These events centered in a relatively small area, with high intensity and short duration. They paralyzed traffic, especially around concave flyovers. For a whole basin or the whole city, these events were only medium or large rain events, but by occurring in a single part of the urban area they caused enormous damage (Table 3.1).

Table 3.1 Extreme storm events in Beijing in recent years

Date	Depth	Duration	Consequences
2004.07.10–2004.07.11	53 mm on average, 159 mm at max	21 h	41 roads were heavily flooded, the highest ponding exceeded 1.7 m, 5 bungalows collapsed, 90 air defense fortifications were drowned.
2011.06.23	Maximum hourly rainfall 128.9 mm		Three deaths, 22 roads were paralyzed, 3 subway lines in danger, 1295 trees fell.
2012.7.21–2012.7.22	215 mm on average in urban areas, maximum daily precipitation 541 mm	19 h	Hourly precipitation exceeded 70 mm in more than 1/6 of the whole city.
			The peak flow in the Juma River reached 2570 m^3/s, and that in the North Canal was 1200 m^3/s. Several regions faced torrential floods of depth over 2 m.
			This storm caused 79 deaths. By July 28th, 1.19 million people were affected, farmland totaling 5.4 billion m^2 was damaged, 11.9 thousand houses collapsed, and 40 thousand cars were drowned.
			The direct economic loss reached 11.835 billion yuan.
2016.7.19–7.21	203 mm on average across the whole city, 274 mm on average across urban areas, the maximum depth was 422 mm	55 h	The total precipitation and duration both exceeded the 7.21 storm. Soil was waterlogged and fluvial floods occurred in several rivers.
			Ten districts, 97 towns and over 100 thousand people were affected. 485 breaches were found. 3394 houses collapsed. 21,380 ha of farmland were damaged. The direct economic loss was 2.15 billion yuan.

3.1.2 Characteristics of the Extreme Storm Events in Beijing

3.1.2.1 Frequencies of the Storms

Analysis on the frequencies of storms in Beijing region in the recent five decades shows the following (Fig. 3.4):

(1) Regional storms, which means that all areas in Beijing received over 25 mm rainfall within 24 h, occurred more frequently before 1980, happening 6–8 times annually; after 1980, the precipitation in Beijing region decreased notably, as well as the occurrence of regional storms, down to five times a year.

(2) In the recent decade, the storms in Beijing region have been showing new patterns. These storms are created by one single small-scale cumulonimbus cloud or a rain cell, and are concentrated on a small area. This weather is more random, and it appears/disappears very quickly, which adds difficulty to forecasting. These storms could easily cause local water logging and traffic paralysis.

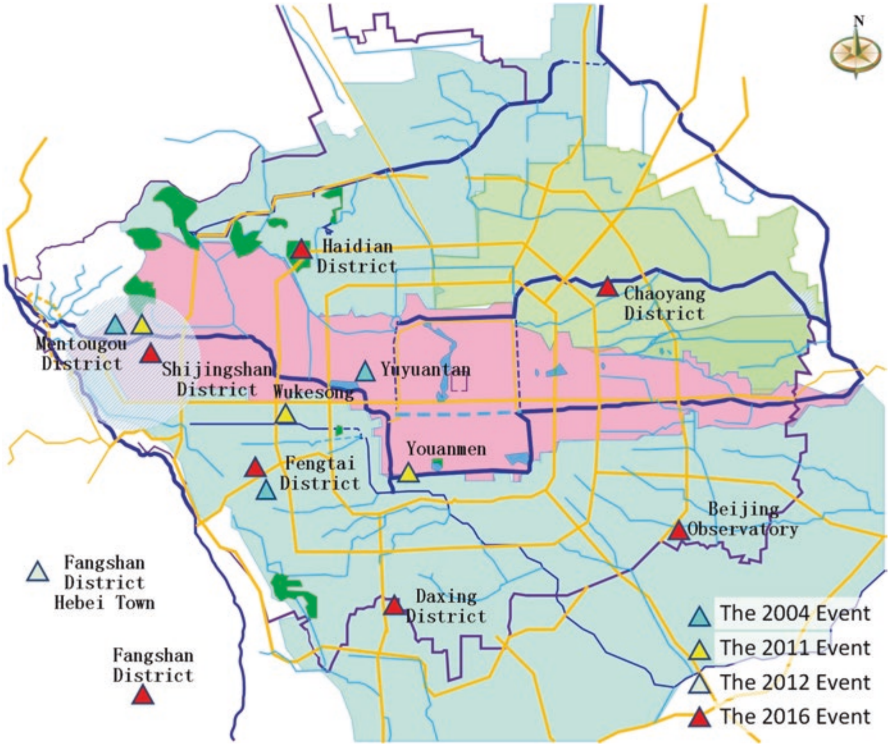

Fig. 3.4 Storm centers

(3) According to statistics from 2003–2012, the short-duration extreme storms that produced over 70 mm rainfall in 1 h happened 82 times in the last 10 years. This figure has tended to climb after 2000, along with the intensity of these storms (Fig. 3.5).

3.1.3 Causes of the Pluvial Flood Disasters in Beijing

3.1.3.1 Urban Development

Changes in land utilization in Beijing have significantly altered hydraulic processes, such as canopy interception, evaporation, transpiration and infiltration. Road construction has disturbed the natural surface draining system, and affected the runoff process. While urban impervious areas have expanded, grasslands, woods, farmland and water bodies have all shrunk. As a result, the runoff coefficient has increased. These alterations to the ground surface in Beijing's urban areas, and the new rainfall-runoff pattern accompany them, are important factors in the extreme storm-flood events (Wang 2011).

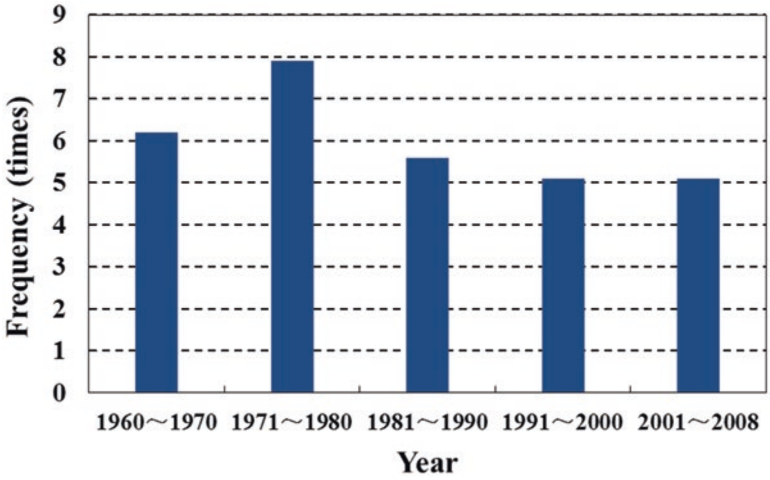

Fig. 3.5 The temporal trend of frequencies of storms in Beijing region

Table 3.2 Comparison of the flood events on “12.07.21” and “63.08.09” at the Lejia Garden Station

Event	Rainfall depth (mm)	Runoff depth (mm)	Runoff coefficient	Peak time (h)	Flood duration (h)	Peak flow (m^3/s)
63.08.09	359.1	187.3	0.52	20	44	261
12.07.21	197	106.4	0.54	7	16	440

According to statistical data, the impervious area in the central Beijing districts has increased from 60% in the 1960s to the current 85%, while the area of water surface decreased by 80 hm^2. This means that the natural water storage volume decreased by 400,000 m^3 for an average water depth of 0.5 m. The shrinking of water bodies directly caused a surface runoff increase and, consequently, greater pressure on urban pipeline systems.

Moreover, rapid urban development has caused a heat island effect in central Beijing, and in several big cities nearby. The strong thermal updraft confronts high-level cold air and creates rainfall that concentrates on urban areas. In comparison, the surrounding rural areas have received less rainfall.

Taking Lejia Garden Station on Tonghui River as an example, the flood events on July 21st, 2012 and August 9th, 1963 are compared in Table 3.2.

3.1.3.2 Low Flood and Drainage Standard in the City

Currently, the flood prevention standard of the whole city is to resist storms of a 200-year return period (mainly focusing on the Yongding River), and that of the four main inner rivers are the 20-year storm, the 50-year storm or the 100-year storm. However, for the basic hydrological units of urban catchments, such as residential quarters, rainwater drainers, roads and flyovers, the design standard storm is usually the 1-year storm event. For important roads, or areas where even short periods of waterlogging could cause serious damage (Liu et al. 2011), the design standard is usually the 3-year–5-year storm event, and for particularly important regions that is the 5-year–10-year storm event. If the intensity of a short-duration storm exceeds that of the 10-year event, i.e. precipitation exceeds 65 mm per hour, the urban drainage system would exceed its capacity and waterlogging would occur (Hou 2015; Suriya and Mudgal 2012).

3.2 Urban Flood Management in Beijing

The establishment of the flood prevention standard is a systematic issue. Firstly, the drainage system usually consists of subcatchments, rain grates, rain drainers, branch drains, main drains, riverways and pumping stations if the drainage area is low (Shi et al. 2006). Any problem in any part of this system can cause inefficient drainage or waterlogging in the system. Secondly, the drainage capacity depends upon that of the receiving river, which depends upon the capacity and conditions of the downstream river (Debo and Reese 2002).

The extreme storms in Beijing in recent years are typically short-duration, of high intensity and are concentrated, which brings new challenges to traditional urban drainage system. Therefore, reconstruction of drainage systems, storage infrastructures and riverways is needed in response to these new problems.

3.2.1 Upgrading and Reconstruction of Rainwater Pumping Stations

In Beijing there are 192 rainwater pumping stations, which are able to drain 2,360,000 m^3/h. These rainwater stations are mostly built along with roads or flyovers in different periods, so they were designed according to very different standards. For example, 90 rainwater stations are in the central districts. Four stations (4%) among them are designed for 1-year rain events; 81 stations (90%) are designed 2 or 3-year rain events, and five stations (6%) are designed for 5-year events. However, in recent years the storms that produce over 70 mm of rainfall per hour occur more frequently, and most stations are overwhelmed.

In addition, the runoff coefficient has increased along with the expansion of hard ground. In the last 5 years, the urban surface runoff coefficient has increased by 15%, from 0.55 to 0.63. Catchment areas, especially around flyovers, are flooded and face waterlogging as water exceeds the capacity of water pumps.

To secure the safety of the city, Beijing launched the "Three-year Project of Rainwater Pumping Stations Upgrading and Rainwater Harvesting in Beijing Urban Districts" in 2013. The project has upgraded 77 pumping stations at low-ground

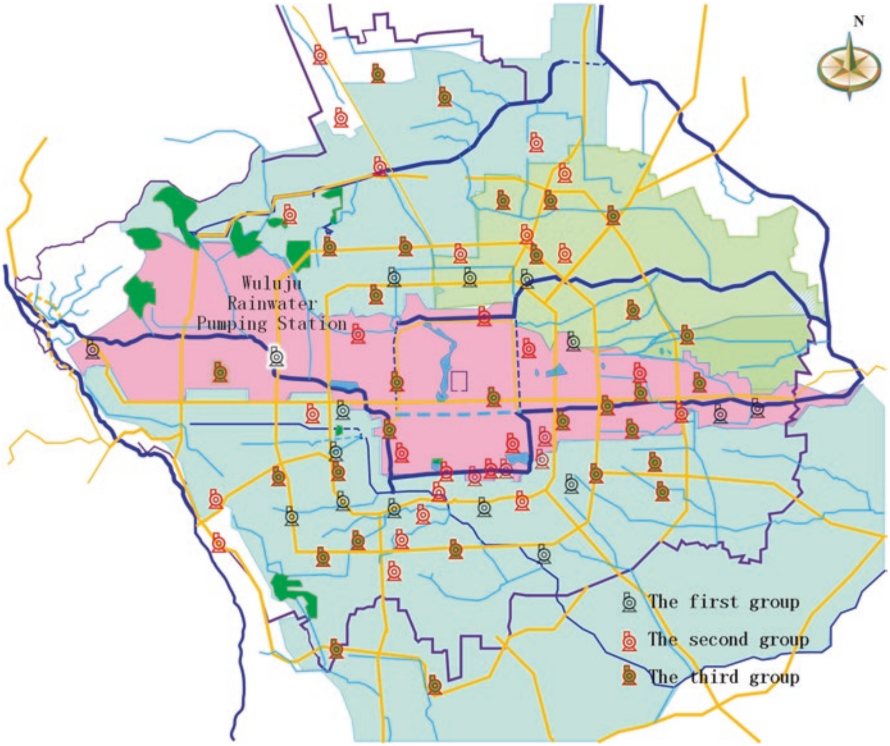

Fig. 3.6 Rebuilt pumps in Beijing central districts

flyovers in different groups. The project reconstructed rainwater harvesting systems, enlarged water pumps (enlarging the total pumping capacity from 374,000 m^3/h to 718,000 m^3/s), built 60 new storage tanks (creating 210,000 m^3 of storage volume) and drainage pipelines. The goal of implementation is to keep the main roads clear under 10-year storm conditions. In addition, new storage tanks built under greenbelts, parks and parking lots can harvest rainwater for recycling (Fig. 3.6).

Example: Upgrading in Wuluju Rainwater Pumping Station

The Wuluju Rainwater Pumping Station Upgrading Project has been finished and is ready to be used. This project included rainwater harvesting system reconstruction, water pump enhancement, new storage tank and drainage pipeline construction. As the upgrade projects of rainwater pumping stations were usually at corners of districts or busy traffic spots, the construction sites were very limited. To deal with this problem, pipe-jacking construction was applied. Two pipes of 3 m diameter, 150 m length were set as storage tanks, able to store 2090 m^3 of water. This method significantly reduced the work of land requisition and saved on costs (Fig. 3.7).

Fig. 3.7 A 3 m-diameter drainer and storage tank at the Wuluju Rainwater Pumping Station

3.2.2 Improvement Projects of Small/Medium Rivers

There are 425 small/medium rivers totaling 6448 km in length in Beijing. The ungoverned rivers were usually polluted and unable to drain efficiently. To deal with this problem, Beijing announced the "Beijing Implementation and Construction Plan for Hydraulic Engineering" in 2013, organizing the dredging and improvement of 1460 km of river channels where flood risks were high, infrastructures were weak, population was large or there were important objects. Riverways were properly connected to surrounding underground drainage pipelines, improving the flood prevention standard from being under the 5-year event to being over the 10-year event or 20-year event.

There are four approaches to the management of small or medium rivers: infiltration, storage, retention or drainage. The specific method used depends on the local urban-rural layout, the economic conditions and social environment. The primary problems with urban channels are the disconnection of water bodies and pollution. For plain rivers, managers should build water networks based on natural conditions. For rivers in mountainous regions, the villages and roads along the rivers should be key focuses for protection, and flood water should be channeled out with full respect to the local natural landscape.

Moreover, riverway management should be consistent and integrated with six tasks: (1) pollution control; (2) water body connection; (3) the South-to-North Water Diversion Project and groundwater recharge; (4) the construction of flood detention and storage areas; (5) water-soil conservation and afforestation of plain regions, and (6) greenbelt construction and tourism development (Fig. 3.8).

Fig. 3.8 Construction sites

3.2.3 Sponge City Construction

The construction of sponge cities is comprehensive, systematic engineering. It involves Low Impact Development, drainage and flood prevention, rainwater reuse, groundwater restoration, flood disaster relief and other fields. It requires taking precedence over rainwater harvest and using natural routes to drain rainwater, to purify rainwater or to allow infiltration when improving urban drainage systems. In the philosophy of sponge city construction, the impact of urban development on the ecological environment should be minimal. The aim is to avoid waterlogging and pluvial flood disasters in non-extreme rain events, to clear malodorous, black rivers, and to relieve the urban heat island effect (Liu 2016).

For a sponge-city built-up region, no less than 70% of annual precipitation should be retained or reused locally (Ning et al. 2017). For instance, urban green spaces should be able to absorb all the rainwater falling onto them, and take in the surface runoff from surrounding impervious areas to their maximum capacities (Zhang et al. 2014; Shao et al. 2016). Roads and plazas should collect, purify and reuse rainwaters, lifting pressure on the drainage system. By 2020, the sponge-city region should account for 20% of the built-up area of Beijing, and 80% by 2030. New constructions or districts should be planned and built to the sponge-city standard, while old urban areas should be transformed gradually (Fig. 3.9).

3.2.4 The West Suburb Stormwater Regulation Project

The West Suburb Sandpit Construction was one of the key elements of the flood prevention regulation of Beijing's central districts. Water division by a control sluice ensures drainage in three catchments totally approximately 27 km^2 under 100-year storm conditions. Construction included the sluice and two buried culverts that connected to two sandpits individually. The larger sandpit is 680,000 m^3 and able to contain 700,000 m^3 water (Figs. 3.10 and 3.11).

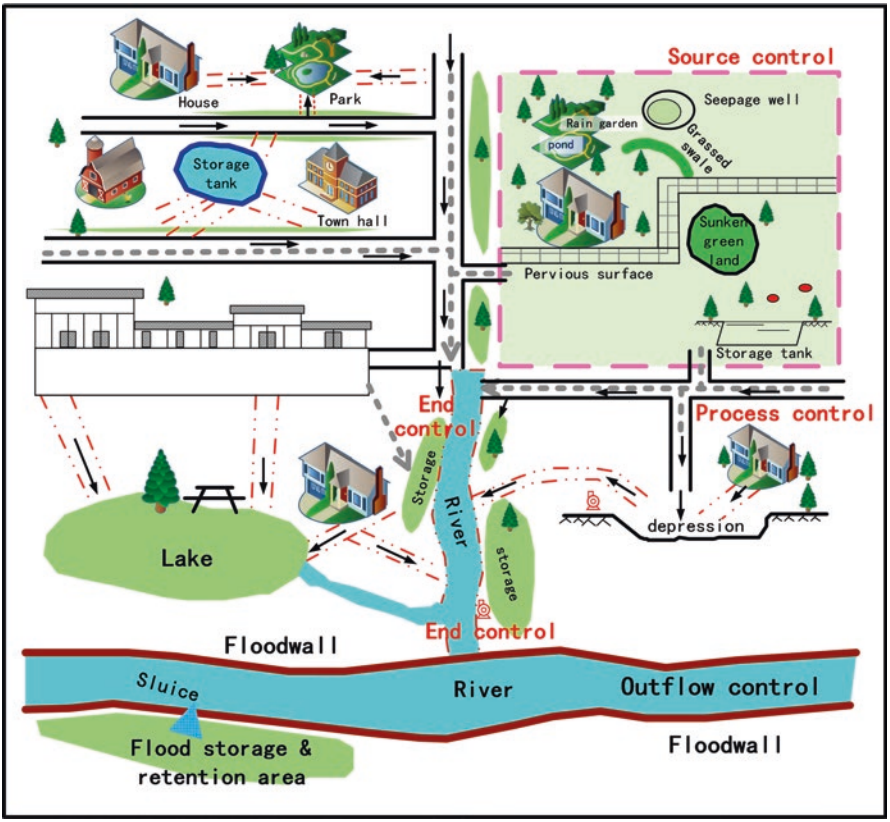

Fig. 3.9 Approaches of sponge city construction

3.3 Urban Pluvial Flood Warning and Emergency Management

Storms in recent years have brought extraordinary number of casualties and economic loss, which has exposed problems such as weaknesses in flood prevention facilities, a deficiency of equipment and stocks for emergencies, late statistical reports, narrow warning coverage, defective command systems and people's weak awareness of flood disasters (Wang et al. 2017). Learning from experiences, Beijing established a new flood prevention command system called "1 + 7 + 5 + 16".

The "1" means strengthening command effectiveness over flood prevention work. Beijing established the flood prevention headquarters to organize the entire flood response operation, with the deputy mayor taking charge.

The "7" means establishing 7 branch units to manage flood prevention in specific fields, namely publicity, housing and construction, traffic, underground systems, geological disasters, tourist attractions and integrated support. The housing and

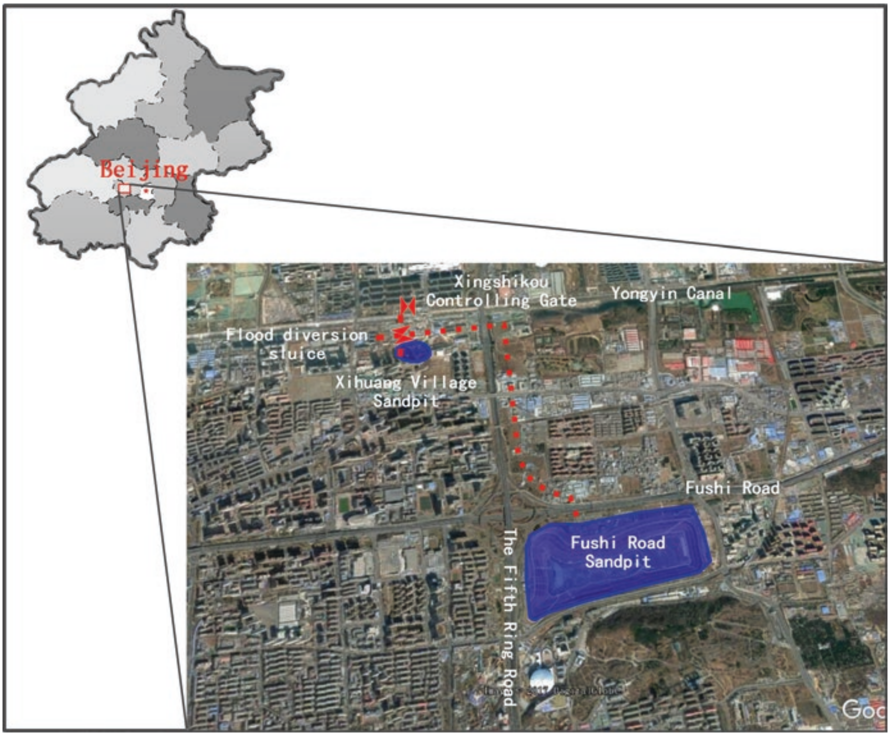

Fig. 3.10 Layout of the West Suburb Sandpit Project

construction branch helps all buildings, ongoing constructions and general underground facilities through floods safely. The traffic branch guarantees the safety of roads and urban rails during storms. The underground system branch focuses on protection and emergency management for water, electricity, gas, heat supply and other vital supply lines. The geological disaster branch takes charge of precautions and control over areas liable to geological disasters and goaves. The tourist attraction branch takes charge of flood prevention at tourist attractions. The integrated support branch organizes and coordinates all the branches in general. The publicity branch improves public awareness of urban flood disasters and related self-rescue education.

The “5” means strengthening protection construction along 5 main rivers. Five command offices have been established for organizing and supervising the flood prevention, emergency rescue and disaster relief work in the Yongding River catchment, the Chaobai River catchment, the North Canal catchment, the Qing River catchment and the Ji River catchment.

Fig. 3.11 Before-and-after comparison of the West Suburb Sandpit Project

The "16" means placing responsibilities on 16 county administrative chiefs. The county command offices organize and supervise all flood disaster prevention and response work within the county boundary.

Flood control discussion and announcement protocols were also improved. The discussion system with meteorological departments, and a flood season news release system, were established to normalize flood warning announcement work (Henonin et al. 2013). A basin cooperation system was established to help counties in the same basin unit deal with flood disasters together. For key targets of flood prevention, governments, industries and operation units should collaborate on planning, teamwork, safety measures and disaster relief (Rosenthal and Kouzmin 1996).

Army and armed police forces should also be united on flood control work, especially in extreme events. The supervisory work and the responsibility investigation system should be improved. Officers who do not perform their duties should be called to account. The principles are “unified command, unified dispatching, unified decision making”. Oversight should be strengthened and measures such as self-examination and inter-checking should be taken. The implementation of responsibility systems, planning, teamwork, emergency commodity, safety measures, publicity, training and exercise should be checked (Petak 1982). Flood drills of different types, patterns and in different regions should be carried out. Emergency precautions should be improved. The release of warning information should be enhanced, and the flood response plans should be operable (Apel et al. 2006). Emergency commodities should be secured and necessary funding guaranteed. The operation and maintenance of hydraulic engineering facilities should be ensured.

Internet technology, the internet of things, and the Intelligent Water Network were also applied. Automated remote monitoring systems were built for urban drainage infrastructures. Dense hydrological monitoring on urban roads, blocks, lakes and other water bodies, as well as monitoring over rainwater drainage pipelines, enables real-time knowledge about urban storm and flood disaster conditions, which is the basis for quicker emergency management (Fig. 3.12).

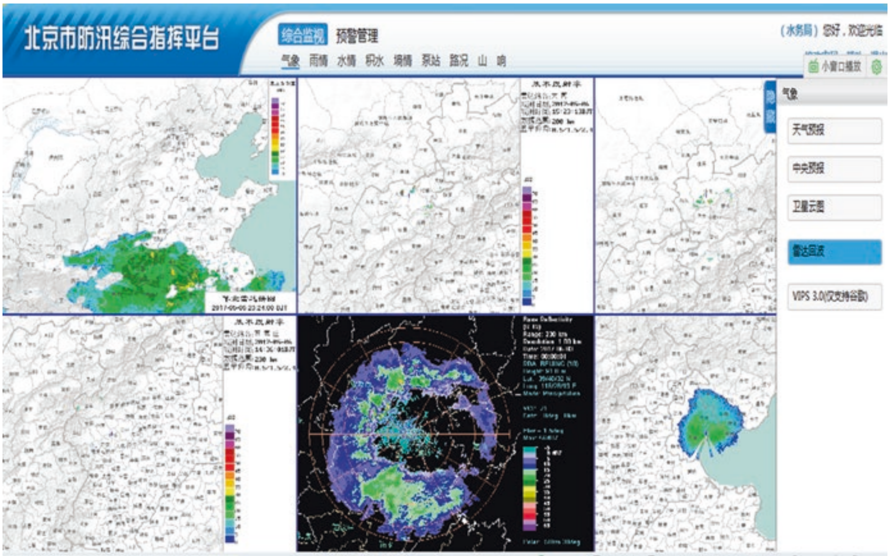

Fig. 3.12 Beijing flood control command platform

3.4 The Prospect of Urban Flood Management in Beijing

Flood prevention in Beijing is related to the reform and development of the capital of China, so it is particularly important to improve the quality of flood control work.

3.4.1 Further Improvement of the Flood Control Management System

Firstly, Beijing should strengthen the "1 + 7 + 5 + 16" command system to realize the river basin management. It is also important to implement monitoring and communication mechanisms. To achieve that goal, Beijing will improve the system and regulation protocols.

Secondly, the work of flood prevention management should be divided and classified. Both normal and emergency working systems should be established, standardized and institutionalized.

Thirdly, Beijing's rescue teams should be more specialized and professional. Meanwhile, social volunteers should be united, establishing a linkage mechanism.

3.4.2 Further Improvement of Flood Control Plans

Firstly, risk assessments should be conducted for key areas. To secure the safety of people and transport facilities, risk assessments should be conducted at weak spots, especially overpasses and underground spaces.

Secondly, linkage mechanisms should be built between departments, especially for the management of emergencies in public places, such as the main transport stations, airports and train stations (Yajie and Su 2005). If there are large quantities of passengers stranded in those places, related departments are responsible for taking steps to resettle passengers.

Thirdly, supervisory mechanisms should be developed. The responsibility system is such that the head of the department is the first person responsible. The execution of flood control plans and emergency response should be specified, insuring the measures and information can be transferred to towns, sub-districts, villages and people.

Fourthly, professional plans for flood regulation should be improved. The detailed regulation mode for regional rainfall or medium/small rains should be developed. The plan's foundation is risk assessment; its basis is hydrological forecasting and its measure is a scheduling model. Beijing should make an elaborate scheduling model for the water systems' connecting rivers and lakes, and also develop emergency measures for floor drains.

3.4.3 Further Strengthening the Flood Warning System

Firstly, the system of warning dissemination should be improved, including its targets, standards, the programs, region identification and content. Beijing should build a joint work system and develop regulations for disaster prevention. It is important to guarantee the efficient co-operation between departments.

Secondly, the government should further mobilize society. Governments at all levels should intensify their efforts and clarify responsibilities in aspects such as publicity of warnings and disaster relief knowledge, the government order, job deployment and media announcements. Weather, land and traffic management information should be integrated to realize the publication of all-around and multi-channel warning information.

Thirdly, the ways in which warning information is transferred to the public should be diverse. Radio, television, websites, newspapers, microblogs and mobile phone messages should all be utilised. Warning information messages should also be easy to understand. Beijing will comprehensively improve the capacity, timeliness and coverage of the flood warnings release. Before the advent of disaster, the warning messages will be transferred to every citizen.

Fourthly, the research on flood control should be conducted, to improve the judgment of magnitude and risk of storms (Local Capability Self-assessment and Accreditation Tool, Florida Emergency Preparedness Association 2002). Weather forecast and discussion work should be reinforced, especially for the risk assessment on all kinds of rainfall regime, to deploy flood control work and the rescue force easily. In a word, more research should be conducted on the patterns of heavy rains and floods, realizing the more elaborate and precise warning system.

3.4.4 Further Strengthening Social Management and Public Awareness of Flood Prevention

Urban flood control is not only a technical endeavour, but also involves social management. Social management and education to increase public awareness of flood prevention should be directed to all citizens.

Firstly, all members of society should pay more attention to flood prevention and flood control. Governments should give positive guidance to let all sectors take part voluntarily. The popularization of knowledge of flood control and disaster relief is also very important. The main point is to enhance: the risk aversion ability and self-rescuing ability of the public; the ability of staff to deal with emergency situations; the commanding ability of new leaders; the degree of cooperation between sectors, and the emergency capacity of rescue teams.

Secondly, the standard mechanism of social management should be developed and varying contingency plans should be created. Effective cooperation should be achieved. Flood drills should be normalized and popularized. Governments should build volunteer teams and try to cover all counties and villages. The volunteers should be trained systematically under the guidance of professionals.

Thirdly, particular attention should be paid to publicity and education, increasing public awareness of flood prevention and disaster relief. The self-saving awareness and ability of citizens, especially students, mountain villagers, people in rural-urban continuum, outlanders and migrant population, should be improved.

Fourthly, posters, brochures, public service advertisements, the internet, microblogs, radio, television, street newspapers and billboards should be utilised to disseminate knowledge of flood prevention and mitigation (Tedim and Carvalho 2010). Every company, school, scenic spot, village, community and family should be reached. Knowledge of flood prevention and safety should be communicated in the squares and streets, to reach every family and every citizen.

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