The Optimization of Flood Control Man-Made Channel Systems in Northwest Beijing: Responding to the Challenges of Climate Change and Extreme Weather

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Abstract: Northwest Beijing has frequently suffered from flooding in recent years, and the existing artificial aqueduct system has certain limitations in flood prevention effect. Especially when heavy rainfall comes, the precipitation often exceeds the carrying capacity of the existing drainage system, leading to serious waterlogging and flooding disasters. Therefore, it is of great significance to explore the optimization measures of aqueduct design and management. Based on the field study, this paper analyzes the deficiencies of the aqueduct system in the region in response to extreme weather events and proposes a plan to improve the system's diversion and flood control capacity through design optimization, intelligent monitoring and early warning, and natural ecological management from multiple perspectives. This paper shows that insufficient redundancy in aqueduct design and poor maintenance are the main challenges, while intelligent management and public participation mechanisms can help improve the system's responsiveness and adaptability. This study provides new ideas for the design of urban hydraulic projects, especially to cope with floods, mudslides and other disasters caused by climate change.

1 INTRODUCTION

Climate change has led to a high incidence of extreme weather events, especially the increase in the frequency and intensity of extreme precipitation events, which has put tremendous pressure on the infrastructure of major cities around the world. Flooding has become one of the major challenges for many cities, not only endangering the safety of residents' lives and property, but also having a serious impact on key urban functions such as transportation, water supply, and electricity. According to the United Nations, a large proportion of global flooding occurs in urban areas, a risk that is further exacerbated by climate change (Xuehai, 2024). Urbanization has accelerated surface hardening and reduced the water storage capacity of natural water systems, making cities more vulnerable to flooding when faced with extreme precipitation (Zhou, 2023). Therefore, how to mitigate the impacts of flooding through effective water resource management has become a key topic of research.

Currently, there are various research methods for coping with urban flooding, including Low Impact Development (LID) techniques (UN-Habitat, 2022). Monitoring and management of urban drainage networks using remote sensing and Geographic Information Systems (GIS) (Ding, 2014). Among them, artificial aqueducts, as an important infrastructure, have attracted much attention due to their significant role in guiding urban runoff, rapid drainage, and water storage and flood control.

This paper argues that aqueduct design optimization and systematic management can significantly improve the ability of cities to withstand flooding, especially when dealing with extreme precipitation events (Li, 2023).

This paper takes Northwest Beijing as the research object, discusses the current situation and problems of its existing artificial aqueduct system in flood prevention and flood control, analyzes the optimized design scheme, and provides effective solution ideas for urban flood control management.

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2 OVERVIEW ANALYSIS OF THE STUDY AREA

2.1 Overview of Beijing's Geographic Location and Flood Risk

Beijing is located in the north of the North China Plain in northern China, at the junction of the eastern Taihang Mountains and the southern Yanshan Mountains. The overall topography of the city gradually decreases from northwest to southeast, with mostly mountains in the northwest and plains in the southeast. Due to this geographic location, the northwestern area of Beijing becomes a key area for precipitation and flash flood convergence, while the plains in the southeast are prone to waterlogging and the formation of inland floods (Liu, 2015).

Northwestern Beijing, including Changping, Yanqing, and Mentougou, has a complex topography dominated by mountains and hills. The region is rich in rivers and valleys and is prone to heavy precipitation and flash floods during heavy rainfall. Due to the steep terrain, heavy rainfall in the northwestern mountainous areas is very likely to converge into rapid flows and quickly pool into flash floods, posing a greater threat of flooding to downstream areas (Meteorological Bureau, 1990).

Beijing has a typical monsoon climate, with precipitation mainly concentrated in the summer months of July and August, accounting for about 70% or more of the annual precipitation. In the northwestern part of the country, precipitation is relatively large due to the uplift effect of the terrain, but it is unevenly distributed, and heavy rainfall events are frequent, especially during heavy rainfall, which can easily lead to flash floods and mudslides.

2.2 Distribution of Water Systems

Beijing's water system mainly includes the Yongding River, Chaobai River and Wenyu River. The Yongding River basin in the northwestern part of the city is one of the most important water systems in Beijing, but it is also susceptible to flash floods and mudslides due to the fact that it flows through mountainous and hilly areas. In addition, the numerous small streams and valleys in the northwestern region rapidly accumulate water during rainfall, resulting in rapid flood confluence and high flow rates, exacerbating the risk of flooding (Figure 1).

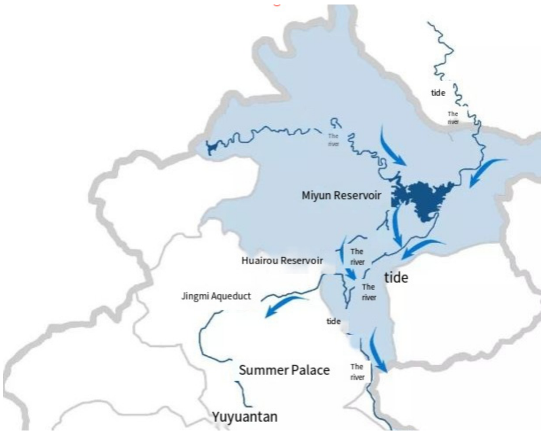

Figure 1: Map of water systems in northwestern Beijing (Li, 2023).

This article will focus on why the existing man-made aqueduct system in the Northwest Fifth Ring Road of Beijing is not able to fully withstand flooding. What are the main challenges in gutter design and flood management?

3 DESIGN

From the design point of view of water conservancy engineering, the main task of the artificial canal and river system is to guide and control the stormwater runoff in order to reduce the impact of flooding on the city. In this paper, a field study was conducted to observe the situation of rivers in northwest Beijing (Qing River, Beisha River, Yongding River, Yuanmingyuan River, Xijiao Line Drainage Canal, and Zizhuyuan River). Artificial canals and river systems fulfil their roles of diversion, diversion, flood control, and water storage mainly through their dimensions, layout structures, and drainage network structures (Wang, 2011).

Traditional canal systems are often designed based on historical rainfall data and lack consideration for extreme weather events. The warm semi-arid and semi-humid monsoon climate of Beijing (with distinct dry and rainy seasons, long duration of the rainy season, high cumulative rainfall, strong winds, and obvious convective characteristics with some extremes) requires a higher degree of adaptability and flexibility in the design of the aqueduct. For example, the cross-section of the drains should be designed to accommodate stormwater runoff of varying intensities with some redundancy (adding additional drainage channels or structures) to cope with extreme weather events (Ma, 2018).

With the complex topography of northwestern Beijing, man-made drains need to be closely connected to natural water systems and drainage pipes to ensure that stormwater is quickly discharged to a safe place. This requires full consideration of geographical factors such as terrain elevation and catchment paths in the layout of the drains.

4 SOLUTION ANALYSIS

Design and optimization: Dynamic simulation of the aqueduct system is carried out using the SWMM modelling tool, which can simulate the water storage system or the aqueduct system under any scenario. For example, if the average rainfall over a period of time is set for an area of apartments, and the roof of each apartment is covered with greenery, the rainwater is stored for a certain period of time on the roofs of the apartments in the greenery-covered areas, and then flows into the apartment's aqueducts, then into the city's aqueducts, and ultimately into the man-made canals or rivers. This makes it easier to ensure that the design of the distribution system is adaptable to different rainfall scenarios.

In terms of natural ecological management, this paper suggests the construction of small natural parks next to man-made aqueducts and rivers to enhance the filtering and storage of rainwater in aqueducts by incorporating natural landscapes, such as wetlands and vegetated buffer zones, which can improve flood control and the urban environment. The Yuanmingyuan and the Summer Palace are the most successful cases in northwest Beijing, but their specifications and costs are also huge. But if you just build linear parks along the banks of rivers, they can also serve the same purpose of water storage and flood control.

From the point of view of management and maintenance, man-made aqueducts and rivers require not only rational design but also proper management and maintenance. Many aqueducts were designed with adequate drainage and water conveyance capacity, but due to a lack of maintenance over a long period of time, problems such as silt and garbage accumulation have occurred, resulting in poor drainage. As in the case of the river park proposed above, the trees and vegetation inside the park will drop a large number of leaves, twigs flowers, etc. every year and these will seriously affect the proper functioning of the drainage system. Therefore, it is very important and meaningful to maintain the drains and rivers regularly.

If not cleaned in time, the drains will fail at critical moments and cause serious flooding. Also, smarter management and maintenance models are essential. Traditional management of drains relies on manual inspections and regular maintenance, but with the development of technology, IoT devices and sensor networks can help to monitor the operation of drains in real time, and identify blockages or points of failure more quickly and with less effort.

4.1 Smart Monitoring and Early Warning System

By installing smart sensors such as rotary slurry flow meters and multi-parameter water quality analyzers to monitor changes in water levels, flow rates and water quality in drains, real-time flood risk warnings are provided and automatic reminders are given to maintain or activate drainage equipment. Such systems can be integrated with meteorological forecast data for advanced flood risk assessment.

Drawing on the public reporting system used by Goldmind, mobile applications are used to engage citizens in the management of drains, where citizens can report blockages or breakages they find, which in turn allows professionals to carry out maintenance and repairs, improving the responsiveness of drains.

From a sustainability perspective, while addressing flooding, the aqueduct system also needs to consider sustainable development, especially the long-term health of the urban environment and ecosystems. Runoff during the rainy season in Beijing is a potential water resource if it can be properly collected and treated, the management and reuse of precipitation resources, such as for urban power generation, greening, landscape water and other areas.

This will not only alleviate the problem of urban flooding but also improve the efficiency of water resource utilization. Moreover, flood water often carries a large number of pollutants (organic pollutants, metals, chemical pollutants, and microbial pathogens), which may affect the water quality of the downstream water bodies after entering the aqueduct. Therefore, the design of aqueduct systems should not only consider drainage but also incorporate water quality purification features (Bach, 2017).

4.2 Harvesting Rainwater for Reuse

By setting up rainwater collection ponds at suitable locations in urban or suburban areas, the precipitation from nearby areas (residential areas, roads and other hardened areas) can be collected to the maximum extent, and through filtration and sedimentation, floating particles and larger pollutants can be removed, and then through sand filtration and secondary sedimentation, the vast majority of particles obtained can be removed, and then after that chlorine disinfection or ultraviolet ray disinfection can be used to kill the microorganisms and pathogens in the water, and finally, the ph value is adjusted to a usable range. The water can then be used for non-potable water supplies such as irrigation, cleaning, cooling water and toilet flushing.

Incorporating filtration layers and settling basins directly into the man-made aqueduct system reduces the chance of pollutants entering the natural water body. This can be at the intersection of each aqueduct, which is usually equipped with a sluice gate. A filter layer that can be raised and lowered at the inlet can be installed, consisting of a large barrage and gravel. It can be ensured that the drains do not become clogged with clumps or larger pollutants during any time, resulting in the loss of unclogging. Natural biological filtration can also be done using the river parks mentioned above, where wetland plants, aquatic organisms and other natural elements purify the water. They absorb some of the nutrients in the runoff, such as nitrogen and phosphorus, and convert these potential pollutants into harmless biomass through plant growth, thus reducing the risk of eutrophication of the water body. It also stops the soil on both sides of the aqueduct from being excessively washed into the aqueduct by the water flow.

5 CONCLUSION

This paper discusses the limitations and challenges of the existing artificial aqueduct system in flood prevention and control by analyzing the geographic characteristics, precipitation distribution, and water system in northwest Beijing. By combining multiple perspectives of hydraulic engineering design, system maintenance and intelligent management, and natural ecological management, it is found that although the existing aqueduct system can prevent and control flooding to a certain extent, it still suffers from insufficient design redundancy and poor maintenance in coping with extreme weather events.

In addition, the study points out that the flood prevention and control capacity of the aqueduct system can be effectively improved by using modelling tools such as SWMM for dynamic simulation, enhancing the flexibility of aqueduct design, introducing intelligent monitoring systems and public participation mechanisms, and natural ecological management tools.

With the frequent occurrence of extreme climate events, the design and management of man-made aqueduct systems need to be further optimized to better adapt to the flooding risks associated with climate change. Meanwhile, this study not only provides practical guidance for urban flood control in Beijing but also provides a reference for the construction of water conservancy projects and urban management in other similar areas. The efficiency and sustainability of urban water management systems can be further enhanced in the future through more interdisciplinary studies and field tests, leading to higher ecological and social stability.

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