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Nature-inspired stormwater management practice: The ecological wisdom underlying the Tuanchen drainage system in Beijing, China and its contemporary relevance

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HIGHLIGHTS

- The nature inspired design was found in Tuancheng drainage system.
- Trapezoid bricks, C-shaped culvert and soil improvement are three smart designs.
- The simulation of TCHM model proved the performance of Tuancheng drainage system.
- Exploring ancient ecological wisdom could help us to address modern issues.

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ABSTRACT

There are many outstanding constructions in ancient Chinese cities that are still in use in their unique local landscapes. An example of successful ecological engineering is the Tuancheng drainage system in Beijing. This paper presents a technical analysis of this drainage system and describes a hydrological model built in Stella® for a one-time rainstorm event and for annual water balance analyses. The results demonstrate how well the drainage criteria were chosen and prove that the implementation was exceptionally successful. An example of smart design solutions is the underground circular C-shaped drainage system in the terrace, where at each turning point, there is a pit to collect rainwater. In addition, the inverted paving by trapezoidal bricks and soil improvements contributed to the rapid infiltration of rainwater. During intense rainstorms, the system effectively attenuated stormwater and increased the infiltration rate. During drought conditions, such as in 1965, with only 226 mm of rainfall, the system increased soil water retention by 27 mm. The Tuancheng drainage system is an excellent example of an engineering solution managing drainage and storage, on- and underground, and using gray and green infrastructure to create a hydrological landscape functionally equivalent to natural conditions. Exploring ancient wisdom and using the ideas of our ancestors can help us to find more effective and efficient strategies to manage urban stormwater.

1. Introduction

The present study focuses on Theme 4 discussed in the editorial by Xiang (2014), exploring ecological wisdom as an important element of sustainable development. The focus of both the International Symposium held in Chongqing in October 2014 and the special issue of *Landscape and Urban Planning* was to pursue answers to the questions presented in this editorial. One of the central principles for this symposium and the special issue was to report evidence-based and case-specific research contributing to a better understanding of ecological wisdom. Urban drainage is naturally a serious problem, and potential solutions could benefit from looking backwards and around for relevant ecological wisdom (Xiang, 2013). This is especially true for China, where urban stormwater management has been largely less efficient compared with other industrialized countries. We investigated the ancient urban drainage systems of Beijing, specifically the Tuancheng drainage system, to explore the ideas, principles, strategies, and approaches used there for the management of urban stormwater and to determine how this can inform contemporary stormwater management in China.

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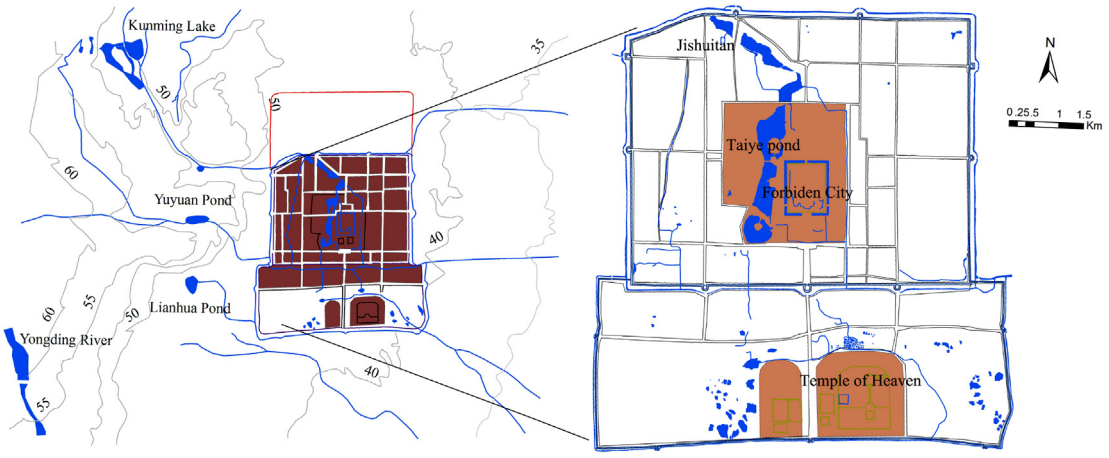

Fig. 1. The drainage system of Beijing during the *Ming* and *Qing* Dynasties.

With rapid urbanization and precipitation patterns becoming more unpredictable as a result of climate change, urban flooding has become a serious socio-environmental problem in China, causing property damage, heavy casualties, traffic paralysis, water pollution and economic losses (Li, 2012). On July 21st, 2012, for example, a tragic instance of catastrophic urban flood in Beijing (the 7.21 Beijing Rainstorm) resulted in 37 deaths and an estimated loss of at least 10 billion RMB. More than 100 of the 661 largest cities in China suffer from flooding problems during monsoon season, while over 400 cities experience some degree of water shortage (Du, 2012; Li, 2012). This annoying contrast between flooding and drought in urban areas is expectedly caused by changes in land cover (decreased permeability) exacerbated with the ongoing climate change (Zhou, 2014).

In recent decades, there has been increasing interest in ecological engineering and ecological design (Todd, Brown, & Wells, 2003), which attempt to apply nature-inspired methods in designing engineering solutions. Indeed, over thousands of years of co-evolution with nature, people adopted the principle of learning from and working with nature and ingeniously designed and built systems that provide real and lasting good. Many ideas underlying these time-honored projects become the cornerstone of contemporary stormwater management practices (Che, Qiao, & Wang, 2013; Fletcher et al., 2014), including low-impact development (LID) (USEPA, 2000), best management practices (BMPs) (Muthukrishnan, Madge, & Selvakumaret, 2006), and sustainable urban drainage systems (SUDS) (Sharma, 2008).

Quite illuminating among these projects is the ancient urban drainage system in Beijing and its miniature replica, the Tuancheng drainage system. In this paper we review the design of that system demonstrating the ecological wisdom of the ancestors who managed to achieve a sustained and adequate ecological performance of an urban infrastructure. We then use a hydrological model built in Stella® to explore a particular storm and flooding event and to perform annual water balance analyses. The results demonstrate how well the drainage criteria were chosen and prove that the implementation was exceptionally successful.

2. The evolution of urban drainage systems in Beijing and the design of Tuancheng

2.1. A brief history of urban drainage systems in Beijing

Beijing city is surrounded by hills to the northwest and lies on an alluvial plane that slopes to the southeast towards the ocean. As early as the *Western Zhou* Dynasty (*1046–771 BCE*), urban drainage was provided by ditches and channels, which have been found in archaeological digs. It was not until the *Yuan* Dynasty (*1271–1368 CE*) that an integrated drainage and retention lake system was built, coincident with the planning and construction of the capital city *Yuan dadu*. A natural surface water system was used to channel stormwater in the city, and a complete open-channel-hidden-culvert drainage system was built to collect surface water within the inner city. The river and lake systems outside the imperial city, including the Gaoliang River, Tonghui River and Jishuitan Lake, were primarily used for water transport and served as important components of the urban drainage system (Fig. 1). Inside the Imperial city, the palace drainage system included the Jinshui River, Taiye Pond, open channels and hidden ditches. For example, some Yuan culverts and channels were discovered next to major avenues in modern Beijing. The main roads and streets in *Dadu* were located next to drainage channels. In light of the geographical and climatic conditions of Beijing, both drainage and storage devices were considered in the design. To ensure the smooth flow of runoff and to increase the flow rate, the complex drainage system used topography, with higher elevations in the northwest and sloping towards the southeast. In addition to diverting water to natural rivers, many lakes and ponds were excavated and utilized to increase storm water retention (Du & Zheng, 2010; Hou, 1985).

Although Beijing continued to serve as the capital of China in the *Ming* and *Qing* dynasties, the overall pattern of *Yuan dadu*, in the central region, changed. The regions in the north diminished and expanded into the South City, ultimately forming a convex pattern. With the relocation of the city center, Nanhai Pond was excavated, extending the area of Taiye Pond. Most of the drainage system of *Yuan dadu* was preserved with some minor changes at different times, adding canals in every corner of the city. Some of the *Ming* and *Qing* drainage improvements have been found in the Forbidden City, where a network of drainage lines, open ditches and covered ditches connected all of the palaces and courtyards. Generally, water was gathered through east-west sewer lines flowing into the north-south line and subsequently into Jinshui River (the river in front of the Gate of Supreme Harmony). During the *Ming* and *Qing* dynasties, there was a regulation mandating that the ditches in the Forbidden City be cleaned in spring. These watercourses remain in use today (Fig. 1). It has been estimated that the channel density of the metropolitan area in Beijing during that time was 1.07 km per km^2, with a total capacity of 19.35 million m^3, and every square meter had a storage capacity of 0.32 m^3 (Wu, 1995).

In the middle of the *Qing* Dynasty, with the construction of imperial gardens in the northwestern suburbs of Beijing (e.g., Chaungchunyuan, Yuanmingyuan or the Old Summer Palace,

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