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ORIGINAL ARTICLE

Aligning ancient and modern approaches to sustainable urban water management in China: Ningbo as a "Blue-Green City" in the "Sponge City" campaign

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Modern urban flood and water management emphasises holistic strategies that reduce flood risk while providing cobenefits to urban economies, societies, and environments. The "Blue-Green City" concept provides a viable framework for putting this into practice. Ningbo, is a coastal city with high flood risk, whose history as a Chinese "water town" demonstrates that approaches to water management implicit to the "Blue-Green" concept were practiced in ancient times, and lessons can be learned from these applications. Furthermore, recent launch of the "Sponge City" campaign by China's National Government demonstrates the political will to implement sustainable flood and water management in ways consistent with the "Blue-Green" ideals. Selection of Ningbo for a pilot project presents the opportunity to integrate new "Sponge city" approaches with ancient "Blue-Green" principles, within the contexts of both new urban development and retrofit. Reinventing traditional approaches to urban water management and governance offers the possibility of maintaining flood risk at acceptable levels without constraining urban growth in China and other countries experiencing rapid urban development.

KEYWORDS
Blue-Green Cities, integrated flood risk management, Sponge Cities, integrated water management, sustainable drainage systems, water-sensitive urban design

1 | INTRODUCTION

1.1 | Overview

Flooding can be a catastrophic natural hazard and mitigating flood losses is a priority for disaster risk reduction (UNISDR, 2015). In recent decades, approaches to flood management in developed countries have evolved from prevention to risk management, employing holistic approaches that provide a range of cobenefits through, for example, water quality improvement, restoration of river ecology, and enhanced recreational opportunities, in addition to reducing flood risk (Downs & Thorne, 2000; Jha, Bloch, & Lamond, 2012). Sustainable Drainage Systems (SuDS), "Blue-Green" infrastructure (BGI) and Water Sensitive Urban Design (WSUD) are recognised as mechanisms to integrate the water cycle with urban development while helping meet ongoing challenges of climate change and rapid urban growth (Ashley et al., 2013; Novotny et al., 2010; Wong & Brown, 2009).

Innovative approaches to flood and water management are also gaining momentum in developing countries, including China (e.g., Zhang et al., 2016), though the need for location-specific adaptations related to regional variabilities in climate, demographics, and the stage of development must be taken into account (Higgitt, 2015). It follows that the first step in updating national Chinese water management

TABLE 1 Comparison between Blue-Green and Grey infrastructure on various functions

		Blue-Green infrastructure	Grey infrastructure
Concept of design		Creating landscape mimicking natural water cycle in urban environment (O'Donnell, Lamond, & Thorne, 2018)	Creating sizable channel and drainage systems to direct excessive precipitation or surface flow from urban areas in a short period of time (Fleming, 2002).
Flood control		Reducing peak flow during small or mild floods (Guan, Ahilan, Yu, Peng, & Wright, 2018; Haghighatafshar et al., 2018)	Discharge designed amount of excessive flow in short period of time (Hutter, 2007; Schanze, 2006)
Sediment control		Creating a heathy balance of sediment loading on floodplain basin (Ahilan, Guan, Sleigh, Wright, & Chang, 2018; Guan et al., 2018)	Relying on dredging of deposited sediments on the bed of channels and culverts (Thorne, 2014)
Additional direct environmental benefit	Water purification	√	—
	Drought mitigation	√	If water storage is designed in the system
	Reducing urban Heat Island effect	√	—
	Habitat enhancement	√	—

policy to meet flood-related challenges lies in recognising the potential for specific flood risk management interventions to take advantage of local climate, land-use, socio-political, and governance conditions.

In this context, this study examines historic urban flood and water management practices in the city of Ningbo, to illustrate that sustainable urban water management has long been practiced and identify synergies that exist with the "Blue-Green City" ideal of reconfiguring the urban water cycle to resemble the natural water cycle. Elements of the ancient surface water management system that align with the contemporary "Blue-Green City" concept, and those that diverge from it, are discussed. The impacts of current urban redevelopment and expansion in Ningbo on the ancient water management system are evaluated and it is argued that urban flood and water management professionals could learn lessons from ancient practices, and should seek to incorporate ancient infrastructure into modern systems by recognising it as BGI capable of reducing flood risk while better enabling communities to "live with water". These arguments are consistent with the *Technical Guide for Constructing Sponge Cities* (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2014). Inclusion of Ningbo in the second round of the "Sponge City" campaign, presents a great opportunity to rediscover and re-invent ancient "Blue-Green" strategies.

1.2 | The Blue-Green concept and Sponge City initiatives proposed by the Chinese government

A "Blue-Green City" aims to recreate a naturally oriented water cycle in an urban environment by integrating restored and/or newly created water bodies with green infrastructure, to generate a range of environmental, economic, and social benefits (Hoyer et al., 2011; Novotny et al., 2010). Blue-Green approaches aim to work with some of the single-purpose elements of the existing, grey infrastructure (such as flood embankments and pipes), while replacing other elements with multifunctional BGI, that provides multiple cobenefits to a range of beneficiaries (Hoang et al., 2016). For instance, introducing BGI (e.g., green roofs, bioswales, deculverted urban streams) can not only reduce flood risk but also mitigate the urban heat island effect and the impacts of traffic noise, while improving water quality, providing access to green spaces, uplifting neighbourhood aesthetics and strengthening the community's sense of place (Lawson et al., 2014; Stahre, 2008; Voskamp & Van de Ven, 2015).

Table 1 presents a comparison of environmental benefits between the blue-green infrastructure (BGI) and grey infrastructure. A Blue-Green City might not preserve natural features present prior to urbanisation, and more commonly features engineered, green infrastructure that *mimics* nature. Furthermore, integrating grey infrastructure with Blue-Green assets creates and optimises the multiple benefits of SuDS (Thorne, 2015). Widespread implementation of multibeneficial BGI in the United Kingdom (Ellis et al., 2016), United States (BES, 2010), Europe (Stahre, 2008), Singapore (Tan et al., 2009), and Australia (Adams & Jayasuriya, 2014), provides evidence of the potential advantages of adopting Blue-Green approaches in Chinese cities.

In 2013, the Chinese government declared its intention to convert Chinese cities into "Sponge Cities": that is, cities that (like a sponge) absorb excessive inputs of water from excessive precipitation or river floods, retaining that water for use between input events and during prolonged dry periods. While this concept is simple in principle, the wide variety of natural landscapes and hydro-climates in China requires diverse approaches to create "Sponge Cities" in practice (Yin & Liu, 2015; Yu, 2015a). In 2015, the Chinese central government initially financed 16 "Sponge City" districts throughout the country as "pilot projects", implementing drainage systems featuring site-specific mixtures of rain-gardens, urban meadows and wetlands, permeable pavements, and bio-swales. A priori, the Sponge and Blue-Green City concepts fit together conformably (Lawson et al., 2014; Novotny et al., 2010), particularly in regions where flood risk and water security pose significant hazards to the sustainability of urban conurbations.

When the Sponge City initiative was announced, the government of Zhejiang province, where City of Ningbo is situated, introduced the slogan"Wu Shui Gong Chih (五水共治)" which stresses the need to concurrently address five issues related to water (Water Management Office, Water Resources Department of Zhejiang Province, 2014):

1. pollution remediation;
2. flood mitigation;
3. reducing saturated soils by improving the drainage system;
4. securing the freshwater supply, and;
5. reducing unnecessary water consumption.

Integrating grey infrastructure with BGI, as well as conversion of Ningbo to a sponge city, is entirely relevant to addressing the combination of water quality and quantity objectives included in the Province's new policy and slogan.

2 | HISTORICAL URBAN WATER AND FLOOD RISK MANAGEMENT IN NINGBO

2.1 | Location and importance

Sustainable management of stormwater, flooding, and freshwater resources pose particular challenges in rapidly growing, deltaic and coastal cities in China, including those in the Yangtze River Delta (YRD) Economic Zone. The City of Ningbo in Zhejiang province, is located on the south-east coast of China, within the YRD Economic Zone. Ningbo represents a type of city that would benefit significantly from becoming a Blue-Green/Sponge City.

The region's abundant rainfall and complex hydrology drive a dense network of rivers, lakes, estuaries, and wetlands (Xu et al., 2014) which, since ancient times, has been supplemented by canals constructed for water supply, transportation, irrigation, and drainage (Wu, 1989). The region is scattered with the settlements the Chinese people call "water towns" (水乡 and pronounced, Shui Xiang). Water towns are defined by a distinct architecture and way of life, centred on a dense network of natural waterbodies and canals (Qiu, 2013; Zhou, 2014). These communities have long been adept at living in a watery environment by, for instance, using water-borne transport more frequently than land-based transport in their daily routines. For example, before automobiles became popular, residential areas inside the Ningbo city wall were usually built with the front door facing the land while the back door connected to a waterway along which goods and produce were transported and delivered (Zhou, 2008a).

However, recent economic development has facilitated rapid urbanisation (Woetzel et al., 2009), with many ancient waterways being filled-in to facilitate urban development. Consequently, the density of the surface water network has decreased (Chen et al., 2007). The increasing area of impermeable surface associated with urban expansion has reduced the capacity to infiltrate rainfall to groundwater (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2014). For example, between 1997 and 2012, built-up areas in Jiangsu, Zhejiang, and Shanghai (the two provinces and metropolis that make up the YRD Economic Zone) expanded by almost three times (from 2,406 to 6,950 km^2) (Figure 1). During the same period, the area under cultivation decreased, especially post-2002 (Zhang et al., 2016). Urban expansion has been most rapid in Zhejiang (745–2,296 km^2 between 1997 and 2012), where

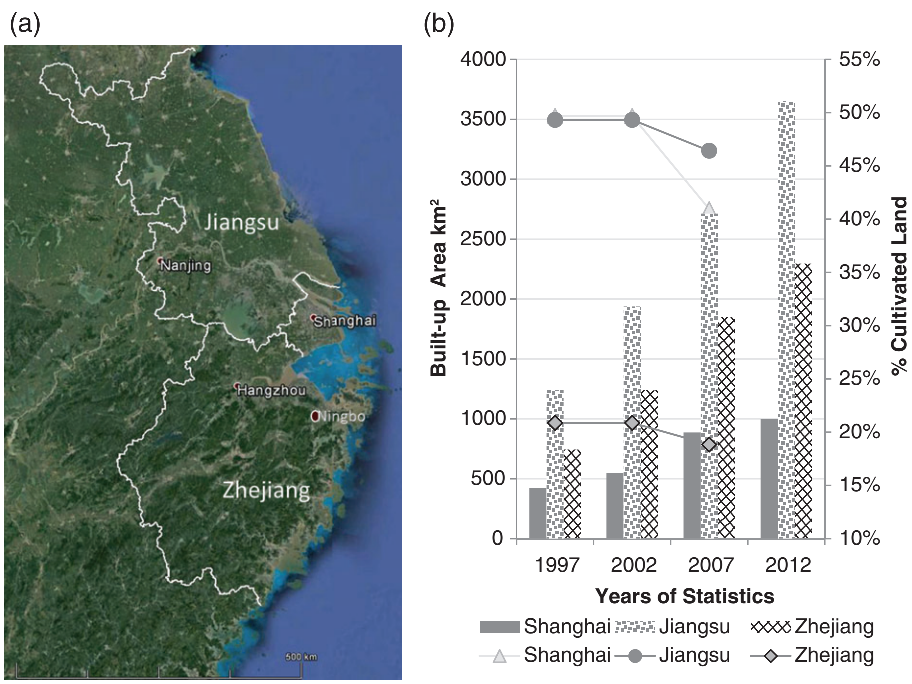

FIGURE 1 Land-use change in Yangtze River Delta Economic Zone. (a) Delineation of the Yangtze River Delta on an aerial photo of east coast of China and (b) statistics of land use. Bars represent built-up area (km^2); lines represent percentages of cultivated land (raw data obtained from China Data Centre, University of Michigan, 2016)

Ningbo is located, and the proportion of cultivated land in this mountainous province (about 20%) is significantly lower than that in the other administrative areas, making agricultural land particularly vulnerable to urban expansion. Specifically, in the Ningbo metropolitan area, the built-up area increased from 64 km^2 in 1997, to 102 km^2 in 2002, 221 km^2 in 2007, and 290 km^2 in 2012 (China Data Centre, University of Michigan, 2016); a fourfold increase. Expansion of the built-up area in Ningbo is reflective and representative of the dominance of the development and urbanisation over agriculture in the YRD economic zone.

2.2 | Climate characteristics of Ningbo

Annual rainfall in Ningbo averages 1,400 mm and the city is subjected to intense precipitation of short or long duration. Cyclonic depressions (plum rains) occur in early summer, while the summer monsoon and typhoons bring heavy and prolonged rainfall during late-summer and early-autumn, that can lead to surface water and groundwater flooding. The city is also vulnerable to fluvial floods that rush down to the coastal plain from mountainous catchments inland (Tang et al., 2015). In addition, the YRD region is susceptible to estuarine and marine flooding due to extreme high water elevations that occur when spring tides coincide with typhoon-driven storm surges (Gu et al., 2011). Overall, the high and highly variable precipitation leads to significant risks of pluvial, fluvial, groundwater and coastal flooding, especially during the summer and early autumn.

As a result of its rapid urban growth, coupled with climate change (e.g., increased intensity/frequency of rainstorms as noted by the World Bank, 2011) and relative sea level rise (due to delta subsidence and eustatic sea level rise), in terms of flood risk, Ningbo is ranked among the top 20 among coastal cities, globally. Based on current trends in population and economic growth, it is predicted that by 2070, Ningbo will be ranked 14th out of 136 port cities with high exposure to climate extremes (Chan et al., 2012; Hanson et al., 2011).

2.3 | Historical development of Ningbo City and its water management

Ningbo, initially named Mingzhou, has been a prefectural capital since 738 AD. The city was originally situated on a patch of higher ground about 20 km southwest of the current city centre (Figure 2) because frequent flooding and the limited availability of freshwater hindered development in the floodplain itself. Ningbo relocated to its present site within the floodplain during the Tang Dynasty (833 AD) following completion of extensive engineering works designed to reduce flood risk while securing the supply of freshwater for municipal use and agricultural development throughout the floodplain (Lu, 2007; Zhou, 2008a). That relocation made possible the development of the City as a port. These engineering works included Tuoshan Weir, constructed to limit tidal penetration along the Ying-Fenghua River system and to divert up to 70% of the freshwater draining from the mountains to the east to Moon Lake, within the old, walled city via the Nantang River, which was the second major constructed feature (Figure 2). Since the 1960s, the water conservation function of these works has been largely superseded by upstream dams and reservoirs (Shang et al., 2006), although water gates along the Nantang River are still used to divert excessive runoff from the mountains into the tidal river system in order to prevent fluvial flooding (Chen, 2000).

These ancient water control works were constructed using natural materials (stones, mud, and soil) reinforced by fibrous materials such as the roots and stems of plants (Yao,

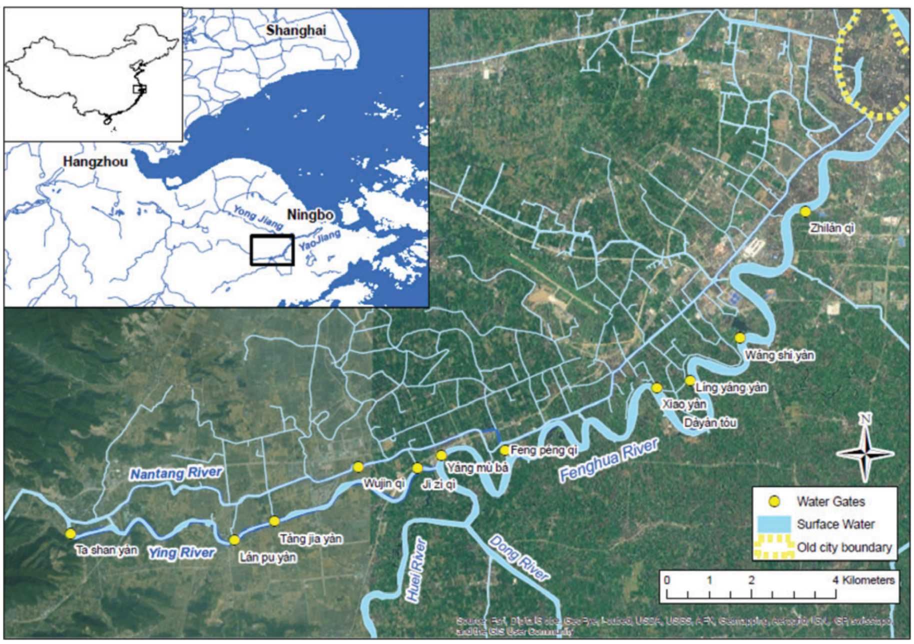

FIGURE 2 Location map of Ningbo. Yellow dashed line indicates the old boundary of the Ningbo city Centre after 833 AD, located where the Fenghua River confluences with a river from the north to form the Yong River. Upstream of Fenghua River are Dong, Huei and Ying Rivers. Tuoshan Weir (located at *Ta shan yan* on the map, where the Ying and Nantang rivers, a freshwater channel created in 831 AD, separate) prevents salt water from entering the Nantang River during high tides. Blue lines indicate the complex network of canals and natural water bodies connected to Nantang River that are still identifiable at present from the aerial photos of Google Earth (2012). Yellow dots indicate water gates controlling water levels along the Nantang River designated in maps in the *Yin Xian Tong Chi,* which were drawn in the 1930s. The name of Wujingqi, a gate presented in Figure 3 and Figure 4 is underlined in red

FIGURE 3 Contrast between an embankment made of artificial and natural materials. (a) Contrasting channel bank treatments adjacent to Wujingqi: The section on the left has been reinforced using concrete and masonry and can easily support modern buildings and a roadway, while the section to the right, which is still formed in soil reinforced by trees and shrubs, can only support an old-style of building. (b) Contrasting bank treatments along a channel connecting a water gate on the Nantang River to the Fenghua River at TangJiaShi Yan: The near bank is covered by concrete that is cracked and failing. The opposite bank is stabilised by natural vegetation with little or no artificial reinforcement and probably resembles conditions that pertained prior to the availability of artificial materials such as concrete (both photographs by the authors, December 6, 2014)

1987 citing, "*Nong Shu - the Book of Agriculture*", written during the 13 century; Wang, 2012). Consequently, these structures allowed surface water to infiltrate to groundwater. In an early example of bio-engineering, canal embankments were planted with mulberry bushes (these are generally termed *Morus*—a name that mostly refers to *Morus alba Linn.* However, depending on the area and climate, these bushes could also be other species of *Morus* within the family *Moraceae*). These plants simultaneously stabilise the soil and provide food for silkworms (Zhou, 2012). This practice continues today around the TaiHu (Tai Lake) in Huzhou District. Over time, many of these artificial channels became indistinguishable from the pre-existing, natural water bodies they were built to link, supporting biodiversity while meeting contemporary society's needs for freshwater and land drainage. In this aspect, the design and function of these ancient canals align strongly with the "Blue-Green" concept and they may reasonably be described as prescient forms of BGI. In this context, it is notable that ancient water management typically used a complex network of small waterways and waterbodies to supply domestic and irrigation water to the villages in west Ningbo (Figure 2), and that parts of this network are believed even to predate construction of Tuoshan weir itself (Chen, 2000). The network was initially constructed using natural materials (parts of which are still identifiable today), though later on structures built from natural materials were gradually replaced with ones constructed using concrete and steel (Figure 3).

Until the middle of the 20th century, the growth and prosperity of Ningbo was intertwined with continued development of its surface water network. The waterway system, initially constructed for freshwater supply, irrigation, drainage and detention, evolved into an efficient inland navigation network (Griffiths et al., 2013). This enhanced the socio-political importance of the Ningbo when nearby Hangzhou was the capital of China (1129 to 1276 AD) because ambassadors from Korea and Japan were frequently received via these waterways (Lu, 2007). During the Age of Discovery (between the 15th to 18th centuries), Ningbo became an internationally important port on the Maritime Silk Road thanks to its liveability and connectivity to its hinterland via the extensive inland water transportation network.

Historical accounts indicate that in the Ningbo area, the general public has actively participated in construction and maintenance of water gates and embankments for centuries—either by donating money or contributing to the labour force, according to their means (Chen, 2000; Zhou, 2008c, pp. 98–100). Local gentry, entrepreneurs and people of high social status (typically, local "opinion leaders") financed local-scale construction and dredging, while Local Government officials solicited money through the upper hierarchy of the government. County and Prefecture-level Governments led large-scale projects such as construction of Tuoshan Weir (Shang et al., 2006). In this context, Zhou (2008b, pp. 42–43) describes how unofficial, community organisations and a "hierarchy of donation" formed, based on the social norm to support public affairs, including bridge building and waterway maintenance. Strong and highly organised public engagement resulted from common recognition of the vital importance of freshwater by urban residents and farmers alike (Zhou, 2008b). The need for collaboration between communities in maintaining water management infrastructure has enhanced the sense of social interdependence in rice-growing region, covering where Ningbo located (Talhelm et al., 2014).

2.4 | Transformation of the water management system in the late-20th and early-21st centuries

During the 1960s, a series of dams was built on streams in headwater basins draining to the Fenghua River in response to increasing demand for freshwater (Zhang, 2015; Zhejiang Province Yin County Local Gazetteer Editorial Committee, 1996). These works reduced reliance on the ancient freshwater network. The dams also fulfil a function of controlling flash floods emanating from the mountainous headwater basins. However, recent extreme precipitation events in quantity and intensity, potentially associated with the ongoing global climate change, indicate that the flood capacity of the dams may be insufficient to protect Ningbo in future (Hanson et al., 2011). Furthermore, these upstream reservoirs do little to mitigate coastal and marine flood risks driven by high tides and storm surges. Additionally, the storage capacity of these reservoirs is sufficient for municipal supply, but insufficient to use river regulation counter problems of deteriorating surface water quality downstream where urbanisation and industrialisation continue intensively.

Further, while many of the secondary channels in the network have been filled-in and built over, and some of the water gates controlling flows between the Nantang and Fenghua Rivers have disappeared, in other places new gates have been added and existing gates have been deepened and widened. The gates are now electrically powered and centrally controlled. The materials used to build them are now exclusively concrete and steel. Like the urbanisation that drives it, renovation is an ongoing process that has spread up and downstream from the old city centre (Tang et al., 2016). For example, in the urban fringed of Ningbo, renovation of an ancient water gate named Wujingqi, a designated historical heritage, took place in 2015 (Figure 4).

The reduced navigation function of the channel network is apparent from the form of the redesigned link-channels and water gates (Gong & Hsu, 2011). The old link-channels and structures sometimes included distinctive, wedge-shaped cross-embankment channels designed to allow large vessels to be transferred between the Nantang and Fenghua Rivers. Many newly constructed structures lack this feature, while a flood wall or barrier has been built across the boat transfer channel at others (Figure 5). These modifications symbolise the diminished navigation-function of the waterways and disappearance of the “water town” lifestyle in modern Ningbo.

The point here is that, although irrigation remains the main consumptive use of water (Hsu & Chu, 2015) and some inland navigation along Ningbo's waterways continues, the primary function of the surface water network now relates to urban drainage and flood control. Renovation and upgrading of channels and embankments along the Nantang, Ying and Fenghua Rivers has been necessary to drain surface runoff from expanded impervious surfaces while providing flood security to communities occupying what were until recently agricultural fields (Tang et al., 2016). Furthermore, these works involve replacing natural materials originally used with concrete and steel, converting what was “Blue-Green Infrastructure” into “Grey” infrastructure.

During the early years of the 21st century, the flood management function of the remaining, ancient BGI further diminished as agricultural land use was replaced with residential and industrial development. The availability of aerial photographs taken prior to and following urbanisation has allowed the impacts to be quantified (Tang et al., 2016). For example, analysis of waterways and surface water bodies around three of the main water gates adjacent to the Nantang River (Wujingqi situated at urban fringe, and Xingchunqi and Chenglang Yan located within the urban core near the old city centre) demonstrates that the open water areas have decreased markedly, while impermeable pavement has expanded substantially (Figure 6).

Specifically, between 2006 and 2016, the ratio of open surface water area to the land area around the Wujingqi

FIGURE 4 Preparation of a water gate renovation between the Nantang and Fenghua Rivers at Wujingqi at urban fridge of Ningbo. (a) The old Wujingqi from Nantang River side and (b) from Fenghua River side prior to commencement of the work in December 2014. (c) Channel connecting the Nantang and Fenghua Rivers in (b) emptied during construction in August 2015. (d) The completed new gate, photo taken in September 2017 from the position similar to (c). Photographs by the authors

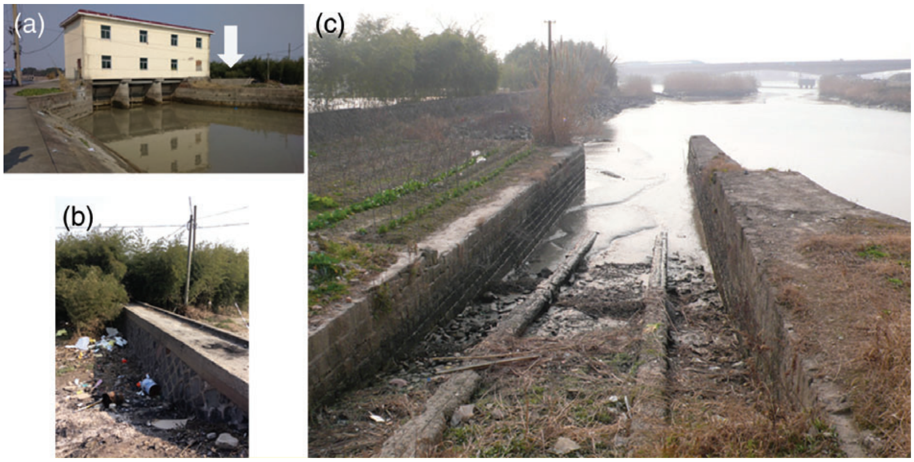

FIGURE 5 Fongpongqi, a water gate connecting Nantang and Fenghua rivers. (a) Modern control structure viewed from the Fenghua river side. White arrow indicates the wall built across the old "wedge-shaped" structure built which allows boats to be moved across the embankment between Nantang and Fenghua rivers (photograph by Vickie Wang, January 8, 2015). (b) Flood wall built across the old boat transfer structure (photograph by authors, January 8, 2015). (c) Photograph taken from top of the flood wall shown in (b) and showing the now derelict "wedge-shaped" ramp. View is towards the Fenghua River (photograph by authors, January 21, 2015)

gate decreased from 20 to 15% while that around Xingchunqi decreased from almost 80 to 55%. The percentage of impermeable surface in the urban core areas (Xingchunqi and Chenglang Yang) was already high (65–75%) at the beginning of the analysis period. Hence, expansion in impermeable surface area is most obvious at the urban fringe (Wujingqi). Additionally, a field survey identified redundant bridges at Xianshu Qi and Xiajia. These structures cross watercourses that no longer exist (Figure 7), indicating that former channels have been filled-in, with the reclaimed land being used for urban development and paved over.

Overall, the redesigned structures have been modified to better protect from flooding the area between the Nantang and Fenghua Rivers, where agricultural land has been developed for residential and industrial use. Enlargement, redesign, and relocation of these water gates from near the Nantang River to close to the Fenghua River, together with closure of vessel transfer channels in the embankment between the rivers, are actions consistent with operation of the system solely for flood control and abandonment of other water resource management functions, such as navigation (Tang et al., 2016). This, together with replacement of natural with artificial materials, means that these features can now legitimately be classified as single-function, grey infrastructure.

That said, connectivity between the Nantang and Fenghua Rivers is being maintained by the new link channels, water gates, and associated structures. The renovated system still has the capacity to manage water levels in ways that would support multiple functions, including those related to delivering the social and environmental benefits formerly provided by the ancient freshwater network (derived from the Nantang River). Therefore, the *potential* still exists for reinstating their use as fully multifunctional, Blue-Green assets.

In summary, the wet climate, coastal delta location, and long history of water management in Ningbo, coupled with the massive scale of recent urban development, suggest that management of future flood risks and surface water resources is challenging. This makes the City of Ningbo an ideal candidate for consideration of how, in the context of the "Sponge City" initiative, lessons learned in the past might inform urban water decision-making in the future.

3 | REASSESSING AND REINVENTING THE NEW BENEFITS OF ANCIENT WATER CONSERVANCY SYSTEM

3.1 | Recognising Blue-Green practices implicit to the ancient freshwater water management and their loss in the modern era

Discussion has thus far focused on engineered structures created in ancient times and subsequently renovated and modified in modern times. The form of renovation indicates that the waterway systems retain certain values for modern water management, though their purpose has evolved as they have been adapted to changing land use.

This freshwater management system has made habitation and agriculture possible in this area for centuries (Chen, 2000). On this basis, there are lessons that can be learned from the proven sustainability of the surface water resource and the way that it was developed and managed, at least until the late 20th century. Specifically, aspects of the managing surface water in west Ningbo exemplify "Blue-Green" principles of maintaining a naturally oriented hydrological cycle while using and valuing water as resource, in all its forms.

In addition to the installation of waterways and water gates, crops were selected by farmers to be flood resilient: rice paddy (*Oryza sativa*) is capable of surviving under mild flood conditions (The Office of the Gene Technology Regulator, 2005; Lu, 2007); lotus (*Nelumbo nucifera*) is preferred in low-lying fields between the Nantang and Fenghua Rivers to increase the capacity of the land to accommodate excess runoff while maintaining agricultural productivity during the wet season. Wise crop selection, coupled with the capacity

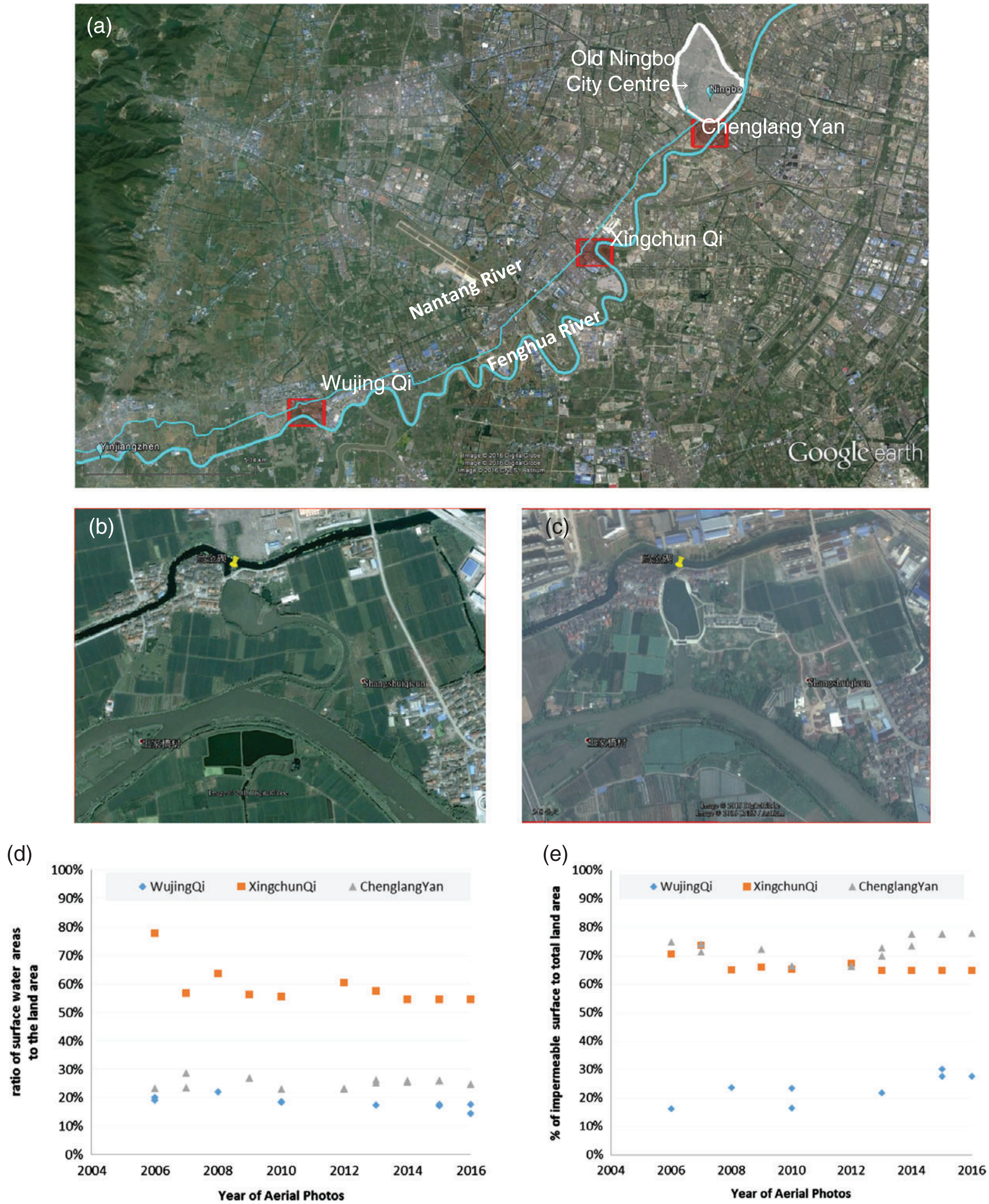

FIGURE 6 Spatial analysis of recent changes in land-use between the Nantang and Fenghua Rivers. The base map is digitised from an aerial photo dated February, 2016. (a) Study areas located near three important water gates. Red rectangles (about 83 ha) delineate study areas subject to land-use change analysis. (b) Aerial photograph of the area surrounding Wujingqi, dated 2006. (c) Aerial photograph of the area surrounding Wujingqi, dated 2016. Note that part of the open channel that existed in 2006 has been filled-in and turned into a residential area. (d) Changes water surface areas within the study areas. (e) Changes in impermeable areas (industrial and residential buildings, paved roads) as percentages of the dry land area

of the channel network to manage flood water, meant that up until the 1990s, agricultural land in the west Yinzhou District of Ningbo was able to accommodate nearly 14 million m^3 of flood water (*Yin Xian Chi,* Zhejiang Province Yin County Local Gazetteer Editorial Committee, 1996) while still being agriculturally productive.

3.2 | The case for re-implementing BGI to manage future flood risk in Ningbo sustainably

Urban growth in Ningbo, like other Chinese coastal cities, has accelerated since the late-1970s. The urban area, population, and level of prosperity have all increased significantly.

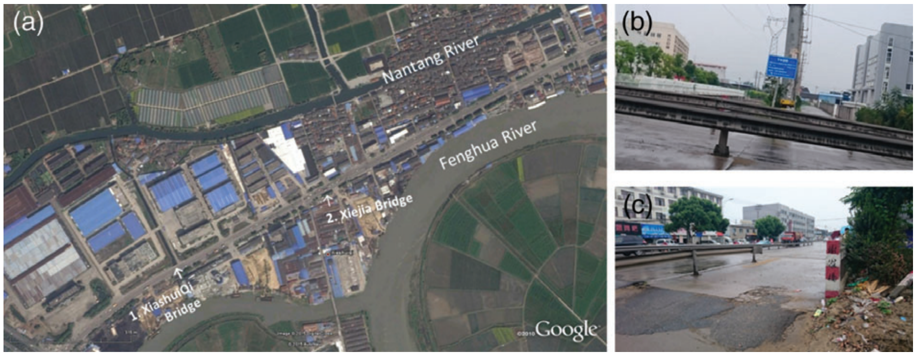

FIGURE 7 Disappearing freshwater channels in Ningbo. (a) Aerial photograph showing the locations of two redundant bridges between the Nantang and Fenghua rivers (dated April 1, 2015). (b) Xianshu Qi Bridge, which is named after a water gate and link channel that no longer exists (dated August 13, 2015). (c) Xiajia Bridge, which no longer crosses any watercourse (dated August 13, 2015). Photographs by the authors

Consequentially, the numbers of properties, people and economic assets at risk of flooding, have also increased and these trends are expected to continue. Concurrently, the probability of flooding in Ningbo and other coastal cities has also increased (Hallegatte et al., 2013), due to climate change and relative sea level rise, coupled with increases in the areas of impervious surface and reductions in the density of surface water drainage channels.

In many of the ancient "water towns" turned Chinese coastal mega-cities (e.g., Shanghai, Guangzhou, and Shenzhen), improvements to drainage systems have not kept pace with urban growth (Balica et al., 2012; Francesch-Huidobro et al., 2016). Ningbo, in common with these cities, is increasingly reliant on ageing, grey infrastructure (piped, subsurface stormwater storage and drainage systems and hard, engineered flood defence structures) to manage flood risks that are growing year-on-year. It is uncertain that expanding grey infrastructure alone will be sufficient to tackle future risks and, it remains to be determined whether engineered solutions represent value for money compared to Blue-Green approaches.

In Ningbo, heavy rainfall and a storm surge caused by Typhoon Fitow in 2013 exceeded the capacity of the existing, grey infrastructure (typically designed to manage only the 1- to 5-year rainfall events), highlighting the need for an advanced approach to managing future urban flood risk. This could be achieved by increasing the strength of the grey infrastructure or adding alterative BGI. Ideally, flood defence infrastructure should do this while creating multiple cobenefits for the urban economy, society, and environment under nonflood conditions (Hoang et al., 2016). These may be better achieved by adding BGI as part of the flood risk management. Future flood risk management approaches must also be adaptive to the fast-changing city-scape, the preferences of citizens and uncertainty associated with rates and degrees of climate change. The preferences of the citizens also depend very much on the technology available, and the economic status as well as social development at the time.

The historical analysis presented here suggests that elements of the ancient Chinese methods of managing surface water, reintroduced in combination with modern "Blue-Green" concepts and infrastructure, could represent a more sustainable and cost-effective approach to urban flood and water management, based on treating flood water as a resource as well as a hazard.

4 | CHALLENGES TO THE IMPLEMENTATION OF BGI PRINCIPLES

4.1 | Holistic water management and the "Sponge City" initiative

Policy shifts have been signalled recently by Chinese Central Government, most notably through the "Sponge City" campaign (Lu, 2014; Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2014; Wang, 2015), as mentioned in the Introduction section. In fact, in 2016, the "Sponge City" programme was expanded to 30 pilot studies, including an area of Ningbo. This expansion demonstrates the Central Government's strong political will to effect a change in urban water management practice. This attitude promoted the update of the evaluation standards for future development in Chinese mega-cities such as Tianjin, Shanghai, and Beijing (Chen, 2015; Yu, 2015b). The ambition of the Central Government to elicit change is also demonstrated by a quote from *Xinhua Finance,* who reported in April 2016 that, "over 20 provinces and cities [will] launch relevant planning to push the development of Sponge City and initiate over 1000 projects" (Yi, 2016).

The new policy directives indicate that Chinese government officials at various administrative levels recognise that over-reliance on grey infrastructure is not a viable solution to ensuring reliable supply of freshwater to Chinese cities like Ningbo while keeping flood risk at acceptable levels and meeting multiple other objectives relating to public well-being and sustainable urban development.

4.2 | Overcoming barriers to innovation and the role of public consultation in Chinese Urban Water Management

The strong political will underpinning the "Sponge City" campaign, coupled with a "command and control" style of environmental management in China, may help to overcome at least some of the socio-political uncertainties that currently limit widespread implementation of BGI in the West (O'Donnell et al., 2017; Thorne et al., 2015). Nonetheless, there is a lack of data on public perceptions and attitudes to BGI in China and the "Sponge Cities" campaign focuses heavily on the technical aspects of urban water management. For example, public consultation is not addressed in the technical guidance published by the Government (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2014). Lack of a mechanism for public consultation has also been recognised as an issue in water pollution management in Ningbo (Hsu & Chu, 2015).

Authoritarian implementation of new urban water management policies without significant public engagement may appear to be effective during planning and construction. However, lack of education, outreach and communication with stakeholders and publics affected by BGI reduces the probability of their future involvement in infrastructure maintenance (Everett et al., 2015). Similarly, only when the beneficiaries appreciate the social and environmental benefits of BGI and SuDS, can the monetised values of the assets offset the potentially high costs of constructing and maintaining BGI (Bastien et al., 2011). These findings suggest that the "Sponge City" campaign might benefit similarly from extended public engagement, consultation, and involvement.

In contrast to the modern China, historically in China, public participation in establishing and maintaining water management infrastructure was organised based on social hierarchy. These systems, which originated in close-knit, village communities, gradually disappeared during the 20th century due to urbanisation and ingress of large numbers of migrant workers in the early years of the 21st century. Notwithstanding this, a modern version of the ancient type of social activity was observed between 2011 and 2014 in Yinjiang Village at the Ningbo urban fringe, where the Tuoshan Weir is located. The local community there raised money to restore a dilapidated bridge to its original, grand style and re-installed it across a waterway near the bridge's original location. Such examples are, however, now rare. Few embankments observed along the Nantang and Fenghua Rivers involve the local community; instead, the works were planned, constructed, and funded by City or Local Government.

4.3 | Reinventing Ningbo's blue-green heritage through implementing the "Sponge City" pilot project

In this paper, it is established that, as a Chinese "water town", Ningbo is and always has been a "Blue-Green City." Historically, both BGI (complex networks of natural and artificial channels built with natural materials) and Blue-Green approaches to water and flood risk management (water-sensitive land use, management, and crop selection) were used to mimic the natural water cycle while optimising the cobenefits of sustainable urban/rural water management. However, we have also demonstrated that opportunities for multifunctional water management have diminished and the ancient BG approaches to facilitating such opportunities are disappearing.

While those remaining elements of the ancient freshwater network provide convenient and cost-effective opportunities for implementation of modern BGI, urban, and industrial development across large areas precludes re-creation of ancient Ningbo's flood water management network. It would not be feasible to build every new urban area as Low Intensity Development (LID) and conversion of recently developed areas back to the floodable agriculture fields of the past is simply not an option. Additionally, some experts point out that it is more challenging to retrofit BGI in the old city (as will happen under the "Sponge City" pilot project in Ningbo), than it would be to install BGI in newly developed areas (Lu, 2014). *In essence, there is no possibility of recreating Ningbo's ancient freshwater network as modern BGI.*

Similarly, reintroducing rice or lotus as Blue-Green agricultural crops in existing and planned wetlands would be inappropriate, because these species have a little capacity to remove pollutants from contaminated urban runoff, let alone to be harvested as safely edible agriculture produce. It must be recognised these species, though being utilised widely in the ancient agricultural-led water management for their peculiar flood-resistant life cycles and economic values, have little significant role to play in addressing modern Ningbo's water quality issues. In fact, native floral species such as Water Pennywort (*Hydrocotyle ranunculoides*), Reeds (*Phragmites, Sparganium and Typha*), and Bamboo (*Bambuseae*) are most effective in removing key pollutants (e.g., total nitrogen, phosphate) in modern water ways and are popular choices for urban watershed restoration in Chinese cities, including Ningbo (Zhou et al., 2011).

Accepting that a wholesale, "Back to the Future" re-creation of Ningbo's ancient BGI is impossible and that reintroducing historical water and flood risk management practices would be inappropriate, there *are* still opportunities to reinstate parts of the old water network in Ningbo as modern BGI. For example, the "Eco-corridor" under construction in the East New Town of Ningbo (Figure 8) demonstrates the feasibility of rehabilitating parts of long abandoned waterways to enhance their multifunctionality as biodiverse, Blue-Green urban spaces that provide recreational opportunities while accommodating and cleansing contaminated urban runoff (www.asla.org; Chang, 2015). Within the Eco-corridor, BGI features include woodlands, rain-gardens, cascades of wetlands, meandering streams and open water areas, all constructed to establish an effective water treatment train based on a seminatural ecosystem (Tang et al., 2015).

Implementation of this modern BGI as part of urban development symbolises the recent policy reversal: from reclamation of a waterway as land for intensive industrialisation

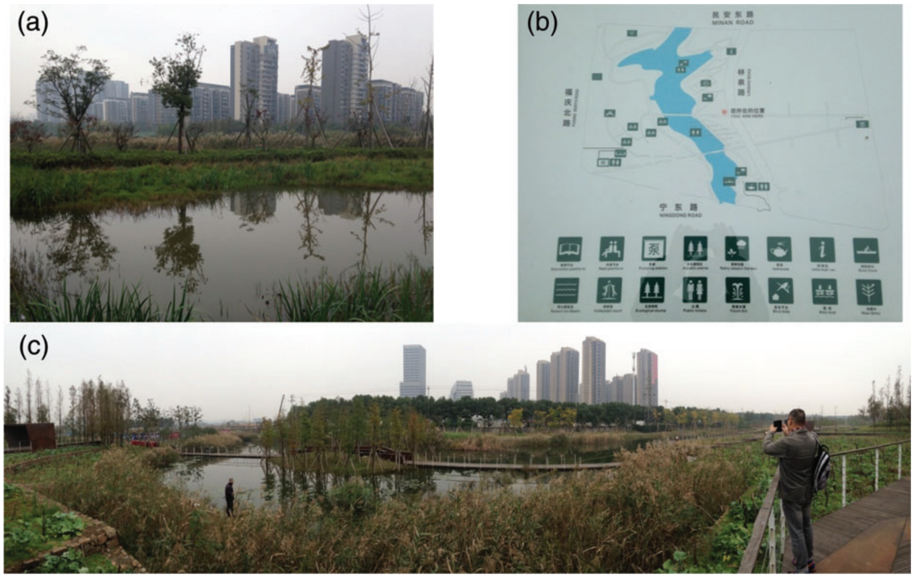

FIGURE 8 Eco-corridor in the East New Town, Ningbo buffers areas of high density residential, commercial and industrial development while (according to an information board in the eco-corridor) providing, "*ecological purification, water storage and a place for people to escape far from the noisy city and to learn or do exercise*". (a) Pocket wetland. (b) Map showing range of eco-features and public facilities. (c) Local residents fishing and viewing the corridor (photograph by authors, November 25, 2016)

and urbanisation to reintroduction of sustainable water management through recreating a more natural water cycle.

Given that opportunities for LID in Ningbo are limited, areas of high-density development like that in the East New Town will need to be interspersed with patches and corridors of BGI that have the capacity to buffer new development and maintain environmental quality at the level desired by Ningbo's growing population (Cheng, 2015). This will be challenging but it is possible, as has been demonstrated in recent redevelopment of the Portland metropolitan area in Oregon (Ozawa & Yeakley, 2007). To achieve similar outcomes in Ningbo, implementation of BGI and Blue-Green approaches will require urban planning by teams with multidisciplinary expertise, who engage with stakeholders to identify suitable locations for hydrological eco-buffers, design the necessary BGI, landscape the sites appropriately, and select the most advantageous species for creating wetlands and surface water treatment trains. In this future, while ancient principles of sustainability and public engagement will be reinstated and opportunities to restore abandoned waterways will be taken, the key to success will be for innovation in the design and implementation of modern BGI, in the spirit of the national "Sponge City" campaign.

5 | CONCLUSIONS

Flood and water management has gradually shifted from engineering solutions that address single issues towards a more holistic approach that generates economic, social, and environmental benefits. The "Blue-Green City" concept, SuDS, and WSUD are gaining international momentum and are implicit to China's "Sponge City" campaign, launched in 2013.

In Ningbo and other Chinese coastal "water towns", ancient practices of water management bear a striking resemblance to the "Blue-Green City" concept. For example, construction of a seminatural channel network to divert freshwater from upstream catchments for municipal use and irrigation employed BGI such as wetlands and rice paddies to increase agricultural productivity while mitigating flood and drought risks. This demonstrates that Blue-Green approaches have worked in the past and should be reconsidered in the context of the need for innovation to deal with future urban flood and water challenges.

This is necessary because urban flood risk is a serious issue for Chinese coastal cities, having been exacerbated by rapid urbanisation and industrialisation (Du et al., 2015). For example, current pluvial, fluvial, and coastal flood risks in Ningbo are far higher than they were historically, when land-use was dominated by agriculture and the area of impermeable surfaces was much smaller. While re-creating the ancient water management network or reversion to agricultural land-uses are not feasible, strategic use of the remnants of the ancient systems should be part of urban redevelopment and ecological restoration that creates a new generation BGI to meet the environmental expectations of current and future civic societies.

Based on successful examples of multibeneficial BGI in the United Kingdom, Europe, United States, Singapore, and Australia, increasing the density of the surface water network in Ningbo by reconnecting old waterways with newly installed BGI (urban forests, bioswales, wetland cascades, deculverted natural watercourses, etc.) is highly likely to be more beneficial than relying solely on piped drainage and concrete-lined surface water channels. The Eco-corridor in Ningbo (Chang, 2015) is a good example of this type of approach as its design has succeeded in increasing the East New Town's capacity to store and treat surface water, while also providing multiple cobenefits as a public amenity and "green lung".

It is concluded that there are great opportunities to integrate BGI into current urban development. However, in contrast to the "Blue-Green" approach to urban flood and water design, which involves intensive public consultation and stakeholder engagement, implementation of the "Sponge City" campaign and modern BGI appears, at this stage, to be organised relatively top-down.

In the modern era, the public are rarely able to contribute to discussions around how and where water and flood risk infrastructure should be built. This is unfortunate as BGI has been found to be most beneficial when and where public participation is strong and local communities are fully engaged in decision-making from the planning stages through to construction and maintenance. This is the case because, for the cobenefits of BGI to be realised in practice, the beneficiaries need to appreciate the multiple benefits that it can provide.

Consequently, a "Blue-Green Cities" style of public participation and community engagement in urban flood and water management could be trialled within the "Sponge City" policy. The aim should be to identify how public involvement in the style that suits socio-cultural contexts of the Chinese communities can contribute to the fulfilment of the overall potential of the "Sponge City" policy, and to achieve its objectives for sustainable urban water management outcomes in resilient urban communities.

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Conflict of interests

All Authors declare no conflict of interest.

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