



Evaluation of a Double Pipe Technology- Performance for Sponge City



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Abstract

Precipitation, evaporation and runoff patterns are changing, resulting in uncertainty about the security of water supply, the quality of drinking water, flood management in urban environments and the long-term health of natural ecosystems. The particular aspects for China are described where, with increasing urbanization, flooding has become a regular occurrence in response, China is developing “sponge cities” to attain resilience to stormwater. This paper describes a novel technology with significant potential; the principle of the ‘double pipe technology’ which involves placement of a perforated pipe below a stormwater pipe, encourages passage from the stormwater pipe down to a second pipe, a perforated pipe. This allows temporary storage in the lower pipe and enhances exfiltration from the lower pipe to the underlying aquifer. A conceptual model of the double pipe technology is provided, and the results show that the surcharge potential in the stormwater pipe is dramatically decreased. The lower pipe is able to capture, store, and eventually infiltrate into the groundwater, storm water runoff where the exfiltrate water from the lower pipe 56% to 62% of the total annual rainfall to be released to groundwater. This would truly enhance groundwater levels and decrease subsidence in areas where this is a major concern (particularly related to coastal zone cities in China).

Introduction

China is a country with severe water problems including dimensions of water scarcity, flooding, and water pollution, all of which have been intensifying in urban areas and threatening socio-economic development. In recent years, urban flooding has become very frequent, pervasive, and severe. For example, it was reported that 641 out of 654 Chinese cities have incurred frequent floods in a survey conducted by the Ministry of Housing and Urban Rural Development (MOHURD). This study showed that over the period 2008–2010, 62% of 351 cities surveyed suffered urban flooding, and 39% experienced flooding on three or more occasions. Since 2008, the number of Chinese cities affected by floods has more than doubled, and at least 130 cities have experienced flooding nearly every year [1].

Making matters worse are also important issues of subsidence, with consequences that will exacerbate urban flooding problems. Land subsidence caused by extensive groundwater pumping has become a factor which cannot be ignored in the sustainable exploitation of groundwater resources. The Hangzhou-Jiaxing-Huzhou Plain is one of the locations with China’s most severe land subsidence problems; the region has experienced dramatic land

subsidence since the 1960s. Historical records of groundwater extraction, hydraulic head, and land subsidence show the latter to be the result of continual and excessive extraction of groundwater from deep confined aquifers [2].

For Beijing, almost two-thirds of the urban water supply comes from groundwater [3]. In recent years, water consumption has sharply increased due to the rapid expansion of Beijing’s population [4]. Groundwater extraction was measured as $2.6 \times 10^9 \text{m}^3/\text{yr}$, with an overexploitation of approximately $1 \times 10^6 \text{m}^3/\text{year}$ [5]. This long-term overexploitation of groundwater has caused a substantial decline in groundwater and land subsidence. By the end of 2010, the land subsidence area reached $4.2 \times 10^3 \text{km}^2$ and 66% of the Beijing plain has been affected by land subsidence ($>50 \text{mm}$), with a maximum sinking of 1.23m. As a consequence, attention is being given to alleviate issues of both flooding and subsidence. In this context, the double pipe technology described herein has particular merit since it can assist with attenuating flooding while also decreasing land subsidence by infiltrating surface water to groundwater. This paper describes research results investigating the potential performance of application of the double pipe technology in Beijing.

Background

China began to focus on the pattern of urban construction a decade ago, when continuous inland flooding shocked citizens. From 2012 to 2014, 180 cities annually incurred inland flooding caused by stormwater. In July 2012, the Chinese capital's heaviest rainstorm in six decades caused serious inland flooding and killed 79 people, with property damage of \$1.8 billion. The frequent mishaps and disasters caused by inland flooding in large cities caused authorities and citizens to be in favor of 'green' rather than 'grey' and unordered, urbanization. China's 12th five-year plan proposed to pay more attention to the storage and recycling of stormwater. As China has become increasingly urbanized, flooding has become a regular occurrence in its cities; 62% of Chinese cities surveyed experienced floods and direct economic losses of up to \$100 billion between 2011 and 2014. The 2016 flooding affected more than 60 million people-more than 200 people were killed and \$22 billion in losses were suffered across China.

Hence, assessment of future changes in urban flooding is very important for managing urban floods by designing new, and re-designing existing, urban infrastructures to be more resilient in response to the impacts of future climate change. While it is speculated that urban floods are speculated to increase in the future, their magnitudes are hard to assess due to uncertainties associated with future climate change scenarios, as well as the under-representation of plausible climate change mitigation and adaptation strategies in the models [6]. Further, severe weather is likely to become one of the greatest reasons for higher costs in the future delivery of water services and managing infrastructure [7]. Precipitation, evaporation and runoff patterns are changing, resulting in uncertainty about the security of water supply, the quality of drinking water, flood management in urban environments and the long-term health of natural ecosystems [8].

Insofar as the issue of subsidence, groundwater over-extraction, waterway degradation, and urban flooding are forcing China's cities to address this vicious cycle. The intent of the sponge city initiative requires a holistic and sustained effort, including effective environmental governance [9]. The optimal goals of the sponge city are that the stormwater generated from rainfall events could be absorbed, stored, infiltrated and cleaned with the natural and/or manmade facilities and the rainfall and stormwater could be transformed into water resources that could be utilized during drought [10]. The recycled water can be used to improve sustainability of recharge-depleted aquifers, offset potable water demand, and help to meet demands of industry and irrigation of urban farmlands [10,11]. It is of great importance, and there is urgency, to explore methods that can minimize the impact of the urbanization process on the natural environment.

In that context, as examples, important cities in northern China experience arid and semi-arid climates, with an average annual rainfall of less than 600mm with precipitation concentrated within the rainy season from May to October. Major urban water problems in these areas include severe water shortages. Therefore, urban

rainwater resource utilization continues to be the focus of sponge city construction in northern China. However, the degree of ability to decrease flooding by infiltration may be limited in some regions due to the shallow vadose zone, hence negating the opportunity to reduce urban runoff and waterlogging by employing some source control measures [12]. The concept of sponge city/LID began to be promoted in new development areas. A milestone of green construction was December 2013, when China's president proposed to develop "sponge cities" with attained resilience to stormwater. From this moment on, national and local policies and guidelines related to the sponge city initiative, including LID, have been issued. As defined in the policy announcement, a sponge city should alleviate the adverse effects of urban construction and recycle 70% of stormwater in-situ by combining five kinds of measures including permeation, retention, storage, purification, and reuse before discharge.

As Wang et al. [13] reported, China has developed 30 pilot sponge cities, billions of Chinese Yuan have been invested in sponge city introduction, and many projects are already in operation although the challenges of urban flooding continue. In the last three years, more than 80% of China's large cities experienced urban flooding; in fact, Beijing, as well as Wuhan and Guangzhou, are flooded more than once a year. By implementing the sponge city projects in cities, China hopes to mitigate urban flooding using different methods, including: minimizing the impacts of urban development on the natural environment through LID; slowing the rate of growth in impervious areas of cities; making an effort to implement green infrastructure; and developing drainage network systems. The sponge city strategy replaces a prior objective of "rapid draining" in urban water management with preserving rainwater as a resource. Accordingly, the Sponge City Project (SCP) advocates for various forms of utilization of rainwater as water sources of cities. One objective of the SCP is to improve urban living experiences that involve water issues by adjusting urban microclimates with various approaches, such as maintaining and raising water areas and enhancing the implementation of urban water landscapes and green infrastructure in cities.

A technology that has significant potential to assist in enhancing green infrastructure is the principle of the 'double pipe technology' which involves placement of a perforated pipe below a stormwater pipe. The basis of the methodology is to encourage passage from the stormwater pipe down to the perforated pipe, as illustrated in Figure 1. This allows temporary storage in the lower pipe and enhances exfiltration from the lower pipe to the underlying aquifer. To evaluate the performance potential, a computer simulation of the response is described herein. The physical regime modelled is defined in Section 3 below.

Case Study Subdivision

The test case (a hypothetical area but representative of Beijing) is shown in Figure 2. It has three catch basins with a total contributing area of 1.44 hectares (ha), with sub-areas sizes contributing from 0.54, 0.48 and 0.42ha each, respectively. The land use has

been assumed as typical urban areas with 75% impervious and land slope of 0.5% towards each catch basin. It is also assumed that infiltration is governed by the Horton equation. To design the size of the storm sewer, a 5-year recurrence interval storm and rainfall duration of two hours was utilized, and the rational method to select pipe sizes. The rainfall Intensity duration and return period relationship for Beijing, China was utilized [14]:

$$I = 12.0 (1+0.811 \text{ LOG}_{10} (\text{Tr}) / (\text{D}+8))^{0.711} \text{ for } \text{D} < 120 \text{ min}$$

$$I = 13.9 (1+1.091 \text{ LOG}_{10} (\text{Tr}) / (\text{D}+10))^{0.759} \text{ for } \text{D} \text{ from } 120 \text{ to } 360 \text{ min}$$

Where I is rainfall intensity in mm/min, Tr is return period in years and D is duration in minutes, as per Table 1.

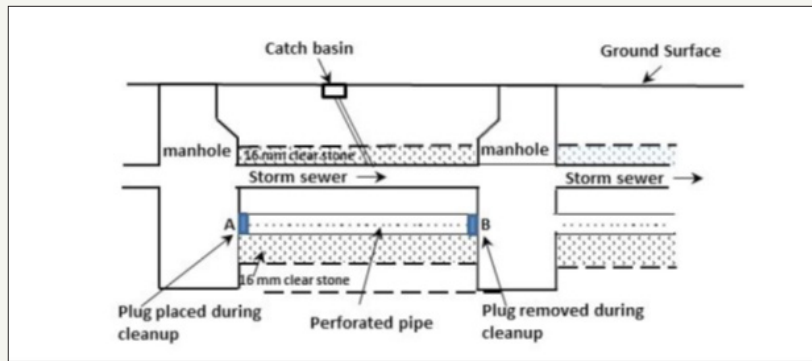


Figure 1: Schematic of Double Pipe Technology Scenario.

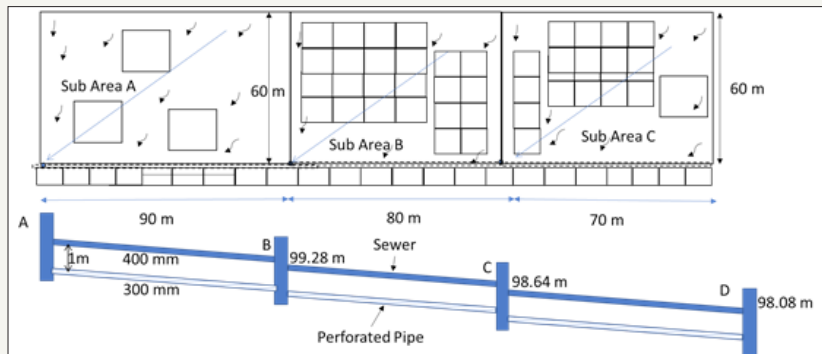


Figure 2: Schematic of Test Case Area.

Table 1: Intensity of rainfall for various time durations and return periods [14].

Tr	Yr	5	5	5	5	5	5	5	5
D	minutes	5	10	15	30	60	120	180	360
I	mm/minute	2.74	2.23	1.91	1.37	0.92	0.59	0.46	0.28
I	mm/hour	164.50	134.07	114.40	81.90	55.02	35.43	27.62	16.59
Amount	mm	13.71	22.35	28.60	40.95	55.02	70.86	82.86	99.54

The configuration of the lower pipe, to facilitate exfiltration and thereby to replenish groundwater, while also preserving the sediment accumulation to avoid clogging of the granular material around the lower pipe (and hence, continued ability to continue to recharge groundwater) is as depicted in Figure 3. The receiving media of soil (using 15mm of clear stone) around the perforated

pipe is capable of absorbing the amount of water ex-filtrated from perforated pipe. The results are shown in Table 2. To estimate the capacity of flows through the perforations into the vadose zone surrounding the lower pipe, orifice flow conditions were assumed, and orifice equations used [15-17].

Table 2: Total Ex-filtration Volume from the Perforated Pipe for a 5-Year 2hr Storm.

Section	Length (m)	M ³	% of Total Rainfall Ex-filtrated
A-D	240	560	56.1

Findings from calculation sequence

From computer modelling, the net result of the scenario of using the double pipe design, resulted in the following results:

- The surcharge potential in the storm sewer is dramatically decreased. The lower pipes can capture, store, and eventually infiltrate into the groundwater, storm water runoff from a two-hour duration, 5-year recurrence interval storm [18,19].
- Overall, over a 40-year time history, the potential exists to exfiltrate water from the lower pipe, at levels varying from 56%

to 62% of the total annual rainfall. This would truly enhance groundwater levels and decrease subsidence in areas where this is a major concern (particularly related to coastal zone cities in China).

c) The findings indicate that so long as the groundwater is >1m below the depth of the lower pipe, the exfiltration will occur.

d) Decreasing the flooding from heavy storms can be captured (the so-called heavy storms that occur several times a year). For major events (e.g. the 25 to 100-year storms), there is only a modest effect due to the magnitudes of the storms.

e) The costs of placement of placing the second pipe increase the overall cost of the installation of this system are about 15% extra and, given the magnitudes of flooding and the resulting damages, this is a technology that has considerable merit.

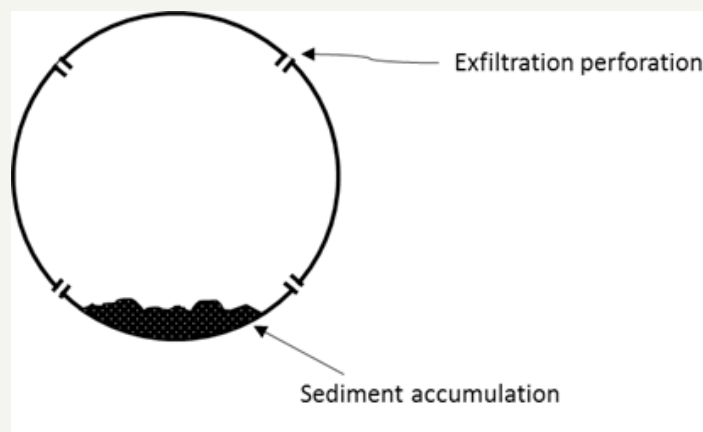


Figure 1: Schematic of Double Pipe Technology Scenario.

Conclusion

There is widespread evidence of major flooding events in urban cities in China. One option that warrants consideration is to use a double pipe system where substantial portions of the storm water can be transferred to the lower pipe where exfiltration will take place. The extent to which this would assist in the lowering of the flood damages could very well be substantial. The costs for such additional implementation of the lower storm water pipe are relatively modest (15 percent increase), if undertaken at the time of the construction of the storm water system.

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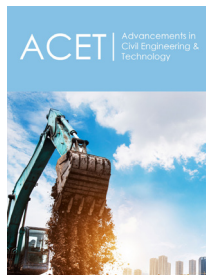
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