Stormwater pollution and management initiatives in Shanghai

Pollution des eaux pluviales et initiatives de gestion à Shanghai

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RÉSUMÉ

Depuis quelques décennies, le développement urbain de la Municipalité de Shanghai entre en conflit et est freiné par des problématiques liées au management des eaux pluviales. Pollution entrainée par les eaux pluviales, Inondation urbaines, Potabilité de l'eau. Chaque année à la saison des pluies, on enregistre 33 millions de mètres cubes d'eaux qui sont rejetés par le système d'assainissement pour cause d'engorgement et se déversent dans la rivière de Suzhou. On estime en moyenne par année que 186 000 personnes sont affectées et que les pertes économiques dues aux inondations sont d'environ 52.7 millions US$.

La Municipalité a récemment décidé de conduire différents pilotes tests dont le Management Intégré de la Ressource en Eau (IWRM), Système de collecte/Utilisation des eaux, Réservoir de stockage des eaux pluviales pour éviter les débordements du système d'assainissement. Elle devrait permettre un meilleur management des eaux pluviales et une stabilisation du réseau aquifère.

Il reste à ce jour de nombreux challenges à adresser: Avoir une approche intégrant une préservation de la biodiversité et du biotope, définir une période de révision du système d'égout plus régulière, promouvoir la réutilisation des eaux de pluies, gestion des inondations, etc.

ABSTRACT

Stormwater problems have become troubles restricting urban development of Shanghai in recent decades with regard to stormwater pollution, urban waterlogging disasters and potable water shortage under increasing pressure of rapid urbanization. There were 33 million cubic meters CSOs flew into the Suzhou Creek in the inner city of Shanghai in rainy season every year. Additionally, an annual average number of 186000 people were affected and the average annual direct economic losses caused due to urban waterlogging disasters reached up to US$ 52.7 million.

Integrated Water Resources Management (IWRM), Low Impact Development (LID), rainwater utilization, stormwater storage tank for combined sewer overflows (CSOs) and other initiatives have been done for stormwater management and sustaining a site's predevelopment hydrologic regime in recent years.

There are still a lot stormwater management issues need to be solved in Shanghai, including ecological stormwater management approach ,increasing design return period for sewer systems, piloting a sewage charge for stormwater, drawing up a stormwater master plan, subsidy for rainwater utilization, stormwater pipeline rehabilitation, building tunnels to reduce stormwater pollution and waterlogging disasters, et al.

KEYWORDS

Combined sewer overflows (CSOs), Integrated Water Resources Management (IWRM), Low Impact Developments (LID), Storm water management, Waterlogging disaster

1 INTRODUCTION

Shanghai, one of the most important economic centres of China, possesses abundant water resources. Firstly, Shanghai is densely covered with 33127 rivers and 26 lakes, and 10% of the area is covered with water (Che et al., 2012a). Secondly, the Yangtze River, the largest in China and the third longest in the world, flowing from the Tibetan Plateau in the west to the East China Sea is flowing through Shanghai (Che et al., 2012b). Thirdly, Shanghai receives an average annual rainfall of 1,200 mm because of a northern subtropical maritime monsoon climate (Lü et al., 2012a).

However, the water quality in most of water function areas that still failed to meet the national standard made Shanghai in a pollution-induced water shortage. It was born of local pollutions and pollutions from upstream Taihu Lake which has been heavily polluted for many years (Lü, 2011).

In recent decades, industrial and domestic pollutions have been effectively controlled and thus stormwater pollution has become the main factor affecting the quality of water bodies in Shanghai. In recent 10 years, Shanghai has started to focus on stormwater pollution control and stormwater management (Lü et al., 2012b).

2 STORMWATER POLLUTION AND MANAGEMENT ISSUES

2.1 Stormwater pollution

Combined and separate sewer systems are coexisting in Shanghai. All of the new towns and new development areas are made up of separate sewer systems and the combined sewer systems are near Suzhou Creek in the inner city of Shanghai. Wastewaters are piped to sewage treatment plants in dry weather, while wastewater and stormwater are pumped into the nearby rivers in wet weather because of low capacity of wastewater treatment plants, especially in rainstorm weather (Lü, 2011).

In 2002, there were 366 planned stormwater drainage systems with the catchment area of 85600 ha and the pump drainage capacity of 4274 cubic meters per second. 237 planned stormwater drainage systems have been constructed up to 2008. There were 261 planned stormwater drainage systems have been constructed with the pump drainage capacity of 3068 cubic meters per second up to 2012. However, 29% planned stormwater drainage systems still have not been constructed up to 2012 and the stormwater pollution would flow into the nearby rivers in such areas.

2.1.1 Combined sewer overflows (CSOs) pollution

Combined sewer systems are near Suzhou Creek in the inner city of Shanghai. From the year 2006 to 2010, there were 33 million cubic meters CSOs flowing into the river in wet weather every year and almost 60% of CSOs occurred in July to September. There were about 8 billion cubic meters, which was the maximum, flowing into the river occurred in August.

From the year 2006 to 2010, the event mean concentration (EMC) of CSOs was a little lower than Shanghai local discharge standard for municipal sewerage system and was 6-15 times than the worst level of national standard for water quality of river. When stormwater occurred, the water where CSOs flowing into the river was always dark and smelly to make many fish dead, and COD_{Cr} of the polluted river water was raised from 20 mg/L to 180 mg/L within 2-5 minutes. The pollution phenomenon will last for 18-36 hours.

Table 1 Stormwater pollution in Shanghai (Lü, 2011)

Pollution	TSS (mg/L)	COD_{Cr} (mg/L)	BOD_5 (mg/L)	TP (mg/L)	NH_4^+-N (mg/L)
EMC of CSOs in inner city	280~900	250~410	30~100	2~4	25~35
EMC of pollution of separate sewer system in inner city	400~1600	160~760	11~30	0.4~1.1	0.9~2.6
EMC of pollution of separate sewer system in new development areas	100~300	60~210	10~23	0.2~0.4	0.8~1.5
Shanghai local discharge standard for municipal sewerage system	⩽400	⩽500	⩽300	⩽8	⩽40
The worst level of national standard for water quality of river	/	⩽40	⩽10	⩽0.4	⩽2

2.1.2 First flush pollution of separate sewer system

EMC of pollution of the separate sewer system in Shanghai was a little lower than the Shanghai local discharge standard for municipal sewerage system except TSS, but much higher than the worst level of national standard for water quality of river except TP and NH_4^+-N (Table 1). Additionally, the degree of pollution of separate sewer system in the inner city is much higher than that in the new development areas (Lü, 2011).

2.2 Urban waterlogging

2.2.1 Waterlogging disasters

There was an average annual number of 186000 people that were affected and the average annual direct economic losses caused due to urban waterlogging disasters reached up to US$ 52.7 million from the year 1998 to 2009 (Table 2). Stormwater inundated 200 streets and flew into 50000 houses and the waterlogging disaster made the direct economic loss of US$ 215.6 million during the “Matsa Typhoon” in 2005, while stormwater inundated 142 streets during the “Anemones Typhoon” in 2012.

Table 2 Urban waterlogging disasters in Shanghai from 1998 to 2009

Year	May-September Precipitation (mm)	Number of people affected (thousand people)	Direct economic losses (US$ million)
1998	654.8	11.6	6.3
1999	713.6	201.7	152.4
2000	566.5	107.1	32.9
2001	1087.7	252.7	51.4
2002	644.2	108.2	67.5
2003	430.5	4	2.9
2004	407	17.9	8.1
2005	565.8	1036.9	275.7
2006	442.8	0	0.0
2007	604	72.3	28.4
2008	674	50.7	6.3
2009	698.2	0	0.0

Data source: Shanghai Water Resources Bulletin (1998-2009)

2.2.2 Reasons for waterlogging

There are at least three reasons for the waterlogging disasters in Shanghai in recent decades.

Firstly, the unique characteristics of rainfall in Shanghai lead to the waterlogging disasters. Shanghai records an average value of 132 days with precipitation annually, which equals to a yearly precipitation of 1200mm. Influenced by typhoons in summer, sixty percent of the rainfall pours down in wet weather from May to September. Short duration and high intensity are the characteristics of rainfall in the wet weather in Shanghai and a record was 108.5 mm from 7:00 (am) to 8:00 (am) on August 24, 2008.

Secondly, urban expansion and its effects play a major role in the causes of waterlogging disasters. As one of the most urbanized city in China, urbanization rate of Shanghai rapidly increased from 75% in year 2000 to 89% in year 2011.On the one hand, rapid urbanization alters land cover to impervious surface, and produces larger runoff coefficient and runoff. On the other hand, rivers that store floodwater, especially the small ones, are filled. From year 1860 to year 2003, more than 310 rivers in the inner city of Shanghai as long as 520km disappeared. The water area dropped 10.46km^2, with a decrease of 3.61% in the rate of water area. Simultaneously, the total river storage capacity reduced 2.03 million cubic meters, equalling to more than 80% of the former capacity.

Thirdly, the design return period for sewer system is very low in Shanghai. At the present time, most of the constructed sewer systems in Shanghai just can achieve the standard to resist a one-year storm. The planning standard for important areas like central business areas, the EXPO Area, airports and railway stations is to resist a three-to-five-year storm. However, such areas only cover 4% of the planning areas. Compared to metropolises abroad and other large cities in China like Beijing and Guangzhou, standard of drainage in Shanghai is relatively low. Under the present standard in 2012, there are still 105 sewer systems that have not been completely constructed, accounting for 28% of the planned systems.

Table 3 Design return period for sewer system of cities in the world

City	Design return period (year)	Design rainfall intensity (mm/h)				
		1 year	2 years	3 years	5 years	10 years
Shanghai	1 year, 3-5 years for important area	36	44.3	49.6	56.3	65.8
Beijing	3-5 years, 10 years for important area	36	44.6	50	56	65
Guangzhou	1-2 years，2-20 years for important area	50	58.7	63	69	78
Hongkong	10 years, 200 years for main pipes and drains	/	70.7	/	90.4	103
Taipei	5 years, 20 years for important area	/	/	/	79	90
Tokyo	5-10 years	/	/	/	50	60
Atlanta	2-10 years	/	41	/	53	63
Chicago	5 years	/	/	/	45.7	/
Paris	5 years	/	/	/	180	/

2.3 Stormwater management issues

Storm water management issues in Shanghai include: Firstly, the administration has not established a storm water management plan or storm water master plan, and the storm water management framework of whole city has not been built. Secondly, storm water management is not attuned to the city development and management. The government pays more attention to urban construction investment overground than sewer systems underground. Thirdly, about 12% of the storm sewers, that is, over 1200km storm sewers have reached or exceeded their serviceable life (30 to 40 years), which caused the amount of groundwater infiltration reached about 30% to 40% of the average sewage. Maintenance and management of storm sewers is difficult and costly.

3 INITIATIVES FOR STORMWATER MANAGEMENT

3.1 Integrated Water Resources Management (IWRM)

At the national level, river management and drainage systems separately belong to the Ministry of Water Resources and the Ministry of Housing and Urban-Rural Development, which causes a problem of multi-head management in stormwater management. But in Shanghai, the concept of integrated water resource management (IWRM) was firstly accepted, and the Shanghai Water Authority is in charge of unified management including storm water, sewerage, rivers, water supply and other water affairs.

In 2011, the China government announced a new concept of the Strictest Water Resource Management System, and Shanghai is chosen as an experimental area. Storm water management is one of the most important content of the strictest water resource management system. Thus, input to the construction of storm water infrastructure and storm water management will be increased evidently in recent years.

Additionally, storm water management is a major matter in the construction of a water-saving society. Till end of the year 2010, there were three districts (Qingpu District, Jinshan District and Pudong New District), eight eco-industrial parks, one agricultural park, 148 enterprises, 80 school campuses, and 1341 residential communities have been titled “water-saving” by the state government. However, the construction of water-saving society mainly relies on government leading, and is in lack of market regulation and public participation.

Shanghai’s sewage charges are currently based on the consumption of potable water, and there is little correlation between the stormwater generated and utilized by a development area. Yet as stormwater management and regulatory requirements have evolved, Shanghai is doing researches to pilot a sewage charge for stormwater so as to encourage source controls, to awaken public awareness around stormwater issues, and provide a dedicated budget for stormwater management.

3.2 Low Impact Development (LID) and rainwater utilization

Low Impact Development (LID) is a comprehensive land planning and engineering design approach to manage stormwater runoff by using engineered, on-site, small-scale hydrologic controls (Prince George’s County, 1999). There are many LID practices and rainwater utilization systems which have been used in the new development areas in Shanghai, including Shanghai Expo Area, Lingang New City and Spring Dew Mansion Area, et al. However, LID has not been taken as an important approach in the master plan and stormwater management plan of Shanghai, and the proportion of rainwater utilization is less than 10% of the precipitation every year.

3.2.1 Shanghai Expo Area

LID practices and the rainwater utilization systems are adopted in construction of the EXPO Park and many pavilions (Zhang et al., 2010). Some pavilions (like pavilions of China, Norway, Singapore, the United State, London), the Expo Axis, the Expo Center and other pavilions collected and treated roof rainwater for the use of road cleaning and plant irrigating. Besides, case pavilions of Rhone-Aples, Rotterdam, Prague, London, Chengdu, Madrid exhibited. The plan of the post use of EXPO Park also followed LID practices and rainwater utilization technologies.

3.2.2 Lingang New City

Lingang New City is a planned harbor city approximately 70 kilometers southeast of downtown Shanghai. Upon completion in 2020, it is expected to accommodate 1.2 million people and supply the deepwater container port at Yangshan with multi-modal logistic and transportation support (Lü, 2011). The planning area of Lingang New City is about 30000 ha, and almost half of area is coverd by green space. Bio-retention ponds and other LID practices are widely used in Lingang New City so as to make runoff coefficient below 0.6 and to reduce 30% of the stormwater runoff pollotions flowing into the water bodies (Lü et al, 2012b).

3.2.3 Spring Dew Mansion Area

The Spring Dew Mansion Area (SDMA) is the first so-called eco-residential area in Shanghai, which was developed in 2006 by China Vanke Co., the largest real estate developer in China. SDMA stood out among residential areas because of the water-sensitive technologies, including the rainwater utilization system and LID practices such as green roofs, permeable pavements, bio-retention, rain garden and et al. By using such technologies, the runoff coefficient has been decreased from 0.63 (before development) to 0.42 (after development) and US$ 4311 per year was saved by using rainwater as an alternative water resource for potable water to renew lake, irrigate vegetables, wash roads and wash cars (Lü et al., 2012a).

3.3 Stormwater storage tank for CSOs

Storm water storage tanks are widely used for mitigating impacts of CSOs into receiving waterways in the world (Field et al., 1997). There are 11 off-Line storage tanks built in Shanghai (Table 4). During wet weather, the tanks are put into operation for temporary storage of the first flush, and the stored wastewater will be pumped back to the sewer so as to transport the wastewater to the sewage treatment plant during dry weather.

Table 4 Stormwater storage tanks built in Shanghai

Receiving waterway	Location of tank	Type of sewer system	Storage volume (thousand cubic meters)	The year of putting into operation	Amount of CSOs decrease in 2011 (%)	COD_{Cr} of CSOs decrease in 2011 (%)
Suzhou Creek	Chengdu	combined	7.4	2006	5.4	8.1
	Xinchangpin	combined	15	2009	63.6	78.8
	Mengqing Garden	combined	25	2010	78.8	92.3
	Jiangsu	combined	10.8	2011	34.3	47.2
	FurongJiang	combined	12.5	2012	/	/
	Xinshida	combined	15	2011	/	/
Yunzhao Creek	South Yunzhao Road	combined	25	2011	/	/
Huangpu River（Shanghai EXPO Area）	Nanmatou	separate	3.5	2010	/	/
	Puming	separate	8	2010	/	/
	Mengzi	separate	5.5	2010	/	/
	Houtan	separate	3.8	2010	/	/
Total		/	131.5	/		/

Data source from Shanghai Municipal Sewerage Company Ltd (2006-2012).

Tank Chengdu, put into operation in 2006, is the first storm water storage tank for CSOs in China. It has a service area of 3.06km^2 with a storage volume of 7400m^3. From 2006 to 2010, it effectively operated 74 times in wet weather, and cut down an average of 89000m^3 first flush overflow annually, equalling to 8.5% of the first flush overflow. Due to experiments, the average consistencies of COD_{Cr}, NH_4^+-N and TP of inflow were 420mg/L, 30mg/L and 3mg/L, while average consistencies of those of effluent were 270mg/L, 20mg/L and 2.3mg/L. That meant the storm water storage tank would reduce COD_{Cr}, NH_4^+-N and TP by 13.35tons, 0.89toms, and 0.06tons respectively. Owning to the function of storage tank, first flush with high consistency of pollution is intercepted, and sewage flowing into the river hardly causes fishes in the overflow gate dead.

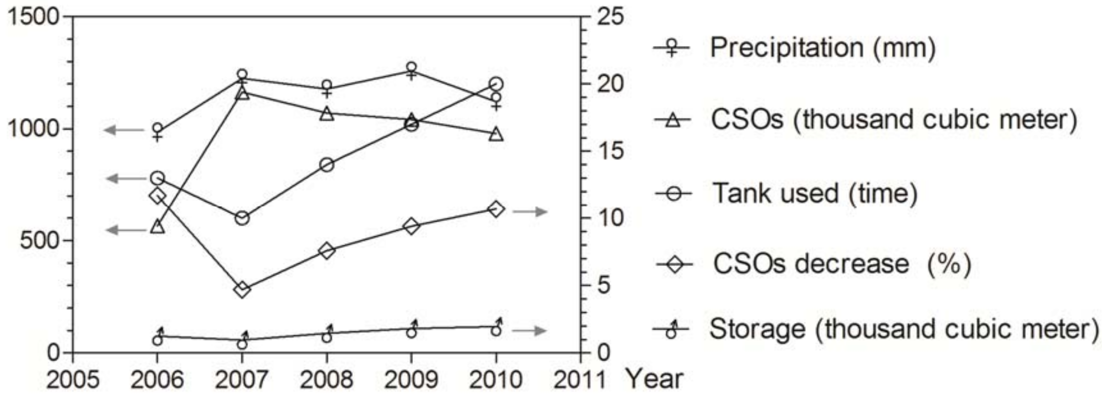

Figure 1 Operation efficiency of the first stormwater storage tank for CSOs in China

Data source from Shanghai Municipal Sewerage Company Ltd (2006-2010).

4 CONCLUSION AND PROSPECT

Combined and separate sewer systems are coexisting in Shanghai. The stormwater pollutions both from combined and separate sewer systems were much higher than the worst level of national standard for water quality of river. There were 33 million cubic meters CSOs flew into the Suzhou Creek in the inner city of Shanghai in wet weather every year and almost 60% of CSOs occurred in July to September from 2006 to 2010.

The short duration and high intensity rainfall, rapid urbanization and lower design return period for sewer system made waterlogging disasters easy to occur in the rainstorm weather. An average annual number of 186000 people were affected and the average annual direct economic losses caused due to urban waterlogging disasters reached up to US$ 52.7 million from the year of 1998 to 2009.

Integrated Water Resources Management (IWRM), Low Impact Development (LID), rainwater utilization, stormwater storage tank for CSOs and other useful initiatives have been done for stormwater management in Shanghai in recent years and sustaining a site's predevelopment hydrologic regime in recent years.

There are still a lot stormwater management issues need to be solved in Shanghai, including ecological stormwater management approach, increasing design return period for sewer systems, piloting a sewage charge for stormwater, drawing up a stormwater master plan, subsidy for rainwater utilization, stormwater pipeline rehabilitation, building tunnels to reduce stormwater pollution and waterlogging disasters, et al.

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