Water Science & Technology | 67.1 | 2013

Design and assessment of urban drainage and water reuse systems for the reconstruction of formerly industrial areas: a case in Beijing

L. Liu, S. Zeng, X. Dong and J. Chen

ABSTRACT

The Shougang Group is an industrial steel enterprise occupying 800 ha in Beijing that will cease production by 2010. The area will be converted to a new financial and commercial zone. The rebuilding of the water infrastructure in this area should address water shortages in Beijing and retain the industrial landmark of a large cooling water tank. A design framework and an assessment system with 11 indicators were developed for this purpose. Four reconstruction schemes are presented here. Scheme 1 is a traditional system that completely depends on outside the municipal facility. Schemes 2, 3, and 4 are systems to separately discharge greywater and blackwater. Scheme 4 uses a vacuum system that allows the reclamation of nutrients. Schemes 2 and 4 use wetland-treated greywater to fill the water tank. Scheme 3 reuses greywater for toilets after on-site treatment. Scheme 2 is recommended due to its lower cost, greater environmental benefit, moderate resource reclamation, and higher technical feasibility.

Key words | indicator system, industrial area reconstruction, scheme design and assessment, source separation, urban drainage system, water reuse

L. Liu
S. Zeng (corresponding author)
X. Dong
J. Chen
Department of Environmental Science & Engineering,
Tsinghua University,
Beijing, 100084,
China
E-mail: *szeng@tsinghua.edu.cn*

INTRODUCTION

Formerly industrial areas usually occupy crucial space and always constrain the development of modern cities. A large number of industrial areas have recently been rebuilt; examples include Granville Industrial Island in Vancouver, Canada, and the industrial area in Ruhr, Germany, representing that country's largest coal and steel manufacturing base. Both of these areas were rebuilt as tourism, cultural, and commercial zones (Liu 2007). The reconstruction of industrial areas often stimulates the regeneration of municipal infrastructures.

The Shougang Group is a large-scale historic industrial steel enterprise occupying nearly 800 ha in western Beijing that will cease production by the end of 2010, in accordance with local air-pollution control strategies. The zone for which planning is discussed in this paper comprises 286 ha of industrial heritage within this area that will be developed to support the financial, commercial, and tourism industries. This area includes many important industrial heritage structures, such as several disused furnaces and a large circulating tank for cooling water storage. The rebuilding of the urban water system must address two problems: water shortage, and the preservation of the cooling water tank. Water shortage is a common issue in such reconstruction efforts, and forms the background for system design in Beijing. Beijing currently has less than 300 m^3 per capita of water resources, which falls below the 500 m^3 standard for the most water-poor regions in the world. The cooling water tank is an impressive industrial landmark, situated in the western portion of the study area, that could serve as a man-made lake with a volume of 1.26 million m^3 and is worthy of preservation. Figure 1 shows the planned land use layout of the case, where the area of public places, roads and squares, lawns and the man-made water body is 98.87, 37.30, 124.86, and 25.34 ha respectively. The system design must meet the challenge of identifying and economically utilizing a new water source. Other critical problems for this water system include stormwater collection and utilization within the context of toxic soils, and the impact of climate change on the system. This paper, however, focuses on the sewer and water reuse systems.

Traditional wastewater treatment and reuse usually employs a centralized system. In such a system, wastewater

doi: 10.2166/wst.2012.516

Figure 1 | Planned land use layout of the case area.

is transported to the wastewater treatment plant (WWTP) by pipe networks, and treated wastewater is reused through a municipal wastewater reclamation process (He *et al.* 2001). In Beijing, treated wastewater has been used to water roads, irrigate lawns, and wash cars (Xu 2007). To overcome the defects of traditional water systems, several new system models and concepts have recently been proposed. Examples include an onsite treatment and reuse system (Orth 2007) and a source separation and greywater reuse system (Ghunmi *et al.* 2008). The greywater discussed here is domestic wastewater, excluding sewage but including bath, laundry, and kitchen wastewater that represent 60–70% of domestic water use, with a low concentration of organic pollutants, nutrients and few pathogens (Friedler 2004; Madungwe & Sakuringwa 2007; Jamrah *et al.* 2008), while blackwater is the water from toilet flushing and comprises 30–40% of domestic wastewater (Maher & Lustig 2003; Friedler & Hadari 2006; Travis *et al.* 2010). Greywater reuse has become a practical option that may conserve water and reduce environmental pollutants (Al-Jayyousi 2003; Campisano & Modica 2010, 2012; Pinto *et al.* 2010). Many cases have been reported on how greywater from single household, multi-storey apartment, school, hotel, sport club, or small community was collected separately, treated and reused for toilet flushing, home gardening and even nutrients recovering (Nolde 1999; Gual *et al.* 2008; Godfrey *et al.* 2009).

Recently, harvested rainwater has been also recognized as a potential unconventional water resource, depending on different underlying surfaces and environmental hydrologic characteristics (Glendenning *et al.* 2012; Palla *et al.* 2012). For the Shougang area, precipitation on the large water body – the cooling tank – will be counted as a supply. As for the roof runoff and road runoff, some Best Management Practice and Low Impact Development measures such as green roof and permeable pavement have been planned, with the main objective of cutting down the runoff flow peak and pollution load, which will not be illustrated in this paper. However, other structural measures aiming at rainwater storage and further in-house utilization are hardly implemented, considering the rainfall-runoff quantity and quality under Beijing's current circumstances. The average annual precipitation since 2000 is only 440 mm within the range of 318–522 mm including snowfall, while the rainfall distribution is quite uneven with July and August contributing 40–60% of the total (China Meteorological Administration 2001–2011). Due to the scarce rainfall and poor air quality in Beijing, the runoff concentration is quite high, for example, the chemical oxygen demand (COD) in roof runoff and express way is around 79–310 mg/l and 122–643 mg/l (Ouyang *et al.* 2010; Hou *et al.* 2012). As a result, when designing the urban water reuse system scheme in the case area, rainwater will not be used as a large-scale stable water source for the regional water supply except for the cooling water tank.

Under such a context, this paper presents a framework for the planning of an urban drainage and water reuse system that takes new technologies into consideration, and illustrates such planning with the case of the Shougang area reconstruction.

METHODS

The planning methodology is discussed here in two parts. The first part describes the development of schemes for urban drainage and water reuse systems, and the second part introduces the assessment system by which the schemes are compared.

System scheme design

The design procedure for urban drainage and water reuse systems in the reconstruction of formerly industrial areas consists of four steps. In step 1, information on planned land use is collected. The type and area of land use represent the type and demands of potential reclaimed water users. In step 2, reclaimed water supply and demand are predicted, and the supply–demand balance is evaluated. As both treated wastewater and greywater are potential water sources, this prediction is based on the area of each land type, the reclaimed water demand index (i.e., amount of demand per land area), the greywater discharge index, and the wastewater discharge index (i.e., amount of supply per land area). Index values are shown in Table 1. It is worth mentioning that the greywater discharge are determined through fixed ratios of greywater to total wastewater, depending on different land use types, as well as the toilet flushing water demands. In step 3, the system structure is determined. The variety of water sources and their corresponding users, including freshwater, treated wastewater, and treated greywater, may affect the system structure in a centralized or decentralized manner. System structure design determines the flow of water and nutrients from the source to the system outlet on the basis of water balance. Industrial legacies that strongly influence this balance and, thereby, the system structure, should be fully considered to ensure the improvement of the landscape. In step 4, the system layout is arranged. Appropriate scales, locations, and technologies for treatment facilities must be determined. The pipe network, including the lengths and diameters of main pipelines, can then be devised in accordance with the system structure.

Table 1 | Land use types and corresponding water indexes [L/(m^2 d)]

Land use type	Reclaimed water demand index	Wastewater discharge index	Greywater discharge index
Residential	1.38 (for toilet flushing)	4.05	2.68
Public places	2.16 (for toilet flushing)	5.46	3.29
Roads and squares	1.50 (for road watering)	–	–
Lawn land	2.00 (for irrigation)	–	–
Mixed residential/ public places	1.77 (for road watering)	4.75	2.98
Waterscape	Cooling water tank	–	–

System scheme assessment

To improve system sustainability in the reconstruction process, an integrated assessment of economic, environmental, resource reclamation and technical risks is required for scheme selection. Due to difficulties in defining boundary and quantification, social costs/benefits are not included in the assessment. The method of comprehensive assessment based on an indicator system is a practical option (Dong *et al*. 2008). An indicator system with 11 indicators that consider different aspects of system performance is developed for this assessment (Table 2). Economic cost indicators may differ in proposed system schemes, depending on facility types. Potential facilities include traditional WWTPs, decentralized (onsite/local) greywater treatment stations, and centralized greywater and blackwater treatment plants. Corresponding pipe networks may be necessary to transport wastewater, greywater, blackwater, and/or reclaimed water, and include relevant pump stations. Only direct costs are involved in the economic indicator computation, without any rebates due to concessional loans, special tariff rates, government subsidies or any other preferential policies. Internal and external environmental impacts are considered in the assessment process.

Table 2 | The indicator system used in scheme assessment

Aspects	Indicators
Economic cost	(1) Construction costs of treatment facilities and pipe networks (2) Operation costs of treatment facilities and pipe networks
Environmental impact	(3) Sewage emissions into planning area (4) Pollutant emissions into planning area (5) Sewage emissions outside of planning area (6) Pollutant emissions outside of planning area
Resource reclamation	(7) Freshwater demand (8) Reclaimed water demand from external municipal facility (9) Nitrogen resources lost (10) Phosphorous resources lost
Technical risk	(11) Immaturity of technology

The determination of total sewage emission may include mixed wastewater, greywater, and/or blackwater. As to pollutant types, COD, total nitrogen (TN), and total phosphorous (TP) should be included. Water and nutrient resources must be considered. In this context, technical risk includes risks due to the lack of design manuals and operational experience for new technologies, such as vacuum blackwater collection. This qualitative indicator is determined by the expert scoring method; higher scores represent less mature technologies and lower scores indicate better system performance.

To compare assessment results of different system schemes, a radar chart can be drawn using Microsoft Excel 2003, which have 11 radii representing 11 indicator axes. As indicators have different scales, a more understandable way is to take one scheme as a baseline, i.e., each scheme is standardized through dividing its indicator values by the corresponding baseline values. For the sake of easy comparison, the radar chart shows the ratios of all schemes to the baseline scheme.

RESULTS AND DISCUSSION

System schemes

According to the wastewater discharging principles of hygienic safety, economic and technical feasibility, and environmental tolerance (Nolde 1999), under the instruction for planning steps (see previous section), four reconstruction schemes have been proposed for the urban drainage and water reuse system of the Shougang industrial area. Figure 2 illustrates the system structures and water balance. The four schemes all accept the service provided by a municipal freshwater supply plant and a municipal WWTP. Both facilities are located outside of the study area. The reclaimed water demands of the four schemes differ, due to differences in the proposed demands of the cooling water tank and toilet flushing.

Scheme 1 is a traditional system discharging sewage to and utilizing reclaimed water sources from the municipal facility outside the study area. The reconstruction zone is thus treated as a typical civil region within the city. It remains unknown, however, whether the current outside WWTP is large enough to accept additional wastewater, and whether sufficient reclaimed water will be available to fulfil the new demand. Plans do not currently exist to construct a new facility that would solve these problems for the case area.

Schemes 2, 3, and 4 are systems that discharge greywater and blackwater separately, which include the addition of domestic greywater discharge pipes. These systems also incorporate internal water reuse, which would alleviate pressure on the wastewater treatment and water reclamation capacities of the external municipal facility.

Schemes 2 and 4 use greywater generated in the study area and treated by a wetland that maintains the cooling water tank, and use reclaimed water from the external municipal facility only for road watering, lawn irrigation, and toilet flushing. The blackwater systems of these two schemes differ. Blackwater is discharged to the external WWTP in scheme 2, whereas scheme 4 uses a vacuum sanitary system that can significantly reduce the water volume of toilet flushing and collects blackwater for sequential nutrient recovery at a blackwater treatment station (Lopez Zavala *et al.* 2002; Jonsson & Vinneras 2007).

Scheme 3 is a system with onsite greywater treatment and reuse in toilets. The blackwater from toilet flushing and remaining greywater from the greywater treatment station are transported together to the external WWTP. Scheme 3 uses reclaimed water from the external municipal facility for road watering, lawn irrigation, and to maintain the landscape of the cooling water tank.

Because the quality of secondarily treated greywater is superior to that of treated wastewater from the WWTP (Eriksson *et al.* 2002), schemes 2 and 4 offer a greater reduction than schemes 1 and 3 in total annual influent into the cooling water tank by decreasing the frequency of water recharge.

Scheme layouts

The layouts of the pipe network systems, pump stations, onsite treatment stations, and building stacks differ among schemes. For all schemes, a surface-flow wetland will be constructed near the inlet of the cooling water tank to purify greywater or reclaimed wastewater. This wetland will be 3.5 ha in area and 0.5 m in depth, and will have a retention time of 2 d.

Scheme 1 has no treatment facility but two pipe systems (wastewater discharge and reclaimed water supply networks), with total lengths of 8,817 and 7,989 m, respectively. The proposed stack for wastewater in buildings is 100–150 mm in diameter.

The layout of the blackwater and reclaimed water pipe networks in scheme 2 is the same as that of scheme 1, differing only in smaller proposed pipe diameters. However,

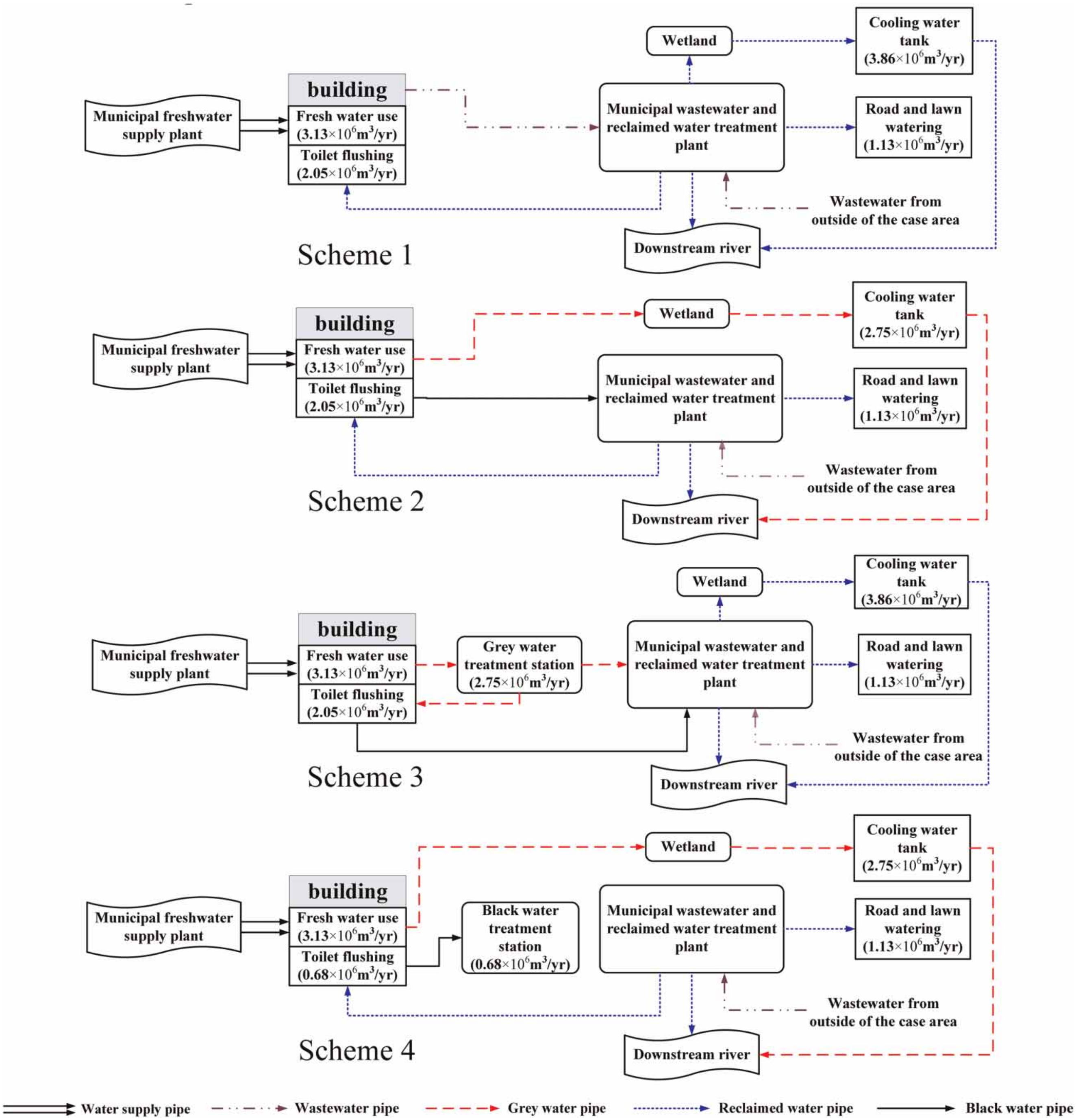

Figure 2 | Structures and water flows of the four schemes.

Scheme 2 incorporates an additional 9,935 m long greywater pipe system. The scale of the greywater pump station is 198.64 L/s, and its proposed location is in the lowest, southeastern area. Scheme 2 proposes two building stack systems, one for blackwater (100 mm diameter) and another for greywater (75–125 mm diameter).

Because greywater is reused onsite in scheme 3, only two municipal pipe networks (for wastewater and reclaimed water) are proposed. Their layouts are the same as in scheme 1, with smaller diameters due to the reduced water demand. This scheme proposes 57 onsite greywater treatment stations at public buildings, with a total scale of

8,574 m^3/d. The stack system of scheme 3 is identical to that of scheme 2.

The municipal pipe systems proposed in scheme 4 are greywater and reclaimed water pipe networks. The networks and pump stations are identical to those of scheme 2, whereas blackwater is collected onsite and transported in a specialized truck to the blackwater treatment station. This scheme proposes 57 onsite blackwater pump stations that collect blackwater through a vacuum pipe system with a total scale of 5,560 L/s. The stack pipe systems are greywater pipes (75–150 mm diameter) and vacuum blackwater pipes (100 mm diameter).

Table 3 | Results of the economic assessment of the four schemes

Indicators	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Construction costs of pump station and pipe networks (×10^6 Yuan)	9.21	12.58	6.96	31.16
Operation costs of pump station and pipe networks (×10^6 Yuan/yr)	0.020	0.029	0.015	0.069
Construction costs of onsite treatment station and building stacks (×10^6 Yuan)	0.60	1.00	15.58	1.00
Operation costs of onsite treatment station and drainage stacks in the building (×10^6 Yuan/yr)	0	0	3.10	0
Construction cost of the wetland (×10^6 Yuan)	4.00	4.00	4.00	4.00
Operation cost of the wetland (×10^6 Yuan/yr)	0.62	0.44	0.62	0.44

Scheme assessment

The four schemes were compared using the indicator system outlined in previous section. Table 3 shows the results of the comparison of economic indicators. The proposed municipal pipe networks in schemes 1 and 3 are simpler and less costly than those in schemes 2 and 4. Scheme 4 requires the construction of numerous blackwater pump stations, incurring heavy costs. Because schemes 2 and 4 reduce total water use amount by the cooling water tank, their wetland operation costs are less than those of schemes 1 and 3.

Table 4 shows the results of environmental indicator comparison. As the recipient body in the planning area, the cooling water tank requires high-quality water. Schemes 2 and 4 use superior-quality treated greywater to maintain the cooling water tank. Schemes 2, 3, and 4 reuse greywater within the study area, reducing sewage and pollutant emissions to external environments.

Table 5 shows the results of resource indicator comparison. The freshwater demands of the four schemes are the same. They differ in the demand for reclaimed water from the external municipal facility, depending on the water

Table 5 | Results of the resource assessment of the four schemes

Indicator	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Freshwater demand (×10^4 m^3/yr)	370.47	370.47	370.47	370.47
Reclaimed water from external WWTP (×10^4 m^3/yr)	703.95	317.95	499.16	180.86
Nitrogen resources lost (×10^3 kg/yr)	250.91	250.91	250.91	0
Phosphorous resources lost (×10^3 kg/yr)	2,171.70	2,171.70	2,171.70	0

Table 4 | Results of the environmental assessment of the four schemes

	Pollutant emissions into planning area (×10^3 kg/yr)			Pollutant emissions outside of planning area (×10^3 kg/yr)			Sewage emissions into planning area (×10^4 m^3/yr)	Sewage emissions outside of planning area (×10^4 m^3/yr)
Scheme	COD	TP	TN	COD	TP	TN		
1	115.80	1.16	5.79	1,397.88	25.89	279.58	386.00	517.73
2	48.19	0.83	4.13	824.75	23.30	271.19	275.39	204.79
3	115.80	1.16	5.79	944.48	23.84	272.94	386.00	312.95
4	48.19	0.83	4.13	824.75	23.30	271.19	275.39	68.26

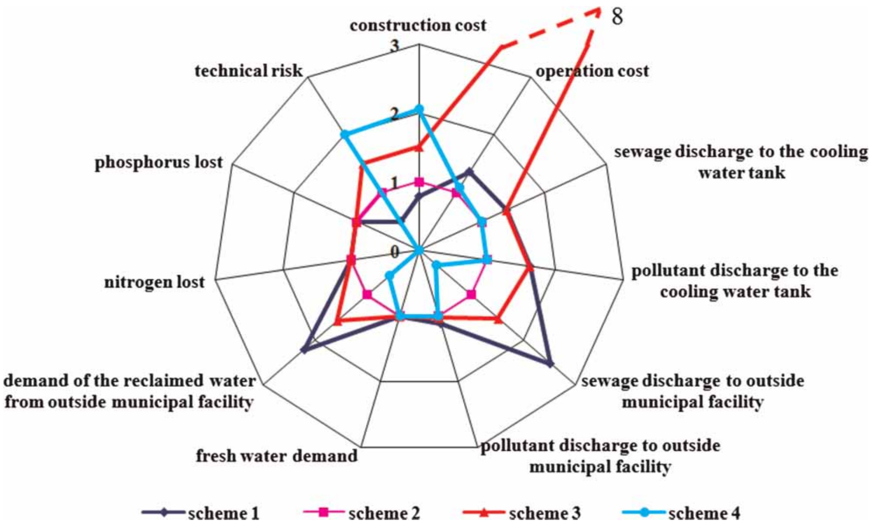

Figure 3 | Results of system assessment.

source used for the cooling water tank. Schemes 2 and 4 thus show greater resource benefits than schemes 1 and 3. Furthermore, scheme 4 proposes the recovery of nitrogen and phosphorous nutrients through blackwater collection technology.

Comparison on the basis of technology maturity revealed that scheme 1 is a traditional water system utilizing mature technology with a detailed design code. However, this scheme does not allow a system upgrade to complete source separation. Scheme 4 incorporates immature technology that needs new design codes, especially for the vacuum system. Schemes 2 and 3 fall between Schemes 1 and 4 for these technology indicators. Because scheme 3 requires numerous onsite greywater treatment stations, its system reliability is lower than that of scheme 2.

These results indicate that scheme 2 is the best option from an economic perspective. Scheme 4 exhibits superior environmental performance and resource reclamation. Technical risk is lowest for scheme 1. After comparing the four schemes, to show the results more clearly, the results were rescaled using scheme 2 as the baseline (Figure 3). We recommend scheme 2 due to its lower cost, greater environmental benefits, moderate resource reclamation, and higher technical feasibility.

CONCLUSION

This paper presented a scientific design and assessment framework for urban drainage and water reuse systems in the reconstruction of formerly industrial areas. Using the reconstruction of the Shougang industrial area in Beijing as a case study, we designed four schemes. Scheme 1 is a traditional sewage drainage and water reuse system with the lowest technical risk, although it lacks clear environmental and resource benefits. Schemes 2, 3, and 4 are systems that discharge greywater and blackwater separately. Greywater is used to maintain the cooling water tank in schemes 2 and 4, maximizing environmental and resource benefits. Scheme 3 is an onsite treatment and decentralized reuse system with the largest budget requirement. Based on our integrated assessment that considered economic cost, environmental impact, resource reclamation, and technical risk, we recommend scheme 2 to the local government.

The stakeholders in this project have expressed different perspectives and system preferences. Local officials strongly support a sustainable urban drainage system that maximizes environmental and resource benefits, and prefer the incorporation of advanced water-conservation concepts. Planners and designers have two voices. Some prefer innovative planning that uses decentralized approaches, but others insist on the superiority of a traditional system that eliminates the technological and operation risks associated with decentralized systems. Developers and investors tend to avoid decentralized systems due to their experience with similar onsite facilities which have been plagued by the lack of O&M professionals and had to close down later. The final recommendation of scheme 2 can comprise these diverse viewpoints quite well.

ACKNOWLEDGEMENTS

This research was funded by the Beijing Municipal Institute of City Planning and Design. The authors are grateful to this institute and to the Shougang Group, who provided support in the data collection phase of research.

REFERENCES

Al-Jayyousi, O. R. 2003 Greywater reuse: towards sustainable water management. *Desalination* **156** (1/3), 181–192.

Campisano, A. & Modica, C. 2010 Experimental investigation on water saving by the reuse of washbasin grey water for toilet flushing. *Urban Water Journal* **7** (1), 17–24.

Campisano, A. & Modica, C. 2012 Optimal sizing of storage tanks for domestic rainwater harvesting in Sicily. *Resources, Conservation and Recycling* **63**, 9–16.

China Meteorological Administration 2001–2011 *Meteorological Yearbook of China (2000–2010)*. CMA, China.

Dong, X., Chen, J., Zeng, S. & Zhao, D. 2008 Integrated assessment of urban drainage system under the framework of uncertainty analysis. *Water Science and Technology* **57** (8), 1227–1234.

Eriksson, E., Auffarth, K., Henze, M. & Ledin, A. 2002 Characteristics of grey wastewater. *Urban Water* **4** (1), 85–104.

Friedler, E. 2004 Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environmental Technology* **25** (9), 997–1008.

Friedler, E. & Hadari, M. 2006 Economic feasibility of onsite greywater reuse in multi-storey buildings. *Desalination* **190** (1/3), 221–234.

Ghunmi, L. A., Zeeman, G., Lier, J. V. & Fayyed, M. 2008 Quantitative and qualitative characteristics of grey water for reuse requirements and treatment alternatives: the case of Jordan. *Water Science and Technology* **58** (7), 1385–1395.

Glendenning, C. J., Van Ogtrop, F. F., Mishra, A. K. & Vervoort, R. W. 2012 Balancing watershed and local scale impacts of rain water harvesting in India – a review. *Agricultural Water Management* **107** (1), 1–13.

Godfrey, S., Labhasetwar, P. & Wate, S. 2009 Greywater reuse in residential schools in Madhya Pradesh, India – a case study of cost-benefit analysis. *Resources, Conservation and Recycling* **53** (5), 287–293.

Gual, M., Moia, A. & March, J. G. 2008 Monitoring of an indoor pilot plant for osmosis rejection and greywater reuse to flush toilets in a hotel. *Desalination* **219** (1–3), 81–88.

He, P., Phan, L., Gu, G. & Hervouet, G. 2001 Reclaimed municipal wastewater – a potential water resource in China. *Water Science and Technology* **43** (10), 51–58.

Hou, P., Ren, Y., Wang, X., Ouyang, Z. & Zhou, X. 2012 Research on evaluation of water quality of Beijing urban stormwater runoff. *Environmental Science* **33** (1), 71–75 (in Chinese).

Jamrah, A., Al-Futaisi, A., Prathapar, S. & Harrasi, A. 2008 Evaluating greywater reuse potential for sustainable water resources management in Oman. *Environmental Monitoring and Assessment* **137** (1–3), 315–327.

Jonsson, H. & Vinneras, B. 2007 Experiences and suggestions for collection systems for source-separated urine and faeces. *Water Science and Technology* **56** (5), 71–76.

Liu, J. 2007 The change from ruin to renaissance – experiences on reconstruction of formerly industrial areas abroad. *Beijing Planning Review* **80** (2), 21–27. (in Chinese).

Lopez Zavala, M. A., Funamizu, N. & Takakuwa, T. 2002 Onsite wastewater differential treatment system: modelling approach. *Water Science and Technology* **46** (6/7), 317–324.

Madungwe, E. & Sakuringwa, S. 2007 Greywater reuse: a strategy for water demand management in Harare? *Physics and Chemistry of the Earth* **32** (15–18), 1231–1236.

Maher, M. & Lustig, T. 2003 Sustainable water cycle design for urban areas. *Water Science and Technology* **47** (7/8), 25–31.

Nolde, E. 1999 Greywater reuse systems for toilet flushing in multi-storey buildings – over ten years experience in Berlin. *Urban Water* **1** (4), 275–284.

Orth, H. 2007 Centralised versus decentralised wastewater systems? *Water Science and Technology* **56** (5), 259–266.

Ouyang, W., Wang, W., Hao, F., Song, K. & Wang, Y. 2010 Pollution characterization of urban stormwater runoff on different underlying surface conditions. *China Environmental Science* **30** (9), 1249–1256 (in Chinese).

Palla, A., Gnecco, I., Lanza, L. G. & La Barbera, P. 2012 Performance analysis of domestic rainwater harvesting systems under various European climate zones. *Resources, Conservation and Recycling* **62**, 71–80.

Pinto, U., Maheshwari, B. L. & Grewal, H. S. 2010 Effects of greywater irrigation on plant growth, water use and soil properties. *Resources, Conservation and Recycling* **54** (7), 429–435.

Travis, M. J., Wiel-Shafran, A., Weisbrod, N., Adar, E. & Gross, A. 2010 Greywater reuse for irrigation: effect on soil properties. *Science of the Total Environment* **408** (12), 2501–2508.

Xu, C. 2007 Research and thinking on water reuse planning in Hangzhou City, China. *Water and Wastewater Engineering* **33** (7), 36–39 (in Chinese).

First received 22 February 2012; accepted in revised form 20 July 2012