Analysis of Sydney's recycled water schemes

Zhuo CHEN[1], Huu Hao NGO[1*], Wenshan GUO[1], Xiaochang WANG[2]

[1]Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia

[2]School of Municipal and Environmental Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055, China

*Corresponding author, Email: h.ngo@uts.edu.au, Tel: +61 (2) 95141693, Fax: + 61(2) 95142633

Abstract Recycled water provides a viable opportunity to partially supplement fresh water supplies as well as substantially alleviate environmental loads. Currently, thousands of recycled water schemes have been successfully conducted in a number of countries and Sydney is one of the leading cities, which has paid great effort in applying water reclamation, recycling and reuse. This study aims to make a comprehensive analysis of recycled water schemes in Sydney for a wide range of end uses such as landscape irrigation, industrial process uses and residential uses (e.g. golf course irrigation, industrial cooling water reuse, toilet flushing and clothes washing etc.). For each representative recycled water scheme, this study investigates the involved wastewater treatment technologies, the effluent water quality compared with specified guideline values and public attitudes towards different end uses. Based on these obtained data, multi criteria analysis (MCA) in terms of risk, cost-benefit, environmental and social aspects can be performed. Consequently, from the analytical results, the good prospects of further expansion and exploration of current and new end uses were

identified towards the integrated water planning and management. The analyses could also help decision makers in making a sound judgment for future recycled water projects.

Keywords Recycled water schemes, end use, water quality, public attitudes, integrated water planning and management

1 Introduction

Prolonged drought conditions, increased water consumption, deteriorated water quality and highly variable climate in Australia have forced water authorities, consumers and local councils to consider recycled water as a supplementary water supply [1]. This can help in alleviating the pressure on existing water supplies, protecting remaining water bodies from being polluted and on the other hand providing a more constant volume of water than rainfall-dependent sources. Particularly, in Sydney, the capital city of the state of New South Wales in Australia, water supply dams have exposed to extreme low water levels (less than 65% of full operating storage) since early 2004 due to extended drought. A large population of 4.5 million people and its continuing 1.3% growth every year also put pressure on current water supply strategies. For these reasons, in addition to mandatory water restrictions, sustainable water reuse projects have been increasingly implemented and explored. Sydney now recycles about 33 gigalitres per year (GL/yr) of wastewater for non-potable uses including agriculture, irrigation, industry and residential indoor and outdoor activities as well as indirect potable reuses. As the city has the highest level of effluent discharge but lower recycling levels than any other Australian cities, the demand to increase water recycling is large. According to 2010 NSW Metropolitan Water Plan [2], recycling will increase to 70

GL/yr by 2015 (equivalent to 12% of Sydney's current water demands) and future water recycling schemes will deliver up to 100 GL/yr of water by 2030.

Basically, the success of recycling schemes depends largely on several issues such as water quality, infrastructure cost, proximity of the sewage treatment plant (STP), availability of suitable land, social/community attitudes, environmental impacts, etc. Thus, they should be carefully considered to ensure that recycled water is managed in an ecologically sustainable and cost-effective way. This paper begins with an outline of the current water recycling schemes in Sydney. As comprehensive analyses of above-mentioned constraints are still lacking, this paper proposes an assessment framework with emphasis on the use of integrated assessment tools (e.g. MCA) in ranking current water recycling schemes and identifying the preeminent water recycling alternatives for future projects. A case study on the Rouse Hill Water Recycling Scheme is conducted afterwards.

2 Water recycling schemes in Sydney

Sydney Water Corporation (SWC), as the biggest government-run water supplier in Australia, have been operating water supply, sewage and large recycled water as well as storm water functions since 1992. Local councils have been left with only small scale onsite water recycling services and residual drainage functions [3]. Presently, there are about 20 large-scale water recycling schemes and 150 smaller local-scale projects running in greater Sydney, with many more in the planning and construction stages [2,4]. Most of these schemes are related to non-potable uses (e.g., irrigation, industry, residential uses and environmental flows) whereas indirect potable reuse and direct potable reuse schemes are not widely discussed.

2.1 Recycled water for agricultural and landscape irrigation

In the last 5 years, the greater Sydney region has paid great effort in expanding and increasing irrigation schemes which uses about 4.6 GL/yr of recycled water for irrigating farms, parks, sports fields and golf courses [5]. For example, large-scale agricultural irrigation schemes such as Carlton Farm, Elizabeth Macarthur Agricultural Institute and Warwick Farm Racecourse are being successfully implemented, saving considerable fresh water and reducing fertilizer costs. Many local authorities are also actively involved in irrigating parks and spots fields with recycled water, including the Hawkesbury campus of University of Western Sydney (UWS), the councils of Penrith, Wollongong and Camden. Besides, Penrith and Ryde city councils also treat and return the backwash water to public swimming pools which are regarded as newly developed end uses. Additionally, irrigating golf courses with recycled water is widely conducted at many golf clubs (e.g., Ashlar Golf Club, Dunheved Golf Club, Richmond Golf Club, Kiama Golf Club, etc.), which has proved to be beneficial during the severe drought of 2002-03 [4,6]. While most of the above-mentioned schemes are centralized ones that import recycled water from nearby STPs, some small scale water recycling schemes are decentralized options with individual on-site wastewater collection, treatment and supply systems. These sewer mining projects include Kogarah Municipal Council’s Beverley Park Water Reclamation Project, Macquarie University Playing Fields Project, Workplace6, North Ryde Golf Club Scheme, Pennant Hills Golf Club Scheme and Sydney Turf Club Scheme. With respect to effluent quality, to ensure its safety and sustainability, NSW water recycling guidelines for irrigation continue to be revised towards more stringent ways so that most of STPs have upgraded their treatment facilities in meeting tertiary or even drinking water quality requirement. For instance, in 2005, SWC carried out extensive alternations to Richmond STP which used to supply secondary effluent to nearby consumers. Intermittently decanted aerated lagoon (IDAL) process coupled with tertiary treatment (e.g., sand filtration, chlorination and dechlorination) have replaced the old trickling filter, resulting in the harmless discharge of nitrogen gas to the atmosphere [7]. Likewise, Ryde City Council has introduced new technologies at Ryde Aquatic Leisure centre where UV treatment has replaced the ozone water treatment system to filter and recover backwash water in swimming pools.

2.2 Recycled water for residential areas

Since only 1% to 4% of residential water consumption is actually used for drinking, SWC has recognized its opportunity for substantial water saving and constructed dual-reticulation pipe systems in some residential areas, supplying recycled water for garden watering, toilet flushing, car washing, etc. For instance, the Rouse Hill Water Recycling Scheme, located at north-western Sydney, is the largest residential water recycling scheme in Australia which started in 2001 and uses up to 2.2 GL/yr of recycled water, serving over 19,000 homes and reducing drinking water demand by about 40% [2]. Another representative demonstration is the Water Reclamation and Management Scheme (WRAMS) owned by Sydney Olympic Park Authority. It has extended the urban water recycling concepts to integrated water management by incorporating both storm water and recycled water in recycled water delivery systems. The novel storm water reservoir design enables storm water from the Olympic Park and excess secondary effluent from STP to be stored and regulated so that the subsequent Water Treatment Plant (WTP) can be operated at any rate to cope with large events. In addition to serve 2,000 houses in neighboring residential suburb of Newington, WRAMS also supplies recycled water to all commercial premises and sporting venues at Sydney Olympic Park [8]. At the same time, some decentralized/localized schemes in remote suburbs are carried out where households have installed greywater diversion and treatment systems either in a group or individually. Taking Mobbs' house in Chippendale for example, about 100 kiloliters per year (KL/yr) of wastewater from the house is processed by three filter beds and UV radiation and then used for toilet flushing, clothes washing and garden watering [6]. Having noticed the great benefits from these dual reticulation schemes, SWC continue to develop large-scale recycling schemes on newly released residential areas. For example, it has now expanded the Rouse Hill Water Recycling Scheme to eventually serve 36,000 homes. A similar scheme at Hoxton Park, south-western Sydney will be completed by 2013 and supply 2.3 GL/yr of recycled water to about 14,000 future homes as well as industrial development areas. As recycled water from these schemes generally has high risk exposure to customers and potential cross connection errors, it is essential to use advanced tertiary water treatment technologies (e.g., microfiltration (MF), reverse osmosis (RO), chlorination and UV disinfection) to achieve higher water quality standard. Current recycled water quality in existing schemes has achieved all mandatory chemical, physical and biological performance standards [4].

2.3 Recycled water for industry

Compared with irrigation and residential uses, industry water consumption is relatively small in Sydney, accounting for 12% of the total water demand. Nevertheless, due to the imposition of water restrictions during drought but constant high water demand in specific industrial sectors, many industrial corporations attempt to solve this problem by improving their water use efficiency with new facilities together with introducing recycled water schemes. For instance, SWC's STPs deliver up to 4 and 20 megalitres per day (ML/d) of recycled water to Eraring Power Station and BlueScope Steel, respectively, where high-quality recycled water treated by MF, RO, UV disinfection and demineralization processes are used as cooling or boiler feed make up water [9]. Besides, BlueScope Steel has also conducted interdepartmental water reuse schemes (wastewater from one sector is reused in another sector) and installed a 300 KL/d onsite treatment plant to provide secondary treated water for internal quench basins [10]. Similar to BlueScope Steel, Port Kembla Coal Terminal also receives recycled water from the Wollongong STP and has been using it for dust suppression since 2009, reducing 70% fresh water consumption. Moreover, a new technology using filtration, de-ionisation and UV treatment to process wastewater from the electroplating has been introduced at Astor Metal Finishes Villawood factory. It is a pioneering technology in Australia and is capable of recovering most of the wastewater. Apart from existing industrial recycling schemes in mining, refinery, fiber cement, commercial laundry and food processing industries, many more projects are being constructed or under consideration. Particularly, the Rosehill-Camellia Recycled Water Scheme, the first one owned by private sectors in NSW, is expected to deliver 4.7 GL/yr of recycled water to six major industrial customers in western Sydney and will become one of the Sydney's largest industrial recycling projects [2, 4]. Even if the treated water is of potable grade in most industrial sector, strict guidelines with the same health standards as for residential recycling schemes are applied because employees engaged in dust suppression or cleaning unavoidably have frequent contact with recycled water.

2.4 Recycled water for the environment

SWC operates 17 inland STPs that discharge recycled water into the Hawkesbury-Nepean River System where water supply dams and weirs have been built in the upper catchment. To release reliable environmental flows and protect the downstream health of the river, these STPs have been upgraded to advanced tertiary standards since 2004. For example, the new St

Marys Water Recycling Plant in the city's west is now in operation as the first of its kind in the world. Tertiary treated wastewater from Penrith, St Marys and Quakers STPs is transferred to this plant and undergone additional ultrafiltration (UF), RO, decarbonation and disinfection processes, substituting 18 GL/yr of drinking water currently being released from Warragamba Dam into the Hawkesbury-Nepean River. Till now, due to high recycled water quality requirement and limited exposure to the public, most of environmental flow schemes are successfully implemented and neither adverse environmental impacts nor human health problems have been identified.

While indirect potable reuse (IPR) schemes have not been pursued in Sydney, incidental IPR do occur since major water supply sources–Warragamba Dam and Nepean River periodically receive effluents from Goulburn and Penrith STPs, respectively. Despite the fact that there is significant dilution of the treated wastewater with the catchment source water in most situations which lowers risk profiles, IPR is a relatively recent topic of public discussion because the initial potable water recycling plant in Quaker's Hill, northwest of Sydney, was put aside during the 1990s owing to public misgiving [3].

3 Assessment framework and methodology

While the water recycling targets are projected to be more aggressive, several constraints (e.g., water quality, cost, site-specific conditions, social/community attitudes, environmental impacts, etc.) may hamper the progress of potential water reuse market. Moreover, the focus on the planning and development of future water recycling schemes is a positive move but leaves open the question of sustainability for existing schemes where large quantity of the population lives. Currently, systematic analyses on these issues have already being conducted in some states of Australia, including Victoria, Australian Capital Territory, Queensland and

South Australia, but that is not the case in New South Wales. Consequently, this paper aims to make a comprehensive analysis of current water recycling schemes in Sydney and identify the preeminent alternatives for future projects using MCA. The decision making framework proposed in Figure 1 is to provide a holistic approach in comparing and arriving at the preferred option.

Figure 1

Based on the above framework, a full assessment procedure related to water recycling schemes can be developed and it should consists of the following main steps [11,12]:

(1) Determination of intentions. The first thing is to determine the major type of the scheme, whether to provide recycled water for agricultural irrigation, industry or indirect potable use, etc. The second is to recognize whether to assess existing schemes, evaluate the viability to upgrade the existing schemes or implement new schemes.

(2) Integrated water recycling assessment planning. This includes: (i) consider the site specific conditions and different end uses of recycled water; (ii) apply the potential assessment criteria (risk of recycled water to health and the environment, operability of STP, environmental impacts, social impacts and public attitudes as well as cost and benefits); and (iii) assess regional water strategy, STP planning strategy and integrated water resource planning.

(3) Identification of options. This step is to apply technical, economic or social principles (e.g., reliability, safety, feasibility, affordability, availability and acceptability) and consult with stakeholders, experts and consumers who are potentially involved in water reuse to sieve out unsuitable options.

(4) Evaluation of options. Once several options are determined, they should be

investigated in detail. In this case, MCA can be carried out with a series of assessment criteria, and then weighting, scoring and normalization techniques are applied to achieve an overall value for each option. The assessment criteria can be selected referring to similar case studies conducted nearby, site assessment report and local planning report, etc. Additionally, weighting is one of the most important processes in MCA that must be carefully assessed to ensure the results of the evaluation are consistent with the preferences of the decision makers. Generally, the higher weights are assigned to more important criteria whereas smaller weights were given to less important criteria with a total sum of 100%. After the weights have been assessed, the component scores can be aggregated. Equations (1) and (2) show the additive model which is one of the predominant aggregation methods in MCA.

$$CA_{ij} = \alpha_1 f(x) + \alpha_2 f(y) + \alpha_3 f(z) + ..., \tag{1}$$

$$CA_i = \sum_{i,j=1,...n} \beta_i CA_{ij} \tag{2}$$

where CA_{ij} is the combined score for any key criteria (e.g., water supply, environmental considerations, costs and benefits, etc.) at co-ordinates *i, j*. α_1, α_2, α_3,…are sub weighting factors and *x*, *y*, *z*,…are the scores of sub-criteria. The final score of one water recycling option (CA_i) is the sum of scores obtained from each key criterion (CA_{ij}) multiplied by corresponding primary weightings (β) [13]. Nevertheless, scores associated with these criteria are complex as their data may come in different forms. While modeling and monitoring results (e.g., water quantity, water quality, greenhouse gas emission and energy use) are usually presented as quantitative estimates, risk assessment, social/community considerations and cost-benefit analyses incorporate a higher degree of qualitative judgment by the person or the project team [14]. Hence, for qualitative data, the state of Victoria has developed a scoring system on a 9-point scale (Table 1) whereas 11-point scale, 5-point scale and 7-point scale have been reportedly used in cases studies at the state of Australian Capital Territory, Queensland and South Australia respectively [11]. As qualitative information is likely to show bias towards or against certain technologies due to personal judgment, it is important to use quantitative data where possible. Quantitative data normally require normalization or data scaling process to make the final score dimensionless thereby enabling comparison because both quantitative criteria and sub-criteria are likely to contain different dimensions (e.g., water quantity, energy use, cost, etc.). There are four data scaling methods in MCA, including min-max approach, zero-max approach, range approach and distance-to-target approach. With regard to min-max and zero-max approaches, the normalized score is expressed in equations (3) and (4) respectively.

$$\mathrm{CA}_{\mathrm{normalized}} = \frac{CA_i - \min(CA_1, CA_2 ... CA_i)}{\max(CA_1, CA_2 ... CA_i) - \min(CA_1, CA_2 ... CA_i)} \quad (3)$$

$$\mathrm{CA}_{\mathrm{normalized}} = \frac{CA_i}{\max(CA_1, CA_2 ... CA_i)} \quad (4)$$

where min(CA_1, CA_2…CA_i) is the minimum score and max(CA_1, CA_2…CA_i) is the maximum score in regard to one criterion among all selected options. The range approach is similar to min-max approach except the denominator where the boundary conditions are set on the basis of other information (e.g., best available technology). Comparatively, as for distance-to-target approach, it is necessary to define a target and express the normalized score as a ratio of the distance (CA_i) to that target [15]. As a result, options are ranked according to their scores. To increase the confidence in making a decision, the final indexes and outcomes are subject to a sensitivity analysis which involves examining how the ranking of options might change under different scoring or weighting systems so as to refine the validity of preferred option within specified bounds.

(5) Implementation of preferred option. Before implementing the preferred option, viability assessment should be conducted again, especially for newly developed schemes. When undertaking detailed design, stakeholders should discuss with SWC and local councils, establish water reuse supply and consumption agreement and prepare an environment improvement plan. If necessary, they should also acquire EPA and other relevant approvals.

(6) Monitoring and review. After implementing the preferred option, monitoring and review are required. The system should also enable comparative analysis against other existing or potential projects.

Table 1

4 A case study on Rouse Hill Water Recycling Scheme - MCA and discussion

The Rouse Hill Water Recycling Scheme is one of the most successful schemes in Australia. However, the end uses of recycled water are limited as most households only utilize it for toilet flushing, garden watering and car washing [16]. Besides, due to no restrictions on the use of recycled water, households in Rouse Hill use significantly greater quantity of water than households without dual reticulation systems so that recycled water use efficiency has been kept low [17]. In regard to the recycled water treatment technology adopted at the study area, Tangsubkul et al. [18] evaluated the existing continuous microfiltration (CMF) system from an environmental perspective by life cycle assessment technique. The study indicated that the CMF option performed relatively poorly under most environmental impact categories due to the high levels of energy and chemical consumption required to produce a high quality effluent. These constraints are likely to limit the sustainable development of water reuse in the long term. Since the capacity of this scheme has already been doubled recently to serve additional 20,000 homes, it is necessary to further expand current end uses as well as improve water use efficiency. For these reasons, to give suggestions on further end uses exploration and water use efficiency improvement, this paper discusses several possible recycled water use options together with their characteristics (Table 2).

Table 2

Furthermore, this paper performs a hypothetical MCA to show how technical, environmental, social and economic criteria are evaluated. Due to lack of quantitative data, all criteria are qualitatively assessed using the scoring system described in Table 1. Based on the collected information in Table 2, higher scores are generally assigned to options with positive impacts whereas negative scores are associated with adverse impacts. For instance, as all options have positive effects on the environment via reduced effluent discharge or lower ecological footprint, positive scores were given to them in Table 3. Yet the varying degree of environmental impacts makes the final scores of these three options towards sub-criteria a little bit different. In addition to scores, Table 3 outlines the corresponding weights of sub-criteria and key criteria. Since the primary objective of the Rouse Hill Water Recycling Scheme is to reduce the nutrient loads on the Hawkesbury-Nepean River system caused by the discharge of treated wastewater, environmental performance has been assigned the highest weight. Other weighting values are based on similar case studies conducted in the state of Victoria [11,12] as well as a survey of Australian water reuse research priorities [21].

According to the obtained results, as all three options generated positive scores, they are greater in value than the current schemes and can have active contributions to the sustainable development. The recycled water for washing machine has been identified as the preferred recycled water use option that best satisfied the overall criteria. To further confirm the result, one-dimensional sensitivity analysis on environmental aspect is performed to vary a single weight and observe the effects on the results of the three options. When assigning a given weight to this criterion, the ratios among the other weights regarding remaining criteria are held constant.

Table 3

As can be seen from Figure 2, the sensitivity analysis indicates that Option 1 is the preferred one when the weight on environmental considerations is relatively high (greater than 22%) whereas Option 2 can be the superior choice if environmental impacts are not the major concerns. Option 3 is never the most preferred alternative for any weight combination. Since the environmental consideration on river system is the prime concern in real case, it is concluded that from a holistic point of view, Option 1 is the recommended option. In respect of implementation, organizational support, decision support, communication support, external interface and consultations are also required.

Figure 2

The above MCA might be improved if the following considerations are taken into accounts:

- Detailed analysis on current STP, the nearby catchment and climate conditions might include to avoid leaving out any key criteria.
- The application of MCA requires a sophisticated decision-making system with more public participation and a considerable amount of computation for exploration and

analysis to minimize the human- caused errors.

- The price of recycled water could also be an important component in analyses.
- Computerized simulation might be required when the number of criteria is more than three.

6 Conclusions

In spite of increasing implementation of water recycling schemes in Sydney for a wide range of fields (e.g., agricultural and landscape irrigation, residential area, industry and the environment), comprehensive analyses on future projects or existing schemes regarding the upgrade and improvement are still lacking. This study proposes an assessment framework and methodology for detailed evaluation of water recycling schemes and conducts a simplified case study at Rouse Hill using MCA approach. The overall results from this qualitative MCA indicate that recycled water for washing machine is the preferred option. With more quantitative assessment data regarding weights and scores are available in future investigations, more detailed MCA as well as computer-based multi-dimensional sensitivity analyses towards a series of potential water recycling options can be performed to achieve more realistic and reliable outcomes. While the case study focuses on one residential recycling scheme, the assessment methodology can be applied to other existing schemes or future projects across Sydney.

Acknowledgements

This study was supported by ARC Linkage Grant (ARCLP100100494). The participation and contribution from Allconnex Water, City West Water, Port Macquarie Hasting Council and Sydney Olympic Park are highly appreciated.

References

1. Al-Rifai J H, Gabelish C L, Schafer A I. Occurrence of pharmaceutically active and non-steroidal estrogenic compounds in three different wastewater recycling schemes in Australia. Chemosphere, 2007, 69: 803—815
2. NSW Office of Water. 2010 Metropolitan Water Plan, 2010. http://www.waterforlife.nsw.gov.au/__data/assets/pdf_file/0020/15275/2010_Metropolitan_Water_Plan.pdf
3. Stenekes N, Colebatch H K, Waite T D, Ashbolt N J. Risk and governance in water recycling: public acceptance revisited. Science, Technology & Human Values, 2006, 31(2): 107—134
4. Sydney Water. Recycling, 2011. http://www.sydneywater.com.au/Water4Life/recycling andreuse/
5. Australian Bureau of Statistics. Water Account Australia 2008-09, 2010. http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/D2335EFFE939C9BCCA2577E700158B1C/$File/46100 _2008-09.pdf
6. Australian Academy of Technological Sciences and Engineering. Water Recycling in Australia 2004, 2004. http://www.atse.org.au/resource-centre/func-startdown/136/
7. Aiken J T, Derry C, Attwater R. Impact of improved recycled water quality on a Sydney irrigation scheme. Water, 2010, 37: 86—90
8. Chapman H. WRAMS, sustainable water recycling. Desalination, 2006, 188: 105—111
9. Anderson J. The environmental benefits of water recycling and reuse. Water Science and Technology, 3(4): 1—10
10. Hird W. Recycled water—case study: BlueScope Steel, Port Kembla Steelworks. Desalination, 2006, 188: 97—103
11. Coutts S S. A recycled water strategy for regional urban communities. Desalination, 2006, 188: 185—194
12. Muthukaruppan M, Arabatzoudis C, Poon J, Hau J, Simmonds K. Alternative water supply sources for industrial users—investigating options for the Altona Industrial Precinit, Victoria. Water, 2011, 38(2): 130—135
13. Jeffrey P, Seaton R, Parsons S, Stephenson T and Jefferson B. Exploring water recycling options for urban environments: a multi-criteria modeling approach. Urban Water, 1999, 1: 187—200
14. Kiker G A, Bridges, T S, Varghese A, Seager T P, Linkov I. Application of multicriteria decision analysis in environmental decision making. Integrated Environmental Assessment and Management, 2005, 1(2): 95—108
15. Benedetto L D, Klemes J. The environmental performance strategy map: an integrated LCA approach to support the strategic decision-making process. Journal of Cleaner Production, 2009, 17: 900—906
16. Cooper E. Rouse Hill and Picton Reuse Schemes: innovative approaches to large-scale reuse. Water Science and Technology: Water Supply, 2003, 3(3): 49—54
17. Toole J O, Sinclair M, Leder K. Recycled water exposure: filling the data gaps. Water, 2008, 35(8): 52—57

18. Tangsubkul N, Beavis P, Moore S J, Lundie S, Waite T D. Life cycle assessment of water recycling technology. Water Resources Management, 2005, 19: 521―537
19. Pham T T N, Ngo H H, Guo W S, Dang H P D, Mainali B, Johnston A, Listowski A. Response of community to the public use of recycled water for washing machine: A case study in Sydney. Australia, Resources, Conservation and Recycling, 2011, 55: 535―540
20. Spaninks F. Estimating the savings from water restrictions in Sydney. Water, 2010, 37(5): 65―70
21. Dillon P. Water reuse in Australia: current status, projections and research. In: Proceedings of the Water Recycling Australia 2000, Adelaide, 2000, 99―104

Table 1 The scoring system

Impact	Score	Impact	Score	Impact	Score
Very much better	+4	Litter better	+1	Much worse	–3
Much better	+3	No change	0	Moderately worse	–2
Moderately better	+2	Very much worse	–4	Little worse	–1

Table 2 Descriptions of three possible recycled water use options

Options	(1) Recycled water for washing machines	(2) Recycled water for swimming pools	(3) Level 1 water restriction on the use of recycled water
Water quality requirement	Current recycled water can be safely used without any quality improvement	Additional advanced treatment (e.g., membrane technology) is required to recycle backwash water	Current recycled water can be safely used. Level 1 restriction includes no use of sprinklers or other watering systems (excluding drip irrigation) as well as no hosing of hard surfaces and vehicles at any time
Water quantity	Laundry generally requires 20% of total water use. Given the total water use is 5.5 GL/yr in Rouse Hill, this option can save around 1.1 GL/yr of fresh water	There are three community swimming pools in Rouse Hill. Given the water use of 80 KL/day for each one, this option can save around 87.6 ML/yr of fresh water	Due to STP failure and maintenance, 15% of the water sold as recycled is clean drinking water. Level 1 restriction can result in 12% reduction of water demand, saving up to 264 ML/yr of recycled water. This equals to save 39.6 ML/yr of fresh water.
Risk	The risk is even lower than recycled water used for toilet flushing because of less exposure	Although the exposure to recycled water is high, the improved quality can sufficiently reduce the risk	Reduced recycled water consumption can reduce its exposure to human and the environment to some extent
Environmental considerations	Reduced effluent discharge and freshwater use	Reduced effluent discharge and freshwater use	High water use efficiency and low ecological footprint
Community attitudes	60% of respondents in Sydney agree this option	13% of 116 householders agree this option	Public acceptability is low as the frequencies of washing hard surfaces, using sprinklers are significantly high in households
Costs and benefits	Need to add extra taps in dual reticulation systems for washing machines. No additional costs on water quality improvement.	Need to add extra taps in dual reticulation systems for swimming pools. Additional costs on water quality improvement are required.	Neither additional taps nor costs on water quality improvement are required.
References	[19]	[4,16]	[20]

Table 3 Summary of key and sub-criteria and weightings

Key criteria	Primary weighting (%)	Sub-criteria	Sub weighting (%)	Scores of options 1	2	3
Water supply	20%	Water quantity and security of supply	50%	+4	+3	+2
		Water quality	50%	+3	+4	+3
Risk related issues	15%	Treatment technology	50%	+3	+4	+3
		Reliability, robustness and safety	50%	+3	+4	+3
Operability	10%	Ease of operation	55%	0	–1	0
		System flexibility to upgrade and extend	45%	0	+1	0
Environmental considerations	25%	Volume of waste generated	20%	+2	+1	+1
		Footprint of plant and infrastructure	20%	+1	+1	+2
		Energy use	15%	+1	+1	+2
		Greenhouse gas emission	15%	+2	+1	+1
		Impact on local ecology	20%	+1	+1	+1
		Impact on groundwater	10%	+1	+1	0
Social/community considerations	15%	Aboriginal, cultural and non-cultural heritage	15%	0	0	0
		Aesthetics	20%	0	+1	0
		Traffic disruption	20%	0	–1	0
		Community/social acceptance	25%	+3	+2	–2
		Community education opportunities	20%	+4	+3	+1
Costs and benefits	15%	Capital cost	50%	–1	–2	0
		Operating cost	50%	–2	–1	0
Total	100%			1.50	1.48	1.22

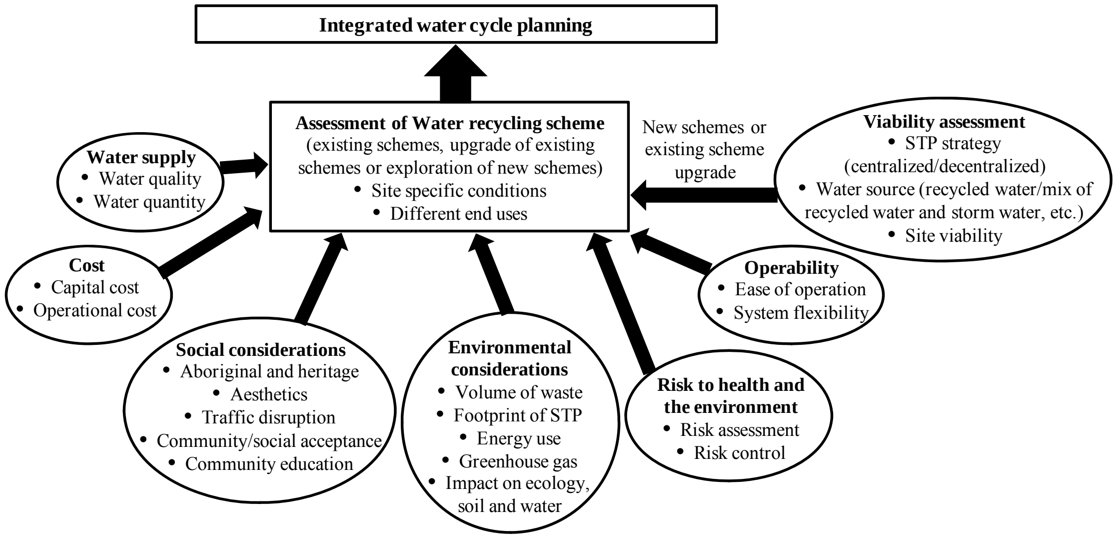

Fig. 1 Outline of the proposed assessment framework for water recycling schemes

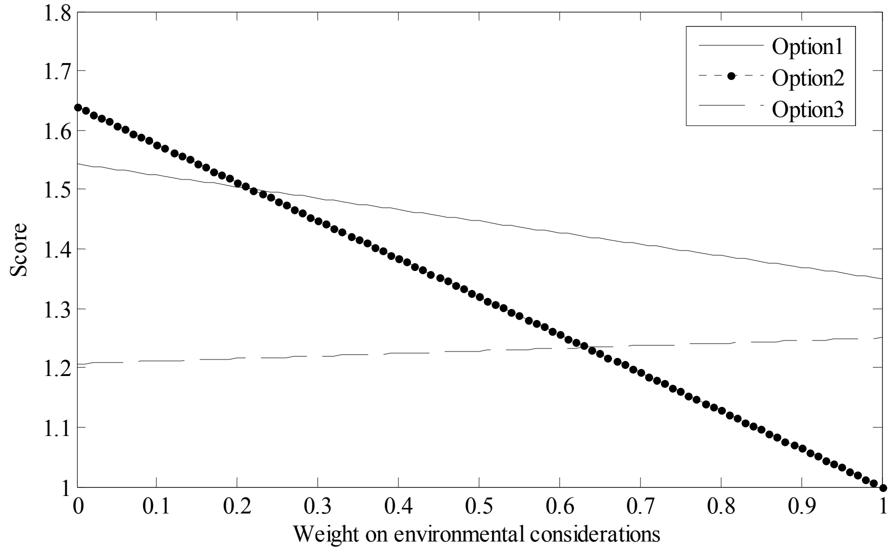

Fig. 2 Sensitivity analysis on the results of the three options