Economic considerations and decision support tool for wastewater reuse scheme planning

R. Hochstrat*, D. Joksimovic, T. Wintgens*, T. Melin* and D. Savic****

*Department of Chemical Engineering, RWTH Aachen University, Turmstr. 46, 52056 Aachen, Germany (E-mail: *hochstrat@ivt.rwth-aachen.de*; *wintgens@ivt.rwth-aachen.de*; *melin@ivt.rwth-aachen.de*)

**University of Exeter, School of Engineering, Computer Science and Mathematics, Centre for Water Systems, Harrison Building, North Park Road, Exeter, EX4 4QF, UK (E-mail: *D.Joksimovic@exeter.ac.uk*; *D.Savic@exeter.ac.uk*)

Water Science & Technology **Vol 56 No 5 pp 175–182** © IWA Publishing 2007

Abstract The reuse of upgraded wastewater for beneficial uses is increasingly adopted and accepted as a tool in water management. However, funding of schemes is still a critical issue. The focus of this paper is on economic considerations of water reuse planning. A survey of pricing mechanisms for reclaimed water revealed that most schemes are subsidised to a great extent. In order to minimise these state contributions to the implementation and operation of reuse projects, their planning should identify a least cost design option. This also has to take into account the established pricing structure for conventional water resources and the possibility of gaining revenues from reclaimed water pricing. The paper presents a case study which takes into account these aspects. It evaluates different scheme designs with regard to their Net Present Value (NPV). It could be demonstrated that for the same charging level, quite different amounts of reclaimed water can be delivered while still producing an overall positive NPV. Moreover, the economic feasibility and competitiveness of a reuse scheme is highly determined by the cost structure of the conventional water market.

Keywords Alternative reuse schemes; cost optimisation; decision support tool; water prices; water reuse

Introduction

Recurring droughts throughout the last decades have revealed that water supply is often insufficiently balanced to the demand and thus vulnerable to extreme climatic events and spatial or seasonal demand peaks. In the context of a more sustainable water management, wastewater reuse represents an alternative dependable water resource.

Wastewater reclamation and reuse activities are increasing steadily worldwide. An overview of major schemes in Europe is depicted in Figure 1. The predominant use of reclaimed water is for agricultural irrigation. Industrial and urban uses as well as environmental enhancement are mainly realised in western European countries (Bixio *et al.*, 2006).

As diverse as the applications are, the possible treatment options range from extensive, natural systems over sand filtration and disinfection schemes to membrane processes. Moreover, the number and types of connected users to a reuse scheme might vary greatly depending on local circumstances. Thus the complexity associated with planning of water reuse schemes is very high due to a large number of design combinations possible. This requires a formalised approach to determine the lowest-cost alternatives, as pipelines and pumping stations easily make up more than 50% of the construction cost (Compte and Cazurra, 2004, Mujeriego, 2006).

The selection of reuse scheme options under cost considerations is deemed increasingly important, as the Water Framework Directive asks water services to apply the

doi: 10.2166/wst.2007.570

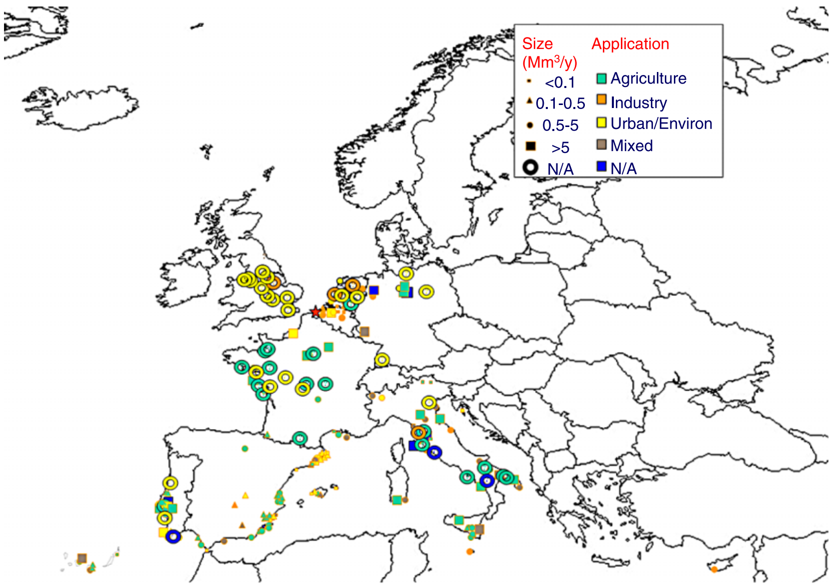

Figure 1 Identifiable water reuse projects in Europe, including their size and intended use (N/A: info not available) (Bixio *et al.*, 2006)

principle of cost recovery and funding of wastewater reuse scheme has been identified as a major barrier for their enhanced implementation (Bixio *et al.*, 2006).

This paper presents a case study aiming to identify least cost design options under a given water price regime.

Methodology and approach

A decision support system (DSS) for Water Treatment for Reuse with Network Distribution (WTRNet) has been developed within the AQUAREC project, which addresses the integrative aspects of planning of water reuse schemes. WTRNet is a tool that can be used to estimate, compare and optimise the lifecycle costs of different scheme layouts (treatment capacity, type of treatment and application, number of end-users, etc.). The results of WTRNet application show that different least-cost designs with the same life-cycle cost can satisfy a demand to different degrees (Joksimovic *et al.*, 2006, 2006a).

Information about pricing water services and reclaimed water was compiled from literature.

Results

Pricing water services

To date, water prices at best reflect the financial cost of providing and administering water services, including all operation and maintenance costs, and capital costs.

The Water Framework Directive aims even higher and demands the establishment of a full cost recovery principle that takes into account the environmental and resource costs associated with damage or negative impact on the aquatic environment. Figure 2 attributes these different cost components to the individual steps along the anthropogenic water cycle, involving abstraction, treatment, use, collection, purification and discharge. Whereas financial costs can be determined exactly, the estimate for resources and environmental costs is much more difficult. Methods to do so are currently being developed in the Common Implementation Strategy for the Water Framework Directive (CIS). It is of vital interest for the promotion of water reuse to put a value to these unaccounted

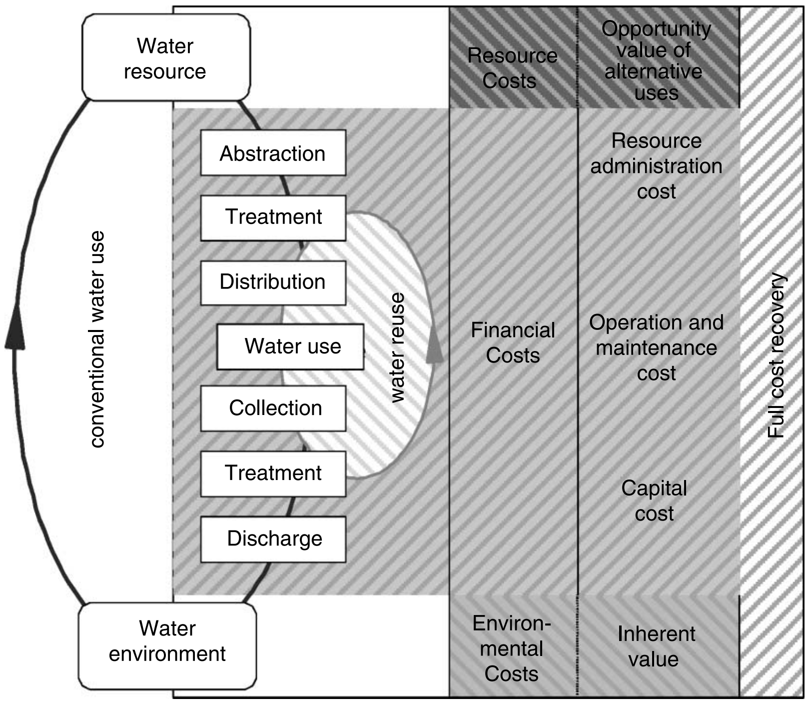

Figure 2 The idea of full-cost recovery – water use and associated cost types according to the Water Framework Directive

externalities. Figure 2 also shows that water reuse may bypass the water environment compartment and in consequence the possible environmental and resource cost.

However, as evaluated in the Aqualibrium project, only a few European Union member states achieve (financial) cost recovery of their water services (England and Wales, Germany and the Nordic countries). In many other countries, the coverage of even the financial cost of water supply is not secured by water prices (Aqualibrium, 2003).

As revenues raised from reclaimed water supply are considered crucial for the viability of reuse projects, price setting is an important issue. Although most projects have carried out a cost analysis, the charges are not designed to recover the costs. Usually, a great share of subsidisation is tacitly accepted (WSAA, 2005). The concepts applied comprise:

- No charging: Many schemes in Australia, which particularly aim to avoid effluent discharge into sensitive aquatic environments, do not charge at all for reclaimed water use (WSAA, 2005).
- Defined percentage of the potable water price: Reclaimed water is often offered for a lower price than potable water. This price signal will highlight the advantages of water reuse for the customers and increase the acceptance. Sydney Water provides reclaimed water for domestic uses in the Rouse Hill residential area for only 30% of the potable water price. In Sydney Olympic Park the price is fixed at 0.15 AUD below the drinking water price (AATSE, 2004; SOPA, 2006).
- Price adjusted to the willingness to pay of users: The ceiling of willingness to pay for different customers varies depending on the expected economic return. Agricultural wastewater reuse in Israel is highly subsidised. The Israeli State fully pays for the conveyance and storage of reclaimed water and also takes over the cost for upgrading wastewater to a high quality level. The users (farmers) are only charged the cost for "low level treatment" suitable for restricted irrigation, 0.098 EUR/m^3. However,

remarkably, this subsidisation is even less costly than treating wastewater to a quality suitable for discharge into surface waters (Fine *et al.*, 2006).

- Same prices for conventional and reclaimed water: In Cyprus, some schemes started selling recycled water for agricultural irrigation at the same price as farmers paid for conventional freshwater, i.e. 0.1 EUR/m^3. As the implementation of the price reform will further increase prices for conventional irrigation water to 0.20 EUR, reclaimed water will become even more competitive (Socratous, 2000; Hidalgo and Irusta, 2005; AQUASTRESS, 2007).

In essence, fixing the price for reclaimed water is always a trade-off of cost distribution between the beneficiaries, the operators and the tax payer in general.

Example of Mogden wastewater treatment works

In order to exemplify the interdependency of charged prices, economic feasibility and need for subsidies of reuse projects, the WTRNet tool was applied in a hypothetical case study. The study investigates the Mogden Sewage Treatment Works in London with regard to water reuse scheme cost optimisation under different price and charge scenarios.

The South East of England is particularly prone to water shortage. For parts of this region the abstraction from surface water is already at its limit during summer and to some extent in winter. Most of the South East has an unacceptable water flow regime in the summer months, and some parts of the region suffer from this in winter, too. In addition, the utilisation of groundwater resources surpasses sustainable abstraction rate (EA, 2001). The drought years 2003 and 2005 have aggravated this situation, forcing Thames Water to impose water use restrictions (hose-pipe ban) on their domestic customers in April 2006 (TW, 2006).

Moreover, this region is projected to experience a higher than average population growth over the next decade (around 9% from 2002–2015). Today, the abstraction for public water supply already accounts for 90% of the water withdrawal in the Thames River Basin District. The Environmental Agency is about to define sustainable abstraction levels (below the current one) which are likely to impact on the water supply services (DEFRA, 2005; POST, 2006). To accommodate the additional demand whilst water resources are further limited, water utilities will have to adapt alternative strategies. All these particular circumstances are supposed to be a favourable environment for the development of water reuse.

Mogden sewage treatment works case study

The Mogden Sewage Treatment Works (STW), located in the London borough of Hounslow, occupies almost 50 ha of land, and it is one of the largest wastewater treatment plants in Europe and the second largest plant run by Thames Water. With a design capacity equivalent to 1.8 million inhabitants (i.e.), it treats wastewater from areas North and West of London. First built in 1936, the Mogden STW treats an average flow of 500,000 m^3/day, which is just over one half of its rated capacity of 810,000 m^3/day. The plant has two parallel treatment trains which include initial screening and de-gritting of raw sewage, primary clarifiers and activated sludge process, in addition to having large volume retention tanks used for wet weather flows exceeding the plant capacity. Average Mogden STW effluent pollutant concentrations were calculated from the data supplied by Thames Water (Adrian Wallis, personal communication), and used to determine effluent upgrade options to satisfy potential end-user demands.

The case study considers five golf courses located in the general vicinity of Mogden STW, Twickenham stadium and Heathrow airport as potential end-users of reclaimed water. The monthly irrigation demands for golf courses, summarised in Table 1, were

Table 1 Estimated demand of golf course and other end-users

Month	End-user daily demand for different months [m^3/d]							
	Airlinks	Wyke Green	Royal Mid Surrey	Richmond	Fulwell	Total	Twickenham Stadium	Heathrow
Jan	82	46	118	61	113	420	600	633
Feb	530	297	766	396	736	2,725	600	633
Mar	634	355	915	473	880	3,257	600	633
Apr	890	498	1,286	665	1,236	4,575	600	633
May	1,168	654	1,687	872	1,622	6,003	600	633
Jun	1,400	784	2,022	1,045	1,945	7,196	600	633
Jul	1,760	986	2,542	1,314	2,445	9,047	600	633
Aug	1,463	819	2,113	1,092	2,032	7,519	600	633
Sep	836	468	1,208	624	1,161	4,297	600	633
Oct	266	149	384	199	370	1,368	600	633
Nov	145	81	209	108	201	744	600	633
Dec	7	4	10	5	9	35	600	633

estimated based on assumed irrigation areas and average weather conditions for London. The demand for reclaimed water at Twickenham stadium was assumed at 600 m^3/d (approximately 60% of 15 L/seat/d). The total reclaimed water demand for Heathrow airport of 633 m^3/d was calculated from the current annual passenger numbers (approximately 70 million) and assuming that reclaimed water could be used to replace 10% of average potable water consumption (33L/passenger/d).

An overview of the location of the Mogden STW relative to the end-users considered is shown in Figure 3, in which the distribution system components are also indicated. Peak (hourly) demand factors of 1.5 and 2.0 were assumed for golf course and other end-users, respectively, for sizing of the distribution system components.

A WTRNet model of the study area was constructed, and optimal water reuse options were determined for all combinations of potential end-users. The optimal water reuse

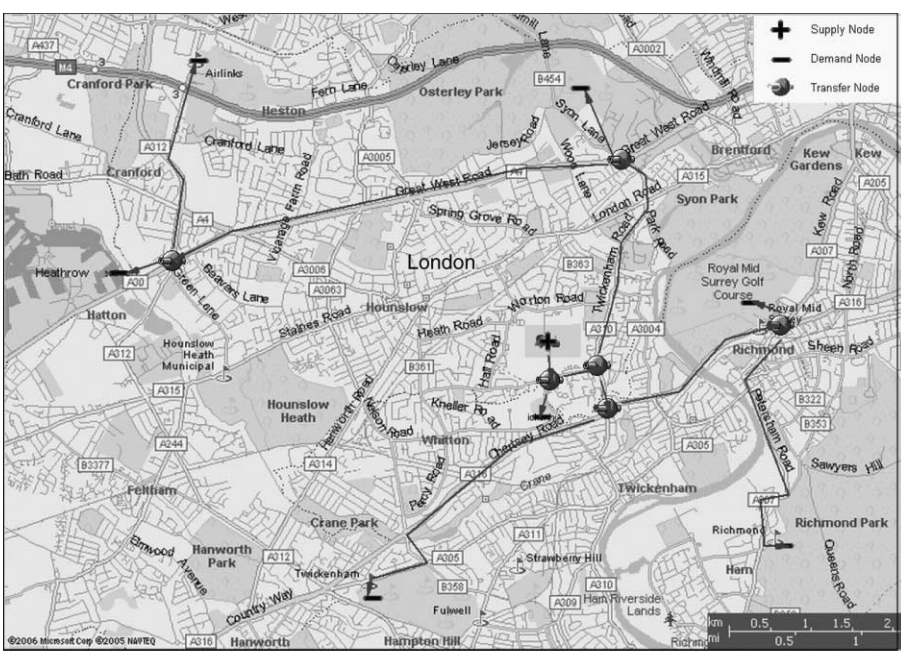

Figure 3 London case study overview

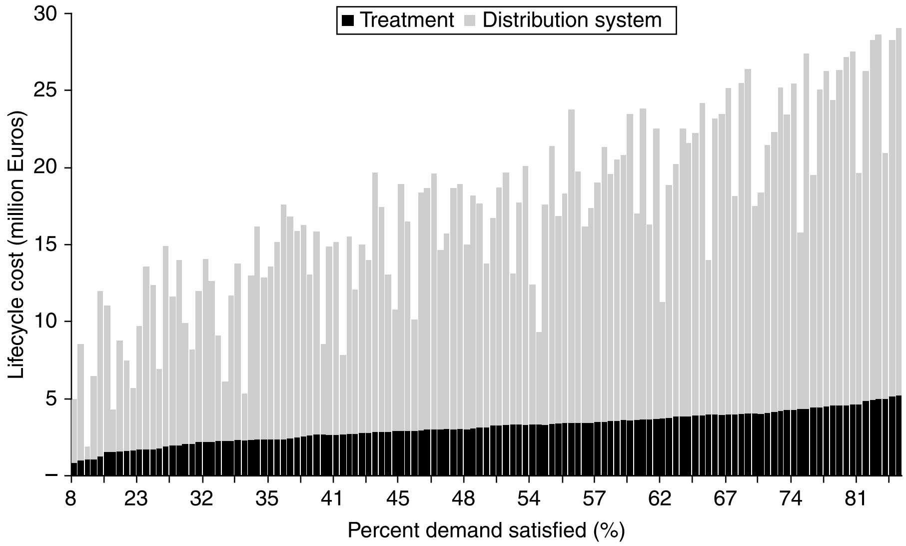

Figure 4 Life cycle cost of different reuse scheme options

options for each combination were determined by first enumerating all combinations of end-users, and then calculating the least-cost treatment train and distribution system for each combination. The results of this analysis, shown in Figure 4, indicate the treatment and distribution costs for providing reclaimed water for all combinations of end-users. While the treatment costs vary almost linearly with the increase in treated volumes, the costs of distribution systems required to supply different end-user combinations vary drastically.

Using the calculated treatment and distribution costs and revenues from the sale of reclaimed water, the treatment and distribution options that resulted in the highest Net Present Value (NPV) for each combination of end-users were calculated using an assumed project lifecycle of 20 years. Different charges for provision of reclaimed water were analysed, representing a percentage of current prices charged to Thames Water customers and shown in Table 2. The reclaimed water prices were considered in 10% increments of volumetric water prices, while the supplementary charge was kept fixed.

Financially viable schemes (i.e. those having a positive NPV) were determined for different levels of potential demand satisfaction. Schemes that required the lowest charge level, expressed in terms of percentage of potable water charges, and having the highest NPV were determined for each level of potential demand satisfaction. The results, as summarised in Table 3, provide an indication of most economical set of users.

In order to satisfy up to 10% of potential demand, which in the case study meant a single end-user, no schemes were found that had a positive NPV. The required charge level in most other cases was 60%, except in cases of high satisfaction of potential

Table 2 Water prices for Thames Water metered customers (Thames Water, 2006a)

	Volumetric rate		Supplementary charge		Fixed charge
	GBP/m^3	EUR/m^3	GBP/yr	EUR/yr	GBP/yr
Standard	0.9510	1.3789			23
Medium volume tariff (>20,000 m^3/yr)	0.8702	1.2618	1,616	2.343	
Large volume tariff (>50,000 m^3/yr)	0.7156	1.0376	9,346	13.552	
Major user volume tariff (>250,000 m^3/yr)	0.6039	0.8756	37,275	54.049	

Table 3 Summary of best financially viable water reuse options

Percent demand satisfied	Required charge level	Supplied end-users	NPV (€)
0–10	–	–	–
10–20	60%	Twickenham	125,253
20–30	70%	Royal Mid Surrey	144,891
30–40	60%	Royal Mid Surrey, Twickenham	539,785
40–50	60%	Royal Mid Surrey, Wyke Green, Twickenham	390,278
50–60	60%	Royal Mid Surrey, Fulwell, Twickenham	798,236
60–70	60%	Royal Mid Surrey, Fulwell, Wyke Green, Twickenham	858,434
70–80	60%	Royal Mid Surrey, Fulwell, Wyke Green, Twickenham, Heathrow	264,865
80–90	70%	Royal Mid Surrey, Fulwell, Wyke Green, Airlinks, Twickenham, Heathrow	1,203,571
90–100	80%	Royal Mid Surrey, Richmond, Fulwell, Wyke Green, Airlinks, Twickenham, Heathrow	1,151,620

demand, where up to 80% of current water prices are needed to make the water reuse schemes economical. The largest overall end-user, Royal Mid Surrey golf course, is included in all but one of the schemes with the highest NPV for given demand satisfaction and required charge levels.

In terms of treatment processes, surface filtration followed by micro filtration was as the least-cost treatment train in all cases. It is also noted that preliminary analyses identified other processes, such as soil aquifer treatment and constructed wetlands, but these were excluded in further analyses due to their inappropriateness for this particular case study.

It is to be noted that the calculation of the NPV as presented above does not account for the potential environmental benefits of any of these reuse schemes, nor does it take into account the avoided abstraction charges, payable for water withdrawal for public water supply or irrigation.

Conclusions

The above analysis demonstrates the need for a tool capable of analysing integrated water reuse projects in order to identify financially feasible water reuse options. The WTRNet tool offers help in evaluating different treatment schemes and can be used to determine least cost design options.

It can therefore be used to support the decision on the most efficient use of funds and justify the selection of particular schemes towards the public and/or funding entities. Evaluating the cost effectiveness of measures, this tool can also contribute to evaluating freshwater saving potential of proposed reuse schemes.

Combining these results with background information on the structure and level of pricing for water services enables the identification of feasible options under given circumstances.

This type of analysis supports the optimisation of supportive economic instruments, such as subsidies, reclaimed water prices and the like.

Acknowledgements

The authors acknowledge the European Commission for having funded this work within the AQUAREC project on "Integrated Concepts for Reuse of Upgraded Wastewater" (EVK1-CT-2002-00130) under the Fifth Framework Programme. Special thanks go to Adrian Wallis, Jonathan Hiscock and Rebecca Birks of Thames Water for kindly providing data on the Mogden sewage treatment plant.

References

AATSE (2004). *Water Recycling in Australia*, Australian Academy of Technological Sciences and Engineering.

Aqualibrium (2003). *European Water Management between Regulation and Competition*. S. Mohajeri, B. Knothe, D.N. Lamothe and J.A. Faby (eds), available from http://www.oieau.fr/aqualibrium.

AQUASTRESS (2007). Draft Deliverable D.2.2-2 Report on Cyprus test site (unpublished).

Bixio, D., Thoeye, C., De Koning, J., Joksimovic, D., Savic, D., Wintgens, T. and Melin, T. (2006). Wastewater reuse in Europe. *Desalination*, **187**, 89–101.

Compte, J. and Cazurra, T. (2004). Water reuse of Barcelona's wastewater plant. In: *Proc. of the International Workshop on Implementation and Operation of Municipal Wastewater Reuse Plants*, Thessaloniki, Greece, March 11–12.

DEFRA (2005). Water Framework Directive Article 5 – Economic Analysis of Water Use. Supporting Document Thames River Basin District.

EA (2001). Water resources for the future. A summary of the strategy for England and Wales.

Fine, P., Halperin, R. and Hadas, E. (2006). Economic considerations for wastewater upgrading alternatives: An Israeli test case. *J. Environ. Manage.*, **78**, 163–169.

Hidalgo, D. and Irusta, R. (2005). The cost of wastewater reclamation and reuse in agricultural production in the Mediterranean countries. In: *Proc. of the IWA Conference on Water Economics, Statistics and Finance*, Rethymo, Greece, 8–10 July 2005.

Joksimovic, D., Kubik, J., Hlavinek, P., Savic, D. and Walters, G. (2006). Development of an integrated simulation model for treatment and distribution of reclaimed water. *Desalination*, **188**, 9–20.

Joksimovic, D., Savic, D. and Walters, G. (2006a). An integrated approach to least-cost planning of water reuse schemes. *Wat. Sci. Tech.: Water Supply*, **6**(5), 93–100.

Mujeriego, R. (2006). La reutilización planificada del agua para regadio - Aspectos conceptuales, técnicos, reglamentarios y de gestión. XI Congreso Nacional de Comunidades de Regantes de Espana, Palma de Mallorca, Spain, 15–20 May 2006, http://www.fenacore.org/.

POST (2006). Balancing water supply and the environment. postnote February 2006 Number 259 Parliamentary Office of Science and Technology.

Socratous, G. (2000). *Study for Management of Water in Cyprus*. Water Development Department, Ministry of Agriculture, Natural Resources and Environment, available at http://www.moa.gov.cy.

SOPA (2006). Sydney Olympic Park - Urban water reuse & integrated water management. Ed. Sydney Olympic Park Authority.

Thames Water (2006). Drought Update, Summer 2006.

Thames Water (2006a). Large volume – prices for your business 2006/07.

WSAA (2005). Pricing for Recycled Water. Occasional Paper No. 12, February 2005, Water Services Association of Australia.