The Role of Effluent Reuse In Sustainable Urban Water Systems: Untapped Opportunities

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EXECUTIVE SUMMARY

The main objective of sustainable urban water systems is to satisfy the water related needs of the community at the lowest cost to society whilst minimising environmental and social impacts.

This paper explores these objectives in relation to effluent reuse in urban areas. It describes the evolutionary progress of urban water reuse from agricultural reuse, to large scale industrial reuse, and then to dual reticulation for urban developments. It argues that the next step in this progression is to more fully implement the principles of the water quality cascade, and to use the benefits associated with reducing sewage and water transport costs to trade off increased costs associated with distributed treatment and reuse systems.

The other key message of the paper is that there is a logical order of investment in methods of sustainable urban water management, both in terms of unit cost and energy intensity, starting with improved efficiency of water use. These options, improved water efficiency, generally have the lowest unit cost, with typical levelised costs of $0.1-0.7/kL. They also result in a reduction of energy use from hot water savings and reduced pumping and treatment. Scheme supplies can vary typically from $0.2-1.2/kL, depending on the cost of augmentation, and have energy intensity levels in the range 300-1,000 kWh/ML. High level reuse can cost between less than $1/kL for large scale industrial reuse, to over $3/kL for dual reticulation schemes. The energy intensity of high level reuse can be as high as 4,000 kWh/ML.

The implications of this are clear. Water efficiency options must be invested in first, and to the maximum extent possible. In future, investment in reuse needs to focus on reducing the demand for potable water. In order to avoid the duplication of costs, it needs to be directed to a reduction in the costs of transport of water and sewage. This is particularly the case for sewage transport, where a number of studies indicate that the economies of scale that have been assumed to exist may not, in fact be present. In other words, larger, more centralised networks and treatment systems do not necessarily reduce the per lot cost over the whole life cycle, compared to distributed networks. Several studies have now looked at a mixture of best practice water efficiency, rainwater capture and reuse, effluent reuse in a distributed manner, and 'smart sewers'. The latter includes small diameter pressurised sewer systems coupled with on site storage, which eliminates wet weather infiltration and also allows control over loading on sewage treatment plants.

These options appear likely to offer cost advantages and also reduce net water use and wastewater discharge by over 70% in some coastal Australian cities, compared to average developments. These options are the next stage of the evolutionary ladder for effluent reuse.

INTRODUCTION

Increased pressures on urban water supplies due to population growth, climate variability resulting in less reliable yields from existing storages and the detrimental impact of discharges from urban development, are causing water service providers to question whether investment in additional supply side options is the most sustainable strategy to meet customer needs. Although urban and industrial water demand is less significant then that of the irrigated agricultural sector, urban water service providers are leading the search for new ways to provide their services by such means as investing in water efficiency (e.g. leakage reduction, demand management) and source substitution (e.g. rainwater tanks, application of water quality cascade principles and effluent reuse). In many cases, water service providers are finding that these other approaches have a lower unit cost (present value $/ML supplied or saved) compared to supply side options, when whole-of-society costs and benefits are included.

Developing “sustainable urban water systems” is becoming more pressing, considering the level of new development in urban areas. The roles of water efficiency, water quality cascade and effluent reuse are an important untapped opportunity. This paper considers possible directions in which urban water systems could develop, with a particular focus on the role of water quality cascade and effluent reuse. The first two sections outline the concept of sustainable urban water systems and the principles of water quality cascade. The third section describes the history of effluent reuse and how it fits into the bigger context of sustainable urban water systems, including costs and energy use implications. The fourth section describes the potential for effluent reuse to play a significant role in new developments and therefore to become an important component of the transition to new system configurations. Finally, the last two sections describe some perhaps unexpected considerations and elements that will enable that transition to happen.

SUSTAINABLE URBAN WATER SYSTEMS

The main objective of sustainable urban water systems is to satisfy the water related needs of the community at the lowest cost to society whilst minimising environmental and social impacts.

Looking at this in more detail:

- providing water related services at lowest cost to society uses the principles of least cost planning (also known as integrated resource planning), whereby a water service provider determines a range of options which at lowest cost provide their customers with the water related *services* they require rather than the water itself. This recognises that customers do not necessarily want more water, rather they want the services that water provides, such as aesthetically pleasing landscapes, sanitation and clean clothes (Howe and White 1999).

- minimising environmental impacts includes reducing the impact of extracting water from aquatic ecosystems, reducing energy use and associated greenhouse gas emissions, reducing materials use such as the raw materials associated with pipelines and minimising the generation and discharge of wastes and pollutants such as nutrients that ultimately impact on the environment, if discharged, for example into sensitive receiving waters.

- minimising social impacts includes protecting public health, (one of the foundation principles of sanitation systems), ensuring equitable access to water related services, ensuring the empowerment and engagement of communities to determine the levels of service they require, the types of systems that will provide these services and the allocation of resources to meet these needs, relative to other needs in the community.

WATER QUALITY CASCADE

The principle of the water quality cascade involves matching the end use of water with the quality of the water source, and utilising all water sources to meet water service needs. For example, when potable water is brought into a typical household, instead of using the high grade water only once in the traditional linear approach, higher quality wastewater discharged from end uses such as bathroom and laundry are treated to an appropriate level within the household and reused for end uses such as garden irrigation and/or toilet flushing. By using these principles, water service providers are able to reduce both the potable demand of the household and the effluent discharged to sewer and ultimately into the environment. Similarly, rainwater can be added to the water quality cascade. Rainwater has a dissolved solids concentration that is less than most potable water supplies, and significantly less than many (eg Perth, Adelaide, Alice Springs) and can be usefully used at the top of the water quality cascade (eg evaporative air conditioners, cooling tower make up water).

UNIT COSTS AND ENERGY CONSIDERATIONS

The use of reclaimed effluent in the urban context has tended to follow an evolutionary path such as the following:

- reuse for agriculture or recreational areas (e.g. playing fields, golf courses), where the primary objective has been effluent disposal, rather than using the effluent to displace potable demand;
- large scale industrial reuse, including power stations[1], and heavy industry reuse such as steel works[2];
- dual reticulation for residential and commercial use, or so called ‘third pipe’ systems, in which reclaimed effluent is reticulated back to customers via a duplicated water supply system often from an existing ‘regional scale’ sewage treatment plant[3].

The development of these options has often been intended to meet the objective of reducing effluent disposal, rather than reducing demand for water from potable water supply schemes. What is noteworthy is that each extension of effluent reuse treatment

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[1] For example, the Eraring Power Station in the Hunter Valley in NSW, Australia which is supplied with reclaimed effluent by Hunter Water Corporation.

[2] For example, the BHP steelworks in Wollongong, in NSW, Australia which is about to be supplied with 20 ML/d of treated effluent by Sydney Water Corporation.

[3] Many such systems now exist, including at Rouse Hill and Newington in NSW, Australia. The end uses supplied by these systems are usually either outdoor use only, or outdoor use plus toilet flushing. Permission has recently been granted for the Newington development to apply reclaimed effluent to washing machine use.

generally has a higher unit cost than the one before it, thus making it difficult for water service providers to justify implementing reuse schemes in many areas. For example, in the case of agricultural reuse, the effluent reused often requires a lower standard of treatment and supplies a significant demand, thus reducing the unit cost. In the case of large scale industrial reuse, despite the need for high levels of treatment, the demand is large, thereby reducing the unit cost, although not to the level attained for agricultural reuse (this depends on the piping distances required). Dual reticulation systems generally have a higher unit cost because of the high treatment level required, the duplication of reticulation infrastructure (without an offsetting reduction in sewage transport infrastructure) and the lower demand of potential end uses such as outdoor water use and toilet use. This has been shown in many eastern coast towns and cities in Australia[4].

The next step in this evolutionary progression will be the development of systems of distributed treatment and reuse of effluent at the 'estate' or 'household scale' rather than at the 'regional scale' for example, and the associated reallocation of costs from transport to treatment[5]. This represents an application of the principles of the water quality cascade.

A range of measures then are available to meet demand for water related services, including:

- existing reticulated potable supply from surface and groundwater sources;
- improved efficiency of water use, freeing up water resources and therefore considered equivalent to supply in terms of satisfying demand for water related services; and
- source substitution and reuse, including supply from rainfall via roof or other sources of runoff and appropriately treated reclaimed effluent.

The relative unit costs and energy intensity of these measures needs to be considered when prioritising investment. Actual unit costs will vary according to context and location, but generally will be in the order:

efficiency measures < existing sources < source substitution and reuse

Typical unit costs for efficiency measures range from negligible to $1.00/kL, with an average less than $0.5/kL. Operating costs for existing sources can be as low as $0.2/kL, but if marginal capacity[6] costs are included can exceed $1.00/kL. The unit cost of source substitution and reuse is generally in excess of $1.00/kL when the capital costs are included (White and Howe 1998).

Some typical unit costs are summarised in Table 1.

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[4] In places where reclaimed effluent is used to supply outdoor water use and toilets, these are two end uses that are in many areas, decreasing in demand. In the case of outdoor water demand this is a result of urban consolidation and in the case of water demand in toilets, it is due to the widespread use of the 6/3 litre dual flush toilet since 1993.

[5] It is commonly found that over 50 per cent of the costs associated with water service provision are invested in transport in the form of pipelines and pumps rather than treatment.

[6] Marginal capacity costs are the unit costs that can be attributed to the capital cost of augmentation.

Table 1 Typical levelised costs for various demand and supply side options (from White and Howe 1998)

Option Type	Typical levelised cost to community (¢/kL)
Pricing	0-2
Restrictions	5-10
Shower head giveaway	10-20
Residential indoor assessment/ retrofit	20-30
Active leakage control	20-50
Tap timers/ education	20-50
Non residential efficiency	40-60
Residential outdoor assessment (retic systems)	50-70
Toilet retrofit	70-80
Typical augmentation	80-100
Typical reuse	90-150

This hierarchy is mirrored by the energy intensity of these measures, with efficiency measures *reducing* energy consumption by up to 25,000 kWh/ML of water saved, due to reduced hot water demand[7], with typical existing sources as well as some source substitution and reuse options *increasing* energy consumption by 500 to 1,000 kWh/ML. Note that a treatment method such as reverse osmosis can *increase* energy consumption by around 4,000 kWh/ML.

A NEW WAY OF PROVIDING WATER SERVICES

The hierarchy of unit costs assumes that the costs are in addition to existing costs of providing water, sewage and stormwater infrastructure. This is appropriate for the use of a least cost planning, or integrated resource planning approach (Howe and White 1999). If, however, these measures are combined in new developments in a distributed (decentralised) manner, reducing or offsetting the cost of the reticulation system, then a 'capital cost breakthrough' is possible.

In practice, this means a significant change to the way that infrastructure is provided and managed, a change of increasing interest in a number of places internationally. In Australia, a number of studies have been undertaken of this approach as applied to new, usually greenfield developments[8] (Mitchell and White 2003; GHD 2003). These considered the use of a combination of:

- significantly improved water efficiency;
- maximising use of rainwater capture and reuse locally within buildings/lots or on an 'estate scale'; and
- maximising treatment and reuse of effluent within buildings/lots or on an 'estate scale'.

These studies build on research suggesting that the traditionally perceived economy of scale within water and sewerage systems may not in fact be fixed. The per-connection

[7] When measures such as AAA-rated showerheads and front loading washing machines are introduced.

[8] A number of individual buildings are now implementing this idea, such as the 60L green building at Carlton, Victoria, Australia. It has also been proposed for the new Sydney Water Headquarters, at Parramatta in New South Wales, Australia (Chanan, White, Jha and Howe 2003).

costs of treatment may reduce with scale, but the per-connection costs of transport do not (Clark 1997; Booker 1999; Fane, Ashbolt and White 2002). Many of the configurations considered in these studies assume that sewer reticulation would be based on ‘smart sewers’ utilising on-site storage and treatment, with transfers of effluent through pressurised, small bore sewers, increasing control of sewer flows and eliminating infiltration, inflow and exfiltration. The principles of water quality cascade are maximised by using rainwater for indoor uses such as kitchen, showering and laundry[9] (and evaporative air-conditioners where these are used), whilst treated wastewater from these end uses is used for toilet flushing and outdoor water use. Maximising efficiency helps this water balance and depending on rainfall and other local conditions, can result in reductions of more than 80 per cent in net demand from potable supplies and reductions in effluent discharge of more than 90 per cent. The present value costs of infrastructure to achieve this are demonstrated to be similar to those of conventional systems[10].

In terms of reliance on ‘regional scale’ water and wastewater services, these savings can be applied to both residential and commercial and industrial properties, thus providing significant opportunities for providing water related services differently in the future to cater for the growing population.

Further, the role of nutrient pathways in the provision of sustainable urban water services has been neglected. New ways of thinking are required to enable us to separate nutrients at source to minimise effluent treatment requirements and maximise the use of this valuable resource. A typical example is the use of urine separation, where urine, which contains the majority of the nutrients[11] found in household wastewater, is separated at source (e.g. urine separating toilets), treated and then used as fertiliser.

DECISION MAKING

How can we, as a community, develop a sustainable urban water future, in light of the major investment we have made in current systems? Is it possible to keep our existing systems and incorporate new sustainable urban water systems? What planning framework can we use?

A candidate for this is ‘backcasting’, essentially the opposite of forecasting. Forecasting is concerned with existing trends and is generally used to generate ‘business-as-usual’ scenarios that pre-suppose continuation of existing trends and paradigms into the future. Backcasting is a method to explore the means by which specified future states can be attained.

Forecasting has been the primary method used in the planning of water related services for many years, but as forecasting methods are based on dominant trends, they tend to describe futures that look much like the present and are of little use in generating solutions that presuppose the breaking of trends (Dreborg 1996). Their value as a predictive tool

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[9] Rainwater is especially useful for supplying evaporative air conditioners where these are used, due to its low concentration of total dissolved solids, thus reducing blowdown volumes.

[10] In the study undertaken by the Institute for Sustainable Futures and CSIRO, which considered alternative servicing options for Edmondson Park in Sydney, the capital costs of the various options with a range of scales of treatment and reuse were within 10 per cent of each other (Mitchell and White 2003). Similar results, including operating costs, have been obtained for the Pimpama-Coomera development in Queensland’s Gold Coast (GHD 2002, Shaun Cox pers. comm.).

[11] European studies indicate that the highest proportion of nutrients discharged in typical household wastewater are contained in urine – nitrogen 81% and phosphorus 48% (Skjelhaugen et al 1997; Jenssen 1999)

also diminishes rapidly as the timescale under consideration increases, because the method is unable to anticipate surprises and discontinuities.

These limitations encouraged the development of alternative and complementary approaches, including backcasting, to assist in developing more complete sets of future scenarios. Backcasting works back from the future to the present and is concerned:

> *not with what futures are likely to happen, but with how desirable futures can be attained. It…[involves] working backwards from a particular desired future end-point to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach that point (Robinson 1990, p. 822-823).*

Perhaps one of the most powerful combinations of methods to help in the planning of sustainable water futures combines backcasting with participatory decision making using representative and deliberative processes. Methods such as citizen's juries, consensus conferences and planning cells (see Carson and Gelber 2002), combine the representativeness that comes from random selection with the deliberation that arises from dialogue and information sharing associated with hearings and expert testimony. These methods have been used to a limited extent in relation to water service provision and provide considerable potential as a way to implement sustainable urban water systems.

A WAY FORWARD

It is clear there are a number of related issues to be addressed if we are to move toward a more sustainable urban water system. Firstly, we need to apply the principles of integrated resource planning to our consideration of what options to invest in, otherwise we will ignore the importance of investing in water efficiency. Rushing straight to effluent reuse will ultimately waste this valuable resource because of a lack of efficiency. Secondly, we need to recognise that the most valuable forms of effluent reuse are those that offset potable demand and reduce the costs of infrastructure, by shifting costs from transport of water and sewage toward treatment.

New urban developments provide a useful opportunity for the transition from our present system of centralised once-through water carriage, to a more sustainable and efficient configuration of decentralised systems with local treatment and reuse at the 'lot' or 'estate' scale. Both greenfield and infill developments provide this opportunity, as the full consequences of augmenting existing water, wastewater and stormwater systems can be costed and the full benefits of using a more sustainable approach can be understood. Thirdly, we need to recognise that in order to move towards more sustainable urban water systems, a number of issues need to be reviewed and modified. It will be necessary to consider the current management of assets, calculation of safety factors required within each system, methods of calculation of capital and operating costs, health regulations, transfer of costs and benefits between individuals, and the levels of service required.,

Many of these steps have already been taken in isolated cases but if we are to take advantage of the untapped opportunities that water efficiency, source substitution and reuse can provide, we must begin to look at these issues with a more holistic and consistent approach.

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