

Role of decentralised systems in the transition of urban water systems

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ABSTRACT

Provision of conventional centralised water, wastewater and stormwater systems for urban municipal services has been common practice for over 100 years. These systems center around the protection of human health, ensuring reliable water supply and minimizing flooding; often with minimal consideration of the environmental and ecological impacts associated with fresh water extraction and wastewater discharge. These urban water systems are facing unprecedented challenges in this century from the emerging issues of climate variability, population growth, aging infrastructure, urbanisation and resource constraints. In this context, the current level of urban water service provision can't be provided within the existing centralised system framework, unless there is a significant increase in investment, to enlarge and rehabilitate the existing centralized systems. Water service providers and managers are therefore considering alternative and sustainable means of providing water services in this environment. Decentralised and distributed water and wastewater systems, which are planned within an integrated water management concept, are being promoted either in combination with centralised systems; or alone as the sustainable solution for urban water servicing. Current urban water systems are beginning to undergo a transition, where decentralised systems will play a major role in the long-term sustainability of these systems to meet the above mentioned challenges. However, since decentralized systems are relatively new and involve increased complexity there are wide knowledge gaps in their planning, design, implementation, operation and management, which are impeding their uptake. This paper summarises the role of decentralized systems in the transitioning of centralised systems to a more sustainable state and discusses some of the complexities in the implementation of these systems.

Key words | centralised systems, climate change, decentralised systems, human health, population growth, sustainability

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INTRODUCTION

Conventional urban water supply systems, transport treated fresh water to urban areas from distant catchments, and treat wastewater for disposal to receiving waters via large-scale pipe networks. In such systems, surface water is generally the main source of water, which is collected in large dams to meet the seasonal variability in demand. As the lifespan of these assets is large, generally state and

federal agencies have subsidised the provision of these systems, which have provided considerable benefits to modern society, via the provision of reliable services and increased health benefits. However, the increased pressure on water resources due to rapid urbanisation and population growth; the aging and refurbishment needs of our infrastructure; as well as the need to minimise contaminant

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loads to receiving environments, have raised questions regarding the long term viability of conventional centralised solutions to providing essential water services.

Rapid urbanisation and population growth are either changing the densities within the existing urban areas or expanding the boundaries of the urban areas, thus increasing the pressure on the existing municipal systems for expansion and renewal. New urban areas are also developing in close vicinity to environmentally sensitive areas, where wastewater can't be discharged through conventional means. Similarly some of the developments can't be connected with conventional water supply and wastewater treatment systems due to the long transportation distances for freshwater in and wastewater out. Some of these issues and the role of decentralised solutions are presented in Figure 1.

In this context, a centralised approach can constrain the potential to adapt water supply systems to local opportunities and needs. For example in centralised systems, a large amount of high quality water is used for toilet flushing and subsequent transportation of human waste through sewers to a treatment plant. A decentralised approach offers the opportunity to use local water sources

and close the loop on waste streams via a 'fit for purpose' approach that matches the quality of source water to the quality requirements of each end-use. Separate collection and treatment of various waste streams, and recovery of valuable water, nutrients and energy is also possible through these systems (Wilderer 2001). This can avoid many of the problems associated with 'end-of-pipe technology' by identifying different qualities of wastewater and treating them appropriately for reuse (Otterpohl *et al.* 1997), which can offer significant advantage by enabling opportunities for localised water reuse (Gikas & Tchobanoglous 2009).

Decentralised systems also allow a flexible approach in the provision of water services that considers multiple objectives in the local context. These include flood alleviation, landscape amenity and environmental protection. Such systems offer an alternative approach to the provision of water, wastewater and stormwater services to urban areas, which may ultimately be integrated with existing centralised systems or alternatively offer a standalone solution where the provision of centralised systems is not technically, economically or environmentally feasible. These systems can thereby enable existing centralised systems

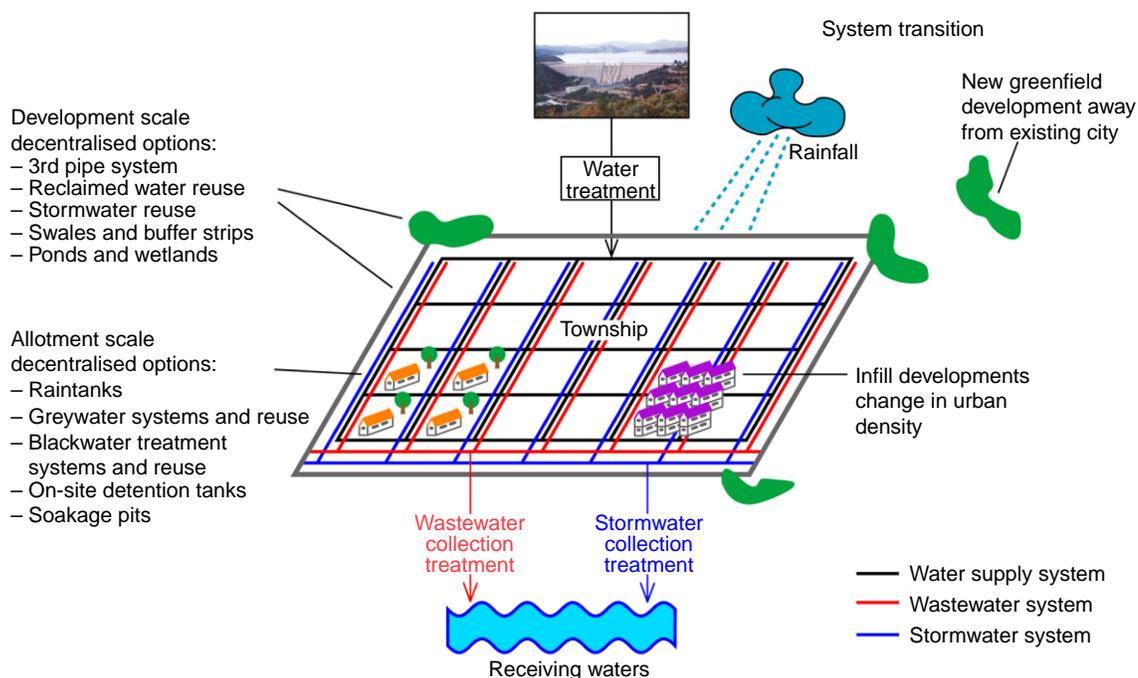


Figure 1 | Centralised water system and new developments due to urbanisation.

to continue servicing their customers in a sustainable manner with no or limited capacity expansion.

TRANSITIONAL APPROACHES

The provision of water services to urban developments is undergoing a major transition in the current environment which is aimed at improving sustainability and ensuring the long-term security of water resources. To address these issues integrated urban water management concepts for providing water and wastewater services are being developed and their application for greenfield development sites has attracted world-wide interest and stimulated research across the globe. The area of retrofitting existing developments with integrated water management techniques is new and has yet to be explored to a significant extent, with only the planning and conceptualisation stages of integrated water systems undergoing detailed exploration. These techniques incorporate decentralised systems which offer a reduction of the water and wastewater loads on existing urban water infrastructure, freshwater resources and waste receiving environments.

A number of structural and non-structural solutions can be used to achieve integrated urban water management and water sensitive urban design objectives. The selection of these solutions will depend on a large number of factors including: the type of development, scale, catchment conditions, climate, customer acceptance, and the allocation of financial resources. Some examples of structural solutions are rainwater tanks, grey-water treatment and reuse, wastewater reuse, stormwater use, on-site detention tanks, buffers, swales, bioretention devices and ponds (Sharma *et al.* 2008). Some of these allotment and development scale tools are listed in Figure 1. There are many technologies and systems available, from which a selection for specific application can be made. If correctly selected, implemented and maintained, these technologies are likely to satisfy the requirements for meeting scarcity of water concerns, community expectations, financial constraints, changing spatial configurations, population densities, community behaviour, flood risk and wastewater related ecological problems etc. A number of case studies, which demonstrate the role of decentralised systems are presented in the following sections.

CASE STUDY 1

The planning and selection of appropriate technologies for infill development is currently a very subjective process. A study by Sharma *et al.* (2007) discussed the planning of an infill development comprising 20 high-rise buildings, of 10 stories each, with 64 residences in each building. These buildings were proposed in a radius of 2 km and would impose a population load of nearly 2,600 persons on the existing infrastructure. The study indicated that the water supply demand and wastewater flows to sewer could be reduced by 53% in comparison to conventional approaches, if decentralised systems are implemented in conjunction with the existing systems. In this approach decentralised wastewater treatment at the building scale would be implemented by using effluent reuse for toilet flushing, washing machines and outdoor usage. The centralised systems and building scale wastewater treatment and reuse system configurations are shown in Figure 2(A, B). Table 1 highlights the water balance study conducted for three options:

- A. A conventional approach—with potable water supply for all end usage,
- B. Building scale wastewater treatment and reuse for toilet flushing, washing machines and outdoor use with high demand management and
- C. Centralised reclaimed water reuse for toilet supply, washing machines and outdoor from sewer mining.

It can be seen from Table 1 that the additional water flows in the water network system can be reduced from 269 kL/day to as low as 126 kL/day and similarly the flows in sewerage system from 254 kL/day to 117 kL/day with local wastewater treatment and fit for purpose reuse. Providing water and wastewater services with conventional approaches would require significant upsizing of pipelines over a long distance in addition to the additional load on the freshwater resources and waste receiving environment. Such a scenario could have jeopardised the further planning of such a development.

This study illustrated that, the load on existing infrastructure for municipal services for water supply distribution/treatment and wastewater collection/treatment can be reduced significantly with the implementation of

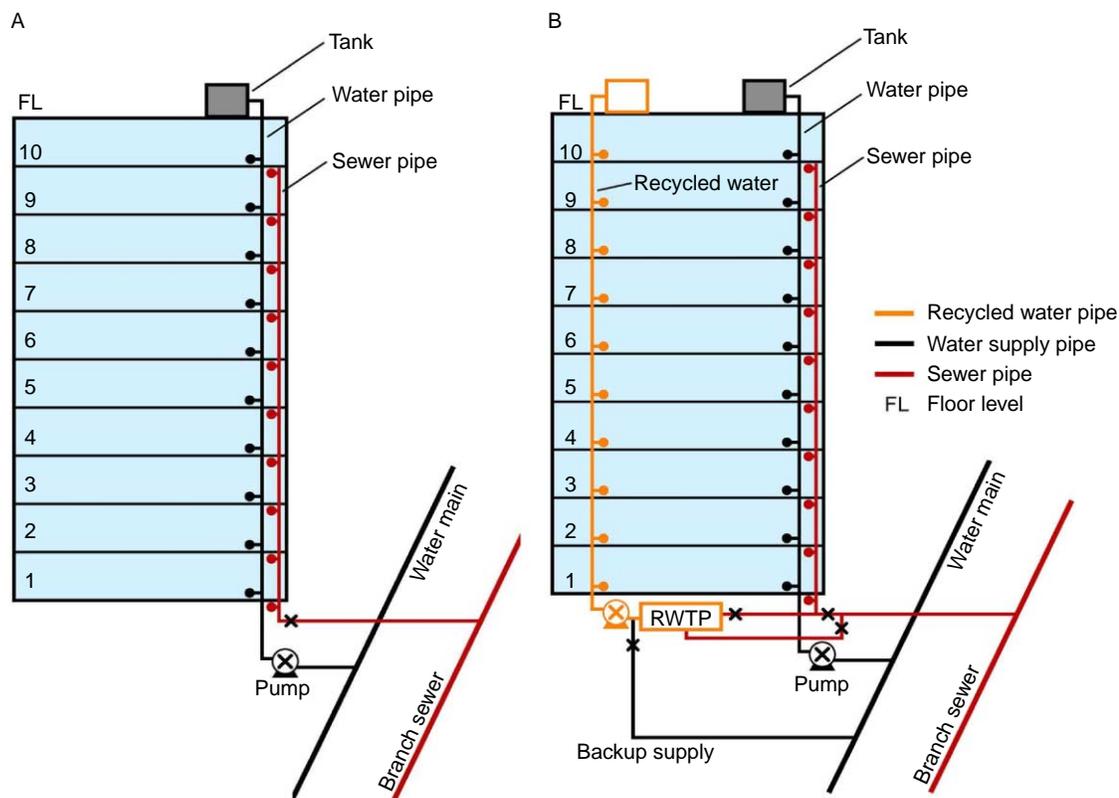


Figure 2 | Centralised systems (A) and building scale wastewater treatment and reuse (B).

decentralised systems. This approach also reduces the loads on freshwater resources and the waste receiving environment. There are also other ecological and environmental benefits such as a reduction in energy demands from long distance pumping needs, and ecosystem preservation due to reduced nutrient discharges.

CASE STUDY 2

In another proposed 3,062 ha greenfield development for a population of 80,000 at the northern periphery of the

city of Melbourne, it was proposed that a decentralized solution could provide sustainable water and wastewater services for the development (Sharma *et al.* 2009). Four options considered for the development were:

- Servicing through conventional approaches/systems,
- Local development scale wastewater treatment and reuse for toilet supply and external usage,
- Local development scale stormwater collection, treatment and reuse same as for Option B and
- Self-sustained allotments with on-site blackwater/grey-water treatment/reuse for non-potable purposes

Table 1 | Water balance results

Option	Additional potable water demand (kL/day)	Additional wastewater generated (kL/day)	Wastewater reuse adopting decentralised systems (kL/day)	Wastewater to existing sewers (kL/day)
A. Centralised systems	269	254	0.0	254
B. Building scale waste water treatment/reuse	126	194	76	117
C. Local sewer mining	168	254	97	157

and rainwater collection as well as usage for potable water supply.

No centralised reticulated water and wastewater systems were proposed in Option D for residential areas. Analysis indicated that only close to 90% reliability in water supply services could be achieved through the self-sustained approaches noted in Option D: this was primarily due to climate variability and the unavailability of water supply from outside sources. A detailed economic and environmental assessment of all these options was conducted for comparison purposes as well as option selection. These analyses included water and contaminant flow estimation, conceptual design of infrastructure, life cycle costing (LCC) and life cycle analysis (LCA). Based on the analysis Option D was rejected due to limited reliability and high cost. Option B was selected as the preferred servicing option. This option reduced the additional load on freshwater resources by 43%, and wastewater flows to the receiving environment by 50%. This reduced the additional daily water flows through water systems from nearly 40 ML to 22 ML. Similarly additional wastewater flows through the sewer system was reduced from 31 ML/day to 15 ML/day. Such reductions indicate that it is possible to achieve significant reductions in infrastructure upsizing requirements in order to meet the additional demand for the proposed development. The significant reduction in nutrient loads to receiving water (Port Phillip Bay) was also the highlight by this option, which is critical for the integrity of the bay's marine ecosystem. The water balance results of the study is presented in [Table 2](#).

These studies indicate that the transition of existing urban water systems to a more sustainable state is achievable by the implementation of allotment scale decentralized systems such as rainwater tanks, grey-water

treatment/reuse and on-site stormwater detention. These systems have significant impact on the potable water reduction, wastewater flows and stormwater peak reduction in existing urban water systems. In addition, the implementation of these solutions can create additional capacity for future population expansion with a reduction of flow through the infrastructure and lower loads on fresh water resources, as well as receiving water environments.

CASE STUDY 3

Urban water services in the Australian Capital Territory (ACT) are currently provided through conventional centralised systems, involving large-scale water distribution, wastewater collection, as well as water and wastewater treatment. In this case, the study was conducted to assist Environment ACT (Department of Environment) in setting broad policies for future water services in Canberra for prediction of the effects of various decentralised water servicing scenarios, including demand management options, rainwater tanks, grey-water use, on-site detention tanks, gross pollutant traps, as well as swales and ponds. The results of this study indicated that demand management tools or a combination of grey-water and rainwater use for existing suburbs best achieves potable water reductions, while third pipe systems are the preferred option for greenfield sites. Rainwater and stormwater reuse from stormwater ponds within the catchments provided the highest reduction in nutrient discharge from the study areas. As a result of the study, Environment ACT amended planning controls to facilitate installation of rainwater tanks and grey-water systems, and commenced a Government funded rebate scheme for rainwater tanks (Sharma *et al.* 2008). [Table 3](#) below presents the outcomes of the analysis; it can be seen that reductions of up to 34%

Table 2 | Summary of average daily water outputs for various options

Options	Imported water use (ML/day)	Stormwater runoff, not reused (ML/day)	Wastewater to sewer, not reused (ML/day)	Stormwater/rainwater use (ML/day)	Greywater/reclaimed water use (ML/day)
A. Conventional approaches	39.6	26.7	31.3	0	0
B. Local wastewater reuse	22.7	26.7	15.6	0	9.6
C. Local stormwater reuse	22.7	17.6	24.7	9.1	0
D. Self sustained systems	11.3	20.0	14.9	6.4	3.4

in potable water demand was achievable with the implementation of rainwater tanks and grey-water treatment/usage systems.

COMPLEXITIES IN IMPLEMENTING DECENTRALIZED SYSTEMS

The selection of the most appropriate decentralized system for an integrated water-servicing solution is complex and thus requires the development of a cohesive framework, because assessment of individual technologies in isolation can lead to inappropriate analysis. For example, an initial investigation of a simple decentralised ‘rainwater tank’ system has highlighted their highly variable energy usage which varies from 1.3 to 5 kWh/kL (Beal *et al.* 2008; Retamal *et al.* 2009). This raises the question of whether the saving of one resource (i.e. water) is at the expense of another resource (i.e. energy). This highlights the need for an improved understanding of optimal rainwater tank system configuration, as well as the energy-water nexus. Similar investigations are required for a number of decentralised water and wastewater treatment technologies for water–energy interaction and the impact on planning and environmental aspects. Ho *et al.* (2010) reported energy consumption in two decentralised wastewater treatment plants (A: immersed membrane reactor; and B: a train of septic tanks, fabric filter and microfiltration) near Brisbane, Queensland. It was shown that system A used three times more electricity than system B. However consumption converged to a similar greenhouse gas (GHG) footprint when methane emissions from septic tanks were taken into account. It highlights the need for comprehensive environmental assessment of different technologies.

These systems are complex in nature and thus need detailed assessment of their challenges in terms of economics, public and environmental health, system implementation, as well as operational and management issues. There are a small number of assessment models currently available and their application and development is continuing (Hellstrom *et al.* 2000; Ashley *et al.* 2004; Lundie *et al.* 2005; Lundie *et al.* 2006). However, these systems are new and are lacking in governance, operation and management sub-models, engineering design codes, installation guidelines, and risk assessment methods. The verification of design, delivery, management, as well as reliability and sustainability aspects along with associated externalities of these integrated water systems have yet to be investigated in detail.

In a centralized servicing approach, publically-funded water utilities bear the cost of installing the water and wastewater systems, while in decentralized systems the cost is generally transferred to allotment owners who largely bear the direct cost of capital investment, and ongoing maintenance and operation, the extent of which depends upon the nature of the system (Sharma *et al.* 2009). Figure 3 shows the cost analysis of servicing options described in Case study 2. As shown in Figure 3, the cost to allotment holders increases with greater implementation of more decentralized systems. In the case of the self-sustained development, option D in case study 2, the cost to the allotment holder is relatively high. Currently no generally accepted economic model exists to allow equitable distribution of the cost between the water utility, the state and the allotment holder. In this context, consideration of the environmental benefits to both the wider community and the local community is required for evaluating the suitability of decentralised systems. Additionally,

Table 3 | Effect of on-site water saving measures on potable water demand—Gungaharra area

Water/wastewater/ stormwater	Base case	Rainwater tanks in use		Greywater for garden irrigation		Rainwater tanks and greywater for garden irrigation use	
	ML/yr	ML/yr	% reduction	ML/yr	% reduction	ML/yr	% reduction
Potable water	1,588	1,213	23	1,396	13	1,041	34
Wastewater	1,362	1,362	0	1,175	14	1,176	14
Stormwater	1,771	1,406	21	1,770	0	1,424	20

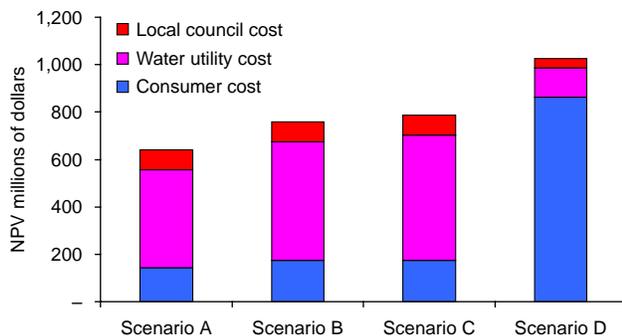


Figure 3 | Life cycle cost distribution among various stakeholders. Note: see Table 2 for description of specific options.

in decentralised systems many of the management responsibilities are shifted onto allotment owners without much social research into the receptivity of householders to accept such costs or the impact on performance and reliability over the lifetime of the system. Such an approach can lead to the failure of systems that will ultimately have reduce the uptake of these systems and thus the long term sustainability of existing systems. A number of other issues need consideration for the mainstream application of decentralised systems. There is the need for the water sector to (i) foster the development of the workforce skills required for the maintenance and operation of decentralised systems; (ii) update the existing design guidelines; (iii) develop appropriate management, governance and regulatory frameworks; and (iv) increase the understanding of the reliability and risks associated with these systems over their lifetime.

CONCLUSIONS

Various examples demonstrate that decentralised systems can play a major role in the transition of current urban water systems to a more sustainable state and can address challenges faced by climate variability, population growth and urbanisation. The burden on fresh water resources, urban water infrastructure and receiving environments can be reduced with the implementation of decentralised systems in conjunction with centralised systems. As these systems are new and complex, wide knowledge gaps exist in their planning, design, implementation, operation, management, governance, reliability, resilience and risk.

Research at all levels is required to reduce knowledge gaps for the greater uptake of these systems.

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