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Risks to the long-term viability of residential non-potable water schemes: a review

Camilla West, Steven Kenway, Zhiguo Yuan

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Risks to the long-term viability of residential non-potable water schemes: a review
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Authors
Camilla West, Steven Kenway, Zhiguo Yuan

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Cooperative Research Centre for Water Sensitive Cities
Level 1, 8 Scenic Blvd
Building 74, Clayton Campus
Monash University
Clayton, VIC 3800
p. +61 3 9902 4985
e. admin@crcwsc.org.au
w. www.watersensitivecities.org.au

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Executive summary

Progression towards sustainable urban water management in Australia has seen a reduction in potable water demand through the introduction of water conservation measures, the diversification of water supply sources and the use of fit-for-purpose water supplies (Chong et al., 2009). Residential non-potable water schemes have been implemented in response to water supply security concerns, constrained centralised infrastructure and increased environmental degradation (Burn et al., 2012, Davis and Farrelly, 2009, Myers et al., 2013, Leonard et al., 2013).

A proportion of non-potable water schemes implemented in residential developments in Australia have been largely successful in demonstrating performance and sustainability attributes, however just as many have encountered significant challenges either at the construction phase, resulting in delay in scheme commissioning, or during the operational phase, resulting in decommissioning of the scheme in some cases (Taylor et al., 2011, Institute for Sustainable Futures, 2013l).

To date, public health risks associated with the provision of non-potable water have been of primary concern, with risk assessments focused predominately on microbial and chemical hazards (Natural Resource Management Ministerial Council et al., 2006, Chapman et al., 2006, Page and Levett, 2010). However, few public health impacts of non-potable water schemes have been reported (Hambly et al., 2012). Investigation of residential non-potable water schemes indicates that schemes have predominately been decommissioned due to financial challenges arising from changing regulatory, technical, economic, social and/or environmental conditions either during the construction or operational phase of the scheme (Institute for Sustainable Futures, 2013l, Moglia et al., 2011).

A major factor impacting the long-term viability of residential non-potable water schemes was found to be the variance between forecast and actual demand (Institute for Sustainable Futures, 2013f). Water demands are influenced by a range of varying conditions including population growth, climate variability, water conservation behaviour and attitudes, technological advances and water pricing (Institute for Sustainable Futures, 2013f). Schemes are often designed on optimistic forecasts of demand and supply with limited consideration to changing conditions, varying treatment performance or downtime requirements of scheme components.

Estimates of supply and demand for non-potable water schemes should incorporate an assessment of varying conditions on scheme performance. Learnings from historical schemes, pertaining to all potential risks which may derail a project, should be considered at the planning stage of a scheme. This would enable the full range of potential outcomes of a scheme to be assessed in order to develop appropriate management strategies.

A better understanding of risks would enable the creation of more robust and resilient water schemes. By understanding the factors contributing to risks, the schemes may be modified to operate more efficiently with less technical challenges. Once risk is fully understood and risk management strategies have been developed, investors will be well informed and able to decide if the potential benefits of the scheme outweigh the cost and unmitigated risks.

Introduction

The Australian Millennium Drought of 2000 to 2010, in conjunction with population growth, environmental degradation and constrained water and wastewater infrastructure, has seen the diversification from conventional water and wastewater services to the integration of alternative services in urban areas. A significant shift from a siloed approach to water, wastewater and stormwater management has transpired with integrated urban water management becoming the new paradigm (Mitchell, 2004, Mitchell, 2006).

Integrated urban water management adopts a comprehensive approach to urban water services, where water supply, stormwater management and wastewater management are viewed as components of an integrated system and synergies between stakeholders and organisational frameworks are paramount (Mitchell, 2006). Integrated urban water management expands the traditional objectives of urban water supply, wastewater management and stormwater management to consider ecologically sustainable development by reducing the take of water from surface water and groundwater sources, reducing the discharge of wastewater effluent to surface waters and slowing and reducing stormwater runoff to vulnerable habitats (Nelson, 2008).

Integrated urban water management places an emphasis on both demand-side and supply-side management, utilisation of alternative and localised water and wastewater services and the provision of fit-for-purpose water supplies, where water of varying quality is supplied to suitable end-uses (Mitchell, 2006). As a result, urban areas of Australia have seen the uptake of non-potable water schemes in greenfield or infill residential developments comprising rainwater harvesting, stormwater harvesting, greywater recycling and/or wastewater treatment and recycling (Sharma et al., 2013, Cook et al., 2009, Mitchell, 2006).

In 2013 – 2014 Sydney Water saved around 13 gigalitres (GL) of drinking water by recycled 47 gigalitres, of which around 2 gigalitres was utilised for residential purposes (Sydney Water, 2014). City of Sydney has committed to reducing wastewater discharge by 30 percent (%) and replacing 30 percent of mains water demand by 2030 with non-potable water generated from local water resources, including stormwater harvesting, wastewater treatment and recycling, rainwater harvesting and greywater recycling (City of Sydney, 2012). In Adelaide, stormwater harvesting schemes are expected to harvest up to 18 gigalitres per year (approximately nine percent of the total annual water use) and wastewater reuse is expected to increase to nearly 45 percent (Government of South Australia, 2010). Of these non-potable water schemes, a large proportion will be used for toilet flushing, garden watering and outdoor use in residential developments, while in Victoria approval has been granted for the use of recycled water in residential laundry washing machines (South East Water, 2015).

A proportion of non-potable water schemes implemented in residential developments in Australia have been largely successful in demonstrating performance and sustainability attributes, however, just as many have encountered significant challenges either at the construction phase, resulting in the scheme not being commissioned, or during the operational phase, resulting in decommissioning of the scheme in some cases (Taylor et al., 2011, Institute for Sustainable Futures, 2013l).

In cases where schemes have been decommissioned or have encountered ongoing technical or financial challenges, the objectives of the scheme to enhance water supply security, improve wastewater management and reduce pollutant discharges to the environment have not been fully realised. In addition, community expectations have not been met and reputational damage has ensued.

In many cases, the lack of understanding of risks pertaining to non-potable water schemes stems from the propensity to report on success stories only, with minimal learnings disseminated from less than successful cases (Mitchell, 2006, Muston, 2004). This potentially propagates risks to future schemes as scheme planning and design is undertaken without knowledge of the potential hazards which may arise.

A holistic understanding of the full range of risks to non-potable water schemes is required, with an initial understanding derived from successful and less than successful schemes. Understanding the full range of risks to a scheme will enable better decision making, with appropriate risk assessment during the planning phase informing risk management during the operational phase (Marsden Jacob Associates, 2013). Residential non-potable water schemes have the potential to provide a range of financial, environmental and social benefits; the challenge is to manage risks in order for the benefits of such schemes to be realised.

Scope of this Report

The work sought to systematically review the conditions leading to premature decommissioning of non-potable water schemes in residential developments and to develop an improved understanding of the full range of risks to the long-term viability of schemes. In order to identify risks to the long-term viability of schemes, an understanding of the objectives of schemes and the perceived and actual benefits of non-potable water schemes in residential developments was developed.

Information was gathered through detailed literature review and through discussions with water industry personnel. The detailed literature review included academic papers, published literature from conferences, book chapters, regulatory documents and industry reports. Specifically, literature pertaining to the following was reviewed:

- Objectives of non-potable water schemes in residential developments;
- Perceived and actual benefits of non-potable water schemes in residential developments;
- Challenges, impediments or risks to the ability of non-potable water schemes to meet objectives; and
- Case studies of non-potable water schemes in residential developments.

Water industry personnel were consulted in order to substantiate and expand on the learnings from the detailed literature review and to obtain additional information specific to individual case studies. The reviewed case studies ranged from cluster to precinct scale non-potable water schemes in residential areas comprising varying configurations of infrastructure, as listed in Appendix A.

This report describes the outcomes of the literature and case study review, commencing with a review of the current contextual environment of rainwater harvesting, stormwater harvesting, greywater recycling and wastewater treatment and recycling schemes, the perceived benefits of these schemes and risks to their long-term viability.

The benefits of non-potable water schemes in residential developments and risks to the long-term viability of such schemes are addressed in the latter half of this report. The report concludes with discussion on learning from past experience and incorporating risk assessment at the planning stage of a non-potable water scheme.

The case studies addressed in this report are predominately owned, operated and managed by water utilities and hence the target readers of this report are water utility personnel. Learnings from this report may also benefit regulators, developers, consultants and researchers.

Residential non-potable water schemes

Overview

Rainwater harvesting, stormwater harvesting, greywater recycling and wastewater treatment and recycling have become increasingly common in urban areas for the supply of non-potable water, and in some cases potable water (through rainwater harvesting), to residential developments. The Millennium Drought increased focus on demand-side measures for water conservation, including acknowledgment that a number of end-uses, such as public open space irrigation, garden watering and toilet flushing, do not require water of potable quality. As a result, the provision of alternative water sources for fit-for-purpose supply has been brought to attention and the environmental benefits of non-potable water schemes publicised (Mitchell, 2004).

Non-potable water schemes have since been implemented in varying configurations and at varying scales across the urban landscape. Sharma et al. (2013) identified the following scales of non-potable water schemes, as illustrated in Figure 1:

- household scale: management measures and/or treatment technologies that provide water and wastewater services at the individual property scale, such as rainwater tanks and greywater recycling, and are owned and operated by property holders;
- cluster or development scale: schemes which provide for multiple dwellings or a whole development, are sourced and treated within proximity to the dwellings and are managed either by a body corporate or water utility. Schemes include rainwater harvesting, wastewater treatment and recycling with third pipe distribution and stormwater harvesting; and
- distributed schemes: schemes which generally provide services to large developments and are owned and operated by water utilities.

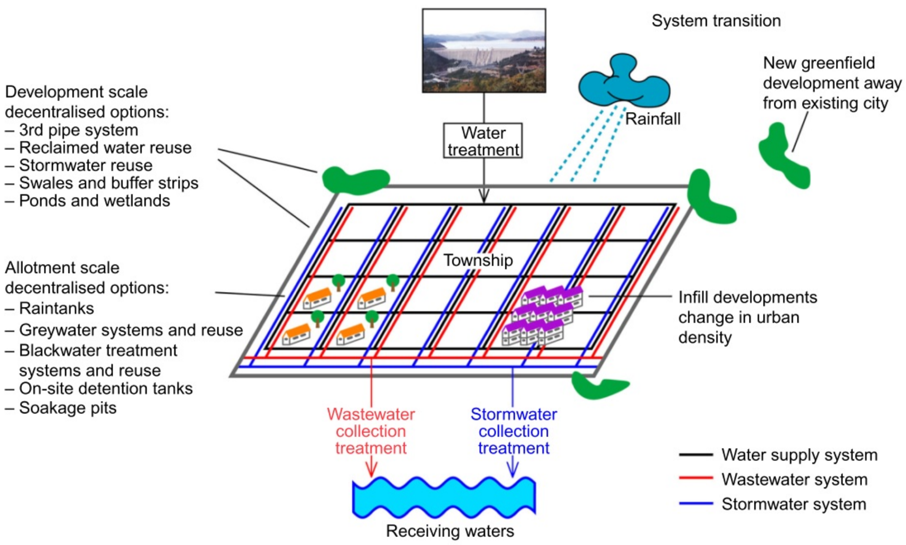

Figure 1. Scales of non-potable water schemes in urban areas (Sharma et al., 2013, Sharma et al., 2010)

Rainwater harvesting

Overview

For the purposes of this report, residential rainwater harvesting is defined as the process of diverting, collecting and storing rainwater from a roof area (Cook et al., 2009, Diaper, 2004b). Rainwater is typically stored in a tank and is used to service a single household or a cluster of households in a communal setting (Mitchell, 2006). The information provided in the following sections pertains to rainwater harvesting for non-potable water supply only.

The advent of water demand management programs, changing water regulations and the provision of government rebates for water conservation measures resulted in an increase in rainwater harvesting in urban areas. According to the Bureau of Statistics, 34 percent of Australian households living in a dwelling suitable for a rainwater tank had a rainwater tank in March 2013, as opposed to 32 percent in 2010 and 24 percent in 2007 (Australian Bureau of Statistics, 2013), as illustrated in Figure 2. Of the rainwater tanks installed in capital cities, 33 percent were connected by pipe to a tap or outlet inside the dwelling (Australian Bureau of Statistics, 2013).

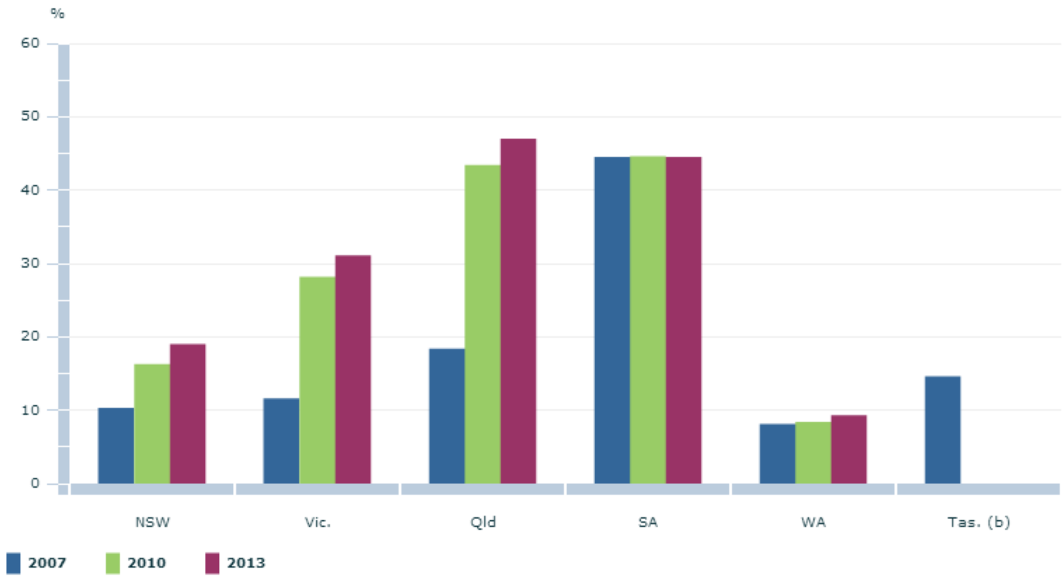

Figure 2. Households with a rainwater tank installed by state capital city (Australian Bureau of Statistics, 2013)

Regulations

The regulatory environment surrounding rainwater tanks in Australia has changed dramatically post Millennium Drought. While some states are still advocating the implementation of rainwater tanks, and government rebates are provided in the case of Victoria (Department of Sustainability and Environment, 2012), the mandatory requirement to install rainwater tanks in all new developments has been removed in all states. Some states of Australia specify water reduction targets for residential dwellings, such as through BASIX in NSW. These water reduction targets may be achieved through the implementation of rainwater tanks, though are predominately achieved through the application of water efficient appliances and fixtures.

Numerous guidelines have been prepared for the installation and operation of rainwater tanks in residential developments. The key guidelines adopted are the *Australian Guidelines for Recycled Water: Stormwater Harvesting and Use* (Natural Resource Management Ministerial Council et al., 2009b) and *Guidance on use of rainwater tanks* (enHealth, 2010). Table 1 summarises the current regulatory environment surrounding use of rainwater tanks for non-potable application in residential areas, as referenced by each Government agency.

Table 1. Rainwater tank regulations, rebates and guidelines for residential non-potable water supply (current as of May 2015)

State	Specific rainwater tank regulations	Rebate as of May, 2015	Rainwater tank guidelines
Australian Capital Territory	ACT Government requires new developments or redevelopments to demonstrate 40% water efficiency target and proposes rainwater tanks as Option 1 (ACT Government Environment and Planning, 2014). ACT Planning and Land Authority and ActewAGL specify requirement for approval of tanks over 20,000 litre capacity (ACT Government Environment and Planning, 2014). ACT Health support rainwater use for all purposes except drinking or cooking (ACT Planning and Land Authority, 2010).	None	*Rainwater tanks: Guidelines for residential properties in Canberra* (ACT Planning and Land Authority, 2010)
New South Wales	BASIX, the Building Sustainability Index, is an integral part of the development application process in NSW and supports the installation of rainwater tanks in new developments (New South Wales Government Planning & Environment, Undated). Local Council regulations may vary though typically approval is required for tanks over 10,000 litre capacity. Sydney Water and NSW Health support rainwater use for all purposes except drinking or cooking (ACT Planning and Land Authority, 2010).	None	*Rainwater Tank Design and Installation Handbook* (Australian Rainwater Industry Development Association and Master Plumbers and Mechanical Services Association of Australia, 2008)
Northern Territory	Department of Lands, Planning and the Environment specify that a building permit is required where a tank stand is 600 mm or more above ground level (Department of Land Resource Management, 2013).	Rural areas only	*Rainwater Tanks – Central Australia* (Department of Land Resource Management, 2013) *Darwin Region Water Supply Strategy 2013*

State	Specific rainwater tank regulations	Rebate as of May, 2015	Rainwater tank guidelines
			(Power and Water Corporation, 2013)
Queensland	Local Council regulations: • typically require building permits or plumbing approval • typically only support use for toilet flushing, cold water washing machine and outdoor use (Department of Housing and Public Works, 2013)	None	*Queensland Development Code MP 4.2* (Department of Housing and Public Works, 2013)
South Australia	South Australian building rules require that new dwellings and some redevelopments have an additional water supply, of which the most common installed are minimum-sized rainwater tanks (Department of Primary Industries and Resources, 2006).	None	*Building Advisory Notice – Mandatory plumbed rainwater tanks for Class 1 building* (Department of Primary Industries and Resources, 2006)
Tasmania	Local Council regulations vary though typically all water storages require a Council Plumbing Permit (Hobart City Council, Undated-b).	None	*Guidance on use of rainwater tanks* (enHealth, 2010)

State	Specific rainwater tank regulations	Rebate as of May, 2015	Rainwater tank guidelines
Victoria	Local Council regulations vary though a building or planning permit is generally not required for rainwater tanks in single residential developments. To comply for Living Victoria water rebate, rainwater tanks must be designed, manufactured and certified to relevant Australian Guidelines (Department of Sustainability and Environment, 2012).	Living Victoria water rebate: • Up to $1,500 per household (not available for houses that received building permit after 1 May 2011) • $2,000 for small business with 50 or fewer employees (Department of Sustainability and Environment, 2012)	*Rainwater Use in Urban Communities: Guidelines for Non–drinking Applications in Multi-residential, Commercial and Community Facilities* (Department of Health, 2013)
Western Australia	Local Council regulations of which most require that a building application is approved before a rainwater tank can be installed.	Water Corporation, through H2O Assist, provides reduced prices on specific rainwater tanks (Water Corporation, Undated)	*Guidance on use of rainwater tanks* (enHealth, 2010)

Scheme configuration

Rainwater harvesting schemes are classified into three basic types (Diaper, 2004b):

- Direct feed system: water is supplied from the storage tank to end uses under pressure by a demand driven pump.
- Header tank system: rainwater is pumped from the storage tank to a header tank that is located above the points of use where it is then supplied by gravity from the header tank to the end use.
- Gravity systems: storage tank is located above the points of use such that water is supplied to end uses under gravity.

Gravity systems typically have a small storage capacity and are used primarily to supply outdoor uses, such as garden irrigation (Diaper, 2004b). Where rainwater tanks supply indoor uses through a direct feed system, a backup from mains supply is provided either through a trickle top-up system or through a mains switch (Diaper, 2004b). The most common non-potable indoor uses supplied by rainwater include the toilet cistern and cold washing machine tap.

Rainwater tanks are often fitted with a first flush device to divert runoff from the roof that is likely to be contaminated by high levels of sediment, heavy metals and zoonotic faecal material (Gardner and Vieritz, 2010). First flush devices comprise a float-actuated valve which diverts rainwater to the collection tank only after the first flush reservoir is full (Gardner and Vieritz, 2010). There is evidence, however, that first flush devices only have limited capability for reducing contaminant discharge to a storage tank and that valves may easily become blocked if poorly maintained (Gardner and Vieritz, 2010).

Technological innovation

Numerous options are now available for rainwater collection and storage including low-profile, modular containers; rainwater bladder tanks that can be stored under a house or deck; underground tanks and portable tanks.

Tank Talk is a phone application developed iota, the commercial arm of South East Water, which enables a rainwater tank owner to remotely instruct the rainwater tank to release water at a controlled rate according to rain or storm predictions received from the Bureau of Meteorology (Iota, 2015). The development of the application is based on the premise that rainwater tanks aid in the reduction of stormwater runoff impacts to drainage infrastructure, roads and surface water systems. The application also enables monitoring of consumption and use of the rainwater tank in real time.

Benefits of rainwater harvesting

Potable water savings

Rainwater tanks provide around 25 percent reduction in potable water requirements when rainwater is supplied for non-potable purposes, as indicated in Table 2. Rainwater tanks are able to catch light or intermittent rainfall events, thereby providing some contingency during drought or variable climatic conditions (Australian Rainwater Industry Development Group and Master Plumbers' & Mechanical Services Association of Australia, 2008).

Table 2. Rainwater harvesting for residential non-potable water supply

Location	Monitoring program description	Tank capacity	End-use	Average rainwater tank supply	Study reference
South East Queensland	20 detached residential homes with similar internally plumbed rainwater tanks monitored over a 12 month period	2.5 kL to 7.6 kL	External garden taps, toilet and cold washing machine tap	40 kL/household/year 26% reduction (based on average 151 kL/household/year total water use in study area)	(Umapathi et al., 2013)
South East Queensland	Desktop analysis of internally plumbed rainwater tanks using council water billing data	Range of capacities	External garden taps, toilet and cold washing machine tap	50 kL/household/year 25% reduction (based on average 197.8 kL/household/year total water use in study area)	(Beal et al., 2011)
Sydney, New South Wales	52 households with internally plumbed rainwater tanks monitored over a 12 month period	4.2 kL (average)	External garden taps, toilet and cold washing machine tap	38 kL/household/year 19% reduction (based on average 197 kL/household/year total water use in study area)	(Sydney Water, 2011)

Financial

The wide spread implementation of rainwater harvesting in urban areas, and associated reduction in water demand from the centralised water supply system, may aid in deferring capital investment of infrastructure upgrades (Marsden Jacob Associates, 2007). Coombes et al. (2002) estimated that the use of rainwater tanks in the lower Hunter region, along with other source control measures, may delay the construction of new water supply headworks infrastructure by up to 34 years corresponding to an estimated $67 million present worth savings.

Environmental

Rainwater tanks may provide on-site retention during storm events, potentially reducing the impact of peak discharge in minor storm events and reducing the quantity of pollutants discharging to stormwater drains and waterways (Diaper, 2004a, Australian Rainwater Industry Development Group and Master Plumbers’ & Mechanical Services Association of Australia, 2008).

A study undertaken by Burns et al. (2010) simulated a range of hypothetical urban developments and rainwater harvesting scenarios and found that typical allotment-scale rainwater harvesting configurations may reduce the frequency of stormwater runoff and annual variability to that of natural, pre-development conditions.

Social

An indirect benefit of rainwater harvesting may be the potential improvement in understanding of the water cycle by owners of a rainwater tank, and, as a result, the more efficient use of water (Binney and Macintyre, 2012).

Risks to the long-term viability of rainwater harvesting

Potable water savings

The supply of water from rainwater tanks is dependent on a range of factors including location, climatic conditions, area of connected roof, available tank capacity, end-use and seasonal demands (Sydney Water, 2011). The yield of a rainwater tank is dependent on volume and timing of run-off and may vary greatly dependent on the climatic conditions of the region (Marsden Jacob Associates, 2007).

Estimates of supply from rainwater tanks are often optimistic and not achieved (Marlow and Tjandraatmadja, 2014). In Melbourne, where 30 percent of the population has a rainwater tank, only 5 gigaliters per year is supplied from rainwater harvesting which represents 1.2 percent of the city's total water use and 1.4 percent of its municipal supply (Living Victoria Ministerial Advisory Council, 2011).

Financial

Numerous studies have been undertaken to assess the cost effectiveness of residential rainwater tanks in Australia with majority identifying that rainwater tanks represent a relatively high cost source when compared to other water sources (Marsden Jacob Associates, 2007, Binney and Macintyre, 2012, Hall, 2013, Marsden Jacob Associates, 2009). A unit cost assessment undertaken by Marsden Jacob identified that property owners who install a rainwater tank will likely face a net financial loss over time (Marsden Jacob Associates, 2007).

A study undertaken for Master Builders Queensland compared the estimated levelised cost of rainwater tanks to other water supply sources, as shown in Figure 3, and identified that the most likely cost of water from a 5,000 litre rainwater tank in Brisbane or Cairns is approximately $3.15 - $3.20 per kilolitre, though may be as high as $11.90 per kilolitre (Binney and Macintyre, 2012).

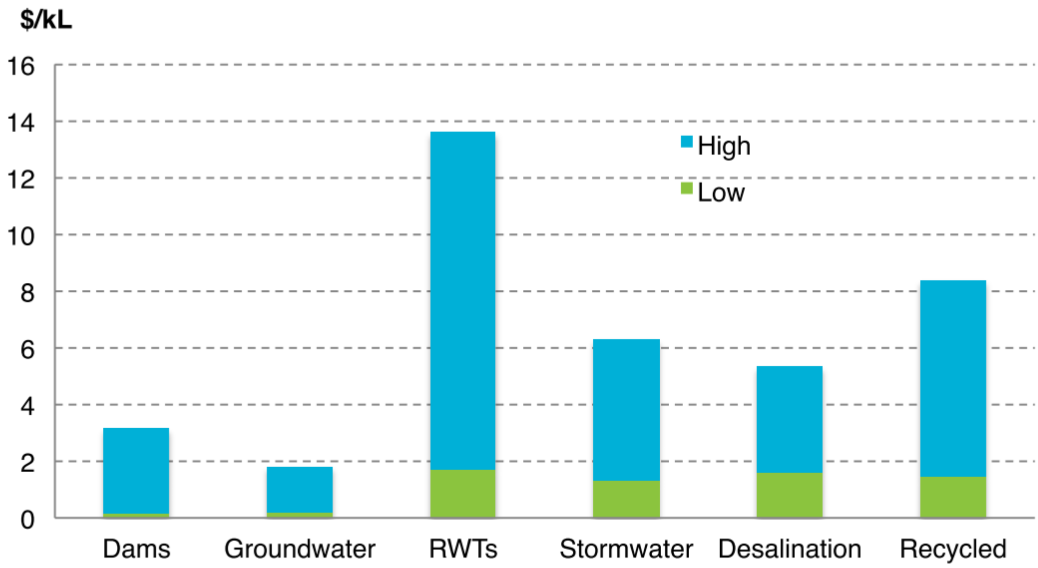

Figure 3. Estimated levelised cost of water supply options ($2012) (Binney and Macintyre, 2012)

The high cost of rainwater tanks inhibits large scale uptake of this alternative water source. Operational costs, such as for pump replacement, may lead to homeowners reconnecting end-uses to the mains water supply rather than re-instating the use of the rainwater tank.

Environmental

Concern over the energy intensity of rainwater harvesting schemes has resulted in a range of monitoring campaigns undertaken to identify the specific energy requirements under different scheme configurations. The monitoring outcomes indicated that rainwater scheme energy requirements vary markedly dependent on scheme configuration, as illustrated in Table 3.

Table 3. Rainwater harvesting energy requirements

Location	Number of dwellings	End-use	Energy for rainwater supply per dwelling (kWh/kL)	Study reference
Brisbane, Queensland	4-6	Potable and non-potable	2.1 – 3.8	(Gardner et al., 2006) (Beal et al., 2008)
Gold Coast, Queensland	40	Potable and non-potable	1.4 (median)	(Hood et al., 2010)
Gold Coast, Queensland	5	Non-potable	1.0 – 1.7	(Talebpour et al., 2011)
Sydney, New South Wales	8	Non-potable	0.9 – 2.3	(Retamal et al., 2009)
Melbourne, Victoria	31	Non-potable	0.6 – 11.6	(Water Conservation Group and 'us' Utility Services, 2009)

A study undertaken by Retamal et al. found that common single household rainwater harvesting schemes had an energy intensity of approximately 1.5 kilowatts per kilolitre (kWh/kL) (Retamal et al., 2009). While this energy requirement is significantly less than that for desalination, 3.6 kilowatts per kilolitre on average (Kenway et al., 2008), it is higher than that of conventional centralised water supply which is typically less than 1 kilowatts per kilolitre.

Retamal et al. (2009) found that the energy intensity and overall energy consumption was affected predominately by the system configuration including the pump type, switching system and pressure vessel. Lower flow end uses such as toilet flushing contributed to higher energy intensity, while the overall energy consumption was dependent on the water use behaviour and presence of water efficient appliances.

Tjaandraatmadja et al. suggested that overall energy footprint of rainwater harvesting schemes could be markedly reduced through appropriate selection of scheme components, specifically the brand and motor capacity of pumps (Tjandraatmadja et al., 2013).

Social

The Commonwealth Government Environmental Health Standing Committee (enHealth, 2010) states that the risk of illness arising from consumption of rainwater in most areas of Australia is relatively low dependent on the following factors:

- The water is visually clear;
- The water has little taste or smell; and
- Collection of rainwater is via a well maintained tank and roof catchment system.

While the risk of contamination is relatively low, there is still potential that chemical, physical and microbial contamination may occur during collection and storage of rainwater (enHealth, 2010). The condition of rainwater tanks and rainwater supply is dependent on maintenance by the homeowner, and while maintenance requirements are not overly onerous, most roof catchments and rainwater tanks are typically poorly maintained.

As government agencies are unable to rely on homeowners to undertake the required maintenance of roof catchments and rainwater tanks, and there is potential for contamination to occur during collection and storage of rainwater, the use of un-treated rainwater for potable purposes is discouraged (enHealth, 2010).

Stormwater harvesting

Overview

Stormwater harvesting schemes have become increasingly popular for irrigation of small to medium scale open space areas such as playing fields, golf courses and parks and gardens (Water by Design, 2009, Department of Environment and Conservation, 2006). More recently, stormwater harvesting schemes have provided non-potable water supply for residential developments (Leonard et al., 2013, Page et al., 2013).

Stormwater harvesting is the process of diverting, storing and treating stormwater runoff in urban areas for reuse (Diaper, 2004b). Stormwater harvesting differs from rainwater harvesting as stormwater is collected from street and other hard or impervious surfaces, and creeks or drains rather than from roof areas.

Stormwater harvesting schemes may be managed by private operators, developers, Council or water utilities, depending on the purpose of the stormwater harvesting scheme. More recently, stormwater harvesting schemes have been combined with aquifer storage and recovery, which is the process of injecting water into a suitable aquifer for storage and later reuse (Dandy et al., 2013).

Regulations

The *Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse* (Natural Resource Management Ministerial Council et al., 2009b) provide guidance on assessing, designing, implementing, operating and managing a stormwater harvesting scheme to supply recycled water for varying end-uses applications. The *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (Natural Resource Management Ministerial Council et al., 2009a) provide a framework for managing aquifer recharge and for identifying and preventing hazards.

Table 4 provides a summary of the local, state and national guidelines associated with stormwater harvesting schemes and supply for residential end-uses, as referenced by each Government agency.

Table 4. Stormwater harvesting regulations and guidelines for residential non-potable water supply (current as of May 2015)

State	Specific stormwater harvesting regulations	Stormwater harvesting guidelines
Australian Capital Territory	Local Council approval is likely required.	*Waterways: Water Sensitive Urban Design General Code* (ACT Planning and Land Authority, 2007)
New South Wales	BASIX supports the implementation of stormwater harvesting in new developments. Local Council approval is required for installation, operation and maintenance of privately operated recycled water schemes (Sydney Water, 2013). Consultation with NSW Health is required as a component of the local Council approval process (Sydney Water, 2013). 'Stormwater Harvesting and Re-use Agreement' required to be approved by Sydney Water (Sydney Water, 2013). Stormwater harvesting proposals from local government require approval from OEH (Office of Water).	*Managing Urban Stormwater: Harvesting and Reuse* (Department of Environment and Conservation, 2006) *Interim NSW Guidelines for Management of Private Recycled Water Scheme* (Department of Water and Energy, 2008a) *Stormwater harvesting: How to collect and re-use stormwater from Sydney Water's stormwater system* (Sydney Water, 2013)
Northern Territory	Local Council approval is likely required.	*Darwin Region Water Supply Strategy 2013* (Power and Water Corporation, 2013)
Queensland	Local Council approval is required for building works, to connect to stormwater infrastructure and for plumbing approval. State Government approval is required for extraction of water from waterways or aquifers.	*Harvesting the potential of stormwater* (Brisbane City, 2008) *Draft Stormwater harvesting guidelines* (Water by Design, 2009)
South Australia	Local Council approval is likely required.	*Water for good: a plan to ensure our water future to 2050* (Government of South Australia, 2010)
Tasmania	Local Council approval is likely required.	*Stormwater Strategy 2012–2017* (Hobart City Council, 2012)
Victoria	Some stormwater recycling schemes may require approval or a permit from the local council under the *Planning and Environment Act 1987* or *Building Act 1993.*	*Stormwater harvesting: Guidelines for stormwater harvesting* (Melbourne Water, Undated)

State	Specific stormwater harvesting regulations	Stormwater harvesting guidelines
	Melbourne Water regulations: • If stormwater is flowing to the sea via a drain, all of the stormwater may be harvested; • If stormwater is flowing to a stream from an existing development, up to 50 per cent of existing stormwater can be harvested for consumptive use; and • If stormwater is generated from a new development, all is available for consumption (Melbourne Water, Undated).	
Western Australia	Local Council approval is likely required.	*Stormwater Management Manual for Western Australia* (Department of Environment, 2004)

Scheme configuration

The configuration of stormwater harvesting schemes varies dependent on the location and nature of the scheme and the proposed end-use. Typically, a stormwater harvesting scheme will comprise collection, storage, treatment and distribution components (Diaper, 2004b).

Stormwater harvesting schemes which provide water for irrigation of open spaces generally require a low level of treatment, which may comprise constructed wetlands, ponds, sand filters, gross pollutant traps, swales or bio-retention systems (Diaper, 2004b, Water by Design, 2009). Stormwater harvesting schemes which supply household non-potable demand require a higher level of treatment, typically in the form of UV radiation, chlorination or ozonation (Diaper, 2004b, Water by Design, 2009).

Stormwater harvesting schemes may be implemented at cluster, neighbourhood, district or whole of catchment scale dependent on the objectives and the end-use of the scheme. A summary of stormwater harvesting schemes at varying scales for residential purposes in urban areas is provided in Table 5.

Table 5. Operational stormwater harvesting schemes for residential non-potable water supply

Case study	Development description	Scheme description	End-use	Reference
Christie Walk, Adelaide, South Australia	27 dwellings, mix of townhouses and apartments with communal indoor and outdoor spaces	Roof and surface runoff is captured and stored in 2 x 20,000 L underground tanks	Garden irrigation and toilet flushing	(Leonard et al., 2013)
Mawson Lakes, Adelaide, South Australia	4,000 households, commercial centre, technology park, two schools and university campus	Water from the Parafield Wetlands Harvesting (ASR) Scheme (consisting of an upstream storage basin, downstream sedimentation tank, treatment wetland and aquifer storage) is mixed with treated wastewater and undergoes disinfection treatment (chlorination) then distribution via third pipe to residences	Garden and open space irrigation, general outdoor use and toilet flushing	(Leonard et al., 2013)
Lochiel Park, Adelaide, South Australia	109 medium sized residential developments	Stormwater is captured, treated using a gross pollutant trap and wetland and stored in T2 aquifer	Proposed extraction from aquifer for garden and open space irrigation and toilet flushing	(Leonard et al., 2013)
Kogarah Town Square, Sydney, New South Wales	193 residential apartments, a public library and town square	Stormwater runoff from the site is captured in underground storage tanks and treated through a screen filter and disinfection	Garden and open space irrigation, toilet flushing, car washing and town square water feature	(Mitchell, 2004)

Case study	Development description	Scheme description	End-use	Reference
		unit		
Sydney Olympic Park, Sydney, New South Wales	2,000 households in Newington Estate	Stormwater is captured in two storages and a series of wetlands, then combined with reclaimed wastewater prior to undergoing microfiltration and disinfection	Garden and open space irrigation, toilet flushing and outdoor use	(Mitchell, 2004)

Technological innovation

The Fitzgibbon Stormwater Harvesting Scheme (FiSH), once commissioned, will be the first scheme in Australia to provide treated stormwater to residential developments for non-potable water supply. The FiSH scheme is located at the Fitzgibbon Chase development in South East Queensland and has been designed to provide up to 89 megalitres per year (ML/yr) of non-potable water for irrigation, toilet flushing, cold water laundry and other outdoor uses. The scheme will divert stormwater runoff from a channel running through the site prior to treatment through a filtration and disinfection system and distribution through a third pipe system (Bligh Tanner, Undated, Waterways, 2011).

Benefits of stormwater harvesting

Potable water savings

Centralised water savings achieved by stormwater harvesting schemes is dependent on the nature of the scheme, with the supply potential significantly dependent on the storage capacity of the scheme and climatic conditions of the region.

The current supply capacity of the Parafield Stormwater Harvesting scheme is 1,100 megalitres per year with the second stage expected to increase the supply to 2,100 megalitres per year (City of Salisbury, Undated). Hatt et al. reviewed seven stormwater harvesting schemes and found the percent of mean annual runoff collected to range from 20 to 100 percent, and the reductions in potable water demand to range from 17 to 65 percent (Hatt et al., 2004). In 2010, an estimated 5 gigalitres of stormwater was harvested in Melbourne which equated to 1.2 percent of Melbourne's total consumption (412 gigalitres) (Living Victoria Ministerial Advisory Council, 2011).

Financial

The financial viability of a stormwater harvesting scheme is dependent on the scale of the scheme, with larger schemes providing greater economies of scale. KBR (KBR, 2004) estimated that, where space exists for larger schemes with urban catchments of 200 ha or more, the cost per kilolitre can become equal or lower than potable water costs.

Binney & Macintyre estimated that the unit cost of stormwater harvesting schemes ranges between $1.00 per kilolitre to $6.00 per kilolitre, similar to that of desalination schemes though less than non-potable recycled wastewater schemes (see Figure 3) (Binney and Macintyre, 2012).

Environmental

Stormwater harvesting can reduce the volume of water and pollutants flowing into the drainage system thereby potentially reducing the impacts of urbanisation on aquatic ecosystems. In new urban developments, harvesting stormwater can reduce the need for, and capacity of, on-site detention and other stormwater management measures (Department of Environment and Conservation, 2006).

The process of capture, storage and treatment of stormwater through wetlands allows time for effective settlement and filtering of suspended matter to which most toxic pollutants are attached. The result is that around 90 percent of pollutants and 70 percent of nutrients are removed from the inflow captured by the stormwater treatment scheme (KBR, 2004).

Stormwater harvesting schemes can provide attenuation of post-development hydrology with the diversion and capture of low flow events. Some benefit for flood management at the one to two year Average Recurrence Interval (ARI) is provided by stormwater harvesting, though little benefit is likely to be provided for higher ARI events (KBR, 2004, Fletcher et al., 2008).

Social

Stormwater harvesting schemes may be designed to provide aesthetic value through wetlands, reedbeds and storage lakes. Leonard et al. (Leonard et al., 2013) found that there was an overall sense of pride within the community at Mawson Lakes for their recycled water status. In addition, the value of allotments fronting constructed water bodies is thought to provide a premium of some 20 – 30 percent (KBR, 2004).

Risks to the long-term viability of stormwater harvesting

Potable water savings

The extent of benefits from a stormwater harvesting scheme depend on a range of factors, including climatic conditions, land use conditions, the condition of the wastewater network which affects sewer overflows to stormwater, the end-use water demand variability and the design of the scheme, specifically the flow diverted to the scheme and the storage volume provided (KBR, 2004, Department of Environment and Conservation, 2006).

The quality of stormwater from a harvesting scheme or managed aquifer recharge scheme may vary significantly throughout the year as a result of changing climatic and land use conditions. In some cases, the water quality may not be suitable for the proposed end-use, resulting in reduction in the potable water savings proposed to be achieved by the scheme.

Financial

The financial viability of a stormwater harvesting scheme is dependent on the scale of the scheme, with larger schemes providing greater economies of scale. Binney and Macintyre (2012) estimated the unit cost of stormwater harvesting schemes to range between $0.5 per kilolitre and $6.2 per kilolitre (see Figure 3).

The Mawson Lakes dual reticulation scheme, which comprises blended stormwater and treated wastewater and was designed to supply 800 megalitres per year for non-potable residential use, has a levelised cost of $2.65 per kilolitre (Dandy et al., 2013). Dandy et al. (2013) estimated the levelised cost of a range of stormwater harvesting options based on the cost of infrastructure for the Parafield and Mawson Lakes scheme, as listed in Table 6.

Table 6. Estimated levelised cost of residential stormwater harvesting schemes

Development type	Third pipe system (toilet flushing, washing machine and garden watering)	Average annual supply (ML/year)	Levelised Cost ($/kL)
Greenfield	Without aquifer storage and then disinfection	370	5.2
Brownfield		370	6.9
Greenfield	With aquifer storage and recovery then disinfection	880	3.5
Brownfield		880	5.2
Greenfield	Without aquifer storage and blending with treated wastewater and disinfection	1000	3.4
Brownfield		1000	5.1
Greenfield	With aquifer storage and recovery then disinfection, and blending with treated wastewater and disinfection (current practice)	2100	2.7
Brownfield		2100	4.5

Environmental

Wetlands or storages associated with stormwater harvesting schemes may provide a location for birds to reside and nest, potentially increasing the treatment requirements of the harvested stormwater (KBR, 2004, Marlow et al., 2013).

Social

Stormwater harvesting storages may provide a potential habitat for mosquitoes and associated mosquito-borne diseases and pose risk of drowning, especially to children (Department of Environment and Conservation, 2006). Complaints were recorded by the community at Mawson Lakes regarding poor maintenance of the lake, wetlands and surrounding areas, with the lake 'looking dirty' and rubbish accumulating around the shores (Leonard et al., 2013).

Greywater recycling

Overview

Greywater reuse comprises the diversion and/or treatment of household wastewater that has not come in contact with human toilet waste. Greywater may be classified as 'light' where collected water does not include kitchen sink or dishwasher waste and 'dark' includes all waste except sewage (Allen et al., 2010). Greywater may be recycled on a household, cluster or development scale and used for provision of outdoor and indoor non-potable end-uses dependent on the level of treatment.

Regulations

The regulation of greywater recycling is dependent on the location, nature and end-use of the scheme. Rebates of up to $500 were previously provided in some states for greywater diversion devices and treatment systems, though is now only available in Victoria (Department of Sustainability and Environment, 2012). Table 7 provides a summary of the current regulation relating to greywater recycling in urban areas, as referenced by each Government agency.

Scheme configuration

Greywater recycling schemes range from simple low-cost diversion devices for direct reuse, to complex treatment processes and may be classified into three main categories:

- diversion schemes: diversion and immediate reuse;
- physical and chemical treatment schemes: storage and treatment of greywater through infiltration and disinfection processes; and
- biological treatment schemes: biological water processing technologies (Allen et al., 2010).

Diversion schemes

The NSW Department of Water and Energy (Department of Water and Energy, 2008c) and Western Australian Department of Health (Department of Health, 2010) recommend the use of untreated greywater from a diversion device for sub-surface irrigation only. Greywater diversion devices incorporate a hand activated switch or tap to divert greywater.

An example of such a scheme is the Grey Flow PRO™ by Advanced Waste Water Systems implemented at Josh's House, a sustainable home in Perth, Western Australia (Josh Byrne & Associates, 2012). The Grey Flow PRO™ diverts filtered greywater to the greywater irrigation system.

Physical and chemical treatment schemes

In order to store greywater, treatment must be provided to reduce bacteria and microorganisms that multiply in stagnant greywater (Boyjoo et al., 2013). Physical and chemical greywater treatment systems typically utilise disinfection and filtration to remove contaminants (Wong et al., 2011).

An example of such a scheme is the ReWater™ greywater treatment scheme which comprises a surge tank, sand media filtration tank and piping to an outdoor irrigation system (NovaTec Consultants, 2004).

Table 7. Greywater recycling regulations, rebates and guidelines for residential non-potable water supply (current as of May 2015)

State	Specific greywater recycling regulations	Greywater recycling guidelines
Australian Capital Territory	The ACT Government does not have a formal approval process specifically for domestic greywater treatment systems (ACT Government, 2007). Approval is required for changes to plumbing.	*Greywater Use: Guidelines for residential properties in Canberra* (ACT Government, 2007)
New South Wales	Local Council approval is not required if carried out in accordance with the Plumbing and Drainage Code of Practice and other regulations (see guidelines for further regulations).	*NSW guidelines for greywater reuse in sewered, single household residential premises* (Department of Water and Energy, 2008c)
Northern Territory	Greywater treatment systems must be installed and certified by a self-certifying plumber in accordance with the provisions of the Building Act (Power and Water Corporation, 2010).	*Greywater reuse: an alternative water source* (Power and Water Corporation, 2010) *Darwin Region Water Supply Strategy 2013* (Power and Water Corporation, 2013)
Queensland	Local Council approval is required to install a greywater diversion device or a greywater treatment system.	*Queensland Water Recycling Guidelines* (Environment Protection Agency, 2005)
South Australia	SA Health approves treatment and reuse of recycled greywater. Local Council approves planning and development aspects and Office of the Technical Regulator approves changes to plumbing (Department of Health and Ageing, 2012).	*South Australian Recycled Water Guidelines* (Department of Health and Ageing, 2012)
Tasmania	A ‘Special Plumbing Permit’ is required from Hobart City Council for the installation of a permanent greywater system (Hobart City Council, Undated-a).	*Environmental Guidelines for the Use of Recycled Water in Tasmania* (Department of Primary Industries Water and Environment, 2002)
Victoria	Local Council approval is required.	*Guidelines for Environmental Management: Code of practice – Onsite wastewater management (Environment Protection Agency Victoria, 2013)*
Western Australia	Local Council approval is required.	*Code of Practice for the Reuse of Greywater in Western Australia 2010* (Department of Health, 2010) *Guidelines for the Use of Non-potable Recycled Water in Western Australia* (Department of Health, 2011)

Biological treatment schemes
Biological treatment systems may comprise aerobic biological treatment or membrane bioreactors (MBR). Nubian Oasis, an Australian company, has developed a modular greywater treatment system that includes membrane filters and aerobic biological treatment to treat from 1 to 50 megalitres per day (Allen et al., 2010).

The Inkerman D'Lux development in Melbourne, Victoria, trialled the use of a lint trap, membrane bioreactor and ultra-violet disinfection system for the treatment of greywater and stormwater collected from the development. The treated water was used for sub-surface irrigation and toilet flushing (Goddard, 2006).

Technological innovation

Research is currently being conducted by the CRC for Water Sensitive Cities to investigate the use of green walls for treatment of greywater from residential and office buildings. Greywater would be used as a water source for green walls with the excess greywater treated and collected. Using greywater as a water source for the green wall would reduce the demand for potable water supply, reduce the discharge of greywater to the centralised sewer network and maintain the aesthetic value of the green wall. Research is also being undertaken by the CRC for Water Sensitive Cities to assess the feasibility of using a 3D electrochemical system, combining adsorption and electrochemical oxidation of organic pollutants and microorganisms, for treatment and reuse of greywater.

Benefits of greywater recycling

Potable water savings
Savings of potable water achieved through the reuse of greywater varies dependent on the nature and end-use of the scheme (Penn et al., 2014). Sinclair et al. identified an average 10 percent saving of potable water through the use of greywater recycling in over 1,000 Melbourne households during a five year period, which included three years of drought (Sinclair et al., 2013). A study undertaken of the Payne Road development indicated that the use of treated greywater for sub-surface irrigation reduced the centralised water demand by 1.6 ML over a four year period (Turner et al., 2013).

Financial
Greywater diversion devices are relatively cheap to purchase at a cost of around $500 - $1,000 (Allen et al., 2010, Rainwater Tanks Direct, 2013). The Grey Flow PRO™ by Advanced Waste Water Systems ranges from $1,500 to $3,000 dependent on the selected features.

A study undertaken by Tapsuwan investigating residents willingness to pay for alternative water services, identified that 67 percent of the sampled population indicated a higher willingness to pay for greywater diversion devices than the market price (Tapsuwan et al., 2014).

Environmental
Recycling of greywater not only reduces the demand on the centralised water supply, but also reduces the volume of waste discharged to the centralised sewer network and thereby the volume of treated wastewater discharged to the environment (Diaper et al., 2007).

Social
Recycling of greywater may provide sufficient water supply for irrigation of gardens during periods of drought, thereby reducing the impact of water restrictions on the resident.

Risks to the long-term viability of greywater recycling

Potable water savings
Cluster scale greywater treatment schemes have not been overly successful to date with a number of schemes decommissioned due to poor performance, high operational and maintenance costs and challenges with resignation of responsibility (Goddard, 2006, Sinclair et al., 2013, Leonard et al., 2013). In these instances, the potable water savings have not been realised.

Financial
The financial requirements of greywater treatment schemes is dependent on the treatment capability, though is often in excess of that which an average income earner is willing to pay.

The Biolytix system installed at the Payne Road development cost $16,000 per lot and required regular, on-going maintenance fees (Urban Water Policy and Management, 2010). Biolytix Water has since gone into liquidation, citing poor sales as a result of increased rainfall, though other reports suggest that the system was inherently flawed with numerous homeowners complaining of failed systems (Sinclair, 2011, Hoffman, 2011).

The greywater treatment scheme at the Inkerman D'Lux development was decommissioned after seven years of operation as the residents were not willing to pay the cost for replacement of failed treatment components (South East Water, 2014).

Environmental

Long-term irrigation with untreated greywater can lead to build-up of salts, surfactants, alkalinity, oil, grease and boron (Boyjoo et al., 2013). Build-up of pollutants has the potential to affect plant health, soil properties and groundwater quality. A four year investigation of the Payne Road development indicated that there was a significant risk of phosphorus interacting with the surrounding environment as a result of greywater irrigation post treatment through a Biolytix system (Turner et al., 2013). In addition, greywater recycling may exacerbate sewer blockages, corrosion and odour through the reduction in flow and increase in pollutant concentrations in sewer networks (Penn et al., 2014, Marleni et al., 2012).

Social

The performance of a greywater diversion or treatment scheme in a single household is dependent on the appropriate management and maintenance of the system. Incorrect management of greywater, such as storing untreated greywater for a period greater than 24 hours, may result in unsuitable outcomes such as malodours and mosquito infestation (Allen et al., 2010). Poor performance and high operational costs of some greywater treatment systems may result in a negative experience for residents (Leonard et al., 2013).

Wastewater treatment and recycling

Overview

Wastewater treatment and recycling for provision of residential non-potable water in urban areas commenced in 1996 with the western Sydney 'Rouse Hill Scheme' (Law, 1996). The distribution of recycled wastewater through dual pipe systems has since emerged as an important strategy for augmenting water supplies, reducing the volume of wastewater discharged to the environment and reducing demands on environmental water sources (Grigg et al., 2013).

Regulations

A number of governmental bodies in each State of Australia have committed to recycling of treated wastewater effluent, including Perth Water Corporation who has committed to recycling 30 percent of treated wastewater by 2030 (Water Corporation, 2009) and Government of South Australia who plan to increase reuse to nearly 45 percent (Government of South Australia, 2010).

The *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)* (Natural Resource Management Ministerial Council et al., 2006) provide a nationally consistent approach to the use of recycled water based on a risk management approach. Each state and territory has specific guidelines, with approvals made on a case-by-case basis dependent on the type and nature of the recycling scheme. Table 8 provides a summary of regulations and guidelines for wastewater treatment and recycling schemes in each State, as referenced by each Government agency.

Table 8. Wastewater treatment and recycling regulations, rebates and guidelines for residential non-potable water supply (current as of May 2015)

State	Specific wastewater treatment and recycling regulations	Wastewater treatment and recycling guidelines
Australian Capital Territory	Most schemes developed in the ACT are small and therefore require a protection agreement, which is set up with the Environmental Protection Authority and the proponents. ACT Health is involved in the development of the agreement.	*ACT Environment and Health Wastewater Reuse Guidelines* (ACT Environment and Health, 1997)
New South Wales	The environmental protection licence for recycled water treatment facilities is issued by NSW Environmental Protection Authority (EPA). *Local Government Act 1993* licences council schemes. The *Water Industry Competition Act 2006* encourages competition in the water industry, fosters innovative recycling projects and licences private water recycling schemes.	*Interim NSW Guidelines for Management of Private Recycled Water Schemes* (Department of Water and Energy, 2008a)
Northern Territory	A recycled water scheme must be approved by the Department of Health.	*Guidelines for Wastewater Works Design Approval of Recycled Water Systems* (Department of Health, 2014) *Darwin Region water supply strategy* (Power and Water Corporation, 2013)
Queensland	A Recycled Water Management Plan must be approved by the Department of Energy and Water Supply under the *Water Supply (Safety and Reliability) Act 2008* (Environment Protection Agency, 2005). All Water Service Providers in South East Queensland except Redland and Logan City Councils allow for the provision of non-drinking water networks which may supplement the potable water network. Recycled water networks will be approved by the relevant service provider on a case by case basis (Gold Coast City Council et al., 2013).	*SEQ Water Supply and Sewerage Design & Construction Code* (Gold Coast City Council et al., 2013) *Queensland Water Recycling Guidelines* (Environment Protection Agency, 2005)
South Australia	All recycling schemes using treated sewage or greywater require approval from DHA prior to operation.	*South Australian Recycled Water Guidelines* (Department of Health and Ageing, 2012)
Tasmania	Approval of a Development Proposal and Environmental	*Environmental Guidelines for the Use of Recycled Water*

State	Specific wastewater treatment and recycling regulations	Wastewater treatment and recycling guidelines
	Management Plan (DPEMP) by the Environment Protection Authority.	*in Tasmania* (Department of Primary Industries Water and Environment, 2002)
Victoria	All Class A water recycling schemes in Victoria require approval from EPA and endorsement from the Department of Health. This approval/endorsement is based upon the demonstration that the performance objectives identified within these guidelines will be met.	*Guidelines for Environmental Management: Use of reclaimed water* (Environment Protection Authority Victoria, 2003) *Guidelines for Environmental Management: Dual pipe water recycling schemes – health and environmental risk management* (Environment Protection Authority Victoria, 2005)
Western Australia	Department of Health regulates the design, construction, connection, operation and maintenance of sewage schemes and the management of required health standards of potable and non-drinking water supplied by service providers in accordance with the *Health Act 1911*.	*Guidelines for the Use of Non-potable Recycled Water in Western Australia* (Department of Health, 2011)

Scheme configuration

Wastewater treatment and recycling schemes may be implemented at varying scales and configurations in urban areas, as illustrated in Figure 4 (Gikas and Tchobanoglous, 2009). Localised schemes, where wastewater is collected, treated and reused at the vicinity of wastewater generation, typically support cluster or precinct scale developments. In some instances, the scheme may be disconnected from the centralised sewer network, with solid waste from the facility reused on-site. In urban areas of Australia, localised schemes are typically connected to the centralised sewer network, with solids discharged on a periodic basis (Muston, 2012, Urban Water Policy and Management, 2010).

Sewer mining is the process of extracting, treating and reusing wastewater locally before it reaches the centralised wastewater treatment plant (Gikas and Tchobanoglous, 2009). At the Central Park residential development in Sydney, wastewater is collected on-site and combined with wastewater mined from the centralised network before undergoing treatment through a membrane bioreactor facility, incorporating ultraviolet disinfection and reverse osmosis, located in the basement of the development (Flow Systems, 2014). Recycled water is supplied to the Central Park development through a dual reticulation network for toilet flushing, cold washing machine taps and garden irrigation.

Semi-centralised wastewater treatment and recycling schemes, such as the Rouse Hill scheme in Sydney's northwest, supply treated wastewater to multiple suburbs. Recycled water is stored in reservoirs close to the location of use prior to flowing via gravity to end users through a dual reticulation network (Gikas and Tchobanoglous, 2009).

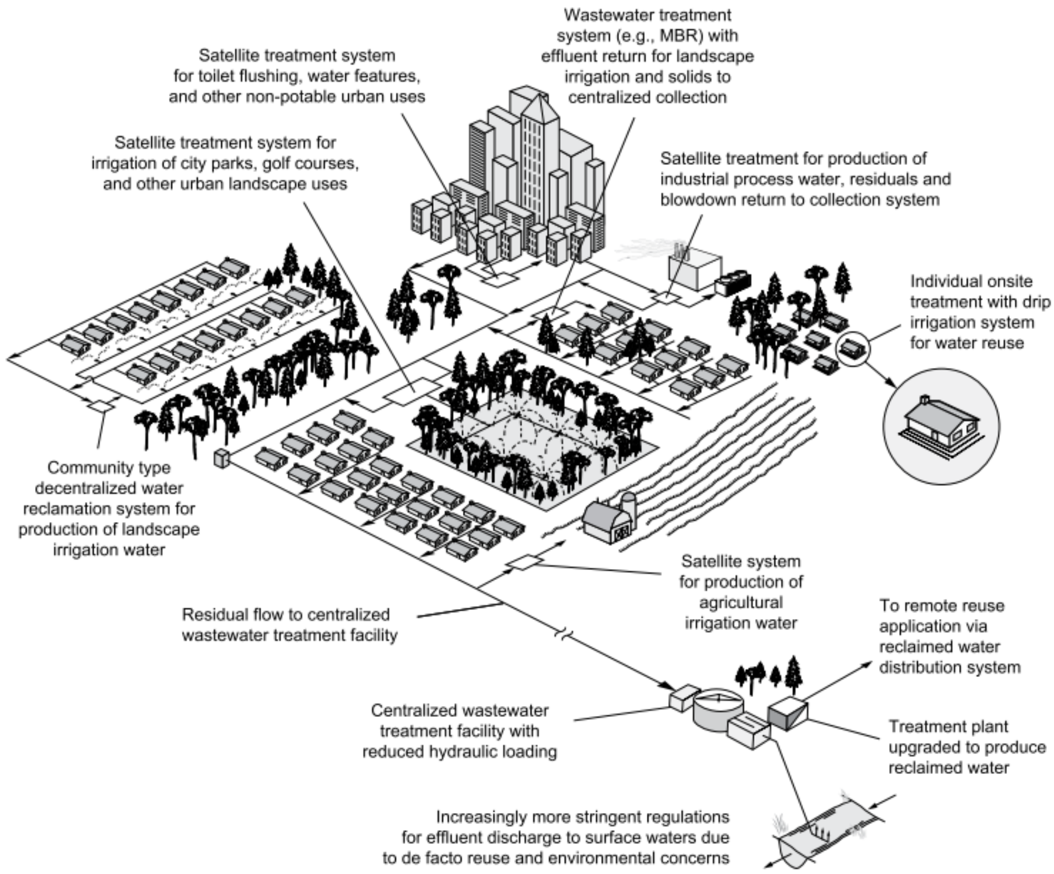

Figure 4. Wastewater treatment and recycling schemes in urban areas (Gikas and Tchobanoglous, 2009)

Technological innovation

Despite the high quality of recycled wastewater effluent and few documented health impacts as a result of cross-connections, the occurrence of cross-connections has caused concern over the public health risks associated with dual reticulation schemes (Hambly et al., 2012). As a result, a number of research projects have been initiated to identify reliable and cost-effective methods for identifying cross-connections in dual reticulation schemes (Hambly et al., 2012, Storey et al., Undated). Ultraviolet absorbance and fluorescence techniques for identification of amino acids and proteins in wastewater are being investigated while electrical conductivity (EC) sensors are being trialled at a recycled wastewater treatment plant to test the level of cross contamination of recycled wastewater that can be detected through monitoring EC (Hambly et al., 2012, Clearwater, 2014).

Benefits of wastewater treatment and recycling

Potable water savings

One of the main reasons for implementing wastewater treatment and recycling is to extend the reach of water supplies and reduce the demand on surface water systems. Table 9 provides examples of operational wastewater treatment and recycling schemes in Australia and the potable water reduction proposed to be achieved.

Table 9. Wastewater treatment and recycling schemes for residential non-potable water supply

Case study	Recycling scheme	End-use	Capacity	Reference
Rouse Hill, Sydney, New South Wales	Class A recycled wastewater	Dual reticulation to 18,000 homes for toilet flushing, garden watering and washing cars	19,000 ML/yr	(Sydney Water, 2009)
Aurora, Melbourne, Victoria	Class A membrane plant followed by ultraviolet and chlorine disinfection	Dual reticulation to 9,000 dwellings for toilet flushing, garden watering and outdoor use	1,280 ML/yr	(Apostolidis et al., 2011)
Sydney Olympic Park, Sydney, New South Wales	Combined sewer mining and stormwater harvesting followed by advanced tertiary treatment	Dual reticulation to suburb of Newington for toilet flushing, garden watering and car washing	800 ML/yr	(Apostolidis et al., 2011)
Mawson Lakes, Adelaide, South Australia	Class A recycled wastewater mixed with treated stormwater	Dual reticulation to 4,000 households Mawson Lakes	800 ML/yr	(Leonard et al., 2013)

Financial

A retrospective assessment of recycled wastewater schemes undertaken by Grigg et al. (Grigg et al., 2013) identified that wastewater treatment and recycling schemes help delay expansions or upgrades to the potable water system (Grigg et al., 2013. Grigg et al. (2013) identified that the operation time of the centralised water treatment plant in Dunedin, Florida had been reduced as a result of wastewater treatment and recycling.

Wastewater treatment and recycling may aid in reducing treated effluent disposal costs from a centralised wastewater treatment facility, although urban schemes often have lower avoided costs due to the lower unit operating cost and the large sunk investment in ocean outfall infrastructure (Marsden Jacob Associates, 2014a). Some savings in distribution, storage and reticulation may be possible in greenfield schemes where the centralised infrastructure does not yet extend (Marsden Jacob Associates, 2014a).

Environmental

Discharge of treated wastewater to surface water systems or ocean outfalls can affect the ecosystem function of receiving waters. Implementation of wastewater treatment and recycling schemes offer more options for the management and disposal of wastewater and may aid in reducing nutrient rich discharges to impacted receiving water bodies.

Wastewater treatment and recycling may aid in reducing the urban heat island effect by maintaining open space irrigation, even in times of drought, thereby reducing maximum temperatures in the surrounding local area due to evapotranspiration (Marsden Jacob Associates, 2013).

Social

As wastewater supply is not seasonally dependent, wastewater treatment and recycling can provide for unrestricted garden watering and irrigation supply during drought periods. In this instance, wastewater treatment and recycling may be a means for maintaining aesthetic values, especially in public open space areas.

Risks to the long-term viability of wastewater treatment and recycling

Potable water savings

The potable water saving achieved by a wastewater treatment and recycling scheme is dependent on the nature and end-use of the scheme. Schemes that provide for non-potable household demands are more reliable than schemes that only provide for garden watering or irrigation.

Financial

The cost of providing recycled wastewater has been identified as a major concern for water utilities and a barrier to the widespread implementation of recycled wastewater schemes in urban areas (Marsden Jacob Associates, 2013, South East Water, 2014, Taylor et al., 2011). Of those schemes that have been decommissioned, the operational costs of the scheme were the driving factor for decommissioning (South East Water, 2014).

The capital and operating costs of recycled wastewater schemes vary greatly dependent on the system configuration, treatment requirements, location and end-use demand. Unanticipated technical issues and monitoring requirements have been common in a number of schemes, significantly adding to the operational costs of the scheme (Taylor et al., 2011, South East Water, 2014, Institute for Sustainable Futures, 2013l). The direct costs of recycled wastewater schemes often exceed that of the centralised water service and are difficult to finance from user charges alone (Marsden Jacob Associates, 2013). Table 10 provides a summary of the cost of urban wastewater treatment and recycling schemes in Australia.

Table 10. Unit cost estimates of wastewater treatment and recycling schemes

Location	Use of recycled water	Cost estimate ($/kL)	Reference
Olympic Park, NSW	Residential	$1.60+ (operating cost only) [1]	(Marsden Jacob Associates, 2013)
Rouse Hill, NSW	Residential	$3.00 - $4.00 [1]	(Marsden Jacob Associates, 2013)
Aurora, Vic	Residential	~$1.96 (operating cost only) [2]	(Institute for Sustainable Futures, 2013a)
Melbourne Eastern STP		>$3.00 [1]	(Marsden Jacob Associates, 2013)
Pimpama Coomera, QLD	Residential	$8.90 [3]	(Taylor et al., 2011)

[1] 2006$, [2] 2004$, [3] 2011$

Community willingness to pay varies dependent on the scheme location, configuration and end-use requirements, though majority of the community expect to pay significantly less for non-potable water than potable water (Leonard et al., 2013, Marsden Jacob Associates, 2013). Residents of Lochiel Park expected the price of non-potable water to be 75 percent of mains, but when the tiered pricing system was introduced they faced prices greater than the Tier 1 mains water cost. Community and Council appealed to SA Water and the price was lowered to 90 percent of Tier 1 mains water, the result being reduced revenue for SA Water (Leonard et al., 2013).

Marsden Jacob (2014) found that the value of having access to recycled water at Rouse Hill is $4,949 on average per property based on the median property value. While this value is significant, it is unlikely to cover the full costs of recycled water provision (Marsden Jacob Associates, 2014e).

Technical challenges encountered in wastewater treatment and recycling schemes, often arising from a variance in forecast and actual demand, significantly contribute to the operating costs of a scheme

(Taylor et al., 2011, Institute for Sustainable Futures, 2013l). Grigg et al. (2013) identified a number of such challenges in wastewater treatment and recycling schemes throughout the USA, as follows:

- The reduction in potable water demand as a result of providing recycled wastewater for non-potable purposes in Redwood City, California, has resulted in water quality issues in the potable water network due to increased hydraulic residence times.
- A greater supply of recycled wastewater than demand in Tampa, Florida, has resulted in stagnation and biological growth in the recycled wastewater network.
- In Orlando, Florida, water conservation measures are implemented to keep from shutting down the recycled wastewater scheme due to low pressure in the distribution network as a result of demand exceeding supply.
- Yelm, Washington, was required to increase the wastewater storage capacity to ensure adequate supply during peak demand without having to upgrade the recycled wastewater treatment plant.

The Pimpama Coomera Class A+ recycled wastewater scheme on the Gold Coast, Queensland, was designed to provide for toilet flushing, garden watering and other outdoor uses for up to 65,000 homes. Despite being a significant engineering feat and winning a number of international awards, the dual reticulation scheme was subjected to a number of challenges which have subsequently resulted in the scheme being decommissioned (Taylor et al., 2011).

The challenges arose predominately as a result of the deviance in forecast and actual demand and were exacerbated by treatment difficulties and cross-connections. Taylor at al. (2011) specified the challenges as follows:

- changing climatic conditions: significant rainfall after drought;
- behavioural change: water conservation measures adopted;
- decrease in land development and lot sales;
- treatment difficulties requiring 33 percent of the water to be retreated (increasing chemical and energy consumption);
- treatment difficulties due to reduced demand (increased energy requirements);
- reduced water quality at the extremities of the network as a result of low flows and increased hydraulic residence times;
- cross-connection incidents; and
- significant monitoring and auditing requirements.

As a result, operational costs greatly exceeded user charges and the scheme was decommissioned in mid-2014. The scheme was also seen as a test case by other water utilities, with Redland and Logan City Council deciding that the financial risk of dual reticulation schemes was too great for smaller water utilities to consider (Taylor et al., 2011, Gold Coast City Council et al., 2013).

Environmental

In some instances, wastewater treatment and recycling schemes are implemented with the aim of reducing nutrient discharges to a surface water system or ocean outfall. While ambitious nutrient offset targets are set, these targets are often not met due to changes in climatic conditions, operating conditions of the wastewater treatment and recycling scheme and/or demand for recycled wastewater (Institute for Sustainable Futures, 2013y).

While the energy efficiency of small scale membrane treatment systems is improving as knowledge and experience improves, the treatment and delivery of recycled wastewater is typically more energy intensive than conventional water supply, though is less intensive than desalination (Futures, 2013).

Social

The major public health concerns relating to recycled wastewater are cross-connections and inadvertent use of recycled wastewater as potable water. Cross-connections have been recorded at Rouse Hill, Sydney Olympic Park and Pimpama Coomera, though few illnesses have been reported (Muston, 2012).

Cross-connections where mixing of recycled wastewater and potable water occur, present a complex problem for detection because of the changing pressure differential between systems and a variable pattern of mixing (Grigg et al., 2013). As knowledge and experience improves in the installation of dual reticulation networks, the number of cross-connection occurrences should decrease.

Integrating non-potable water schemes in urban water service portfolios

Integrated urban water management has seen the introduction of alternative water sources at varying scales across the urban landscape (Mitchell, 2004, Marlow and Tjandraatmadja, 2014). The diversification of water services is thought to provide a range of financial, environmental and social benefits (Institute for Sustainable Futures, 2013l, Chanan and Woods, 2006, Leonard et al., 2013). Increasing the type, scale and configuration of water infrastructure in urban areas will, however, increase the range and extent of risks associated with service provision. The challenge is to manage these risks in order for the benefits of alternative water sources to be realised.

Benefits of non-potable water schemes

The perceived and actual benefits of non-potable water schemes have been widely reported and pertain predominately to increased water supply security, reduced demand on natural resources, reduced environmental degradation, and in some instances, affordability and improved community satisfaction (Leonard et al., 2013, Binney et al., 2010, Marlow et al., 2013, Wong et al., 2011, Institute for Sustainable Futures, 2013l).

Water supply security

Phasing in of alternative water sources on an ‘as needs basis’ in urban areas can aid in reducing the demand on the centralised water and wastewater system, with the integrated design increasing productivity of the larger system (Daigger and Crawford, 2007). This is particularly pertinent for developments on the periphery of centralised infrastructure or in areas in which existing infrastructure is at capacity.

The Aurora development in Melbourne, Victoria, was located in an area that was not serviced by a trunk sewer and there was no intention by the water utility to provide a trunk sewer within the following ten years. This, in addition to the strong sustainable development agenda in place at the time, provided the incentive to implement a recycled wastewater scheme at the greenfield residential development (Institute for Sustainable Futures, 2013a).

Diversifying the provision of water, wastewater and stormwater services provides a greater degree of independence and resilience to changing conditions and to external shocks such as droughts and fires (Australian Academy of Technological Sciences and Engineering, 2012, Binney et al., 2010). In periods of drought, developments comprising non-potable water services will be significantly less affected by water restrictions than those serviced only by the centralised system.

The Parafield Stormwater Harvesting Scheme in South Australia supplies recycled water to 4,000 residences, saving approximately 800 megalitres per year of mains water which comprises water drawn from the River Murray (Page et al., 2013). During the Millennium Drought, most residents of Salisbury, South Australia, were required to limit or cease outdoor watering, while residents serviced by the Parafield Stormwater Harvesting Scheme were not as severely affected by water restrictions due to the availability of non-potable water (Biggs et al., 2009).

Environmental

As the true value of water and environmental protection becomes more evident, as does the understanding that resources must be used sustainably if the quality of life that has evolved over the last century is to continue (Gikas and Tchobanoglous, 2009). Non-potable water schemes have the potential to better utilise resources, to mimic nature and the natural water cycle and to reduce impacts to environmental values (Wong et al., 2011, Australian Academy of Technological Sciences and Engineering, 2012). Using alternative water sources reduces the demand on surface water or groundwater systems, potentially contributing to the maintenance of environmental flows (Mitchell, 2006). Non-potable water sources, such as rainwater and stormwater harvesting, have the potential to provide for pollution control, ecological regeneration and enhancement of urban amenity (Marlow et al., 2013).

Recycled water schemes are often implemented in order to reduce discharge of treated wastewater effluent, containing high nutrient concentrations, to sensitive waterways. The Rouse Hill wastewater treatment and recycling scheme in Sydney was Australia's first full scale application of residential non-potable reuse and was developed to reduce the volume of treated effluent discharged to the Hawkesbury River system (Law, 1996).

In addition, there may be increased opportunity to integrate energy and water schemes and to optimise energy requirements of smaller, localised water and wastewater schemes than currently exists for the larger, centralised water and wastewater system.

Economic/Financial

Non-potable water schemes may help delay expansions or upgrades to the centralised water and wastewater system (Coombes et al., 2002, Daigger and Crawford, 2007). Traditional water and wastewater pipe network design is driven to a large extent by the need to cater for peak demands, therefore mitigation of these peaks may allow deferral of investment and reduction in capital costs (Marsden Jacob Associates, 2014a).

While non-potable water sources, such as rainwater tanks and wastewater treatment and recycling, are typically more expensive on a unit cost basis than conventional water and wastewater services, the enhanced resilience of multiple water sources may be worth the costs. There is economic value in resilience, especially when faced with changing climatic conditions, aging and capacity constrained water and wastewater infrastructure, increased environmental degradation and increasing water and energy prices (Nelson, 2012).

Social

There is increasing evidence that the provision of alternative water services increases community knowledge and understanding of the value of water and environmental protection. Non-potable water schemes in residential developments help to instil a sense of pride in the community and improve environmental awareness (Leonard et al., 2013, Water Services Association of Australia, 2003).

Risks to the long-term viability of non-potable water schemes

Assessment of risks associated with non-potable water schemes have largely focused on technical and operational risks where they relate to environmental and public health impacts (Huxedurp et al., 2014). Public health risks associated with the provision of non-potable water have been of primary concern, with risk assessments focused predominately on microbial and chemical hazards (Natural Resource Management Ministerial Council et al., 2006, Chapman et al., 2006, Page and Levett, 2010).

However, few public health impacts of non-potable water schemes have been reported to date (Hambly et al., 2012). Non-potable water schemes have predominately been decommissioned due to financial challenges arising from changing political, economic, social, technical, legal or environmental conditions during the construction or operational phase of a scheme (Institute for Sustainable Futures, 2013l, Moglia et al., 2011). Changing conditions within the contextual environment of a non-potable water scheme, with the potential to impact the operational performance of a scheme, are illustrated in Figure 5. Changing conditions and potential impacts have been identified through detailed review of grey and academic literature and through discussions with water industry personnel.

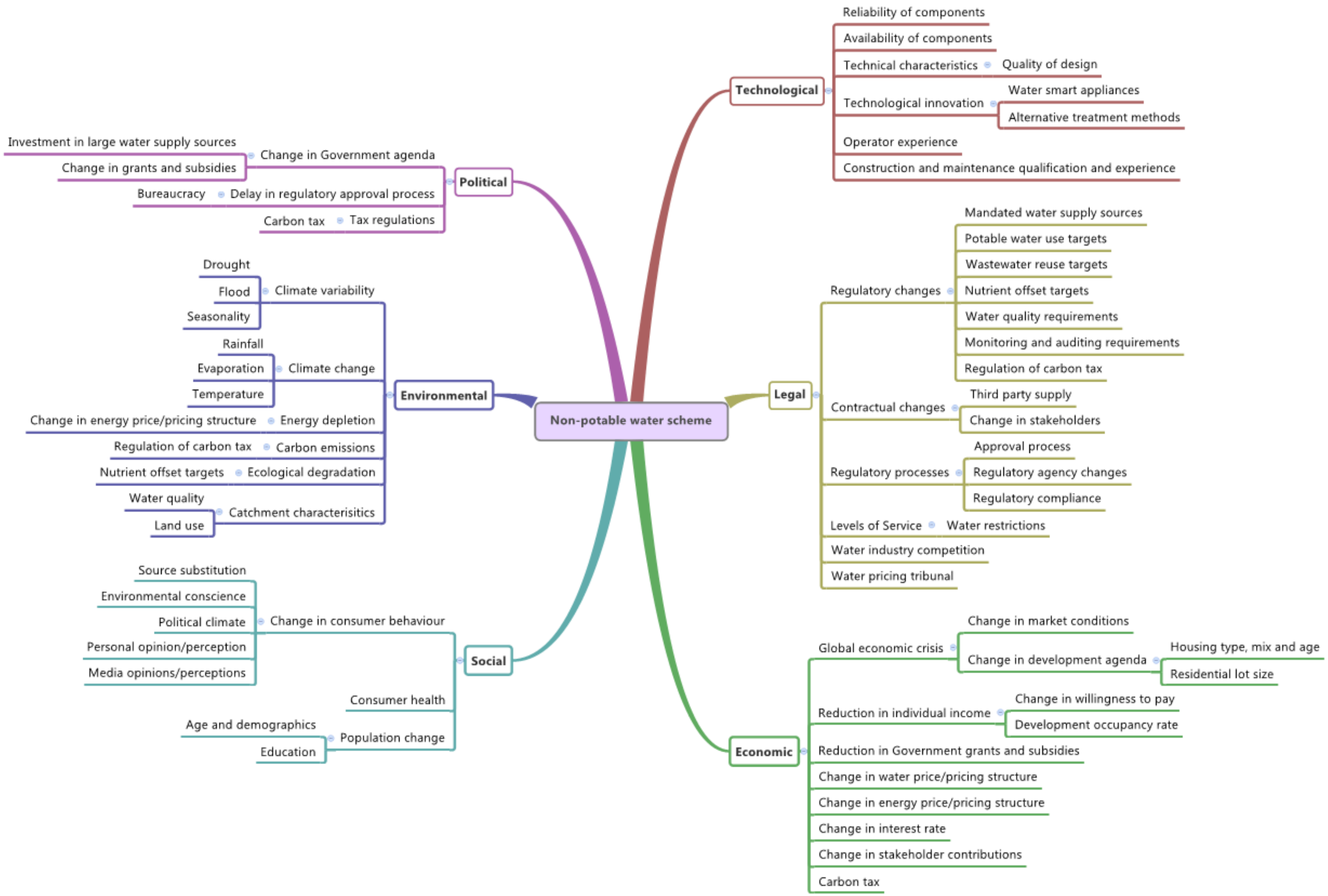

Figure 5. Political, environmental, social, technological, legal and economic influences on residential non-potable water schemes

Risks to water supply security

A major risk to the long-term viability of non-potable water schemes and the ability of schemes to meet water supply objectives is the variance between forecast and actual demand (Institute for Sustainable Futures, 2013f). Water demands are influenced by a range of changing conditions including population growth, climate variability, water conservation behaviour and attitudes, technological advances and water pricing (Institute for Sustainable Futures, 2013f). There is often a significant time delay between planning and implementation of non-potable water schemes, particularly in urban areas, and the conditions under which a scheme is designed may change dramatically during that time (see Figure 6). These conditions are particularly difficult to forecast or plan for (Institute for Sustainable Futures, 2013l). In addition, schemes are often designed on optimistic forecasts of demand and supply with limited consideration to changing conditions, varying treatment performance or downtime requirements of scheme components.

The Institute for Sustainable Futures (2013l) reviewed eight water recycling schemes to identify risks to the supply and demand of these schemes. Table 11 summarises the outcomes of this work and lists additional risks identified through investigation of case studies, documented in Appendix A, and discussions with water industry personnel.

Table 11. Risk to the supply and demand of non-potable water schemes (adapted from (Institute for Sustainable Futures, 2013l))

<table>
<tr><th rowspan="2">Risk factor</th><th colspan="2">Source volume or quality</th><th colspan="2">Demand volume or quality</th></tr>
<tr><th>Gradual impact</th><th>Sudden impact</th><th>Gradual impact</th><th>Sudden impact</th></tr>
<tr><td rowspan="2">Political</td><td>Subsidies for specific water sources</td><td>Scheme decommissioned</td><td>Change in government policies and attitudes</td><td>Investment in alternative supply e.g. desalination</td></tr>
<tr><td>Water restrictions implemented or relaxed</td><td></td><td>Water restrictions implemented or relaxed</td><td></td></tr>
<tr><td rowspan="2">Environmental</td><td colspan="2">Seasonality of rainfall and stormwater flows</td><td rowspan="2">Change in climatic conditions</td><td rowspan="2">Drought breaks</td></tr>
<tr><td colspan="2">Change in climatic conditions</td></tr>
<tr><td rowspan="2">Social</td><td>Change in rate of development property sales</td><td rowspan="2"></td><td>Change in rate of development property sales</td><td rowspan="2"></td></tr>
<tr><td>Behavioural changes</td><td>Behavioural changes</td></tr>
<tr><td rowspan="2">Technical</td><td rowspan="2">On-going technical issues</td><td>Change in source water quality</td><td rowspan="2"></td><td>Change in quality requirements</td></tr>
<tr><td>Technical issues causing periodic shut down of scheme</td><td></td></tr>
<tr><td>Legal</td><td>Delay due to regulatory processes</td><td>Change in regulatory requirements</td><td></td><td>Change in regulatory requirements</td></tr>
<tr><td rowspan="2">Economic</td><td rowspan="2"></td><td rowspan="2">Significant source of wastewater is removed</td><td colspan="2">Change in economic conditions</td></tr>
<tr><td colspan="2">Change in price of potable and/or non-potable water</td></tr>
</table>

Variance in forecast and actual demand may result in impacts to the optimal operation of a treatment system, reduced ability of a scheme to meet proposed water supply and wastewater discharge reduction targets, financial viability of a scheme and overall perceived performance of schemes (Institute for Sustainable Futures, 2013l, Institute for Sustainable Futures, 2013f). At the construction stage, a variance in forecast and actual demand may result in delay to the commissioning of a recycled water treatment plant. If the delay is extensive, the plant may require re-servicing prior to commissioning, at a significant additional cost to the plant owner.

Reduced demand has the potential to impact all components of an operational recycled water scheme including treatment, storage and distribution. In the treatment system, low flows may cause aeration issues, excessive growth of filamentous bacteria, membrane failure and the requirement to retreat water. Treated water may be required to be stored for longer periods of time prior to distribution, resulting in reduced water quality and the requirement for additional chlorine disinfection at storage locations. In the distribution network, low flows may result in inadequate pressure, sediment build-up and blockages, stagnation and biological growth and inadequate water quality at extremities due to long hydraulic residence times. Technical challenges as a result of low flows increase both energy requirements and operational costs of the recycled water scheme. In addition, each time the plant is offline, potable water is provided in place of non-potable water and wastewater is discharged to the centralised sewer network, reducing the mains water savings and wastewater discharge reduction targets proposed for the recycled water scheme.

Poor design and/or analysis of non-potable water schemes may also significantly influence potable water savings. A combined grey water and rainwater recycling scheme installed in a UK office building was proposed to provide a potable water savings of 36 percent, however a two year monitoring program identified that the potable water savings were -8.5 percent in 2011 and -10 percent in 2012 (Castleton et al., 2014). Greywater is collected from wash basins and showers within the office building and combined with collected rainwater for treatment through a multimedia filter prior to reuse for toilet flushing. The monitoring study identified that the quantity of greywater collected was less than the system filter required for backwashing, and top-up potable water was required to complete the backwash process (Castleton et al., 2014). This highlights the importance of realistic system analysis at the planning stage of a non-potable water scheme.

Political risks

The provision of Government grants and subsidies encouraged the uptake of alternative water sources during the Millennium Drought. While this facilitated the initial implementation of non-potable water schemes, it has resulted in a dependence on Government grants and subsidies and reduced the sense of scheme ownership in some cases. Schemes that now require upgrading to cater for increased demand will potentially be stalled due to a lack of motivation by the scheme owner to invest in the required upgrade.

Changes in Government agenda and Government policies, such as removal of mandated wastewater targets, in addition to the lack of Government grants and subsidies, may result in a lack of interest by a water utility to invest in the operation and maintenance of a scheme encountering on-going technical challenges. The end of the drought has further exacerbated this issue by reducing the sense of responsibility to maintain and operate a scheme on a long-term basis. Non-potable water schemes were perceived by some as a short-term strategy during the Millennium Drought rather than a long-term, permanent addition to urban water service portfolios.

In addition, changes in political leadership will likely impact on the long-term viability of residential non-potable water schemes. Strong leadership on sustainable water management, such as that of the Victorian Government (Ferguson et al., 2013), has seen the continued support of residential non-potable water schemes, though in other regions where the political support is not prominent, residential non-potable water schemes will likely become redundant.

Non-potable water schemes are often implemented as test cases to assess the validity and operability of a scheme. Decisions are then made by other proponents on the success, or lack thereof, of such schemes. The reputational damage that arises from a less than successful scheme may be significant enough to result in long-term decisions being made with respect to future schemes (Taylor et al., 2011).

Environmental risks

Climate variability has significantly influenced the performance of a large proportion of residential non-potable water schemes. A scheme designed on a water balance that does not adequately consider or account for varying climatic conditions will potentially encounter a variance between forecast and actual demand as a result of reduced irrigation and outdoor watering end-use requirements (Taylor et al., 2011). This was the case for a number of non-potable water schemes designed during the Millennium Drought though commissioned towards the end of the Millennium Drought when potable water supplies had returned to pre-drought conditions.

Changes in catchment characteristics have the potential to influence the source water quality and quantity of a stormwater harvesting or wastewater treatment and recycling scheme. Variance in water quality, as a result of land use changes, changing climatic conditions and/or pollutant discharge in a catchment, may be particularly problematic for less robust treatment systems.

The positive and negative risks to the environment, particularly cumulative risks, of non-potable water schemes are yet to be identified. If non-potable water schemes are implemented on a wide scale in urban areas, how will this change the energy requirements and greenhouse gas emissions of the combined water and wastewater services of a city? In addition, how will the hydrological and hydrogeological processes of the city change and what impact will that have on environmental sustainability?

Social risks

Change in consumer behaviour has the potential to influence the outcomes of a residential non-potable water scheme either through reduced or increased demand. Environmental conscience may incentivise a consumer to plant native vegetation thereby reducing outdoor watering requirements, or a consumer opposed to the use of recycled water for outdoor uses will opt to using potable water instead.

In some instances, the provision of a non-potable water source has resulted in an increase in potable water usage through the security gained by having two water sources (Institute for Sustainable Futures, 2013a). As a result, the potable water reduction target for the development has been compromised.

When implementing a non-potable water scheme in a residential development it is essential that all stakeholders are included on the journey. The community and developers should be informed by water utilities of the risks associated with the proposed commitment to provide non-potable water and the potential for the scheme to be decommissioned if performance is poor or operational costs are too high. Stakeholders should be advised of the risks at the onset of implementation of schemes in order to manage expectations and be aware of the potential for failure (Marsden Jacob Associates, 2013).

Technological risks

Treatment performance can be variable, particularly for small scale or first generation schemes, which reduces the certainty of outcomes and promotes a tendency to overdesign, provide redundancy and choose more traditional approaches to water management. Performance data is essential to enable learning and knowledge development, though there has been a lack of performance data collected and disseminated from operational non-potable water schemes. This may result in stakeholders lacking the fundamental information needed to ensure optimal scheme design, construction and operation (Moglia and Sharma, 2013).

Long-term operation and maintenance of non-potable water schemes is still proving challenging with water utilities often not wanting to take on the risks or anticipated burden (Sharma et al., 2012, Marlow et al., 2013). The Fitzgibbon Chase development near Brisbane, Queensland, was to comprise stormwater harvesting for non-potable residential uses and rainwater harvesting from residential roofs that would be collected, treated and returned back to the potable network for water supply (Bligh Tanner, Undated). Both scheme components are constructed and ready to operate though require a long-term owner and operator before they can commence operation.

Qualification and experience of construction and maintenance personnel and treatment plant operators has influenced the technological performance of non-potable water schemes, resulting in cross-connection issues, poor maintenance of membranes and loss of plant control (Fairbairn, 2006). Operators may be experienced with a water treatment plant for wastewater treatment and recycling, though struggle with operation of the plant for treatment of harvested stormwater due to the varying water quality and hydrologic characteristics of stormwater.

The impacts to centralised infrastructure from non-potable water schemes are still under investigation. Greywater and wastewater treatment and recycling may exacerbate sewer blockages, corrosion and odour by reduced flow and increased pollutant concentrations in sewer networks (Marleni et al., 2012).

Questions remain around the provision of fire flow water when a non-potable water scheme is implemented. Reduction in potable water demand may change the flow and pressure characteristics of the distribution network potentially impacting the ability to provide for fire flow (Water by Design, 2009). Fire flow requirements may be supplied by non-potable water, though if a dual reticulation scheme which was designed to provide for fire flow is decommissioned, will the potable water distribution network be capable of providing for fire flow?

Legal/regulatory risks

While there are significantly less regulatory and institutional barriers to the development of non-potable water schemes than there has been in the past, there is still a void between the encouragement of non-potable water schemes by government agencies and the implementation of such schemes by developers. The City of Sydney released Sydney Decentralised Water Master Plan in 2012 which commits to replacing 30 percent of mains water demand with recycled or alternative non-potable water and to reduce sediments and suspended sediment loads discharged to waterways by 50 percent and nutrients by 15 percent by 2030 (City of Sydney, 2012). City of Sydney proposes to develop recycled wastewater and stormwater harvesting schemes, however, their challenge now is to incentivise developers to construct dual reticulation in greenfield and infill developments for connection to future non-potable water schemes. Without this being a mandated requirement and with little incentive for the developer, developers have been reluctant.

The compliance requirements specified in the Australian Guidelines for Water Recycling (2006), which pertain to approvals, validation, monitoring and reporting, are both costly and resource intensive, often impeding investment for smaller schemes and councils (Institute for Sustainable Futures, 2013x). Regulatory changes, such as varying water quality requirements or increased monitoring and auditing requirements, may result in the requirement for additional resources and additional expenditure to manage and adhere to the regulatory change.

Changes in developer charges or water pricing during the construction phase of a scheme results in increased cost to the water utility and reduced revenue, which may not have been anticipated at the planning stage when design of the scheme was undertaken (Institute for Sustainable Futures, 2013a).

Economic/financial

Assessing the financial viability of non-potable water schemes and distributing costs fairly and adequately across all stakeholders is a major challenge. In most cases, residential non-potable water schemes have not proven their financial viability, with unit costs typically exceeding that of conventional water and wastewater services (Sharma et al., 2013). Estimating the value of externalities associated with non-potable water schemes is challenging and difficult to achieve without bias interwoven in the assessment process (Marsden Jacob Associates, 2014a).

The global economic crisis severely impacted a large proportion of residential non-potable water schemes operational at the time. Changes in market conditions, changes in development agenda and reduced individual income resulted in redesign of subdivisions and slower rate of lot sales, subsequently reducing demand for non-potable water (Institute for Sustainable Futures, 2013a, Taylor et al., 2011).

Change in energy price has the potential to significantly influence residential non-potable water schemes in the future. Wastewater treatment and recycling schemes typically have a higher energy requirement than potable water, 1.1-1.8 kilowatts per kilolitre specific energy consumption compared to 0.3-0.6 kilowatts per kilolitre, though are less energy intensive than seawater desalination at 4.0-5.5 kilowatts per kilolitre (Australian Water Recycling Centre of Excellence, 2014). As energy prices rise, so will operational costs of residential non-potable water schemes.

The Pimpama Coomera Class A+ recycled wastewater scheme had an energy consumption of 2.1 kilowatts per kilolitre in 2011 as a result of technical issues, including excess air in the aeration systems and the requirement to retreat 33 percent of the treated effluent (Taylor et al., 2011). The high energy requirement played a role in increasing operational costs above that which was forecast or could be recovered through consumer charges, ultimately leading to decommissioning of the scheme.

Assessing risks and resilience of non-potable water schemes

Understanding the risks associated with non-potable water schemes, the likelihood and consequence of such risks and undertaking risk assessment during the planning stage of a scheme, will aid decision makers in assessing the impact of risks to the long-term viability of a scheme. Incorporating risk profiles and reliability attributes in the water balance assessment for a non-potable water scheme will enable improved estimates of the potential supply and demand characteristics of a scheme. Probabilistic outcomes of supply and demand will in turn enable assessment of the potential range in long-term financial outlay required for a scheme.

A better understanding of risks would enable the creation of more robust and resilient water schemes. By understanding the factors contributing to risks, the schemes may be modified to operate more efficiently with less technical challenges. Once risk is fully understood and risk management strategies have been developed, investors will be well informed and able to decide if the potential benefits of the scheme outweigh the cost and unmitigated risks (Marsden Jacob Associates, 2013).

Learning from past experience

Residential non-potable water schemes have been in operation in urban areas of Australia for over a decade, with a number of schemes operational during that time. Data on the technical, financial, environmental and social performance of non-potable water schemes is increasing in availability, though there still remains a gap in understanding of the life-cycle performance, costs, risks and benefits of non-potable water schemes (Marlow and Tjandraatmadja, 2014). A concerted effort is required to collect and collate information from non-potable water schemes. This would include data from both successful and less than successful schemes, as decommissioned schemes will provide for significant learnings.

Figure 6 provides a timeline of events that occurred during planning, implementation and operation of the Pimpama Coomera dual reticulation scheme. Wastewater treatment plant inflow rates, projected uptake rates of recycled wastewater and actual uptake rates of recycled wastewater have been estimated based on information obtained from Taylor et al. (Taylor et al., 2011) and Suggate (Suggate, 2009).

Figure 6 illustrates the impact of changing regulatory, climatic and economic conditions on the supply and demand of recycled wastewater from the scheme, compared to that which was forecast.

Risk and uncertainty assessment at the planning stage

The Institute for Sustainable Futures (Institute for Sustainable Futures, 2013l) identified that risks to the long-term viability of non-potable water schemes go well beyond technical risks; though business risks, such as market, legal, contractual, political and financial, have received inadequate attention to date. Learnings from historical schemes, pertaining to all potential risks which may derail a project, should be considered at the planning stage of a scheme and used to assess the full range of potential outcomes of a scheme and to facilitate the development of adaptive management strategies.

Estimates of supply and demand for non-potable water schemes should, at the least, incorporate an assessment of varying climatic conditions on scheme performance. Undertaking uncertainty analysis on development property sales, behavioural changes of end-users and potential technical failures of scheme components would enable probabilistic analysis of the potential supply, demand, financial and environmental performance of residential non-potable water schemes.

Urich and Rauch (Urich and Rauch, 2014) identified that most modelling approaches used to assess urban water schemes are tested on a few scenarios only, which provides limited insight into scheme performance given the deep uncertainty of future conditions with respect to climate, population growth and water demand. Infrastructure design and planning processes rely heavily on projections of these key parameters which often do not eventuate (Urich and Rauch, 2014). The authors recommend that adaptation strategies should be tested considering all potential future uncertainties, rather than forecasting the scheme performance on a few scenarios only.

Marsden Jacobs (Marsden Jacob Associates, 2013) suggest three techniques for use in Cost Benefit Analysis of non-potable water schemes to assist in assessing the impact of potential risks on the financial viability of a scheme:

- scenario analysis: used when a precise estimate of probabilities is unable to be determined though subjective assessment may be possible;
- threshold analysis: used to identify the conditions required for a scheme to justify a certain investment decision; and
- real options analysis: used to analyse the value of investments, including contingency investments.

Incorporation of variability and uncertainty in demand forecasts, and upfront assessment of associated risks, is essential to improve the operational performance of residential non-potable water schemes (Institute for Sustainable Futures, 2013f).

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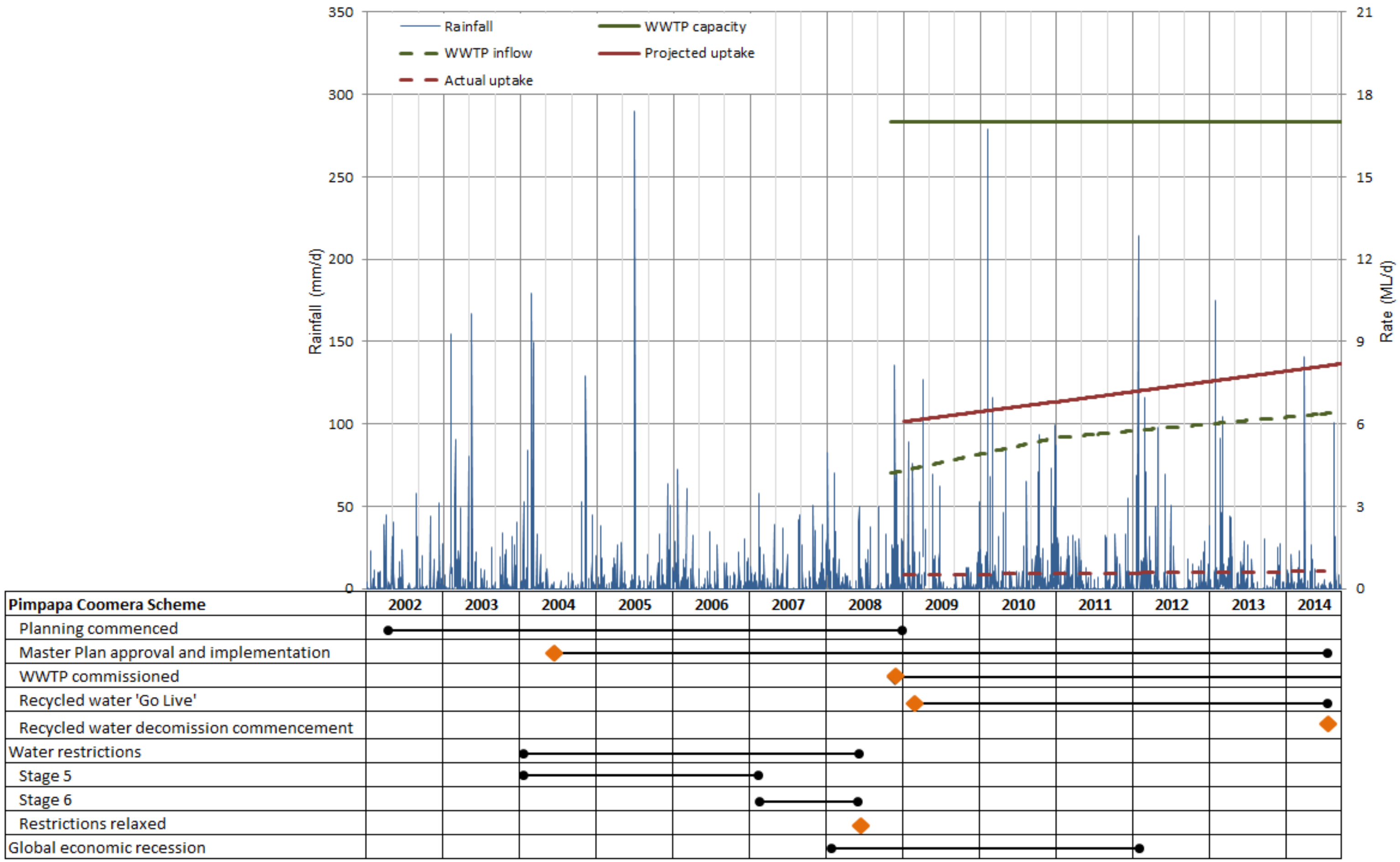

Figure 6. Pimpama Coomera recycled water scheme timeline (Taylor et al., 2011, Suggate, 2009, Council of the City of Gold Coast, 2014, Gold Coast City Council, 2003)

Glossary

Aquifer Storage and Recovery –Involves the process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Brownfield sites – Development on sites that have previously been used for urban land uses.

Climate change – Variations in historic weather patterns due to increases in the Earth's average temperature resulting from increased greenhouse gases in the Atmosphere.

Demand management – An approach that is used to intentionally reduce the consumption of water through specific initiatives, normally either to conserve supplies or defer augmentations.

Desalination – The process of removing dissolved salts from seawater (or brackish water) so that it becomes suitable for drinking or other productive uses.

Drinking water (potable water) – Water that is fit for human consumption.

Effluent – The outflow of wastewater from any water processing system or device.

Fit for purpose – quality of water is suitable for designated end-use.

Greenfield sites – Development on open land (usually greater than 4000 square metres) that has not previously been developed for urban land use.

Greywater – Household wastewater from the laundry, bathroom and kitchen.

Integrated urban water management - a comprehensive approach to urban water services, where water supply, stormwater management and wastewater management are viewed as components of an integrated system.

Levelised cost – the present value of the total capital and operational cost over the economic life converted to equal annual payments.

Non-potable – water that is not of drinking quality, but may be suitable for other purposes.

Recycled water – Water derived from wastewater systems or stormwater drainage systems that has been treated to a standard that is appropriate for its intended use.

Reverse osmosis (RO) - An advanced method of wastewater treatment that relies on a semipermeable membrane to separate water from its impurities.

Risk - The likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm.

Risk assessment - The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 4360:1999).

Risk management - The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.

Sewer mining – The localized harvesting of raw sewage that is treated to a safe level 0as required for a particular use.

Stormwater – Water that flows off roofs, properties and roads during rain events.

Surface water – water flowing over land or collected in a dam or reservoir.

Wastewater – Contaminated water before it undergoes any form of treatment. The water may be contaminated with solids, chemicals, or changes in temperature.

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Appendix A - Residential non-potable water schemes

Table 12. Residential non-potable water schemes

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
Victoria	WestWyck Ecovillage, Melbourne, Victoria	Brownfield ecovillage 30 residents	Class A recycled greywater	AquaClarus treatment tank for shower and bath greywater recycling, comprising biological/bacterial treatment, membrane filtration, ultra-violet treament to Class A standard	Garden watering Toilet flushing Car washing Laundry - clothes washing	Highly sustainable ecovillage for 'one planet' living	Body Corporate
	Avenue Estate, Melbourne, Victoria	Brownfield development 58 residential households	Class A recycled stormwater	Stormwater captured at a nearby wetland and treated at Troups Creek pilot stormwater recycling plant	Garden watering Toilet flushing Car washing Fire fighting	Test case for contributing to recycled water target	South East Water
	Werribee, Victoria	Greenfield residential development Scheme designed to service 20,000 lots	Class A recycled wastewater	Sewage treated at Western Treatment Plant, salt reduction through RO and ASR	Garden watering Toilet flushing Car washing Laundry - clothes washing Irrigation of public open spaces Fire fighting	Reduce potable water use and discharge of pollutants to bay	City West Water

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
Victoria	Inkerman D'LUX development, Melbourne, Victoria	Infill development 236 residential apartments	Class A recycled greywater and stormwater - *decommissioned*	Greywater collected from bathrooms and stored in balance tank with lint trap for pre-treatment, with overflow discharged to sewer. Stormwater collected in subsurface flow wetland, with overflow discharged to stormwater system. Membrane bioreactor and UV disinfection system treat blended greywater and stormwater. Treated water stored in header tank with potable water top up.	Toilet flushing Sub-surface garden irrigation	Stormwater management requirements and test case for on-site recycling	Body Corporate owned system; South East Water responsible for operation and maintenance
	Aurora development, Melbourne, Victoria	Greenfield residential development Scheme was designed to service 8,500 lots and currently services 2,500	Class A recycled wastewater	Sewage treated to Class A at Aurora recycled water plant - 3.5 ML/d capacity; stored in 280 ML storage lagoon during winter when demands are low and re-treated for supply in summer	Garden watering Toilet flushing Car washing Laundry - clothes washing Irrigation of public open spaces	Test case for contributing to recycled water target	Yarra Valley Water
	Pakenham and Officer, Victoria	Urban growth area 2,000 lots serviced in 2013, proposed to service 15,000 lots	Class A recycled wastewater	Sewage treated to Class A at Pakenham recycled water plant - 4 ML/d capacity	Garden watering Toilet flushing Car washing Laundry - clothes washing	Reduce potable water use and discharge of pollutants to bay	South East Water

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
	Cranbourne, Victoria	Greenfield residential development Scheme designed to service 4,000 lots	Class A recycled wastewater	Advanced tertiary treatment plant adjacent to Eastern Treatment Plant then pumped to South Eastern Pipeline for distribution, winter storage available for recycled water	Garden watering Toilet flushing Car washing Laundry - clothes washing	Reduce potable water use and discharge of pollutants to bay	South East Water
	Melton, Victoria	Growth area 719 properties serviced in Eynesbury in 2014, 292 serviced in Toolern; up to 20,000 properties to be serviced dependent on servicing option selection	Class A recycled wastewater	Sewage treated to Class A at Melton recycled water plant	Garden watering Toilet flushing Car washing Irrigation of public open spaces Fire fighting	Reduce potable water use and discharge of pollutants to bay	Western Water
South Australia	New Haven Village, Adelaide, South Australia	Residential village 65 residences	Class A recycled stormwater and wastewater	Stormwater captured on-site is mixed with domestic wastewater and is treated through aeration, settlement, sand filtration and UV disinfection	Toilet flushing Sub-surface garden irrigation	Demonstration project for sustainable living	Body Corporate

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
South Australia	Christie Walk, Adelaide, South Australia	Brownfield development Mix of townhouses and apartments with communal indoor and outdoor spaces, 27 separate developments	Rainwater and stormwater harvesting	2 x 20,000 L storage tanks collecting roof and surface water runoff, installed under the car park/courtyard spaces; overflow pumped to street drainage; 3 x small above ground rainwater tanks collecting rainwater of other roofs	Garden watering Toilet flushing	Demonstration project for sustainable living	Residents
	Lochiel Park, Adelaide, South Australia	Brownfield development Medium sized residential development of 109 dwellings	Stormwater harvesting and ASR *– not yet operational*	Stormwater passes through a gross pollutant trap and wetland prior to injection into T2 aquifer Household rainwater tanks, some above ground and some large underground tanks, with mains water top up and hot water disinfection	ASR proposed for garden watering, toilet flushing and open space irrigation (not yet operational) Rainwater tanks are connected to hot water supply tank, washing machines and shower heads	Demonstration project for sustainable living	Stormwater harvesting scheme is managed by City of Salisbury with distribution managed by SA Water Developer currently responsible for site, though proposed takeover by City of Campbelltown

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
South Australia	Mawson Lakes, Adelaide, South Australia	Large-scale mixed use development consisting of approximately 4,000 households, a commercial centre, technology park, two schools and a university campus	Class A recycled stormwater and wastewater	Water from the Parafield Wetlands Harvesting (ASR) Scheme (consisting of an upstream storage basin, downstream sedimentation tank, treatment wetland and aquifer storage) is mixed with treated wastewater from the Bolivar Wastewater Treatment Plant and undergoes disinfection treatment (chlorination) then distribution via third pipe to residences	Garden watering Toilet flushing Car washing Irrigation of public open spaces	Demonstration project for sustainable living	Parafield Wetlands Harvesting Scheme managed by City of Salisbury Third pipe system managed by SA Water
	Aldinga Southern Urban Reuse Project, South Adelaide, South Australia	Greenfield development Scheme was designed to service up to 8,000 new households	Class A recycled wastewater	Secondary effluent from Christies Beach WWTP is sent to Aldinga RWTP for tertiary treatment. The finished water is stored in 2 x 5 ML membrane-lined, covered storage basins to service daily product water demands to the dual reticulation network; up to 1,600 ML/yr supplied.	Garden watering Toilet flushing Car washing	Ensure sufficient supply to the south of Adelaide	SA Water

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
New South Wales	Central Park development, Sydney, New South Wales	Infill development 1,800 apartments, shops, cafes, restaurants and offices	Sewer mining and on-site Class A recycled wastewater	Membrane Bioreactor and Reverse Osmosis (RO) technologies built in the basement of the residential building	Garden watering Toilet flushing Cold washing machine tap	Striving for the highest possible environmental rating	Central Park Water (Flow Systems)
	Rouse Hill, Sydney, New South Wales	Scheme services over 60,000 residents in Rouse Hill, Stanhope Gardens, Glenwood, Kellyville Ridge, Parklea, Acacia Gardens, Beaumont Hills, Quakers Hill, The Ponds and Castle Hill	Class A recycled water	Reclaimed water is stored close to the areas of use in three reservoirs with total capacity of 6,000 m^3. Rouse Hill Recycled Water Plant includes biological processes and filtering and disinfection using ultraviolet radiation and superchlorination. Reclaimed water flows via gravity to end-users fitted with purple pipes.	Garden watering Toilet flushing Car washing	Implemented predominately to reduce impacts to water quality of Hawkesbury River	Sydney Water
	Sydney Olympic Park, Sydney, New South Wales	Scheme services 2,400 medium density residential households, industry, commercial and sporting facilities	Class A recycled stormwater and wastewater	Stormwater is collected from catchment and passes through treatment ponds prior to combined storage with treated effluent from the Water Reclamation Plant. Blended water is then treated at the Water Treatment Plant prior to distribution via dual reticulation to Sydney Olympic Park and	Garden watering Toilet flushing Car washing Fire fighting	Water conservation, waste minimization and pollution control	Sydney Olympic Park Authority

Location		**Development type and scale**	**Non-potable water scheme**	**Collection and treatment system**	**End-use**	**Reason for implementation**	**Owner and operator**
				Newington.			
New South Wales	Pitt Town development, Sydney, New South Wales	Brownfield development 140 customers currently serviced, up to 850 customers anticipated	Sewer mining and on-site Class A recycled wastewater	Seven filtration and purification processes including MBR and UV	Garden watering Toilet flushing Cold washing machine tap	Striving for the highest possible environmental rating	Pitt Town Water (Flow Systems)
Queensland	Payne Road (Silva Park Estate), Brisbane, Queensland	Brownfield development 22 large residential lots	Household-scale greywater recycling for garden watering	Greywater collected from bathrooms and laundry and treated through a Biolytix system installed on each lot	Treated greywater for sub surface irrigation; treated rainwater for potable supply	Maximise reuse and demonstrate water sensitive urban design principles	Body Corporate
	Fitzgibbon Chase development, north Brisbane, Queensland	Brownfield development 1,300 dwellings	Rainwater and stormwater harvesting – *not yet operational*	Filtering and disinfection of stormwater; rainwater treated by water treatment plant prior to distribution into town water network	Rainwater tanks connected to toilet, laundry and external taps; large scale rainwater harvesting collected, treated and returned to the grid and stormwater harvesting for open space irrigation	Maximise reuse and demonstrate water sensitive urban design principles	Economic Development Queensland

Location		Development type and scale	Non-potable water scheme	Collection and treatment system	End-use	Reason for implementation	Owner and operator
Queensland	Rochedale Urban Development, Brisbane, South East Queensland	Brownfield development 400 residential lots, commercial and office buildings	Class A recycled wastewater – *not operational*	Class A non-potable water was to be provided by Western Corridor recycled water pipeline	Dual reticulation for garden watering, outdoor uses, public open space irrigation, fire hydrant supply and commercial and industrial uses; rainwater tanks connected to toilet, laundry and hot water system	Marketed as a 'clean and green community' with 'innovative, integrated water management strategies that will see Rochedale become Brisbane's first water smart suburb'	Queensland Urban Utilities
	Pimpama Coomera, Queensland	Brownfield development 65,000 homes by 2056	Rainwater harvesting Class A+ recycled wastewater – *decommissioned*	Alum and chlorine dosing of the secondary clarified effluent followed by media filtration, ultrafiltration, ultraviolet (UV) disinfection and further chlorination – 17 ML/d treatment plant	Recycled wastewater for toilet flushing, outdoor use and fire fighting; rainwater supply for non-potable in house demands	Protecting receiving water quality of the Pimpama Coomera and Southern Moreton Bay	Gold Coast Water
	South Caboolture, Queensland	Greenfield development 3,500 lot development	Class A+ recycled wastewater – *decommissioned*	Caboolture Water Reclamation Plant - 10 ML/d advanced tertiary treatment plant	Garden irrigation Flushing toilet Non-potable outdoor use	Plant was originally designed for IPR though is now only used for non-potable application due to public opposition	Unity Water

CRC for
Water Sensitive Cities

Cooperative Research Centre for Water Sensitive Cities

Lvl 1, 8 Scenic Blvd
Monash University, Clayton,
Victoria 3800, Australia

info@crcwsc.org.au

www.watersensitivecities.org.au