Future urban water supplies

Stewart Burn

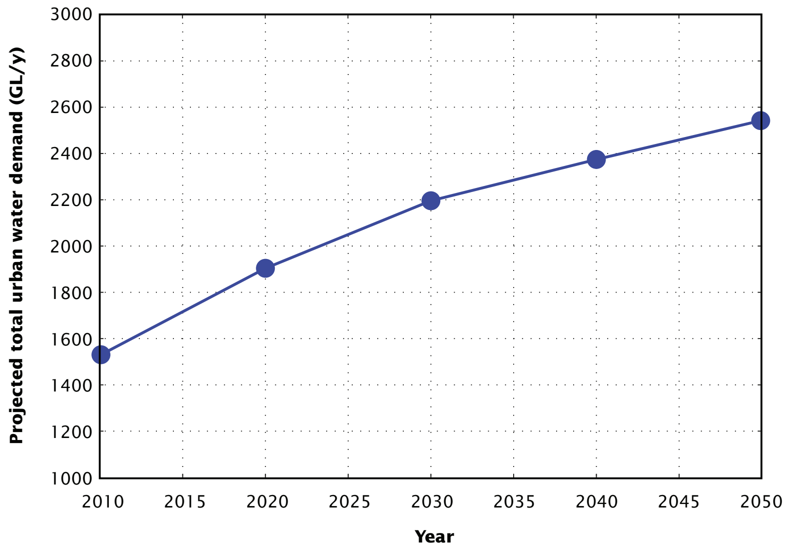
Key messages

- Australia's largest cities are forecast to require 1150 GL/year (or 73%) above the current supply of 1505 GL/year by 2050. In addition, current supplies will probably reduce as a result of climate change, requiring additional augmentation.
- Desalination is the most adopted technology to date, providing 484 to 674 GL/year of additional water. There is potential for major improvements in the efficiency and cost of desalination.
- Other potential water sources include rainwater tanks, capturing and reusing stormwater, and indirect potable recycling – all of which have their particular strengths and weaknesses.
- Traditionally, financial and technical considerations were emphasised when exploring new water supply options; now, consideration is also being given to social acceptability, and environmental costs and benefits. There will be different solutions to new supplies for each city, given their very different situations.

The need to augment urban water supplies

As outlined in the preceding chapter, 10–20 million extra people will be living in Australian cities in 50 years time. Population growth will create a demand for an additional 1150 GL or 73% of water by 2056 (Figure 7.1).[1] In the past, large dams were built to meet that growing demand but recently other options have been considered and used, such as desalination plants, recycling, stormwater harvesting, and rainwater tanks. This chapter explores the merits and prospects of these options as new methods of supplying water.

Growth in demand for water was accommodated until recently by reducing per capita use (see Chapter 6). By 2001–02, each capital city's water consumption had grown close to, or exceeded, its reliable supply from surface or groundwater sources (Figure 7.2), and the millennium drought in southern Australia revealed the vulnerability of existing supplies. Augmentation of water supply became critical, and most states built desalination plants (Table 7.1).[2] Desalination has the advantage of not being dependent on variable catchment runoff or groundwater recharge, which was a critical consideration during the drought.



◂ ***Figure 7.1****: The projected total water demand in Australia's major cities (the sum of demands in Canberra, Perth, Adelaide, Sydney, South East Queensland and Melbourne) as a result of growing population.*[1]

Climate change in southern Australia is predicted to reduce the long-term yield of dams and groundwater systems (see Chapter 2). In Melbourne, for example, the predicted reduction in surface water inflows to urban water storages is 10% by 2020 and 20% by 2050.[3] Higher temperatures and reduced precipitation could also increase urban water demand because cities use about 30–40% of residential water for irrigating domestic gardens and public parks. More water tends to be used when the weather is warm and dry (e.g. in evaporative cooling and swimming pools). Based on studies in Melbourne[3] and Sydney[4], the increase in urban demand due to climate change will be 1% in 2020 and 5% in 2050. This is a small increase compared with the expected reduction in surface water inflows, but the growing demand and dwindling supplies will produce a widening gap, requiring new supplies.

The recent national investment in 484 GL of desalination capacity (expandable to 674 GL) will suffice in most cities until approximately 2026 (Table 7.2). Beyond 2026, new sources of water will be needed in some cities, giving a 15-year opportunity to undertake new solutions. For inland cities and towns, desalination is not feasible and other options, including the purchase of irrigation entitlements, are needed. Canberra is currently augmenting supplies with stormwater harvesting and an enlarged dam.

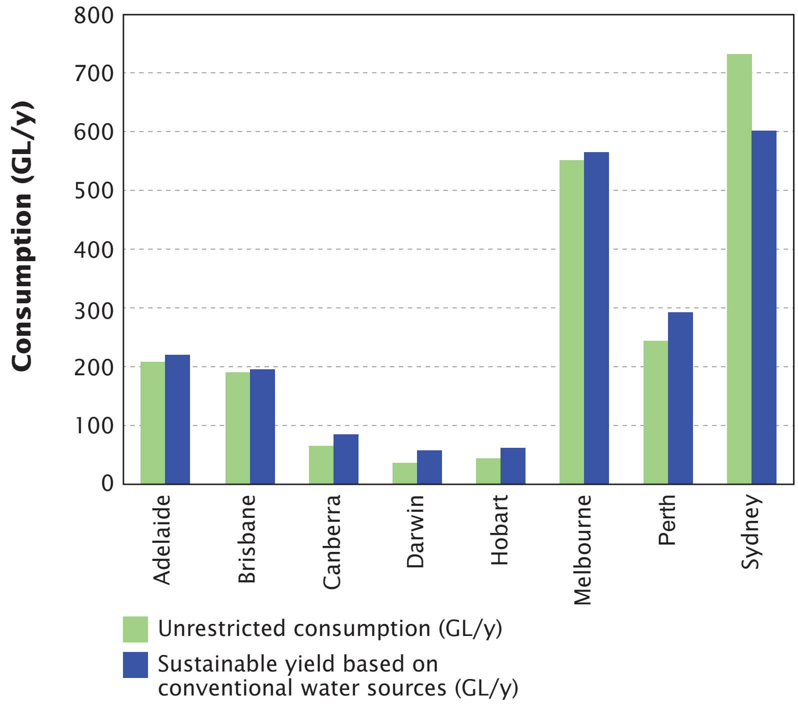


Figure 7.2: *Comparison of 2001–02 unrestricted consumption and sustainable yield based on conventional surface and groundwater sources in Australian major cities, showing that consumption had grown to the limit of sustainable yield of the supplies.*[2]

Table 7.1: Current desalination capacity installed (or being built) and total proposed capacity in Australia's capital cities.[1]

City	Current capacity – gigalitres	Maximum proposed capacity – gigalitres	Maximum desalination compared with consumption 2008–9
Adelaide	100	100	73%
Brisbane and SEQ	49	49	22%
Canberra	0	0	0%
Darwin	0	0	0%
Hobart	0	0	0%
Melbourne	150	200	42%
Perth	95	145	38%
Sydney	90	180	18%
Total	**484**	**674**	

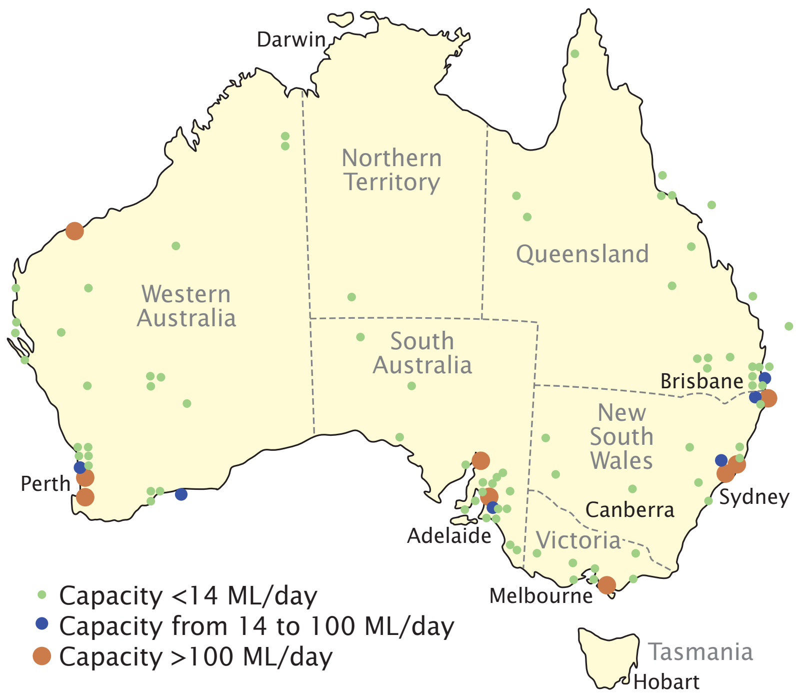
Desalination plant at Kwinana, Western Australia. Photo: Western Australian Water Corporation.

Table 7.2: Predicted water availability (in GL/year) in 2026 for Australia's capital cities.[5,6,7,8,9]

	Current yield	2026 yield with climate change	Current desalination capacity	Total capacity (2026)	Urban water consumption 2009	Predicted consumption in 2026	Predicted surplus (deficit) 2026
Adelaide	216	194	100	294	138	176	**118**
Brisbane and SEQ	476	428	49	477	223	499	**–22**
Canberra	104	80	0	80	46	75	**5**
Darwin	42	38	0	38	37	55	**–17**
Hobart	803	723	0	723	40	40	**683**
Melbourne	555	500	150	650	360	516	**134**
Perth	256	230	95	325	250	285	**38**
Sydney	603	543	90	633	492	619	**14**

Desalination

Australia has a long history of water desalination. Initial drivers were the need for potable water from the sea, or from brackish groundwater in the case of arid and remote communities (Figure 7.3). Early applications of desalination were all small-scale plants deploying a range of technologies. Australia's six largest coastal cities all now have desalination plants in place or under construction to ensure reliable water supply (Figure 7.3). These plants use reverse osmosis because it has a proven history of use and has low energy and capital costs compared with other available desalination technologies.



▸ ***Figure 7.3****: Location and size of desalination activities across Australia.*[10]

Reverse osmosis (Figure 7.4) uses a membrane to filter and remove salt ions, large molecules, bacteria, and disease-causing pathogens from sea water by applying pressure to the water on the input side of a semi-permeable membrane. The salt is retained on the pressurised side of the membrane and pure water passes to the other.

Reverse osmosis has a number of shortcomings. Although the membrane is impervious to salt, it can let through chemicals such as pesticides and herbicides, so for potable water it still requires a pure source. Reverse osmosis removes all the naturally occurring salts to give un-buffered water that is deficient in calcium and other essential minerals, so to ensure that it is appropriate to drink these are added back into the water.

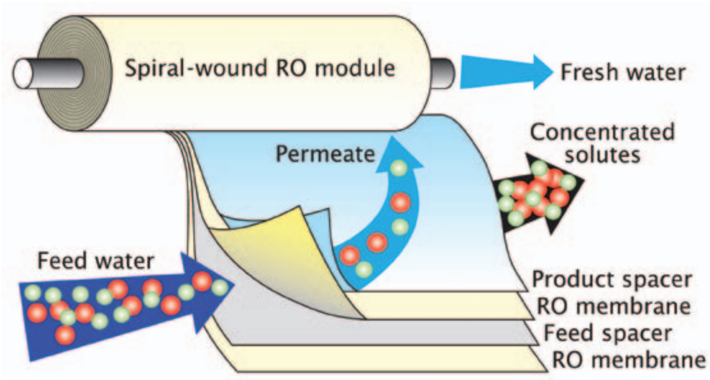


Figure 7.4: Schematic of the reverse osmosis (RO) process.[11] (Adapted from nanoh2o.com.)

Reverse osmosis is also relatively inefficient – all the input water must be chemically pre-treated and filtered even though a large proportion of the input is returned to the ocean as a concentrated brine stream. In the Perth plant, this brine is equivalent to 60–65% of the input water stream. Reverse osmosis also uses significant amounts of electricity to pressurise the input water (for example, the highly efficient Perth plant uses power equivalent to that for 27 000 homes).

It is expected that the existing trend to use reverse osmosis for urban and industrial water desalination will continue. Research is examining ways to make the process more efficient and reduce the amount of energy needed. A range of emerging technologies increase efficiency by either pre-treating water, reducing membrane fouling, improving the throughput of water and rejection of pollutants, or reducing the pressure at which the systems operate.

Pre-treatment is essential to prevent fouling of membranes for at least half of the major reverse osmosis seawater desalination plants installed around the world. Inorganic salts, colloidal and particulate matter, organic compounds and microorganisms present in the feed water reduce membrane efficiency and lifespan. The main pre-treatment used is coagulation. However, coagulation only removes some pollutants and can produce small flocculants that penetrate and block membrane pores. New coagulants formulated for a number of water sources aim to greatly improve flocculent size, capture more pollutants, reduce membrane fouling, and can be easily washed from membranes.[12] Technologies are also being developed to allow membrane surfaces to be treated with sugars that have excellent anti-fouling properties.

Several emerging technologies have the potential to improve the efficiency of reverse osmosis, for example polymer membranes (Figure 7.5), but it may be decades before some of these are mature enough for widespread application. These technologies could also be applied to water recycling and the treatment of industrial waste streams, enabling water reuse.

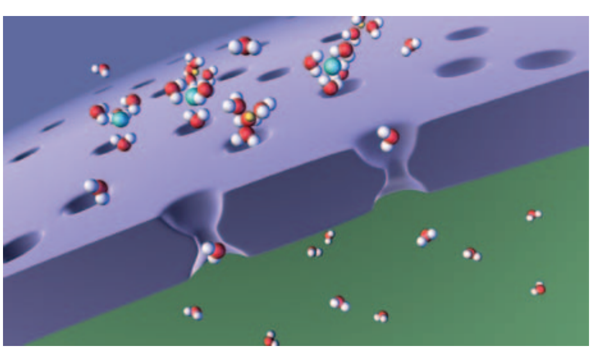
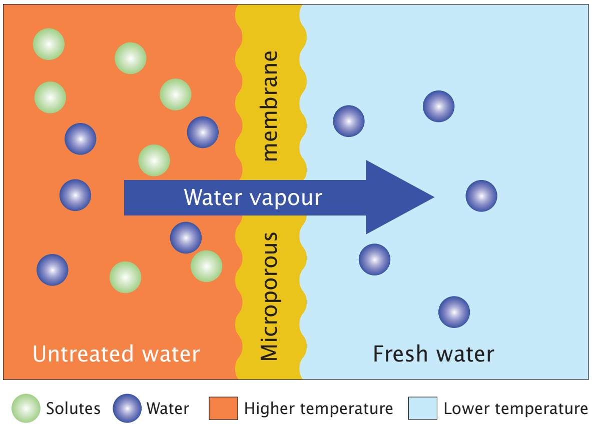


Figure 7.5: Schematic of a new polymer membrane which uses microscopically small hour-glass pores to allow water molecules to pass through the membrane while larger salt ions and other molecules are unable to pass through. The polymer mimics the shape of micropores found in nature.

Carbon nanotechnology can possibly be used to produce membranes that are effectively forests of microscopic tubes. It is claimed that these tubes offer an almost frictionless flow of water while retaining salt. They also have the potential for low membrane fouling, enabling simple regeneration of the membrane. Membranes with permeability that is significantly higher than conventional materials are being examined for desalination performance.[13,14]



▸ ***Figure 7.6***: *Schematic showing water vapour passing through a membrane from the high temperature to low temperature compartments in the membrane distillation process.*

Membrane distillation (Figure 7.6) is a thermal process, which uses any low-quality heat source, to enable water vapour to pass through a specialised membrane leaving pollutants in the remaining liquid. Membrane distillation works at atmospheric pressure and recovers up to 80% of clean water relative to 40% for reverse osmosis. Current limitations are a low throughput and membrane fouling.[15] Alternatively, a combination of permeation and evaporation (‘pervaporation’) can be used to pass water through a polymer membrane with evaporation on the far side of the membrane providing a pressure difference to maintain flow. This technique has potential to be very efficient but it is limited at present by low flow rates.[16,17] Electrodialysis is a low-pressure, direct current electrical process for removing salts from brackish water that is showing potential for treating highly saline waste water. It does not remove pathogens effectively, but the resultant water is considered suitable for irrigation and can be produced at an operation cost of $100/ML – considerably lower than for potable supplies.

Rainwater tanks

Urban households are increasingly adopting rainwater tanks as a water source. Rainwater tanks were traditionally used in rural areas that did not have a reticulated supply, but their use has proliferated in cities in response to government policies to reduce demand on centralised water supplies (Figure 7.7). From 1994 to 2010, the number of capital city households that use a rainwater tank has more than doubled, increasing from 407 000 to 1 030 000.[18,19] Urban rainwater tanks are mainly used for garden watering and toilet flushing, which are a large component of domestic water use. Capture and use of rainwater moderates peak stormwater runoff and reduces discharge of nutrients to rivers and estuaries. Rainwater is not permitted to be used as a potable supply in some cities because the water is untreated and could be contaminated by metals, organic matter, and microorganisms.

It is expected that the number of urban rainwater tanks will continue to increase because most jurisdictions have mandated installation of water-saving features for new buildings. Rainwater tanks are one way of meeting this requirement (e.g. the Development Regulations in South Australia require all new houses and units to have connection to an additional water source to supplement mains water).

How effective rainwater tanks are as a new supply of water depends on how much they reduce demand on centralised supplies and how much energy they use. Water billing data from South East Queensland shows an average water saving of 30 kL/household/year from rainwater tanks (approximately one-tenth of domestic supply), while tank modelling showed a saving of 46 kL/household/year could be achieved from internal usage.[20] Savings depend upon how well households use the water, the design of the system, and seasonal rainfall.

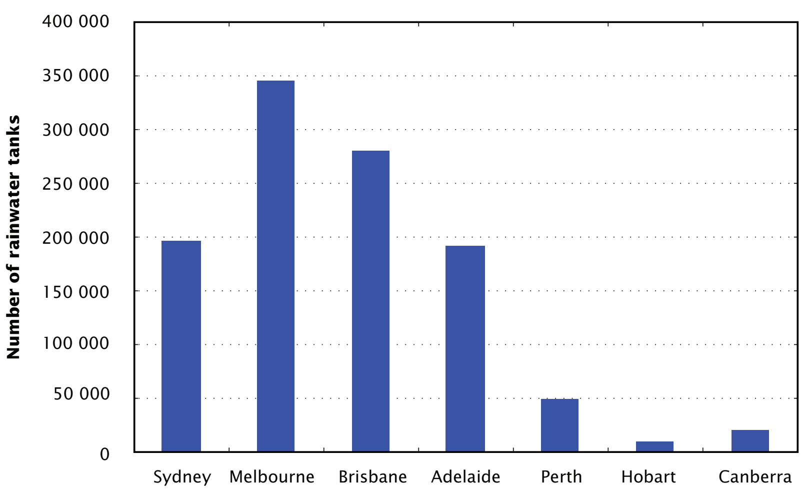


Figure 7.7*: The number of urban rainwater tanks in major Australian cities in 2010.*[18]

The use of tank water usually requires the use of a pump, which, in turn, raises questions about their energy efficiency. Very high variations in energy use are reported (from 0.6 to 11.6 kWh/kL) and the process can exceed the energy used per kilolitre to produce water by desalination (Figure 7.8). The high variation is caused by the use of different types of pumps and accessories, and energy use could be reduced through better design and operation. The potential for improvements in energy and water use makes a case for providing professional services, supported by automated control systems, to improve and maintain the performance of rainwater tanks.

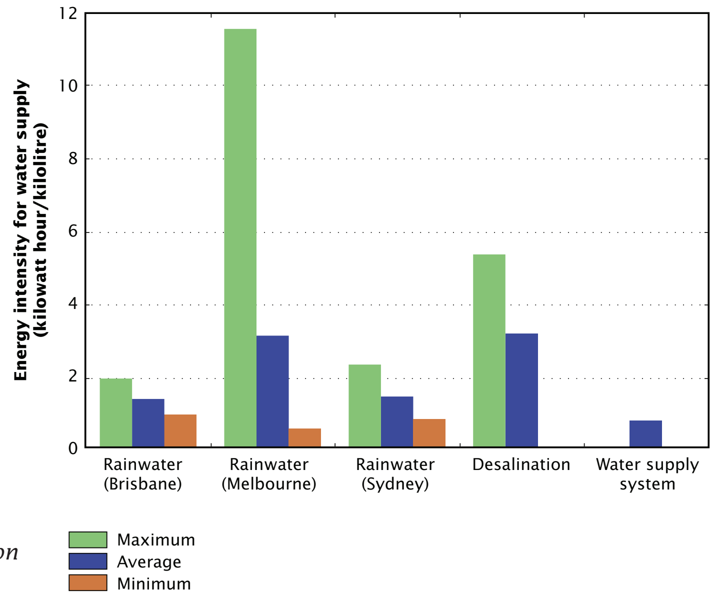
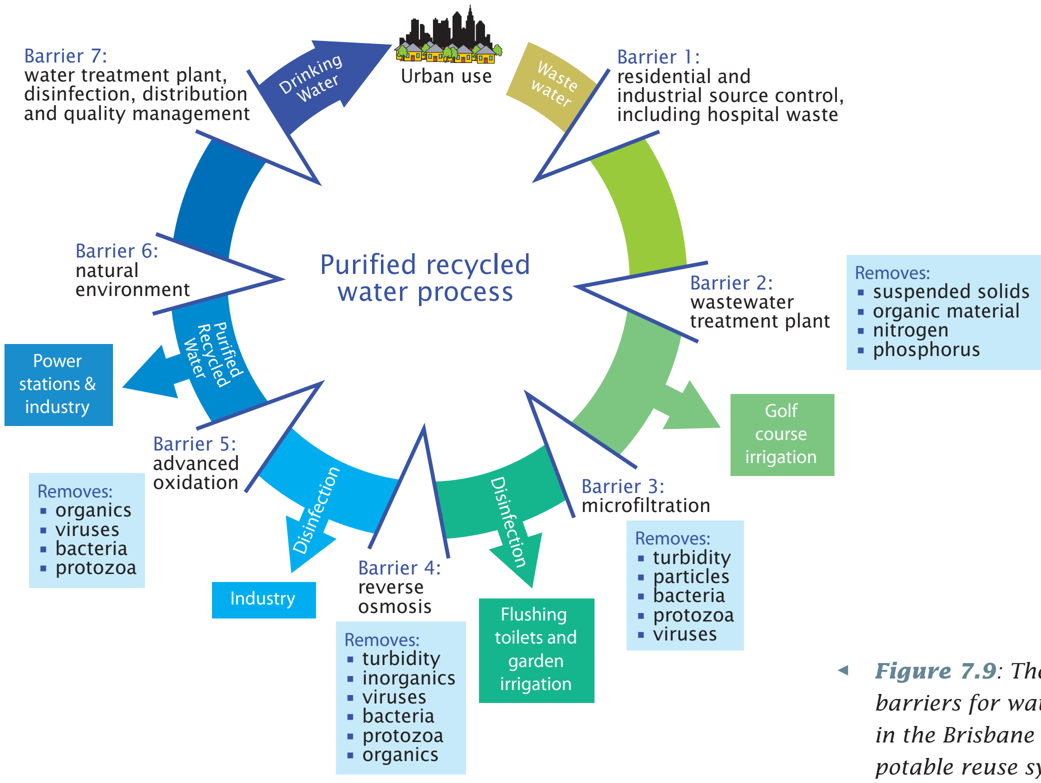


Figure 7.8: The range of energy use of rainwater tanks, compared with desalination and water supply from dams (CSIRO data).

Recycled water

Water is commonly used once and then discarded, but significant efforts are now being made to recycle wastewater. Recycling and reuse can contribute to sustainability by reducing the economic and environmental costs of wastewater disposal and by providing an alternative water source to substitute for centralised potable supplies. Most efforts have reused water for non-potable purposes, such as for irrigation of crops, pasture, public gardens, and sporting fields. By the mid 1990s, water recycling was supplying water to industry for cooling and industrial processes, and new residential developments in New South Wales and Victoria via third-pipe systems for outdoor use and toilet flushing.

Recent urban water shortages have raised the prospect of indirect potable reuse, where sewage is treated to a level that meets drinking water standards and is stored in an existing reservoir from where it can be extracted for later use. Key international examples of this process in place are Singapore, where about 2.5% of total daily water consumption is reused water,[21] and Orange County in the United States of America.[22] In both these cases, there was considerable emphasis placed on public awareness and education about the scheme, including the development of an education program. The Queensland Government commissioned the Western Corridor Scheme, which is based on a seven-barrier system (Figure 7.9), including storage of treated water in the Wivenhoe Dam. This system can supply up to 66 GL/year of reused water into the South East Queensland water system. Indirect potable reuse has been quietly in place for decades along a few Australian rivers. Canberra's wastewater is treated and disposed of in the Murrumbidgee River, while towns downstream, such as Wagga Wagga, Leeton, Griffith, and Adelaide, extract and treat the river water for potable supplies, as is the common practice for virtually all European river cities.



◂ ***Figure 7.9****: The seven barriers for water treatment in the Brisbane indirect potable reuse system.*[23]

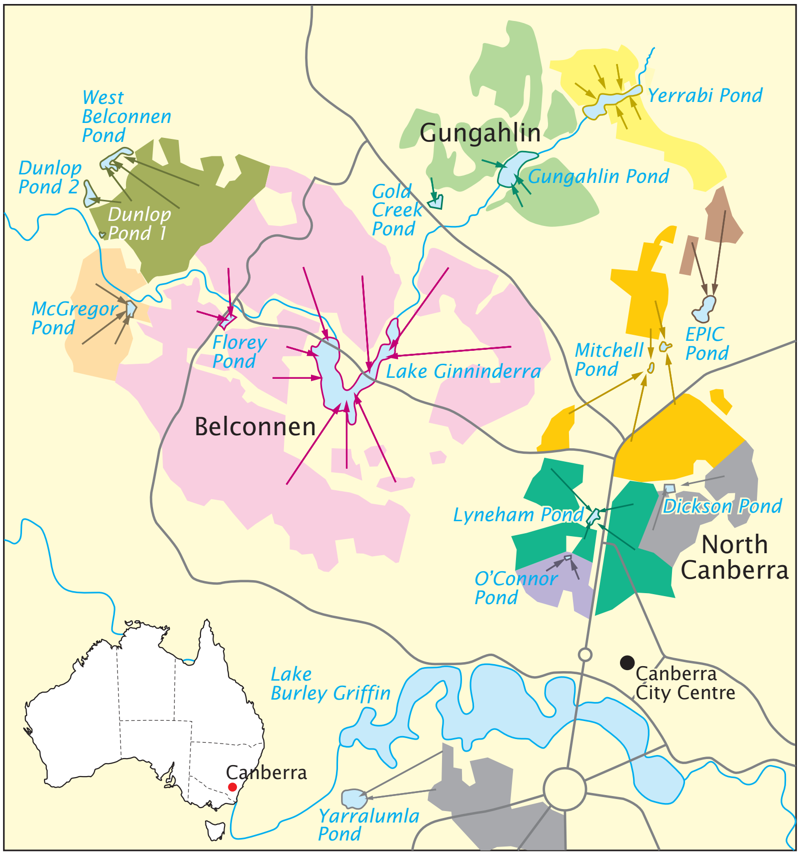
There are substantial community concerns regarding the safety or necessity for use of recycled wastewater, centring on the potential for harmful contaminants that may enter the drinking water system – either because of a failure in the treatment system, how it is operated, or due to some unforseen contaminant. Particular concern has been expressed over control of industrial and hospital contaminants. The Western Corridor Scheme in Brisbane was built at a time of impending water crisis, but now that the Wivenhoe Dam has filled, the water is used only for cooling in a power station and some other industrial uses.

Reuse systems contain advanced water treatment such as dual membrane systems that combine micro- or ultra-filtration with reverse osmosis. In many cases, advanced oxidation using ultraviolet disinfection is used as an additional treatment barrier to ensure almost complete removal of all traces of biological and chemical contaminants. Pathogens have been excluded up to 99.99% and virtually all organic compounds removed.[24, 25,26] Trace chemicals are at concentrations tens to hundreds of times less than the limits set by the Australian Drinking Water Guidelines.[23, 24,27]

Despite the demonstrated effectiveness of advanced water treatment plants, regulators require that potable recycling is done in an indirect manner using some form of natural reservoir between the advanced water treatment and the drinking water treatment plant. For example, the Western Australian Government plans to use aquifers for storage. These natural environments also remove or reduce any pathogens or organic chemicals present and provide an additional control point through dilution and prolonged storage. This allows scheme operators and regulators to intercede if a system malfunction causes pollutants to pass through the treatment plant. In this respect, rapid detection techniques that can almost instantaneously determine if a treatment barrier has failed are needed to ensure the operational effectiveness of treatment plants. It should be recognised, though, that pathogens and chemicals may enter a reservoir or aquifer from catchment land use. Despite all the measures to make potable recycling safe, community resistance remains strong and it may not be swayed, even by strong consultation and education.

Stormwater capture

Stormwater is a large resource that could be collected from urban runoff to substitute for existing supplies and reduce the costs and environmental impacts of disposal.[28] Many municipal councils capture stormwater for non-potable use. For example, new stormwater harvesting projects proposed for Adelaide will increase the total stormwater harvesting capacity from 6 GL/year to about 20 GL/year by 2013 and up to 60 GL/year by 2050.[29] Non-potable water use in Canberra could be supplied from stormwater entering the city's urban lakes and from new ponds (Figure 7.10). These lakes and ponds have the potential to supply 3.3 GL/year, which was 7.6% of Canberra's total consumption in 2007–08.[30] In most capital cities, the limitations for urban



▸ ***Figure 7.10****: Existing and planned lakes and ponds to capture stormwater in the northern suburbs of Canberra. The storages will be used to provide water for surrounding parks and gardens.*[30]

stormwater harvesting are centred on storage sites for the large volumes of water and the high costs of water treatment.

Urban stormwater contains pollutants that are a human health risk and can limit the recreational use of rivers, bays, and beaches. The pollutants of greatest risk to human health include heavy metals, hydrocarbons, organic chemicals, and organisms that can cause disease. The advanced treatment systems used for wastewater are not economically practical for stormwater application because stormwater is dispersed across the urban area rather than being collected centrally in pipes. Alternative treatment processes such as filtering through wetlands or aquifers need to be used to allow cost-effective treatment.

Storage of harvested stormwater is a large barrier to its use. Appropriate places are urban lakes and wetlands, and in brackish aquifers as pioneered in Adelaide and now implemented in most states and territories. Stormwater recycling, using aquifers to store water from which it is later pumped (Figure 7.11), is used increasingly where there are suitable aquifers.

Examples of aquifer storage and recovery projects include the Mawson Lakes scheme in Adelaide, which uses reclaimed wastewater from the Bolivar Wastewater Treatment Plant, blends it with harvested urban stormwater and then injects it into an aquifer. When needed, up to 0.8 GL/year of water is withdrawn from the aquifer and reticulated to 4000 homes for non-potable reuse.

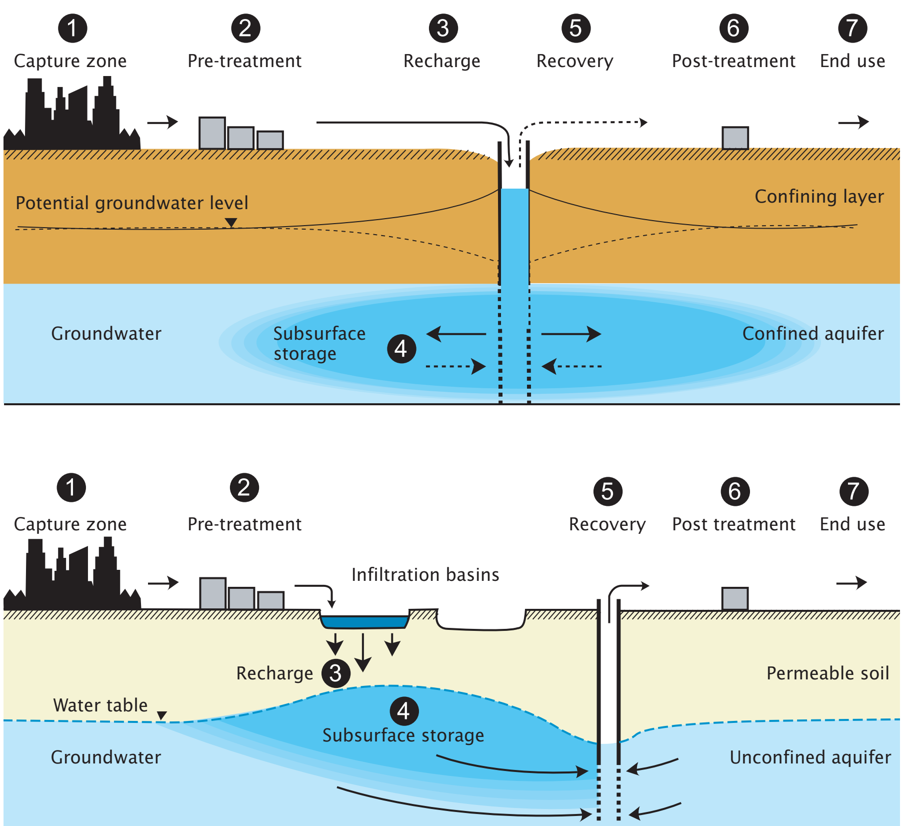


***Figure 7.11**: Elements of managed aquifer recharge. At top, aquifer storage, transfer, and recovery in a confined aquifer. At bottom, soil aquifer treatment in an unconfined aquifer.*

Replacing a stormwater pipe. Photo: Tracey Nicholls, CSIRO.

Stormwater harvesting in the City of Orange (New South Wales) is the first large-scale, potable stormwater harvesting project in Australia and uses the local aquifer for storage and additional treatment.

An advantage of aquifer storage and recovery is the natural filtering and treatment of water that occurs while it passes slowly through the aquifer, although it should be noted that the effect of stormwater injection on chemical reactions in the aquifer must be fully understood to ensure that good water quality is achieved.

Reducing reservoir evaporation

Reservoirs still remain the main source of water for cities, but they lose large volumes of water through evaporation. In dry periods, reservoir levels decline over a period of several years, and the loss of water to evaporation can be as large as the water supplied to the city. For example, Brisbane's three water supply reservoirs can lose 248 GL/year through evaporation, which is comparable to their supply rate of 240 GL/year. A range of evaporation reduction techniques has been considered for small dams but the only likely technique for large dams is the use of a monolayer on the water surface. Monolayers are artificially synthesised long-chain alcohol films one molecule thick (approximately 2 millionths of a millimetre) that inhibit evaporation when applied to a water surface. Evaporation reductions of between 10% and 30% have been recorded for small trials, but new polymers have the potential to double that. Monolayers have not yet been applied to large reservoirs because of limitations of cost relative to water savings, potential effects on water quality, and break-up by winds. Before monolayers could be applied to potable water reservoirs, the potential impact on water ecology and recreational use would need to be fully quantified, as well as any potential impact of the products of biodegradation of the monolayers on water treatment. Financial analysis of the benefits of monolayers has indicated that they have the potential to supply additional water at a cost of $0.28 to $0.68 per kilolitre.[31]

Choosing the best options

This chapter has outlined a range of new options for urban water supplies. Added to these are traditional sources of large dams and groundwater supplies, and continuing improvements in demand management. Suitable options for augmenting water supplies will vary from city to city, with very large differences in the cost, social, and environmental practicality of each option, depending upon the circumstances of each city. Each of the major Australian cities also has a different vulnerability to increased pressures on supplies from population growth, climate variability, and climate change.

Comprehensive planning and risk assessment can be used to determine the optimum portfolio of approaches for each city.[28] This might include decisions on the reliability of supply required into the future, which is often expressed in terms of the acceptable frequency of water restrictions. Given recent unprecedented droughts and the risk from climate change, the risk assessments should be evaluated using a range of possible future conditions and identifying the risks, probabilities, and mitigation strategies associated with each climate scenario. Some of the

A Canberra suburban lake used for stormwater capture and reuse. Photo: Greg Heath, CSIRO.

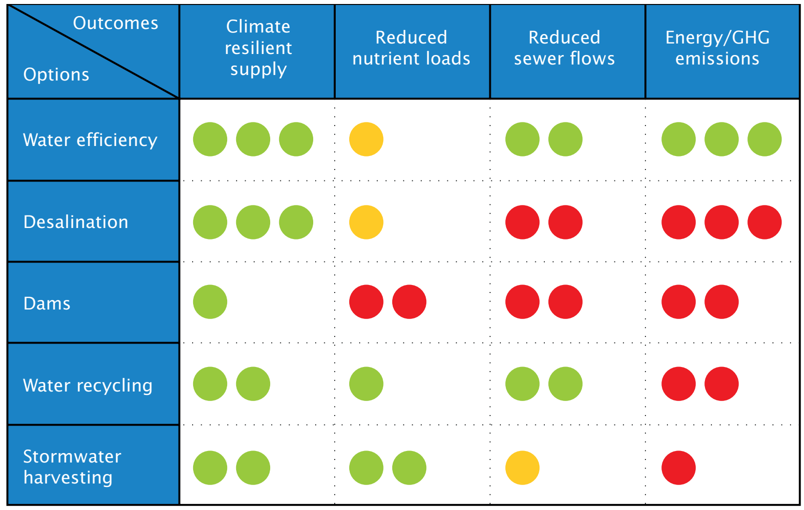


__Figure 7.12__: A simple rating of urban water supply options against considerations other than cost. These might influence both environmental costs and benefits and social acceptance of the options. Green dots represent the strengths of the options; red dots represent the weaknesses; and orange dots indicate no affect.

options, such as desalination plants, take several years to progress from planning to operation, requiring long lead times, but they also involve very large capital expenditures so there are financial incentives not to build them too soon.

Traditionally, a heavy emphasis has been placed on financial and technical considerations when exploring water supply options. Now, more consideration is given to the social acceptability and environmental cost or benefit of an option and techniques such as multi-criteria analysis can more broadly inform decision making. Figure 7.12 shows, for the purpose of illustration, a simple example of some of the supply options ranked against four considerations other than cost and technical feasibility. Strong differences are shown and different options would be chosen depending upon how important each factor was to the particular city.

Technical feasibility and the cost of the different supply options varies strongly between Australian cities. Figure 7.13 shows the spread of costs for various options across a number of cities. One of the reasons for large differences in costs is the relatively high cost of pumping over

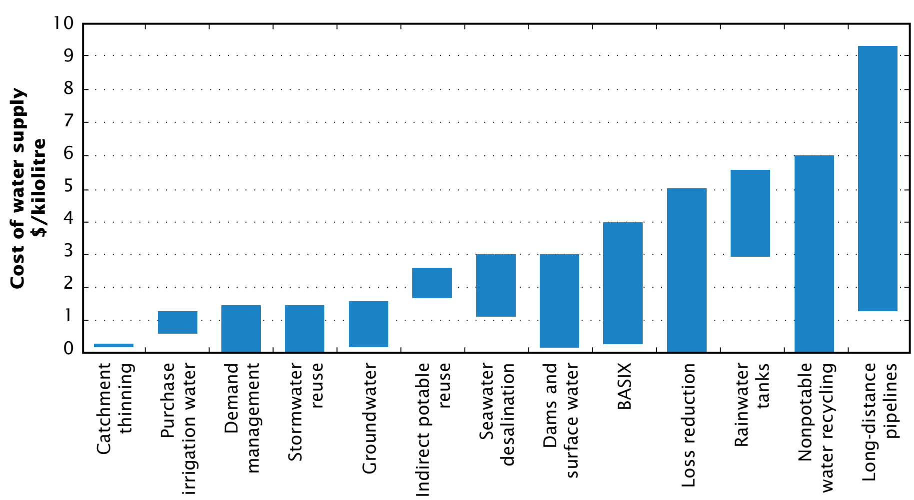


__Figure 7.13__: The range of costs to provide additional water to Sydney, Adelaide, Perth, and Newcastle (2006 dollars). 'BASIX' refers to improvements in building sustainability including water saving.[32] (Adapted with permission from Marsden Jacob Associates, 2006.)

long distances or to higher elevations. The distance and elevation to transport recycled water from sewage treatment plants to points of use has a large bearing on its cost. Pumping costs often eliminate inter-basin transfers of water as a good option under normal circumstances, although under drought conditions these may become critical, as has recently occurred in Victoria and Queensland. The cheapest option shown in Figure 7.13 is thinning of forests in water supply catchments to increase runoff, but it is the least proven and most speculative option.

Stormwater capture is probably the most difficult option to assess because it relies heavily upon the availability of storage. For example, the application of managed aquifer recharge across a city is only possible where suitable high-yielding and high-water-quality aquifers exist. Sydney and Melbourne have highly variable aquifers across the urban area, with most of Melbourne's aquifers yielding less than 0.4 ML/day and only the lower tertiary aquifer centred on Werribee in the city's west offering viable yields of between 1 and 5 ML/day. Stormwater capture is most cost-effective in new urban developments where it can be incorporated at the planning stage. Re-engineering existing urban developments is a lot less feasible. Cities are now combining decentralised systems of local stormwater harvesting and rainwater tanks with their existing centralised supply infrastructure. The costs, risk factors, and benefits of different combinations of decentralised and centralised supplies need to be fully evaluated.

In making decisions on the viable options, it must be remembered that major water supply infrastructure is designed to be used for decades, so lifetime costs need to be considered in the decision-making process. New supplies will mostly be more energy intensive and, because it is expected that energy and greenhouse gas emission costs are likely to rise significantly, these factors should be taken into account.

Further reading

Dillon P, Pavelic P, Page D, Beringen H and Ward J (2009) 'Managed aquifer recharge: an introduction'. Waterlines Report Series No 13. Feb 2009. National Water Commission, Canberra, <http://www.nwc.gov.au/resources/documents/waterlines_MAR_completeREPLACE.pdf>.

Environment Protection and Heritage Council (2009) *Australian Guidelines for Water Recycling*. The Environment Protection and Heritage Council, Canberra, <http://www.ephc.gov.au/taxonomy/term/39>.

Hoang M, Bolto B, Haskard C, Barron O, Gray S and Leslie G (2009) 'Desalination in Australia'. CSIRO Water for a Healthy Country Flagship, Canberra, <http://www.csiro.au/files/files/ppcz.pdf>.

Water Services Association of Australia (2010) 'Implications of population growth in Australia on urban water resources'. Occasional Paper No. 25, July 2010. WSAA, Melbourne.