Urban water supply in a carbon constrained Australia

Water-energy linkages

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This paper was motivated by the Australian Federal Government climate change adaptation initiatives. The authors are members of the Australian Climate Change Adaptation Research Network for Settlements and Infrastructure (ACCARNSI), one of eight networks within the National Climate Change Adaptation Research Facility (NCCARF)

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Abstract

Increasing population pressure, natural climate variability and susceptibility to projected climate change impacts have potential to place increasing strain on existing water infrastructure in Australia. Traditional water infrastructure has generally focused on meeting urban water demand via a range of 'low-energy' approaches predominantly based on the capture and storage of surface runoff; however, this approach is proving to be no longer sufficient in satisfying the increasing urban water demand.

Water service providers have been seeking to minimise supply risk through systems approaches such as demand management and more importantly, through the implementation of a diverse range of energy-intensive climate-independent solutions. To date, water service providers have investigated numerous options and implemented a range of alternative water sources such as desalination, groundwater extraction, pipeline distributions and recycling schemes. These water sources, however, rely on advanced technologies some of which incur much higher operational energy costs, and to date, many attempts to address emerging water supply problems in Australia have come at an increased economic and environmental cost.

Detailed assessments and understanding of the 'water–energy nexus'—the interactive relationship between water and energy—are crucial precursors to enable the water sector to reduce its operational energy costs and facilitate the design of water and energy systems capable of realising any synergistic benefits. Under the current paradigm, in which energy supply and pricing issues are becoming increasingly important in the public sphere, having an improved understanding of this linkage will allow water service providers and the general community to be more aware of the energy impacts of key water infrastructure and be more responsive to future changes in the cost of their energy supplies.

This discussion paper looks at options for securing Australia's urban water supply by addressing the water–energy nexus, current energy requirements and associated operational energy costs for a number of important water and wastewater treatment technologies. Additionally, a review of various water supply options currently implemented by water service providers is presented from an energy perspective. Finally, system management approaches as well as other alternative low-energy water supply or savings options are discussed.

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1 Introduction

Australia’s capital cities and major urban areas have traditionally relied on surface waters to meet the increasing demand for potable water arising from the increase of per capita water usage and population growth. In the past decade, however, authorities responsible for water supply have turned to non-traditional sources of water, such as seawater, wastewater, brackish groundwater and stormwater, as alternative supplies to meet demands and to provide increased reliability of supply (MJA 2006).

Most proposed new water sources require more advanced technologies (Kenway *et al*. 2008; PRI 2008) and are more energy-intensive than traditional sources. This means that they use more energy per unit of water provided at specified quality to the consumer. Unfortunately, such solutions also increase the so-called *carbon footprint* of the utility – the total greenhouse gas emissions generated, calculated on a total or per capita basis.

Increased concern about climate change and the need to mitigate greenhouse gas emissions has focused attention on water-related energy use and water’s greenhouse gas implications. Further, for climate change adaptation to be effective, it is essential that long-term strategies mitigate greenhouse gas emissions and other forms of widespread pollution (US Department of Energy 2005; PRI 2008).

This report has been prepared for the Australian Climate Change Adaptation Resarch Network for Settlements and Infrastructure (ACCARNSI) with the objectives of addressing issues of energy use and more broadly carbon mitigation in the context of water supply adaptation strategies. The aim of this report has been to stimulate debate amongst water professionals and the general public regarding future direction of Australia’s water supply and the associated impacts this will have on both climate change mitigation and adaptation strategies.

Specifically, this discussion paper addresses the implications of higher-energy alternative water sources by assessing the nexus between water supply and energy use. Quantifying the energy consumptions of specific treatment and hydraulic systems, as well as quantifying the embodied energy (i.e. that required for construction and maintenance of the infrastructure) and economic evaluations will require detailed assessment by suitably-qualified professional staff.

2 Fundamentals

In order to quantify water supply operational energy costs it is important to understand the fundamental physical properties of water that affect operational energy requirements (as shown in Table 1). These energy requirements are generalised to give an impression of the overall trend in operational processes and are do not necessarily represent site-specific values which vary depending on localised pumping efficiency, system design and materials used.

Firstly, water has low viscosity; it flows easily whilst laminar but readily transitions to turbulent flow, which dissipates energy and increases the required pumping energy. Secondly, water is dense and requires high-energy inputs to lift and finally water has a large heat capacity requiring high-energy inputs to evaporate.

Table 1: Physical properties of water at 20°C and atmospheric pressure

Property	***Value***	***Operational process***	***Energy required (kWh/kL)***	***Est. cost ($/ML)***
Viscosity	$\mu = 10^{-3}$ Pa.s	moving (1 km)	0.012	$24
Weight	1 kL = 1 tonne	lifting (1 km)	2.8	$560
Heat capacity	$c_p = 1.2$ kWh/kL/°C	heating by 25°C	30	$6,000
Specific heat of vaporisation	$\Delta H_v = 630$ kWh/kL	evaporation (turning water to steam at 100°C)	630	$126,000

Note: Energy costs ~ $0.20 per kWh (Energy Australia 2010) and evaporation results from a temperature increase of 80°C.

In practical terms, implications of these physical properties correspond to three main processes used in water utilities. Moving water 1 km horizontally, at a velocity of 5 m/s in a 0.6 m steel pipe, requires only minor energy inputs – around 0.012 kWh/kL - due to losses associated with turbulence, a process that is largely independent of its low viscosity. By contrast, lifting water, a function of its weight, requires 2.8 kWh/kL each kilometre. In reality, transporting water requires both moving and lifting processes, therefore, transporting water across a large city (~100 km) or across a state (~1000 km), including elevation changes can result in large incurred costs and energy consumption.

Heating water is even more energy intensive and therefore an expensive process. Conventional domestic and industrial hot water systems typically require 30 kWh/kL with an estimated cost of $6,000 per megalitre. Since oceanic evaporation and subsequent precipitation generates most of Australia’s pristine runoff, this natural hydrological process minimises traditional water supply operational energy requirements delivering what would normally cost an estimated $126,000 per megalitre if this process was emulated by conventional technology.

3 Australian Hydrology

Australia is the driest inhabited continent on Earth, receiving on average less than 460 mm of rainfall annually (BoM 2009). This low rainfall combined with high annual evaporation results in surface runoff being the lowest of any continent; only 12 % of Australia's annual average rainfall becomes runoff with the remaining amount accounted for by evaporation, vegetation or stored in lakes, wetlands and aquifers (NLWRA 2001; WQRA 2006). Further, Australia's rainfall and runoff has more variability than any other continent (Ladson 2008).

In spite of claims of consistent drying trends across the Australian continent as a whole, much longer-term rainfall analyses indicate significant fluctuations in mean annual rainfall over epochs of up to 50 years. This has been most clearly and recently illustrated by Kamruzzaman *et al.*, (2011) for south-eastern Australia. Historical stationarity should not be assumed when considering the development of Australia's water resources (Milly *et al*. 2008; Water Corporation 2010). Rather, we presently lack sufficient long term data and reliable predictions to resolve this question.

Figure 1 compares Australia's annual average rainfall and evaporation contour maps based on 30 years of rainfall data and 10 years for evaporation. It is evident that the majority of Australia maintains a water deficit resulting from annual average evaporation exceeding precipitation.

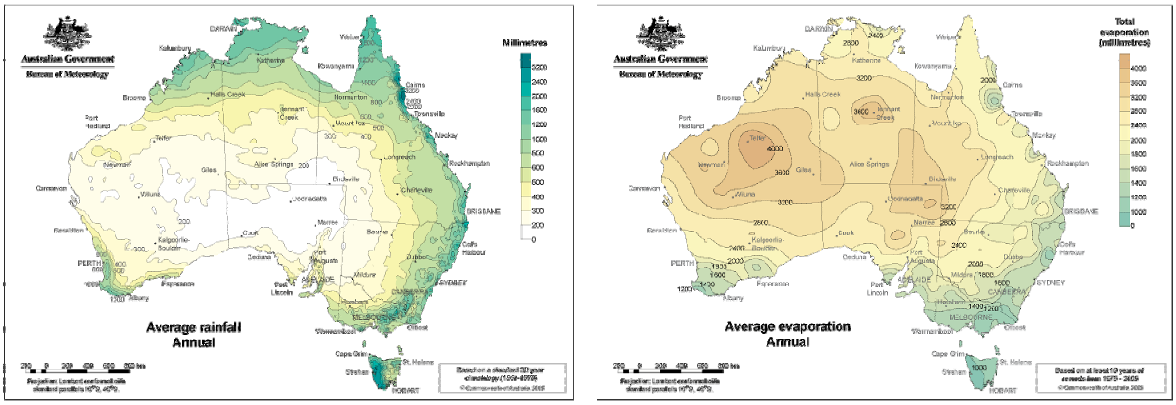

Figure 1: Comparison of Australia's average annual rainfall and evaporation (BoM 2009)

Annual average rainfall and evaporation for Australia's capital cities are quantified in Figure 2 where it can be seen that for each city, except Sydney, evaporation far exceeds annual mean rainfall. It is therefore clearly desirable to minimise reservoir surface evaporation and also adapt present supplies towards more climate insensitive methods.

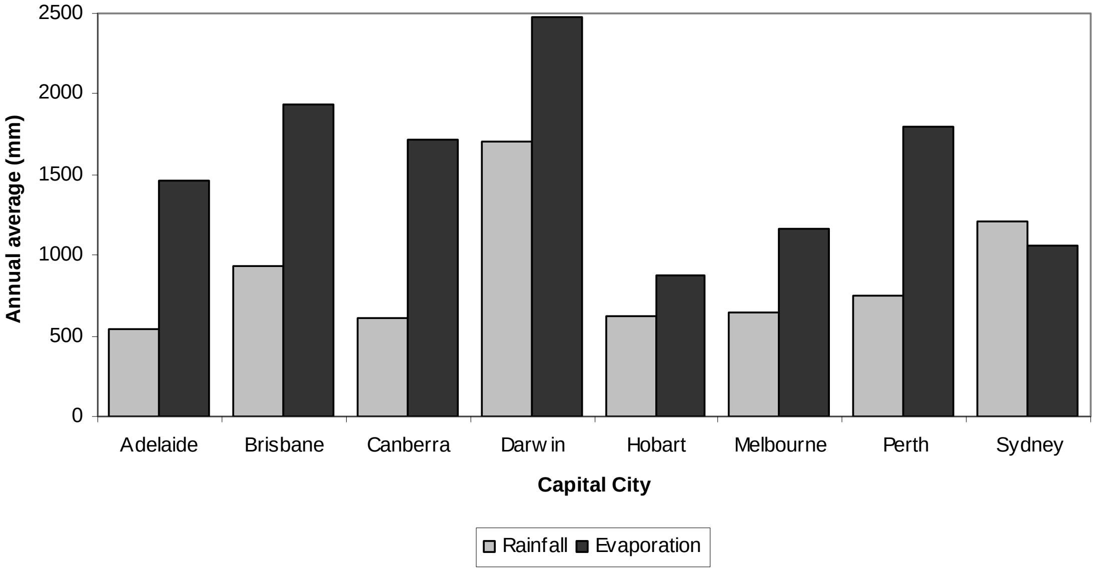

Figure 2: Average annual rainfall and evaporation for Australian capital cities (BoM 2009)

4 Development of Australia's Water Resources

Development of Australia's water resources has traditionally exploited inexpensive solutions with minimal operational energy. However, expanding water demand coupled with Australia's natural climate variability has resulted in water suppliers increasing water supply sources via energy intensive climate-independent alternatives such as desalination or recycled water. Unfortunately, these sources often require higher operational energy needs posing the added risk of being linked to the price of energy (IWA 2008). When the cost of energy increases, the cost of water will also increase, with greater likelihood of being impacted by internationally- or domestically-applied carbon constraints.

As water utilities adapt to changing water supply conditions through diversifying water sources, it is important to realise the impacts these high-energy solutions will have on the mitigation of climate change. The need for climate change mitigation and improvements in the sustainability of infrastructure means that development approaches need to be critically assessed. This paper discusses two broad strategies that address the development of Australia's water resources focusing on energy implications. These two strategies are:

1) Developing alternative water sources; and
2) Systems management approaches.

4.1 Developing Alternative Water Sources

In Australia, six alternative water sources are generally accessible or have been explored for development. These are:

a) Storing pristine runoff;
b) Groundwater sources;
c) Rainwater tanks;
d) Urban runoff;
e) Recycling; and
f) Desalination.

This section briefly discusses each of these alternative water sources, and includes a summary at the end of the section in Table 3.

4.1.1 Storing pristine runoff

Storing pristine catchment runoff in reservoirs is a low-energy method that is widely employed in Australia's capital cities. With the exception of Perth, Australia's major urban centers are supplied primarily by surface water sources. Due to the low and variable nature of rainfall and runoff, Australia stores more water than any other country in dams, around three times the amount relative to consumption than in Europe or America (MJA 2006). South-east Queensland has a storage capacity of six times its annual water usage, Sydney has four times, Melbourne three.

Storing pristine runoff requires minimal treatment due to the purity of catchment-based rainfall and the pristine nature of many Australian catchments as well as minimal operational energy due to the elevated location of dams. There is significant energy subsidy from natural processes that evaporate, purify, transport and precipitate water at elevation at no cost to the community (see Table 2). Further, there is very little treatment needed for this water as it has generally low levels of contamination (See Appendix).

Table 2: Comparison of natural versus water utility energy input in storing pristine runoff

Process	***Energy Requirement (kWh/kL)***	
	Natural	***Water utility***
Evaporation	630	-
Lifting (500m)	1.4	-
Moving (10km)	0.12	-
Treatment	-	0.3*
Piping (30km)	-	3.6
Total	**631.52**	**3.9**
Percent of total	**99.4%**	**0.6%**

Notes: * based on Kenway *et al*. (2008). See Appendix.

However, there are several problems associated with supplementing existing water supply in this way:

1. There is a limit to the amount of water pristine runoff can provide. Future climate change is likely to affect the reliability and security of urban and rural water systems worldwide, and the anticipated impacts from climate change will pose significant challenges for maintaining adequate water supplies to meet these needs into the future. This is especially true for Australia, where

forecasts are for reduced rainfall, higher evaporation, lower streamflows and more frequent and prolonged droughts across various regions of the continent, in particular much of southern and eastern Australia (Hennessy et al., 2007).

2. As water is stored above ground in open reservoirs, high evaporation occurs over the exposed surface area resulting in large water losses.
3. Sedimentation occurs in dams depleting downstream nutrient levels and increasing the need for agricultural fertilisers (Stedman 2009b). This also reduces dam capacity.
4. Dams result in reduced downstream flows and blockage of migrant pathways resulting in adverse impacts on natural ecosystems.
5. Operating a ‘one dam system’ like Sydney and Melbourne potentially involves increased and significant climate risk. Diversified sources alleviate this risk and build resilience thereby reducing lengthy and severe restrictions during drought periods.
6. Dam building has become controversial with strong public opposition to new reservoir construction due to upstream flooding issues and concerns regarding environmental impact.

These barriers reduce the likelihood of significantly expanding surface storages and using surface runoff in order to augment Australia’s water resources into the future.

4.1.2 Groundwater sources

Australia has extensive groundwater stores (WQRA 2006) with the Great Artesian Basin, for example, underlying 23% of the continent and being one of the world’s largest aquifers (Herczeg 2008). Advantages of groundwater sources lie in their negligible direct evaporation and the low levels of water treatment required to potable standard. However, pumping costs associated with lifting water can consume significant energy (See Appendix) depending on the depth and natural pressure gradients within the aquifer. Groundwater extraction is currently widely employed in many areas of Australia with approximately 60% of the water supplied to Perth coming from groundwater (WQRA 2006).

Unfortunately, historic and current water extraction rates are at, or higher than, long-term sustainable extraction limits (Herczeg 2008) significantly straining these sources. Other problems associated with further developing groundwater sources in Australia include:

1. Large aquifer storages are required to procure the volumes needed to expand and maintain suitable volumes for increasing demand.
2. Energy is required to pump water (up to 0.48-0.53 kWh/kL) (see Appendix).
3. Groundwater resources are not well documented in most areas and the sustainability of the resource is not well understood. Uncertainty in surface-ground-water connectivity means recharge times are uncertain and the sustainable extraction rate of the system is difficult to assess.
4. Groundwater sources are easily contaminated by point-source and diffuse contamination sources and can be extremely difficult to remediate, therefore requiring stringent controls on aquifer maintenance and localised pollution sources.

4.1.3 Rainwater tanks

Household rainwater tanks are a traditional rural approach for collecting water but have been thought of as largely inappropriate for urban use (EnHealth Council 2005; Davis 2007). These are much more prevalent outside cities (35%) than within capital cities (12%) (ABS 2010) with 19-21 % of Australian households owning rainwater tanks (EnHealth Council 2005; ABS 2010).

In recent decades, there has been an increasing trend for implementing rainwater tanks in urban areas as state and federal government policies encourage their use (e.g. BASIX in NSW, Retamal *et al*. 2009) and water-sensitive urban design (Argue 2004) has focused attention towards onsite storage, onsite use and downstream flood mitigation (e.g. Argue 2004; UPRCT 2004; Landcom 2007). This decentralised approach reduces pumping costs and allows for relatively low operational energy inputs when using water for non-potable standard (see Appendix). However, for potable use treatment processes such as filtration and UV can be recommended (Lye 2009) adding significantly to the operational energy cost.

The general limitation to the use of rainwater tanks is associated with the concern that water supply authorities have negligible direct control over tank use and cannot rely on the tank water being available as needed by water planning. Additionally, these dispersed collection and treatment systems can be expensive to maintain (Davis 2007) and may become contaminated during collection or by particulate matter in urban areas (WQRA 2006; Hamdan 2009; Lye 2009).

Further Reading:

- EnHealth Council (2005) National Public Health Partnership 2004 Guidance on use of Rainwater Tanks, available at <http://enhealth.nphp.gov.au/council/pubs/pdf/rainwater_tanks.pdf>.
- Hallman M, Grant T, Nicholas A (2003) *Yarra Valley Water life Cycle Assessment and Life Cycle Costing of Water Tanks as a Supplement to Mains Water Supply*, Centre for Design at RMIT, available at <http://www.yvw.com.au/yvw/groups/public/documents/document/yvw1001682.pdf>.
- Marsden Jacob Associates (MJA) (2007) *The economics of rainwater tanks and alternative water supply options*, prepared for the Australian Conservation Foundation, nature Conservation Council (NSW) and Environment Victoria, April 2007.
- Retamal M, Glassmire J, Abeysuriya K, Turner A, White S (2009) *The water-energy nexus: investigation into the energy implications of household rainwater systems*, (prepared for CSIRO), Institute of Sustainable Futures, University of Technology, Sydney.

4.1.4 Urban runoff

Potentially, large volumes of water can be collected within areas with high urbanisation and in certain areas it is used as a non-potable source. Fletcher *et al.* (2008) and others (Brown and Ryan 2001; Rauch *et al* 2005; Queensland Water Commission 2008; Walker 2009) argue stormwater harvesting is a viable alternative water supply for Australia’s urban areas. The development of water-sensitive urban design (Argue 2004) has focused on reducing urban flooding whilst simultaneously reducing its degree of contamination. Although significant networks of urban stormwater structures have been constructed in Australian cities and towns over the past two decades, these are designed only for short term storage of runoff to maximize flood mitigation performance (NSW Government 2005, Appendix J4).

There are barriers when trying to capture, treat and distribute urban runoff, mainly a result of scale, quality and practicality. These include:

1. The nature of rainfall events create rapid inflows making storage and treatment very difficult (Davis 2007). Large storage tanks or reservoirs would be required to capture just a fraction of this runoff and stormwater storage could exacerbate flood risk in some coastal cities and low-lying cities and towns.
2. Urban runoff is highly contaminated with sediment and soluble contaminants (Commonwealth of Australia 2002; Austroads 2003; Davis 2007). It is estimated that contaminated stormwater causes up to half the pollution in surface and groundwater sources (WQRA 2006). Further, there is no control over contaminant levels in stormwater runoff pipes. Urban wetlands may reduce this contamination and promote aquifer storage and recovery (ASR) ponds (Davis 2007). However, stormwater sediment contamination within pond systems will lead to hyperconcentrated deposits that may be expensive to treat and dispose of, and to date studies on the remediation of these deposits are limited. In the absence of solutions to these significant contamination problems, high levels of energy usage are potentially required to adequately treat stormwater and transport it to suitable storage locations.
3. Current stormwater infrastructure is owned by multiple stakeholders making it difficult to coordinate effort to utilise this resource.

However, there are specific initiatives around Australia to develop urban runoff for water supply (for example see the Centre for water sensitive cities http://www.watersensitivecities.org.au/).

Further Reading:

- Commonwealth of Australia (2002) *Introduction to Urban Stormwater Management in Australia,* Prepared for Environment Australia, Department of the Environment and Heritage, Commonwealth of Australia, 2002.
- Fletcher TD, Deletic A, Mitchell VG, Hatt BE (2008) Reuse of urban runoff in Australia: a review of recent advances and remaining challenges, Journal of Environmental Quality, 5:S116-27.
- Hamdan SM (2009) A literature based study of stormwater harvesting as a new water resource, *Water Science and Technology*, 60(5):1327-39.
- Rauch W, Seggelke K, Brown R, Krebs P (2005) Integrated approaches in urban storm drainage: where do we stand? *Environmental Management,* 35(4):396-409.

4.1.5 Recycling

Recycling or treat and reuse schemes are less climate-dependent than surface water, but require higher operational energy costs associated with membrane technologies and pumping (ATSE 2004; Rodriguez *et al*. 2009). These systems close the water loop and transform the linear, segmented supply chain into an integrated water cycle; a strong move toward sustainability. There are a variety of applications for this water depending on treatment levels, approach and scale. Treating and reusing water can occur at a centralised or decentralised scale. Highly treated water can be used for watering lawns, in third pipeline networks, in industrial or agricultural reuse and direct or indirect potable reuse (ATSE 2004; Rodriguez *et al*. 2009). Australian recycling is currently very limited with Australian cities, on average, recycling around eight percent of their wastewater (ATSE 2004; MJA 2006). Most of this occurs in inland regional areas where the availability of low energy surface waters is scarce, the cost of wastewater disposal is high, and where there is likely an appropriate use for recycled water at a low energy cost.

Drawbacks from recycling systems are that they require a high-energy consumption – approximately 1 kWh/kL - to achieve drinking water quality. This is almost 20 times more energy than conventional water treatment from pristine sources (See Appendix). Furthermore, centralised indirect reuse schemes require pumping water great distances to allow treated water to dilute and be retained in environmental buffers, increasing energy requirements (MJA 2006; Rodriguez *et al*. 2009). Therefore, in the context of discussions of sustainability it is important to observe that water reuse may require higher operational energy. In addition, cross-connection between waste- and potable water pose health risks, if varying amounts of pathogens, pharmaceutical chemicals and other trace chemicals may be able to pass through the treatment and filtering process, potentially causing harm to humans (Rodriguez *et al*. 2009). There are limitations placed on potential reuse schemes from regulatory authorities such as the EPA and the Australian Drinking Water Quality Guidelines (ADWQ). When considering alternative supply options, these guidelines must be carefully adhered to, placing bureaucratic limitations on reuse schemes. Treat and reuse schemes generally have experienced opposition in Australia and struggle to gain community acceptance (Hurlimann and Dolnicar, 2010) although unplanned indirect potable reuse does exist in some areas.

Further Reading:

- Australian Academy of Technological Sciences and Engineering (ATSE) (2004) *Water Recycling in Australia*, May.
- Hurlimann A and Dolnicar S (2010) When public opposition defeats alternative water projects – The case of Toowoomba Australia, *Water Research*, 44(1):287-297
- Rodriguez C, Van Buynder P, Lugg R, Blair P, Devine B, Cook A, Weinstein P (2009) Indirect potable reuse: a sustainable water supply alternative, *International Journal of Environmental Research and Public Health*, 6(3):1174-209

4.1.6 Desalination

Desalination of seawater has distinct advantages as an alternative water supply for the following reasons:

1. A virtually limitless supply exists;
2. Desalination is a climate-independent solution;
3. Desalinated water can be injected directly into the main water distribution grid within close proximity to the treatment plant reducing pumping costs;
4. Ongoing research into lower-energy desalination technologies such as energy recovery exchangers has led to a significant drop in operational energy use with current reverse osmosis (RO) plants using just 20% of the energy used in first generation RO plants (National Water Commission, 2008); and
5. Public acceptance of this technology.

However, there are significant drawbacks; roughly 70 times more energy is required to desalinate water than conventional water treatment from pristine sources using reverse osmosis membranes and even with current advancements in energy recovery, over four times as much energy - 4 kWh/kL - is needed when compared to recycling schemes (see Appendix) (Crittenden *et al*. 2005; National Water Commission 2008). Where conditions are less advantageous, such as high salinity, operational requirements raise to 5-7.5 kWh/kL (California Coastal Commission 2004; National Water Commission 2008; Stedman 2009a). For example, Queensland’s Gold Coast desalination plant uses more than 5 kWh/kL (Queensland Water Commission 2008). Furthermore, the hyper-concentrated brine by-product may have adverse impacts on marine ecosystems if not handled appropriately (Davis 2007; National Water Commission 2008).

Further Reading:

- California Coastal Commission (2004) *Seawater Desalination and the California Coastal Act*, March 2004.
- National Water Commission (2008) Emerging trends in desalination: A review, Waterlines report, national Water Commission, Canberra.

4.2 Systems Management Approaches

The second approach to developing Australia's water resources is to manage existing water supply more efficiently. Six areas are identified where systems management approaches could play a role in improving water energy relationships:

a) Appropriate source and treatment;
b) Bulk water transport
c) Demand management;
d) Crisis management;
e) Soft approaches; and
f) Source separation.

4.2.1 Appropriate source and treatment

The recent paradigm in water supply is to treat all water to a potable standard, however, agriculture, commercial, industrial and residential water quality needs differ, so supplying the same level of potable water to all sources is potentially wasteful. A developing alternative approach is treat for purpose (Mitchell 2006; WQRA 2006) which uses less energy and yields consequent economic and environmental benefits. Most water that is 'used' does not need to be treated to potable standards and can be substituted with non-potable water. For example, substitution of potable with non-potable water in power stations cooling systems, mining operations and many other industries would save the treatment costs for that water. Furthermore, households could use different water qualities for different purposes (UPRCT, 2004, Practice Note 4, Table 3, with less than 2% being used for potable purposes). For example, washing clothes, gardening, and sewage removal do not require potable water. In 2007, more than 54% of Australian households reported using grey water as a source, most of which was used in the garden (ABS 2010). The volume of grey water used could be improved though third pipeline systems, greater decentralised reuse or potable water delivered in conjunction with other household delivery services. These would all result in significant reductions in the operational energy used to treat water but theymight require duplicate infrastructure or increases in embodied energy.

Further Reading:

- Mitchell VG (2006) Applying integrated urban water management concepts: a review of Australian experience, *Environmental Management*, 37(5):589-605.

Table 3: Summary of alternative water sources

	Water quality	Advantages	Disadvantages	Energy use	Adaptive capacity [1]	Current use	Future use
Storing pristine runoff	Pristine	Pristine, low energy water, large volumes	Ecological impact and capital cost of large dams, evaporation over exposed surface area	Low (minimal treatment)	Very low	Widely used (over 500 major dams)	Very few new dams can be built
Groundwater sources	Pristine, but generally not potable in urban areas	Negligible evaporation, large volumes	Large aquifers are required, they are easily contaminated, recharge uncertainty, overuse	Medium	Low	Widely used	Potential for storing water in aquifers for reuse (managed aquifer recharge)
Rainwater tanks	Pristine, but generally not potable in urban areas	Captures water onsite, no major infrastructure required	Decentralised systems are difficult to monitor and control	Very low for non-potable, increases significantly for treatment prior to consumption	Medium	Widely used (~20% of households) mostly in rural areas	Greater uptake in urban areas, readily adaptive in rural areas
Urban runoff	Mildly contaminated [2]	Large volumes can be collected from impervious urban areas	Contaminated water, energy use, storage issues, inconsistency of supply	Indeterminate	Low	Widely used as a supply of non-potable water, e.g. irrigation of parks	Growth in managed aquifer recharge, although potable potential debatable
Recycling & Reuse	Highly contaminated	Less climate dependent, closes the water loop	Public perception, energy use, consumption issues	High	Medium [3]	Widespread non-potable reuse, growth in indirect potable reuse	Potential for widespread use depending on public perception and energy consumption issues
Desalination	Saline water, highly contaminated	Climate independent, unlimited supply, public perception	High capital cost, energy use, disposal of hyper-concentrated brine byproduct	Very high	Medium [3]	Extensive growth in sector since 2006. Currently 6 major plants in use/development	Highly energy dependent

[1] Defined based on the ability to adapt to changing environments

[2] The use of urban runoff as a potable water source is controversial in the water sector mainly due to its level of contamination

[3] Will result in intermediate high energy use

4.2.2 Bulk water Transport

Bulk water transport involves the movement of large volumes of water great distances. This can be achieved through a variety of ways including, crude-oil carriers converted to water carriers, long distance pipelines or ‘water-bags’ floating on rivers or ocean currents. Some drought-affected regions in Australia have considered some of these options but analyses have discovered that the energy required for moving water vast distances is generally prohibitive (see Appendix). In the US, to pump water in a pipeline 500 km from the Colorado River to Los Angeles consumes around 1.6 - 2.4 kWh/kL (Dale 2003). In Queensland, bulk transport of water over 100 km consumes 1 kWh/kL (Queensland Water Commission 2008). Adding these costs to existing water treatment significantly increases the energy needed for water supply as well as the characteristic carbon footprint.

Further Reading:

- Dale L (2003) Electricity price and Southern California’s water supply options, *Resources, Conservation and Recycling*, 42(4):337-50.
- Edmonds (2009) Float water bags south for Murray: scientist, ABC News Online.
- Queensland Water Commission (2008) *South East Queensland Water Strategy*, Brisbane: Queensland Water Commission.

4.2.3 Demand Management

Demand management involves appropriate pricing of water to reduce overall demand growth and motivate improved efficiency of use and equipment operations. These measures contribute towards reducing the need for large infrastructure upgrades that increase water capacity required for population growth. In Australia there still remains great potential for implementing demand management such as full cost pricing, water efficiency labelling, loss reduction and private water trusts (Turner *et al*. 2005; MJA 2006). Even though installation of some examples of conservation devices such as water efficient showerheads and dual flush toilets has more than doubled from 1994 to 2007 (ABS 2010), there are still many water conservation devices which have yet to gain a foothold in the market. It would be appropriate to quantify operational energy embodied in water delivery and transfer this cost onto consumers through a variable pricing tariff. However, social welfare and equity issues may need to be considered (Barnett and O’Neill, 2010). The principle difficulty with demand management is community objections to the increased cost of a fundamental commodity.

Further Reading:

- Turner A., White S., Snelling C. (2005) End use and demand management training: a training package for the water industry, developed for Water Services Association of Australia, Institute for Sustainable Futures.

4.2.4 Crisis Management

Climate change is expected to increase the severity and duration of Australia’s flood and drought cycles (Garnaut 2008, page 133) creating the need for greater crisis management systems. In order to cope with these extreme events, water supply infrastructure and water sources need to be robust and resilient to these changes. One option involving built-in redundancy allows infrastructure to be operated in different ways during different extremes. For example, during relatively wet periods high-energy operating infrastructure could be reduced and replaced by low cost, low-energy solutions. Conversely, this high-energy infrastructure redundancy could be fully activated during prolonged drought periods.

Crisis management can also be used to find solutions for emergency water supplies which are increasingly being used in drought-affected areas. A sequence of management options that increase the cost of water as the drought deepens will potentially stimulate economic innovation and more rapid uptake of water saving technologies, thereby reducing overall use.. Issues associated with maintenance, reliability and efficiency (and economic viability) of an intermittently operated potable water supply will need to be carefully considered. For example, biofilm formation under stagnant conditions might lead to compromised water quality when systems are recommissioned.

4.2.5 Soft approaches

Soft approaches rely on carefully planned and managed centralised infrastructure but complement this with small-scale decentralised facilities and improvements in overall productivity (Gleick 2002; Gleick 2003). This decentralised approach moves water over much shorter distances, consuming less energy in pumping costs. This approach further applies economic tools such as markets and pricing, but with the goal of encouraging efficient use, equitable distribution of the resource, and sustainable system operation over time (Gleick 2002). The soft path for water also strives to improve the productivity of water use rather than seek endless sources of new supply (Gleick 2002; Gleick 2003). Many examples of water efficient technologies exist including waterless 'dry' toilets (www.ecosan.co.za); vacuum toilets (Envirovac, Inc.); reticulating showers (Quench showers); waterless dishwashers (Rockpool); and waterless clothes washing (www.xerosltd.com, Airwash and Naturewash). Reticulating showers in particular recycle both water and energy (heated water) and in doing so are a prime example for highlighting domestic water-energy synergies. However, consumer acceptance of these technologies and their associated cost and affordability need to be carefully examined.

Further Reading:

- Gleick PH (2002) Soft water paths, *Nature*, Vol. 418, pp.373
- Gleick PH (2003) Global freshwater resources: soft-path solutions for the 21st century, *Science*, Vol. 302, pp. 1524-27
- Peter-Varbanets M, Zurbrugg C, Swartz C, Pronk W (2009) Decentralized systems for potable water and the potential of membrane technology, *Water Resources*, 42(2):245-65.

4.2.6 Source Separation

Source separation of wastewater through waterless urinals, urine diversion, grey water and black water collection allows for recovery of energy through the production of biogas, nutrients and reduction of water use (Zeeman *et al.* 2008). Vacuum toilets with vacuum pipe collection systems use significantly less water per flush. This allows streams to be more concentrated and allows valuable nitrogen, potassium and phosphorus to be collected (Zeeman *et al.* 2008). Phosphorus in particular is a finite resource and is in high demand for agricultural fertilisers. Many of these systems are currently being trialled around the world. In Australia, a trial of urine separation toilets is underway involving 10 toilets installed in communities in the Currumbin Valley, near the Gold Coast (Leslie 2010).

Further Reading:

- Leslie G (2010) *Discussion Paper Theme 4: Sustainability – Life Cycle Assessment and Integrated Resource Management Strategies*, Australian Water Recycling Centre of Excellence.
- Zeeman G, Kujawa K, Mes T, Hernandez L, Graaff MD, Abu-Ghunmi L, Mels A, Meulman B, Temmink H, Buisman C, Lier J, Lettinga G (2008) Anaerobic treatment as a core technology for energy, nutrients and water recovery from source-separated domestic waste(water), *Water Science and Technology*, 57(8)1207-1212. doi:10.2166/wst.2008.101.

5 Embodied Energy

This paper focuses on operational energy or energy used over the life-cycle of water assets as opposed to embodied energy. This is because operational energy is likely to outweigh embodied energy in urban water services provision (Kenway *et al.* 2008), however, this may be contrary with decentralised systems where duplicate infrastructure is required. Specific life-cycle assessments need to be undertaken for urban water systems to adequately evaluate the full impacts of alternative water supplies (Kenway *et al*. 2008).

6 Final Comments

Two potential primary paths lie ahead for developing Australia's water resources in the context of assumed continued growth of Australia's population: high energy and low energy options.

Australia is a wealthy country with abundant fossil fuels and can potentially elect energy-intensive solutions that provide quicker financial returns and are arguably acceptable in the short-term. Present questions exist regarding their sustainability in terms of environmental degradation and availability of energy supply in the medium- to long-term. Proposed emissions reduction targets will require implementation of a decarbonisation of the energy sector and the economy in shorter timeframes. This raises specific questions regarding adoption of high-energy water supply solutions such as desalination.

Instead, we must acknowledge Australia's unique hydrology and use a combination of low energy approaches to reduce our water supplies overall impact on the environment. This will include, minimising evaporation, appropriate source and reuse, introducing greater water efficiency legislation, demand management, applying reuse with a keen eye on energy consumption, and importantly, a judicious use of present membrane technologies. Furthermore, we need to change the current paradigm in water sources; instead of a once-through system where water use equals wastewater production we need a holistic integrated approach with an adaptive management approach (see Pahl-Wostl 2007). Policy change may also be required so that authorities are not reimbursed on a basis of volumes treated/procured but rather water service provisions and efficiency achievements.

Such approaches will save both water and energy, reducing greenhouse gas emissions and transitioning towards more sustainable practice in our utilities. Decisions can now lock in more sustainable approaches whilst avoiding significant investment in energy inefficient technologies.

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Appendix

Energy use in water treatment plants

Energy use for water utilities varies significantly between treatment plants and different cities. This energy use variation is caused by a number of factors including (MJA 2006; Kenway *et al*. 2008):

- Plants
  - design flow rate
  - level of treatment
  - scale of plant
  - source of energy
- Location
  - type of water source
  - topography
  - distance and lift required in distribution systems

This variation between plants means that data on energy use is generally an average or a wide range. For example, Anderson *et al*. (2009) estimates Sydney Water uses approximately 2% of grid energy in NSW (not including the Kurnell desalination plant). Kenway *et al.* (2008) found after performing a high-level assessment that energy use by water and wastewater utilities in Australian capital cities comprised 0.2% of total energy use by urban systems in 2006/07. In the United States, data is more consistent, with water and wastewater utilities using approximately 2 - 5% of the nation's electricity, and energy accounting for more than 10% of the utilities total operating costs (Tchobanoglous *et al*. 2003; Carlson and Walburger 2007; King *et al*. 2008; Stedman 2009b). Of course, due to the uptake of high energy using processes in water and wastewater treatment, such as UV, ozone disinfection and membrane filtration, these energy figures are likely to increase (Carlson and Walburger 2007).

The energy consumption data for individual cities highlights that local circumstances and regulations have a significant impact on the energy use profile. Figure 3 provides an aggregation of data for Australian cities and Auckland broken down into the individual demands for energy. In Adelaide, Perth and Sydney, water supply required the highest energy input for 2006/07; in Melbourne and the Gold Coast, wastewater disposal used larger amounts of energy. Cities such as Adelaide and Perth use significantly more energy per customer than cities such as Melbourne and Auckland.

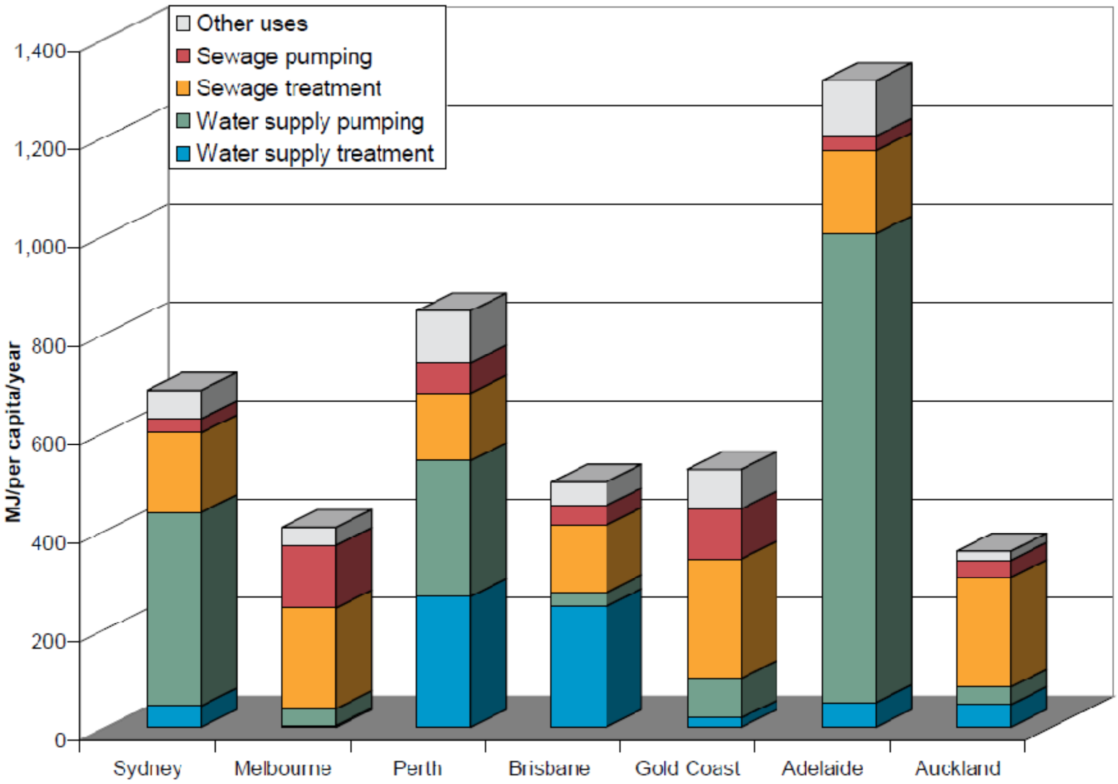

Figure 3: Energy use for water and wastewater services (2006/07) (Kenway *et al*. 2008)

Figure 4 provides an alternative perspective of the energy demands of each city. The high energy requirement for pumping for both Adelaide's and Sydney's water supplies and the relatively high energy use in tertiary wastewater treatment in Auckland and the Gold Coast are apparent. At the other end of the scale, Adelaide has particularly low energy requirements for wastewater pumping, while Sydney and Melbourne use very little energy for water treatment. Since these figures relate to the financial year 2006/07, they reflect the local circumstances during that period. These 2006/07 data indicate very clearly that pumping water is extremely energy-intensive.

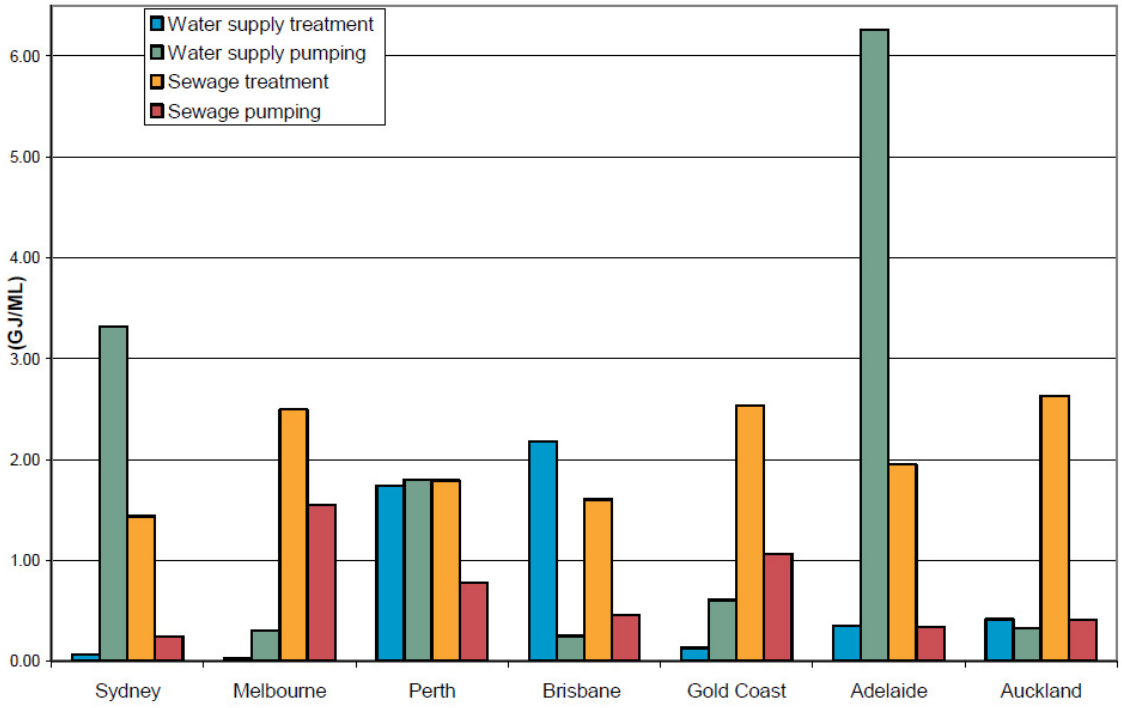

Figure 4: Energy use intensity of water and wastewater services by city (2006/07) (Kenway *et al*. 2008)

Figure 4 also shows the distribution between water and wastewater energy consumptions. In Sydney, Perth, Brisbane and Adelaide water supply consumes more energy than treatment. Conversely, Melbourne, Gold Coast and Auckland have much higher energy consumption for wastewater treatment.

Water treatment plants

Water treatment plants vary widely in total energy use. Figure 5 shows the distribution of US annual water utility electricity use. Water treatment plants energy requirements are usually characterised by their water source – ground or surface (Burton 1996; Carlson and Walburger 2007). This is because pumping often dominates water utility energy use (Figure 4). Burton (1996) found that ground water utilities use up to 99% of their energy for pumping whereas surface water utilities use up to 95% with the remaining for treatment processes.

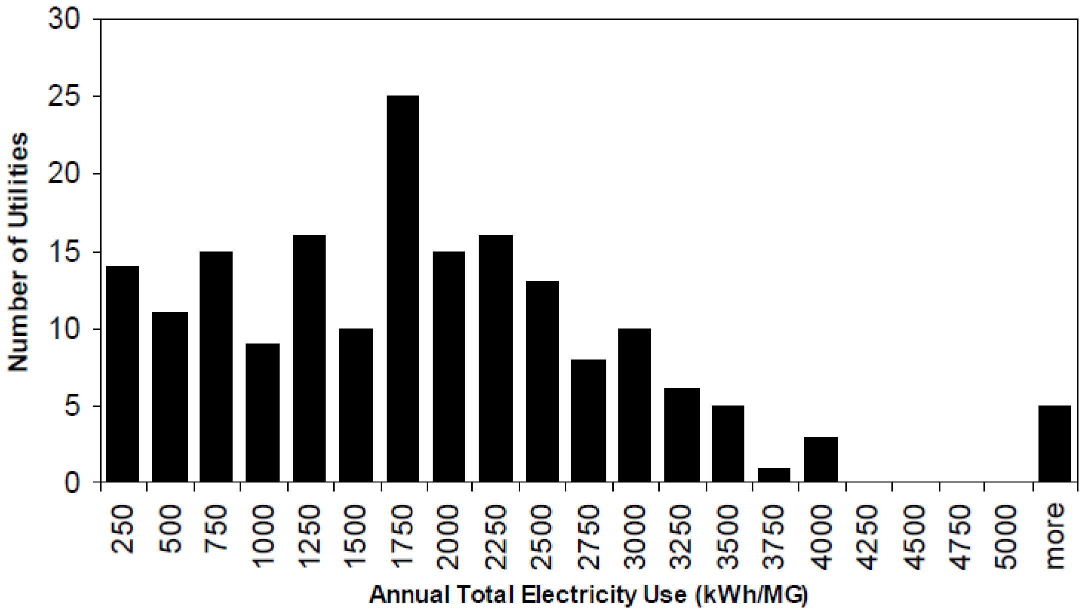

Figure 5: Annual water utility flow normalised energy use distribution (Carlson and Walburger 2007)

Marsh and Sharma (2007), King *et al*. (2008), Kenway *et al*. (2008) and others determined the energy requirements for water treatment options presented in Table 4. It is clear that as freshwater supplies become strained water sources once considered unusable, including brackish groundwater and seawater, are being exploited at higher operational energy cost. These solutions can require 10 - 12 times the energy use of standard drinking water treatment.

Table 4: Energy requirements for water treatment based on source

Source/treatment type	***Energy use (kWh/kL)***				
	King et al. 2008	***Marsh and Sharma 2007***	***Kenway et al. 2008 (Range)***	***Kenway et al. 2008 (Average)***	***Other(s)***
Conventional water treatment plant (Surface water)	0.4	0.4 – 0.6	0.1 – 0.5	0.3	0.08 – 1 # 0.02 *
Ground water (~120m deep)	0.48 - 0.53				
Pumping for conventional water			0.07 – 1.7	0.5	
Brackish Ground water	1.0 - 2.6	0.7 – 1.2			
RO on Wastewater (reuse)		0.8 – 1.0	1 – 1.5	1.2	1.2 – 2.1 *
Rainwater Tanks					1.5 ^
Pumping energy for desalination			1.0 – 2.0	1.5	
Bulk Water Transport (500 km)					1.6 – 2.4* 5.0``
RO on Seawater (desalination)	2.6 - 4.4	3.0 – 5.0	3.5 – 4.0	3.7	4.5 * 5-7.5^^

Notes: RO on treated wastewater for re-use does not include the energy for tertiary wastewater treatment; # (Carlson and Walburger 2007), * (Dale 2003), ^ (Retamal *et al*. 2009), `` (Queensland Water Commission 2008) ^^(California Coastal Commission 2004)

It is clear that although there is a large range in the data, as we move down the table energy requirements generally increase. In terms of operational energy we should aim to focus on processes which are higher on the table as these are less energy intensive. Desalination is clearly the most energy intensive process requiring 2.6–7.5 kWh/kL.

It should also be noted that retrofitting new technologies, such as UV disinfection and membrane filtration, into existing plants can also increase the energy requirements of the plant. Carlson and Walburger (2007) note the energy impact of new water treatment technologies which are presented in Table 5 along with associated economic cost.

Table 5: Energy impact of new water treatment technologies (Carlson and Walburger 2007)

Treatment Technology	Increase in energy required (kWh/kL)	***Est. cost ($/ML)***
UV Disinfection	0.19 - 0.26	38 - 52
Nanofiltration (Membranes)	0.476	95
Ultrafiltration (Membranes)	0.264	53
Low pressure microfiltration (Membranes)	0.026	5
Ozone	0.044	9

Note: Energy costs ~ $0.20 per kWh (Energy Australia 2010)