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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 mu

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 ergy

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)

4.1 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 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>.

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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 crea

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 desalination plant uses more than 5 kWh/kL (Queensland Water Commission 2008). Furthermore, the hyper-concentrated brin

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 -

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

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).

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

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Walker S (2009)

Appendix

Energy use in water treatment plants

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 fohig22d (et 9.596(8))i]n TJ tiaryu)$]er

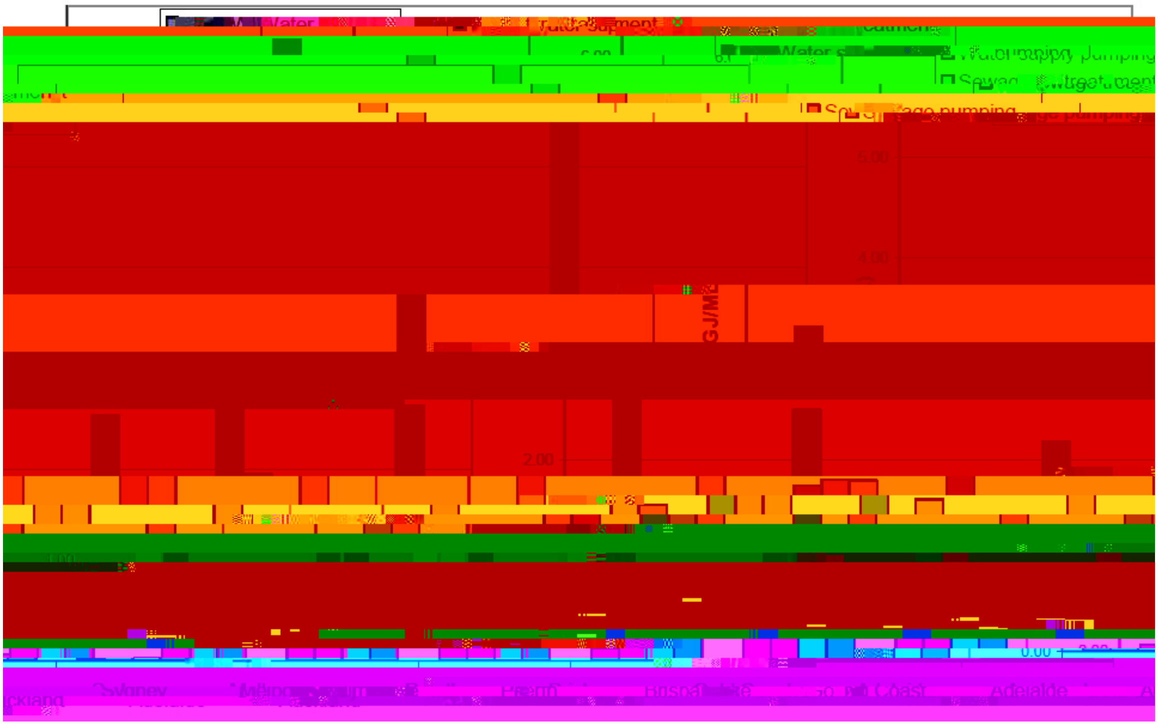

Figure 4: Energy use intensity of water and wastewater services by city (2006/07) (Kenway *et al*. 2008)

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 b

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)