Delivering an essential and sustainable water plan for Sydney, Australia

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ABSTRACT

The water supply for Sydney, which is the largest city in Australia, has been affected by variable climate patterns which include long periods of drought. Water resource needs for the future will be significantly affected by climate change and population growth. A ‘Water for Life’ equation has been adopted as a multi-faceted approach to achieving future, sustainable water security. The four parts of the equation are dams, recycling, water efficiency and desalination. Significant achievements have been made over the last 10 years which have allowed us to bolster the demand/supply balance by 50%. In the future, a portfolio approach will be used to select schemes for water supply security. Major factors considered will include construction and operational cost, volume of water saved or produced, public health and environmental risk, customer and community acceptance and political willpower.

Key words | dams, desalination, recycling, water efficiency

INTRODUCTION

We, as a water industry, face a huge challenge – to raise public awareness of the linkages between the supply of water, energy, environmental outcomes and the social and economic cost of each water resource option. Australia is at the vanguard of developments in water resource management. Our climate demands different solutions for water supply sustainability when compared to many other developed countries.

Our future water resource equation is affected by two major variable inputs, climate change and population growth. There are still many unknowns about how both these factors will affect the demand supply balance, the quality of the raw product to be treated and the reliability of supply.

Whilst a variety of water resource options are being used, the Australian agenda on water for urban areas has been heavily focussed on the pros and cons of desalination plants. Currently there are three major desalination plants operating with another four under construction. The good work that is happening in other areas, such as recycling and demand management, rarely receives the acknowledgement it deserves.

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SYDNEY’S APPROACH TO WATER RESOURCE MANAGEMENT – WATER FOR LIFE

Sydney is the largest city in Australia with a population of 4.4 million people and is located on the temperate east coast. The average annual rainfall is 868 mm, with a historical variation between 394 and 1,900 mm. Rainfall is quite variable with some droughts, such as our most recent, extending for 7 years. Average water demand is 1,400,000 m³/d total or 0.318 m³/person/day.

The city has a history of expanding its water resource capability when existing supply systems have been under severe threat. It began with a move from a small stream in the heart of Sydney, which quickly became polluted, to some swamps that were fed by a spring from an underground aquifer. This was then followed by the development of the Southern Dams in the early 1900s, Warragamba Dam in the 1960s and finally the Shoalhaven Scheme in the 1980s. More recently, recycled water systems and desalination have been the preferred water resource solution.
In each case the pivotal decisions to expand supply were not openly accepted by the whole community. But if one takes a retrospective view, the decisions were justified. For example if the Shoalhaven Scheme had not been available during our last drought, Sydney’s water supply would have been reduced to 12%, a level that would have caused extreme concern in the community.

Sydney Water, working with the state government and other utilities under a Metropolitan Water Plan, has developed a diversified approach to secure water supply to meet the needs of a growing population during future droughts. We have adopted a Water for Life equation which consists of a four-pronged approach to achieving a demand/supply balance.

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Water for Life = Dams + Recycling + Water Efficiency + Desalination
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Sydney’s water consumption has decreased from 0.416 m$^3$ per person per day in 1999 to 0.309 m$^3$ per person per day in 2010. This has been achieved by a combination of periods of both voluntary and regulated restrictions and the Water for Life approach. It is interesting to note that customers’ demand patterns have not reverted back to previous water usage levels after restrictions were eased 2 years ago.

The savings in demand from the regulated and non-regulated initiatives, other than restrictions, are shown in Figure 1. Whilst demand has decreased substantially, supply capability has increased by approximately 400,000 m$^3$/d. The Sydney Water approach has bolstered the demand/supply balance by approximately 50% in the last 10-year period.

**DAMS**

Our dams, which are some of the largest in the world, are still the mainstay of our water supply systems. Warragamba Dam is large, having a total capacity of 2,057,000,000 m$^3$. The other six main storages, which are closer to the coast, contribute a capacity of 328,000,000 m$^3$. Increasingly the dams are becoming more variable in terms of reliability. There is reasonably strong evidence that climate change is affecting the quantum of rainfall in the inland catchments compared to the coastal catchments. We have also experienced some unexpected water quality issues such as a blue-green algal bloom on Warragamba in 2007.

It costs approximately $0.74 per m$^3$ to purchase and treat drinking water in our main delivery system. However, this relatively cheap cost is based on depreciated assets that were installed in the early and mid-twentieth century; the people of Sydney are benefiting from investments made by previous generations.

The construction of new dams has been taken off the national agenda by environment and community acceptance concerns. Additionally strategic decision makers are tending towards water supply options with relatively short planning and construction timetables, thus delaying expenditure until adverse drought events arise.

**WATER RECYCLING**

Recycled water, including stormwater, is the potential supply option that is the most contentious within the community. Utilities are often maligned for not taking this option, but they can also be at odds with other sectors of the community if they move too quickly. Two indirect potable reuse schemes in the state of Queensland are examples of this dilemma. One, in the town of Toowoomba, was proposed but never built due to a ‘no’ vote in a local government referendum. Brisbane constructed and connected a high quality reuse scheme into its storage dams, but a change of political willpower has meant that the scheme has never been fully commissioned.
Non-potable reuse schemes are not as controversial and there appears to be general acceptance for a variety of different types of schemes within the community. Non-potable reuse schemes now account for 51 GL per annum of Sydney’s water supply. The degree of treatment for these schemes varies depending on the type of usage.

Most of Sydney’s inland wastewater treatment plants now supply effluent for a mixture of third pipe systems, agricultural or golf course irrigation, environmental flow replacement and industrial water. In Wollongong, a 20,000 m$^3$/d plant supplies Bluescope Steel and other surrounding industrial sites. At Rouse Hill, houses have a dual pipe reticulation system with recycled water being used for toilet flushing and outdoor watering. This type of system will be considered in new growth areas in the future but will only be adopted if it is shown to have a competitive long run marginal cost advantage or if there are environmental requirements that preclude other solutions. We have recently commissioned a 50,000 m$^3$/d plant at St Marys that will replace dam releases for environmental flows in the Nepean River. A 10,000 m$^3$/d plant is just about to come on line to supply industrial sites in the south-western suburbs of Sydney. A summary of the non-potable reuse schemes is shown in Table 1 below.

The water quality targets for recycled water schemes are very much dependent on the end-use. For example, golf course irrigation schemes have targets for faecal coliforms <10 CFU/100 mL, turbidity <2 NTU, TDS < 500 mg/L, TN < 50 mg/L, TP < 10 mg/L. The requirements for the industrial water for the Bluescope steel plant is much more stringent with targets for E. coli <1 org/100 mL, TDS < 85 mg/L, TN < 5 mg/L, TP < 1 mg/L.

The Bluescope Steel plant is typical of the double membrane systems and is designed with continuous microfiltration (CMF) with a flux of 0.052 m$^3$/hr/m$^2$ and reverse osmosis (RO) with an average flux across the skid of about 0.0175 m$^3$/hr/m$^2$.

Seeking additional reuse opportunities that are economically viable is now becoming more problematic. The major untapped resources for wastewater are from our deep ocean outfall systems. The major impediment is not the cost of treatment but rather the cost of piping and pumping to customers. This issue plus storage also limits stormwater harvesting.

**Rouse Hill dual reticulation system case study**

Rouse Hill Water Recycling Plant provides wastewater treatment and polishing of effluent for recycled water use to a growth centre in Sydney’s north-west. The plant presently provides services for 19,000 homes and this is predicted to increase to 35,000.

A dual reticulation system was constructed in the new development area in the late 1990s and was

<table>
<thead>
<tr>
<th>Recycled water scheme</th>
<th>Capacity m$^3$/d</th>
<th>Treatment processes</th>
<th>Recycled water usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rouse Hill</td>
<td>10,000</td>
<td>Tertiary wastewater, medium pressure UV, super chlorination</td>
<td>Dual reticulation toilets and outdoor use</td>
</tr>
<tr>
<td>Wollongong – Bluescope Steel</td>
<td>20,000</td>
<td>Tertiary wastewater, CMF, RO</td>
<td>Industrial water for steel plant</td>
</tr>
<tr>
<td>Wollongong – other</td>
<td>1,500</td>
<td>Tertiary wastewater, chlorination</td>
<td>Dust suppression</td>
</tr>
<tr>
<td>St Marys</td>
<td>50,000</td>
<td>Tertiary wastewater, CMF, RO</td>
<td>Replacement (environmental) flow to Nepean River</td>
</tr>
<tr>
<td>Camellia-Rosehil</td>
<td>10,000</td>
<td>Secondary wastewater, UF, RO</td>
<td>Industrial water to various supply points</td>
</tr>
<tr>
<td>5 off Wastewater treatment plants</td>
<td>1,500</td>
<td>Tertiary treatment</td>
<td>Golf course/sporting field irrigation</td>
</tr>
<tr>
<td>4 off Wastewater treatment plants</td>
<td>4,500</td>
<td>Tertiary/advanced tertiary treatment</td>
<td>Agricultural schemes – dairy, lucerne, etc.</td>
</tr>
<tr>
<td>All wastewater treatment plants</td>
<td>45,000</td>
<td>Various levels of treatment</td>
<td>Industrial water within each plant</td>
</tr>
</tbody>
</table>
commissioned in 2001. The scheme was initiated as a response to regulator requirements that severely restricted the discharge of any additional contaminant loads to the sensitive local waterways (De Rooy & Engelbrecht 2006). A detailed risk review was carried out prior to design and construction. It covered product liability, customer, financial, public health and environmental issues. A due diligence framework was developed to control ongoing actions both before and after plant commissioning. The primary control mechanism for risks is to treat the water to such a high standard that it will not cause harm if inadvertently consumed.

The process design for the treatment plant has twice been changed from the initial multi-barrier design which consisted of advanced tertiary wastewater treatment followed by ozonation, CMF, superchlorination and dechlorination (Fairbairn 2006). The ozone generator unit was problematic, causing excessive downtime for recycling. It was decommissioned in 2003, after the completion of a successful, Health Department sanctioned, 30-day proving period using CMF only.

The next major change was the introduction of an in-line medium pressure UV system as a substitute for CMF. UV is a more economic process in terms of long run costs, Craik et al. (2000) employed a neonatal mouse infectivity assay in a study of the inactivation of Cryptosporidium parvum oocysts in drinking water. They found that an inactivation of 2 log units could readily be achieved at UV dose of 10 mJ/cm² and 3 log units at 25 mJ/cm². Additionally, the US National Water Research Institute and American Water Works Association Research Foundation Disinfection Guidelines for Drinking Water and Water Reuse had been modified in 2000 to allow for filtered recycled water to be disinfected by UV only (NWRI & AWWARF 2000). Sydney Water worked with the University of New South Wales Centre for Water and Wastewater Technology to develop a challenge-testing programme to confirm these outcomes for the Rouse Hill process train (Storey et al. 2007). Pilot testing showed that the proposed medium pressure UV unit was capable of greater than 3 log reduction of both Cryptosporidium and E. coli. Following approval by the Health Department, the change to UV was implemented in 2007 and the plant has been operating successfully since that time using the process shown in Figure 2.

There are a number of major risks to be controlled in the ongoing operation of a dual reticulation system. The mitigation measures include:

- Optimisation of treatment processes to achieve the required microbiological log reductions. This relates not only to the UV system but also to the other parts of the water recycling plant. In particular the deep bed filters have to be operated to achieve low turbidities to enable the UV to function effectively.
- Inlet flow monitoring to ensure that sudden spikes of contaminants do not overwhelm treatment processes plus smoothing of flows to ensure consistency of operation.
- Plumbing controls and inspections to ensure that cross connections do not occur between potable systems and household recycle systems and that outside taps are correctly labelled. In the case of Rouse Hill, there have been four cross connections despite rigorous controls having been put in place to prevent this occurrence. Sydney Water has engaged in a targeted research programme to ascertain whether additives can be used in the recycled water system to enable cross connections
to be quickly identified by customers. Anti-ingestant agents were eliminated on the basis of either cost, chlorine demand, malodour or variable detection range. Colourants tested were found to fail due to chlorine oxidation or staining. Early warning contaminant monitoring systems are limited by cost considerations. Effective instruments are available but it is too expensive to distribute them throughout the recycled water system.

- An ongoing customer programme to ensure that changing population movements within the area are aware of the uses allowed for recycled water. There is also an ongoing concern with the possibility of the home handyman causing a cross connection.

**WATER EFFICIENCY**

Water efficiency measures are delivering savings of approximately 24% of Sydney’s water needs. Three main areas of water usage have been, and will continue to be targeted. These are:

- A reduction in domestic usage by programmes to introduce water saving devices for showerheads, tap flow regulators and toilets (dual flush or toilet cistern arrestors for single flush), encouragement of whitegood suppliers to provide four star rated appliances, a Love Your Garden Program and rainwater tanks.
- A reduction in industrial and commercial usage by our Every Drop Counts Business Program. We work one on one with businesses to identify how they can cost effectively reduce water consumption in their manufacturing or commercial processes. The programme has actively demonstrated to many businesses that they can still meet their requirements by using less water at a reduced total production cost.
- A reduction in system leakage. Sydney Water has an A1 ranking for leakage based on the World Bank International Leakage Index which factors in length and age of pipes and nature of soil in different locations. We currently use acoustic techniques to check 18,000 km of pipes per year, this is almost equivalent to our installed stock of water pipes. Minimum night flows are also monitored to determine at risk systems. We have also been implementing a pressure management programme in 45 zones to reduce those areas that have a head higher than 65 m. This programme reduces both leaks and pipe breaks in these zones.

The water efficiency measures and recycled water initiatives are forecast to achieve savings of more than 128,000,000 m³ in the 2010–2011 financial year. Savings from the main programmes are shown in Table 2 below.

**DESALINATION**

The fourth part of our approach to water supply is desalination. The sea is an almost infinite water resource but the supply of water from this resource has created a great deal of public debate, due to the cost and environmental impacts of the treatment processes. In our case the choice of desalination rather than recycling was based on a considered comparison of risks, costs, social and environmental acceptability and time to implement.

The plant, which has now been successfully operating for one and a half years, has a capacity of 250,000 m³/d and is capable of supplying 15% of the city’s average day demand. The inlet and outlet pipework has been constructed for a capacity of 500,000 m³/d. The plant’s energy usage is fully offset by renewable energy from a wind farm near Canberra.

Some of the key aspects for the development of the plant included:

- A rigorous planning and feasibility study covering technical, environmental, energy, economic and project delivery considerations (Roddy & Port 2009, 2011).

**Table 2** | Forecast total water savings 2010–2011 (Sydney Water 2010)

<table>
<thead>
<tr>
<th>Programme</th>
<th>Savings m³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>15,825,000</td>
</tr>
<tr>
<td>Business</td>
<td>25,846,000</td>
</tr>
<tr>
<td>Schools programme</td>
<td>501,000</td>
</tr>
<tr>
<td>Leak reduction</td>
<td>31,518,000</td>
</tr>
<tr>
<td>Regulatory measures</td>
<td>37,642,000</td>
</tr>
<tr>
<td>Pilot R&amp;D</td>
<td>653,000</td>
</tr>
<tr>
<td>Recycled water</td>
<td>14,422,000</td>
</tr>
<tr>
<td>Total</td>
<td>128,233,000</td>
</tr>
</tbody>
</table>
An extensive marine and estuarine monitoring programme that is continuing into the operating phase (Trousdale et al. 2009). Extensive hydrodynamic and oceanographic modelling enabled the intake and the concentrate outlet discharges to be located relatively close to the coastal shoreline. The inlet is located in a relatively high-energy rocky reef zone so that the risk of entrainment of sand into the inlet tunnel is minimised. The ocean returns to normal salt and temperature levels within 50–75 m of the outlets. Marine monitoring has shown it does not impact on fish or marine life outside this zone.

An advanced blueprint concept design based on pre-design and pilot testing (Rapenne et al. 2007). The pilot testing compared the performance of granular media filtration with ultrafiltration (UF) for pre-treatment. The performance was assessed by monitoring fouling potential using Silt Density Index (SDI) measurements and microorganism content using flow cytometry. The granular media filters, which were selected, were more consistent in terms of SDI and also removed more total organic carbon but were not quite as good as UF for microorganism removal. The pilot testing also showed that a second filtration stage was not required, flocculation provided no benefit and that the filtration rate could be increased by 25%.

Design with 6% excess capacity to provide for necessary maintenance and downtime.

Design of the main RO process train to maximise energy recovery by utilisation of Dual Work Exchanger Energy Recovery units which have a recovery efficiency of about 97%. As seawater passes through the first pass membranes at high pressure, most of the pressure remains in the brine stream. This pressurised brine is used to pump part of the seawater feed to the train avoiding waste of that energy. Additionally a split of the high quality first pass permeate has been incorporated into the design to allow some permeate to bypass the second RO pass. The modular design of the plant mitigates against component failure.

Matching final water quality parameters such as alkalinity and chloramine residual so that the water could not be distinguished from water supplied from our other sources.

A procurement model for the plant and its associated inlet infrastructure, which was covered by a Design-Construct/Operate-Maintain contract. The 18 km delivery main, which includes above ground pipelines, tunnels through urban areas and a large segment laid in a trench on the bottom of Botany Bay, was carried out by a separate Alliance contract. There were three energy contracts, one for the wind farm, one for the electrical supply agreement and another for the supply of renewable energy certificates.

The commissioning of the plant has been relatively trouble free and it is now a key part of our water system. Under a Sydney’s Metropolitan Water Plan it will be taken off-line when dam storages are above 80% capacity and will go back on-line under full production when storages fall below 70%.

COMMERCIAL CONSIDERATIONS

A range of factors needs to be considered before selecting preferred solutions for improving the demand supply balance. This selection process is like a portfolio approach where a number of schemes and programmes are chosen to balance supply and demand with the choice dependent on factors like cost, reliability and volume produced or saved. Some factors are applicable to a whole of utility approach whilst others are relevant for discrete areas such as new developments. The major factors are:

- The cost of design, construction and ongoing operation and maintenance of a scheme. For Sydney, the comparative costs of options are shown in Table 3.
- The volume of water saved or produced.
- Public health risk.
- Environmental risk.

Table 3 | Comparative costs of supply and demand options

<table>
<thead>
<tr>
<th>Supply/demand option</th>
<th>Cost $ per m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dams (regulated value)</td>
<td>0.74</td>
</tr>
<tr>
<td>Dams (replacement value)</td>
<td>1.32</td>
</tr>
<tr>
<td>Desalination Stage 1</td>
<td>2.24</td>
</tr>
<tr>
<td>Desalination Stage 2</td>
<td>1.99</td>
</tr>
<tr>
<td>Recycled water (industrial)</td>
<td>1.00–4.00</td>
</tr>
<tr>
<td>Recycled water (residential)</td>
<td>4.00–6.00</td>
</tr>
<tr>
<td>Rainwater tanks</td>
<td>≥5.00</td>
</tr>
<tr>
<td>Water efficiency</td>
<td>1.50–3.50</td>
</tr>
</tbody>
</table>
Customer and community acceptance.
Political willpower.
Regulation.

Although dams are the cheapest option they are unlikely to be used in the near future due to environmental concerns and the time taken to implement this type of water security measure (5–10 years). Comparatively desalination plants can be designed and built within 2–3 years. Industrial recycle water schemes are very dependent on having final users close by the wastewater source and residential recycle schemes are hindered by dual pipe systems needs. Water efficiency should be carefully costed as compared to other initiatives, e.g. the length of mains for which leakage reduction is conducted in Sydney is based on calculations of an economic level of leakage.

THE FUTURE

Sydney Water will continue to pursue a diversified set of water resource demand/supply opportunities consistent with the Water for Life equation in the future (Hetherington 2011).

There are however some critical emerging issues which will affect future decision making. The main issues on the horizon are:

1. Growth – Sydney’s population is expected to grow from 4.6 million in 2006 to 6 million by 2036 (New South Wales Department of Planning 2008 Release). The majority of growth, up to 60–70%, is expected to be infill. So there will be many challenges with the capacity and capability of existing infrastructure. New opportunities to restrict water demand are developing. A number of five and six star rated buildings have been or are being constructed. These buildings have their own in-built wastewater/stormwater recycling systems, which reduce demand for potable water and reduce effluent requirements for the sewerage systems. There are still debates occurring about how such systems will be operated to meet health and environmental requirements. A Water Industry Competition Act also provides opportunities for the private sector to introduce new recycling schemes from sewer mining and other sources.

2. Climate change – data show some indications of changes in temperatures, evaporation rates and rainfall patterns. For example between 1950 and 2005 average annual mean temperatures in Sydney have increased by approximately 1 °C. The inland storages receive less inflow when compared to coastal storages. Average annual dam inflows for the period 1949 to 1990 were over 300% higher than for the period 1990 to 2006. Droughts are also introducing new water quality issues to be dealt with, such as blue-green algal blooms.

3. Acceptability of indirect potable reuse – many large cities in Europe and the USA have indirect potable reuse as their major water resource. Usually it is water withdrawn from a river system downstream from wastewater treatment plant discharges. The water is treated to contemporary standards that meet customers’ requirements for both health and aesthetics. The query for Australia in the future is not so much one of whether we can do it from a technological perspective but whether or not we can move public sentiment to overcome the ‘yuck’ factor.

4. Energy – increasingly decisions about the viability of water resource options are integrally linked to the provision of energy. The linkage has ramifications from economic and environmental perspectives. The energy market place is undergoing rapid change with increasing costs, energy trading commodities, schemes for carbon pollution reduction and alternative power supply sources. Water supply solutions such as desalination and recycling are usually power hungry. The cost of energy provision will therefore be a major factor.

Sydney now has a stable supply of water to meet its needs in the medium term future. Continued use and adaptation of the diversified supply/demand initiatives in Water for Life strategy will allow the city’s longer term future needs to be met.

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