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Desalination and water reuse—sustainably drought proofing Australia

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ABSTRACT

Desalination has simply been too expensive for major application in Australia and the world, but rising costs of developing our remaining water resources (partly due to climate change), coupled with a growing demand for water supplies of varying quality for domestic, mining and industrial purposes, are making us look more closely at the rapidly developing desalination technologies. Water agencies in Australia have increasingly become involved in desalination initiatives. This has led to a greater understanding of desalination technologies, specifically seawater reverse osmosis (SWRO) and brackish water reverse osmosis (BWRO) and their consequent use as water supply options for industrial, mining and municipal purposes. A comparison of the basic features of the Australian market, the rapid adoption of the technology, the costs, the technology variations and its expected future to the rest of the world markets will be undertaken. Arguments in relation to the sustainability of Australia's SWRO plants and SWRO in general are presented. The paper will argue why SWRO is one of the most sustainable water sources in Australia and the world, replacing conventional sources for future development. This paper will touch on financing, contracting, design, operational and environmental characteristics related to SWRO and demonstrate why Australia's projects are leading the world in terms of sustainable desalination. Australia's six major seawater desalination plants, "The Big Six" will be discussed. New technologies and other forms of desalination and their applications, such as the growth of BWRO desalination in the coal seam gas extraction industry and SWRO in mining will be mentioned. Future developments in desalination will be discussed. The general status of world desalination will be presented.

Keywords: Australia; Desalination; Seawater concentrate management; Energy use; Ecological footprint; Sustainable water source; Triple bottom line

1. Introduction

In the face of the driest winter on record, the Perth Seawater Desalination Plant (PSDP) commenced delivering an annual capacity of 45 million m^3 of much needed drinking water into the Integrated Water Supply Scheme (IWSS) in November 2006.

The PSDP, located at Kwinana, 31 km south of Perth, Western Australia, has been heralded as a landmark in the development of the Australian water industry. It is a strong and worthy contender to be regarded as a world-leading model for future sustainable seawater desalination plants globally. At a peak capacity of 144 MLD, the AU$387 million plant (which includes AU$63 million of integration assets), is the largest operating seawater desalination plant outside of the Middle East, and Australia's first large-scale desalination facility for public water consumption.

The PSDP was the largest seawater desalination plant in the southern and eastern hemispheres and

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maintained this status into until the Sydney plant is commissioned in early 2011. At full capacity, it is the biggest single water source feeding into the IWSS, providing some 17% of Perth's water needs.

An 82 MW wind farm supplies over 272 GWh of energy per year to Perth's electricity grid. The PSDP consumes 185 GWh of energy per year from the grid making it the world largest desalination plant using renewable energy. Coupling this energy source with the low specific energy consumption achieved from the plants novel design, incorporating isobaric energy recovery devices (ERDs) (PX) from ®ERI, ensures that it is the world's most energy conscious plant.

Considering the plants partial two pass system which produces a permeate at less than 100 mg l^{-1} TDS, from a feedwater salinity of 35,000 mg l^{-1}, the achievement of a specific energy consumption of less than 3.6 kWh m^{-3} is remarkable.

Other unique aspects of the plant include the partial second pass which has been included to ensure a bromide content of less than 0.1 mg l^{-1} in the product water and Degremont's proprietary Densadeg sludge thicker to ensure dewatered sludge can be safely transported and disposed of to landfill. Although inert and the fact that PSDP is located along an industrial zone, Water Corporation committed to prohibit the return of ferric sulphate sludge to the ocean to ensure that there were no aesthetic impacts on the white sandy coastline.

Further, in order to meet the strict environmental conditions, the seawater concentrate is returned 470 m into the ocean via a 40-port diffuser, with nozzles spaced at 5 m intervals, to ensure total mixing of seawater concentrate within 50 m of each side of the last 200 m of pipeline. Therefore, the discharge is effectively no different from the naturally occurring seawater in terms of its salinity and meets the Environmental Protection Authority (EPA)'s stringent criteria. Extensive real-time monitoring in Cockburn Sound will continue together with annual marine habitat mapping to ensure long term impacts of the project continue to be managed.

The additional cost for the average residential customer is AU$36 per annum, less than AU$0.63 per week, as stated by the (then) Premier of Western Australia on announcement of the project in July 2004 has come to fruition as originally estimated.

Taking all the above factors into account and considering the plants small physical footprint (on land and in the sea), this plant is one of the most sustainable water sources in Australia, and the only water source in Australia that wholly caters for the triple bottom line, economic, social and environmental factors. All other sources only cater for the double bottom line, economic and social factors.

2. Concentrate discharge

The PSDP treatment line includes a full backwash water facility based on clarification/thickening and sludge dewatering using centrifugation. The clarified backwash water is mixed with the (RO) brine before discharge. The brine discharge was subject to a specific design, based on a scale model testing study.

To ensure that the environment is protected, a series of marine monitoring studies were commissioned prior to and as part of the environmental approvals. These included; Whole Effluent Toxicity testing on simulated brine and actual seawater concentrate at commissioning and 12 mo after commissioning, sediment oxygen demand tests, international literature review of dissolved oxygen levels, ecological investigations, cause effect models, and an intensive baseline investigation commissioned to document water quality and macrobenthic fauna present prior to operations.

Before and during operations a real time monitoring system, located at three points within Cockburn Sound feeds data back to the plant constantly. At 1 min intervals, temperature and conductivity is being recorded at 1–2 m intervals through the water column, and dissolved oxygen is recorded at the bottom of each monitoring buoy and at mid-depth. Management responses have been agreed with the regulator in the event agreed trigger levels are reached.

Baseline water quality monitoring and testing in the discharge area as discussed above was undertaken many months before plant commissioning. This baseline monitoring included the following parameters:

- light intensity
- salinity depth profile
- temperature depth profile
- dissolved oxygen depth profile
- turbidity
- Secchi depth
- nutrients concentration (phosphorus, nitrogen, ammonium, nitrates and nitrites)
- metals
- phytoplankton

Western Australia's environmental regulator, the EPA set strict criteria for the concentrate discharge, requiring the salinity within 50 m of the discharge point to be within 1.2 ppt of background levels. By the time the discharge is 1 km offshore, salinity must be within 0.8 ppt of background levels. Extensive modelling revealed that salinity represents the most constraining water quality parameter.

The plant's true environmental standing was confirmed by field campaigns which, included tracing an environmentally benign dye added to the plant discharge, which showed that the desalination discharge rapidly mixes with the surrounding waters. Stratification in the sound is mostly drive through temperature, not salinity gradients.

As the plant is fully automated specific care has been taken in relation to instrumentation to ensure reliable and safe operation of the plant. Analytical panels assess information from sensors installed at the intake, pre-treatment, first pass RO feed second pass RO and potable water systems. These incorporate hydrocarbon monitors, turbidity meters, pH meters, ORP, on-line SDI, conductivity and temperature as required. Residual chlorine and fluoride are also monitored for the drinking water. Parameters such as dissolved oxygen and ORP are also monitored in the discharge water back to the sea to ensure that strict environmental guidelines are adhered to.

3. Major environmental issues

3.1. Energy

Desalination is an energy intensive process. RO requires significantly less energy than that of thermal distillation. The energy often comes from fossil fuels, so as well as the expense, there is the disadvantage of CO_2 emissions. Critics say desalination could worsen climate change, by adding to greenhouse gases, and contribute to water shortage. Ironically it is what will solve water shortage.

As SWRO technology improves, energy inputs and hence CO_2 emissions will decline, particularly in relation to large-scale desalination plants. The use of RO membrane technology (essentially filtering water through a membrane under pressure) rather than distillation (boiling and condensation) lessens the energy requirement because the water does not need to change state from liquid to vapour.

High energy use and consequent high greenhouse gas emissions are an aspect of desalination that needs to be addressed from an environmental perspective. A plant similar to Perth's, even with ERD connected, will consume about 24 MW of electricity to produce about 45 million m^3 of water per year. This represents about 185 GWh y^{-1} (which is 21.1 MW average) of energy per year which equals the amount of electricity needed by about 30,000 households. The opportunity to use renewable energy arose for PSDP and this plants energy is supplemented with energy injected into the grid from a new wind farm constructed north of the city.

Proposing offsets such as carbon offsets (tree planting) can be expensive and can lock up water reserves if not planted in carefully chosen locations (e.g., catchment thinning proposals). The nuclear energy debate and solar-thermal technologies in Australia continue to develop. However, as the ongoing need for large-scale water sources increase, energy sources will continue to be key part of the desalination equation, and must be thought through carefully during planning.

To put it into perspective, the energy required to permanently produce 80% of Perth's water supply, that is, enough water for over 1,360,000 people and their homes and gardens, is about the energy the Queen Mary II sailing continuously (satisfying 3000 passengers in luxury) would consume. The QM II has a power output/requirement of 118 MW as opposed to 21 MW of power required for PSDP.

3.2. Backwash material

The PSDP discharge products that have been carefully managed include; the seawater intake screen washings, clarified backwash effluent from the media filtration plant, RO plant seawater concentrate stream, neutralised RO plant chemical clean wastewater and RO plant flushing water.

The PSDP has been engineered to ensure that backwash materials (solids) are disposed to landfill. This decision was made due to the presence of ferric sulphate and poly DADMAC (an organic coagulant) added to coagulate particulate and colloidal material from the influent seawater, and concerns about possible discolouration of the white sandy beaches, should this backwash be discharged at sea. Solid wastes from the intake screens, media filters and lime system are captured in the wastewater treatment clarifier. The sludge from the clarifier is dewatered by centrifugation to a spadeable cake for disposal to landfill. Offsite environmental management considerations include the salt content of the sludge; the quantity of the sludge; and handling quality of the sludge.

3.3. Seawater concentrate discharge

In order to meet the strict environmental conditions, the seawater concentrate is returned 514 yards into the ocean via a 40-port diffuser, at a velocity of 4 m s^{-1} through nozzles spaced at 5 m intervals, to ensure total mixing of seawater concentrate within 50 m of each side of the last 200 m of pipeline. This has proved to be highly affective and there are no issues in relation to concentrate discharge.

4. Footprint

The PSDP is functionally laid out in an area of 6.5 ha which can be regarded as its terrestrial footprint. Extensive computer modelling supported by a die test, as previously discussed, suggests that the diffuser with its 40 nozzles spaced at 5 m intervals will ensure that the returning seawater concentrate is effectively mixed within an area of less than 2.5 ha. It can then be argued that the spatial area of influence attributed to the plant on land and sea is only 9 ha.

However to ensure that the total environmental effect of the plant is considered, we have to take into account the area attributed to the wind farm. The wind farm that has been constructed to inject the 185 GWh y^{-1} into the grid at Badgingarra, 200 km north of Perth and covers an area of 46 km^2, so with two thirds of its energy earmarked for the PSDP the terrestrial area attributed to power generation is 31 km^2. This area is still actively farmed as the only impact is the base of the 36 turbines (48 in total) which cannot be used for grazing. You will however find the farmers herds in lines in the shade of the turbines during the heat of the day.

Should we compare this plant to Perth's largest surface water supply source namely, Serpentine Dam, which when constructed in 1961 had an assured yield of 45 million m^3 y at 98% reliability. This dam has a catchment area of some 660 km^2 which cannot be used for any other land use. It is now mostly a dry dam basin of 1066 ha. There are no fish ladders and no in-stream flow releases. Since 1961 the reservoirs yield has been de-rated on three occasions and the assured yield in 2005 was 14 million m^3 y^{-1} at 98% reliability. In 2006 the reservoirs yield plummeted to 5 million m^3 y^{-1}, almost a tenth of the PSDP yield at 100% reliability.

We can now also argue that Serpentine Dam and many other Western Australian and Australian dams have had other environmental impacts. In most cases fish ladders have not been provided to allow for migration of fish, inadequate or no in-stream flows occur which definitely has an affect on river ecology, both upstream, downstream and in estuaries. Further, there is an impoundment of silt, contaminants and nutrients within the dam basin which once again affects river ecology upstream and downstream.

There is also the physical scar of the dam structure and the associated greenhouse gasses and carbon emissions that occurred during construction. When the total mass balance of all the environmental impacts are accounted for, a dam can have a massive environmental footprint.

It does not take much scientific deduction to work out which source has the largest environmental footprint. The one positive for the surface water source is that it has protected 660 km^2 of re-growth native forest, had it been old growth forest this would have been prized.

The bottom line is that the cost of water from the PSDP is the true **triple bottom line** cost of water as all the environmental, social and economic aspects have been inserted into the equation.

5. Existing and future Australian SWRO plants

5.1. Western Australia

1. Perth Seawater Desalination Plant (PSDP) 144 MLD (2006) – 2007 GWI Winner
2. Southern Seawater Desalination Plant I (SSDP) 150 MLD (Completed)
3. Southern Seawater Desalination Plant II (SSDP) 150 MLD (Under Construction)
4. Cape Preston (WA) CP Mining 140 MLD (Construction commenced 2009)
5. Future Plant North of Perth up to 150 + MLD (Future)
6. Future West Pilbara Desalination Plant possible up to 40 MLD (Long Term Future)
7. Southern Ocean (Esperance) for Kalgoorlie up to 40 MLD (Future)
8. Albany SWRO Plant up to 40 MLD (Future)
9. Cape Lambert MCC mining, Pilbara, Western Australia, 120 MLD (2012)
10. Barrow Island, Gorgon LNG, WA, 5 MLD (Current)
11. Okajee SWRO up to 40 MLD (Future)
12. Southdown Magnetite Mine, Grange Resources 33 MLD at planning stage (2011)

5.2. Victoria

13. Wanthaggi 1 up to 450 MLD being bid (Under Construction)
14. Wanthaggi 2 up additional 150 MLD being planned (Future)

5.3. New South Wales

15. Kurnell 1–250 MLD completed - 2011 GWI Winner
16. Kurnell 2–250 MLD to be constructed in future
17. Gosford-Wyong, up to 50 MLD, future potential

5.4. Queensland

18. Gold Coast Desalination Plant – 133 MLD completed (2009) – 2009 GWI Winner
19. North of Brisbane up to 400 MLD (Long Term Future)
20. Agnes Water 5 MLD complete

5.5. South Australia

21. Adelaide Plant 1–150 MLD under construction
22. Adelaide Plant 2–150 MLD under construction
23. Olympic Dam (BHP) 200 MLD at planning stage (2012)

A brief review of some of the desalination plants Australia follows and includes major seawater plants, brackish water and wastewater reuse.

6. Western Australia

The PSDP, as per description above (refer to Fig. 1). This plant was the winner of the GWI World Membrane Desalination Plant of the Year 2007. The success of PSDP has led to the Water Corporation constructing a second plant. The SSDP with a capacity of 150 MLD (refer to Fig. 2) has recently been constructed on an open ocean site south of Perth, just north of Bunbury by Spanish consortium, Technicas Reunidas S.A/Valoriza Agua. The plant is currently being duplicated. Similar to the Kwinana plant, it will be powered by energy from renewable sources. A third plant north of Perth is envisaged in the future.

CITIC Pacific Sino Iron operations, at Karratha in the Pilbara, will be one the world's largest mines. To supply both the mine and township a consortium led by IDE is building a 140 MLD plant in stages at Cape Preston. The first stage is expected to be delivering water in 2012.

Fig. 1. Perth seawater desalination plant.

Fig. 2. Southern seawater desalination plant.

Fig. 3. Gold coast desalination plant.

7. Queensland

Desalination is a key component of both the Gold Coast Waterfuture Strategy and the Southeast Queensland Regional Drought Strategy Contingency Supply Plan. The plant at Tugun, close to the Gold Coast Airport has been completed and produces 125 MLD. A 25 km pipeline delivers the water to the Water Grid, SE Queensland's bulk water supply network. The plant was built by the Gold Coast Alliance, a Veolia-John Holland Joint Venture, in alliance with Gold Coast Water and the State Government. The plant will be operated for 10 y by Veolia in alliance with the Gold Coast Water and the State Government. This plant was the winner of the GWI World Membrane Desalination Plant of the Year 2009.

8. New South Wales

Sydney Water has built one of the world's largest RO desalination plants. All ancillary components are sized to provide capacity for 500 MLD of water, that is, about

Fig. 4. Sydney desalination plant.

a third of Sydney's drinking water needs. The site is the Kurnell Peninsula, south of Botany Bay, which already hosts an oil refinery. The first 250 MLD stage was completed in 2010 and includes a 15 km pipeline under Botany Bay. The total cost was approximately $2 billion and. The Blue Water Joint Venture, consisting of John Holland Group Pty Ltd and Veolia Water, designed and built the plant and Veolia Water operates and maintains the plant. The plant is owned by Sydney Water. Sydney Water, in a similar model to Water Corporation of Western Australia will purchase renewable energy from a wind farm, equivalent to the energy consumed in the plant resulting in no net greenhouse gas emissions as a result of operation. This plant was the winner of the GWI World Membrane Desalination Plant of the Year 2011.

9. Victoria

The State Government committed to building a 450 MLD desalination plant to ensure reliable supplies for southern Victoria. The site is near Wonthaggi, Gippsland, with intakes and saline outfalls into Bass Strait, rather than into the Port Phillip or Westernport Bays, or the Surf Coast. It is being delivered by the private sector as a BOOT project using Victoria's Public Private Partnerships framework. Expressions of interest were sought in late 2008 and construction of the plant was awarded to AquaSure, a consortium consisting of Suez Environment, Degremont, Thiess and Macquarie Capital Group. Construction commenced in 2009 and the plant is expected to start delivering water by the middle of 2012. The $3.5 billion project includes a 85 km pipeline to connect the plant to Melbourne's Cardinia Reservoir east of the city. It will be capable of providing around a third of Melbourne's annual water supply. The plant is estimated to use about 90 MW of power, the equivalent of which will be purchased from renewable energy sources.

Fig. 5. Melbourne desalination plant (artist's impression).

Fig. 6. Adelaide desalination plant (artist's impression).

10. South Australia

A 300 MLD desalination plant for Adelaide is under construction on a site adjacent to Mobil refinery site at Port Stanvac on St Vincent Gulf, south of the city. SA Water is the lead agency to deliver this project. Following independent operation of a pilot plant, expressions of interest were sought in July 2008. A contract for $1.255 billion for the desalination plant and marine works was awarded to AdelaideAqua (a consortium comprising Acciona Agua, McConnell Dowell, Abigroup and Trility) in February 2009. The Transfer Pipeline, Power Supply infrastructure and other works are being carried out by other contractors. The 1.824 billion project achieved First Water in October 2011. The overall project is on target to deliver the full 300 MLD capacity within the original approval date of December 2012.

BHP Billiton, one of the world's largest resources companies produces copper, uranium, gold and silver from its Olympic Dam mining and processing plant near Roxby Downs in the north of South Australia. As a result

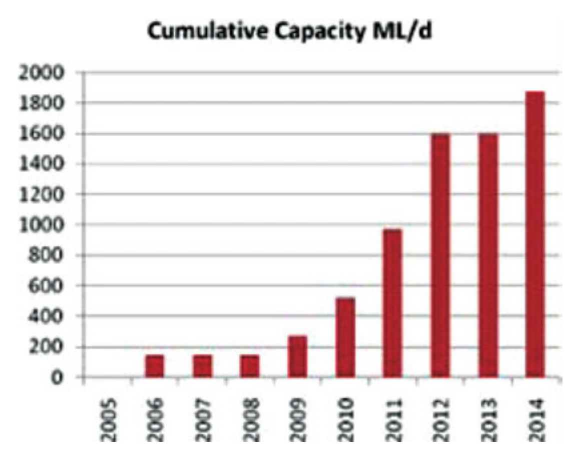

Fig. 7. Cumulative capacity of Australia's seawater RO plants for 10 y 2005–2014.

of expansion, additional water resources are required. The preferred water supply involves the following infrastructure:

- Seawater desalination plant with a capacity of up to 280 MLD. Infrastructure includes offshore intake and outfall structures, pre-treatment facilities, desalination plant development and post treatment/storage. The preferred plant location is adjacent to Whyalla, South Australia, but there have been concerns with the impact of the eject stream on the spawning grounds of the giant cuttle fish, which may necessitate an alternative site.
- Transfer pipeline system capable of transferring potable water to Olympic Dam. The estimated pipeline length is 320 km, with a nominal pipeline diameter in excess of 1.0 m.
- Three or four potable water booster pumping stations with power capacities up to 6 MW.
- Construction of additional water storage facilities in the region of 1 million m^3. The most likely form of construction will be lined and covered water storage dams.

11. Thermal plants

Two thermal desalination plants have been constructed recently in Western Australia for industrial applications. These are a 3.6 MLD MVC plant on the Burrup Peninsula for Burrup Fertilisers Ammonia Plant and a 7.2 MLD MED plant at Ravensthorpe for BHP Billiton's Ravensthorpe Nickel Plant. The Ravensthorpe plant is currently mothballed (along with the mine) as a result of the 2008/2009 Global Financial Crisis.

12. Other potable and industrial plants

There are thought to be more than 500 small RO plants servicing remote mining and oil and gas sites, power stations, medical (dialysis), food and beverage plants and coastal and island communities. Osmoflo, the largest Australian desalination company, alone has built more than 270 plants since 1991. The first RO plant was thought to have been installed by Permutit at Cook, a siding on the Trans Australia Railway in the Nullarbor Plain in 1968 (Masters 2009). The first large scale brackish water RO plant (35 MLD) was built at Bayswater Power Station in NSW in 1987 for cooling water salinity control.

Much of the inland water is brackish and in some cases hypersaline. In many cases plants operate at low recovery which means significant volumes of concentrate is wasted to evaporation or injection. The Water Corporation of Western Australia is exploring a number of methods to improve recovery. In conjunction with Osmoflo, it is piloting a combination of ion exchange and RO at Yalgoo, inland from Geraldton, termed High Efficiency RO (HERO), to increase recovery from a silica rich groundwater from 55% to more than 90%. Water Corporation is also piloting electrodialysis reversal (EDR) on similar water at Wiluna and is understood to be achieving more than 85% recovery.

13. Wastewater reuse

The application of membranes for treatment of recycled wastewater has two advantages. Firstly membranes provide a barrier against micro-organisms, and also a large proportion of pharmaceutical chemicals; secondly, if extended to RO, salinity is reduced. The former is important if indirect potable use is the target, the latter is more important for industrial re-use, as in boiler make-up and cooling towers.

14. Queensland

Brisbane's WWTP at Luggage Point has been delivering about 8 MLD of recycled water to the BP refinery since 2002, and has a final stage of RO to reduce salinity Starting in 2007, the Western Corridor Recycled Water Project (WCRWP) has been completed and is capable of delivering over 230 MLD of purified water for two power stations, industry, agriculture and finally back to Wivenhoe Dam where it will ultimately be added to Brisbane's main potable water supply.

The WCRWP collects secondary treated wastewater from Brisbane's and Ipswich's major treatment plants at Luggage Point, Gibson island, Bundamba, Goodna, Wacol and Oxley. The treated wastewater is further treated within three new Advanced Water Treatment Plants (AWTPs). The AWTPs treat the wastewater to the highest standard through a multi-barrier treatment system including microfiltration (MF) and RO and advanced oxidation. The project includes some 200 km of pipelines. The first stage was the commissioning of the AWTP at Bundamba. Stage 1A has a design output capacity of 20 MLD. Stage 1B followed with a design output capacity of 80 MLD. Flows into the Bundamba AWTP are sourced from Bundamba wastewater treatment plant (WWTP) (for Stage 1A) and then supplemented by additional flows from Goodna, Wacol and Oxley WWTPs (Stage 1B). Bundamba 1B incorporates the first use of Koch 18″ diameter pressure vessels and membranes in a large scale plant.

Stage 2 of the project involved the construction of two AWTP's at Gibson Island and Luggage Point. The Gibson Island AWTP has an initial capacity of 35 MLD with an ultimate capacity of 50 MLD. The Luggage Point AWTP has an initial capacity of 82 MLD but can be upgraded to 102 MLD. Both AWTP's provide water for transfer through the distribution pipelines with additional capacity to produce water for local reuse to be added as local reuse demand arises.

The scheme is bold and large by world standards. However, public acceptance of reuse has been difficult. Following heavy rains in early 2009, the Queensland Government announced that indirect potable reuse would be deferred until the storage levels in the reservoirs dropped below 40% (several years away). A recent announcement that a new dam planned for Traveston to supply Brisbane has been refused environmental approval by the Federal Government, so indirect potable reuse may be reinstated earlier. The Queensland Government has also announced that two new 120 MLD seawater desalination plants will also be built to ensure water supply into the future.

15. New South Wales

About 20 MLD of high quality recycled water is being delivered to BlueScope Steel from a new recycled water plant at Sydney Water's Wollongong Sewage Treatment Plant (STP). This replaces 7.3 million m^3 of the drinking water per year previously drawn from the local Avon Dam. This represents a 57% reduction of drinking water consumption by Sydney Water's largest customer. The plant at Wollongong uses MF and RO membrane processes to produce high quality recycled water suitable for a range of industrial purposes such as cooling systems. An upgrade in the near future is being discussed.

The Western Sydney Recycled Water Initiative will recycle 27 million m^3 y^{-1} of water. The additional recycling will occur in the new growth areas to the north west and south west of Sydney where housing will be supplied with recycled water for non-drinking household purposes as well as irrigation for agriculture. Sydney Water has identified seven large water users in the Camellia and Smithfield areas to be provided with recycled water for the replacement of their drinking water usage. This recycled water will be used for industrial and irrigation purposes saving up to 6 million m^3 of drinking water a year. Treated effluent from the Liverpool to Ashfield Pipeline will be further treated at a recycled water plant which is likely to be based at Fairfield. The recycled water plant will use MF and RO to treat the water to a very high quality for industrial use. A pipe network will be constructed to distribute the recycled water to Sydney Water's customers.

The Western Replacement Flows Project involves connecting three STP at Penrith, St Mary's and Quakers Hill and transferring 50 MLD of treated wastewater from these plants to a new AWTP at St Mary's. This plant will have MF followed by RO to ensure total nitrogen levels are less than 1 mg l^{-1}. The new plant will treat the wastewater to an even higher standard than the treated wastewater currently released into the Hawkesbury-Nepean River from the three plants. This will improve the quality of the downstream reaches of the river and so reduce the amount of potable water which has to be released from the upstream Warragamba Dam for environmental purposes.

16. Victoria

Melbourne's Western Treatment Plant supplies recycled water of quite high salinity, typically 1200 mg l^{-1}, to a near-by market garden complex, where it has to be blended with river water to reduce its salinity to an acceptable level. Pilot trials of two types of RO and EDR have been conducted to assess the feasibility of partially desalinating the recycled water at source. Currently some 3 million m^3 y^{-1} are supplied, with a further 5 million m^3 y^{-1} for industrial, recreational and residential purposes.

Melbourne's Eastern Treatment plant supplies treated water to new residential developments. It is treated by ultrafiltration as a final pathogen barrier, but the salinity is only about 500 mg l^{-1} so RO is not necessary. A target of 5 million m^3 y^{-1} of treated water has been set.

The Gippsland Water Factory was completed in 2008 and treats 8 MLD of combined domestic and industrial wastewater by MBR and RO for supply to a major industrial user, the Maryvale paper mill. The eventual target is for 35 MLD. Apart from the treatment plant, the overall transfer system includes 75 km of pipeline and 8 sewer pump stations. To date approximately 37 km of pipeline has been completed.

17. Western Australia

In April 2005, the Water Corporation—against a backdrop of drying climate and a rapidly growing population—released the "Source Development Plan for the Integrated Water Supply Scheme". This formally recognised recycled water via groundwater replenishment as a potential drinking water source, with the earliest date of implementation being 2014. A scheme treating and replenishing the entire flow from Beenyup WWTP could allow an increase in groundwater abstraction of up to 30 million m^3 y^{-1} for drinking water supply. A trial of the approach is planned, whereby 5 MLD of high quality water would be injected to the Leederville aquifer after ultra-filtration, RO, and possibly advanced oxidation. Design definition is under way for the trial, and it is planned to have the plant in operation by early 2010 and it will be operated for 3 y.

Water Corporation has also constructed stage one of the Kwinana Water Recycling Plant (KWRP) in 2005. This treats flow from the Woodman Point WWTP to produce up to 17 MLD of RO treated water for use by various industries in the Kwinana industrial area, including oil refineries, fertiliser and paint manufacturers and steel smelting operations. Demand now exceeds supply for the product water, and Water Corporation are close to completing design of the Stage 2 expansion of the plant by 10 MLD, and are liaising with existing and potential customers to increase or commence supply of the high quality RO water.

18. Technological improvements for future

We are all well aware of the great strides made in the advancement of RO, be it new construction and pipe materials, membranes including RO and ultra-filtration pre-treatment membranes, anti-scalant, (ERD) and efficient pumps and electric motors.

In years to come, with all the latest components, such as large diameter-high rejection membranes (including boron and bromide), the footprint attributed to seawater RO plants will reduce, making them by far the least environmentally intrusive water sources in semi-arid regions such as Australia, Spain, China and California to mention a few.

The use of ultra-filtration membranes to pre-treat seawater may also result in the current residuals handling facilities being utilised in Australian and world desalination becoming obsolete on future plants (Perth II may prove this). Water utilities have approached the environmental protection authorities with the proposal of returning chemical free backwash to the ocean together with seawater concentrate. This may be feasible if ultra-filtration eliminates the use of coagulants and other chemicals.

New technologies such as forward osmosis (reverse-RO, entropy recovery-osmotic power), may also become commercially viable. Osmotic Power utilises two sources of different salinity waters or liquids (e.g., seawater RO concentrate and wastewater) in combination with a semi permeable membrane, an ERD (isobaric based), a booster pump and a Pelton impulse turbine in one instance or directly via the SWRO plant ERD system. Utilising this equipment and the osmotic pressure that exists between these two liquids, energy can be recovered. This device has already been patented and prototypes constructed. Other patents supporting the ERD directly have also been patented. A SWRO plant the size of PSDP located near a wastewater outfall can utilise the energy produced (5 MW) from the osmotic pressure difference to power the associated desalination plant.

Taking the giant leaps that are occurring in creating freshwater from seawater, I know where I would invest if I had to invest in water infrastructure.

19. It’s all about energy

The world’s current global warming crisis is totally centred on mankind’s insatiable appetite for energy. The world’s climate change, which has occurred mainly due to the production of energy, has resulted in areas experiencing drastic and unprecedented water shortages. Ironically, the only way to create water in these areas is to use energy intensive means to produce water, such as desalination. This only results in higher energy demands and so the whole situation snowballs further out of control.

The only way to counter this is to produce unlimited clean energy, no matter what the cost. This can not only be done using renewable energy, no matter how attractive this may seem. It is highly impractical and unachievable.

This is where nuclear fusion comes to the fore. This will become mankind’s saviour in the next 30 y. It is however this period where renewable energy and nuclear fission will reign supreme. The use of coal fired power stations has to be regarded as mankind’s ultimate environmental vandalism. Not only does the burning of coal contribute to most of the world’s carbon emissions, it also produces all of the mercury found in the oceans and to the acid rain that prevails. Wake up world.

20. Why desalination is sustainable and the future solution

- SWRO reflects the “true benchmark value of water”, the “triple bottom line” as environmental, social and financial costs are all included in the unit cost of water. No conventional source adequately caters for environmental costs.
- SWRO is drought free and provides a totally new source, contrary to recycling.
- SWRO submerged intakes adequately designed, entrain negligible algae, zooplankton and no fish. Entrainment of sea life is minimal with well-designed submerged open intakes with low velocity. Only some algae and zooplankton (and no fish) in minuscule quantities are entrained. Sludge has currently been analysed at an Australian Desalination Plant to assess the constitution—only 1.5% biological, for example, 150 kg d^{-1}, mostly algae.

- SWRO does not disturb rivers, estuaries and associated habitat (fish, frogs, birds, siltation, stagnation and in-stream flows).
- SWRO does not disturb aquifers and associated habitat (water table, springs, acid sulphate soils and stygofauna).
- SWRO seawater concentrate discharges and residuals can be environmentally managed (this has been proven beyond any doubt in Perth) 5.
- SWRO can use wind or any renewable energy to ensure no emissions.
- SWRO has the smallest environmental and terrestrial footprint of any source (Perth 6.5 ha of Land + 2.5 ha of Sea + wind farm 31 km^2 of Land for 17% of the city's water).
- SWRO can be located near to where it is needed.
- SWRO need not utilise long pipelines/canals (no need for millions of tons of steel, cement or massive excavations—such as required when "bringing water down from the north" and using four times less energy as once mooted for Western Australia).
- SWRO results in minimal greenhouse gas production during the manufacture of components.
- SWRO results in minimal greenhouse gas production during the construction of the plant.
- SWRO results in zero evaporation or siltation.
- SWRO water quality is not affected by fires, first rain or activities in catchments which can affect water quality and run-off (Melbourne Fires etc.).
- SWRO could ultimately be partially powered by osmotic power (a new form of renewable energy). Locate SWRO Plants adjacent to WWT Plants.
- SWRO can utilise greenhouse off–sets from renewable energy development from anywhere in the world, after all climate change is a global issue.
- SWRO can be provided at full capacity within 2 y of environmental clearances being obtained.
- It's all about energy.

21. Conclusions

To say investment in desalination technology in Australia over the past 5 y has been astonishing is almost an understatement. A combination of RO technological advancement, unit cost reduction, climate change, long term drought, population growth and Government inaction in the late 1990s and early 2000s has resulted in an expected increase in water supplied by desalination during the 10 y period from 2005–2015 from less than 100 MLD to more than 1800 MLD. This includes six very large plants, "The Big Six" to supply Perth, Brisbane, Sydney, Adelaide and Melbourne.

It may be said that desalination has "come of age" in Australia. The Federal and Western Australian Governments have recognized this by the establishment of a $20 m National Centre of Excellence in Desalination based at Murdoch University in Perth. In addition, Australia was chosen to host the International Desalination Association's World Congress which was held in Perth in September 2011.

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