water e-journal
Online Journal of the Australian Water Association
ISSN 2206-1991
Volume 1 No 1 2016
http://dx.doi.org/10.21139/wej.2016.003

SEAWATER DESALINATION: A SUSTAINABLE SOLUTION TO WORLD WATER SHORTAGE

PLANNING, DESIGN, CONSTRUCTION AND OPERATION OF THE ADELAIDE DESALINATION PLANT

JE Blesing, C Pelekani

ABSTRACT

As world population increases disproportionately in urban centres, stress on existing natural water supplies (with respect to quantity and quality) continues to increase.

There are many parts of the world currently experiencing drought conditions combined with a water supply that is unfit for human consumption, resulting in disease and death. Scarcity of water also results in reduced availability for food production. Alternative water sources are necessary for sustainable development.

Seawater desalination can provide a climate-independent source of drinking water; however, the process is perceived by some in the community as energy-intensive and environmentally damaging.

This paper addresses the methodology adopted, based on sustainability principles, for the planning, design, construction and operation of the Adelaide Desalination Plant (ADP) in South Australia – the largest investment ever made by the South Australian Water Corporation (SA Water).

INTRODUCTION

In mid-2013, the world's population was estimated at 7,095,217,980[1], and growing at a rate of 1.14%[2]. At this growth rate, the population will double in 61 years. The disproportionate increase in urban centres will place increasing pressure on already stressed natural water resources.

The availability of freshwater from natural resources, including groundwater, is determined by rainfall and, as such, is affected by climatic conditions, particularly drought.

While dams increase storage volumes and can attenuate the variability of climatic conditions, they are ultimately limited by the availability of rainwater supply in the first instance. Dams also have significant environmental impacts on inundated areas and downstream with the restriction of natural flows.

Supply from rivers is dependent on climatic conditions. Across the globe many rivers are becoming increasingly contaminated due to man-made discharges and excessive draw-off for agricultural uses. Groundwater supplies are finite and cannot be relied on to help create a sustainable water future.

The availability of seawater is not affected by climatic conditions and if freshwater can be extracted from the sea in a sustainable manner it could provide a viable solution.

WATER SUPPLY IN SOUTH AUSTRALIA

South Australia is the driest state in the driest inhabited continent in the world. Adelaide's catchment storage capacity is small by Australian capital city standards, with approximately 12 months of storage. Natural catchment run-off is augmented by water pumped from the River Murray, which can vary from 40% in an average rainfall year to more than 90% during drought periods.

In 2006–2007 the state, and indeed most of Australia, was experiencing a severe drought. The water level in the River Murray was at record low levels, with significant water restrictions imposed. Catchment storage capacity could not be increased, and as the River Murray also supplies water to agriculture and industry operations, including communities in the adjacent states of New South Wales and Victoria, water quality was impaired (elevated salinity, low dissolved oxygen, toxic algal blooms).

Figure 1 shows water levels in the River Murray (red line) and annual rainfall in the Mount Lofty Ranges catchment area.

In 2007, the South Australian Government established a Desalination Working Group (DWG), with representation from key government departments.

---

[1] *Matt Rosenberg: World Population – Current and Historic Counts. geography.about.com*

[2] *Matt Rosenberg: Overview of Population Growth Rates. geography.about.com*

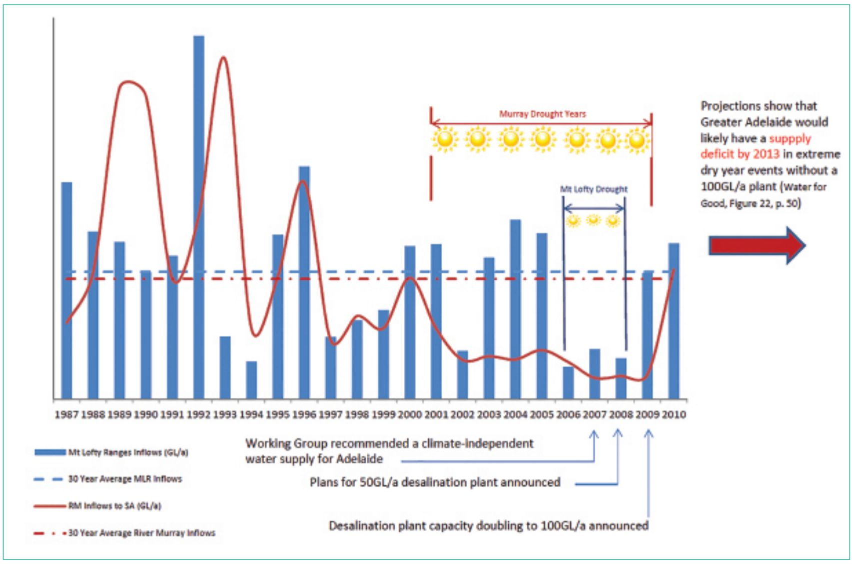


Figure 1. Annual water resources – South Australia.

Provided by SA Government: (www.environment.sa.gov.au/about-us/our-plans)

The DWG considered a range of water supply options including increasing the capacity of the state's largest reservoir (Mount Bold – 45,900GL), stormwater harvesting and wastewater recycling. Water reuse was considered unviable as a direct source of potable water, but current schemes should continue for agricultural and green space use. Seawater desalination was identified as the only climate-independent source of water.

The DWG recommended construction of a seawater reverse osmosis desalination plant, located at Port Stanvac. Seawater depth and proximity to local infrastructure were considered optimal at this location.

From the DWG's report and subsequent work by SA Water, the plant design brief included the following criteria:

- Plant capacity of 50GL/year, expandable to 100GL/year;
- Low energy consumption (< 4.5kWh/m³ of potable water produced);
- Minimal impact on the seawater environment (near-field and far-field);
- Minimal impact on terrestrial environment;
- Positive outcome for the local urban community;
- Electricity supply provided from renewable energy sources.

CRITERIA FOR ADELAIDE DESALINATION PLANT

In order to achieve sustainability success, the desalination plant needed to satisfy the DWG criteria. Key criteria included:

- Intake systems must not negatively impact on the local marine environment (e.g. low intake velocity, no seabed erosion, located away from nurseries);
- Saline concentrate discharge water (brine) must not adversely impact the local marine environment (no chemicals, foreign particles, high temperatures, high velocities, seabed erosion, or marine flora and fauna impact);
- Maximum efficiency of plant operation in terms of energy consumption and seawater abstraction;
- Minimum impact on the local environment during construction;
- Minimum or positive impact on the local environment after construction;

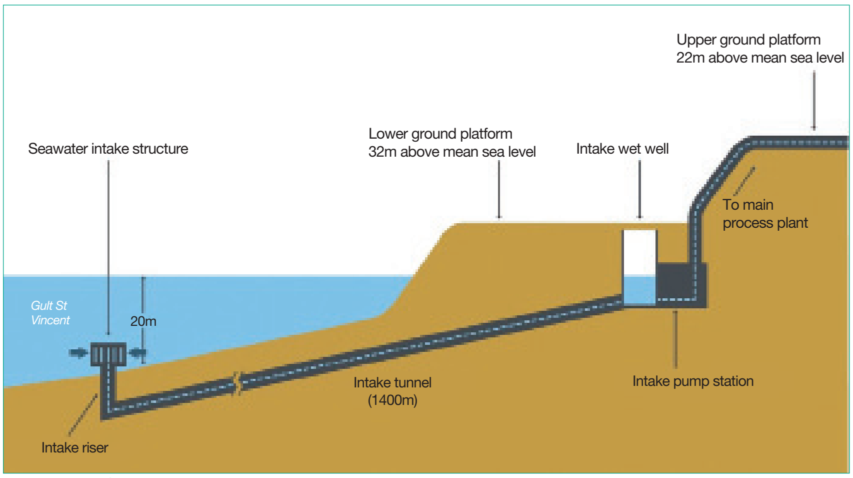


Figure 2. Seawater intake system.

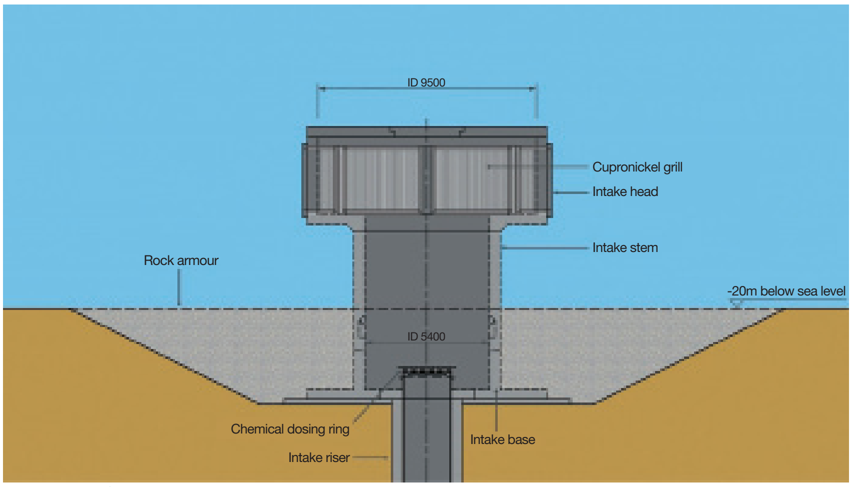


Figure 3. Section through seawater intake.

- Energy supply from renewable energy sources.

Initial Concept Design And Environment Impact Assessment

In January 2008, a cross-functional team was established by SA Water to prepare an environmental impact statement (EIS), develop a detailed plant concept (reference design) for cost estimation and budget allocation, and set up a pilot plant to generate data to support the EIS and technical aspects of the project tender. A link to the summary EIS document is provided in the footnote below[3].

The EIS included detailed water quality analysis to establish the optimum location for the seawater intake and discharge, considering water depth, local current flow patterns and marine flora and fauna. Extensive marine studies were undertaken, overseen by an independent technical review panel, ensuring the results and associated recommendations were accepted by the Environmental Protection Authority.

In August 2008, a pilot plant was set up on the shore of Gulf St Vincent, adjacent to the proposed site for the Adelaide Desalination Plant (ADP), to investigate alternative seawater pre-treatment systems and aspects of reverse osmosis desalination and post-treatment, including ecotoxicity testing of seawater and concentrate samples.

Ultrafiltration was found to provide more consistent filtered water quality than conventional treatment, which required careful monitoring of coagulant and polymer chemical dosing conditions.

The EIS was completed in November 2008, with a key component being the establishment of design criteria for the ADP. Outcome-based performance criteria were identified through the environmental assessment process to ensure the objectives for minimising impacts would be achieved. These criteria became the basis of the regulatory approval conditions and were included in the contract documents for both construction and operational phases of the ADP.

In February 2009, the tender for the design and construction of the full-scale plant was awarded to AdelaideAqua, a consortium consisting of Acciona Agua (Spain; process design) and McConnell Dowell and Lend Lease (Australia; civil, structural, mechanical and electrical design and construction), incorporating the regulatory approval conditions associated with the EIS.

Environmental Impact – Intake System

The seawater intake is located 1.4km offshore in deep, clean water with a sandy bottom (Figure 2). This location was chosen after exhaustive studies of the marine environment in Gulf St Vincent.

The intake header (Figure 3) is equipped with a 100mm bar screen to restrict entry by larger fish species and material that might otherwise become trapped in the tunnel. Intake velocity at full plant load is 0.08m/s at the entry, 0.34m/s in the chamber, 2.28m/s in the inlet branch pipe and 1.16m/s in the 2.8m diameter tunnel. The low velocities at the intake entry prevent entrapment of marine organisms and the location minimises entrainment of fish larvae, reducing impacts to local fish species in the area. Locating the intake head away from reefs or nursery habitats also substantially reduces impacts on the local fish species in the region.

Environmental Impact – Outfall System

The outfall discharge diffuser system (Figure 4) is located 1.1km from the shoreline and 400m from the intake

---

[3] *www.sa.gov.au/topics/housing-property-and-land/building-and-development/building-and-development-applications/major-development-applications-and-assessments/major-development-proposals/desalination-plant-port-stanvac*

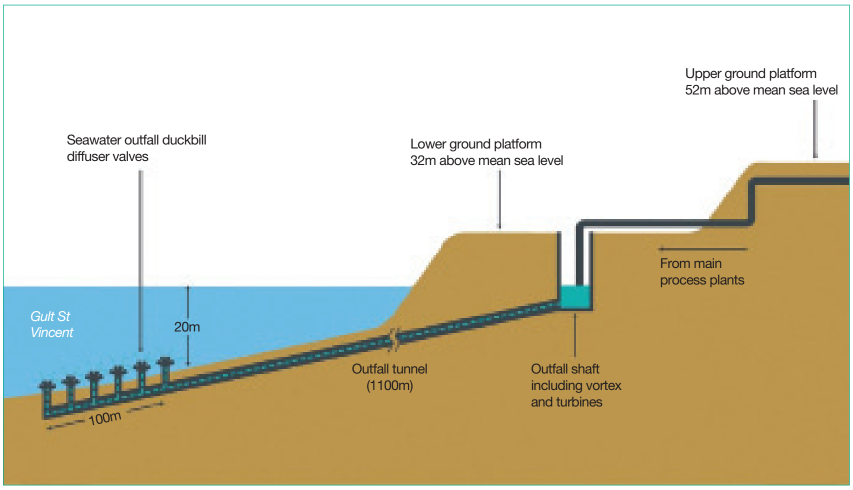


Figure 4. The outfall system.

Figure 5. Discharge diffuser.

chamber. It comprises six multi-nozzle diffuser heads (Figure 5), with each nozzle fitted with a duckbill valve that opens progressively with increasing pressure as flows increase. This maintains a discharge jet velocity as required to achieve rapid dispersion of the saline concentrate.

Five marine buoys (Figure 6) monitor diffuser performance. Four buoys are radially located 100m from, and surrounding, the outfall location. The fifth buoy is 15km from the diffusers and provides a measurement of ambient seawater conditions. The diffuser buoys are attached to sensing devices located 0.5m above the seabed and measure salinity and temperature; transmitting the data every hour to the plant's SCADA system.

Figure 6. Marine buoy.

This realtime data transmission (via telemetry) system allows the operator to verify compliance with the Environment Protection Authority (EPA) discharge licence conditions. The data is publicly available on the EPA website. To date, salinity concentrations 100m from the outfall have not exceeded the license condition of 1.3ppt (parts per thousand) above ambient, over a six-hour period.

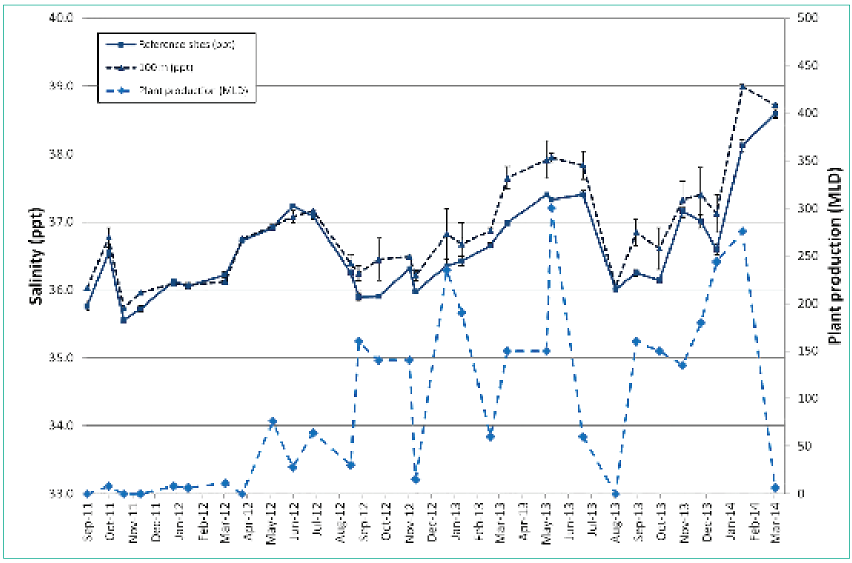
The average salinity difference observed between reference (ambient salinity concentrations) and 100m sites is 0.4ppt with a maximum of 0.9ppt (February 2014 at a production rate of 274ML/day). Figure 7 shows, graphically, data taken directly from the monitoring buoys.

To date, the outfall has successfully achieved dilution criteria set by the South Australian EPA with no discernible impacts on marine biota.

Energy-Efficient Operation

The key criteria affecting the energy-efficient operation of a desalination plant include:

- Optimal abstraction of raw seawater for processing;
- Optimal duty curves for pumping systems across the full range of operation;
- Use of energy recovery devices to recover pressure energy from waste saline concentrate;
- Effective pre-treatment to deliver consistently good-quality 'clean' seawater to the sensitive RO membranes (minimise rate of fouling and chemical cleaning requirements);
- Management of process waste streams (treatment and reuse versus discharge);
- Energy recovery from other waste streams;
- Use of renewable energy for ancillary plant uses;
- Process design to achieve optimal energy efficiency across required production flow range;



Provided by SA Water ADP Contract Operations Group.

Figure 7. Comparison of salinity concentrations.

Figure 8. Disc filters at the main process plant.

Figure 9. The ultra-filtration plant.

- Incorporation of energy-efficient principles such as solar passive design and natural ventilation of buildings.

These criteria are discussed in the following sections.

Clean seawater

The seawater intake is located 1.4km offshore in deep (20m), relatively clean water over a sandy bottom. Typical raw water turbidity is less than 1 NTU. Raw seawater gravitates through a 2.8m diameter tunnel to the intake pump station where it passes through band screens to remove particulate matter larger than 3mm.

Screened seawater is pumped to the process plant (located 52m above sea level) where it passes through banks of disc filters (Figure 8). These filters remove particles larger than 100 micron and are necessary to protect the downstream ultrafiltration membrane fibres, as well as to remove barnacle larvae that could attach to downstream concrete surfaces and upset the UF system.

The disc-filtered seawater is processed through a submerged ultra-filtration system (Figure 9) to remove particles greater than 0.1 microns (0.04 micron nominal pore size). This is necessary for removal of colloidal and fine silt material, as well as most viruses and bacteria.

The high quality of the UF filtrate assists in:

- Minimising fouling of the RO membranes;
- Reducing operating pressure and chemical cleaning requirements;
- Increasing the life of the RO membranes;
- Reducing solid waste disposal.

Silt density index (SDI) measurement is the industry standard for assessing the quality of water fed to RO membranes. The target SDI for ADP operation is less than 3.0. Available operating data reveals an average SDI of 2.4, with a range of 1.4-3.0.

Energy recovery – pressure exchange system

The clean filtered seawater is supplied

Figure 10. ERI pressure exchange energy recovery units.

Figure 11. Energy recovery turbines.

to the RO plant at a pressure of 2bar. Approximately half of the UF filtrate flow (coinciding with the nominal 50% recovery of the first pass RO units) is supplied to fixed-speed high pressure pumps, which elevate the pressure to 70bar prior to entry into the first-pass RO units.

The remaining UF filtrate is diverted to isobaric pressure exchanger arrays driven by the recovered pressure energy of the reject saline in conjunction with small booster pumps, to supply an equal amount of filtrate to the RO membranes as the main pressure pumps, at the same 70bar pressure. The energy transfer efficiency is greater than 96%.

The use of pressure exchangers (Figure 10) effectively reduces the energy requirement of the overall desalination process by more than 40%, and the RO pumping system by 45% or 24,300kW.

Energy recovery from depressurised saline concentrate

The main process plant is located 52m above sea level (RL 52.0).

The saline concentrate from the RO plant, after leaving the pressure exchange units at a pressure of about 2bar, flows by gravity to storage tanks at RL52 (but partly underground). This water is then allowed to flow by gravity to two Francis turbines (Figure 11) located above the outfall tunnel inlet at RL 13.85.

The turbines drive generators to produce 1,290kW of electricity (at full plant load), which is fed directly back into the intake pump power system, recovering some of the pump energy lost to the intake pumps to lift the seawater to RL52.0. The electrical energy saving is approximately 2.5% at full production.

Recycling of process wastewater

The disc filters and UF membranes require regular backwashing to remove captured particulate matter. Dirty washwater is transferred to an adjacent treatment facility where solids

Figure 12. RO hall.

Figures 5 to 10 are of plant installed at ADP.

are removed and clarified seawater can then be recycled back to the UF system, reducing intake pumping requirements.

In practice, however, the actual operating recovery of the UF system (>97%) is greater than the design value of 94%, resulting in less than half the anticipated washwater production. The reduced dirty backwash volume allows marine discharge to be more cost-effective and reduces fouling risk to the UF system.

Permeate recovery

The Adelaide Desalination Plant has a unique RO membrane design array, whereby the first-pass pressure vessels contain two types of membranes: three front elements of high surface area to reduce the lead flux and, hence, required operating pressure; then five rear elements of higher permeability to maximise permeate productivity.

Permeate is separately extracted from the front and the rear. The front permeate is then polished by a second-pass 'front' RO system via backpressure from the first-pass front (i.e. no additional pumping required). The reject concentrate from this polishing step is blended with the first-pass rear permeate.

The blended rear permeate is under low pressure (< 1.5bar) and requires pumping to a separate second-pass 'rear' brackish water RO system for polishing (to reduce salinity and boron). This membrane array design results in a lower lead flux that reduces the fouling rate and operating pressure, both of which assist in minimising energy consumption. Figure 13 shows the arrangement schematically.

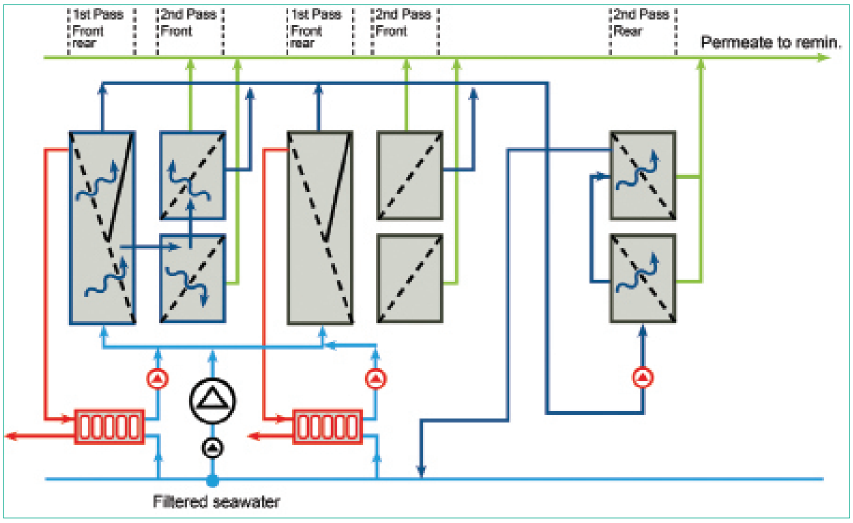


Figure 13. RO system schematic.

The final permeate discharged to the drinking water storage tanks meets the stringent water quality requirements of SA Water, in particular, chloride < 80mg/l, boron < 0.5mg/l and alkalinity > 70mg/l. Reject concentrate from the second-pass rear RO units is recycled back to the first-pass RO, enabling an overall RO system recovery of 48.5% to be consistently achieved. This value is higher than typical industry standards (<45%), and results in optimised abstraction of fresh seawater.

Actual operating data reveals a recovery range of 47.3–49.9%, with an average of 48.6% (December 2013–December 2014).

Solar power

Two 100kW rated capacity photovoltaic systems are installed on the roofs of the process plant buildings. The generated electricity is used to augment supply for ancillary building services (lighting, ventilation and air conditioning).

Operating efficiency

The plant is also designed to allow production rates from 30ML/day up to 300ML/day in 15ML/day increments. This flexibility was required by SA Water, as desalinated water can be supplied direct to customers, with water supply zones automatically adjusted by the Network Planning

Figure 14. A windfarm in South Australia.

group to optimise the mix of water supplies at any particular time.

Innovative process design and judicial selection of pumps equipped with variable speed drive enables the required production flexibility without compromising energy use targets for the plant over the whole operating range.

Key outcomes

The tender documents for the ADP specified a maximum energy consumption of 4.5kWh/kL of drinking water produced. Actual operating data for the period from January 2013 to October 2014 (under normal operating conditions) yielded a range of 3.47–3.7 kWh/kL.

Energy Source

The South Australian Government (through SA Water) has negotiated a contract for the supply of electricity for 20 years with AGL, requiring the energy to be fully sourced from renewable energy sources such as wind farm power generation.

Until 2003, South Australia had only one operating windfarm with a generation capacity of 150kW. As of 2015, there are 16 operating windfarms in the state with a total generation capacity of 1,473MW, with a further 680MW with planning approval, and 1,150MW proposed or in feasibility study stage[4].

CONCLUSIONS

The Adelaide Desalination Plant sets the standard for environment and sustainability stewardship in new water projects. The project employed sound sustainability principles from the initial planning stages, through design, construction and operation. The project also resulted in significant enhancement of the local environment.

The Adelaide Desalination Plant has achieved:

- A climate-independent source of drinking water for Adelaide (through to 2050);
- Low energy consumption through innovative and efficient plant design and energy recovery systems;
- Minimal impact on the marine environment during construction and after two years of operation;
- Energy supply offset by 100% accredited renewable energy sourced in South Australia;
- Flexible production capability without compromising energy efficiency;
- Minimal impact on the local residential community during construction.

Adelaide's freshwater needs are reflected in many localities worldwide. The need for alternative, sustainable sources of water for growth and development is ever-growing, especially with increasing global population, disproportionately in urban centres. The sustainability principles adopted for the Adelaide Desalination Project are an example of how seawater can provide a viable and sustainable freshwater source, independent of climatic conditions, for the benefit of future generations.

THE AUTHORS

Jonathon (Joe) Blesing (email: Jonathon.Blesing@aurecongroup.com) is a Technical Director at Aurecon with 40 years of diverse professional engineering experience in South Australia, Queensland and South East Asia. He has specialist expertise in multidiscipline projects including upstream oil and gas facilities, infrastructure water and wastewater systems, ore processing plant, manufacturing plant, and special purpose and large-scale HVAC systems. Joe was engaged as Team Leader and Mechanical Engineering Leader, SA Water Technical Support Team, based on the ADP site from project commencement March 2009 to Project Handover December 2012.

Con Pelekani (email: Con.Pelekani@sawater.com.au) is the Manager for Water Treatment Performance and Optimisation, Operations and Maintenance at SA Water. He has expertise in water quality and advanced treatment process design, operations and R&D. In 2008, Con was seconded to the Adelaide Desalination Project as the Principal Water Treatment Engineer. He was involved in the development of the Environmental Impact Statement, lead technical support for the design, construction and operation of the $10M Pilot Plant and tender evaluation team and Engineering Team Lead (Process) for the full-scale plant.

---

[4] en.wikipedia.org/wiki/Wind_power_in_South_Australia