ASIRC Report No.: R05-2207

Overview of Treatment Processes for the Production of Fit for Purpose Water: Desalination and Membrane Technologies

AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES AND ENGINEERING (ATSE)

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Executive Summary

Water is unquestionably vital to life on earth and a fundamental resource in the economic prosperity of any country. To facilitate and maintain sustainable economic development, countries around the globe are increasingly looking to desalination of seawater for drinking water supplementation and reclamation of once-used or recycled waters.

The stress on Victoria's water resources will increase in the future caused by an increase in the population of Victoria and uncertainty from climate change. The Victorian Government has recognised the future increased strain on the State's water resources and has outlined a range of actions that include strategic investment in water recycling and alternative supplies.

This report presents an overview of desalination processes to provide fit for purpose water, including drinking water for consideration in the Victorian context. It was found that:

- Desalination is a technically viable and increasingly attractive strategy to extend the available water supply;
- Desalination is economically feasible with the cost of water produced from desalination processes being directly related to the salt concentration of the source water;
- Social issues may include the public acceptance of using recycled water for domestic dual-pipe systems, industrial and agricultural purposes;
- Environmental issues are associated with brine concentrate disposal, energy consumption and associated greenhouse gas production; and
- Reverse osmosis is becoming the technology of choice with continued advances being made to reduce the total energy consumption and lower the cost of water produced.

Desalination technologies can be categorised into two types: thermal technologies and membrane-based technologies. Within these, the commercially competitive processes are membrane-based reverse osmosis and thermal multi-stage flash distillation. Since the late 1990s, the most significant trend in desalination is the rapid growth of the membrane technology market. Reasons for this include improved membrane performance as well as technological and associated energy efficiency improvements.

Historically, thermal desalination plants have been applied to produce potable water from seawater. Thermal desalination plants require large amounts of energy for their operation, however, their energy consumption is independent of the salinity levels of the feed water. The associated costs of high-energy consumption have particularly high restraining effects on small and medium-sized desalination plants. Thermal desalination plants therefore require large economies of scale and are often co-located with power generation plants.

Membrane-based desalination processes generally have lower capital cost and energy requirements and a higher space/production ratio. The modularity of membrane technologies allows for up- or downgrade and minimal interruption to operation during maintenance. Membrane-based processes include reverse osmosis, membrane filtration, electrodialysis and membrane bioreactor technologies. Reverse osmosis is considered an economically viable technology for seawater desalination, water reclamation and brackish water desalination at small to large scales.

Large-scale seawater desalination is one option to supplement existing potable water resources in Victoria, but there are significant implications in terms of environmental, economic and social issues that require consideration.

For Melbourne, the location of a seawater desalination plant is reliant on consistent quality feed water, a distribution network for the product water and disposal options for the concentrate stream. An environmental study conducted on Port Phillip Bay found that the waters of the bay have the same salinity as seawater. Thus, it may be feasible to locate a desalination plant on the bay, but the feasibility should be assessed in more detail. The requirements for distribution and proximity to existing water distribution infrastructure in Melbourne would also largely be influenced by the size of a desalination plant installed.

All desalination processes produce a waste stream, the disposal of which needs to be considered with regard to the environmental impact. The waste stream is concentrated in salts and, generally, the concentrate reflects the characteristics of the source or feed water, only at a much more concentrated level. Commonly, the concentrate stream is therefore discharged to the surface water body it was sourced from or to evaporation ponds. Overall, the costs associated with either disposal management option are influenced by the location of the plant, land availability in the case of evaporation ponds, conveyance costs to transport concentrate, outfall construction and operation costs as well as environmental monitoring costs in the case of ocean discharge.

A seawater desalination plant for the purpose of supplementing existing drinking water sources will require an economic cost driver. Capital investment may stimulate particular sectors of the Victorian economy and can be maximised if plant and equipment is sourced locally.

Social benefits include increased employment from construction activities, however ongoing operation and maintenance may not require a large labour force. Social issues that need to be addressed include the public perception of using recycled water for residential dual pipe systems, irrigation purposes or market gardens.

A high-level analysis of the costs and benefits of thermal and membrane-based desalination technologies is shown in the table below. The primary cost driver was found to be related to the type of feed water sourced in combination with the desalination process chosen.

Plant	Technology	Type of water processed	Daily production capacity (m^3)	Average cost (AUD/m^3) (AUD 2005)
Nordkanal, Germany	MBR	Recycled	45,000	0.41
Yellowater Study	NF	Well	115,000	0.48
Eraring Power Station	MF/RO	Recycled	4,000	0.48
IDE Technologies study	MED	Sea	100,000	0.59
Madwar and Tarazi study	RO	Recycled	10,000	0.64
Ashkelon, Israel	RO	Sea	273,973	0.73
IDE Technologies study	MSF	Sea	100,000	0.81
Brownsville, USA	RO	River	94,635	0.87
Dry Creek Study	EDR	Brackish	10,000	1.20
Corpus Christi, USA	RO	Sea	94,635	1.20
Madwar and Tarazi study	RO	Sea	10,000	1.40
Freeport, USA	RO	River	37,854	1.43
City of Great Hope Study	MVC	Sea	3,775	3.19
		Range		***0.44-3.19***

Energy is the largest variable cost of desalination after a plant has been built. Lower salinity feed water, such as recycled water, brackish or well water reduce the energy requirements of membrane desalination processes and contribute to an overall lower cost of water as indicated in the table above. Large economies of scale further contribute to lower the cost of water produced irrespective of the desalination process. At small economies of scale, water produced from high salinity feed water by reverse osmosis was found to become more expensive.

Other significant variable costs that impact on the cost of water produced include membrane replacement, operations and maintenance and labour costs. In addition, the combination of feed water and output water use further impacts on the cost of operating the plant, with the production of water for drinking purposes tending to be more expensive.

Some pre-treatment and post-treatment for desalination is generally required. Pre-treatment is necessary to control scaling, metal oxide fouling, biological activity and colloidal and particulate fouling on membranes. Conventional media filtration and chemical addition for coagulation and flocculation is a method of choice commonly employed for seawater desalination by reverse osmosis. Microfiltration and ultrafiltration pre-treatment is increasingly used for water reclamation by reverse osmosis. In thermal desalination, the addition of antiscalant chemicals and operation at lower temperatures is used to control scaling, whilst using chloride resistant construction materials mitigates corrosion. Nanofiltration is considered a possible pre-treatment for thermal desalination processes, as it would facilitate higher brine temperature operation at lower scaling potential.

Product water made from all desalination technologies has a low mineral content and alkalinity and therefore a high corrosion potential, which requires stabilisation before it is introduced into any water supply system. If not stabilised, the water will attempt to do so itself by dissolving (corroding) materials it comes in contact with. Product water can be pH adjusted and stabilised by the reintroduction of chemicals such as sodium bicarbonate, caustic soda, soda ash and chemical or hydrated lime.

Globally, desalination is increasingly being used to provide an alternative water source with reverse osmosis being used more extensively than other processes. The largest seawater reverse osmosis plant at Ashkelon in Israel is designed to produce up to 273,000 m^3/d of drinking water at a cost of USD 0.53/m^3. Large-scale water reclamation by reverse osmosis is achieved in California at the Water Factory 21 and in Singapore with significant environmental, social and economic benefits.

Several existing examples are available of Australian experience in desalinating seawater or reclaiming water for beneficial reuse with concomitant benefits for the surrounding communities and the environment. The Western Australian Government has chosen seawater desalination as the means to supplement Perth's water supply while the NSW Government has recently endorsed a large-scale seawater desalination plant for Sydney. There are also small-scale brackish or seawater desalination plants around Australia, including Dalby in Queensland, Broken Hill in New South Wales or Penneshaw in South Australia, supplying small or remote communities with drinking water. Desalination is highly advanced in Western Australia where there are number of desalination plants servicing the mining industry in addition to remote communities. Advanced water reclamation is also increasingly applied in other States of Australia. At Wollongong, New South Wales, a water reclamation plant will provide Bluescope Steel with 20,000 m^3/d product water. East of Melbourne, Victoria, the Eastern Irrigation Scheme supplies 30,000 m^3/d of Class A recycled water to surrounding market gardens, recreational and sports grounds, industries and municipal councils. In Gippsland, Victoria, a Water Factory project is being developed to supply fit for purpose water for industrial use utilising membrane bioreactor technology as well as membrane filtration and reverse osmosis.

The projected annual shortfall in Melbourne's water supply in the future is about 93 million m^3. A plant producing this amount of desalinated seawater by reverse osmosis would require around 390 GWh or about a 1% increase in Victoria's energy requirements. Greenhouse gas emissions are related to the amount of energy produced and the energy consumption for a plant requiring 390 GWh per year would therefore release approximately 540,000 tonnes of carbon dioxide per year if coal-fired power generation was utilised. Brackish water RO desalination has a lower energy use of 1.0-2.5 kWh/m^3 compared to seawater RO desalination of 4.5-8.5 kWh/m^3. These energy uses and associated greenhouse gas emissions are much lower than for other technologies such as multi-stage flash distillation where the total energy consumption is between 10.5-13 kWh/m^3.

Renewable energies may be used in desalination processes and include wind, solar thermal, photovoltaic and geothermal. Matching renewable energies with desalination units, however, requires a number of important factors to be considered. The possibility of non-steady power inputs from the renewable energy source may result in the desalination plant operating in sub-optimal conditions and may cause operational problems. It therefore has to be considered whether the desalination plant is to be operated only when the renewable energy system supplies power or whether an energy storage facility is added to allow continuous operation. Embodied in wind and solar renewable energy systems are energies required to construct the system. These energies have associated greenhouse gas emissions resulting from the construction and infrastructure of the system and this may need to be considered from a whole-of-life approach to adequately reflect the true energy cost and associated greenhouse gas emission.

Alternative (or novel) technologies to membrane or thermal processes have been employed or demonstrated, however, further investment in these is often required to see a significant shift in the desalination cost curve. Some of these technologies may have the potential to reduce the overall cost of desalination but have yet to be demonstrated on a large scale. In California, a new seawater desalination process being trialled is dual pass nanofiltration that potentially offers lower operating costs and greater energy savings compared to conventional reverse osmosis.

Alternative water supply options, such as desalination, that meet or exceed society's water demand offer, as an additional benefit, the potential to free up water in catchments. For example, desalination of seawater producing potable water might reduce the need to draw from other sources used to supply potable water. Alternatively, application of desalination technologies for the reclamation of water suitable for industrial, agricultural or domestic re-use might then reduce the demand of potable water used by industry and potentially reduce demand for river and catchment water. The economics of the desalination of these water supplies, in comparison to the treatment of seawater, suggests that further similar desalination projects also need to be considered in addition to the desalination of seawater for the production of drinking water.

Critical factors that need to be assessed for the desalination of brackish groundwater include the nature of the aquifer, the economic cost of the water produced and the cost of the technology. The main consideration for the useful application of desalination technologies for the treatment of brackish groundwater will be whether or not the aquifer properties are suitable.

In the future, the value of good quality water from catchments, groundwater and other sources is likely to rise whereas the economics of producing or reclaiming water from desalination technologies will continue to show a further decline in the cost curve. The cost benefit assessment in this study suggests that desalination is a feasible means to provide alternative water sources. Reverse osmosis is increasing in popularity in its applicability to a broad range of feed water at economic cost and energy requirements. Advances in energy requirements along with the scientific advances in membrane technologies are likely to contribute to further cost reductions for desalinated water from membrane-based processes.

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Abbreviations

AGO	Australian Greenhouse Office
ASTM	American Society for Testing and Materials
AUD	Australian dollars
BOT	Build, operate, transfer
CA	Cellulose acetate
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ED/EDR	Electrodialysis / Electrodialysis reversal
EIP	Environmental Improvement Plan
EMF	Electromagnetic field
EPA	Environment Protection Authority
DAF	Dissolved air flotation
DC	Direct current
DOC	Dissolved organic carbon
DSE	Department of Sustainability and Environment
GCC	Gulf Cooperation Council
GJ	Giga joules
GL	Giga litres
GTL	Gas to liquid
GWh	Gigawatt hours
GWRS	Groundwater Replenishment System (California)
HFF	Hollow fine fibre
HTTF	Horizontal tube thin film
IAEA	International Atomic Energy Agency
kPa	Kilo Pascals
kWh	Kilowatt hours
MBR	Membrane bioreactor
MDBC	Murray Darling Basin Commisssion
MD	Micro distillation
MED	Multiple effect distillation
MF	Microfiltration
ML	Mega litres
ML/d	Mega (million) litres per day
MPa	Mega Pascals
MSF	Multi-stage flash distillation (evaporation)
MVC	Mechanical vapour compression
MWh	Megawatt hours
NF	Nanofiltration
NRC	National Research Council
OCWD	Orange Country Water District
psi	Pounds per square inch
PV	Photovoltaic
REIP	Regional Environmental Improvement Plan

RES	Renewable energy sources
RO	Reverse osmosis
SBC	Sequencing batch reactor
SDI	Silt density index
SDN	Simultaneous nitrification-denitrification
STP	Sewage treatment plant
TDS	Total dissolved solids
TVC	Thermal vapour compression
TWDB	Texas Water Development Board
UF	Ultrafiltration
USD	United States dollars
UV	Ultra violet
VCD	Vapour compression distillation
VTE	Vertical tube evaporator
WACC	Weighted average cost of capital
WA EPA	Environmental Protection Agency of Western Australia
ZLD	Zero liquid discharge

1. Introduction

The increase in the number of people living in Victoria is placing an increased stress on Victoria's water resources. In the Victorian Government White Paper *Securing Our Water Future Together* [DSE, 2004], it is estimated that by 2030 the population of Melbourne will increase by more than one million and that of regional Victoria by greater than 350,000. On this basis alone, the demand for water would exceed supply before 2020 if the amount of water used per capita remained at the average of the 1990s [DSE, 2004].

Climate change is also increasing the stress on the State's water resources. Since 1950, the average temperature in Victoria has increased by 0.09ºC per decade [CSIRO, 2002]. For the Greater Melbourne Region, climate models suggest higher probabilities of decreased rainfall due to its location at the junction of the Southern Australian and Tasmanian weather patterns coupled with an increase in the number of hot (above 35°C) days [CSIRO, 2005]. Rainfall patterns in Victoria show significant decadal to multi-decadal variability. As a result of this variability, trends in annual rainfall from the 1880s to the present date are not strong, however, since 1970 there has been a significant decrease in annual rainfall as is illustrated in Figure 1 [BOM, 2005] (the average change in temperature over the period is also shown in the figure).

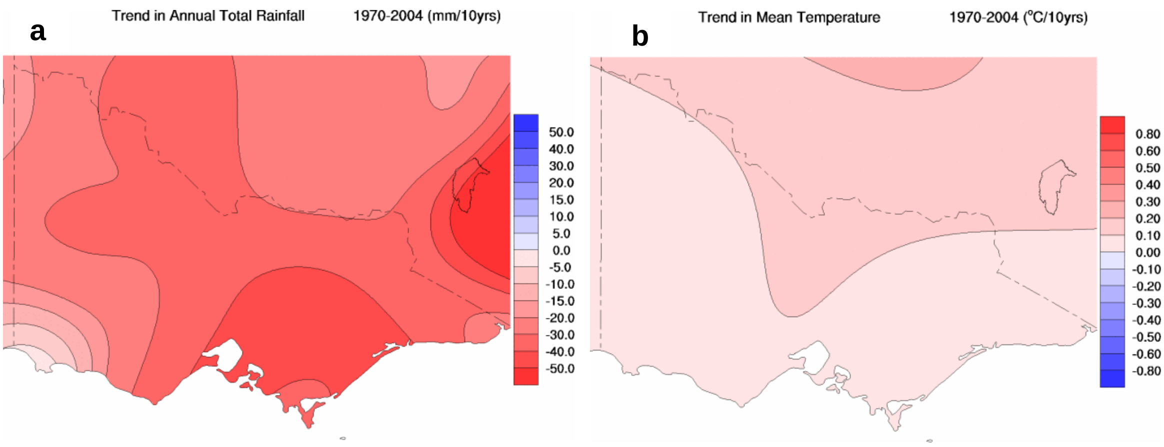

Figure 1: Trends in (a) annual total rainfall and (b) mean temperature in Victoria over the period 1970-2004 [BOM, 2005]

As can be seen from the data presented in Figure 1, in the period 1970-2004, the total rainfall in Victoria has decreased across the State, by as much as 40-50 mm per decade in some areas. Associated with this decrease in rainfall has been an increase in mean temperature.

In addition to assessing observed historical climate change, Whetton *et al*. [CSIRO, 2002] and Howe *et al*. [CSIRO, 2005] also assessed predicted climate change in Victoria and

Melbourne, respectively. The more recent study by Howe *et al*. [CSIRO, 2005], in relation to climate change for Melbourne, supports the projected climate changes described by Whetton *et al*. [CSIRO, 2002] more widely for Victoria with predicted change based on results from global climate models drawn from the latest findings of the Intergovernmental Panel on Climate Change. On average, the State is predicted to be about 1ºC (range: 0.2-2.0ºC) warmer by 2030 and about 3ºC (range: 0.7-6.0ºC) warmer by 2070. The warming is projected to be greatest in summer and least in winter [CSIRO, 2002]. In addition, less rainfall is likely for Victoria, although decadal rainfall variability will continue to be an important feature of the Victorian climate [CSIRO, 2005]. Decreases are largest in spring (between -3 and -14% in 2030 and -9 and -40% in 2070) [CSIRO, 2002]. The projected warmer conditions will lead to increased evaporation and, when combined with the projected decrease in rainfall, most locations in Victoria show a decrease in available moisture. The projected decrease in available moisture will place additional stress on Victoria’s water resources.

2. Study Objectives

The Victorian Government recognised the future increased strain on the State's water resources and outlined a range of actions in their White Paper on water, *Securing Our Water Future Together* [DSE, 2004]. These actions included strategic investment in water recycling and alternative supplies. One specific action (Action 5.38) committed the Victorian Government to investigate the environmental, social and economic costs and benefits of the large-scale application of desalination. As part of this commitment, the Department of Sustainability and Environment (DSE) requested an overview of applications of desalination and membrane technologies for the production of fit for purpose water.

The aim of the project was to provide a stand alone overview report into these technologies for the production of fit for purpose water and to assess the costs and benefits of various desalination and membrane treatment processes.

The two main objectives of the overview were to:

- Gain an understanding of the current application of desalination across Australia and internationally; and
- Provide a high level analysis of the costs and benefits of desalination and membrane technologies.

A key requirement of the overview was a focus on the advantages and disadvantages of the processes and technologies to provide water for a given purpose. Detailed technical descriptions of the technologies are not provided in the overview.

Both desalination and water treated with membrane technologies are potential alternative sources of water for a variety of purposes. Membrane technologies are growing in importance in relation to both large-scale seawater and brackish water desalination and water reclamation processes. In recognition of these factors, the overview report will examine the use of the technologies in seawater and brackish water desalination and advanced water treatment.

The thrust of the overview was on the production of water fit for purpose at greater or equal to 20,000 m^3/d, but special consideration was given to the production of potable (drinking) water. In addition, technologies that do not lend themselves to greater economies of scale, but may be useful in small-scale applications, also formed part of the wider discussion. A review of the current state of new or emergent technologies, which may not have reached commercial potential, was also included in the study.

The emphasis of the overview was on Victoria and the need to provide water now and into the future in a sustainable manner. For this purpose, other Australian desalination operations and concepts were evaluated to provide a broad picture of desalination technologies applicable to particular situations in Australia.

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3. Desalination

The world is increasingly reaching critical limitations in the availability of freshwater for agricultural, industrial and domestic use. In many regions, a growing population, increases in the standard of living and climate changes have resulted in an increased demand on freshwater that greatly exceeds the capability of existing supply infrastructures. The problem is exacerbated by increases in both pollution and salinity of freshwater resources.

With this growing demand for potable water, now and into the future, desalination is broadly seen as a viable and increasingly economic strategy to extend the available water supply. Desalination is undertaken to remove dissolved solids and produce potable water from feed waters such as seawater, brackish water, inland waters and, increasingly, to reclaim recycled water. It is a highly complex process which requires efficient and accurate control systems for the maintenance of optimum operating conditions to minimise production cost and scale formation. Factors that have the largest effect on the cost of desalination are feed water quality (salinity levels), product water quality, energy costs as well as economies of scale [Alatiqi *et al.*, 1999; Dore, 2005].

Whilst water desalination was initiated during the early part of the 20th century, expansion and spread of the industry occurred during the 1960s to 1980s. In 2002, the IDA Worldwide Desalting Plants Inventory Report reported on 15,000 plants producing 32 million m^3/d of desalinated water and in 2005, over 17,000 desalination plants in 120 countries worldwide with a total production capacity of 38 million m^3/d make up about 1% of the world's drinking water supply [Voutchov, 2005; Ebensperger and Isley, 2005]. Seawater desalination is being applied at 58% of installed capacity worldwide, followed by brackish water desalination accounting for 23% of installed capacity [Ebensperger and Isley, 2005; Schiffler, 2004]. Figure 2 outlines the global desalting capacity by feed water sources.

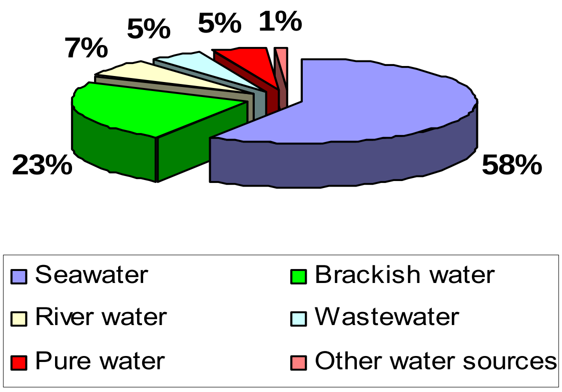

Figure 2: Global installed desalination capacity by feed water sources [IDA, 2002]

A recent study into the worldwide desalination market expects the expenditure between 2005 and 2015 to be around USD 95 billion, of which USD 48 billion will be derived from new capacity (USD 30 billion capital expenditure and USD 18 billion operational expenditure). A large market will continue to be the Arabian Gulf area. Large growth is anticipated for the Mediterranean Rim, including Spain, Libya, Algeria and Israel. Large-scale municipal desalination plans are also expected for the United States, China and India [GWIP, 2004].

A range of desalination technologies is employed throughout the world as a means to produce potable, and other fit for purpose water, and are basically categorised into two types: thermal technologies and membrane-based technologies.

Thermal technologies include the following specific types of processes:

- Multi-stage flash distillation (MSF);
- Multiple effect distillation (MED); and
- Vapour compression distillation (VCD).

Membrane technologies include the following specific types of processes:

- Reverse osmosis (RO);
- Electrodialysis (ED) and electrodialysis reversal (EDR); and
- Nanofiltration (NF).

The commercially competitive processes are membrane-based RO and thermal MSF evaporation. Several other membrane technologies are available for treatment of water to varying degrees. Those used in pre-treatment of desalination plants and discussed as such in this report include:

- Microfiltration (MF);
- Ultrafiltration (UF); and
- Nanofiltration (NF).

Figure 3 outlines the two families of desalination technologies along with the respective membrane pre-treatment technologies available or employed in desalination.

During the early period of desalination expansion, the industry standard was MSF desalination. From 1980 to 1999, RO desalination started to gain acceptance in the market through significant advances in membrane development that lowered the cost of operation. It is forecast that membrane processes, and in particular RO, will continue to take market share from thermal desalination, with 59% of the total new build capacity being membrane based [GWIP, 2004].

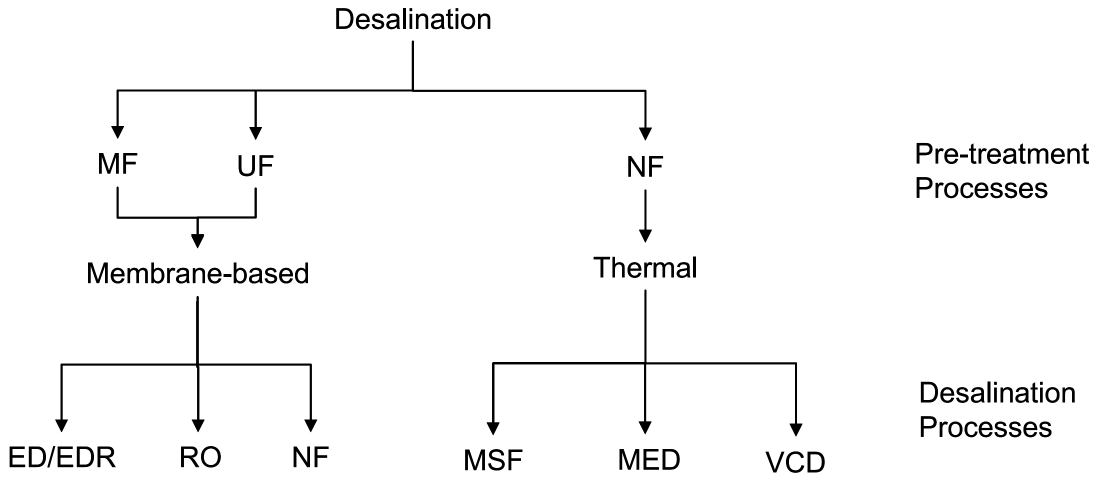

Figure 3: Desalination technology families and processes

Historically, thermal plants have been applied to produce potable water from seawater. The processes used include MSF, MED and VCD. Thermal plants are rarely used for the treatment of water with a low salt content due to the relatively constant capital and operating cost irrespective of the feed water quality. Thermal desalting involves the evaporation or distillation of feed water into vapour with subsequent condensation into a liquid state. This requires power in the form of thermal as well as electrical energy, as operating temperatures can extend to 120°C. This energy requirement can make up between 50-70% of the total operating cost and it is thus not surprising that many of the large-scale thermal desalination plants are co-located with power stations or industries with thermal process energy waste. Similarly, thermal processes are found less in countries where the coupling with power stations is not possible or difficult (e.g. Spain). Some 54% of desalination plants contracted within the last ten years employ thermal processes, with almost 76-80% of all thermal plants being installed on the Arabian Peninsula and within the Gulf Cooperation Council (GCC) [Wangnick, 2005; Hajeeh and Al-Othman, 2005]. The globally installed desalting capacity by process in 2002 is shown in Figure 4.

Membrane technologies have been applied to brackish waters and waters with low salinity levels. Membrane technologies are based on separation techniques facilitated by membranes to move either water or salt into two induced zones of differing concentrations. Since the 1960s, two practical options for brackish water desalination are ED/EDR and RO. Electrodialysis is mainly applied to water of low salinity or in niche areas such as ultrapure water production, pharmaceutical production, boiler feed water or nitrate removal, while RO can be used for a much wider spectrum of feed water sources, including seawater. This wide spectrum has, in recent times, been expanded to also include some of the more difficult surface water sources, including recycled water, by integrating UF or MF with low fouling RO membranes [Glueckstern, 2004]. Since the late 1990s the most significant trend in desalination is the increased growth of the membrane technology market with annual growth rates between 11% for RO and 35% for UF and MF, in particular. Reasons for this include improved membrane performance but also technological improvements that now make membrane desalination a viable alternative in many water supply applications in addition to cost reduction of RO elements. Energy requirements are much lower than for thermal processes and make up around 44% of the total operating cost. Other costs, associated with maintenance and part replacement, however, can contribute significantly to the total operating cost [Velter, 2004; Schiffler, 2004].

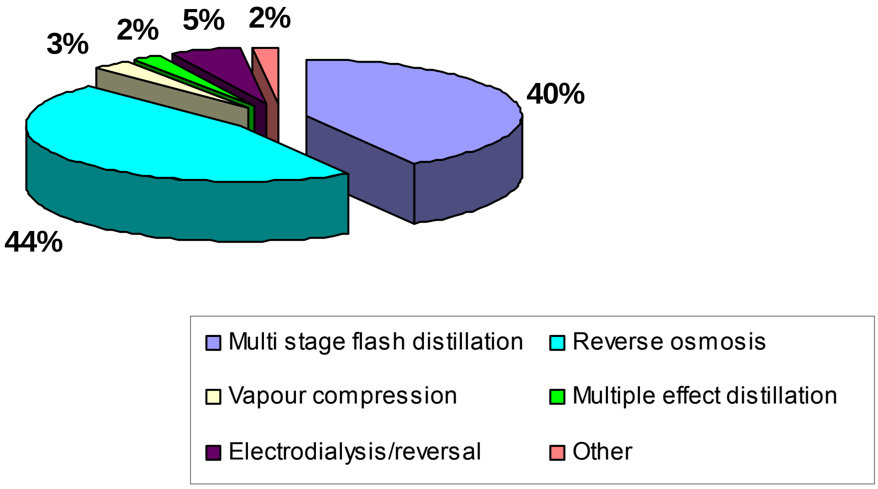

Figure 4: **Global installed desalting capacity by process [IDA, 2002]**

In Australia, desalination technology is predominantly used in industrial processes and power generation. Mines and power stations use desalinated water in process and boiler feed water applications or for complying with discharge legislations. Whilst many smaller RO plants are installed for public water supply, a 130,000 m^3/d seawater reverse osmosis desalination plant for the production of potable water is being constructed for Perth, at Kwinana next to the Kwinana power station. This will make it the largest seawater desalination plant in Australia. Currently, Bayswater Power Station in NSW employs RO to desalinate 35,000 m^3/d of discharge water before supplying it to the plant for reuse, making it the largest zero-discharge plant in the world.

Trends in Australia have shown that RO was the largest desalination process employed in desalination plants in 2000, followed by vapour compression (Figure 5). The data contained in the Desalting Plants Inventory Report No. 16 indicated that Australia had a total of 134 desalination plants contracted, with a combined capacity of 239,000 m^3/d [Wangnick, 2000].

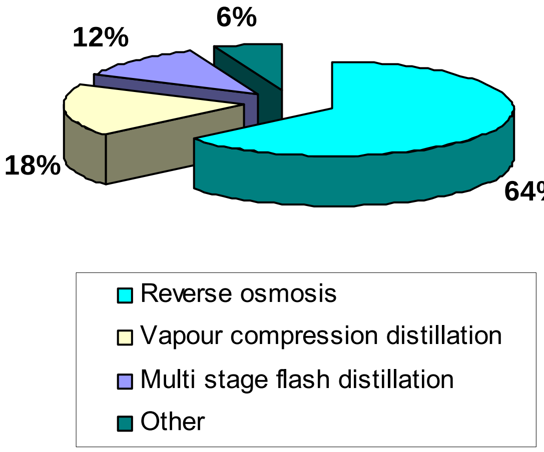

Figure 5: **Installed capacity in Australia by process [Water Corporation, 2000]**

As an arid continent, Australia is faced with limited supplies of potable water resources, impacted by rising levels of saline groundwater. It is therefore not surprising that, in contrast to worldwide feed water sources, Australia predominantly desalinates brackish water. Figure 6 illustrates the use of desalination by feed water source in Australia in 2000. The utilisation of desalination to treat pumped groundwater or brackish water not only produces water fit for purpose or potable water, but also helps to manage salinity threats, e.g. by re-injecting desalinated water into groundwater aquifers for blending and dilution .

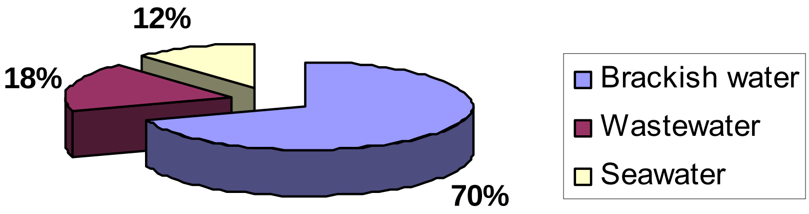

Figure 6: **Feed water sourced for desalination in Australia [Water Corporation, 2000]**

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4. Desalination Applications

Treatment of different feed sources of water by desalination has become a practical solution to ensuring adequate water supply. Desalting seawater, brackish, inland saline water and recycled water removes dissolved salts, pathogenic, colloidal and other contaminants. It increases the utility of water from the various sources, thereby supplementing existing supplies of drinking water or fit for purpose water. Desalting processes are used in industrial applications to produce ultrapure water or water of very high quality, thereby enhancing the productivity of various industries. Desalination adds an element of diversity and, therefore, insurance to a water system because it is fundamentally different from the conventional water sources it may complement. The Australian Drinking Water Guidelines [ADWG, 2004] state that based on taste, total dissolved solids in drinking water should not exceed 500 mg/L. Saline waters are characterised by their amount of total dissolved solids (TDS) as shown in Table 1 below.

Table 1: Typical TDS levels of different water sources

Type	TDS (mg/L)
Freshwater	< 1,000
Mildly brackish water	1,000 to 5,000
Moderately brackish water	5,000 to 15,000
Heavily brackish water	15,000 to 35,000
Seawater*	32,000 to 37,000
Recycled water**	500 to 1,200

Source: Watson *et al.* [2003]

* Higher in the Arabian Gulf and some other areas

** Depending on sewage treatment system and inputs

The technology of desalting has broad scale application where water has a high value and desalination plants are generally located close to the point of use. In the following sections, some of the applications of desalination technologies with reference to feed sources are summarised.

4.1.1. Seawater

Seawater desalination for the supplementation of existing potable water sources and for ensuring potable water supplies during periods of droughts is undertaken in many places around the world. Coastal locations may present a virtually unlimited source of water of reasonably uniform quality to be fed into the desalination process as well as an economic and convenient sink for disposing of the concentrate or reject. In particular, dual-purpose plants for power and water production are best located near an unlimited supply of cooling water. Desalted seawater can of course be supplied to areas a considerable distance from the point of production. The distance that water is conveyed, however, may be limited by the cost of constructing and operating the transport routes along the distribution system.

In the case of Sydney, where the feasibility of the largest seawater RO plant in the world is currently under investigation, the need to construct larger tunnels for water distribution from the desalination plant near a shoreline to a central distribution point is likely to add considerably to the capital cost of the desalination scheme.

4.1.2. Brackish Water

In areas where traditional sources of freshwater are limited by capacity or stressed by competing uses, such as irrigation and industrial needs, sources of brackish water may be utilised to supplement that water demand. These may come from estuary systems, ground water sources or inland rivers and lakes. Generally, brackish water sources are lower in salinity than seawater, however, in cases of droughts the freshwater flow into such systems may be depleted and salinities may increase beyond the ability of the desalting plant to produce potable water.

4.1.3. Recycled Water

Water reclamation from industrial and municipal STPs for reuse in applications such as irrigation, industrial reuse or ground and surface water recharge has seen strong growth in recent years. In Victoria, the Eastern Irrigation Scheme, a joint project between Earth Tech and Melbourne Water, is one such example where water is reclaimed from a sewage treatment process and treated using dual UF membrane technology for the purpose of irrigation.

In Orange County, California, the Groundwater Replenishment System (GWRS) STP treated water and recycles it using MF/RO membrane processes followed by ultraviolet (UV) light and hydrogen peroxide treatment for injection along the coast to maintain a seawater intrusion barrier to keep the Pacific Ocean out of the local groundwater basin. Water will also be allowed to percolate into the groundwater basin along the same natural filtering path rainwater takes through the ground. The project will make use of more than 25 years of water purification experience that began in 1976 with the first injection of reclaimed water into the coastal barrier.

Eraring Power Station on the shore of Lake Macquarie in New South Wales receives treated water from the nearby Dora Creek STP and reclaims it using MF/RO for use in and around the power station. This process has been operational for eleven years and has reduced the power station's demand on freshwater by 75%. The plant is discussed further in terms of its triple bottom line outcome in Case Example 2.

5. Membrane Technologies

Membrane processes of commercial importance in desalination are NF, RO and ED/EDR. Semi-permeable or ion specific membranes are increasingly used in desalination, on both a small and large-scale. The underlying process is based on physical separation of contaminants from the feed water. This can be achieved by applying pressure or an electrical charge against the membrane. Reverse osmosis and NF are examples of the former mechanism, electrodialysis of the latter. Table 2 provides an overview of removal capabilities of each of membrane process.

Table 2: Overview of typical particle removal achieved by membrane processes with application to potable water [WHO, 2004; Duranceau and Henthorne, 2004]

Process	Operating Pressure in kPa	Pore Size (µm)	Approximate particle size removed
RO	1000-5000	≥ 0.0001	Metal ions (monovalent), aqueous salts
ED/EDR	-	-	Metal ions, aqueous salts
NF	500-1000	≥ 0.001	Metal ions (divalent) organic chemicals (humus), hardness, synthetic dyes, herbicides, pesticides, sugars, detergents, soaps, radionuclides, cysts, viruses
UF	30-50	≥ 0.01	Organic macromolecules, colloids, protein, gelatin, viruses
MF	30-50	≥ 0.1	Turbidity, clay, asbestos, algae, bacteria

Advantages of the RO process include fewer membrane cleanings and longer membrane life [Duranceaou and Henthorne, 2004]. Nanofiltration or softening membranes for pre-treatment are used predominantly to treat low salinity brackish or surface water and applicable to distillation desalination processes. At the city of Long Beach in California, a new proprietary technology to convert seawater into high-quality drinking water in the most cost-effective manner is being developed. The Long Beach dual pass NF method is 20-30% more energy-efficient than traditional desalination methods and promises to significantly cut costs. This emerging technology is further discussed in Section 11.4.

For liquid separations, most MF, UF, RO and NF membranes are made from synthetic organic polymers. Cellulose acetate (CA) or polysulfone/polyamide are typical materials used in RO membranes. Cellulose acetate membranes are relatively easy to make, have excellent mechanical properties and have a much higher tolerance to chlorine than membranes based on polyamides [Sagle and Freeman, 2004]. Some of the shortcomings that new membrane materials, such as thin-filmed organic composites, address are that CA membranes tend to hydrolyse over time which decreases their selectivity. Also, they are very sensitive to pH changes and salt rejection of CA membranes decreases with increasing temperature. There are four main types of modules for holding the membranes: plate-and-frame, tubular, spiral wound and hollow fibre. Spiral wound and hollow fibre are two popular models applied to desalination by RO or filtration. Hollow fibre modules consist of bundles of hollow fibres in a pressure vessel. If employed in membrane bioreactors (MBRs), they are sometimes suspended in the feed solution and permeate is collected from one end of the fibres [Sagle and Freeman, 2004].

Membrane technologies offer several benefits for the treatment of water derived either from ground, surface or sea as well as recycled water. The costs of membrane treated water have significantly fallen and it has been estimated that for the same capital investment spent on seawater RO desalination in 1980, 27 times more water could be produced by systems in 2001 [Pankrantz, 2004; ARI, 2001]. A study of RO desalination plants in the early nineties found that on average it cost USD 1.00 to desalinate one cubic metre of seawater. By the end of the decade that average cost had dropped to about 70 US cents and is expected to decrease by another 20% over the next five to ten years. In addition, several other factors make membrane technology an attractive water desalination and treatment option, including:

- High efficiency and operational simplicity;
- High selectivity and compatibility;
- Low energy and chemical consumption;
- Smaller footprint;
- Good stability and modularity; and
- Easy control and scale-up.

A particular case can be made for water reclamation where the drivers for using membrane technologies to achieve quality reusable product water are the relatively low TDS levels in feed water, higher recovery rates and lower cost compared to seawater desalination. The NEWater experience in Singapore is a showcase example for using RO membrane technology to achieve significant water reclamation. Similarly, the use of MBRs is gaining more acceptance as process scaling has advanced significantly.

5.1. Reverse Osmosis

Reverse osmosis is a mature technology that has progressed from small, specialised treatment schemes some 30 years ago to a wide range of applications covering specialised separations, water reclamation and potable water preparation.

While osmosis refers to the transport of solvent (e.g.: water) through a semi-permeable membrane from a lower concentration gradient of solute to that of a higher concentration gradient, in RO, pressure is applied to the surface of a saline solution, forcing pure water to pass from the solution through a semi-permeable membrane that rejects most solute ions and molecules. By using pressures around 7 MPa, it is possible to produce potable water from seawater in a single pass [Pankratz, 2004]. The quantity of pure water that passes through the membrane in RO is a result of the pressure differential between applied pressure and osmotic pressure of the saline solution. Figure 7 outlines the basic principles of osmosis and reverse osmosis.

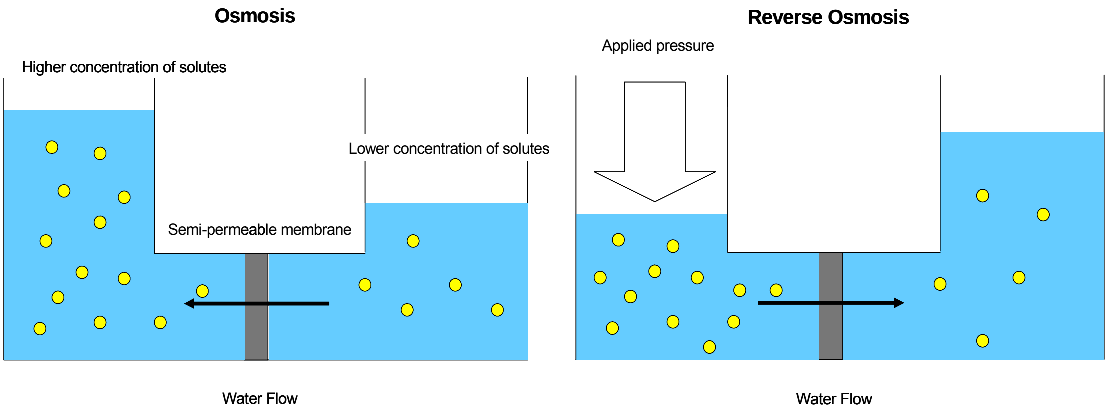

Figure 7: Schematic illustration of osmosis and reverse osmosis

Membrane elements utilised in RO desalination systems come in spiral wound configurations or hollow fibre modules. The critical parameters of these membrane modules are salt rejection and water permeability. Average permeate flow per commercial membrane element of about 37 m^2 active membrane area ranges from 12 to 23 m^3/d for seawater and brackish feed water, respectively [Wilf, 2004]. Membrane elements are connected in series inside a pressure vessel, which can operate with six to eight elements connected in series. For a 20,000 m^3/d seawater RO plant using eight elements this would translate to about 208 pressure vessels. The critical process and cost issue in RO systems is the prevention of membrane fouling and scaling due to microbial growth and salt deposition. The dependency of RO plants on high quality feed water to provide stable and reliable operation means pre-treatment of feed water is critical in RO desalination and needs to be given prudent consideration. Depending on feed water source and quality, UF or MF pre-treatment is applied for removal of scale-forming and fouling materials from feed water before it is passed through the RO membranes.

The inherent modularity of RO plants lends itself to the design and development of RO plants with greater economies of scale and reduced unit cost of desalinated water. Less saline waters, such as brackish water or waters with a salinity less than 5000 mg/L TDS, can be desalinated at lower pressures and concomitant energy requirements. Process temperatures employed range between 0-40°C for membrane desalination and energy consumption is largely attributable to the high pressure pumps required relative to feed water salinity to generate salt water permeation through the membranes. Overall, the energy consumption is much lower than for thermal processes, making RO plants largely independent of power plants for energy efficiency [Ebensperger and Isley, 2005].

Reverse osmosis desalination is found to be most suitable to regions where seawater or brackish water is readily available. Advantages of RO desalination over MSF desalination include lower energy consumption, easy start/stop operation for maintenance due to modular design without interrupting the entire plant and smaller area footprint with high space/production capacity ratio.

The main drivers for the desalination costs decreasing over the last 20 years are associated with savings due to scientific advances in membrane technologies and economies of scale.

Advances in membrane technology have led to:

- MF/UF membrane pre-treatment;
- Increases in membrane productivity;
- Extended membrane life; and
- Reduced energy use through lower feed pressures and higher water recoveries.

Savings associated with the economics of desalination are due to:

- Advances in membrane technologies;
- Large plants giving greater economies of scale;
- Larger RO trains and pumps available off the shelf;
- Improved project risk to finance profiles; and
- Co-location with power plants.

Costs of desalination by RO have been consistently falling since the 1980s and are projected to arrive at AUD 0.6/m^3 by 2010 [Voutchkov, 2005]. The largest seawater RO plant project, at 100 million m^3 per year, is located in Ashkelon in Israel. The plant is expected to produce water in 2005 and has offered the lowest price for desalinated water, at USD 0.527 per m^3, yet [Kronenberg, 2004]. The decreasing trend of total water cost for RO for large seawater desalination plants, either installed or projected, is outlined in Figure 8 using an average 2003 USD value.

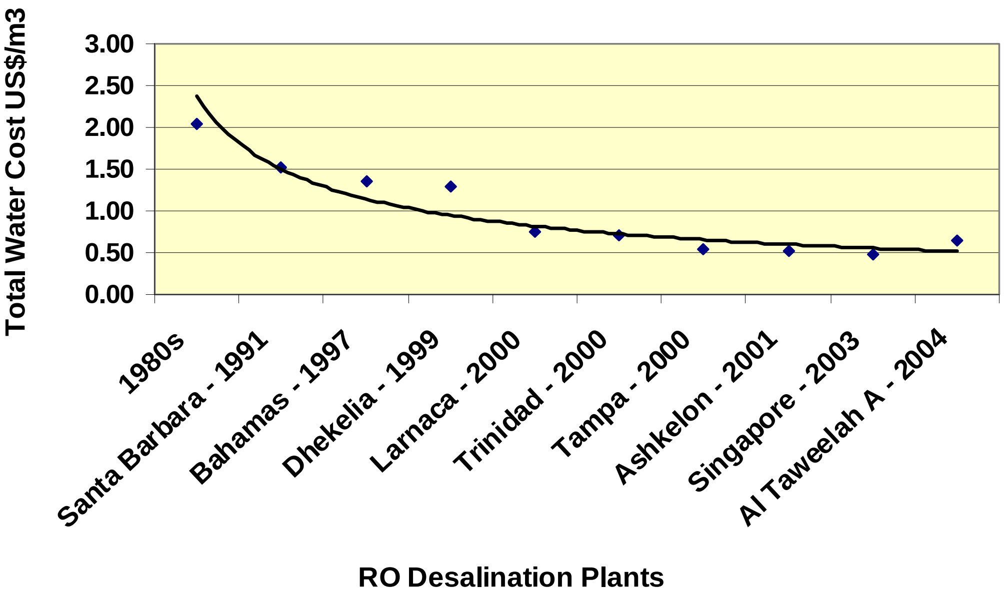

Figure 8: **Trend in water cost decline for seawater desalination with RO [Crisp, 2005]**

5.2. Electrodialysis / Electrodialysis Reversal

Electrodialysis was one of the first commercially available large-scale water desalination processes since membranes became widely available more than 40 years ago and is still widely used all over the world for the production of potable water from brackish water [Strathmann, 2004]. In water desalination, ED is competing directly with distillation, RO and more recently NF.

Electrodialysis and EDR use cation-and anion-specific membranes that are semi-permeable to ions based on their charge. Electrodialysis is an electrically driven process in which charged ions are pulled through a stack of cation and anion membranes (membrane stack) under the influence of a low voltage direct current (DC) field. Ions in the water are attracted to either the anion or cation electrode and concentrated, leaving a much lower ionic concentration in the water of the alternate channel. In EDR, the DC field in the membrane stack is periodically switched resulting in the reversal of the polarity of the electrodes and this causes a break up and flush out of scales and fouling agents deposited on the membranes before they can build up. This reversal reduces the need to add anti-scaling chemicals into the desalination process, thereby reducing costs. Electrodialysis or EDR is used in desalination of lower salinity water, especially brackish water and is increasingly being optimised for desalting of recycled water. At higher salt concentrations (> 12,000 mg/L TDS), the cost of the ED process becomes uneconomical as it is proportional to the salt concentration in the feed water [Reahl, 2004; Oren *et al.*, 2002]. Figure 9 schematically outlines the principle of ED desalination.

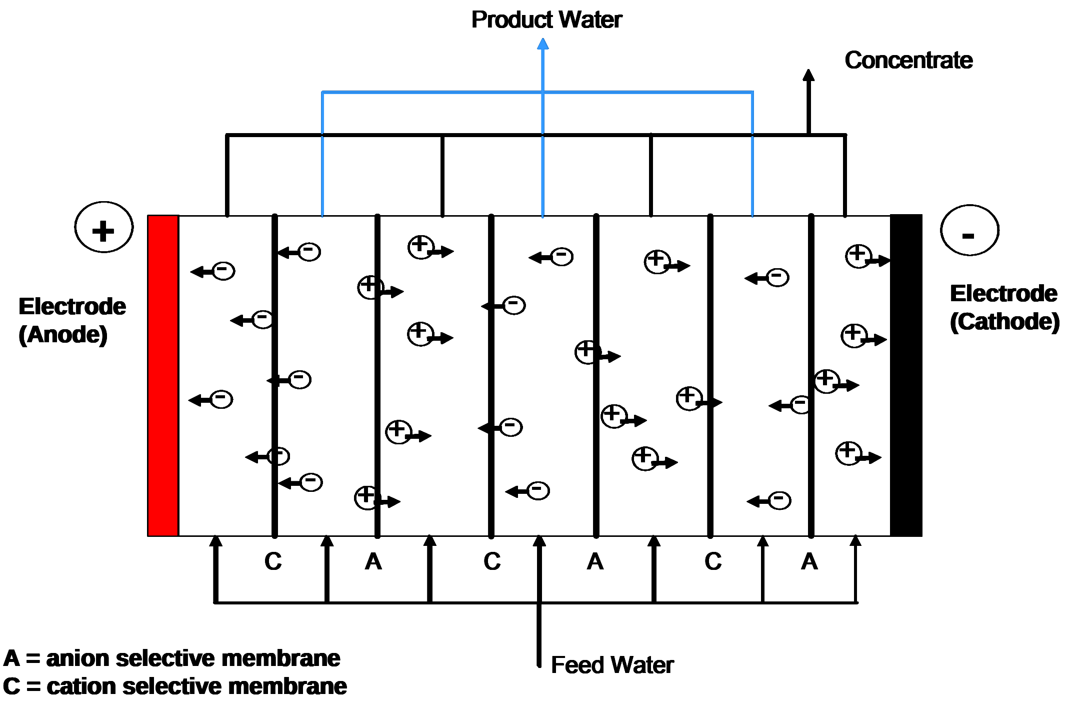

Figure 9: **Principle of electrodialysis under constant DC current field.**

One of the drawbacks of ED/EDR is that the process only removes ions and charged matter. Therefore, ED/EDR does not serve as a barrier to bacteria, colloidal material or silica present in the feed water and furthermore does not remove taste or odour components.

With continuous operation, fouling and scale deposits may form on membrane surfaces which result in an increase in membrane stack resistance and power requirements. Pre-treatment will depend on the feed water quality and is normally undertaken to remove alkaline scalants, iron, manganese and suspended solids. Polarity reversal reduces the need for adding acid to the feed water and helps to clean membrane surfaces of scalants and foulants, thus EDR has less stringent pre-treatment requirements.

5.3. Membrane Filtration

Pressure driven membrane filtration processes are increasingly replacing conventional treatment as they facilitate consistent feed water quality at reduced economic and environmental cost. The choice of membrane types used in pre-treatment depends on feed water and product water quality and requirements of the desalination technology used. The following sections describe the three membrane filtration processes that are widely used in desalination.

When water evaporates, the dissolved minerals in the water concentrate. The minerals and contaminants eventually reach a concentration where they precipitate as scale and interfere with the performance of both thermal and membrane desalination technologies. Typically, chemicals are added to the water to inhibit the formation of scale, control algae and bacteria, and provide corrosion protection. Feed water pre-treatment is therefore one of the major factors determining the success or failure of desalination installations, specifically in RO desalination, but also for distillation processes.

Traditionally, pre-treatment options for desalination processes have consisted of mechanical methods utilising cartridge and media filters supported by extensive chemical treatment. Flocculant dosing ($FeCl_3$), chlorine scavenger dosing ($NaHSO_3$) and addition of anti-scaling agents (e.g. H_2SO_4) are some of the chemical methods applied to improve feed water quality. Specific additives are required to prevent corrosion and preserve RO membranes and introduction of these into the process at various points results in a complicated system in which problems such as biofouling after addition of a chlorine scavenger or fouling by organic compounds can result. Seasonal variations in seawater quality and frequent cleaning to minimise efficiency losses further add to conventional pre-treatments contributing significantly to the total cost of desalination.

5.3.1. Microfiltration and Ultrafiltration

Membrane filtration using MF and UF as pre-treatment steps to RO desalination has been used since the 1990s. Microfiltration membranes accounted for the largest share of total demand in 2003 and represent an established and more mature segment of the market, benefiting from their wide use as a pre-treatment membrane. For treatment of reclaimed water to EPA Victoria class A guidelines, protozoa and viruses must be removed to < 1 protozoa or enteric virus per 50 litre [EPA, 2003]. Microfiltration and UF membranes are capable of achieving significant microbiological contaminant reduction, as outlined in Table 3, making them also attractive as stand-alone treatment technologies [Peters and Forbes, 2005; WHO, 2004].

Table 3: Typical log reduction values achieved by MF and UF [Peters and Forbes, 2005; WHO, 2004]]

Contaminant (relative size)	MF (0.08 – 0.22 µm pore size)	UF (0.01 – 0.05 µm pore size)
Giardia (5 – 15 µm)	> 4.7 to > 7.0 log reduction	> 4.7 to > 7.0 log reduction
Cryptosporidium (2 – 5 µm)	> 4.4 to > 6.9 log reduction	> 4.4 to > 7.0 log reduction
Virus (0.01 – 0.1 µm)	< 1 log reduction	> 6 log reduction
Total coliform (> 0.2 µm)	> 4 log reduction	> 7 log reduction

Microfiltration and UF occurs by a sieving mechanism, making it capable of removing bacteria and cysts from the feed water. It is a process for separating material of colloidal size and larger and can be operated in two ways: as a through-flow filter (dead-end filtration) or in a cross-flow mode. Cross-flow filtration is more energy intensive than through-flow, as energy is required to pump the fluid across the membrane surface but has the advantage of sweeping deposited particles off the membrane. Currently, most MF systems operate in the conventional through-flow mode. The particles retained accumulate and are disposed with the membrane. Ultrafiltration provides an improvement in feed water quality over MF with a barrier surface capable of removing not only suspended solids but also waterborne pathogens, dissolved macromolecules and colloids. Studies utilising a combination of UF-RO desalination showed that UF provided excellent pre-treatment for the RO, with no RO cleaning required for six months [Pearce et al., 2004]. In addition, the UF pre-treatment allowed for a much more aggressive flux and recovery operation at the RO.

Dual membrane processes featuring MF and RO are installed and used in water reclamation and seawater RO. Two MF trains, as installed at the Wollongong STP for advanced water reclamation, are shown in Figure 10. Hollow fibre membranes allow feed water to enter through the centre of the membrane fibre and clean water is filtered through to the outside. In such installations, the membranes are backwashed at regular intervals ranging from 15 minutes to one hour to remove solids built up on the membrane surface during filtration (Figure 11).

Ultrafiltration followed by a disinfection step was used in the Eastern Irrigation Scheme in a Victorian pilot study to treat secondary effluent for reuse. The trial demonstrated the ability of the UF technology to achieve 80 to 85% recovery at the EPA Victoria Class A guidelines.

Figure 10: Microfiltration trains at Wollongong

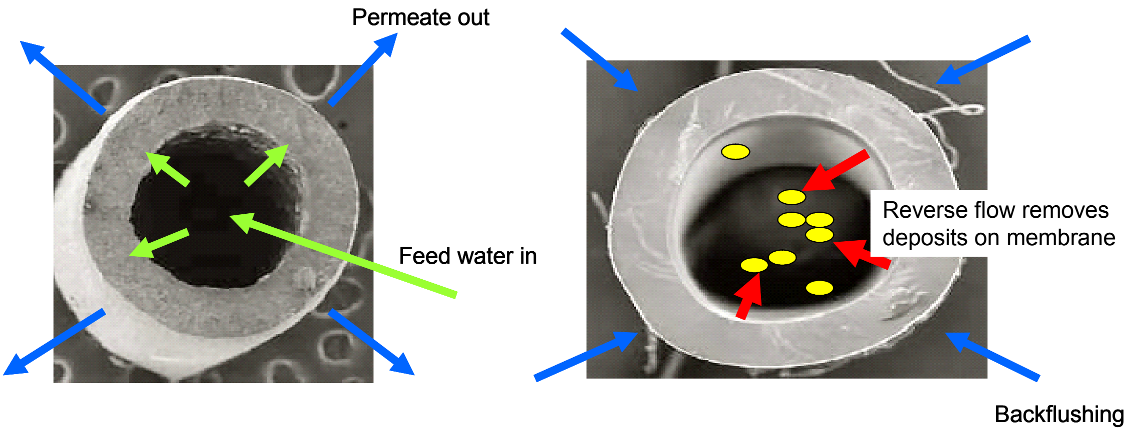

Figure 11: **Principle of membrane filtration through hollow fibre membranes (left) and backwashing to remove build-up of solids (right)**

5.3.2. Nanofiltration

Nanofiltration is a lower pressure RO technology and has been applied in potable water production as well as water reclamation. The process combines two separation mechanisms, the removal of uncharged components at the nano-scale through size exclusion and the removal of multivalent ions through charge effects between solution and membrane surface. Nanofiltration membranes have many applications in water treatment. Several NF membranes are available to remove hardness from ground and surface waters, pesticides and other micro-pollutants. Nanofiltration is also increasingly applied as an efficient and economic technology for desalinating and recycling water used in many industrial processes. Applications include the removal of organic loadings from water used in food manufacturing, colour in water used by the textile industry, treatment of opium alkaloid industrial effluents as well promising removal rates of hexavalent chromium and lead [Hilal *et al*., 2004; AMTA, 2005]. Like all membrane technologies, NF membranes also suffer from mechanisms leading to fouling at the membrane surface.

The introduction of NF as a pre-treatment is viewed to have implications for the RO or MSF desalination process itself [Van der Bruggen and Vandecasteele, 2002; Hilal, 2004]. Pre-treatment using NF technology facilitates the removal of divalent ions such as calcium and magnesium, suspended solids, the lowering of the Salt Density Index (SDI) and minimises microbial contamination. Colloidal fouling tendencies of RO membranes are relative to the feed waters SDI, an ASTM method for measuring small particulate/colloidal loading in water. It is recognised that the introduction of NF as a pre-treatment for RO or MSF desalination will lead to a breakthrough in the application because it improves the feed water quality, thereby allowing RO to be operated at lower pressures and enhancing MSF top brine temperatures. This results in lower operating costs for both desalination processes, higher recovery and less need for chemical or anti-scaling additives [Van der Bruggen and Vandecasteele, 2002; Hilal, 2004].

5.4. Membrane Bioreactors

Research into combining membranes with biological processes for wastewater treatment began over 30 years ago and membrane bioreactors have been used commercially for the last 20 years. Today, over 1,500 membrane bioreactor plants have been commissioned to treat both industrial and municipal wastewater and reliably produce quality product water.

The use of MBRs has progressed to full-scale application with the largest operational MBR treating 45,000 m^3/d at Nordkanal, Germany and a 76,000 m^3/d MBR being under construction at the Al Ansab STP in the Sultanate of Oman [Kwong *et al*., 2005]. Commercial MBR systems have proven both reliable in performance and simple to operate with low membrane failure rates resulting in reduced capital and operational costs. This coupled with increased focus on water recycling and the need to achieve higher discharge standards, to satisfy legislation requirements, means that the use of MBR technology is becoming a realistic option for advanced water treatment for the production of water fit for purpose.

The UF or MF membranes utilised in MBR systems have pore sizes such that water and most solute species pass through the membrane whilst other larger species, such as solids and microorganisms, are retained. In an MBR, membrane filtration occurs either within the bioreactor as a submerged flat sheet or hollow fibre installation (Figure 12) or via recirculation through an external hollow membrane. Advantages of MBR systems in water reclamation are a small footprint compared to conventional treatment systems, ease of use and operation and the potential to retrofit into already existing treatment infrastructure.

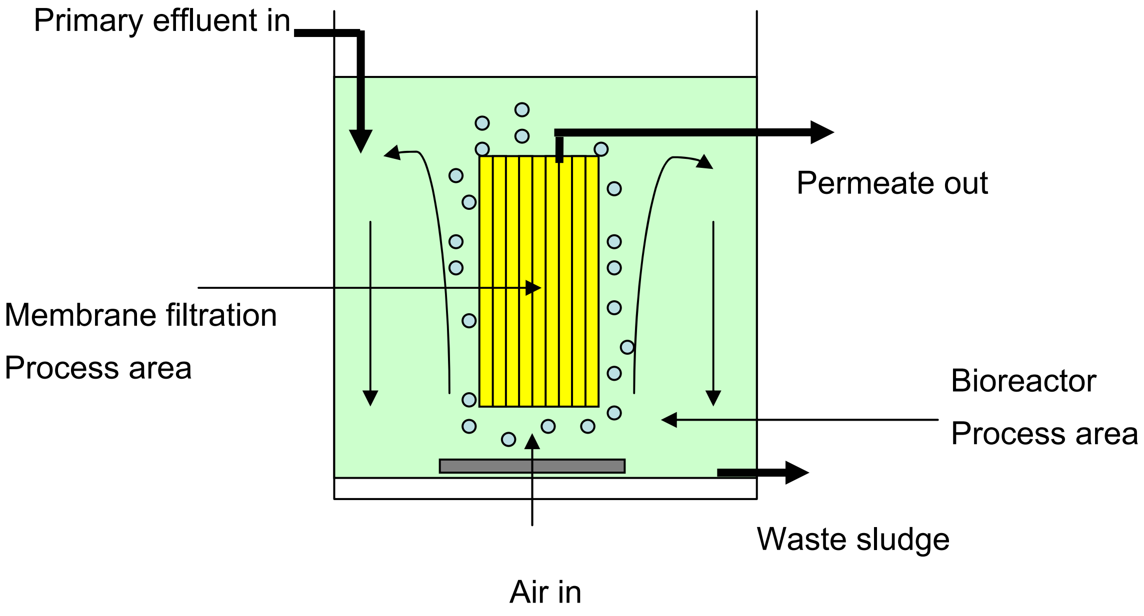

Figure 12: Submerged, flat sheet membrane bioreactor process

The first commercial scale MBR in Australia was commissioned at Picnic Bay on Magnetic Island in Queensland in late 2002. The decision to consider a MBR for water treatment was made necessary by the stringent tertiary treatment standards imposed to protect the Great Barrier Reef. The plant has consistently produced very high quality water at 540 m^3/d for recycling or discharge to the sensitive waters of the Great Barrier Reef Marine Park.

The largest MBR system in Australia, a 5,100 m^3/d plant at Victor Harbor in South Australia, is scheduled to commence operation in 2005. The MBR technology is integrated with a simultaneous nitrification-denitrification technology and is estimated to reduce phosphorus discharge by 99% compared with the discharge from the existing treatment plant. It is expected that a significant proportion of the Class A recycled water will be reused for unrestricted irrigation of agriculture, parks and gardens [SA Water, 2005a].

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6. Thermal Technologies

Desalination plants, particularly thermal ones, require large amounts of energy for their operation. In some instances up to 70% of a plants operating cost have been reported to be for the provision of energy for the operation of the plant. The high operating costs may make the cost of water produced more expensive than other water supply options. Associated costs of high energy consumption for distillation desalination technologies have particularly high restraining effects on small and medium-sized desalination needs. The arrangement of thermal plants, operating in conjunction with power production, so called dual-purpose plants, and, more recently through integration with RO plants [Almulla *et al*., 2005], can result in lowering the primary fuel cost of the desalting plant by 60-70%, thus reducing the cost of the produced water significantly [Watson *et al*., 2003].

At the beginning of the 1960s, the only process available for seawater desalination was distillation. Then, the only feasible and economic option to achieve large-scale capacities was by dual purpose, electric power/seawater desalination plants using MSF technology. Expansion of the use of RO membrane and other water distillation technologies, such as MED and VCD, along with the energy and capital investment intensity of MSF plants have seen a gradual decline in MSF operated desalination plants worldwide.

For MSF, the cost of water produced has decreased by an average of 44% per decade over the past 50 years [Ebensperger and Isley, 2005]. The water cost for very large thermal desalination plants on the Arabian Peninsula range from USD 0.60/m^3 for MSF to USD 0.80/m^3 for MED coupled with VCD [Wangnick, 2005]. Examples of large-scale thermal desalination plants include Taweelah B in the United Arab Emirates (350,000 m^3/d) where seawater is desalinated using MSF, Hidd in Bahrain (136,000 m^3/d) and Alba in Bahrain where a MED-TVC process is employed to desalinate 43,000 m^3/d.

Multi-stage flash desalination is generally the process of choice for dual purpose facilities and for applications that cannot be performed by RO or EDR treatment, such as highly saline feed waters (greater than 50,000 mg/L TDS) or in situations where the feed water conditions would adversely affect the performance and life expectancy of membranes. Improvements in MED and VCD technologies have achieved lower capital costs as well as a reduction of power consumed, making these processes economically competitive with MSF desalination for all but the largest dual purpose installations [Watson *et al*., 2003].

6.1. Multi-stage Flash Distillation

Distillation is a phase separation method where saline water is heated to produce water vapour, which is then condensed to produce freshwater. In essence, distillation processes mimic the natural water cycle in that saline water is heated, producing water vapour which in turn condenses to form freshwater.

Multi-stage flash distillation operates on the principle of lowering the pressure in a sealed container such that the boiling point of a liquid is reduced. A hot saline solution is driven through a series of evaporation chambers which are held below the saturation vapour pressure of the water. A fraction of the water is flashed (evaporated) into steam, with vapour condensing in the upper sections of the flash chambers and collected as plant product. Multi-stage flash systems typically have a number of stages; one MSF stage is outlined in Figure 13.

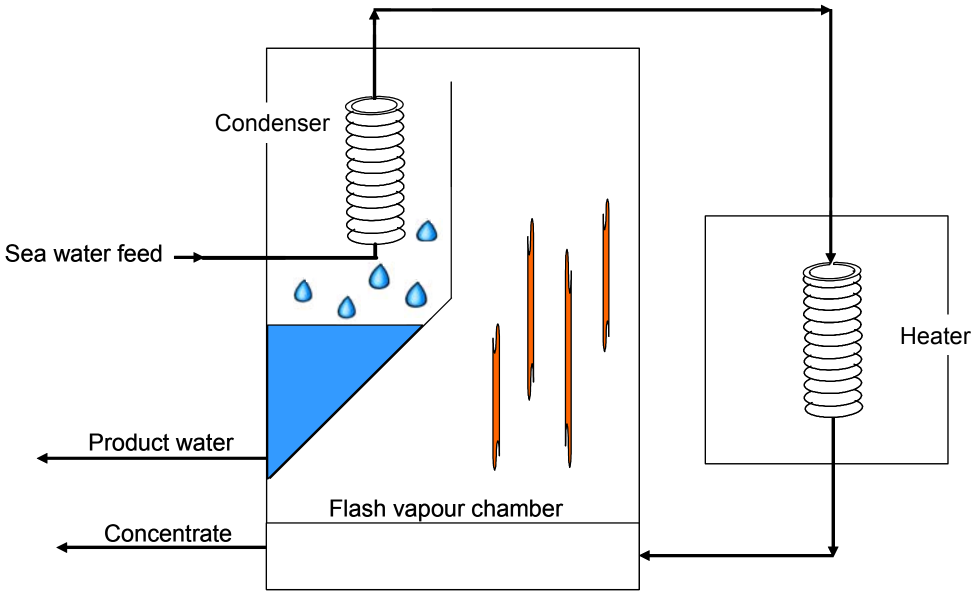

Figure 13: One MSF stage showing flashing chamber and condensing section

There are two major arrangements used in MSF, the brine recirculation and once-through arrangements. The majority of the operating MSF plants are based on brine recirculation. The once-through system requires a large amount of chemicals and feed seawater compared to the recirculation system. An additional drawback of the once-through design is that the entire feed must be pre-treated before entering the unit to minimise the effects of corrosion and scaling.

Based on the type of design, operating temperatures for the once-through and recycle designs are usually limited to between 90 and 110°C. Therefore, the steam production in thermal systems represents the main energy factor and many large MSF desalination plants are co-located near power stations that can supply waste heat to enhance the energy efficiency. Such dual purpose MSF desalination plants are economically attractive because the cost of the plant is allocated to two products, lower financial investment due to the sharing of facilities, less fuel consumption and less required labour. Disadvantages of dual purpose MSF include a reduced overall flexibility and a slightly lower availability factor [Al-Mutaz and Al-Namlah, 2004].

6.2. Multiple Effect Distillation

The MED process has a fairly long history. It is the oldest large-scale evaporative process used for the concentration of chemicals and food products, and it was the first process used for producing significant amounts of desalted water from seawater. However, its large-scale application to desalination began only during the past two decades. During MED, ambient pressure is reduced in the various stages as the temperature decreases, allowing the feed water to undergo multiple boiling without having to supply additional heat after the first stage. Inside the units, steam is condensed on one side of a tube wall while saline water is evaporated on the other side. In the process, a series of condensation and evaporation processes takes place, each called an “effect”, and the energy used for evaporation is the heat of condensation of the steam. The combined condensed vapour constitutes the final product water. Typically eight to sixteen effects are used in a large MED plant.

Multiple effect distillation plants have been built in vertical tube or horizontal tube arrangements. In the vertical tube evaporator (VTE), the seawater boils in a thin film flowing inside the tubes and steam condenses on the heat transfer tubes. In the horizontal tube thin film (HTTF) evaporator, the seawater feed is sprayed on the outer surface of the tubes and vapour flows inside the horizontal tubes, where it condenses to product water. The advantage is that the overall heat transfer coefficient is about three times that of a submerged tube desalination plant. A schematic outline of a horizontal tube MED effect process is illustrated in Figure 14.

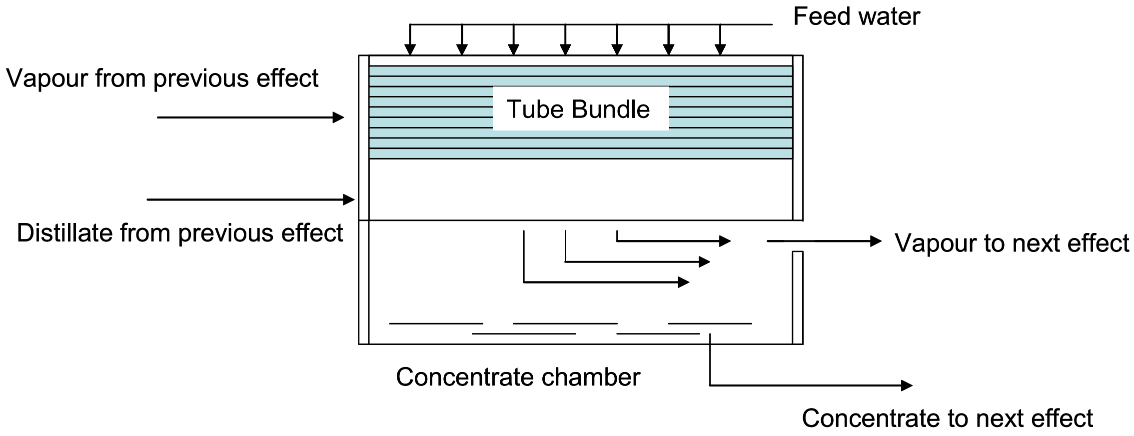

Figure 14: Multiple effect distillation horizontal tube arrangement showing single effect

However, HTTF evaporation is sensitive to the distribution of brine on tubes, and the seawater supply to each effect should be large enough to prevent dry spots. A significant improvement in heat transfer is achieved by using oval tubes for distribution and film thinning. A low temperature (LT: up to 70°C) version of the HTTF is the LT-MED, which is gaining more acceptance for low and medium capacity desalination plants, owing to following advantages:

- Lower energy consumption;
- Higher heat transfer coefficient;
- Compactness;
- High product water quality; and
- Reduced pre-treatment.

These newer LT-MED systems have also been studied in combination with solar energy input as small-scale desalination plants for remote areas [El-Nashar, 2001].

6.3. Vapour Compression Distillation

Vapour compression distillation has been in use over 100 years and is a proven means to reduce the energy requirements for evaporation. It has seen significant growth for desalination applications since the 1980s and is similar in process operation to MED. In a vapour compression evaporator system, the vapour released from the boiling solution is mechanically compressed, which in turn raises the vapour pressure and saturation temperature such that it may be returned for reuse as heating steam. The heat present in the vapour is used to evaporate more water instead of being rejected to a cooling medium in a condenser. Low temperature VCD is a simple, reliable process and produces high quality product water (5–25 mg/L TDS). Figure 15 provides a schematic illustration of the process. Feed water enters the process and is sprayed over the tube surfaces as shown in the figure for a horizontal arrangement or distributed to tube ends in the case of a vertical arrangement. A portion of feed water flowing down the inside tube surfaces is then vaporised through the action of heat on the outside surfaces of the tube. The vapour generated is then passed to either a thermal or mechanical compressor. Compressing the vapour raises the temperature by a sufficient amount to serve as the heat source. The distillate stream is formed as the vapour gives up its heat, condenses and is then pumped to the post-treatment system. A steam supply is required to initiate start-up, but once operational, additional heat is not required unless operating conditions or feed water temperature change.

A number of desalination plants are installed worldwide for producing good quality water from saline water for industrial and municipal use. However, VCD plants have the disadvantage of restricted plant capacity due to scale limitations for large size vapour compressors [IAEA, 2000].

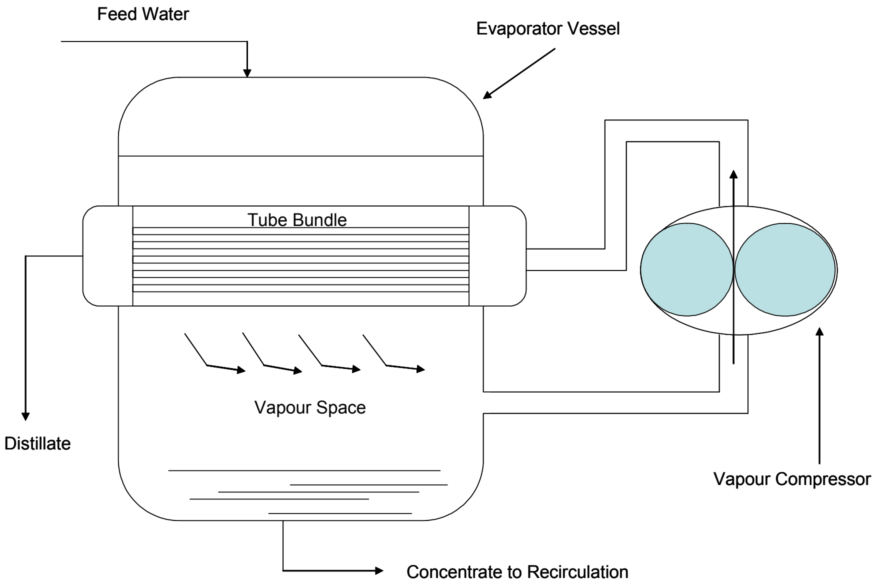

Figure 15: Schematic outline of horizontal tube arrangement VCD

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7. Pre-treatment

Some pre-treatment for a desalination or water reclamation plant is generally required. Pre-treatment ensures that constituents present in the feed water do not impede on the performance of the plant or result in a reduction in the output of the plant and quality of the product water. Each technology has different requirements for the quality of feed water entering the process. Some of the concerns that need to be addressed when choosing a particular technology are also considered in this section.

7.1. Pre-treatment for Membrane-based Desalination Plants

The configuration of membranes used in RO and ED/EDR processes makes them highly susceptible to a variety of scalants and foulants. Most plants therefore pre-treat feed waters prior to the desalination process to prevent membranes from clogging. The main goals of pre-treatment for membrane desalination are to control:

- Membrane scaling (e.g. by calcium sulfate and calcium carbonate);
- Metal oxide fouling (oxides of ferric iron and manganese);
- Biological activity (biofouling and biofilm formation); and
- Colloidal and particulate fouling (clays, colloidal colour).

Each source of feed water to a membrane presents its own unique treatment challenge. Silica and hydrogen sulfide are particularly troublesome when it comes to causing operational problems and membrane damage [Watson *et al.*, 2003]. Silica is largely unaffected by passage through an ED/EDR system but RO membranes reject silica and generally require the silica concentration to be less than 120 mg/L. Inhibitors added to the feed water are used to control silica precipitation on RO membranes. Hydrogen sulfide, like all gases is passed by RO membranes and appears in both, permeate and concentrate. It is common practice to deal with hydrogen sulfide in post-treatment, since the removal from the permeate is more effective and less costly. In ED/EDR however, hydrogen sulfide must be removed from the feed water to prevent oxidation and resultant membrane fouling with colloidal sulfur [Watson *et al.*, 2003].

Commonly used membrane filtration processes include MF and UF which progressively remove suspended and dissolved solids. This pre-treatment can add substantially to the projects capital and operating cost. Conventional media filtration, providing pre-treatment by using mostly chemical addition for coagulation and flocculation and sand or cartridge filtration is another method of choice commonly employed. Desalination plans in Perth and Sydney are considering conventional media filtration over membrane filtration as a pre-treatment for seawater desalination by RO.

Conventional systems produce RO feed water of an acceptable quality when properly tuned and seawater is of good and consistent quality. However, fluctuations in water quality coupled with low removal efficiency of colloidal particles may lead to problems that are detrimental to the operation of RO membranes. Ineffective pre-treatment can lead to problems with RO systems that include:

- Increased rate of membrane fouling;
- Higher rate of membrane cleaning required;
- Lower permeate recovery rates;
- Higher operating pressure;
- Reduced membrane life; and
- Reduced productivity.

Just how important the selection of a suitable pre-treatment is for RO desalination was seen at Tampa Bay, Florida (see Section 12.1.2). The largest North American seawater RO plant is intended to produce 95,000 m^3/d of product water providing up to 10% of the wholesale water supply for the Tampa Bay area. The plant originally used two-stage dual sand pre-treatment to remove turbidity, algae, organic and other particulate matter from the incoming seawater. This pre-treatment was not capable of delivering feed water of the recommended quality for the RO membranes. A crucial plant performance test in 2003 revealed 31 deficiencies in the plant, including excessive membrane silting. Further troubles compounding the situation included a sudden influx of Asian green mussels in the bay which clogged up the filters. As a result, the membranes fouled too quickly and the plant was far from achieving the water production it had been designed to deliver. In late 2003, a series of alternative pre-treatment technologies that could remedy the problems at the plant were tested with immersed UF membranes delivering a SDI that was consistently below that of the RO membrane manufacturer specifications [Wolf and Siverns, 2004].

7.2. Pre-treatment for Thermal Desalination Plants

As thermal desalination technologies operate on principles involving high temperatures the main concerns for a reduction in performance of the system stem from:

- Scaling of the heat exchanger tube surfaces;
- Corrosion of the plant components;
- Erosion by suspended solids; and
- Various effects of other constituents.

In distillation processes, calcium sulfate ($CaSO_4$), magnesium hydroxide ($Mg(OH)_2$) and calcium carbonate ($CaCO_3$) can cause scaling on the tube surfaces as these compounds precipitate out of the water. Traditional means of controlling scaling have involved the addition of anti-scalants or operating plants at lower temperatures. Nanofiltration is one pre-treatment technique that is sometimes used to reduce the potential of calcium sulfate scaling in distillation processes [Watson *et al.*, 2003].

Corrosion within the evaporator depends on the amount of gases entering the unit, operating temperature, pH and concentration of chloride ions. De-aerators and decarbonators are used to minimise the amount of corrosive gases entering the system, whilst the use of chloride resistant construction materials is the only effective means by which chloride corrosion can be minimised. The maximum temperature of operation is determined by the process type and chemicals used in pre-treatment whilst the pH of the feed water can be lowered with acid to prevent formation of bicarbonate ion (HCO_3^-), an ion responsible for the formation of calcium carbonate and magnesium hydroxide scaling.

Sand is the main suspended solid of concern for distillation processes. If sand is allowed to enter the evaporator, the tubing surfaces can erode leading to early replacement and consequent increase in the cost of water. In addition, sand can also plug spray nozzles, which can result in more frequent shut-downs for cleaning. Similarly, oil contamination must be removed to prevent fouling in the evaporator whilst marine growth is usually controlled by the early addition of chlorine into the feed water.

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8. Post-treatment

Product water from a desalination process requires post-treatment to prepare it for potable water use and various industrial applications. Post-treatment practices are generally determined by law or regulatory compliance. Regardless of what other post-treatment steps are employed, disinfection is required for municipal drinking water systems.

Product water from a desalting process, and particularly a membrane-based process, is essentially free of pathogenic organisms and would be deemed fit for drinking. However, disinfection is required before introducing this product water into the existing municipal drinking water system. Foremost, disinfection is the single process that has the greatest impact on drinking water safety resulting in substantial decreases in waterborne diseases and is therefore one of risk management [ADWG, 2004]. Furthermore, post-treating product water from a desalination process with a disinfectant ensures that a disinfection residual is present throughout the water distribution system and helps prevent contaminants from entering the distribution system due to membrane tears or leaks. Disinfection of product water can be achieved in a number of ways. Effectiveness of disinfection depends on:

- The nature and concentration of the disinfecting agent;
- The type of microorganisms present;
- Contact time;
- Satisfactory mixing;
- The degree to which the microorganisms are protected by adsorption or attachment;
- The level of competing inorganic and organic reactants; and
- Turbidity, temperature and pH.

Microorganisms are generally very susceptible to chlorine, chlorine dioxide and ozone but less so to monochloramine. Depending on the type of desalination process used, disinfection by chlorine application may also occur prior to feed water entering the desalination process.

Product water from desalination technologies has a low mineral content and alkalinity and therefore has a high corrosion potential, which requires stabilisation before it is introduced into any water supply system. For distillation processes, the total dissolved solids typically range between 0.5 to 50 mg/L whereas for membrane processes the range can be from 25 to 500 mg/L TDS. If not stabilised, the water will attempt to do so itself by dissolving (corroding) materials it comes in contact with. Product water can be stabilised by the reintroduction of chemicals such as sodium bicarbonate, caustic soda, soda ash and chemical or hydrated lime. Limestone beds have sometimes been used in thermal post-treatment for stabilisation. The benefit of this approach is that both calcium hardness and alkalinity are added to the water at the same time.

Blending of product water with brackish ground water containing significant concentrations of calcium or bicarbonate is another approach for post-treatment stabilisation. Optimum stabilisation however, may not be achieved by blending in all cases and supplemental means such as pH adjustment may be required.

Product water from thermal or membrane desalination processes may contain hydrogen sulfide and/or carbon dioxide gas. Dissolved gas stripping is a further post-treatment process involving the use of packed towers with either forced or induced draft.

9. Advantages and Disadvantages of Technologies

A comparative summary of the relative pros and cons identified for the desalination technologies as applied to seawater desalination is provided in Table 4. There are advantages and disadvantages when comparing membrane with thermal technologies and many factors need to be considered depending on the purpose and objectives for considering a particular desalination process.

Advantages of membrane processes over thermal processes include:

- Lower capital cost and energy requirements;
- Lower footprint and higher space/production ratio;
- Higher recovery ratios;
- Modularity allows for up- or downgrade and minimal interruption to operation when maintenance or membrane replacement is required;
- Less vulnerable to corrosion and scaling due to ambient temperature operation; and
- Membranes reject microbial contamination.

Advantages of thermal processes over membrane processes include:

- Very proven and established technology;
- Higher quality product water produced;
- Less rigid monitoring than for membrane process required;
- Less impacted by quality changes in feed water; and
- No membrane replacement costs.

Comparison of typical costs for seawater desalination by RO and typical thermal processes have shown that for RO the largest cost reduction potential lies in capital costs and energy (Figure 16). For a typical large-scale thermal desalination plant, energy use represents 59% of the typical water costs with the other major expense being capital cost (Figure 17). It would seem that the most effective cost reduction for thermal desalination can be achieved by utilising alternative sources of heat or energy, such as dual purpose plants. In addition, the development of less costly and corrosion-resistant heat transfer surfaces could reduce both capital and energy costs [NRC, 2004].

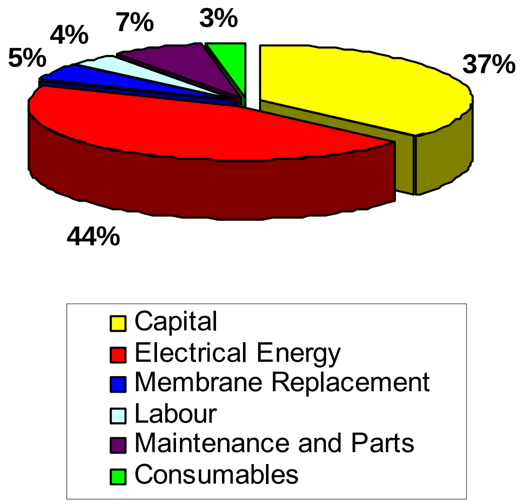

Figure 16: Typical cost structure for RO desalination of seawater [NRC, 2004]

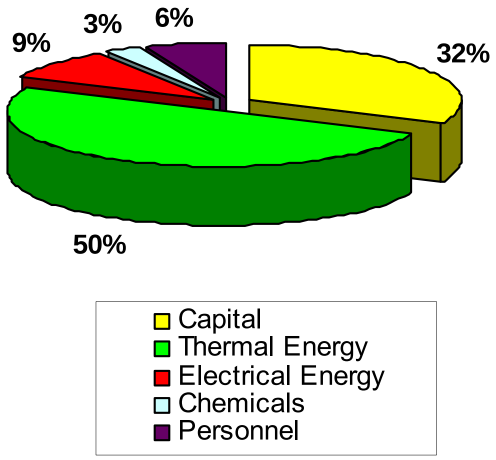

Figure 17: Typical cost structure for large thermal desalination of seawater [NRC, 2004]

Table 4: Pros and cons of desalination processes

Process	Recovery and TDS	Pros	Cons
RO	30-60% recovery possible for single pass (higher recoveries are possible for multiple pass or waters with lower salinity) < 500 mg/L TDS for seawater possible and < less 200 mg/L TDS for brackish water	• Lower energy consumption • Relatively lower investment cost • No cooling water flow • Simple operation and fast start-up • High space/production capacity • Removal of contaminants other than salts achieved • Modular design • Maintenance does not require entire plant to shut-down	• Higher costs for chemical and membrane replacement • Vulnerable to feed water quality changes • Adequate pre-treatment a necessity • Membranes susceptible to biofouling • Mechanical failures due to high pressure operation possible • Appropriately trained and qualified personnel recommended • Minimum membrane life expectancy around five to seven years
ED/EDR	85-94% recovery possible 140 - 600 mg/L TDS	• Energy usage proportional to salts removed not volume treated • Higher membrane life of 7-10 years • Operational at low to moderate pressures	• Only suitable for feed water up to 12,000 mg/L TDS • Periodic cleaning of membranes required • Leaks may occur in membrane stacks • Bacterial contaminants not removed by system and post-treatment required for potable water use
MSF	25-50% recovery in high temperature recyclable MSF plant < 50 mg/L TDS	• Lends itself to large capacity designs • Proven, reliable technology with long operating life • Flashing rather than boiling reduces incidence of scaling • Minimal pre-treatment of feed water required • High quality product water • Plant process and cost independent of salinity level • Heat energy can be sourced by combining with power generation	• Large capital investment required • Energy intensive process • Larger footprint required (land and material) • Corrosion problems if materials of lesser quality used • Slow start-up rates • Maintenance requires entire plant to shut-down • High level of technical knowledge required • Recovery ratio low

Table 4 (cont.): Pros and cons of desalination processes

Process	Recovery and TDS	Pros	Cons
MED	40-65% recovery possible < 10 mg/L TDS	• Large economies of scale • Minimal pre-treatment of feed water required • Very reliable process with minimal requirements for operational staff • Tolerates normal levels of suspended and biological matter • Heat energy can be sourced by combining with power generation • Very high quality product water	• High energy consumption • High capital and operational cost • High quality materials required as process is susceptible to corrosion • Product water requires cooling and blending prior to being used for potable water needs
VCD	~ 50% recovery possible < 10 mg/L TDS	• Developed process with low consumption of chemicals • economic with high salinity (> 50,000 mg/L) • Smaller economies of scale (up to 10,000 m^3/d) • Relatively low energy demand • Lower temperature requirements reduce potential of scale and corrosion • Lower capital and operating costs • Portable designs allow flexibility	• Start-up require auxiliary heating source to generate vapour • Limited to smaller sized plants • Compressor needs higher levels of maintenance

10. Environmental Discharge Considerations

Depending on the type of plant, liquid and solid waste disposal, air quality and noise must all be addressed in the planning process to ensure that desalination plants are designed and operated to minimise pollution.

Thermal pollution exists only with the distillation processes and air pollution is mainly a factor where dual purpose plants are considered. Chemical wastes generated in the process generally require suitable preparation and disposal. Membrane-based desalination and membrane pre-treatment generate solid waste in the form of redundant membrane material that is not readily recycled and is generally disposed in prescribed landfills, the management of which is facing challenges as these are filling up with closures of existing landfill sites imminent in Victoria. Best practice management requirements further impacts on this disposal option. In the case of distillation plants, the most significant solid waste is generated by spent heat transfer tubing. This waste is a more suitable candidate for recycling.

All desalination processes generate low-salinity product water and a high-salinity concentrate stream. Disposal of the concentrate is the most significant consideration for desalination facilities as the environmental impact can be considerable.

For desalination units located near the coast, the option exists to discharge the concentrate stream into the sea. For desalination plants located inland, the issue of concentrate stream disposal becomes more difficult and often costly. The main environmental benefits, however, to arise from applying desalination technologies inland include desalination of saline groundwater, the lowering of water tables in regions affected by dryland salinity and utilisation of saline discharge water from salinity mitigation schemes. Salinity mitigation schemes, many of which are located in the Murray-Darling Basin, produce saline discharge water which can be fed into desalination units and potentially contribute to land remediation and protection of high-value assets [National Dryland Salinity Program, 2001].

10.1. Thermal Impact

Concentrate effluents from thermal desalination plants will be at elevated temperatures, at least 10°C above the feed water, and it is understood that discharge at higher temperatures than the receiving water will impact upon marine life within the region of discharge in a number of ways. The inverse relationship between dissolved oxygen in water and temperature results in a reduction of dissolved oxygen at higher temperatures which is further impacted upon by increases in salinity and affects organisms that require higher dissolved oxygen levels.

10.2. Concentrate Disposal Options

Unlike most industrial processes, the concentrate waste stream from desalination processes is not characterised by process-enhancing chemicals. Rather, the concentrate reflects the characteristics of the source or feed water, only at a much more concentrated level. Although feed water is often pre-treated with chemicals to control scaling, fouling and inhibit biological activity, these chemicals are present at relatively low levels, typically less than 10 mg/L and thus the constituents in the feed water primarily define the concentrate stream [Watson *et al.*, 2003]. The most significant environmental risk associated with desalination processes specific to inland Australia are soil and groundwater contamination with saline water and chemicals, such as antiscalants and antifoulants added during the desalination process.

Backwash from MF/UF processes presents an emerging challenge for desalination plants utilising membrane filtration as pre-treatment. While these processes do not concentrate salt, they concentrate to varying extent suspended solids, organics and microorganisms. Backwash may contain microbial contaminants such as *Giardia* or *Cryptosporidium* and, as such, may require treatment before disposal to receiving waters.

10.2.1. Surface Water Discharge

Surface water discharge is the most common concentrate management practice for brackish water and seawater desalination plants involving the discharge to bodies of surface waters such as oceans, rivers or streams or to the effluent end of sewage treatment plants. For most seawater desalination plants, discharge to the deep sea appears the most economic answer to deal with the quantities of strongly saline concentrate stream which is also of lower pH than seawater in the case of RO desalination. Costs associated with this disposal management option are influenced by the location of the plant, conveyance costs to transport the concentrate, outfall construction and operation costs and environmental monitoring costs [Mickley, 2004a]. Costs associated with the monitoring of environmental effects may be significantly higher if the discharge is in an environmentally sensitive area.

The primary environmental concern is compatibility of the concentrate with the receiving water. An assessment of salinity impact as well as those specific constituents in the concentrate on the receiving water body should be undertaken. The risks of degrading sensitive coastal and marine ecosystems through lowered dissolved oxygen levels and fluctuating water temperature need to be evaluated. For concentrate disposal from thermal desalination plants this is an important consideration as dissolved oxygen concentration decreases with increasing temperature.

The Water Factory 21 (USA) is an example of a water reclamation plant discharging concentrate through an ocean outfall into the Pacific Ocean and is further discussed in Section 12.3.2. The plant provides high quality recycled water, which is injected into the underground aquifers to prevent further seawater intrusion, thereby assisting in the regeneration of the aquifers and decrease of salinity in the groundwater as well as reducing recycled water discharge into the ocean.

10.2.2. Land Application

A historical overview of concentrate management in the United States showed that of 234 desalination plants at the start of 2003 around 8% discharged the concentrate stream to land [Mickley, 2004b]. Land application of concentrate can significantly affect ground water or surface water resources and thus may require pre-dilution to meet ground water compliance. Land application has little economies of scale, thus generally limiting it to smaller plants. Compatibility and tolerance of target vegetation to salinity, percolation rates and irrigation needs, availability and cost of land are some of the factors that would need assessment for such a disposal option.

10.2.3. Discharge to Sewer

Where possible, this disposal option is simple and usually cost-effective. The possibility of discharging to sewer is site dependent and is affected by the distance between the desalination plant and sewer discharge point. In addition, the impact of concentrate salinity on performance of the STP is a critical issue. These criteria and associated costs have limited this disposal option to smaller sized desalination plants in the United States, where some 27% of desalination plants discharged their concentrate stream to the sanitary sewer in 2003 [Mickley, 2004b]. Additional salt loading into a STP, however, may limit future reuse potential of the recycled water. On the other hand, low salinity backwash water from MF or UF systems is routinely discharged to sewer in Australia for treatment at the STP.

10.2.4. Deep Well Injection

The capital cost associated with deep well injection are higher than for surface water discharge and require large economies of scale for this option to be economically viable. Compatibility issues with receiving ground water may require pre-dilution or treatment as well as monitoring, thus adding to costs associated with well depth, pipeline and pumping. Geological characteristics may not be appropriate in many areas as is the case in the United States where Florida is the only State practicing deep well injection within the context of membrane concentrate disposal [Watson *et al.*, 2003].

10.2.5. Zero Liquid Discharge

Lost water in desalination concentrates is increasingly becoming a consideration in cost-benefit analyses. If zero liquid discharge (ZLD) is required, the resulting residue from the concentrate will be in the form of sludge or dry salts. Zero liquid discharge or near-ZLD employs evaporative/crystallisation systems to remove as much water as possible to reduce the cost of concentrate disposal and to improve the options for beneficial use of the salt products. Brine or concentrate concentrators are costly mechanical equipment required in addition to associated energy costs which may be significant. An example of a zero discharge desalination plant is found at the 35,000 m^3/d desalination plant at Bayswater power station in New South Wales where discharge water is desalinated before reusing it in the boiler processes of the power station. The plant has been operational since 1986 and utilises a hybrid system of RO/MVC, where two MVC brine concentrators are key to the system achieving zero discharge.

10.2.6. Evaporation Ponds

Solar evaporation is a viable alternative in more arid climates and for inland desalination plants where discharge to surface water is limited by the availability of receiving water bodies, transport cost and economies of scale. Evaporation ponds are land intensive and therefore may be more applicable in areas with low land value. The costs of evaporation pond systems are mainly driven by the rate of evaporation, the concentrate volume, construction and lining of evaporation ponds, pipelines and monitoring. Compatibility issues for this disposal option with local wildlife may need to be considered. Evaporation ponds are relatively easy to construct, while requiring low maintenance and little operator attention compared to mechanical systems and also make excellent solar stratification ponds which can be used to produce a stored thermal energy gradient. In Australia, the more recently installed medium-scale solar pond system is at the Pyramid Hill commercial salt harvesting facility in Victoria (See Case Example 1). The system generates process heat using saline groundwater which may possibly be used for aquaculture and desalination in addition to use within the commercial salt production sector. Depending on the market for individual salts, and economics of technologies to selectively remove salts, salt recovery in combination with solar ponds may also be considered as a ‘saline effluent to products’ option for desalination plant concentrate.

Case Example 1: Pyramid Hill Victoria – Solar Pond Commercial Salt Harvesting

Pyramid Hill Solar Pond Commercial Salt Harvesting

The commercial salt harvesting facility at Pyramid Hill in Victoria is a good example of the potential that solar pond evaporation technologies may hold for inland disposal of desalination concentrate. A pilot project, undertaken by Pyramid Salt, Geo-Eng Australia and RMIT University, demonstrated the viability of harvesting the salt from the water table. Water at a rate of 150 m^3/d is pumped from the ground and placed in ponds to evaporate. It is estimated that solar ponds in climatic regions similar to northern Victoria can produce process heat (40-80°C) for a wide range of applications at an average cost of about AUD 10 to 15/GJ [RMIT, 2005]. As this feed water is naturally filtered by the sandy subsoil, it is cleaner than the seawater usually used to produce salt and therefore produces a superior product.

Although the Pyramid Hill project allows water to evaporate rather than capturing it as a resource, the potential is clearly demonstrated. The other major advantages of this solar pond facility include the generation of heat energy which can be used to dry salt or on-sold to other local industries. In addition to being an economically viable plant that produces salt for commercial sale, the Pyramid Hill project lowers the saline water table in the surrounding area. Figure CE1.1 shows the solar pond at Pyramid Hill including the mesh of pipes running down the wall of the pond. These circulate freshwater through the bottom of the pond which is heated by the saline pond water. The plastic rings on the surface are used to reduce the circulation effects caused by wind.

Figure CE1.1: Solar Pond at Pyramid Hill [Hignett, 2005]

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11. Alternative and Emerging Technologies

Alternative (or novel) technologies are far-reaching in nature, and investment in these novel technologies will be required to see a significant shift in the desalination cost curve. According to a review for the National Research Council [NRC, 2004], “alternative technologies can be categorised as either nascent and emerging technologies or radical combinations/advances to existing technologies.” By definition, these technologies are currently in an early stage of development or exist only as promising ideas. Some of these technologies are briefly discussed in the following sections along with proven or demonstrated technologies.

11.1. Membrane Distillation

Membrane distillation (MD) is a thermally driven membrane process in which hot feed brine is passed along the surface of a porous membrane. Water is evaporated at the brine-membrane interface of higher vapour pressure and passes through the membrane to the cold distillate side of lower vapour pressure. In the liquid form, the freshwater cannot pass back through the membrane at the membrane-distillate interface. Membrane distillation was introduced on a small-scale in the 1980s and has some advantages over other processes, including low sensitivity to feed concentration and the ability to operate at low temperature, making it more cost-effective if used in combination with waste heat from industry or solar collectors [Hsu *et al*., 2002; Alklaibi and Lior, 2004]. A small-scale solar-driven MD prototype was installed on the island of Ibiza in Spain in 1993 to produce 20 m^3/d of water [Bier and Plantikow, 1995].

11.2. Freeze Desalination

Freeze desalination processes operate on the principle that dissolved salts are naturally excluded during ice crystal formation. Seawater can be desalinated as the water is cooled under controlled conditions to the point where freshwater freezes but dissolved salts remain in pockets of higher salinity brine which is separated from the ice by washing processes. Developed in the 1950s and 1960s, the technology offers the potential of concentrating harmful constituents, however, its application in the production of potable water for municipal purposes has not been commercially successful [Water Corporation, 2000; Sonune and Ghate, 2004].

11.3. Electro-Physico-Chemical Processes

A smaller scale process for treatment of raw sewage or industrial wastewater has been developed involving a dissolved air flotation (DAF) process which removes chemically coagulated particles from the feed water followed by an electrolysis step where the feed water is sanitised. This system has the potential to be used in mining applications or decentralised treatment of wastewater within satellite developments, where high quality effluent is required. Currently the technology is available to treat up to 3,000 m^3/d of feed water with capacities up to 10,000 m^3/d being developed. Estimated water costs for this system are AUD 0.96/m^3 at an energy usage of 9.6 kWh/m^3. The environmental footprint of this system is small; a 3,000 m^3/d unit fits into an area of 200 m^2. A trial at the Wynnum STP in Brisbane has been conducted to demonstrate that the process can produce a Class A water without the need for any biological processes [Taylor, 2005]. The study found that the process employed offered treatment of inorganic substances, scale-forming constituents and heavy metals as well as efficient removal of unregulated pharmaceutically active contaminants.

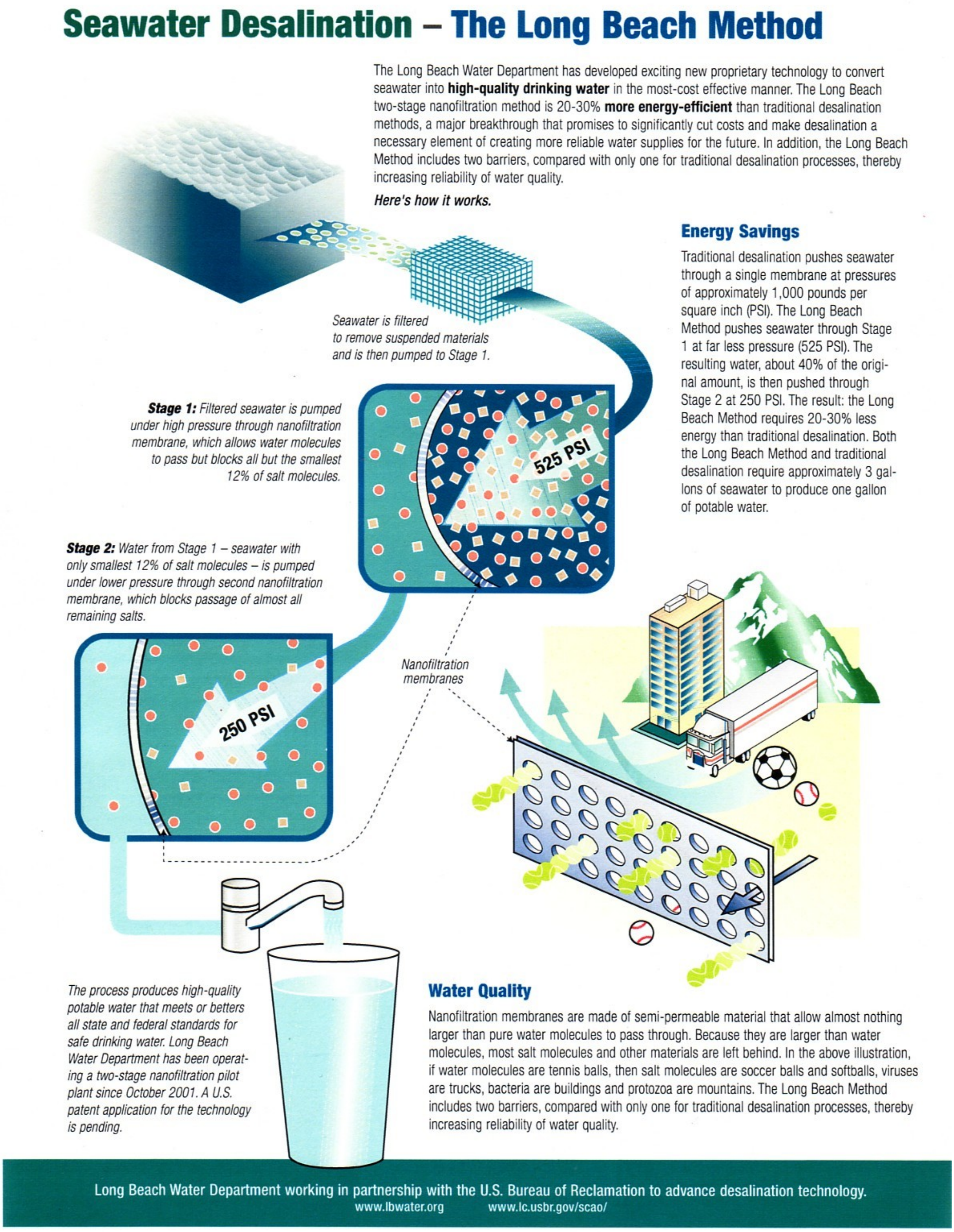
Although this technology is as yet to be proven in the Australian market, the demonstration trial in Brisbane highlighted that if the capital and operating costs can be offset with the avoided cost of other infrastructure such as the upgrade of a trunk sewer or pump station, the technology may offer a simple solution to water reclamation on a smaller scale.

11.4. Dual Pass Nanofiltration Desalination

At Long Beach in California, a new proprietary technology to convert seawater into high quality drinking water in the most cost-effective manner has been demonstrated since 2001 in a small-scale pilot project capable of treating 34 m^3/d. The technology developed utilises NF membranes in a dual pass, relatively low pressure process, now known as the "Long Beach Method", with a recovery of around 33%. Testing at this scale estimated the technology to be 20 to 30% more energy efficient than RO.

Following this pilot demonstration, Long Beach Water, along with the Los Angeles Department of Water and Power and the United States Bureau of Reclamation, is constructing a 1,135 m^3/d prototype two pass NF desalination facility, one of the largest seawater desalination research and development facilities in the United States, at a project cost of USD 8 million.

The facility is expected to be operational in August 2005 and once operational, research will be conducted for a period of 18 months. This research will be among the most advanced seawater desalination research being undertaken anywhere at this time and the data gathered will allow the verification of energy savings of the dual pass NF method and optimisation of the process so that it can be easily duplicated. Among the research being conducted at Long Beach will be a full-scale, side-by-side comparison of the dual pass NF and single-pass RO methods of desalination, the only full-size, energy-use comparison of these two processes being conducted at this time. The Long Beach project will also test many of the newest Energy Recovery Devices being made available [Wattier, 2005]. A description of how the technology is applied to seawater desalination is provided by Long Beach Water and is reproduced in Figure 18. At the same time, Long Beach Water proposes a "under ocean floor seawater intake and discharge system" to demonstrate minimisation of negative environmental impacts typically associated with open ocean intakes. The under ocean floor intake system also provides synergistic benefits as it acts as both, an intake and pre-treatment system, utilising slow sand filtration.



Seawater Desalination – The Long Beach Method

The Long Beach Water Department has developed exciting new proprietary technology to convert seawater into **high-quality drinking water** in the most-cost effective manner. The Long Beach two-stage nanofiltration method is 20-30% **more energy-efficient** than traditional desalination methods, a major breakthrough that promises to significantly cut costs and make desalination a necessary element of creating more reliable water supplies for the future. In addition, the Long Beach Method includes two barriers, compared with only one for traditional desalination processes, thereby increasing reliability of water quality.

Here's how it works.

Seawater is filtered to remove suspended materials and is then pumped to Stage 1.

Stage 1: *Filtered seawater is pumped under high pressure through nanofiltration membrane, which allows water molecules to pass but blocks all but the smallest 12% of salt molecules.*

Stage 2: *Water from Stage 1 – seawater with only smallest 12% of salt molecules – is pumped under lower pressure through second nanofiltration membrane, which blocks passage of almost all remaining salts.*

Energy Savings

Traditional desalination pushes seawater through a single membrane at pressures of approximately 1,000 pounds per square inch (PSI). The Long Beach Method pushes seawater through Stage 1 at far less pressure (525 PSI). The resulting water, about 40% of the original amount, is then pushed through Stage 2 at 250 PSI. The result: the Long Beach Method requires 20-30% less energy than traditional desalination. Both the Long Beach Method and traditional desalination require approximately 3 gallons of seawater to produce one gallon of potable water.

The process produces high-quality potable water that meets or betters all state and federal standards for safe drinking water. Long Beach Water Department has been operating a two-stage nanofiltration pilot plant since October 2001. A U.S. patent application for the technology is pending.

Water Quality

Nanofiltration membranes are made of semi-permeable material that allow almost nothing larger than pure water molecules to pass through. Because they are larger than water molecules, most salt molecules and other materials are left behind. In the above illustration, if water molecules are tennis balls, then salt molecules are soccer balls and softballs, viruses are trucks, bacteria are buildings and protozoa are mountains. The Long Beach Method includes two barriers, compared with only one for traditional desalination processes, thereby increasing reliability of water quality.

Long Beach Water Department working in partnership with the U.S. Bureau of Reclamation to advance desalination technology.
www.lbwater.org www.lc.usbr.gov/scao/

Figure 18: Reproduction of the Long Beach dual nanofiltration method [Long Beach Water, 2005]

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12. Global Trends

Less than three percent of the world's water has a salinity content that can be considered safe for human consumption, with the vast majority of the earth's readily available water being too saline for potable use [NRC, 2004]. Much of the world's freshwater is either trapped in polar icecaps or is located far underground with less than ½ percent being estimated to be easily accessible and of acceptable salinity [Watson *et al*., 2003]. In 2000, the World Health Organisation estimated that 1.1 billion people did not have access to safe water [WHO, 2000].

To facilitate and maintain economic development and minimise the adverse effects of water scarcity, many countries are faced with finding sustainable solutions to supply high quality water. Not only is the reliable supply of drinking water a necessity to sustain communities, other factors, such as environmental impacts on inland and major waterways need to be considered.

Solutions will likely require a combination of approaches, including demand management, recycling, improved water storage capacities and the utilisation of supply-enhancing water treatment technologies. Desalination offers the potential to supplement existing water supplies with desalinated water from otherwise impaired waters such as seawater, brackish or recycled water. However, the production of high quality water by desalination technologies still comes at a substantially higher cost than today's existing water sources, thereby keeping these technologies out of reach for many communities and countries.

Nevertheless, many countries and communities have undertaken large desalination projects to ensure reliable and stable potable water supply, unaffected by periods of drought or other conditions. This section provides some global examples of established and current projects into desalination for the production of potable water or fit for purpose water to sustain the water needs of respective communities and manage water reclamation. A brief summary of some of the larger plants, either operational or under construction is shown in Table 5.

Table 5: Some of the world's large desalination plants

Plant	Process	Location	m^3/d	cost (est.) USD/m^3	Purpose	Operational
Ashkelon	SW-RO	Israel	273,000	0.527	Drinking	Near completion
Tampa Bay	SW-RO	Florida	95,000 (+ 37,000)	0.67	Drinking	Intermittently operational
Singapore TUAS	SW-RO	Singapore	110,000	0.78	Drinking	Near completion
Al Taweelah	SW-RO	UAE	227,300	0.70	Drinking	Under contract
Singapore NEWater	WW-RO	Singapore	74,000 (+ 32,000)	0.57	Reclaim	yes
Water Factory 21	WW-RO	California	57,000	n/a	Aquifer recharge	yes
Al Ansab	WW-MBR	Oman	76,000	n/a	Reclaim	Under construction
Nordkanal	WW-MBR	Germany	43,000	0.31	Environ. flow	yes

SW-RO: Seawater-RO; WW-RO: Wastewater RO; WW-MBR: Wastewater-MBR

12.1. Seawater Desalination

12.1.1. Ashkelon, Israel

Israel has been experiencing a water supply crisis since 1998, the most severe since the existence of the State of Israel. A combination of low precipitation levels, prolonged drought and lack of management of water reserves led to the drying up of existing resources, mainly in coastal and mountain aquifers and the Sea of Galilee-Lake Kinneret. In 2000, Israel launched a Desalination Master Plan to address the water resource crisis. The plan entailed the construction of a number of seawater desalination plants along the Mediterranean coast for the production of water for human consumption. For Israel, the decision to invest in large-scale seawater desalination presented the only practical solution for additional drinking water supply and adding to the overall water balance as Israel's utilisation of existing drinking water sources has almost reached 100% [Dreizin, 2004].

The Ashkelon facility is the first of a series of large-scale desalination plants and will begin producing 50 million m^3 of water in 2005 and from mid-2006 will produce 100 million m^3 of water per year. An artist's impression of the finished plant occupying an area of 75,000 m^2 is reproduced in Figure 19. Reverse osmosis membrane technology was chosen for the Ashkelon facility with gravity dual-media filtration as the pre-treatment. Elevated boron levels are known to exist in the Mediterranean Sea, and with boron having been found to be potentially harmful in drinking water, it is believed that the level should not exceed 0.5 mg/L boron in potable water. For the Ashkelon Plant, this has resulted in designing an optimised, multi-stage RO and a flexible boron ion removal procedure guaranteeing a water quality after post-treatment with a maximum boron content of 0.4 mg/L [Dreizin, 2004].

Capital cost of the plant is estimated to be USD 250 million with a co-located gas turbine power station at an estimated cost of USD 75 million to provide the desalination plant with a dedicated electricity supply. At a published, estimated cost of water of USD 0.527/m^3, it is the lowest unit water cost thus far offered for a project this size. Fixed costs make up 58% of this cost with the remainder being maintenance and operating variable costs [Semiat, 2005; Velter, 2004]. Based on the developed model of this study, the water price for the Ashkelon facility averaged a comparable AUD 0.73/m^3 in 2005 dollars.

Figure 19: Artist's impression of the finished Ashkelon plant [Water Technology, 2005]

The facility is governed by a Build, Operate, Transfer (BOT) agreement entered into by the Water and Desalination Authority of Israel and a special purpose company, V.I.D. Desalination Company Ltd. The main innovation of the project lies in the structuring of a mixed bank/institutional local financing, paving the way for the financing of future projects [Coindreau and Rasoamanana, 2003].

12.1.2. Tampa Bay, Florida

In March 2003, the Tampa Bay Seawater Desalination facility began using seawater to provide a reliable supply of drinking water for the people of the Tampa Bay area. As the largest seawater RO facility in North America, the plant was designed to produce an initial 95,000 m^3/d, with a planned expansion to add a further 37,000 m^3/d in the future. The plant is co-located at Tampa Electric's Big Bend 2,000 MW power station. The facility was conceived as part of the Tampa Bay Water's Master Plan, a regional drinking water supply plan designed to restore the environment and meet the areas future drinking water needs. At 1036 km^2, Tampa Bay is Florida's largest open-water estuary (Figure 20). These unions of sea and stream are among the most fertile junctions on earth, and Tampa Bay is no exception. Discharge of concentrate from the Tampa Bay seawater RO facility has been designed to be on average 1 to 1½% higher than the bay's salinity levels due to a 70:1 dilution with the adjacent power plant cooling water. At this level, the discharge falls well within the yearly natural fluctuations of Tampa Bay. The USD 110 million alternative water supply began producing water in March 2003 but has since operated intermittently.

Figure 20: Landsat TM Scene of Tampa Bay, Florida [USGS, 2005]

In February 2004, the plant was placed in stand-by mode following a series of missed deadlines and failed acceptance tests that eventually cumulated in the bankruptcy of the construction firm. Since August 2004 and until March 2006, the plant has been undergoing intermittent operations, construction of remedy and testing of the remedied plant. Of 31 deficiencies revealed in the plant in 2004, excessive membrane silting compounded by filter clogging by Asian green mussels, had contributed to the plant not operating as efficiently as it should. It was found that enhancements to the plant are necessary to prevent filters and membranes from clogging too quickly. This will add to the plant's operating costs because more energy will need to be expended, more chemicals and more frequent filter replacements will be required. Preliminary estimates for remediation efforts range from USD 8-14 million.

12.1.3. Corpus Christi and Brownsville, Texas

Feasibility studies have been carried out by the Texas Water Development Board (TWDB, 2004) for the proposal of two 95,000 m^3/d seawater desalination projects at Lower Rio Grande Valley-Brownsville and the City of Corpus Christi (Figure 21). Whilst Corpus Christi has developed cost-effective water supplies to meet the needs of its customers until the year 2060, a desalination plant would allow the creation of a surplus upstream in the Nueces and Lower Colorado Rivers that could be offered for sale to other water users. For the Brownsville project, the initial phase of the project is scheduled to begin operations in the year 2010 with an expansion capability to 378,000 m^3/d by the year 2040 if service agreements with neighbouring cities are executed.

Figure 21: Gulf of Mexico coastline of Texas [The University of Texas, 2005]

The Rio Grande is the primary source of water in the Brownsville region. It is over appropriated, vulnerable to droughts and subject to an International Treaty. Desalination would increase overall system reliability. As proposed, the project consists of a screened raw water intake from the Brownsville Ship Channel to avoid the need for raw water pipelines from the open sea. This proposal, however, also means that poorer water quality may need to be considered and a pilot study is suggested to address this issue. Concentrate disposal is into the Gulf of Mexico via a pipeline with a diffuser array. Capital cost of the Brownsville plant was estimated to be USD 151 million in 2004 for a RO plant with annual operating and maintenance costs estimated at USD 11.8 million with 59% representing energy costs. The cost benefit model of this study calculated the cost of water at AUD 0.87/m^3 compared with USD 0.54/m^3 proposed in the feasibility study.

The study into a desalination plant at Corpus Christi proposes feed water pre-treatment by air flotation and granular media filtration before delivery to a two-stage RO plant with pressure exchangers as energy recovery. The proposal also suggests co-location at the Barney Davis Power Plant. Potential advantages for this location are the proximity to the water distribution system and the potential to use the intake and discharge facilities of the power plant, although salinity intake levels at the site and environmental concerns regarding discharge preclude this suggestion at this time. As such, an ocean feed water intake and discharge option will require the construction of a 13 km pipeline from the Gulf of Mexico to the plant site, a considerable capital expense. The capital cost of the project was estimated at USD 197 million in 2004. The annual operating and maintenance cost was estimated to be USD 17.5 million of which energy costs represent approximately 42%. The cost-benefit model conducted in this study confirmed the cost to be AUD 1.20/m^3 in 2005 dollars.

As demonstration projects, these two projects, as well as the river water RO project at Freeport (Section 12.2.1), would require varying degrees of financial assistance to ensure that implementation of the projects would not result in an undue financial burden to the targeted water users. It is estimated that 50% of the future population growth in the United States will occur in the coastal states of California, Texas and Florida. Economic development and growth is encouraged by the availability of water and both California and Florida have adopted performance incentives or subsidies to facilitate the development of new water supply sources by means of seawater desalination and this option is one that may be considered for Texas as well [TWDB, 2004].

12.2. Seawater / River Water Desalination

12.2.1. Freeport, Texas

This proposed project is a Public Private Partnership consisting initially of a 39,000 m^3/d RO plant scheduled to begin operations in the year 2010 with a capability to expand to 190,000 m^3/d. The plant would ideally be situated at the Dow Chemical Complex in Freeport to take advantage of Dow Chemical's existing intake infrastructure, which provides access to both seawater and the waters of the Brazos River. The project's concept is to treat river water preferentially to lower the produced water cost and, when river water is not available, to shift to treatment of seawater. This concept results in lower production costs while still providing a demonstration facility fully capable of producing high quality drinking water entirely from seawater. The disposal of concentrate would also benefit from Dow Chemical's existing permitted discharge infrastructure.

The capital cost of the project was estimated to be USD 93.2 million in 2004. The annual operating and maintenance cost was estimated to be USD 7.3 million of which energy costs represent approximately 43%. Operating at a much smaller capacity than the Brownsville and Corpus Christi proposals, the cost-benefit model of this study showed that the average calculated cost would be higher than the other two proposals at AUD 1.43/m^3 in 2005 dollars.

12.3. Water Reclamation

Water reclamation is a growing trend around the world and is one of the growth areas in membrane desalination applications, and RO in particular. Large-scale water reclamation projects are undertaken in various countries of the world, particularly in areas of dense population and high industrial activity. Using water that has had prior treatment in STPs subsequently in desalination processes captures a valuable resource for reuse and significantly reduces discharge of STP treated water to oceans.

12.3.1. Singapore NEWater

Before its separation from Malaysia in 1965, the island republic of Singapore was already relying on the Malaysian Peninsular for much of its freshwater supply through long-term agreements. About 50% of Singapore's water requirement is piped to the republic via the causeway from the southern Peninsula State of Johor, a source that of late has become a bone of contention that is affecting bilateral relations. Local catchments made up the remainder of Singapore's water requirements and, although located in a climatically wet region with more than 2,500 mm of rainfall annually, Singapore, with almost four million people and a robust economy, has long been on the list of water-stressed nations.

To address the water issue from the supply side, the Singapore Government, in 1999, launched a strategic initiative into alternative and renewable sources of water. This initiative came to be known as the "Four Tap Strategy" and consists of imported water, seawater desalination, collection and treatment of local surface run-off and water reclamation [Seah *et al.*, 2003].

The Singapore Water Reclamation Study ("NEWater Study") was first conceptualised in 1998 as a joint initiative between the Public Utilities Board (PUB) and the Ministry of the Environment. The primary objective of the joint initiative was to determine the suitability of using NEWater as a source of raw water to supplement Singapore's water supply [Singapore Water Reclamation Study, 2002]. Centrepiece of this initiative was the NEWater Factory, a 10,000 m^3/d advanced water reclamation plant employing a dual-membrane (MF and RO) process, followed by UV disinfection treatment. The plant is located on a compact site downstream of the Bedok Water Reclamation Plant (formerly known as Bedok Sewage Treatment Works) and has been operational since 2000. Two more NEWater facilities have since been built and commissioned. A 40,000 m^3/d plant at Kranji entered service at the end of December 2002. The plant was designed to allow an expansion of capacity out to a final, stage 2 capacity of 72,000 m^3/day. At Seletar, a 24,000 m^3/d plant was launched in 2004.

The construction of the Ulu Pandan NEWater Factory will be the fourth and largest NEWater factory in Singapore, supplying more than half of the total NEWater supply for Singapore's use. While the existing NEWater factories in Bedok, Kranji and Seletar are owned and operated by the PUB, the Ulu Pandan NEWater Factory will be developed using a Public Private Partnership approach allowing closer partnership between the private and public sector [Lim, 2005].

12.3.2. Water Factory 21 and Groundwater Replenishment, Orange County

Orange County receives between 330 to 380 mm of rainfall annually, and sustains a population of approximately 2.5 million people. The Orange County Water District (OCWD) manages the substantial groundwater basin that underlies the northwest half of the county and supplies about 75% of the District's total water demand. The remaining 25% is imported from the Colorado River Aqueduct and the State Water Project via the Metropolitan Water District of Southern California. As an agricultural economy developed in the area, the increased demand upon the subsurface water by the county's many wells resulted in a gradual lowering of the water table to below sea level and saw seawater encroaching from the Pacific Ocean on the groundwater basin, the boundaries of which are outlined in Figure 22.

As long ago as the mid-1960s, the OCWD began a pilot-scale reclamation project that developed into the now-famous Water Factory 21. The first blended reclaimed water from Water Factory 21 was injected into the coastal barrier in October 1976.

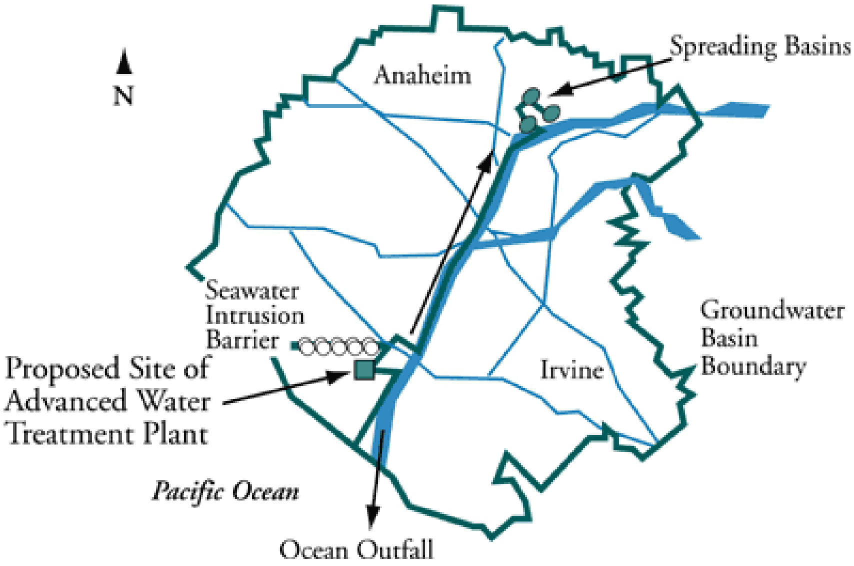


Figure 22: Outline of Groundwater basin boundary of Orange County [OCWD, 2005]

Currently, the Orange Country Water Factory reclaims about 57,000 m^3/day of high quality recycled water to recharge the underground aquifers near the coast to prevent seawater intrusion. Figure 23 schematically outlines the Water Factory 21 treatment process.

To address the long term shortfall and to have reliable water supply, Orange County is implementing the Groundwater Replenishment System (GWRS). This is a large-scale extension of their Water Factory 21 Project, which successfully demonstrated the reliability of dual membrane technology in reclaiming recycled water for injection into the groundwater to protect their potable water supply from seawater intrusion. In GWRS, recycled water will be reclaimed using the latest proven membrane technology of MF and RO. This will produce good quality water which will then be used to replenish the existing groundwater source.

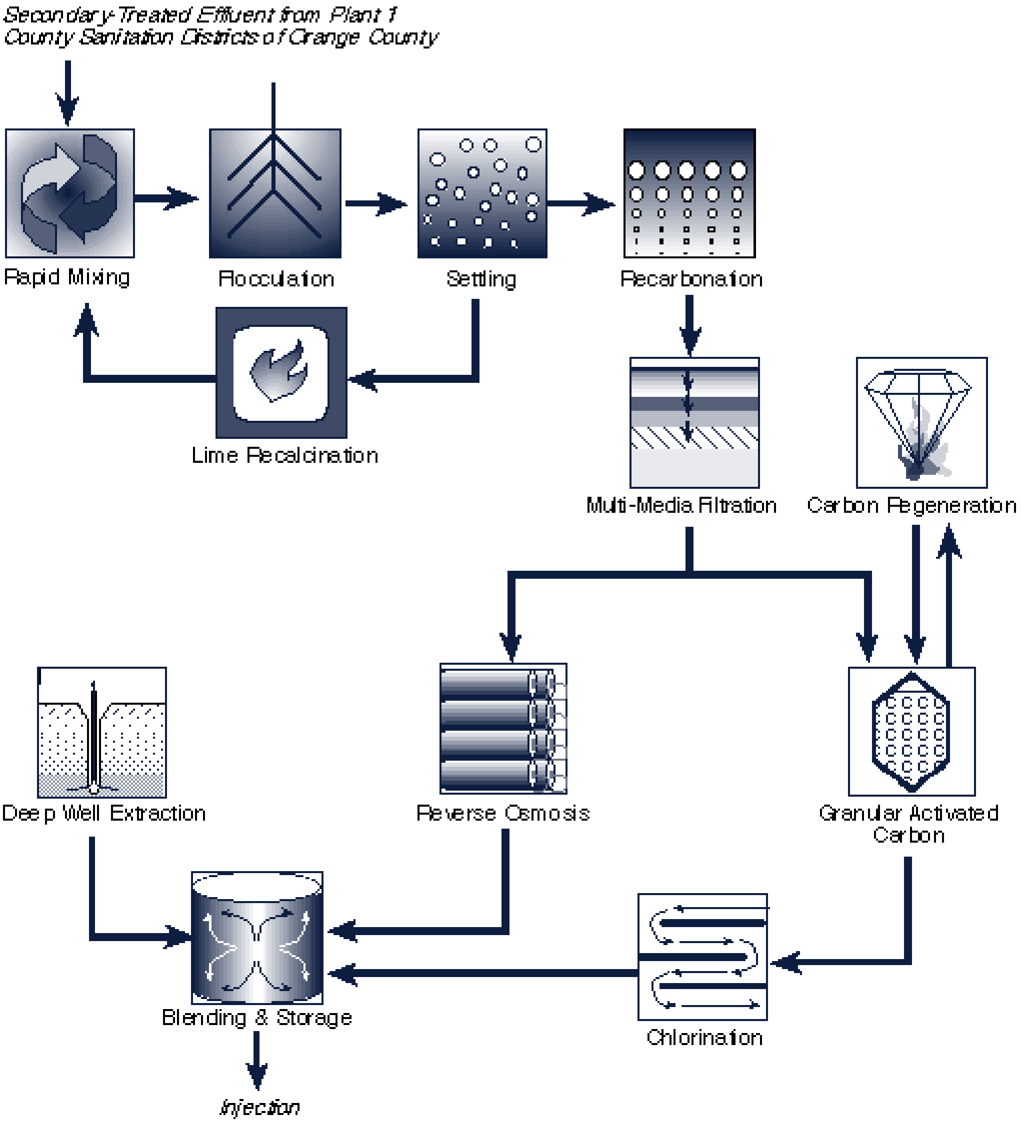


Figure 23: Water Factory 21 treatment process for reclaiming water [OCWD, 2005]

Membrane technology has proven to be more reliable in producing good quality water. The reclaimed water is of better quality than current sources from the Colorado and Santa Ana rivers. It will help minimise the need for imported water from the Colorado River which has high salinity (as high as 1,600 mg/L). Furthermore, the GWRS would obviate the need to transport water by pumping over long distances from Northern California and the Colorado River.

Besides meeting the long term water demand in Orange County, the GWRS aims to reduce recycled water discharge into the sea and protect the beaches. It will avoid the need for a sea outfall which is not acceptable to the community. Furthermore, Orange County found that the GWRS was an economic option to meet the challenges. Because of the low salinity of the reclaimed water, the GWRS would also help to control the build-up of salinity in the groundwater caused by seawater intrusion as a result of excessive abstraction. More importantly, the GWRS would provide Orange County with a robust, reliable and drought-proof water supply to meet increasing water demand and help to diversify its water sources.

13. Trends in Australia

An arid continent by nature, Australia is facing many challenges to meet current and future water demand. Years of drought have exacerbated the situation and States and cities have implemented measures of demand management that have saved billions of litres of water. In the face of continued droughts, adverse climate effects and diminishing freshwater resources, strategies have been developed to assist governments in providing a stable and sustainable water supply that facilitates economic development and healthy communities.

In 2003, the Western Australian Government released a water strategy for Western Australia in response to a water shortage that had reached a critical point [Government of Western Australia, 2003]. The strategy was devised to meet growing water demand in the face of most recent climate predictions indicating that the current dry conditions, which also extend to many other parts of Australia, are likely to continue. The strategy addressed measures of water conservation, water reuse, new supplies and total water cycle management. Desalination is already being used extensively in Western Australian mines and power stations and for the production of potable water to sustain remote communities (Figure 24) and in 2000, the Water Corporation undertook a strategic review into desalination possibilities for Western Australia [Water Corporation, 2000] followed by a more extensive feasibility study into seawater desalination taking a ‘security through diversity’ approach to ensure the water future one step further. On 29 July 2004, the Premier Dr Geoff Gallop announced a key project in this strategy – the Perth Seawater Desalination Plant. On April 14, 2005, the Premier further announced that the Multiplex Degremont Joint Venture would build the new plant.

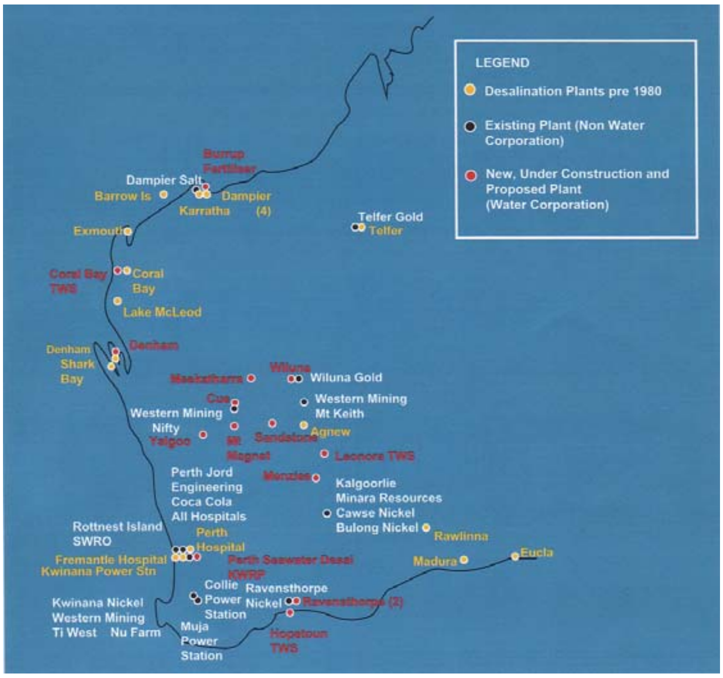


Figure 24: Desalination Plants in Western Australia [Water Corporation, 2005a]

In October 2004, the New South Wales State Government released its 25 year Metropolitan Water Plan *Meeting the challenges - Securing Sydney's water future*. The plan contains a broad range of initiatives, covering infrastructure projects, recycling, demand management and protection of the environment [NSW Government, 2004].

The plan for Sydney was developed to overcome a shortfall between the amount of water that Sydneysiders use and the amount of water provided from the catchments to ensure sustainable water resources to meet Sydney's needs over the next 25 years. It is also the next step in a program to restore the health of the Hawkesbury-Nepean River and the other precious rivers surrounding the city and recognises that Sydney's future growth and economic prosperity needs secure water resources for people, industry and the environment.

On 11 July 2005, the New South Wales Government announced that if Sydney's current water crisis persisted, a desalination plant would be built at Kurnell, in Sydney's south. This announcement comes after an extensive desalination planning study as a sensible contingency investment to ensure that if the current drought continues, a desalination plant could provide Sydney with a reliable source of potable water.

Similarly, Victoria is looking at maintaining and sustaining its water supplies for tomorrow's communities and in 2003 the State Government of Victoria responded with a discussion Green Paper on securing Victoria's water future [DSE, 2003]. Following extensive consultation, the White Paper – *Securing Our Water Future Together* was released as a comprehensive and integrated approach to using water wisely whilst sustaining communities and economic developments without compromising healthy water resources [DSE, 2004].

The following sections provide an outline of some of the water management activities in relation to desalination undertaken in Australia. The range of activities covers desalination for drinking water supplementation as well as water reclamation for fit-for-purpose reuse.

13.1. Seawater Desalination

Large-scale seawater desalination offers the potential to secure bulk drinking water supply and meet growing demands of cities in Australia. Perth has committed to building the first large-scale seawater RO plant, followed by Sydney, where plans are underway to utilise seawater desalination to provide a reliable source of drinking water.

13.1.1. Perth - Kwinana Desalination Plant

Initially, a 30 million m^3 per year desalination plant proposal was assessed by the WA EPA and in May 2003 the EPA considered a revised proposal by the Water Corporation of Western Australia to upgrade the capacity of the Perth Metropolitan Desalination Proposal and concluded that it could be managed to meet the EPA's objectives for the relevant environmental factors. Following this recommendation, the feasibility study was reevaluated and a revised feasibility study completed by June 2003. During the feasibility study review the Water Corporation decided to evaluate the possibility of a 45 million m^3 per year plant and a proposal was adopted in June 2003. Upgrading of the capacity of the approved desalination plant from 30 to 45 million m^3 per year had the benefit of resulting in additional water for the State's Integrated Water Supply Scheme at substantially less cost per unit volume produced, with essentially no environmental effects beyond those recognised in the previously approved proposal, other than a small increase in nitrogen loads which would be mitigated by other Water Corporation activities.

Following the announcement made by the Premier and Water Resources Minister Dr Geoff Gallop on April 14, the Perth seawater desalination plant is now being constructed at Kwinana, adjacent to the Western Power site, and will be the largest of its kind in the southern hemisphere when it comes online in 2006 and with a supply of 130,000 m^3/d (Figure 25). The desalination plant is designed and built by the Multiplex Degremont Joint Venture and will be owned by the Water Corporation and operated by Degremont under a 25 year contract.

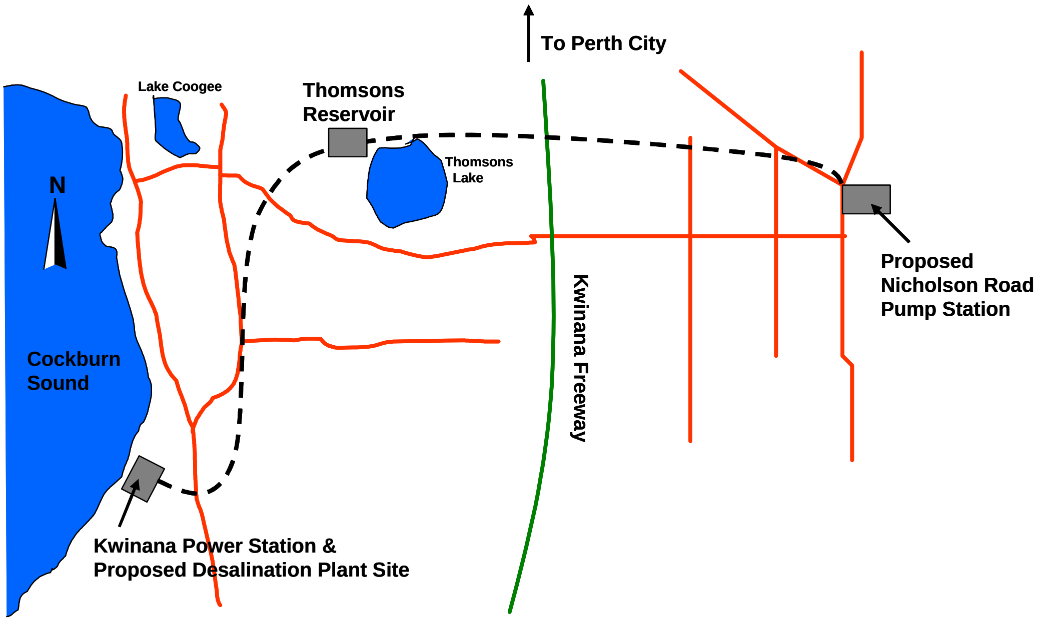


Figure 25: Perth seawater desalination project [Water Corporation, 2004]

The commitment to large-scale seawater desalination in Perth came as a response to climate changes that have seen the water running into Perth's dams drop by ⅔ in the last seven years, a 20% increase in the amount of water used, projected annual population growth of 1.7% to the year 2031, indicating that Perth will be expected to need an extra 150 million m^3 of water per year by 2031.

The plant will utilise RO to desalinate water sourced from Cockburn Sound and, at 17% of Perth's potable water, will be the biggest single, climate independent water source feeding into the Integrated Water Supply Scheme that provides water to 1.5 million people. Pre-treatment of seawater will include flocculation and filters whilst post-treatment includes chlorination, fluoridation and a carbonation facility.

Presently, the capital cost of the plant is estimated at AUD 387 million of which around 16% will be used to upgrade the Integrated Water Supply System infrastructure to accommodate this new water source. Recent estimates suggest that the plant will produce water at a cost of AUD 1.16/m^3, approximately shared by 50% capital cost, 25% operation and maintenance and 25% energy requirements. Energy requirements of the seawater RO plant are estimated at 4.5 kWh/m^3 and the Water Corporation is offsetting this energy with renewable energy sourced from a wind farm that will feed into the electricity grid.

A formal environmental assessment and monitoring study was undertaken to confirm that appropriate operation and management of the desalination plant will have no adverse environmental effects on Cockburn Sound, especially with regard to salinity level build up of discharged concentrate, water removal in relation to tidal movement and ecological effects on marine life. Environmental documents prepared for this project to date are available from the Water Corporation website.

13.1.2. Sydney – Seawater Desalination Plan

The Metropolitan Water Plan for Sydney details plans to ensure that, if the drought continues beyond another two years, a desalination plant for Sydney could be constructed relatively quickly and efficiently. A desalination planning study that had been underway since January 2005 confirmed that seawater desalination was a feasible option able to supply greater Sydney with about one third of its daily water needs from a 500,000 m^3/d desalination plant [Sydney Water, 2005]. The planning study for consideration of plant sizes of 50,000-500,000 m^3/d supplied by electricity from either the grid or through co-location with a gas fired power station followed a methodology which involved technical studies, evaluation and selection criteria, development configurations, design, environmental, social and economic review.

In the study, a number of potential sites were evaluated for suitability of constructing a desalination plant of the estimated size with regard to environmental, social and technical implications and challenges. Kurnell was subsequently selected as the prime location for a large desalination plant, with three potential locations for the plant adjacent to, or nearby, the Caltex Oil Refinery.

On the basis of financial assessment and criteria such as energy consumption, greenhouse gas emission, and indicative water production costs as well as non-quantifiable criteria, RO was found to be the most suitable desalination technology for Sydney. In the preliminary design, costs for desalinated water are estimated to be in the order of AUD 1.44/m^3 for a 500,000 m^3/d plant. The difference to the cost of water quoted for the Perth plant has been attributed to the nature of Sydney's coastline and the required intake, discharge and distribution constructions. The total capital expenditure is estimated to be AUD 1.75 billion for a 500,000 m^3/d plant occupying about 20 hectares and provisions have been made such that the plant could be constructed in less than two years to secure Sydney's water demands should experienced drought and patterns of low rainfall continue in coming years. A capital cost breakdown suggests that around AUD 1 billion is required for the construction of the plant with a further AUD 200 million for intake and discharge construction. On an operating basis, the power purchase has been estimated at 55%.

One of the challenges that Sydney is faced with, is the distribution of the desalinated water into the main water supply of Sydney. As most of Sydney's water is derived from catchments in the west and south, tunnels that distribute this water are large in those regions, whilst they are of smaller diameters within the metropolitan centre. Figure 26 shows the location of major drinking water assets for Sydney. The seawater desalination plant, however, will be located at the coast and a reversal of water flow would necessitate the development of infrastructure to distribute the water from such a site. For the Kurnell site, this also means that water would have to be distributed either via a tunnel across Botany Bay or a pipeline as outlined in Figure 27 [Sydney Water, 2005]. Either option would require careful environmental studies of potential impacts on marine life and habitat and come at a significant cost.

Energy costs were found to be lower for a RO plant than a thermal process and whilst alternative processes exist, these were ruled out because they are either not proven on large-scales or are in developmental stages. For the purpose of evaluation of a suitable technology, only dual purpose plant options were evaluated for thermal desalination options as this was seen as the only option to make efficient use of thermal energy. The analysis was based on a 200,000 m^3/d plant and indicated that thermal desalination based on a MED process would require 2,100 GWh per year, about three times as much energy as required for a RO plant delivering the same capacity. Against this energy criterion, the environmental footprint requirements of different desalination technologies and with consideration to associated greenhouse gas emissions, RO was found to be the preferred technology.

The study further considered a range of power supply options, including renewable energy options with wind power the only one thus far proven at a large-scale. Greenhouse gas mitigation utilising schemes currently available is a method to balance the emissions that will result from the desalination plant over the total life. Total life cycle emission from the plant is associated with material and construction stages (5%) and operation (95%). Any greenhouse gas reduction strategy adopted, however, will influence the final cost of water based on the amount of actual mitigation required.

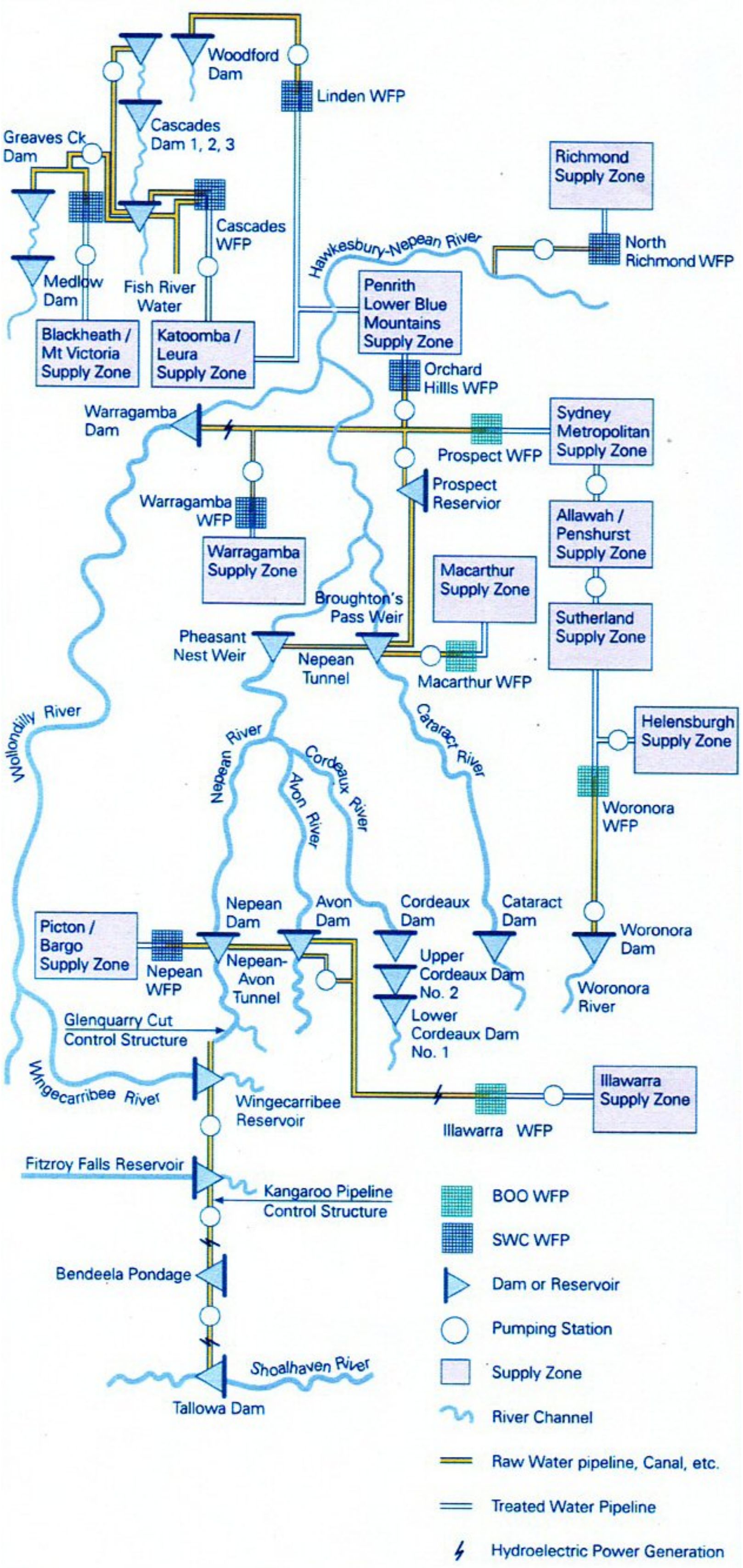


Figure 26: Sydney's water supply system [Sydney Water, 2005]

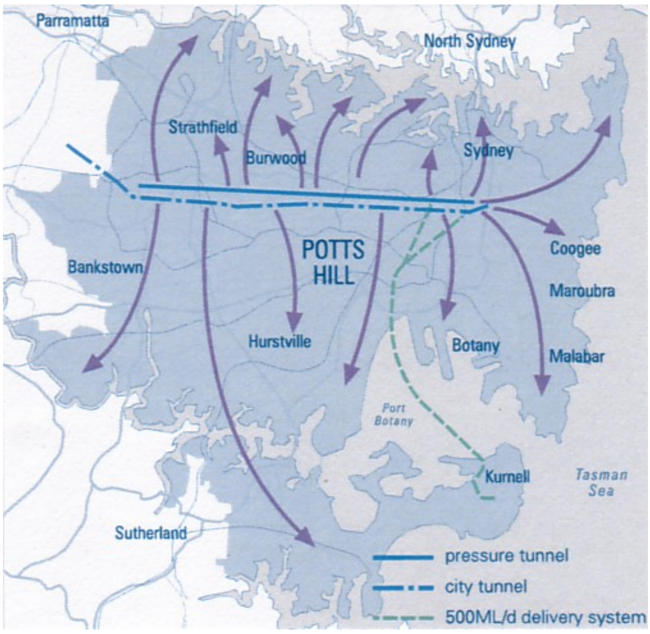


Figure 27: **Sydney's water delivery system outlining proposed integration of desalination plant at Kurnell site [Sydney Water, 2005]**

13.2. Brackish Water Desalination

13.2.1. Harding Dam, WA

The Harding Dam Water Treatment Plant utilises UF technology and is the largest of its type in the Southern Hemisphere. The plant treats surface water from the Harding Dam for supply into the West Pilbara Water Supply Scheme. Prior to the treatment plant, water from the Harding Dam could only be used for six to eight months per year as it was affected by a number of water quality problems (especially after cyclones, bad storms and dam inversions) (Figure 28) . These included turbidity, alkalinity, dissolved organic carbon (DOC), disinfection by-products as well as and taste and odour issues.

Figure 28: **Harding Dam after a cyclone in March 2004 [Photographs courtesy of Z. Tonkovich; Zenon Australia]**

In January 2003, construction of a AUD 30 million plant commenced with a first stage capacity of 45,000 m^3/d and with the provision to expand to 60,000 m^3/d (Figure 29). The plant was commissioned in October 2004 and was the Water Corporation's first serious venture into membrane treatment [Crisp, 2005].

The Harding Dam water pre-treatment consists of an enhanced coagulation and flocculation stage, to maximise the removal of highly dissolved organics. Hollow-fibre UF membranes with pore sizes of 0.035 μm remove bacteria and viruses as well as colour and turbidity. Post-treatment consists of chloramination and fluoride dosing. The remoteness of the plants location dictated that the plant be designed for minimal attendance as well as complete remote monitoring and control.

Figure 29: Harding Dam UF water treatment plant [Photograph courtesy of Z. Tonkovich; Zenon Australia]

13.3. Water Reclamation

Water reclamation for demanding industrial uses is one of the most promising and applied forms of desalination in Australia. Several plants around the country provide industries with reclaimed water, reducing the demand on potable water and demonstrating the economic viability of water reclamation.

There are many industry operated desalination plants supplying water to iron, gold, titanium and nickel mines across the state of Western Australia. Outside of Western Australia, the majority of membrane technology uptake is in the area of water reclamation. The costs of desalinating brackish water is much less than for seawater, therefore, utilising low TDS wastewater from industry or sewage treatment can often be the best source of this water. One of the largest water recycling plant in operation in Australia is the Kwinana Water Reclamation Plant in Perth. The plant has a capacity of 16,700 m^3/d and was commissioned in 2004 for the production of high quality water with a TDS of 40-50 mg/L for industrial use. The plant uses a combination of MF and RO with a recovery of 80% [Crisp, 2005].

In New South Wales, a water reclamation plant is under construction by Sydney Water to supply desalinated water to Bluescope Steel from the Wollongong water reclamation plant with 20,000 m^3/d.

13.3.1. Eraring Power Station, NSW

The utilisation of MF/RO technology at the Eraring Power Station is an excellent example of providing economic returns whilst benefiting the community and the environment. Eraring Power Station is located near Lake Macquarie on the central NSW coast. The power station comprises 4 x 660 MW generators that use about 5 million tonnes of coal per year and produces about 20% of New South Wales electricity. In 1994, Eraring Power Station pioneered the use of MF/RO technology on an industrial scale for water reclamation with the commissioning of a 2,800 m^3/d dual membrane system, enabling the processing of treated water from the nearby Dora Creek STP (see Case Example 2). This feed water is fed into three MF units comprising 90 hollow fibre membrane modules, which remove suspended solids and bacteria. This pre-treatment allows the RO membranes to operate at a 30% higher flux than conventional pre-treatment would provide with an 80% recovery. Prior to entering the two train RO system, the feed water is chemically dosed with chlorine, antifoulants and antiscalants and is passed through a 1 µm disposable cartridge guard filter. The RO concentrate is passed to the station ash dam for disposal while backwash from the MF plant is sent to the Eraring Power Station onsite treatment facility and is recycled back to the feed water receiving tank. At the time of installation, the innovative combination of MF and RO technology was a world first, achieving water at near “boiler feed quality”.

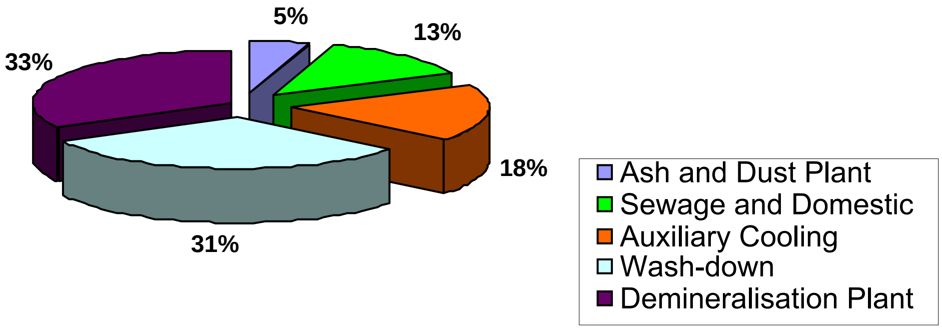
Today, Eraring Power Station produces 70 to 75% of its water needs by use of the water reclamation plant. The installation of this system has had far reaching benefits. For the community, this means greater reliability of potable water supply, roughly equivalent to the needs of 3,000 households. Ocean outfall discharge from the Dora Creek STP is reduced considerably as water is reclaimed at the desalination plant. The local water authority has been able to defer a proposed sewage pipeline to Toronto which was estimated to have AUD 2.4 million in pipeline construction costs.

Case Example 2: Eraring Power Station Water Reclamation Plant

Eraring Power Station Water Reclamation Plant

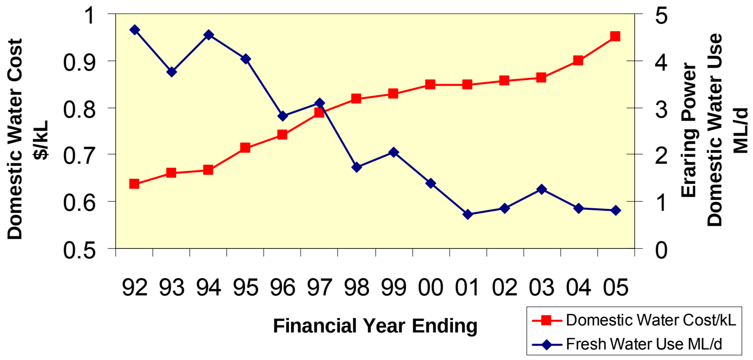
Eraring Power Station is located on the central NSW coast near Newcastle. The power station is comprised of 4 x 660 MW generators and produces about 20% of New South Wales' electricity. The freshwater requirements of the plant for around 4,000 m^3/d are utilised in areas as outlined in Figure CE2.1.

Figure CE2.1: Eraring Power Water Usage 2002/3
(4.08 ML/d average)



As shown in Figure CE2.2, the cost of water had been increasing gradually and in 1992 the total water cost was around AUD 1.1 million initiating investigations into further reducing the cost of water on site. In March 1995, Eraring Power pioneered the use of a MF/RO technology on an industrial scale for water reclamation with the commissioning of a 2,800 m^3/d dual membrane plant, enabling the processing of secondary treatment sewage from the Dora Creek STP. At that time, Eraring Power Station was using approximately 4,200 m^3/d of potable water from the region's potable water supply, and was facing a water shortage due to a drought and increased demand from 25,000 nearby homes. The plant originally consisted of two RO and two MF trains and had a third MF unit installed in 2000.

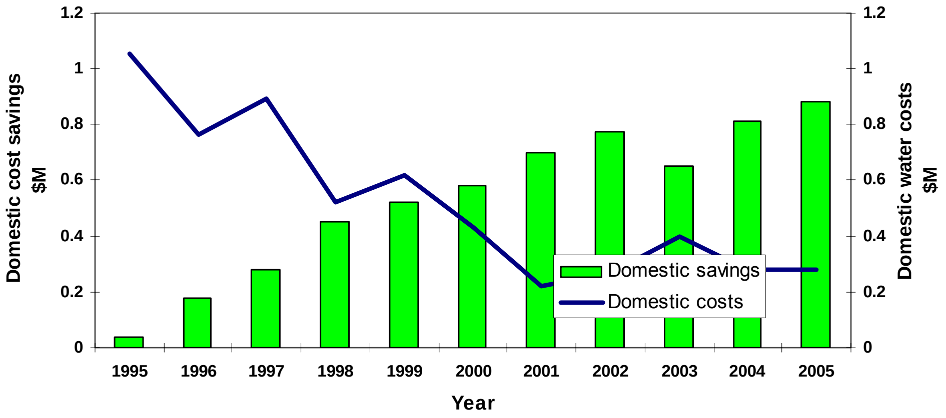
Figure CE2.2: Cost of Domestic Water and Eraring Power Domestic Water Use 1992 - 2005 (est)



Case Example 2: Eraring Power Station Water Reclamation Plant (cont'd)

Since commissioning, Eraring Power's use of the domestic water supply has dropped significantly to approximately 1,000 m^3/d (Figure CE2.2). The plant can produce water at a cost of AUD 0.20/m^3, benefiting from near negligible energy costs of AUD 0.10/m^3 at AUD 50/MWh to the power generator and cheap disposal options of concentrate to ash ponds on-site. Total project costs of AUD 4.63 million also included an upgrade to the RO system in December 1998 and installation of a third MF unit in 2000. Annual cost savings due to the water reclamation plant increased to AUD 800,000 in 2004 (Figure CE2.3). Additionally, cost reductions have been realised for the operation of the demineralising plant processing MF/RO treated water, where greater throughput per regeneration and the reduction in chemicals used approximately save a further AUD 100,000 per year.

Figure CE2.3: Cost Savings and Domestic Water Cost



Membranes for the MF trains were first replaced in 2003 and 2004 and in late 2004 the first RO train had its membranes replaced with second RO train membrane replacement being envisaged for 2005/06. The reclamation plant will have realised full capital cost recovery in 2005 with around 70-75% of all water now produced by the water reclamation plant, a figure that is increasing yearly. Additional benefits for Eraring Power, the local Water Authority and the Community include:

- Enhanced water conservation with an economically practical option reclaiming secondary treated effluent, thereby minimising ocean outfall disposal;
- Minimum disturbance to the environment – concentrate disposal via ash ponds;
- Delaying by 15 years the construction of a planned 11.4 km sewer link between Dora Creek and the ocean outfall; and
- Further augmentation of the domestic water supply system to the local area.

13.3.2. Eastern Irrigation Scheme

On 31 May 2005, the Eastern Irrigation Scheme (EIS) was launched; one of Victoria's largest Class A water recycling schemes. The Eastern Irrigation Scheme recycles 3.5% of the treated water from Melbourne's Eastern Treatment Plant – making it a significant contribution to the Victorian Government's target of 20% water recycling by 2010.

Melbourne's EIS involves a partnership between Melbourne Water and TopAq, a company formed for this purpose by Earth Tech. It supplies 30,000 m^3/d of Class A recycled water via 50 km of pipeline (Figure 30). Customers of the scheme include recreational users, such as golf courses, municipal councils, sports grounds, vegetable and fodder growers, and industrial users keen to secure a reliable source of water. The Class A water from the scheme is also being supplied to South East Water, for dual pipe use in residential developments for toilet flushing and garden use to substitute for potable water.

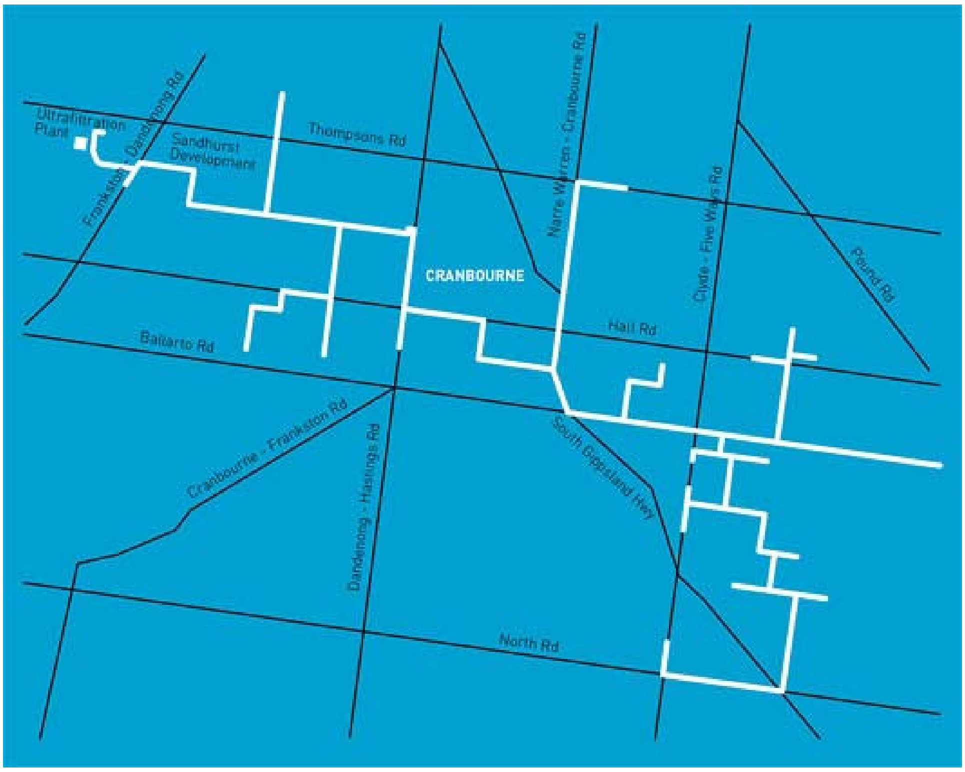


Figure 30: Pipeline network for Eastern Irrigation Scheme [TopAq, 2005]

Feed water is sourced from Melbourne's Eastern Treatment Plant and is treated, at the EIS's UF Plant, which has 640 UF membrane modules (Figure 31). Filtered water from the plant is distributed to a 170 km^2 area around Cranbourne.

EPA Victoria has approved a Regional Environmental Improvement Plan (REIP) for the EIS. The REIP prescribes the framework for managing long-term environmental improvement and sustainability. Nesting under the REIP are specific Environmental Improvement Plans (EIPs) which will define how Class A recycled water is used at each site. Because the conditions and uses at each site vary, it will be necessary to conduct site specific inspections and testing of the soils, drainage characteristics and groundwater quality to ensure that specific site applications of Class A recycled water are managed in a way that fulfils the long-term sustainability established under the REIP [TopAq, 2005].

Figure 31: Ultrafiltration plant at the EIS [TopAq, 2005]

13.3.3. Wollongong Tertiary Treatment and Effluent Reuse Plant

The Wollongong STP receives around 60,000 m^3/d of sewage from the Wollongong area and from the Bellambi and Port Kembla Storm Flow Plants via pipelines for tertiary treatment. The plant is operated by Sydney Water and consists of a STP, comprising activated sludge plants, deep bed filters and UV disinfection. In a new scheme, a water reclamation plant consisting of a biological nutrient removal (BNR) reactor feeding water into a MF/RO desalination followed by CO_2 stripping and chlorination is set to supply recycled water for industrial use at Bluescope Steel. The operation is scheduled to come online in October 2005 processing 20,000 m^3/d of product water to a TDS level of around 50 mg/L. The plant has been designed to be scaleable to 40,000 m^3/d of water reclamation. Bluescope Steel currently receives water from the Avon Dam, which is pumped to the Berkeley reservoir dedicated to Bluescope Steel. The provision of RO treated water to the reservoir will free up demand on the Avon Dam for drinking water purposes, and provide improved certainty of supply to Bluescope Steel in times of drought (see Case Example 3).

Case Example 3: Wollongong Recycled Water Supply Scheme

Wollongong Recycled Water Supply Scheme

Sydney Water operates five coastal sewage treatment plants (STP) in the Illawarra. Under the Illawarra Wastewater Strategy, dry weather flows from the Bellambi and Port Kembla STPs will be transferred via a pipeline to the Wollongong STP for high level treatment and water reclamation. The upgrade to the existing Wollongong STP (Figure CE3.1) involves the construction of a MF/RO desalination plant, a biological nutrient removal (BNR) reactor and augmenting of the existing ocean outfall with a one kilometre pipeline to support the treatment of approximately 59,000 m^3/d of sewage.

Figure CE3.1: Wollongong existing STP (left) and current constructions (right)

The new Wollongong plant will treat water from Bellambi, Port Kembla and Wollongong in a new 40,000 m^3/d BNR plant to augment the existing activated sludge plant with tertiary treatment (Figure CE3.2). The new water recycling supply scheme consists of a MF/RO process which, in the first instance, will treat water from the BNR process to supply Bluescope Steel with 20,000 m^3/d of product water with a TDS of about 50 mg/L. Currently, Bluescope Steel draws its water needs from a reservoir that is fed with unfiltered water from the Avon Dam.

Figure CE3.2: Images from the BNR reactor

Case Example 3: Wollongong Recycled Water Supply Scheme (cont'd)

Under a 15 year agreement reached between Sydney Water and Bluescope Steel, substitution of this water with RO-reclaimed water will not only relieve demand on the Avon Dam, but will also improve certainty of supply to Bluescope Steel. In addition, reuse of reclaimed water will also reduce the discharge to ocean outfalls by 39,000 m^3/d.

The design of the MF-RO facility incorporates a production upgrade option to desalinate 40,000 m^3/d by 2021-25. The MF unit currently consists of eight units with one stand-by unit of 112 membrane modules per unit and has a capacity of 23,600 m^3/d filtrate at a recovery of 87% (Figure CE3.3). The RO unit consists of four units with one stand-by unit and a capacity of 20,000 m^3/d at a recovery of 85% (Figure CE3.4). Post-treatment includes disinfection with sodium hypochlorite and degassing to remove carbon dioxide. Concentrate from the desalination process will be passed to the effluent pump station where it will be diluted with treated water for discharge at the ocean outfall.

Figure CE3.3: Microfiltration trains at Wollongong water recycling plant

Figure CE3.4: Reverse osmosis trains at Wollongong water recycling plant

13.3.4. *Gippsland Water Factory*

Gippsland Water have developed their Water Factory Project which will potentially be implemented in two stages. Currently, Gippsland Water dispose of sewage and industrial wastewater via a regional outfall sewer (ROS). The ROS was built in the 1950s and is still the main disposal sewer servicing the industrial base of the Latrobe Valley [Gippsland Water, 2004a]. However, over half of the length of the ROS is an open channel (Figure 32: the only open sewer in Australia) and its environmental performance is no longer acceptable. Stage 1 of the Water Factory Project seeks to eliminate the odour problems of the ROS, whilst ensuring that the operations of existing, expanded and future industries in the Latrobe Valley are not constrained by the lack of wastewater infrastructure.

Figure 32: The open channel regional outlet sewer in Gippsland [Gippsland Water, 2004b]

In Stage 1 of the Water Factory Project, all wastewater currently received by the ROS in the central Latrobe Valley, that is, upstream of the township of Rosedale, would be piped back to Morwell. At Morwell, a new 35,000 m^3/d MBR treatment plant would be constructed to produce an odour-free Class A quality water and associated sludge digestion, gas collection and power generation. The Stage 1 plant would make available 13,000 m^3/d of water from the MBR for further treatment in an MF/RO plant to produce 10,000 m^3/d of fit-for-purpose water for industrial use. The balance of the Class A water from the MBR, would then be transported via the ROS to Dutson Downs for discharge into Bass Strait via the existing ocean outfall. The reject from the MF/RO plant would also be transported via the ROS. The cost of Stage 1 of the project has been estimated to be AUD 90 million and is expected to be completed by 2007-8 [Gippsland Water, 2004a].

The proposal for Stage 2 of the project includes an augmentation to the MF/RO plant that would permit the total 35,000 m^3/d from the MBR to be treated. This would make 28,000 m^3/d of water available for industrial and other non-potable water uses and the ROS would no longer be required to transfer wastewater. A further augmentation of the plant from 35,000 to 85,000 m^3/d would enable treatment of all the remaining Latrobe Valley wastewater discharge. As proposed, this stage would cost an estimated AUD 135 million and have total water savings of about 55 million m^3 per year. If this stage of the project is approved, it is projected to be completed by 2009-10. The saline reject from the MF/RO process would be discharged via the existing saline wastewater outfall pipeline (Figure 33).

A related proposal, the Eastern Water Recycling Project, involves the transfer of Class A recycled water from Melbourne Water's Eastern Treatment Plant to the Latrobe Valley for use as industrial cooling water and for irrigation purposes in the Macalister Irrigation Area [Gippsland Water, 2004a]. If implemented, this stage would save an additional 135 million m^3 per year of water that would be retained in existing reservoirs such as Blue Rock, Thomson and Glenmaggie. The estimated capital cost of this stage is AUD 500 million. The proposed scenario for the water management across the Gippsland area is shown in Figure 33. Additional benefits from this project may include the pumping of water retained in the Blue Rock reservoir to Melbourne, which would then free up other water supplies that could be utilised by Geelong and Ballarat.

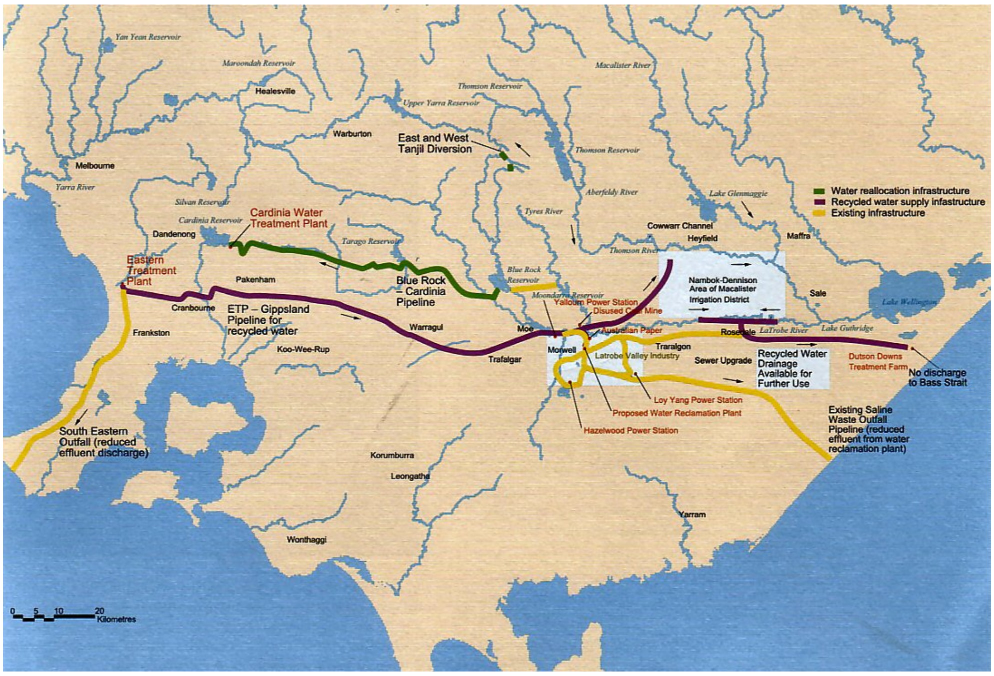


Figure 33: Recycling scenario for Gippsland [DSE, 2004]

13.3.5. Ravensthorpe RO and MED Plants, WA

Ravensthorpe is a small inland community in Western Australia's southern region. A RO desalination plant was commissioned to supplement water supply in years of low rainfall. The RO plant has a maximum treated water capacity of 180 m^3/d and is supplied with water from two brackish bores having salinities of 4,000 and 13,000 mg/L. The configuration of the RO system is two pressure vessels in series with each vessel containing five membrane elements. Permeate water quality is better than 300 mg/L TDS. Recovery rates from the plant are of the order of 70% for the high TDS bore and 84% for the lower TDS bore. Brine is disposed in a disused mine shaft approximately 7 km away.

The Ravensthorpe Nickel Project embodies three nickel deposits near Ravensthorpe and has an expected life of 23 years. Open cut mining operations will produce ore for beneficiation and processing. Major process inputs include sulfur (for sulfuric acid, steam and power), limestone, magnesia and water. The sulfuric acid plant produces acid for the beneficiation and processing of ore, it also produces high pressure steam. Energy for the production of steam is provided during the process of converting sulfur to sulfuric acid.

Due to the high availability of steam and hot water, a low-temperature MED desalination process was the natural choice for water production. BHP Billiton, the parent company have contracted Weir Techna to construct two 3,600 m^3/d MED plants for process and potable water supply. Seawater will be abstracted from the Southern Ocean, east of Hopetoun and pumped to the site via a 46 km long pipeline system. Seawater concentrate will be used as process water and for mine site dust suppression. There will be no return discharge to the sea as concentrate will also be disposed in disused mine shafts.

13.3.6. Burrup Peninsula, WA

The Water Corporation is currently addressing the need to supply water to a range of planned industrial developments (attracted by natural gas reserves) on the Burrup Peninsula. These developments will focus on seawater desalination and water reclamation. The Burrup Peninsula, located in the Pilbara Region of Western Australia, is being developed as a major industrial area for downstream processing. The region may realise up to AUD 10 billion of Gas-to-Liquids (GTL) development over the next 10 years. Several projects are currently under development or investigation in the King Bay – Hearson Cove and Whithnell East Industrial Areas on the Burrup Peninsula.

The Government of Western Australia is assisting the development of industry on the Burrup Peninsula through provision of funding for common user infrastructure. The Water Corporation of Western Australia has provided a seawater supply and wastewater disposal system and a desalination installation inside the Burrup Fertiliser site.

Seawater will be supplied by the Water Corporation to each developer through a common 280,000 m^3/d user supply system for use as feedstock to two seawater cooling towers and as a feedstock for desalination. Brine and wastewater from each plant will be collected and discharged to the ocean through the common user outfall system. The seawater desalination facility on the Burrup Fertiliser site has been installed and is currently being commissioned. The capital cost for the provision of a seawater supply system, wastewater (seawater concentrate, blow-down and treated water) disposal system and power transmission system for the first three stages was of the order of AUD 70 million.

The Burrup Fertilisers project is the first GTL installation constructed on the Burrup Peninsula. It is expected that first product delivery will occur in mid 2005. Since this installation will produce excess electricity at a low cost, the logical desalination process of choice is either MVC or seawater RO. After assessment of all aspects relating to feed water quality, product water quality, desalination plant availability and access to electricity have been taken into account, it was recommended that MVC distillation be the process of choice. Commissioning of the three 1,200 m^3/d MVC units has commenced.

Future desalination installations to support the other GTL processes will be decided on a case by case basis, with energy type and availability most likely to be the prime determinants. A total capacity of 20,000 m^3/d of desalinated water is expected to be realised when all installations are in place.

13.4. Small-scale Remote Community Desalination

13.4.1. Broken Hill

In February of 2004, a 6000 m^3/d RO plant was commissioned for Broken Hill to supply around 25% of the town's water use to a population of some 23,000. Droughts in 2001, 2002 and 2003 caused the salinity to rise in the Darling River as river flow was decreasing and the river levels were dropping. Drinking water, principally sourced from the Darling River, was high in organic loading and became too saline for human consumption. At a capital cost of AUD 4 million the RO plant was installed to reduce TDS to acceptable levels. Once the drought breaks it is proposed to conduct investigations into the conversion of the RO plant to a UF plant and also evaluate other membrane filtration technologies [Alliance News, 2004].

13.4.2. Rottnest Island, WA

Rottnest Island is a holiday resort off the coast of Perth in Western Australia. A seawater RO plant was initiated by the Water Corporation and was constructed in 1995 to produce approximately 220 m^3/d of potable water to supplement the limited supplies of freshwater. Seawater is supplied from bores off the coast with a TDS loading of approximately 40,000 to 42,000 mg/L and treated to a permeate quality of about 500 mg/L TDS. Recently, a series of beach wells have been developed to replace the inland bores which suffer from the effects of sulfate reducing bacteria. Recovery is around 40% and concentrate from the plant is disposed via a pipeline to the sea. With an energy consumption of around 5.0 kWh/m^3 of treated water, a wind turbine of 600 kW was installed in 1995 to minimise the energy usage of the plant and almost solely powers the RO plant (Figure 34). Advantages for the Rottnest Island RO plant included that the feed water extracted from bore holes was of sufficiently pre-filtered quality and, apart from antiscalant and biocide addition, no further pre-treatment is necessary [Crisp, 2005; Water Corporation, 2000].

Figure 34: Wind turbine on Rottnest Island [Water Corporation, 2005b]

13.4.3. Dalby, Qld

The township of Dalby is situated in the Darling-Downs region of Southern Queensland. With a community of 10,000, the township is surrounded by flat, fertile plains and is supported by an economy focusing on agriculture and agricultural services. Significant crops such as cotton are grown under irrigation source water from the Condamine River, being the most significant water course for many miles. Stress upon the river and reduction of water quality from bores have led to the sourcing and identification of alternative options to supplement potable water supply. A 1,700 m^3/d RO desalination plant with a 75% recovery rate was officially opened in September 2004 and now supplies 25-30% of Dalby's water needs. The plant is one of the first municipal desalination projects in Australia and the first in Queensland and desalinates brackish groundwater from bores with the product water being blended at the water treatment plant with groundwater and treated Condamine River water. A 21 hectare evaporation pond complex is used to store and evaporate 150,000 m^3 per year of concentrate generated by the plant.

13.4.4. Penneshaw, Kangaroo Island, SA.

The Penneshaw seawater RO desalination plant on Kangaroo Island supplements Penneshaw's water supply with 300 m^3/d of drinking water (see Case Example 4) and is SA Water's first major seawater RO plant, although a number of private desalination plants are in operation in South Australia to treat brackish water. The small community of Penneshaw on Kangaroo Island had no local access to natural freshwater sources. The solution to provide drinking water to the town was seen by building a AUD 3.5 million seawater desalination plant in 1999 - the first of its kind in Australia - to supplement Penneshaw's needs with the balance of the region's rural settlements water supply being derived from dams and rainwater tanks [SA Water, 2005b; DIT, 2002]. This option was identified to be significantly cheaper than piping mains water from 60 km away.

Case Example 4: Penneshaw Seawater Desalination

Penneshaw Seawater Desalination

The Penneshaw seawater RO desalination plant on Kangaroo Island supplements the town's water supply with 300 m^3/d of drinking water. Penneshaw is the docking point for the commercial ferry which connects Kangaroo Island to mainland SA. Consequentially almost all of the islands considerable tourist flow passes through the small town. Its economy relies heavily upon its eco-tourism image (Figure CE4.1).

Figure CE4.1: Kangaroo Island [Tourism SA, 2005]

The town water supply traditionally relied on privately owned catchment reservoirs. In 1996, increasing problems with the quality and quantity of this water supply led to an investigation of other options. A seawater desalination option was found to be significantly cheaper than piping mains water from 60 km away. The AUD 3.5 million seawater desalination plant was designed and built by a contractor and became operational in 1999. This was SA Water's first experience with desalination and, at the time, a new innovative chemical-free discharge process, based on electromagnetic fields (EMF) was adopted for the seawater RO plant to protect the pristine nature and marine environment and promote the island as a showcase for eco-tourism.

Following construction and commissioning of the plant, continual mechanical failures, pressure vessel failures and significant leaks in both feed and discharge systems resulted in unreliability and desalinated water not achieving the required quality standards [Pelekani *et al.*, 2004]. The pre-treatment filtration equipment, comprising a proprietary particulate filtration unit also did not perform as proposed, and following recurring failure of newly installed pressure vessels in 2000, the plant was completely replaced with a conventional RO system of smaller diameter pressure vessels and two multi-media filters and two cartridge filters for the pre-treatment (Figure CE4.2). Furthermore, the use of the innovative EMF technology had proven too challenging for process design and plant integration and, as such, was discarded.

Case Example 4: Penneshaw Seawater Desalination (cont'd)

Figure CE4.2: Penneshaw seawater RO desalination plant [SA Water, 2005b]

The extensive modifications to the plant have greatly increased the reliability and permeate quality. The original filters and EMF system have been replaced with filter media developed by SA Water. Seawater is first passed through a 0.5 mm screen and treated with UV light to minimise algal and microbial growth before filtration through four parallel media filters. Following a pass through a bank of 15 and 5 µm cartridge filters, this RO feed water receives further UV disinfection to assist in the minimisation of biofouling of the RO membranes. The RO membranes now used in the plant have been selected for their capability of desalinating highly saline seawater in a single pass.

For SA Water to maintain their zero chemical discharge policy and prevent membrane damage, the recovery rate was reduced from the original 40 to 30%, making the plant less efficient than initially designed. Materials used in the initial pipe work construction were found to be effected by crevice corrosion and has been replaced in its entirety with high corrosion resistant materials.

The Penneshaw seawater RO operation highlighted several issues that need to be considered carefully when designing and constructing a desalination plant. These include:

- Wide diameter pressure vessels are more susceptible to leakage and failure than the industry standard 8-inch vessels;
- Capital spent on reliable and robust pre-treatment can significantly reduce plant downtime and operating costs;
- Correct application of welding practices to mitigate corrosion issues and use of high quality materials is essential; and
- New or emerging processes and technologies may not yet be compatible/integrative with plant design and operation.

13.5. Water Reclamation – Membrane Bioreactor Technology

13.5.1. Victor Harbor, SA

The tourist town of Victor Harbor on the Fleurieu Peninsula in South Australia is currently in the process of having its conventional STP replaced with a new plant that will be at the forefront in Australia for the application of immersed MBR technology for municipal wastewater treatment. The new STP is expected to come into operation in late 2005 [McLachlan *et al.*, 2005]. At that point, Victor Harbor will host the largest MBR in Australia treating on average 5,200 m^3/d, with a capability up to 15,000 m^3/d flow at peak times. Project capital cost, including land acquisition and other costs met by SA Water, is approximately AUD 40 million [United Utilities, 2005]. The plant is expected to supply Class A recycled water for unrestricted irrigation of agriculture, parks and gardens, removing microorganisms down to virus size and reducing phosphorous discharge by 95%. Prior to this decision, a research program involving a pilot trial was undertaken and subsequent to the trial a flat plate MBR-SDN (simultaneous denitrification-nitrification) process train was favoured over a Sequencing Batch Reactor-ultrafiltration train process. Post treatment involves UV irradiation before it is fit for unrestricted urban reuse and irrigation as per the Class A requirements.

The impetus for change came from the need to reduce nutrient flow into the Inman River. The river was suffering adverse effects from excess nitrogen and phosphorous, particularly in the dry summer months when flow from the STP was boosted by tourism. Construction of the treatment plant will take about 13 months. Victor Harbor is one of South Australia's most popular holiday and tourist destinations and this new plant will enable further growth and development, which was seen to have been hampered by an outmoded sewage treatment facility.

13.5.2. Environmental Desalination and Aquifer Replenishment

The least developed potential area for desalination technology includes environmental desalination to combat dryland salinity. In some areas of Australia, the rising saline water table is predicted to cause major environmental devastation and damage to property.

One approach is to lower the level of saline groundwater tables via continuous pumping – this brackish water can be desalinated to a saleable freshwater. The freshwater can be pumped into saltpans, or used for aquaculture lakes. This has been successfully trialled in Merredin, WA using a small 10 m^3/d brackish water RO plant. The ability to lower the groundwater in this way is dependent on the type of groundwater flow system in an area [AFFA, 2002].

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14. Cost Benefit Analysis of Desalination Plants

14.1. Introduction

There are two primary methods of desalinating water, one using membrane technologies and the other using thermal technologies. Within each method different technologies exist for the pre-treatment and treatment of water.

This project has undertaken comparative costings of a range of technologies potentially relevant to Victoria's needs. It is emphasised that the costings are indicative and are constrained by information available to the project team and necessary assumptions that are explained later in this section of the report. Sufficient details on cost and plant operation related information on Sydney or Perth was not available to allow for an inclusion of the proposed desalination plants into the cost benefit model.

Cost benefit modelling was undertaken to calculate production costs on a comparable basis. The costs outlined in this report are only for the production and treatment of water and do not represent the final costs of delivering desalinated water to end users. Energy costs have been normalised to represent the likely costs faced by plants operating under Victorian conditions. The basis of this process and other assumptions are outlined in Section 14.3.

The primary cost drivers for all technologies appear to be the type of feed water used in the production process and the application of the product water. The combination of feed water and product water application will determine the energy requirement for plants with higher output quality requirements tending to need more energy. The production of drinking quality water therefore tends to be more expensive than the production of lower quality water. However, there is potential for the production of lower quality water to meet industrial and environmental needs that would otherwise be met by the consumption of drinking quality water. This could increase the availability of high quality water at a lower desalination cost.

Energy is the largest variable cost of desalination after a plant has been built. In this study the energy needs of plants have ranged from 4 to 34% of the overall annual costs, with an average of 20%. Other significant variable costs are membrane replacement, operations and maintenance and labour costs. Table 7 summarises the plant specifications, the types of water processed and the headline results of the cost analysis. All results are reported in costs per unit of output (AUD/m^3 of water produced). Section 14.4 provides detailed commentary on these costs. Section 15 provides a more detailed commentary on other potential costs and benefits that may arise from the production of a desalination plant in Victoria.

14.2. Details of the Cost Benefit Model

Using a cost benefit model, various plant types have been analysed on a cost per m^3 output water.

Information was sought on costs associated with operating and financing desalination plants including:

- plant characteristics (land requirements, annual capacity, expected operating life and ability to generate its own energy supply etc);
- quality of the plants output water; and
- capital and operating costs including initial investment requirements, any additional capital expenditure requirements over the life of the plant, labour costs, energy costs and other operation and maintenance costs.

Unit costs have been converted to annual costs using the plant's annual capacity. For example, if membrane replacement will cost AUD 0.02/m^3, a plant with an annual production capacity of 100 million m^3 is expected to spend AUD 2,000,000 pa on membrane replacement, and this approach has been applied consistently across the modelling.

To compare the different plant types a high-level model was developed to calculate the total costs over the life of the plant. To increase comparability of the plants a number of global assumptions were made and applied consistently across all the examples. These assumptions and the rationale behind them are outlined in Table 6.

Based on the data available and the assumptions outlined above, the model has calculated annual operating costs for the life of the plant. These costs comprise:

- Capital costs;
- Operation and maintenance costs;
- Labour cost; and
- Energy costs.

To compare the investments, the total costs across the assumed lifespan, expressed in 2005 dollars were divided by total production over that period. This provided a cost per m^3 of water produced, which indicates of how cost efficiently a plant desalinates water.

The annual costs for each year of the plant's assumed life were discounted back to 2005 to give the present value of the entire costs of the investment.

The present value measures the investment on an AUD/m^3 basis. Costs that are spread out over a longer period will have a lower present value than if the same costs were spread over a shorter period. This approach therefore costs production in the near future more highly than production which might be delayed until later, because of capacity constraints on the plant. An indicative discount rate of 10% to calculate the present value of costs has been applied.

14.3. Model assumptions and inputs

14.3.1. Model assumptions

Table 6 contains an overview of the assumptions made in the cost benefit analysis. These include assumptions related to weighted average cost of capital, exchange rates, energy requirements, inflation and depreciations.

14.3.2. Energy cost assumptions

The main components of delivered energy costs are the costs of power and the transmission and distribution network costs required to deliver the energy to the customer.

Table 6: Overview of assumptions

Global inputs	Unit	Rationale
Weighted average cost of capital (WACC)	%	Commercial capital investments are normally made on the basis that the risk borne by the investor will be compensated by a financial return. This return is a cost for the purposes of this analysis. The same WACC (10%) has been assumed for all investments. The WACC has also been used as the appropriate discount rate used in the calculations of the present value of costs.
Energy requirements	AUD/kWh	The energy costs of the various plants will differ depending on the country of operation. The model has normalised the costs of energy by using a consistent AUD 0.06/kWh. Refer to Section 14.3.2 (Energy cost assumptions)
Exchange rates	AUD, Euro, USD	All currencies have been converted to Australian dollars (June 2005 rates)
Inflation data	%	Inflation rates have been sourced from the US Treasury and the Reserve Bank of Australia. These rates have been used to convert dollars from various years, depending on the timing of the investment into January 2005 dollars.
Depreciation	%	Depreciation has been calculated based on the straight line method (initial investment / expected life of the asset). Plant lives were provided in source documents and are specific to each plant and technology.

An average delivered energy cost in Victoria of 6 cents per kWh has been assumed. This is based on the principal assumptions that a desalination plant would:

- Be connected to the distribution network as a sub transmission (66 kV) or high voltage (22 kV) customer; and
- Negotiate in the National Electricity Market an average cost of power of about 3.9 cents per kWh, prior to network charges and retail margins.

The actual energy costs experienced by a desalination plant would vary according to the following key factors:

- The wholesale costs of power from the National Electricity Market would be a negotiated commercial outcome. The market cost can vary considerably according to the time of day and year. The price negotiated by the plant with a retailer may vary significantly according to the plant's pattern of demand and whether it has the capacity to interrupt production at times of peak market demand, when the retailer may be exposed to the risks of extremely high or volatile wholesale energy prices. While electricity cannot, in practical terms be stored, desalinated water can. Therefore, if the plant is built with surplus capacity it may not need to run continuously to meet the demand for desalinated water. However, there are significant costs associated with either interrupting continuous operation in a RO plant and start-up costs for thermal desalination plants;
- The demand and load of a very large plant such as Ashkelon would be more likely to be connected directly to the transmission network, than the distribution network. If this were the case, the delivered energy costs of the plant would be reduced because the plant would not incur distribution charges;
- Network charges are normally structured such that plants with higher electrical demand (MW) are more likely to experience lower network costs on a per kWh basis than plants with lower demand; and
- A plant may by-pass wholesale energy altogether by installing its own generation plant. This could be done with or without a network connection to the National Electricity Market:

    - if it were done without a network connection, the plant would not face network charges although some additional capital investment would be required to connect the generation plant to the desalination plant. However, the desalination plant would be exposed to the risks of being entirely dependent on the reliability of a single generation source and would not be exposed to the pricing risks and benefits of connection to the wholesale market. The generation plant would also still require access to a fuel source. If a "renewable" source such as wind or solar power were to be used this could restrict the times at which the desalination plant would be able to operate; and
    - if a connection to the National Electricity Market were maintained, this would reduce the potential to save network costs. However, it would also reduce the desalination plant's reliability risks because it would have access to an

alternative power supply. Also at times of very high wholesale power prices, such as peak times of day in the summer, there would be the potential for the plant to defray its costs by selling electricity back into the grid for brief periods, in place of using it to power the desalination plant.

14.3.3. Plant Overview

Table 7 provides an overview of the plant types and the annual operating capacity. Due to the lack of consistent information, plants are assumed to produce 100% of their annual potential production. The plants range in size from 3.6 million to 100 million m^3 per year. Information about four plants has been sourced from desalination studies. When sourcing the information from these studies, the same global assumptions and normalisation processes were applied as for plants that actually exist and operate.

14.3.4. Model inputs/plant specific assumptions

Table 8 outlines the specific inputs and assumptions made when modelling each of the desalination plants. Unless otherwise stated in the table, labour costs are assumed separate from operation and maintenance costs.

Table 7: Plant background and operational context

Plant (operation/study)	Background
Ashkelon, Israel (operational)	The Ashkelon seawater RO plant is one of the largest desalination plants in the world with a capacity of 100 million m^3 of water a year. The plant is located on 70,000 m^2 of land. The plant was built under a BOT arrangement between the private sector and the Government. After 25 years, the operation of the plant will be transferred to the Government. The benefits of this plant, as outlined by the Israel Water Commission, are that it: 1) ensures sustainable capacity, reliability; quality and costs; 2) caters for increased demand for water; and 3) addresses issues surrounding existing water supply quality. The expected economic life of the plant is assumed to be 25 years, the length of time that private investors will be operating the plant. This assumption is based on the notion that investors will expect their capital to be returned to them over the 25 year private operator period. The actual operational life of the plant will be longer. It is not known how much and whether capital refurbishment may be required at the time of transfer.
Nordkanal, Germany (operational)	The Nordkanal is the world's largest MBR treating municipal wastewater. It produces 16.4 million m^3 a year. Water produced by the Nordkanal plant is primarily used to restore environmental flows in nearby rivers and streams. The plant produces waste products that are burnt at a nearby power station. Currently, the waste produced by the plant is approximately 350-400 m^3 per day. This information has not been used in the quantitative assessment of the desalination plant (refer to Section 14.4).
Corpus Christi, USA (feasibility study)	The Corpus Christi plant is a RO seawater desalination facility with an annual production capacity of 34.4 million m^3. The plant will have an open ocean intake system from the Gulf of Mexico. The primary benefit of the Corpus Christi plant is to allow existing water supplies to be redistributed to other regions. The plant produces brine concentrate that will be passed into the Gulf of Mexico. The capital cost associated with by-product disposal is accounted for in the initial capital investment. The capital investment associated with the by-product disposal represents 11% of the initial capital investment or approximately AUD 28.4 million. This represents AUD 0.08/m^3 or 7% of the average (AUD 2005) production costs of AUD 1.20/m^3

Plant (operation/study)	**Background**
Brownsville, USA (feasibility study)	The Brownsville plant is a RO desalination plant capable of producing 34.5 million m^3 a year. The plant will be situated approximately 10 km from the plant's water source. Brownsville will use screened raw water from a nearby shipping channel. The overall water quality is considered lower than seawater, increasing the energy requirements of the plant. The potential benefits of the Brownsville plant outlined by the Texas Water Development Board [TWDB, 2004] are increased system reliability, increased water availability to towns in surrounding areas and the potential to develop a water rights market. The plant will discharge waste water into the Gulf of Mexico. The capital cost associated with by-product disposal is accounted for in the initial capital investment. The capital investment associated with the by-product disposal represents 22% of the initial capital investment or approximately AUD 42.5 million. This represents AUD 0.11/m^3 or 13% of the average (AUD 2005) production costs of AUD 0.87/m^3.
Freeport, USA (feasibility study)	The Freeport plant uses RO technology to primarily desalinate river water. When river water is not available the plant can switch to seawater. It has an annual production capacity of 13.8 million m^3. The plant will produce drinking quality water. The river water used in the desalination process will result in a lower production compared to a similar plant using seawater. The Freeport plant also takes advantage of existing infrastructure at a nearby chemical plant. Information could not be accessed that would allow cost adjustments to be made for location-specific benefits associated with the shared infrastructure, potentially distorting the initial capital investment required to develop a plant like Freeport. The plant will produce brine concentrate that will be passed into the Gulf of Mexico or a nearby river via the existing infrastructure available at the nearby chemical plant.
Yellowater (worked example)	Nanofiltration is used to desalinate 41.9 million m^3 of well water annually. The purpose of the plant is to reduce water hardness before injecting the water into the city's water supply. The plant is expected to have a 20 year life span.
Dry Creek (worked example)	Electrodialysis reversal is used at Dry Creek to process brackish creek water into drinking water. The plant has an annual production capacity of 3.65 million m^3. The plant is expected to have a 20 year life.

Plant (operation/study)	Background
Madwar and Tarazi study [2002]	Two plants have been costed using data taken from a feasibility study undertaken by Madwar and Tarazi [2002]. Wastewater and seawater plants have been costed based on a series of similar assumptions. Both plants are assumed to have an annual production capacity of 3.6 million m^3. The capital costs provided by the study for both plants include those associated with the treatment systems, system design, materials and construction costs. Running costs include operational staff, maintenance, chemical and energy costs. The assumed life span of the plants is 20 years.
MED/MSF (study)	The MED and MSF plants have been costed using a study undertaken by Ophir and Lokiec [2004]. Both plants are assumed to produce 36.5 million m^3 per year. The MED production process is relatively new. It takes advantage of gains in energy efficiency to lower production costs.
Eraring Power Station (NSW) (operational)	Since 1993, the Eraring Power Station has been supplied with water from a MF/RO plant. The expected life of the plant is 15 years. The desalination plant is relatively small compared to the other plants costed in this study producing 1.46 million m^3 per year. The plant is supplied water from the nearby Dora Creek STP. Factors leading to lower overall production costs are the lower salinity feed water, lower post-treatment costs related to use of water and maintenance of the membranes. The membranes were expected to be replaced every few years, however, due to care and maintenance the membranes have only been replaced once, after ten years of operation at a cost of AUD 120,000. The plant's other benefits have also included reducing its reliance on domestic water supplies.
City of Great Hope (worked example)	This MVC plant has been designed to produce 1.3 million m^3 per year. The plant has an expected life of 30 years. Located near the Atlantic Ocean, the MVC will use seawater in the desalination process.

Table 8: Input costs

Plant location	Process	Capital cost (AUD million)	Energy (kWh/m^3)	Annual membrane replacement (AUD/m^3) (if reported separately)	Annual O&M (AUD/m^3)	Labour (AUD/m^3)
Ashkelon, Israel	RO	289.2	3.88	AUD 0.03/m^3 (for the first 5 years of operation) AUD 0.06/m^3 (for the remainder of the plant's life)	AUD 0.09/m^3 (for the first 5 years of operation) AUD 0.15/m^3 (for the remainder of the plant's life)	AUD 0.04 /m^3 (for the first 5 years of operation) AUD 0.04/m^3 (for the remainder of the plant's life)
Brownsville, USA	RO	197.2	3.68 (total kWh/total annual production)	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.15/m^3 (generated by dividing total O&M costs by total production). O&M includes chemicals, site maintenance and miscellaneous costs	AUD 0.05/m^3 (generated by dividing total labour costs by total production)
City of Great Hope	MVC	9.5	16.1	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 1.45/m^3 (all costs included in one line item including labour, chemicals, steam and repairs and spares)	N/A
Corpus Christi, USA	RO	231.7	3.25 (total kWh/total annual production)	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.34/m^3 (generated by dividing total O&M costs by total production). O&M includes chemicals, site maintenance and miscellaneous costs	AUD 0.05/m^3 (generated by dividing total labour costs by total production)

Plant location	Process	Capital cost (AUD million)	Energy (kWh/m^3)	Annual membrane replacement (AUD/m^3) (if reported separately)	Annual O&M (AUD/m^3)	Labour (AUD/m^3)
Dry Creek	EDR	30.7	1.28	AUD 0.04 /m^3 (figure provided by source documentation, based on a 10% replacement per year)	AUD 0.19/m^3 (all costs included in one line item including labour, chemicals, steam and repairs and spares)	N/A
Eraring Power Station (NSW)	MF/RO	4.7	Energy costs included in O&M.	Membrane replacement has occurred after nine years of operation at cost of AUD 120,000	AUD 0.25/m^3 (assumed to contain all operating costs, including energy and labour no specific analysis is available)	N/A
Freeport, USA	RO	119.8	3.82 calculated using known power costs and average AUD 0.06/kWh	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.28 /m^3 (generated by dividing total O&M costs by total production). O&M includes chemicals, site maintenance and miscellaneous costs	AUD 0.11/m^3 (generated by dividing total labour costs by total production)
IDE Technologies	MED	138.4	1.2	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.11/m^3 calculated by dividing total cost by annual output (includes chemicals and spare parts)	AUD 0.02/m^3 (calculated by dividing total cost by annual output)
IDE Technologies	MSF	148.5	3.5	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.16/m^3 calculated by dividing total cost by annual output (includes chemicals and spare parts)	AUD 0.02/m^3 (calculated by dividing total labour cost by annual output)

Plant location	Process	Capital cost (AUD million)	Energy (kWh/m^3)	Annual membrane replacement (AUD/m^3) (if reported separately)	Annual O&M (AUD/m^3)	Labour (AUD/m^3)
Madwar and Tarazi study/ Wastewater	RO	7.6	1.8	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.23/m^3 (includes chemical and maintenance cost)	AUD 0.08/m^3 (calculated by dividing total labour cost by annual output)
Madwar and Tarazi study/ Seawater	RO	18.6	7.9	All operations and maintenance costs have been reported in O&M, no separate reporting of membrane replacement or maintenance.	AUD 0.33/m^3 (includes chemical and maintenance cost)	AUD 0.07/m^3 (calculated by dividing total labour cost by annual output)
Nordkanal, Germany	MBR	29.9	0.75	All costs other than energy have been assumed using rule of thumb estimates	O&M cost assumed to be AUD 0.13/m^3 (similar to other waste water plants)	AUD 0.79/m^3 indicative figure obtained from other water reclamation plants)
Yellowater	NF	158.2	0.317	AUD 0.22/m^3 (figure provided by source documentation, based on a 14% replacement per year)	AUD 0.04/m^3 (all costs included in one line item including labour, chemicals, steam and repairs and spares)	N/A

14.4. Overall Ranking of Technologies

14.4.1. Ranking by Cost

Eight technologies were costed during this study: MED, RO, MSF, EDR, MBR, MF/RO, MVC and NF. The thirteen plants costed use five different types of intake water: seawater, wastewater, river water, well water and brackish water.

The type of technology used in the desalination process is dependent largely on the type of water processed. For example plants using intake water with high salt levels will tend to have a higher energy requirement. On the other hand, plants using intake water with lower salinity such as well water or recycled water can use less energy intensive technologies such as NF or MED with lower energy requirements.

The quality of water produced also causes production costs to differ. To provide an evaluation of water use, Table 9 includes a column stating if product water is used for drinking water. It is evident in the table below that product water produced from a recycled water source is not used for human consumption and is cheaper to produce. Three of the five lowest cost plants do not produce water fit for human consumption.

While no two technologies studied have identical characteristics they can be ranked on cost, keeping in mind that plants will process and produce different types of water. Table 9 ranks the technologies by their average 2005 costs per m^3.

The three cheapest plants are the MBR, the NF and the MF/RO. Two of these plants, the MBR and MF/RO produce water fit for industrial usage. The NF plant softens reasonable clean well water for drinking purposes. Technologies that produce the most expensive water tend to desalinate salty water to make it fit for human consumption. Nanofiltration is clearly the cheapest desalination plant of the sample set reviewed producing water for human consumption. The primary factor driving lower costs for this plant is the relatively clean well water used in the desalination process.

For a more detailed explanation of the cost drivers for each plant refer to Table 8 which outlines capital costs, energy requirements, membrane replacement costs, operation and maintenance and labour.

Table 9: Ranking by average 2005 costs/m^3

Plant location	Technology	Type of water processed	Daily production capacity (m^3)	Present value of costs (AUD/m^3)*	Average cost (AUD/m^3) (AUD 2005)	Potable water use (Yes/No)
Nordkanal, Germany	MBR	Recycled	45,000	0.16	0.41	No
Yellowater	NF	Well	115,000	0.23	0.48	Yes
Eraring Power Station	MF/RO	Recycled	4,000	0.26	0.48	No
IDE Technologies study**	MED	Sea	100,000	0.27	0.59	Yes
Madwar and Tarazi study Wastewater	RO	Recycled	10,000	0.28	0.64	No
Ashkelon, Israel	RO	Sea	273,973	0.28	0.73	Yes
IDE Technologies study	MSF	Sea	100,000	0.37	0.81	Yes
Brownsville, USA	RO	River	94,635	0.35	0.87	Yes
Dry Creek	EDR	Brackish	10,000	0.56	1.20	Yes
Corpus Christi, USA	RO	Sea	94,635	0.48	1.20	Yes
Madwar and Tarazi study/Seawater	RO	Sea	10,000	0.63	1.40	Yes
Freeport, USA	RO	River	37,854	0.58	1.43	Yes
City of Great Hope	MVC	Sea	3,775	1.06	3.19	Yes
		Range		***0.17-1.29***	***0.44-3.19***	

* The present value of costs is calculated using a discount rate of 10% as described in Table 6

** Ophir and Lokiec [2004]

14.4.2. Cost Distribution

The cost distribution graph (Figure 35) shows the number of plants in a range using AUD 0.25/m^3 intervals, based on 2005 average costs. The shading on the graph shows plants from studies, worked examples, feasibility studies and operational plants and are costed using the data provided. This cost distribution graph shows that plants processing high salinity water will incur higher average costs through higher energy needs. For every AUD 0.25/m^3 interval, the key plant characteristics that determine its position on the graph are discussed.

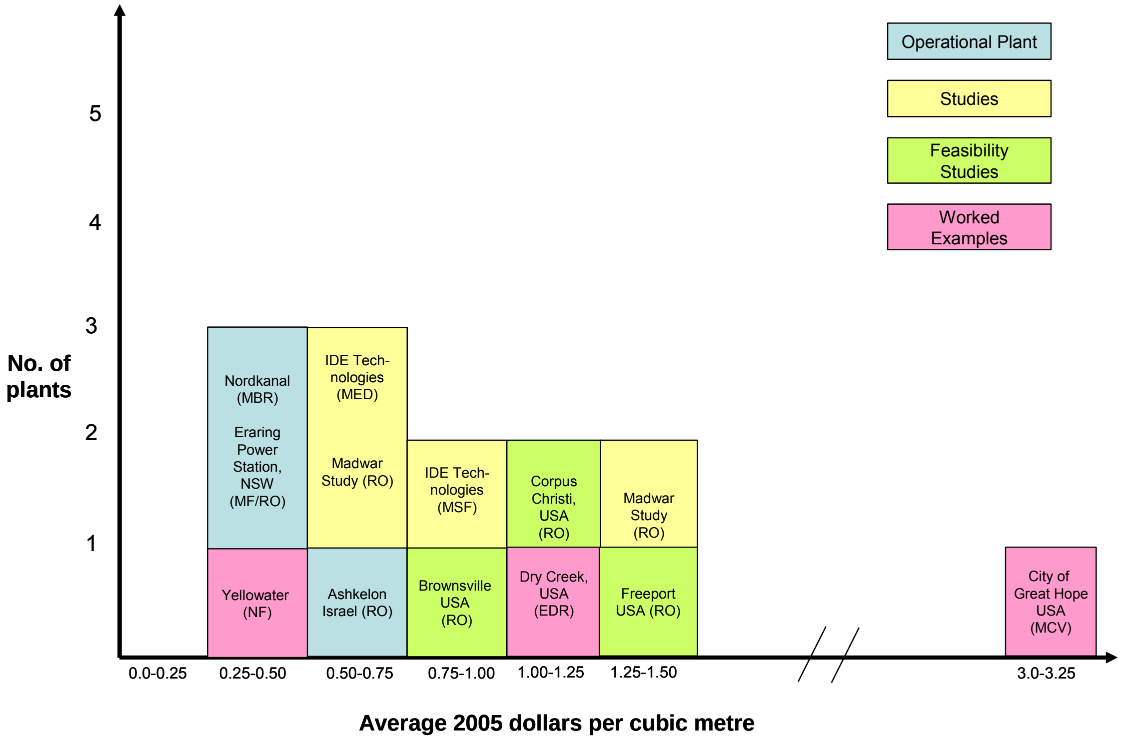

Figure 35: Technology cost distribution

AUD 0.25-0.50/m^3

The plants located in this range are the Nordkanal, Eraring Power Station and Yellowater. These plants either use lower salinity feed water or produce water for non-potable application. Both characteristics lower the overall energy required for desalination.

Both the Nordkanal and the Eraring Power Station plants do not produce water used for human consumption. The water produced by the Eraring desalination plant was designed to produce water for cooling systems in the electricity generation plant located on the same site (the Eraring Power Station desalination plant does not report its energy consumption per cubic metre, reporting instead a total operations, maintenance and labour cost per m^3). The Nordkanal plant produces bathing quality water designed to increase the water levels in the rivers and streams surrounding the plant. The Nordkanal plant only requires 0.75 kWh/m^3, at a normalised Australian cost of AUD $0.05/m^3$.

The Yellowater plant is a NF plant processing well water that has a lower salinity level. The Yellowater plant uses 0.317 kWh/m^3, at a normalised Australian cost of AUD $0.019/m^3$. The primary purpose of the plant is to reduce the hardness of the water supplied to the local town and surrounding area.

AUD $0.50\text{-}0.75/m^3$

Two of the three plants located in this range are not operational, their costs being sourced from other studies. The operational plant is Ashkelon, a seawater RO plant.

Ashkelon's lower overall costs compared to other RO plants and other technologies processing seawater appears to be primarily driven by Ashkelon's economies of scale. This allows it to operate at a lower average cost than a plant with the same specifications but with a reduced annual capacity. The plant has an annual production capacity of 100 million m^3. Ashkelon uses 3.88 kWh/m^3 at a normalised Australian cost of AUD $0.23/m^3$.

The MED plant costed by Ophir and Lokiec [2004] operates at a lower cost. This appears primarily due to the plant technology allowing it to operate at lower temperatures. Lower operational temperatures allow for the plant pipes and machinery to be constructed out of lower quality steel, resulting in lower costs. The MED technology also has a lower energy requirement of 1.2 kWh/m^3.

The RO plant cited in the Madwar and Tarazi study [2002] processes wastewater and has an annual production capacity of 3.6 million m^3. Water produced by this plant is not fit for human consumption. The combination of relatively high quality wastewater intake and low quality output provide a basis for assuming lower production costs. The study cites an estimated energy consumption of 1.8 kWh/m^3.

AUD $0.75\text{-}1.00/m^3$

Brownsville will be a RO plant, with an annual capacity of 34.5 million m^3. Brownsville will have the capacity to operate at a lower average per unit cost. This primarily appears due to economies of scale of the operation and the slightly lower salinity of intake water used by the plant. Brownsville's intake water will come from a shipping channel located near the plant's site thus reducing capital costs for raw water pipelines from the open sea. It is expected to consume energy at a slightly reduced 3.68 KWh/m^3 compared to the average RO plant's energy needs of around 4 kWh/m^3. This represents an estimated saving of AUD $0.02/m^3$.

The MSF technology cited in the IDE study [Ophir and Lokiec, 2004], will process seawater and have an annual production capacity of 36.5 million m^3. MSF is a thermal technology resulting in the plant producing large amount of heat. For the plant to function under these high temperatures, the piping and machinery need to be built with higher quality material, leading to higher initial capital costs. Thermal technologies are also energy intensive, the MSF plant assumed in the IDE study will require 3.5 kWh/m^3.

AUD 1.00-1.25/m^3

The Dry Creek (EDR) plant and the Corpus Christi (RO) plant are in the AUD 1.00-1.25/m^3 range. The Dry Creek plant desalinates brackish surface water and has an annual production capacity of 3.65 million m^3 while the Corpus Christi plant processes seawater on a larger scale with an annual production capacity of 34.4 million m^3.

The Dry Creek plant requires less energy to process brackish water which has relatively low salinity levels. The EDR plant requires 1.28 kWh/m^3. Whilst having lower energy costs significantly lowers the operational cost of the plant, the EDR technology does appear to require larger labour costs and annual membrane replacement costs of AUD 0.053/m^3.

The expected costs of operating the Corpus Christi plant are in the mid-range of all seawater RO plants. The estimated energy requirements of the plant are 3.25 kWh/m^3, well within the range of energy consumption indicated by other seawater desalination plants in the sample reviewed in this study.

AUD 1.25-1.50/m^3

The Freeport RO plant and the Madwar and Tarazi study for a RO plant are expected to fall in the AUD 1.25-1.50/m^3 range. Both plants process seawater and both have relatively small annual productions of 13.8 million m^3 and 3.65 millions m^3, respectively. The energy requirements for both RO plants are high. Freeport is expected to need 3.82 kWh/ m^3 and the Madwar and Tarazi [2002] study plant assumes energy requirements of 7.9 kWh/m^3. This energy consumption assumption appears to be particularly high. Most of the RO plants desalinating seawater require 3-4 kWh/m^3. It is not known why the assumption appears to be high but it is observed that the purpose of the Madwar and Tarazi study was to highlight the benefits of water reclamation over seawater desalination and in particular positive economic advantages attributable to lower salt content compared to seawater.

AUD 3.00-3.25/m^3

Only the MVC plant processing seawater has costs above the AUD 1.25-1.50/m^3 range. The plant suffers from extremely high energy requirements, assumed to be 16.1 kWh/m^3. The plant also has the smallest annual production of 1.37 million m^3.

14.4.3. Ranking by Type of Water Processed

The following tables show a breakdown of plant costs by the type of water used in the desalination process. All tables are sorted by 2005 average cost. Table 10 outlines the seawater desalination technologies,

Table 11 outlines technologies used for water reclamation and Table 12 shows two plants processing river water for drinking water production.

Table 10: **Seawater desalination**

Plant location	Technology	Present value of costs (AUD/m^3)	Average cost (AUD/m^3) (AUD 2005)
IDE Technologies study	MED	0.27	0.59
Ashkelon, Israel	RO	0.28	0.73
IDE Technologies study	MSF	0.37	0.81
Corpus Christi, USA	RO	0.48	1.20
Madwar and Tarazi study/Seawater	RO	0.63	1.40
City of Great Hope	MVC	1.06	3.19
	Range	***0.27-1.06***	***0.59-3.19***

Seawater has the highest average cost for desalination (AUD 1.32/m^3), mainly due to the higher energy requirements needed to purify the water. Three of the six plants above are RO plants and the average cost of a RO plant desalinating seawater is AUD 1.11/m^3. Of the three RO plants listed above, two are in operation. As a result they provide a clearer picture of actual costs than the Madwar and Tarazi [2002] study.

Advanced water reclamation has a significantly lower energy requirement than seawater desalination. However, lower water reclamation costs are contingent on pre-treatment processes designed to remove large impurities before primary desalination takes place. Pre-treatment will often take place off-site at STPs, where recycled water from secondary or tertiary treated sewage is the feed water into the desalination plant.

The water produced by the two plants, Nordkanal and Eraring, is not used for domestic quality drinking water. Rather, they help to conserve existing water reserves. The Eraring MF plant produces water used for cooling the power station located on the same site. The Nordkanal reclaims water to improve environmental flows for nearby rivers and streams. Whilst not producing drinking water, the MBR technology treats water to meet the EU bathing water quality guidelines of surface waters [Janson, 2005]. The benefits of substituting desalinated water for drinking water have not been quantified in this modelling exercise. However, it may be reasonable to assume that there is potential for saving domestic drinking water whenever industry or the environment uses desalinated water in its place.

Table 11: Water Reclamation

Plant location	Technology	Present value of costs (AUD/m^3)	Average cost (AUD/m^3) (AUD 2005)
Nordkanal, Germany	MBR	0.16	0.41
Eraring Power Station	MF/RO	0.26	0.48
Madwar and Tarazi study / Wastewater	RO	0.28	0.64
	Range	***0.16-0.28***	***0.41-0.64***

The only plant cited in

Table 11 to produce drinking quality water is the RO plant listed in the Madwar and Tarazi study. On the basis of energy prices normalised for Victoria, this plant is expected to spend only AUD 0.11/m^3 on electricity or 17% of the 2005 average cost. Compared to the average seawater plants energy cost of around AUD 0.34/m^3 this represents a saving of around AUD 0.23/m^3.

Table 12: River water processing

Plant location	Technology	Present value of costs (AUD/m^3)	Average cost (AUD/m^3) (AUD2005)
Brownsville, USA	RO	0.35	0.87
Freeport, USA	RO	0.58	1.43
	Range	***0.35-0.58***	***0.87-1.43***

The two plants designed to process river water are Brownsville and Freeport. These plants are expected to produce water for a cost of AUD 1.87 and AUD 1.43 per m^3, respectively. The average cost of desalinating river water in this study is AUD 0.17/m^3 lower than desalinating seawater. While cheaper, river water desalination does not represent a significant cost saving compared to seawater in this study. This is due to the fact that the Brownsville plant's intake water is from a shipping channel located near the sea, leading to higher salinity levels and higher energy costs and the Freeport plant is designed to process both river water (primary intake) and seawater (when required).

Table 13 provides an overview of the two remaining types of water, well water and brackish water. As discussed above, the Yellowater plant processes water with lower salinity levels leading to a low energy requirement of 0.317 kWh/m^3 or around AUD 0.02/m^3. The Dry Creek plant processes brackish surface water requiring 1.28 kWh/m^3 or around AUD 0.08/m^3.

Table 13: Other water processed

Plant location	Technology	Type of water processed	Present value of costs (AUD/m^3)	Average cost (AUD/m^3) (AUD2005)
Yellowater, USA	NF	Well	0.23	0.48
Dry Creek, USA	EDR	Brackish	0.56	1.20
		Range	***0.23-0.56***	***0.48-1.2***

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15. Additional Considerations

15.1. Location

A reliable and high quality source of seawater is critical for a desalination plant [Sydney Water, 2005]. For Melbourne, this might suggest that a desalination plant of seawater would need to be located such that it directly sourced water from Bass Strait rather than from Port Phillip Bay. However, CSIRO [1996] conducted an environmental study on Port Phillip Bay which found that the waters of the bay have the same salinity as seawater. The study found that, despite a population of greater than 3 million living around the shores of the bay, it is in good condition and generally healthier and cleaner than other bays around the world that are near large cities. The bay does not suffer from oxygen depletion caused by excessive nutrient levels and toxicant levels are not a current threat to the bay. These findings may make it feasible to locate a desalination plant on the bay, but such feasibility should be assessed in more detail.

All desalination processes use electrical energy, and some such as RO and MVC use electrical power exclusively. Thus, the potential to co-locate a desalination plant with a source of energy (including waste heat) would need to be assessed. For thermal processes, the energy cost of water from a dual-purpose installation is about ½ to ⅓ that of a stand-alone plant [Water Corporation, 2000].

Another factor that will need to be considered in locating a desalination plant of seawater is the proximity to existing water distribution infrastructure. As shown in Figure 26, Sydney's reservoirs are located inland from the coast and, as such, desalinated water produced from the proposed Kurnell plant will be piped to the Waterloo pumping station. This would supply the Potts Hill supply zone, which accounts for approximately one third of Greater Sydney's water usage [Sydney Water, 2005]. The water reservoirs for Melbourne are illustrated in Figure 36. The need to distribute desalinated water produced from the desalination of seawater either from the metropolitan reservoirs (such as Cardinia or Greenvale) or a large pumping station (similar to Waterloo in Sydney) as well as other potential options would need to be further investigated in detail.

The amount of land required for the siting of a RO desalination plant will depend on the size of the plant itself. Both the Perth and Sydney desalination studies [Sydney Water, 2005; Water Corporation, 2000] have indicated that approximately 0.5 ha of land is required for each 50,000 m^3/d production capacity.

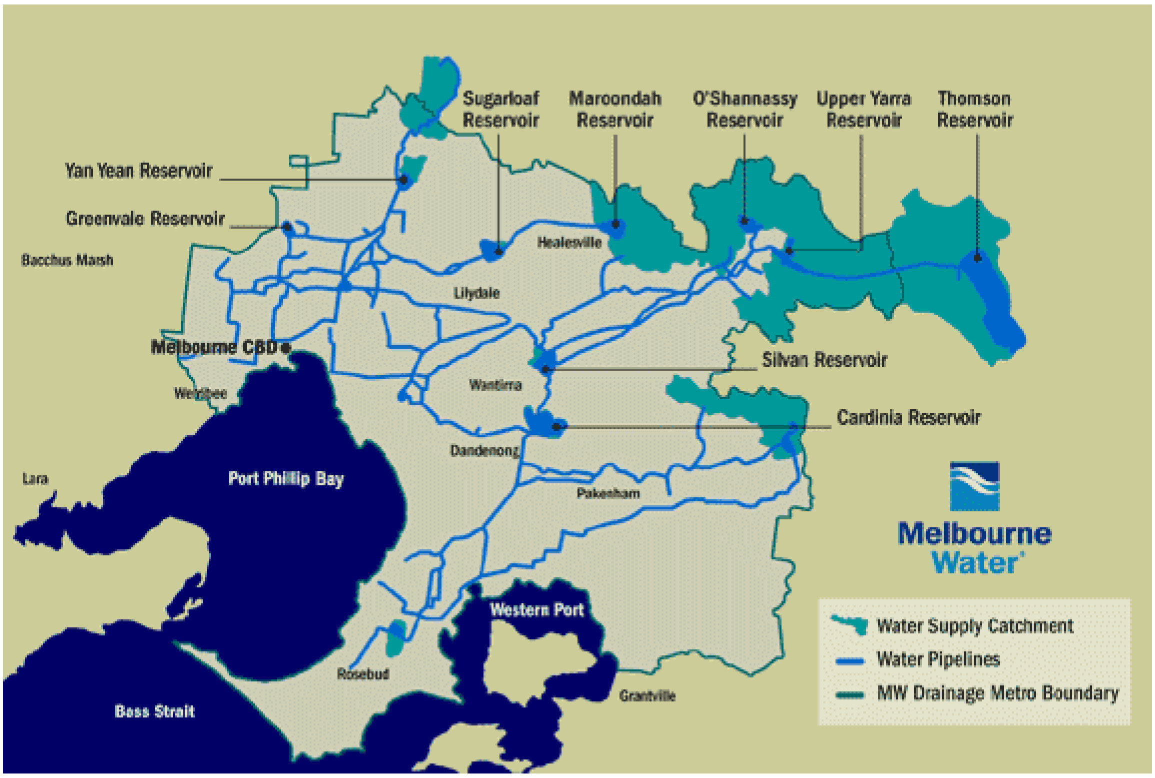


Figure 36: **Melbourne's reservoirs and water pipelines [Melbourne Water, 2005]**

15.2. Distribution

As indicated in Sections 13.1.2 and 15.1, Sydney's proposed desalination plant at Kurnell will require an intake/outfall tunnel for seawater and saline reject as well as a pipeline/tunnel to pipe the treated water from Kurnell to the Waterloo pumping station. These distribution requirements will cost in excess of AUD 500 million (or approximately 30% of the total capital cost) for the 500,000 m^3/d desalination plant proposed.

For Melbourne, the requirements for distribution would also largely depend on the size of any desalination plant installed. For small size plants, pumping to local service networks would be adequate whereas a large size plant would require pumping to a major city supply point. Depending on the volume of desalinated water to be treated and the availability of suitable distribution networks, more than a single desalination plant may be required for the desalination of seawater.

15.3. Economic, Environmental and Social Considerations

This section summarises some of the key broad environmental, economic and social costs and benefits of desalination in a Victorian context. A high-level map of the major inputs and outputs of the desalination process has been constructed to guide this discussion and is shown in Figure 37.

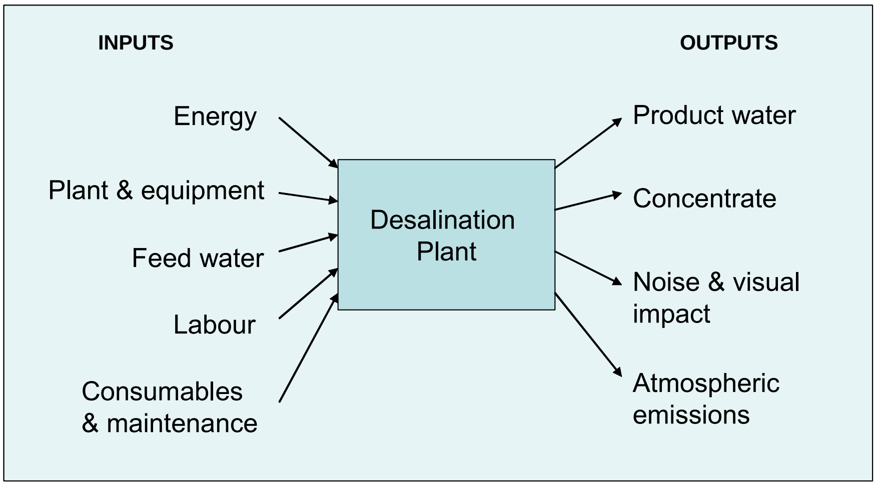


Figure 37: Overview of key inputs and outputs for a desalination plant

Before being used as potable water, desalinated water would require post-treatment in a process called potabilisation. This process ensures that the treated water meets the requirements of the Australian Drinking Water Guidelines [ADWG, 2004]. Currently, approximately 90% of Melbourne's water requires minimal treatment involving disinfection, fluoridation and pH correction. Chlorination is the preferred method of disinfection. This treatment would also be required for water produced from desalination processes. The remaining 10% of Melbourne's water requires a more involved treatment including the additional processes of coagulation and clarification to cause the colour and turbidity particles to settle out, filtration to remove most of the remaining suspended solids and sludge processing.

As indicated previously, all desalination processes have a relatively large requirement of electrical energy. For example, a seawater RO plant consumes approximately 91 GWh of energy per year for each 50,000 m^3/d of production capacity [Sydney Water, 2005]. Greenhouse gas abatement was a consideration in both the Sydney and Perth desalination studies. The Water Corporation may offset the use of energy used in the desalination plant with wind power generation that will be located 150 km from Perth. Sydney Water [2005] also recognised that wind power is the only proven renewable energy option available at a large-scale. However, rather than directly investing in renewable energy options, which may prove to be technically and/or commercially unviable, Sydney Water's preferred option is the purchase of renewable energy certificates as a greenhouse gas mitigation mechanism.

Additional environmental factors that would need to be considered include those associated with construction of a desalination plant, air quality (although these are considered to be of a minor nature), impact on the marine and coastal zone environments for desalination plants located on the coast and the terrestrial environment for inland desalination plants.

Table 14 and Table 15 comment on each input and output, respectively, except energy and product water and the potential environmental, social and economic costs or benefits that might arise. These latter factors are discussed separately as they are more substantive and potentially have greater economic, social and environmental consequences.

A seawater desalination plant for the purpose of supplementing existing drinking water sources will require an economic cost driver. Capital investment may stimulate particular sectors of the Victorian economy and can be maximised if plant and equipment is sourced locally.

Social benefits include that construction may stimulate employment, however ongoing operation and maintenance may not require a large labour force. Social issues that need to be addressed include the public perception of reusing reclaimed water from STP’s for irrigation purposes or market gardens. Recent news headlines on Sydney‘s seawater desalination plans highlight the concerns of public groups of committing to a large financial investment to produce drinking water from seawater. This is seen against potential environmental effects and perceived lower investment in water recycling efforts [The Australian, 2005; The Sydney Morning Herald, 2005; The Australian Financial Review, 2005].

Table 14: **Summary of potential economic, social and environmental costs and benefits for key inputs**

Inputs	Economic costs and benefits	Social costs and benefits	Environmental costs and benefits
Plant and equipment	Construction of a desalination plant will stimulate particular sectors of the Victorian economy as a direct result of building plant and equipment. Local sourcing of plant and equipment will maximise any potential economic benefit.	Construction activity also has the potential to generate direct and indirect employment outcomes, thereby increasing household incomes and providing net social benefit.	Any environmental costs are likely to be associated with temporary disruption during construction generating dust, noise etc.
Feed water	Economic benefits are likely where the desalination plant sources untreated wastewater and the previous disposal of this untreated wastewater generates externalities (e.g. industry disposing untreated water in a river or bay that had a negative impact on other users of that river or bay). Negligible economic costs or benefits are anticipated where abundant supplies of seawater or brackish water are treated for human consumption	Social issues arise when dealing with the reuse of wastewater. Proposals to treat wastewater for human consumption at this stage are considered socially undesirable because of the perception it would contaminate Melbourne's 'pristine' potable water supply [DSE, 2004].	Environmental benefits may arise where previously untreated wastewater is diverted from a sensitive receiving environment.
Labour	Ongoing operations of a desalination plant are likely to employ a relatively small workforce. Desalination is not a labour-intensive activity. New employment does however provide additional household income and generate economic activity and indirect employment.	Refer to comments in "plant and equipment".	N/A
Consumables and maintenance	Ongoing operations will see expenditure with local and overseas suppliers for consumables and maintenance. Local sourcing of consumables and maintenance services will maximise any potential economic benefit.	N/A	Environmental implications may arise depending on the disposal options for consumables that cannot be reused or recycled (e.g. membranes), the quantities for disposal and whether disposed items are environmentally benign or not.

Table 15: Summary of potential economic, social and environmental costs and benefits for key outputs

Outputs	Economic costs and benefits	Social costs and benefits	Environmental costs and benefits
Product water	Economic productivity due to lower cost per unit water for industrial or agricultural reuse and improved certainty of reliable water source.	Perception of taste may be inhibitory to public uptake.	Environmental impact due to higher energy requirements and associated greenhouse gas emissions. Reclaimed water may substitute fresh water in industrial or agricultural operations thus reducing demand on existing sources.
Atmospheric emission	N/A	Section 10 of this report suggests that depending on the type of plant, air quality must be addressed in the planning process to ensure the desalination plant is designed and operated to minimise pollution and consequential social costs (e.g. health implications where there is poor air quality).	Section 10 of this report suggests that depending on the type of plant, air quality must be addressed in the planning process to ensure the desalination plant is designed and operated to minimise pollution and consequential environmental costs.
Concentrate	N/A	N/A	Section 10.2 discusses the environmental implications of the disposal of any liquid or solid concentrate arising from a desalination plant. Any environmental costs will be influenced by the approach taken to concentrate disposal.
Noise and visual impact	N/A	Any social and environmental costs arising from noise and visual impact of the desalination plant are largely dependent on the siting of the plant. These costs might be heightened for example when a relatively noisy facility is located in close proximity to residential areas, or a large and visually unattractive building is proposed for an area with high landscape value.	

15.4. Electricity

The most significant input in terms of overall operating cost for a desalination plant is energy, principally electricity. A high-level analysis of the potential impact of a large desalination plant on the Victoria's electricity sector reveals that current generating capacity could meet the expected increase in demand from a desalination plant.

As indicated in Section 15.6, 93 million m^3 a year is the predicted future water supply shortfall in Melbourne [DSE, 2004]. This could be met by desalinating seawater at a facility of a similar size to the Ashkelon plant (270,000 m^3 per day, or around 100 million m^3 a year). As such, the analysis of electricity demand has been based on the Ashkelon example and assumed that this sized plant operates for about 6,000 hours a year and requires 3.88 kWh/m^3.

The total electricity available in Victoria was around 44,000 GWh in 2002/3 [ESAA, 2004]. A plant with the characteristics described above would increase the total generation requirement in Victoria by around 390 GWh per year, or less than 1%. Whilst an additional 1% represents a sizable load, it could normally be supplied by existing generation facilities. As of June 2003, generation facilities in Victoria had an in principle production capacity of about 74,000 GWh a year. The actual generation in 2002/3 was 52,000 GWh or about 70% of total available generation capacity in Victoria (Note: this is a broad-brush analysis and does not consider the potential for power to be imported to or exported between Victoria and other parts of the National Electricity Market). This indicates that generation capacity exists to accommodate an additional load of 390 GWh.

However, electricity use is not spread evenly throughout the day and peak loads on any given day can be significantly higher than average loads. On relatively few days of extreme peak demand, Victoria's electricity generation system operates close to its maximum capacity. While the additional load from a large desalination plant at these extreme peak times might challenge the system's capacity, it does not necessarily follow that the desalination plant's demand would of itself require additional generation capacity in the market. This is because:

- If actual demand frequently fell within 1% of total generation capacity, the risks to the availability of supply and reserve in Victoria would likely be a market issue in any event, regardless of the desalination plant;
- If the desalination plant is capable of interrupting or scaling back its consumption of power and presumably its production, during the brief periods of critical market demand for electricity, the plant might not be obliged to operate at all times during the day. Consequently, it could take advantage of times of relatively low demand and cheaper pricing. If this were possible, it could still supply water at all times by generating and storing product water; and
- The desalination plant could consider having its own co-generation plant to substitute or supplement any constraint on power from the grid at times of peak demand and pricing; and even if the desalination plant could not modulate its

demand for energy from the grid, many other electricity users can interrupt or reduce their electricity supply at times of peak demand and have electricity supply contracts that are priced to encourage this.

The capacity of the transmission and distribution networks to provide electricity to a desalination plant is also important to the availability of the electricity supply. The risks of constraints on network capacity are dependent on the engineering and geography of the network at the plant's location. Therefore, in the absence of specific site options, this report cannot comment on the risk of network constraints, beyond commenting that in normal circumstances, network issues can often be addressed by system augmentation.

An assessment of the risks associated with incorporating additional load from a desalination plant and the options available to manage these risks is complex. Many potential solutions are available in the electricity market. Accordingly, it would be dangerous to assume that the broad general conclusions summarised above would apply equally in all specific cases. The consequences for energy supply and options for managing peak loads would need to be looked at more closely in a study of more specific proposals. There is also no way of ascertaining at this time which type of generation plant (e.g.: coal, natural gas) would meet this new demand. As such, it is also difficult at this time to discuss the extent to which a desalination plant in Victoria would stimulate a net increase in greenhouse gas production.

The relative power requirements for the various types of desalination processes in the year 2000 are listed in Table 16. It is clear from the data presented in the table that thermal desalination processes require more total energy than RO processes per unit volume of water treated.

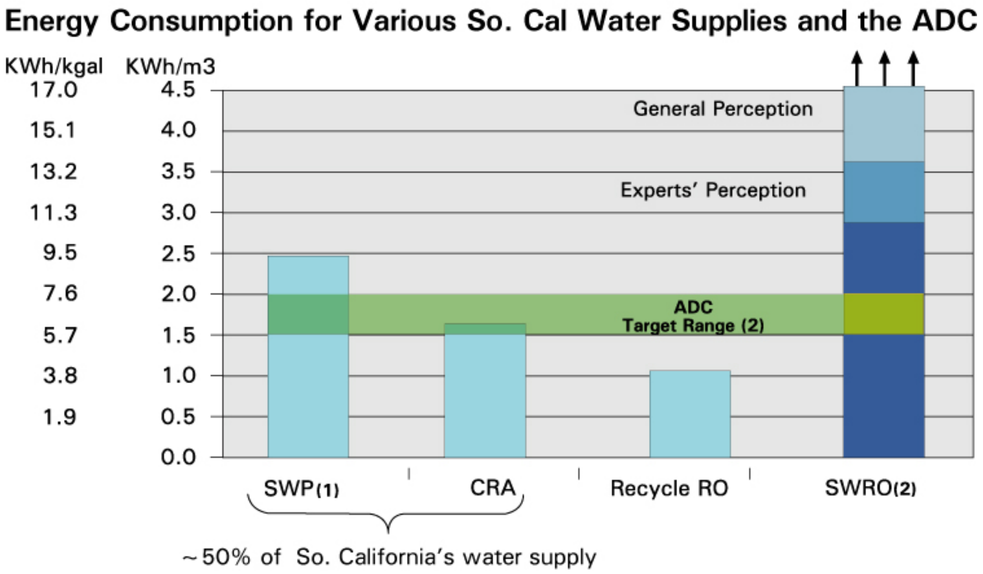
Table 16: Relative power requirements of desalination processes [Water Corporation, 2000]

Process	Gain output ratio*	Electrical energy consumption (kWh/m^3)	Thermal energy consumption (kW/m^3)	Total energy consumption (kWh/m^3)
MSF	8 – 12	3.25 – 3.75	6.75 – 9.75	10.5 – 13
MED	8 – 12	2.5 – 2.9	4.5 – 6.5	7.4 – 9
MED-TVC	8 – 14	2.0 – 2.5	6.5 – 12	9 – 14
MVC	N/A	9.5 – 17	N/A	9.5 – 17
BWRO**	N/A	1.0 – 2.5	N/A	1.0 – 2.5
SWRO***	N/A	4.5 – 8.5	N/A	4.5 – 8.5

* GOR: Gain Output Ratio – the ratio of fresh water output (distillate) to steam.
** BWRO: Brackish water RO
*** SWRO: Seawater RO

Furthermore, a seawater RO technology is currently being piloted in the United States [ADC, 2005] that will reduce the energy consumption by an additional 60%, that is, to be in the range 1.5-2.0 kWh/m^3. The savings gained by this advanced technology are related to a combination of high efficiency pumps, pressure exchangers and motors, low energy membranes, low flux-low pressure design and standard pressure vessels. The current comparison of energy requirement estimates of various water supply processes in Southern California against the Affordable Desalination Collaboration estimates is shown in Figure 38. In this table, the expert's opinion of average seawater RO desalination energy requirements is given to range from 2.9-3.6 kWh/m^3 whilst the general perception is 3.6 kWh/m^3 and above.

Greenhouse gas emissions are related to the amount of energy produced. For electricity generated from brown coal in Victoria, the emission factor is 387 kg CO_2/GJ power delivered and for black coal in New South Wales and Queensland the emission factor is 294 kg CO_2/GJ power produced [AGO, 2001]. Gas-fired power generation releases significantly less carbon dioxide (65-68 kg CO_2/GJ) than coal-fired power generation. On the other hand, solar and wind power generation do not release carbon dioxide during power generation. However, both of these contain embodied energy of the machinery and infrastructures that deliver the energy that is not considered in the greenhouse gas emissions [AGO, 2001]. The energy consumption for a plant requiring 390 GWh per year would therefore release approximately 540,000 tonnes of carbon dioxide per year if coal-fired power generation was utilised.



Energy Consumption for Various So. Cal Water Supplies and the ADC

Notes:
1. SWP does not include distribution beyond Castaic Lake or treatment.
2. ADC target range does not include supply or distribution. I.e. RO Process only.
3. SWP = California State Water Project
4. CRA = Colorado River Aqueduct Project
5. Source: Water Sources Powering Southern California, by Robert C. Wilkinson Ph.D., January 2004.

Figure 38: Comparison of energy consumption in Southern California [ADC, 2005]

As indicated above, the resultant energy consumption has led previous feasibility studies for large-scale desalination plants in Australia to consider renewable energy sources as an option for greenhouse gas abatement (see Section 15.3 and 15.5).

15.5. Alternative Energy Sources

Alternative energy driven desalination systems may be utilisable in certain areas that lend themselves to the alternative energy sources used. Alternative energies include renewable energies as well as nuclear derived energy.

Renewable energies for use in desalination processes include wind, solar thermal, photovoltaic and geothermal. Renewable energy driven desalination systems fall into two categories. The first category includes distillation processes driven by heat produced by the renewable energy systems, while the second includes membrane and distillation processes driven by electricity or mechanical energy produced by renewable energy sources (RES).

Technically mature technologies include solar collectors coupled with MED, photovoltaic coupled with RO and ED/EDR, wind energy conversion coupled with RO and geothermal energy coupled with MED. Demonstration-stage technologies include solar thermal MSF seawater desalination, wind energy coupled with ED and MCV as well as geothermal energy MSF desalination [Loupasis, 2002]. An overview of recommended renewable energy desalination combinations is given in Table 17.

Matching renewable energies with desalination units, however, requires a number of important factors to be considered. A renewable desalination plant can be designed to operate coupled to the grid and off the grid. The latter case can pose the problem of renewable energy variability because most renewable energy systems lack an inherent energy storage mechanism. The produced power varies in time as wind speed or levels of solar irradiance vary. The possibility of non-steady power inputs from RES may result in the desalination plant to operate in sub-optimal conditions and may cause operational problems. It therefore has to be considered whether the desalination plant is to be operated only when the RES supplies power or whether energy is to be stored to allow continuous operation. Higher capital costs of the former, as the plant only operates for part of the time have to be weighed up against the costs of the option of energy storage [Oldach, 2001].

In designing an autonomous renewable desalination plant, the principle of power matching is therefore paramount. In the absence of any type of storage this means that the power supplied by the renewable energy plant must equate to that being required and consumed by the desalination plant. As wind tends to supply in stochastic ways and solar follows a periodic pattern, the challenge remains to create system architectures and control strategies which will achieve the balance between energy supply and demand. The most intuitive way of using geothermal energy for desalination is by applying geothermal heat to a distillation plant. This source can be used directly to provide heat for thermal processes, with technologies of extracting hot water streams directly from underground aquifers or similar being relatively mature and well proven [Loupasis, 2002; Oldach, 2001].

Embodied in wind and solar renewable energy systems are the energies required to construct the system. These energies have associated greenhouse gas emissions resulting from the construction and infrastructure of the system and this may need to be considered from a whole-of-life approach to adequately reflect the true energy cost and associated greenhouse gas emission.

Table 17: Recommended renewable energy – desalination combinations [CRES, 1998]

Feed water available	Product water	RES resource available	System size			Suitable RES desalination combination
			Small 1-50 m^3/d	Medium 50-250 m^3/d	Large > 250 m^3/d	
	Distillate	Solar	✓			Solar distillation
Brackish water	Potable	Solar	✓			PV-RO
	Potable	Solar	✓			PV-ED/EDR
	Potable	Wind	✓	✓		Wind-RO
	Potable	Wind	✓	✓		Wind-ED/EDR
	Distillate	Solar	✓		✓	Solar distillation
	Distillate	Solar		✓	✓	Solar thermal-MED
	Distillate	Solar				Solar thermal-MSF
	Potable	Solar	✓			PV-RO
Seawater	Potable	Solar	✓			PV-ED/EDR
	Potable	Wind	✓	✓		Wind-RO
	Potable	Wind	✓	✓		Wind-ED
	Potable	Wind		✓	✓	Wind-VC
	Potable	Geothermal		✓	✓	Geothermal-MED
	Potable	Geothermal			✓	Geothermal-MSF

The Australian Bureau of Agriculture and Resource Economics [ABARE, 2004] predict a downward trend in total primary energy consumption per real GDP to 2019/20 by 1.1% per year. It is thought that this trend is a consequence of assumed technology improvements, structural change in the composition of activities and relative price changes. This trend may have important implications for renewable energies in Australia and, more specifically, may indicate that Australian industry is moving toward incorporating new technologies as both a source of competitive advantage and greenhouse gas abatement. In terms of marginal cost of abatement, this may imply that technological adoption in the future may be a more viable means than fuel switching [ACCI, 2003].

Interest in using nuclear energy for producing potable water has been growing worldwide in the past decade. This has been motivated by a wide variety of reasons, *inter alia*, from economic competitiveness of nuclear energy to energy supply diversification, conservation of limited fossil fuel resources to environmental protection, and by nuclear technology in industrial development [IAEA, 2000].

Integrated nuclear desalination plants have been operating in Japan and Kazakhstan for many years. At Aktau in Kazakhstan, the liquid metal cooled fast reactor BN-350 has been operating as an energy source for a multipurpose energy complex since 1973, supplying electricity, potable water and heat to the local population and industries. The complex consists of a nuclear reactor, a gas and/or oil fired thermal power station and MED and MSF desalination units. The sea water is taken from the Caspian Sea. The nuclear desalination capacity was about 80,000 m^3/d, however part of this capacity has now been decommissioned. In Japan, several nuclear power plants have seawater desalination systems using heat and/or electricity from the nuclear plant to produce feed water make-up for the steam generators and for on-site supply of potable water. MSF was initially employed, but MED and RO have been found to be more efficient. The individual desalination capacities range from about 1000 to 3000 m^3/d [UIC, 2004].

15.6. Product Water

In Melbourne, the current water demand is around 480 million m^3 per year, and by 2050 predicted to grow to 659 million m^3 per year. The existing system has a capacity to supply 566 million m^3 per year, predicting a future shortfall of around 93 million m^3 per year if predicted demand growth is realised [DSE, 2004].

If this predicted shortfall materialises then Melbourne and Victoria will be water constrained, which raises potential economic, social and environmental consequences. From an economic perspective, water is an essential commodity for the ongoing support of population growth and increased industry activity and agricultural production. From the social perspective, communities are concerned with the provision of a safe and reliable water supply.

At present only 23% of Victoria's rivers are in good environmental health [DSE, 2004]. Further, climate change issues, with predictions of lower rainfall and increasing temperatures, may also compromise the future health of the State's rivers. Alternative water supply options, such as desalination that meet or exceed society's water demand offer the potential to protect or restore environmental flows in rivers and streams. For example, desalination of seawater producing potable water might reduce the need to draw from rivers to supply potable water. Alternatively, desalination producing water suitable for industrial use might then divert potable water from industry to drinking water and potentially reduce demand for river water.

15.7. Water Transport – Additional Energy and Infrastructure Issues

The monetary cost for desalinated water presented earlier in this section of the report evaluates the cost of product water at the “gate” of the desalination plant. Not included in this analysis are the costs associated with either transporting feed water to the desalination plant, or transporting product water to the end user. These potentially come in two parts – water pumping and whether new or existing pipelines and associated infrastructure can deliver the product water to its markets.

If, for example, Melbourne was to desalinate seawater to produce potable water supplies, there could be significant additional energy costs (and associated greenhouse gas emissions) involved, specifically to provide water pumping. Figure 36 illustrates the positioning of Melbourne’s reservoirs and water pipelines. At present, little pumping is required and water from the reservoirs for the most part gravity-feeds into the metropolitan distribution system. However, seawater sourced either from Bass Strait or Port Phillip Bay is at a lower altitude than existing reservoirs and water pipelines. Regardless of whether desalination occurs inland or at sea level, seawater must be pumped uphill from its source to the majority of end users.

Overall these costs, consequential energy demand and water pipeline infrastructure requirements are dependent on the size of the desalination plant installed and distribution requirements. An examination of the characteristics of specific plant and site options is required to take these issues further.

15.8. Alternative Water Harvesting

As indicated in Section 14, the costs of desalination are dependent on the type of feed water treated in the production process and the energy requirement of the process. As such, production of potable water from seawater is more expensive than reclaiming recycled water for use in industrial or agricultural application. Similarly, desalination of brackish water to potable water is cheaper than seawater desalination.

ATSE [2004] have reviewed the recycling of water in Australia. ATSE detailed a number of water recycling activities currently being undertaken in Victoria. These activities have included the use of treated STP waters for agricultural purposes and the irrigation of areas such as golf courses, sewer mining for similar end use purposes and the recycling of grey water for use in gardens and non-potable domestic use. Other projects currently under consideration, such as the Water Factory of Gippsland Water, will involve desalination technologies to produce higher quality water for industrial and other non-potable water usage. The economics of the desalination of these brackish water supplies, in comparison to the treatment of seawater, suggests that further similar desalination projects also need to be considered in addition to the desalination of seawater for potable water usage.

One potential option for the treatment of brackish water using desalination is that of salt-affected groundwater. Dryland salinity is an increasing issue in Australia and the Murray-Darling Basin Commission (MDBC), for example, have examined a number of key initiatives and developments for saline industries in the Murray-Darling Basin [MDBC, 2003]. One of these initiatives is the desalination of saline or brackish waters. The MDBC recognise that the desalination of such waters represents a cost effective source of freshwater and salinity management, however, they also acknowledge that such management options are only applicable in a limited number of scenarios. Critical factors that need to be assessed for the desalination of salt-affected groundwater include the nature of the aquifer, the economic cost of the water produced and the cost of the technology [MDBC, 2003]. In the future, the value of good quality water will rise and the cost of desalination technologies is continuing to fall (see Figure 8). Therefore, the main consideration for the useful application of desalination technologies for the treatment of brackish groundwater in the future will be whether or not the aquifer properties are suitable.

Alternative water harvesting processes are undertaken around the world. Fog collectors as well as rainfall collectors are applied to rural communities and in developing countries make optimum use of natural atmospheric sources of water. At Cerro Talinay in Chile, six fog collectors were installed in 2005 that will produce about 1 m^3 of water a day [Fogquest, 2005]. Likewise, “air to water” machines harvest water from the humidity present in the atmosphere, similar to the hydrologic cycle. These units are available at capacities up to 5 m^3/d and can be operated using solar power.

16. Conclusion

Modern desalination technology has the potential to produce fit for purpose water from most saline water sources including seawater, brackish water, and recycled water. The study's main findings were as follows:

- Desalination is a technically viable and increasingly attractive strategy to extend the available water supply through the production of fit for purpose water for potable, industrial and agricultural applications.
- Desalination is also economically feasible with the cost of water produced from desalination processes being directly related to the salt concentration of the source water.
- Social issues that need to be addressed include the public acceptance of using recycled water for domestic, industrial and agricultural purposes as well as perception of taste of desalinated seawater for drinking water.
- Environmentally, desalination has yet to convincingly resolve issues associated with concentrate disposal, energy consumption and associated greenhouse gas production.
- Of the technologies available for desalination, reverse osmosis is becoming the technology of choice with continued advances being made to reduce the total energy consumption.

It is considered that modern desalination is a valid option technology to meet Melbourne's and Victoria's future water supply needs. Specifically, the following considerations would need to be considered in detail before the applicability of a number of potential desalination scenarios could be adequately addressed for Victoria:

Energy and Greenhouse Gas: Energy is the largest variable cost of desalination after a plant has been built. To meet the predicted future water supply shortfall in Melbourne of 93 million m^3 a year would require a desalination plant that consumed about 390 GWh per year, or 1% of total energy generated in Victoria. This energy consumption would release approximately 540,000 tonnes of CO_2 annually. The source of energy for large-scale desalination activities needs to be considered in more detail, particularly in view of the fact that Victoria's energy requirements at current growth rates will increase by 35% by 2020.

Renewable Energies: Renewable energies, such as solar, wind or geothermal may replace conventional energy sources. However, these may limit the desalination activity in size and location due to possibility of non-steady power inputs and source of renewable energy. Alternatively, abatement schemes should also be investigated if a large desalination plant was considered for Melbourne.

Seawater Quality: A reliable and high quality source of seawater is critical for a seawater desalination plant. Although it has been found that Port Phillip Bay has water salinity similar to that of seawater, the feasibility of locating a desalination plant on Port Phillip or Western Port Bay would need to be assessed in more detail.

Location: The proximity to existing water distribution infrastructure needs to be considered since the transport of water may represent a significant fraction of the total cost of delivering desalinated water. For Melbourne, the requirements for distribution would also largely depend on the size of any desalination plant installed. Depending on the volume of desalinated water required and the availability of suitable distribution networks, the number and location of desalination plants would need to be assessed.

Land Size: The amount of land required for the siting of a desalination plant will depend on the size of the plant itself. Both the Perth and Sydney seawater desalination studies have found that about 0.5 ha of land is required for each 50,000 m^3/d of production capacity.

Groundwater: One potential option for the treatment of brackish water using desalination is that of salt-affected groundwater. The critical factor that needs to be assessed for the useful application of desalination technologies to treat brackish water in the future will be whether or not the aquifer properties are suitable.

Water Reclamation: Water reclamation is seen as a means to supply fit for purpose water. It has the potential to reduce demand on potable and fresh water from catchments and rivers, progress initiatives for improving environmental flows and reduce ocean outfalls. Further market assessment and development for recycled water is essential, including the potential for direct and indirect potable reuse.

Waste Management: Desalination plants produce considerable volumes of saline concentrate. It is essential therefore, that the planning process of a desalination plant addresses issues associated with waste disposal as well as noise and air quality.

For Melbourne, a predicted increase in water demand of around 93 million m^3 per year by 2050 means that if economic growth, industrial activity and social prosperity are to be maintained, current water supply schemes and associated infrastructures need to be consolidated with a range of water supply and demand strategies into an integrated water supply portfolio.

Depending on the relative consumptive needs of water the development of a diversified water supply and water demand portfolio is essential so that it meets the needs of a growing population with regard to drinking water supply without compromising industrial activity and efficiency. A life cycle analysis approach may be of further assistance in evaluating different options as they apply to Melbourne and Victoria. Desalination technologies potentially offer solutions for alternative water production within the context of the waters they can treat and the water quality that is produced.

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Glossary

ACIDIFICATION – the addition of acid to the feed water of a desalting plant, usually to prevent alkaline calcium carbonate and magnesium hydroxide scaling.

ALKALINITY – The ability of water to neutralise an acid because of the presence of bicarbonate, carbonate and hydroxyl ions.

ANTISCALANT – An agent that ties up, and thus inactivates, certain metal ions. It may be added to a feed water to extend the limits of saturation of scaling substances. The sequestering of calcium ions to prevent calcium sulphate precipitation is an example.

ANION – An ion carrying a negative charge. In an electrolytic cell the anion migrates toward the anode.

ANODE – The positive electrode of an electrodialysis cell.

ANNUAL COST – The total yearly cost of owning and operating a desalination plant.

BACKWASH – see Back flush

BACK FLUSH – Reversed flow in a filter, ion-exchange column or membrane filter to remove or wash away accumulated suspended material.

BACTERIA – Microscopic organisms, usually consisting of a single cell.

BLENDING – Mixing waters of different purity and composition to form a diluted solution.

BRACKISH WATER – Saline water with a salt concentration ranging from 1,000 mg/L to about 25,000 mg/L total dissolved solids.

CAPITAL COST – Total capital cost includes the indirect and direct costs. It is the owner's total investment up to the point that the plant is put into useful operation.

CATHODE – The negative electrode of an electrodialysis cell.

CATION – An ion carrying a positive charge. In an electrolytic cell the anion migrates toward the cathode.

CHEMICAL CLEANING – All-inclusive term for any of a number of *in situ* chemical cleaning techniques to remove fouling and scale from membranes and thermal heat transfer surfaces.

COAGULATION – The precipitation of substances in colloidal solutions.

COMPOUND – A substance that can be decomposed by chemical processes into two or more elements or which can be built up from two or more elements (e.g., sodium chloride, NaCl).

CONCENTRATE – The concentrated wastewater flow from desalination processes.

CONDENSATE – Distilled water formed by cooling and condensing water vapour.

CONDUCTIVITY – Quantitative expression for the capability of a particular solution to conduct electricity.

CONTAMINANT – Any undesirable substance in a water source.

DECARBONATION – A process to remove carbonate alkalinity from the feed water as CO_2 gas.

DEMINERALISATION – Any process that removes mineral substances from water.

DESALINATION – Process of removing salts from water sources.

DISTILLATE – The final product water from a distillation plant.

DISTILLATION – A method in which a solution is heated to condense and collect water. A process used in desalination.

DISTRIBUTION SYSTEM – The infrastructure consisting of pipes, conduits, pumps and channels to transport water form one location to another.

DIVALENT ION – An ion carrying a double charge, either positive or negative (e.g. Ca^{2+}, SO_4^{2-}).

DUAL PURPOSE PLANT – A plant that produces both water and electric power.

EFFECT – A single evaporation or single step in a multi-effect evaporator arrangement.

EFFLUENT – Water leaving a system or process (Antonym: influent), often associated with waste streams.

ELECTRODIALYSIS – Process by which ions are transferred through membranes to a more concentrated solution as a result of using a direct current electrical potential.

ELECTRODIALYSIS REVERSAL – Variation of electrodialysis in which polarity and cell function change periodically to maintain efficient performance.

ELECTROLYTE – Compound that disassociates into ions when dissolved in water.

ELEMENT – A simple substance that cannot be decomposed by chemical processes into simpler substances (e.g. hydrogen, oxygen, sodium).

ENERGY RECOVERY – Possible energy saving in reverse osmosis in which the concentrate stream, under pressure, is used to drive a turbine that provides part of the feed pressure requirement.

EVAPORATION – The process by which water is converted to a vapour that can be condensed.

EVAPORATOR – The process devise in which water is boiled and condenses to form a distilled product water.

FEED WATER – Saline water supplied to the desalination plant for processing.

FLASHING – A physical process in which a preheated water encounters a reduced pressure that causes part of the water to boil rapidly or flash into steam.

FLOCCULATION – The binding of small particles together in water after a coagulant has been added.

FOULING – The reduction in performance of processes equipment (heat transfer tubing, membranes, etc.) that occurs as a result of scale build-up, biological growth or the deposition of colloidal material.

GROUND WATER – Water normally found underground and obtained from wells.

HARDNESS – Usually measured in $CaCO_3$. Hardness in water is the sum of calcium and magnesium concentrations, both expressed as calcium carbonate ($CaCO_3$) in milligrams per litre. These constituents cause soaps to precipitate.

HEAT EXCHANGER – An apparatus in which heat is transferred from one medium to another.

HEAT TRANSFER – Physical phenomenon dealing with the flow of heat. The subject is particularly important in the distillation and freezing processes in which heat is transferred from medium to medium, usually through a heat transfer surface.

HYBRID PLANTS – Plants that combine two or more processes.

HYDROLYSIS – A chemical process of decomposition involving splitting of a bond and addition of the ions of water.

INORGANIC – Substances of mineral origin, such as sand, salt, iron, and calcium salts.

INSOLUBLE MATERIALS – Materials that do not dissolve, or dissolve only slightly, in water.

INTAKE EQUIPMENT – The works or structures at the head of a conduit into which the feed water entering the desalting plant is directed.

INVERSE SOLUBILITY – The characteristic attributed to a substance that becomes less soluble with increasing temperature (e.g., calcium carbonate).

ION – An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons. An electrically charged atom, radical, or molecule formed by the loss or gain of electrons.

KWh – Kilowatthours. A measure of electrical usage.

MEMBRANE – In desalting, used to describe a semipermeable film. Membranes used in electrodialysis are permeable to ions of either positive or negative charge. Reverse osmosis and nanofiltration membranes ideally allow the passage of pure water and block the passage of salts.

MICROFILTRATION – A membrane used to treat water, with a 0.05 - 5 micron pore size. The membrane filters out turbidity, algae, *Giarda* and *Cryptosporidium* spores, and bacteria. The membrane operates by sieving.

MICRON – A unit of length equal to one thousandth of a millimeter.

MICROORGANISM – A plant or animal of microscopic size.

MINERAL REDUCTION – Partial removal of dissolved salts from water.

MODULE – The smallest packaged functional assembly of a desalting plant. A section or integral portion of a desalting plant that is used initially to study large-scale technology and critical design features in preparation for subsequent prototype construction.

MOLECULE – The smallest quantity of a compound that possesses all the chemical characteristics of that compound.

MONOVALENT ION – An ion that carries only a single charge, either positive or negative. Example: Na^+, Cl^-.

NANOFILTRATION – A membrane used to desalinate water. The membrane has a molecular weight cutoff of about 100, and rejects ions with greater than 100 molecular weight at about 90 percent. The membrane operates by overcoming osmotic pressure.

ORGANIC – Substances that come from plant or animal sources and always contain carbon.

ORGANIC COMPOUND – A compound in which the major elements are carbon and hydrogen.

OSMOSIS – Movement of water from a dilute solution to a more concentrated solution through a membrane separating the two solutions. See Reverse Osmosis.

OSMOTIC PRESSURE – The potential energy difference between two solutions of different concentrations separated by a permeable membrane.

OXIDATION – The addition of oxygen, removal of hydrogen, or removal of electrons from an element or compound.

PATHOGENS – Disease-causing organisms.

PERMEATE – The product water from a desalting process (also called product).

pH – A number indicating the hydrogen-ion concentration in a solution. Values greater than 7.0 indicate a basic (alkaline) solution; values less than 7.0 indicate an acidic solution.

PILOT PLANT – An experimental unit of small size, usually less than 400 m^3/d capacity, used for early evaluation and development of new, improved processes and to obtain technical and engineering data.

POLYAMIDE – A polymer formed by polymerization of an ester.

POLYMER – A chemical compound formed by polymerization.

POLYMERISATION – A chemical reaction in which smaller molecules of the same kind (or sometimes of two or three different kinds) combine to form larger molecules.

POST-TREATMENT – The processes, such as pH adjustment and chlorination, that may be employed on the product water from a desalting unit.

POTABLE WATER – Water that does not contain objectionable pollution, contamination minerals, or infective agents and is considered suitable for drinking. In desalting, potable water is typically defined as having a salinity less than 500 mg/L TDS and to be in compliance with Federal and State regulations.

PRECIPITATE – A substance separated from a solution by chemical or physical change as an insoluble amorphous or crystalline solid.

PRE-TREATMENT – The processes such as chlorination, clarification, coagulation, scale inhibition, acidification, and de-aeration that may be employed on the feed water to a desalting unit to minimise algae growth, scaling, and corrosion.

PRODUCT WATER – The final desalted water, called “distillate” in distillation, “dilute” in electrodialysis, and “product” in the reverse osmosis and nanofiltration processes.

PROTOTYPE – A full-size, first-of-kind production plant used for development, study, and demonstration of full-sized technology, plant operation, and process economics.

RECOVERY RATIO – The ratio of the product flow rate to the feed water flow rate. This ratio is sometimes called the conversion ratio.

RECURRING COSTS – Plant fixed costs associated with annual tax and insurance costs.

RECYCLED WATER – see WATER RECYCLING

REPLACEABLE ITEMS – Plant equipment with an estimated life less than the useful plant lifetime or the plant design lifetime.

REVERSE OSMOSIS (RO) – Method of desalination which uses pressure to move water from a concentrated solution to a dilute solution through a membrane separating the two solutions. See Osmosis.

SALINE WATER – Water with dissolved solids exceeding the limits of potability. Saline water may include seawater, brackish water, mineralized ground and surface water, and irrigation return flows.

SALT DIFFUSION – The movement of ions or molecules under influence of a concentration difference.

SALT REJECTION – A factor expressing the ability of RO membranes to reject dissolved solids. Usually given as: feed concentration minus product concentration divided by feed concentration, and expressed as percent.

SALT TRANSPORT – Salt that transfers through reverse osmosis membranes, along with water.

SATURATED SOLUTION – A solution that contains the maximum amount of solute that can be dissolved at equilibrium. See Solubility.

SATURATION TEMPERATURE – The temperature of a liquid, under a given pressure, at which boiling and condensing occur.

SCALE – Salts deposited on heat transfer or membrane surfaces that retard the rate of heat transfer or ion or water permeation.

SCALE INHIBITOR – An agent that ties up and, thus, inactivates certain metal ions. It may be added to a feed water to extend the limits of saturation of scaling substances. The sequestering of calcium ions to prevent calcium sulfate precipitation is an example. Also known as antiscalant, sequestering agent.

SEMIPERMEABLE MEMBRANE – A membrane that is permeable for certain molecules or ions only. RO membranes, for example, ideally will pass water but not salt. ED membranes pass ions with a certain charge but not water.

SOFT WATER – A water that has a minimal amount of calcium and magnesium ions. Such waters frequently contain substantial amounts of sodium.

SOLUBILITY – A measure of the maximum amount of a certain substance that can dissolve in a given amount of water, or other solvent, at a given temperature.

SOLUTE – A dissolved substance.

SOLUTION – A homogeneous mixture of substances in which the molecules of the solute are uniformly distributed among the molecules of the solvent, such as water.

SPECIFIC CONDUCTANCE (CONDUCTIVITY) – Quantitative expression for the capability of a particular solution to conduct electricity. It is defined as the conductance of a cube of that particular water that is 1 cm long and has a cross sectional area of 1 cm2. Conductivity is usually expressed in micromohos per centimeter.

STACK – The alternating array of cation and anion permeable membranes, spacers, gaskets, and electrodes used in the electrodialysis desalting process.

STAGE – A unit of desalting equipment capable of purification and separation of the feed water into product and concentrate. If separation is insufficient, more than one stage can be arranged in series.

SURFACE WATER – Water above the water table.

SUSPENDED SUBSTANCE OR SUSPENDED SOLIDS – Materials that are not dissolved but are in suspension in the form of finely divided particles. Suspended materials may be removed by physical means such as filtration.

TUBE BUNDLE – A series of tubes compactly arranged in an evaporator shell to provide the required heat transfer surface.

TURBIDITY – Opaqueness or cloudiness caused by the presence of suspended particles in water, usually stirred-up sediments. The turbidity of a water is measured by its capacity for absorbing or scattering light.

TURBINE CYCLE – Use of turbines to generate power from high-pressure steam. Low pressure effluent steam from such turbines can be used to drive a desalting plant.

ULTRAFILTRATION – A membrane used to treat water with about a 10,000-300,000 molecular size cut-off. The membrane rejects organic macromolecules, viruses, and asbestos. The membrane operates by sieving.

UNIT COST – The cost per unit of product water output (AUD/cubic meter) or per unit energy input (cents/kWh, AUD/MJ).

WASTE CONCENTRATE – See Concentrate Reject (Stream). Sometimes called blowdown.

WATER PERMEABILITY – The capacity of a membrane to allow water to pass through.

WATER RECYCLING/RECLAMATION – Recycling water involves treating wastewater to a standard where it can then be used in industrial processes, irrigation in parks and racetracks and in the home for flushing toilets and watering gardens.

Conversions

1000 L = 1 m^3

1 ML = 1,000,000 L = 1000 m^3

1 Gallon (US) = 0.003785 m^3

1 MGD (mega gallon per day) = 3,785 m^3/d

1000 kPa = 10 bars = 145 psi