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ECONOMIC AND TECHNICAL ASSESSMENT OF DESALINATION TECHNOLOGIES IN AUSTRALIA: WITH PARTICULAR REFERENCE TO NATIONAL ACTION PLAN PRIORITY REGIONS

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SUMMARY OF DESALINATION IN AUSTRALIA AND WORLDWIDE

Of all the Earth's water, 94 percent is salt water from the oceans and 6 percent is fresh. Of the latter, 27 percent is in glaciers and 72 percent is underground (Buros, 2000). While the Earth's salt water resources support commercially important activities such as fishing and transport, it is typically unable to support human life or farming. With the scarcity of fresh water in some parts of the world, desalination techniques have captured attention as an alternative option to increase the range of water resources available.

The great potential of desalination was first realised during WWII and the technology underwent its first intensive period of development following the war. By the late 1960's, commercial scale plants using *distillation* processes to desalt water were common place, with capacities of up to 8,000 kL/day (Buros, 2000) being achievable. In the 1970's, commercial scale desalination processes using *membranes* to filter water, such as Reverse Osmosis (RO) and Electrodialysis (ED) were introduced and used more extensively. As the technology progressed and operational experience increased through the 80's and 90's, the cost of construction and operation reduced significantly. This was particularly the case for the membrane technologies which are now a considerably cheaper prospect for certain applications than the tried and trusted distillation approaches (Buros, 2000).

The International Desalination Association's (IDA, 1998) most recent audit of worldwide desalting capacity states a total installed figure of approximately 22,700 ML/day of which about 85 percent is still in operation. Almost half of the world's capacity is used to desalt seawater in the Middle East and North Africa for municipal water supplies. Saudi Arabia ranks first in total capacity installed (approximately 24 percent of total world capacity), with the United States second (16 percent). As of September 2000, the total installed capacity in Australia of desalination plants greater than 100kL/day was 90ML/day (Water Corporation, 2000), or approximately 1% of worldwide capacity.

The largest desalination plant in Australia is a 35ML/day RO plant at Bayswater, NSW which desalinates discharge water from a power station before recycling it back to the plant for reuse. A substantial number of mines and power stations in Australia use desalination for similar purposes to comply with zero discharge commitments. A limited number of small desalination plants are used for public water supplies in Australia, primarily due to the cost of desalinated water being higher than the cost of water via conventional means.

THE BIOPHYSICAL FRAMEWORK

In an arid continent like Australia, supplies of potable water are a very limited resource. Recent studies undertaken as part of the Murray-Darling Basin Salinity Audit and the National Land and Water Resources Audit have highlighted the potential decline in the quality of water supplies over the next fifty years arising from the impacts of salinity on groundwater and surface water resources. Rising saline groundwater also threatens to severely damage or destroy infrastructure, urban environments and key environmental assets as well as reducing the productive potential of the land.

The National Action Plan (NAP) for Salinity and Water Quality to address salinity related problems has identified 21 priority regions within which salinity and its management is a particular priority. Figure 1 illustrates the general location of these areas.

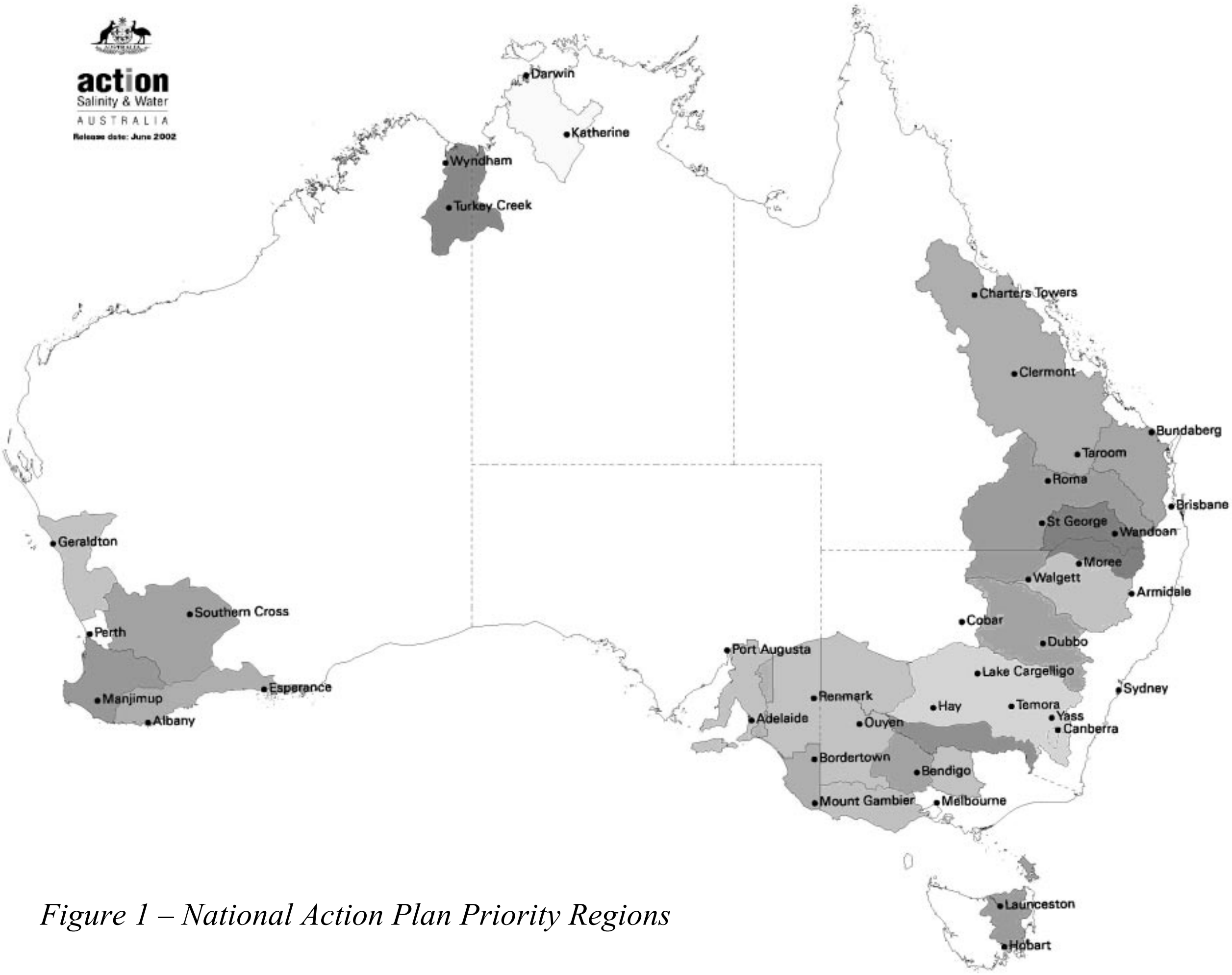

Figure 1 – National Action Plan Priority Regions

The technical understanding of how dryland salinity occurs in Australia has improved significantly in recent years. The concept of Groundwater Flow Systems (GFS) was developed out of the National Land and Water Resources Audit and recognises that dryland salinity is highly correlated to a landscape's underlying geological characteristics and landform. GFS's are now used as a basic criteria when determining an appropriate management response to dryland salinity.

A range of biological responses aimed at using greater quantities of rainfall and/or intercepting groundwater thereby reducing likelihood of dryland salinity in the NAP regions have been proposed. Where the problem is so great that it is neither technically nor financially feasible to use biological management strategies, adapting to and ‘living with’ salinity may be another suitable option.

Engineering approaches to intercept saline surface and groundwater resources is another option for managing the salinity problem. Groundwater pumping to provide feedwater for desalination processes provides not only a source of fresh water for human use but also has the potential to provide environmental benefits via drawdowns in salty groundwater levels and the resultant protection this affords to infrastructure, urban environments and key environmental assets.

POTENTIAL USERS OF DESALINATION

The users of desalination are many and varied. For fresh water, desalination plants have the potential to supply drinking quality water and water for non-consumptive uses (eg, washing, cleaning) for populations ranging in size from individual households right up to small cities. Most owners/operators of this type of desalination plant are individuals, households or private companies providing water for remote mine sites and base camps, however water supply, treatment and distribution corporations are also potential users for the larger capacity units.

Irrigation schemes, power stations, industrial plants and other bodies overseeing the discharge of effluent water may choose to invest in desalination plants to meet their discharge regulations. This is especially the case where their effluent water can potentially flow in to drinking water supplies. These groups may also be interested in desalination at the other end of their operations, where particularly clean feedwater is required (eg, power stations, highly salt-sensitive and high value horticultural products).

There are a great number of organisations in Australia whose role it is to manage and protect the environment. These represent another type of user whose main interest lies in desalination’s ability to generate environmental benefits. Governments of all levels make up the majority of this group, as well as government funded organisations such as catchment management authorities. Private firms looking to generate ‘kudos’ for their environmental stewardship may also see merit in owning/operating a desalination plant designed primarily for environmental outcomes.

BASIC SUMMARY OF DESALINATION TECHNOLOGIES

Desalination is a process that removes dissolved minerals (including but not limited to salt) from feedwater sources such as seawater, brackish water or treated wastewater. Different categories of desalination may be classified according to the process principle used:

- Process based on a physical change in state of the water – i.e. distillation or freezing;
- process using membranes – i.e. reverse osmosis or electrodialysis; and
- process acting on chemical bonds – i.e. ion exchange.

Processes based on chemical bonds are mainly used to produce extremely high quality water for industrial purposes and are therefore not suited to the context of this study. The other two processes, based on physical change of the water and filtering via membranes, are regularly used to treat seawater and brackish water and have been developed over many years in large scale commercial applications. There are also some alternative processes that have not yet reached commercial or widespread acceptance but which in certain circumstances are considered potentially useful. The desalination processes investigated in this study are listed below.

Major Processes:

Membrane

- Reverse Osmosis
- Electrodialysis

Distillation

- Multi-Stage Flash Distillation
- Multiple Effect Distillation
- Vapour Compression Distillation

Alternative Processes:

- Renewable energy powered conventional desalination
- Solar Humidification
- Freezing, and others…..

Membrane processes

Membranes are able to differentiate and selectively separate salts and water. Reverse Osmosis is a pressure driven process, whereby water is forced through the membrane to separate the salts and fresh water. Electrodialysis is a voltage driven process, and uses electrical potential to selectively move ionic salts through the membrane, leaving the product water behind. Figure 2 provides a basic illustration of the processes.

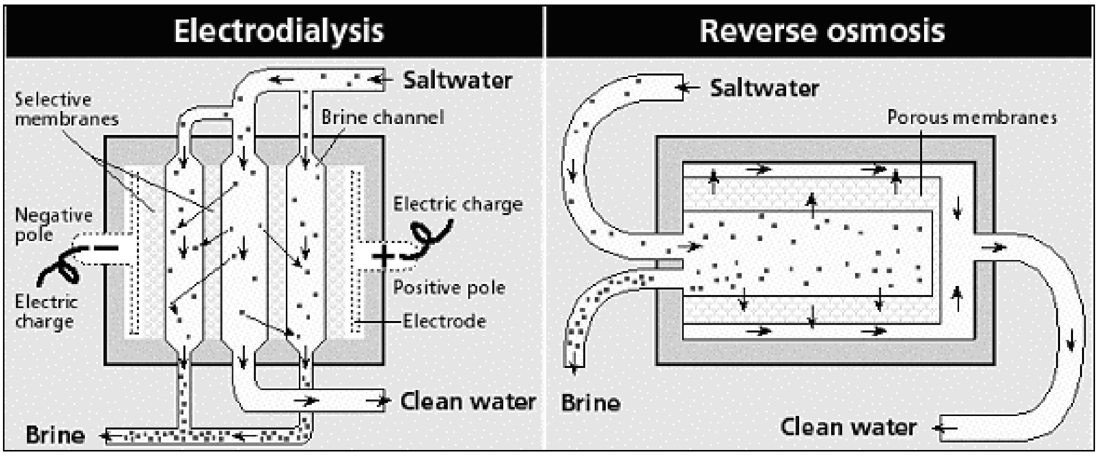

Figure 2 - Basic illustration of Membrane processes

RO systems are found to be most suitable for use in regions where seawater or brackish groundwater is readily available, such as throughout the NAP regions of Australia. RO is by far the most widely used process for desalination in Australia (64% of total national capacity). Examples include at Penneshaw on Kangaroo Island SA, Ravensthorpe in southern WA, Denham north of Perth, Rottnest Island, and some of the remote roadhouses along the highway between Adelaide and Perth in the Great Australian Bight.

The ED process is usually only suitable for brackish feedwaters with a salinity of up to 12,000 mg/L TDS. With higher salinities the process rapidly becomes more costly than other processes. This is because the consumption of power is directly proportional to the salinity of the water to be treated.

Distillation processes

Distillation processes mimic the natural water cycle in that saline water is heated, producing water vapour, which is in turn condensed to form fresh water. Approximately half of the world's desalination capacity is based on the Multistage Flash distillation principle (MSF)

(Buros, 2000). However, this is reflecting a continuing decline in the market, with other water distillation technologies such as Multi-Effect (MED) and Vapour Compression (VC) distillation, rapidly expanding and anticipated to have a more important role in the future as they become more accepted and understood.

MSF and MED are generally used in most of the larger scale seawater desalination plants. These processes require high amounts of energy to desalinate water regardless of the level of salt concentration, hence brackish water desalination (which requires less energy) is usually not a viable option for this technology.

The distillation processes require thermal or mechanical energy to produce evaporation, and as a result tend to have operating cost advantages when low-cost thermal energy is available, eg, from a neighbouring power plant or other heat generating industrial process.

Alternative processes

Variations in the application of the two major desalination processes have led to the development of a number of alternative ways to desalinate saline water. These processes have not as yet achieved the level of commercial success and viability that the above mentioned processes have.

- Renewable energy augmented desalination

Many remote towns and communities rely on costly and often limited supplies of diesel fuel for their energy needs. These and other forms of fossil fuels are sometimes heavily subsidised by government to meet community service obligations (Water Corporation, 2000). Most desalination techniques consume a large amount of energy, therefore finding methods of using renewable energy to power the desalination process is desirable.

Solar collectors or wind energy devices can be used to provide the heat or electrical energy requirements to operate a standard RO, ED or distillation desalination plant. In remote locations and/or where energy costs are high, desalination plants exist that either fully or partly rely on renewable sources for their energy. The economic viability of operating these plants is highly correlated to the cost of producing the solar or wind energy, hence they are best located where solar insolation is high or where prevailing winds are strong.

A large example of solar power desalination is the Abhu Dhabi solar distillation plant in the United Arab Emirates. This plant was commissioned in 1984 and has an output of 85 kL/day of fresh water. The solar collectors take up an area of 1,862 m^2.

Much smaller sized solar powered RO desalination units have been developed and are in operation in rural areas of Australia. These can typically desalinate 400L/day from brackish salinity water of up to 5,000 mg/L TDS. This is enough to provide 2 people with their complete daily water requirements (washing, cooking, bathing, and drinking). Alternatively, this quantity can be used to augment existing water supplies or used for one or two purposes only in which case it can service many more people.

Currently, the use of conventional energy such as mains electricity, to drive desalination devices is still generally more cost effective than using wind and solar power (Buros, 2000). However, as technology improves and the cost of traditional sources of fresh water and energy rise, then renewable energy powered desalination units are likely to become more widespread. This is particularly the case in remote areas without access to reliable and affordable sources of energy where some solar powered desalination plants have already been shown to be the optimal choice (Winter, 2001).

- Solar Humidification

Solar humidification has been a legitimate option for desalinating water since the 19th century (Kunze, 2001; Buros, 2000). In WWII the use of small solar stills on life rafts to provide fresh water was investigated. Solar humidification involves the direct use of solar energy for heating saline water to increase the production of water vapour. The water vapour is then condensed on a cool surface, and the condensate collected as fresh product water. A green house solar still is a good example of this process as illustrated in Figure 3.

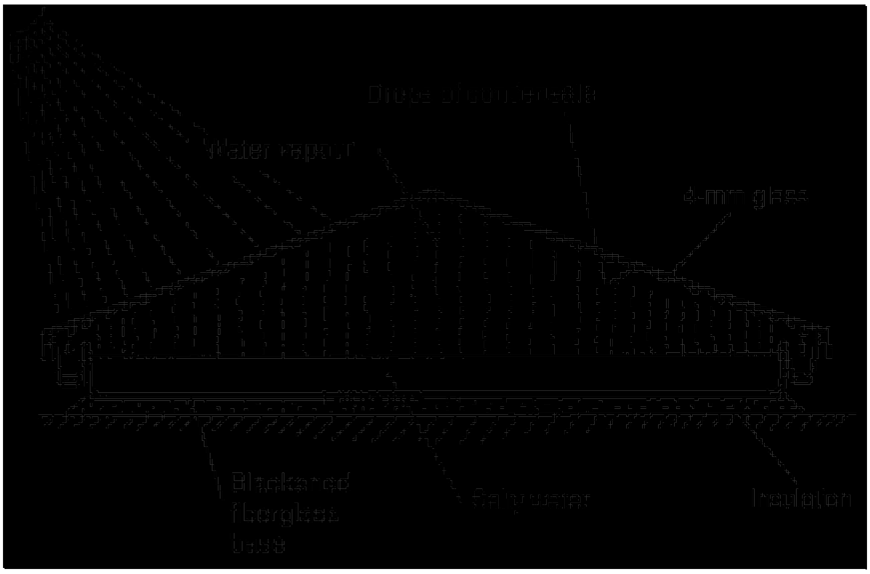

Figure 3 - Basic illustration of the solar humidification process

As a general rule of thumb, well-managed and maintained solar stills require a solar collection area of about one square metre for every three to four litres of fresh water produced per day (Kunze, 2001). Thus, for an 800L/d facility (representing total daily water requirements for four people), a land area ranging from 200-260m^2 would be required depending on efficiency. New breakthroughs in solar still technology such as heat recovery and air mass circulation can reputedly improve the production ratio up to 20L/m^2/day and thus reduce the area required to provide a given amount of water (*ibid.*).

The advantages of the solar humidification process is its relative simplicity to operate and service and obviously its ability to use solar or other renewable power as its source of energy, hence operating costs are very low. However there are restrictions in the use of this technique for large scale production such as large solar collection area requirements, high capital cost, and vulnerability to weather related damage.

- Freeze Desalination

The process of freeze desalination is based on the fact that dissolved salts are naturally initially excluded during the formation of ice crystals. The non-frozen saline component is removed at the appropriate time in the freezing process, and the frozen (fresh) water washed and rinsed to remove any remaining salts adhering to the ice crystals. The ice is then melted to produce fresh product water.

There have been a small number of plants developed and constructed over the past 40 years (Water Corporation, 2000), however the process has not been commercially developed in the production of potable water for municipal purposes. At this stage, freezing desalination technology still has a better application in the treatment of industrial wastes rather than in the production of municipal water (pers. comm., N. Wende).

SUMMARY OF THE MAJOR TECHNOLOGIES AND THEIR APPLICATIONS

Three desalination technologies were selected for more detailed consideration in the study underlying this paper, as these are the technologies that are most likely to be financially viable for the low-capacity production regimes typical in the NAP regions. These technologies are Reverse Osmosis Membrane systems (RO), Electrodialysis Reversal Membrane systems (EDR) and Multi-Effect Distillation systems (MED).

In general, RO plants are cheaper to build and operate than any distillation plant of a similar capacity, but particularly for plants smaller than 300 to 400 kL/day capacities. Distillation is typically only viable for plants of higher capacity than this, and particularly where a low cost, high quality waste heat source is readily available.

If the feedwater TDS is greater than 10,000 mg/L TDS and a low cost, high quality waste heat source is available, than the MED process is generally selected. Other than the waste heat scenario, distillation processes such as MED are only really considered where very high feedwater TDS values greater than 50,000 mg/L TDS occur, and/or for high capacity plants greater than 300 to 400 kL/day.

EDR systems tend to be more costly than RO systems, however this becomes less of an issue as the plant capacity increases - EDR systems are typically only 10% higher in costs than RO systems for plants greater than 100 kL/day. EDR systems have a feedwater TDS limit of 12,000 mg/L TDS, and are generally only considered when high scaling feedwaters are present. EDR systems are therefore only economically viable over an RO system when the feedwater TDS is between 3,000 mg/L to 12,000 mg/L, and the plant capacity required is greater than 100 kL/d, and the feedwater is high scaling. The technical operational boundaries of the three desalination technologies are summarised in Table 1.

Table 1 - Summary of the application of major desalination technologies

Parameter	**Seawater RO**	**Brackish RO**	**MED**	**EDR**
Feed Water Salinity (mg/L TDS)	> 32,000	< 32,000	> 35,000	3,000 – 12,000
Product Water Salinity (mg/L TDS)	< 500	<200	<10	<10
Minimum Product Water Volume	500 L/day	500 L/day	120kL/day	90 kL/day
% Recovery	≤30	≥80	40 - 65	> 90
Energy Required	Electrical Energy	Electrical Energy	Electrical Energy or Waste Heat Energy	Electrical Energy or Waste Heat Energy

Factors affecting technology selection

There are many factors to consider that can significantly influence the cost and selection of a desalination technology. Some of the major issues include:

- **Disposal of wastewater** – disposal of the highly saline wastewater stream from desalination plants is often very costly, so much so as to adversely affect the overall feasibility of the desalination plant. For coastal plants, disposal is commonly achieved via the sea and for inland sites, disposal may be in the form of rivers or streams, salt ponds or impounding underground.

- **Feedwater quality** - the potential yield (quantity) of the source and its chemical and physical composition are all important factors in assessing the viability of a desalination plant and the particular technology to be used. This issue is especially relevant given the salinity context of this study and the impact of groundwater flow systems. Those regions with intermediate or regional groundwater flow systems are most likely to contain aquifers with suitably large flow rates to support desalination plant requirements (NDSP, 2001; pers. comm., G Walker).
- **Energy sources** – energy is often the largest component of total operating costs. Desalted water costs are sensitive to energy prices, therefore cheaper energy is very important.
- **Location** - if the plant is to be remotely located, the technology should be robust and as maintenance free as possible. In this case, the lowest energy requirement may not necessarily be the most significant factor.
- **Pretreatment** – this differs between processes and can influence the relative costs. Pretreatment increases the cost of desalted water, particularly with RO.
- **Freshwater quality required** - this has a small effect, but it can alter the number of stages in desalination processes. The required quality will vary from location to location, due to customer preferences and industry uses.

COSTS OF THE MAJOR PROCESSES

Since all desalination processes can use any type and combination of energy sources and the design varied in any number of ways for the specific conditions faced on site, non-case specific comparisons are difficult to make and are generally not undertaken (Buros, 2000, Water Corporation, 2000; Winter, T. 2002). The users of the desalinated water and any potential environmental benefits are also highly site specific, hence quantitative estimates of benefits cannot be generalised nor extrapolated to other studies such as this one. For these reasons, the cost analysis presented here more accurately resembles a financial cost comparison between three of the most applicable technologies rather than a fully specified economic analysis of all desalination options.

The financial characteristics of a desalting plant are usually expressed in two ways: the capital costs and total annual operating costs per unit of installed capacity, and are measured in units such as dollars per kL per day. Table 2 presents construction and operating costs on this basis for the three major desalination processes examined in this study. Where a range of costs is presented, the lower end of the range generally represents costs for higher capacity plants desalinating lower salinity feed water.

Table 2 - Summary of application of desalination technologies

Parameter	**Seawater RO**	**Brackish RO**	**MED**	**EDR**
Capital Cost [A$/(kL/day of product water)]	1.80 – 2.50	0.60 – 1.80	3.90 – 2.50	3.25 – 0.57
Operating Cost [A$/(kL/day of product water)]	0.65 – 1.50	1.89 – 2.20	With Waste Heat: 0.55 – 0.95 Without Waste Heat: 1.8 – 2.80	1.00 – 2.80

Reducing the cost of desalination can be achieved by improvements in desalination technology, reductions in the cost of energy or increased use of renewable energy, or by value adding to the waste stream. It is a fact that the cost of desalination, particularly for membrane technology, has fallen considerably over the last few decades (Buros, 2000). Energy costs vary by location but generally have also fallen in real terms.

Value adding to the waste stream is a major opportunity to reduce the cost of desalination and increase its competitiveness against traditional means of supplying water. Options include salt and other mineral harvesting, irrigation, aquaculture, and energy (solar ponds). Individual case studies of these can be found in the Options for the Productive Use of Salinity (OPUS) database at http://www.ndsp.gov.au/opus/menu.htm.

Other options to reduce costs include production on reclaimed land, and salt credits.

Comparison with traditional sources of water supply

The cost competitiveness of desalination as a source of fresh water is based on a comparison of its costs of operation with the tariffs charged for existing traditional forms of water supply. A fully specified economic analysis would consider the net cost of both forms of supply. That is, for desalination, the entire process including water sourcing and delivery, brine disposal, offsetting benefits and costs, or external costs, and for traditional mains supplies of water, the *true* non-subsidised cost of provision and allowance for infrastructure depreciation. This approach is outside the scope of this study.

Figure 4 illustrates the cost of piped water for residential purposes in South Australia and Western Australia and compares this to the operational costs of the desalination options as summarised in Table 2.

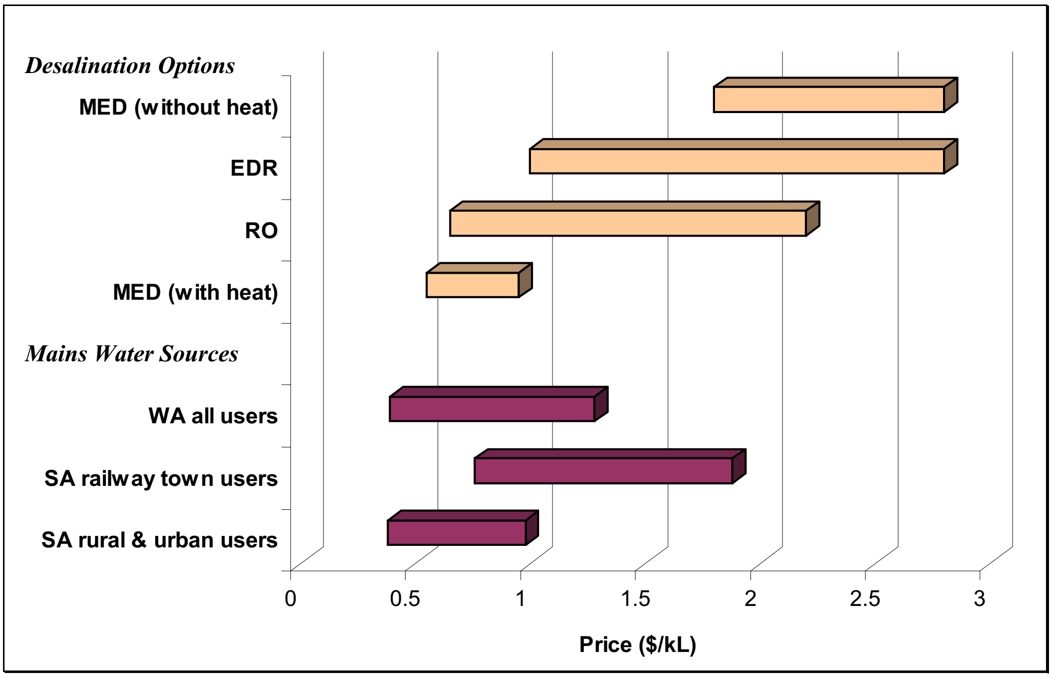

Figure 4 - Cost comparison of desalinated and piped fresh water

The minimum costs shown for desalination technologies relate to larger capacity plants desalinating feedwater at its lowest design optimum, while the upper range of costs relate to the opposite scenario. It should be noted that MED desalination with waste heat is likely to be a realistic option in very few instances, given the small number of industrial centres in NAP regions that contain the industrial processes needed to provide waste heat.

The range of prices illustrated for mains water reflect the differing tariffs charged by water utilities for particular quantities of water use. For example, in SA rural and urban areas there is a two part tariff charged either side of 125KL of water used per year - $0.38/KL for the first 125KL and $0.98 for all usage thereafter. It should be noted that the average yearly usage of water by the vast majority of residential users is such that they would be paying at or only slightly above the lower end of the floating bars illustrated in Figure 4.

Figure 4 illustrates that the least expensive forms of RO desalination are the most cost competitive with traditional mains water supplies, but only in those instances where users are already paying a yearly average of approximately $0.60/kL for their mains water. The least expensive RO plants are those that are desalinating sea water feedwaters at reasonably large quantities (50kL/day or enough for all daily uses of 250 people). In a more realistic NAP setting, groups of approximately 25 or more people (communities or a collection of houses in a small town) would typically require a quantity of water (5kL/day and up) that is able to be supplied by RO or EDR plants at a minimum of $1.00. This is an unattractive option in comparison to mains water for all but the most remote rural water users.

Note that the comparison in Figure 4 contains elements of bias. The costs for desalination are potentially significantly undervalued as they purely relate to plant operation and do not include allowance for the costs of water delivery, brine disposal, capital depreciation and all other non-operational costs. Even with this underestimation, Figure 4 shows that traditional sources of fresh water are more affordable for the great majority of water users.

However, the prices listed for mains water do not include supply charges and it is highly likely that the true cost of providing mains water, particularly for remote and rural users, is not actually being charged. The true unsubsidised cost of providing mains water would vary between regions, however, in some instances it has been shown that existing prices would have to double to cover the costs of provision and a return on capital (AATSE, 1999).

As traditional forms of water supply become scarce and water markets develop, the price charged for mains water is likely to rise. As desalination continues to be used and developed, its price will further reduce making desalinated water as a source of drinking water more cost competitive in a wider range of scenarios.

CONCLUSION

This paper has summarised the technical and financial aspects of desalination in Australia and the world as a source of fresh water for a variety of uses and as a salinity management tool. Being a non-case specific study, this study cannot present a detailed consideration of all the aspects of desalination. But on the basis of a limited quantification and comparison of costs for the major desalination technologies, it is apparent that there are only a limited number of scenarios in which desalination represents a cost effective option.

The instances where desalination is considered a cost effective option are dependant on the absence and/or high cost of traditional forms of water supply. These are mainly in the more remote rural areas, some of which are located in the NAP regions of Australia. Desalination does not appear to stack up as purely a salinity management tool. However, there are a number of ways to reduce the net cost of constructing and operating a desalination plant which will increase its competitiveness against traditional forms of water supply and its cost effectiveness as a salinity management tool. Likewise, as the scarcity and cost of mains water increases, so to does the attractiveness of desalination. Regulatory, market and policy changes that enable the price of water to reflect its true value will accelerate this process.

Further study is needed to:

- Compile visual guides and maps that overlay existing geo-referenced datasets of criteria that influence the choice of desalination. For example, demand, supply and price of traditional forms of water supply, presence and type of energy (including renewable), high yielding GFS's, etc. These will highlight those areas that are most suitable for desalination and prompt decision makers in those areas to consider using it.
- Prepare fully specified BCA of an existing desalination plant or site specific desalination plant proposal. This would enable a more accurate assessment of the cost effectiveness of desalination.
- Integrate biophysical and economic models that process user-entered data to recommend appropriate desalination technologies for particular scenarios. These exist for other countries but have not been developed for Australia.
- Further the technical development of renewable energy augmented desalination plants and technologies that require little maintenance and technical know-how to operate. These types of plants are likely to be suitable for many of the NAP regions in Australia.

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