Department of Natural Resources and Mines

Desalination In Queensland

Final Report

July 2003

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Abbreviations

AFFA	Department of Agriculture, Fisheries and Forestry - Australia
BOO	Build Own Operate
BOOT	Build Own Operate and Transfer
BWRO	Brackish Water Reverse Osmosis
CSM	Coal Seam Methane
D&C	Design and Construct
DBO	Design Build and Operate
DLGP	Department of Local Government & Planning
DNR&M	Department of Natural Resources and Mines
ED	Electrodialysis
EDR	Reverse Electrodialysis
ED(R)	Electrodialysis and Reverse Electrodialysis
EP	Equivalent Population
EPA	Environmental Protection Authority
EPCM	Engineering, Procurement and Construction Management
ERA	Environmental Relevant Activity
GHD	Gutteridge Haskins and Davey
LAT	Lowest Astronomical Tide
MED	Multi Effect Distillation
MSF	Multistage Flash Distillation
MVC	Mechanical Vapour Compression
MF	Micro Filtration
N/A	Not Applicable
NF	Nano Filtration
O&M	Operation and Maintenance
RO	Reverse Osmosis
SS	Suspended Solids
SWRO	Salt Water Reverse Osmosis
TDS	Total Dissolved Solids
TVC	Thermal Vapour Compression
UV	Ultra Filtration
VC	Vapour Compression Distillation
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

Executive Summary

As a result of the prolonged drought conditions recently experienced in Queensland, potable water sources in many areas have been placed under stress. With water supplies becoming depleted or more saline, many urban communities are looking to alternate water sources and technologies that can treat highly saline waters. The Queensland Government established a Drought Urban Water Task Force to address these water supply problems.

This report has been prepared in response to the Drought Urban Water Task Force's request to review the current status of desalination technologies and their suitability to treat urban water supply sources. The main objectives of the report are:

- Review of current desalination technologies being used worldwide and within Queensland.
- Identification of capital and operating costs associated with desalination.
- Identification of factors that may influence the selection of desalination.
- Development of scenarios representative of Queensland communities.

While the drought was the main driver for this report, it is becoming increasingly apparent that evaluation of desalination, as an alternative to more traditional water supply approaches, will be warranted in the ongoing planning of sustainable water supply schemes in Queensland.

Review of Desalination Technologies

A worldwide review of desalination technologies indicated that there are five commonly used technologies:

Thermal Technologies	Membrane Technologies
◗ Multistage Flash Distillation (MSF)	◗ Reverse Osmosis (RO)
◗ Multi Effect Distillation (MED)	◗ Electrodialysis Reversal (EDR)
◗ Vapour Compression Distillation (VC)	

In addition there are a number of emerging or alternate technologies available such as solar humidification, freezing, membrane distillation and hybrid systems. In many instances, alternate technologies are either in developmental stages or their commercial viability is yet to be proven.

Of the five main desalination technologies, thermal processes are generally used in the following applications:

- To treat highly saline waters (predominantly seawater)
- Where large volumes of product water are required.
- In locations where energy costs are low or where a waste heat source is available.

Membrane processes, on the other hand, are more favourable for treating brackish waters (under most conditions) or highly saline wastes where energy costs are high or the flow rates are low.

Factors Influencing Selection of Desalination Technologies

The applicability of desalination is very site specific. Site specific conditions will also determine the type of desalination technology selected. Factors to be considered include:

- Financial issues.
- Energy Requirements.
- Source water characteristics.
- Geographical and location constraints.
- Product water requirements.
- Environmental factors and waste disposal options.
- Operational and maintenance issues
- Utilisation rates.

Capital and Operating and Maintenance Costs

Desalination costs have been sourced for the major desalination technologies and are summarised in the following table.

	Technology	**Capital Costs ($/(kL/d) Production Capacity)**	**Operating Costs ($/kL of Product Water)**
Thermal	Multi Stage Flash Distillation	2,000 – 3,800	Dependant on energy costs
	Multi Effect Distillation	2,500 – 3,900	1.8 – 2.8 (no waste heat available) 0.55 – 0.95 (waste heat available)
	Vapour Compression Distillation	1,600 – 1,700	Dependant on energy costs
Membrane	Reverse Osmosis	700 –1,000 (brackish waters) 1,700 – 2,400 (seawater)	0.65 – 1.50 (brackish waters) 1.89 – 2.20 (seawater)
	Electrodialysis Reversal	570 – 3,250	1.00 – 2.80

Only the desalination equipment costs are represented in the above capital and operating costs. Site specific costs such as establishment of feedwater extraction sites, delivery of feedwater to the plant, delivery of treated water from the plant to the community, provision of energy and process control, more complex pre-treatment steps, brine and backwash disposal need to be individually estimated for each site and added to the above costs.

Desalination equipment does benefit from economy of scale, with large plants costing less per production capacity than smaller facilities. Salinity levels in the feedwater also impacts of reverse osmosis and electrodialysis facilities, with seawater costing considerably more to desalt than brackish waters.

Several options exist with how desalination projects can be delivered and operated. Generally these options are either, Design Build and Operate (DBO) or Build Operate, Own and Transfer (BOOT) contracts. The DBO option places the responsibility of operation and maintenance with the contractor where as the BOOT option results in the owner taking on board all of these responsibilities.

Variations on delivery options exists where an owner may undertake partial operation and maintenance with critical items serviced by specialised contractors. Of the facilities investigated in Queensland it was found that the owners undertook all equipment purchases, operations and maintenance. The suppliers handled major repairs and maintenance.

Desalination in Queensland

Within Queensland it was found that 27 desalination facilities are operational, ranging in size from 22kL/d to over 16,000kL/d. Desalination is being carried out for a variety of reasons, including provision of drinking water for island communities, alternate water sources for inland communities and provision of high quality water for power and processing plants. Reverse osmosis (RO) was found to be the most popular desalination technology, with RO representing over 80% of all desalination facilities. The choice of RO reflects the absence of suitably located waste heat sources or relatively low volumes requiring desalination.

From discussions with the operators of 21 Queensland based desalination facilities the following findings were made:

Product water quality:	No product water quality problems were reported
Chemical usage:	Chemical usage varied depending on feedwater quality and post treatment requirements
Reliability and performance:	Reliability and performance of desalination equipment was considered to be acceptable. While some minor problems were encountered at several sites, it was generally acknowledged that operators were happy with the performance of their system.
Energy sources:	Selection depended on availability of energy which included mains electricity, gas, generators and in one instance an on-site power plant.
Waste management:	Waste management practices varied depending on the size and location of facilities. Common disposal routes included irrigation, evaporation ponds and ocean discharge.
Costs:	Capital costs of the RO facilities were similar to those reported elsewhere in Australia and the world. Maintenance costs varied between facilities, however this may have been more reflective of accounting practices than actual cost differences.

Delivery Options

Desalination facilities can be operated on an intermittent or continuous basis at permanent or mobile locations.

Economic considerations generally drive the decision towards continuous operations, as a desalination plant that runs 80% of the time typically costs 19% more than a plant that runs for 95% of the time. Membrane deterioration is another driver towards continuous operation in RO and EDR facilities.

Desalination facilities can be operated at permanent or mobile installations. Many RO and EDR suppliers will package their units as either skid mounted units or build them into shipping containers. The main limitations of mobile units include:

- Size: mobile units are limited in size by the physical constraints of shipping containers or skid

- Duplicity of associated infrastructure. Infrastructure such as raw water extraction systems, feed and delivery pipework and brine disposal systems are typically built to site specific conditions and not moveable between locations.
- Increased risk of damage to membranes during relocations. Risks include physical damage to membranes as well as potential for membranes to dry out.
- Mobile RO units can only be used in locations with similar feedwater characteristics
- Policies are required to determine which community is to benefit from a mobile unit that may have been financed by a number of communities.

Mobile units however do have some advantages such as:

- Reduced installation costs
- Reduced overall footprint resulting from the compact nature of mobile facilities.
- Mobile units have the ability to respond quickly to water supply in emergency situations

Scenarios

Eight desalination scenarios were developed, covering a variety of potential desalination situations in Queensland. The scenarios ranged from small inland communities relying on brackish groundwater sources to large coastal communities requiring desalination of seawater. The scenarios are summarised below:

No.	**Feedwater Source**	**TDS Concentration mg/L**	**Desalination Plant Capacity**	
			Equivalent Population (EP)	**kL/d (Technology)**
1	Seawater	37,800 mg/L	800	200 (RO)
2	Seawater	35,000 mg/L	30,000	Alternative A: 20,000 (RO) Alternative B: 9,000 (RO) Alternative C: 20,000 (MED)
3	Ground Water	2,000 mg/L	5,000	Alternative A: 1,700 (RO) Alternative B: 1,700 (EDR)
4	Ground Water	3,000 mg/L	1,500	Alternative A: 1,500 (RO) Alternative B: 450 (RO) Alternative C: 1,500 (EDR)
5	Bore Water	3,400 mg/L	Alternative A: 100 Alternative B: 100 Alternative C: 2.5	Alternative A: 100 (RO) Alternative B: 30 (RO) Alternative C: 1.5 (RO)
6	Artesian Water	1,045 mg/L	3,250	Alternative A: 3,900 (RO) Alternative B: 975 (RO) Alternative C: 3,900 (EDR)

No.	Feedwater Source	TDS Concentration mg/L	Desalination Plant Capacity	
			Equivalent Population (EP)	kL/d (Technology)
7	Brackish Water	2,900 mg/L	10,000	Alternative A: 10,000 (RO) Alternative B: 3,000(RO)
8	Coal Seam Methane	3,880 mg/L	800	Alternative A: 400 (RO) Alternative B: 400 (TVC)

Scenarios 2, 4, 5, 6, 7 each incorporate a water conservation sub-option (Alternative B in all cases). For these alternatives, a water consumption allowance of 300 L/P/d has been assumed to illustrate the possible cost savings for communities that adopt water conservation principles.

Option 5 incorporated 3 sub-options: Option A looked at using desalination to supply all the town's water requirements, Option B looked at using desalination to supply only potable water requirements, while Option C looked at supplying each household with an individual 'point of entry' desalination unit.

The scenarios demonstrate:

- Desalination needs to be considered on a case by case basis. Issues such as availability of power, raw water quality, waste disposal and local conditions all need to be carefully considered and accounted for in a desalination system design.
- The cost of desalinating seawater is significantly higher than for brackish waters. This is due to the higher pressures required to overcome the osmotic pressure exerted by more saline solutions. This translates to higher pumping costs. The recovery rates in seawater installations are also lower resulting in the need for higher feedwater extraction, pumping and treatment costs.
- Pre and post treatment are important parts of desalination that depend on raw water quality, technology selected and final application.
- For the scenarios investigated the most common desalination technology selected was reverse osmosis. This was due to the lack of low cost energy and/or waste heat sources and source water quality that favoured membrane systems and economic considerations that favoured RO over EDR. For some scenarios EDR and thermal technologies were investigated to compare treatment costs.
- Larger plants generally have lower production costs, demonstrating the effects of economy of scales.

The scenarios also highlighted the need for detailed raw water quality data and pilot plant studies to confirm pre and post treatment requirements.

The desalination industry is a very mature industry at a global level, with many towns worldwide relying on desalination technologies to provide potable water to their communities. Within Queensland the industry is relatively new, with less than 30 known installations. However with the recent drought conditions and generally depleting high quality ground water sources, interest in desalination is developing. Desalination does have its advantages, including the securing of long term water sources, and is expected to become more prevalent in coastal and inland communities.

1. Introduction

GHD was commissioned by the Department of Natural Resources and Mines (DNR&M) to review current desalination technologies for use in Queensland. A report has been prepared which addresses the costs, advantages and disadvantages (financial and non-financial) and factors influencing selection of currently available desalination technology. This review in particular focuses on those processes that are suitable for desalination of surface water, groundwater and seawater for urban water supply in Queensland (in particular for western communities).

1.1 Objectives

The aim of this report is to consolidate and improve government knowledge on desalination technologies, such that technologically and financially sound decisions can be made with regards the future utilization of desalination to meet potable water demands of urban communities.

In particular this report focuses on:

- Types of desalination technologies currently available and associated advantages and disadvantages.
- The cost of implementing desalination for meeting potable water demands.
- Factors which may influence the selection of desalination.

1.2 Guide to Using this Report

This document is divided into the following sections:

Chapter 1: Introduction

Chapter 2: Background Information

Provides background information of the current water supply issues faced by Queensland Councils and the drivers for this project.

Chapter 3: Desalination Technologies

This section provides a brief overview of commonly used desalination systems. More detailed information on currently available desalination technologies is available in Appendix B.

Chapter 4: Desalination Technology Selection

A detailed discussion of factors that affect desalination technology selection is provided in this section. This section focuses on the long term, high reliability, least cost operation requirements for urban water supply and application to Queensland potable water supply scenarios. Factors covered include:

- Financial issues (capital, operating and maintenance costs), and opportunities that exist to reduce the cost of desalination strategies.
- Energy requirements, including options for energy recovery and/or cogeneration, which reduce overall energy consumption.
- Source water characteristics and product water requirements.

- Constraints imposed by location, and discussion of amount of land required for such facilities.
- Environmental considerations including brine/concentrate waste disposal.

Chapter 5: Decision Tree

Chapter 6: Overview of Queensland Desalination Installations

Owners and operators of current Queensland desalination installations have been contacted and this section provides a valuable summary of issues faced by Queensland Desalination operators. This section covers such questions as:

- Where are the facilities located?
- What type of desalination technology is used at each site?
- What pre-treatment steps are undertaken?
- Why are companies using desalination to treat the water?
- What is their feed water like and what type of product (permeate) water are they after/achieving?
- How much energy are they using and what are their chemical usage rates?
- How reliable is the process in terms of operation and maintenance?
- How much does the desalination process cost, including capital, operating and maintenance costs and overall unit cost (in $/kL)?
- How do they handle their waste streams?

Chapter 7: Delivery and Operational Options

Factors which influence deliver and operational options are addressed in this section, including:

- Mobile versus permanent installations.
- Intermittent versus continuous operation.
- Project delivery and operational options.

Chapter 8: Desalination Scenarios

Scenarios for various source water qualities have been developed, based on actual water quality data indicative of Queensland regions. This document provides eight scenarios, of different capacity size and source water types. The scenarios address the critical issues associated with desalination technology.

Chapter 9: Desalination Technology Suppliers

A list of known desalination suppliers is provided in this section. The suppliers are sorted in order of supplied technology. Contact details for each company are also provided.

Appendix A Glossary of Terminology

A glossary of terminology adopted in this study is provided in Appendix A.

Appendix B Overview of Desalination Technology

This section provides an overview of the different types of desalination technologies currently available. This section is particularly helpful for those people who are starting out on the desalination route. Information covered in this section includes:

- Description of the processes (including diagrams and pictures).
- Process characteristics that are unique to each of the processes and help when comparing suitability of processes.
- An indication of how much each technology will cost (in terms of capital and operating costs) as well as energy considerations.
- Outlines the advantages and disadvantages associated with each technology.
- Current trends in each technology.

Appendix C Pre-treatment

This appendix provides an overview of pre-treatment processes commonly used in desalination systems.

Appendix D Post-treatment

This appendix provides an overview of post-treatment processes commonly used in desalination systems.

Appendix E Desalination Equipment Suppliers

A summary of equipment suppliers, including contact details, are provided in Appendix B.

Databases

- As part of this project, two questionnaires were developed to extract information from equipment suppliers and Queensland desalination facility owners/operators. This information was entered into a MS Access database.

2. Background Information

The Queensland Government has established a Drought Urban Water Task Force to address water supply problems arising from the prolonged drought conditions in Queensland. Source water for many urban water supplies is becoming increasingly saline or drying up. Many communities are now relying on the carting of water, which in the long term is a costly exercise.

The number of community water supplies affected by the drought is continually changing. At the beginning of February 2003 over 150 localities were drought affected in Queensland. Of these, 41 were facing severe water shortages by July 2003 with a further 116 communities were facing problems by July 2004. Following rain in February and March, the number of communities with expected supply depletion by July 2003 has been reduced to two and 31 communities with an expected depletion date before July 2004. These numbers give an indication of the seriousness of the situation that faces Queensland and highlight the need for ongoing water supply planning to take account of drought conditions.

The size of drought affected communities range from 25 to 420,000 persons, with current average daily usages ranging between 5 kL/d and 180 ML/d. These communities are currently relying on ground water (bores), dams, and natural watercourses such as rivers and creeks for their potable water requirements. Many of these water sources are drying up, creating the need to investigate alternative water supplies. Salt-water infiltration into existing potable water supplies is also problematic in some communities.

Desalination is a rapidly advancing technology particularly for the production of potable water. Desalination is the process of removing dissolved salts from saline or brackish water to make it fit for human consumption, domestic, agricultural and industrial purposes. The Drought Urban Task Force has identified the need to evaluate desalination technologies and its potential as a viable treatment option for providing potable water supply to communities in Queensland.

While the current drought was the main driver for investigating this study, there will be situations where the evaluation of desalination as an alternative option to more traditional water supply approaches warrants consideration in the ongoing planning of sustainable water supply schemes in Queensland.

Local governments, consultants and the water industry, may use technical information in this report in general as a starting point for assessing the potential viability of desalination of brackish water or seawater as an option when planning water supply systems.

3. Desalination Technologies

Desalination is the process of removing dissolved salts from saline or brackish water to make it fit for human consumption, domestic, agricultural and industrial purposes. It is widely utilised globally and is very common in water scarce areas such as the Middle East. Technologies for desalination include membrane processes, thermal distillation and ion exchange. Membrane and thermal distillation processes are the most commonly applied technologies in large desalination plants.

This section provides an overview of the two most commonly applied technologies. More detailed information on the two most commonly applied technologies as well as some less commonly applied technologies are available in Appendix B.

3.1 Thermal Desalination Technologies

Thermal desalination technologies rely on distillation processes to remove fresh water from salty water. Saline feedwater is heated until it boils, causing fresh water to evaporate as steam. Salt and other contaminants will not evaporate, rather they remain behind in a highly saline solution called brine. The brine solution is considered a waste or by-product of the desalination process and will require disposal.

There are three main desalination technologies, each adopting the above process principles:

- Multistage Flash Distillation (MSF)
- Multi Effect Distillation (MED)
- Vapour Compression Distillation (VC)

3.2 Membrane Based Desalination Technologies

Membrane based desalination technologies use exclusion membranes to separate fresh water (containing low salt levels) from saline waters. Feedwater is brought to the surface of a membrane, which selectively passes water but excludes salts. The technology is relatively young compared with thermal technologies with the first plants coming into operation during the early 1960's (using the electrodialysis method) and early 1970's (using the reverse osmosis process) (Buros, 2000).

The most common membrane based desalination processes are reverse osmosis (RO) and electrodialysis (EDR).

4. Desalination Technology Selection

There are many factors to consider when selecting the most appropriate desalination technology for each situation, or if desalination technologies even warrant consideration. The factors to be considered include:

- **Financial issues:** including capital, operational and maintenance.
- **Energy Requirements:** including energy source required and availability of energy sources.
- **Source water characteristics and pre-treatment:** including type of water to be treated, location of water sources, need for pre treatment and extraction issues.
- **Product water:** Is post treatment required?
- **Geographical and location constraints:** distance between source waters and end distribution point, availability of skilled operators and maintenance crews.
- **Environmental factors and waste disposal options:** How will the brine or wastewater be treated/disposed of, and is noise an issue?
- **Ability to Upgrade in Future**
- **Operational and maintenance issues:** What support will be available to operate and/or undertake repairs?
- **Mobile and Intermittence Operation:** What period of time is the unit required to operate, continuously or intermittent operation and what is the throughput required?

These factors, as they relate to desalination in general and more specifically to membrane desalination versus thermal desalination, are discussed in more detail in the following sections.

4.1 Financial Issues

Desalination technologies represent significant capital investment, with high on-going operation and maintenance costs. The cost of desalination processes have fallen considerably over the last years, and in many instances the cost of desalination has fallen below conventional treatment processes. The cost trends currently being experienced in the desalination industry are shown in Figure 4-1 below.

When assessing the economic feasibility of a desalination system it is important to consider the following site specific costs:

- Transporting the feedwater to the desalination facility and permeate to the end users.
- Pre-treatment costs (depends on desalination technology selected and feedwater quality)
- Post-treatment costs (depends on end-user expectations)
- Supplying power to the site, as desalination technologies are large consumers of energy.
- Availability of skilled personnel to operate the facilities.
- Brine disposal costs.
- Site specific environmental considerations.

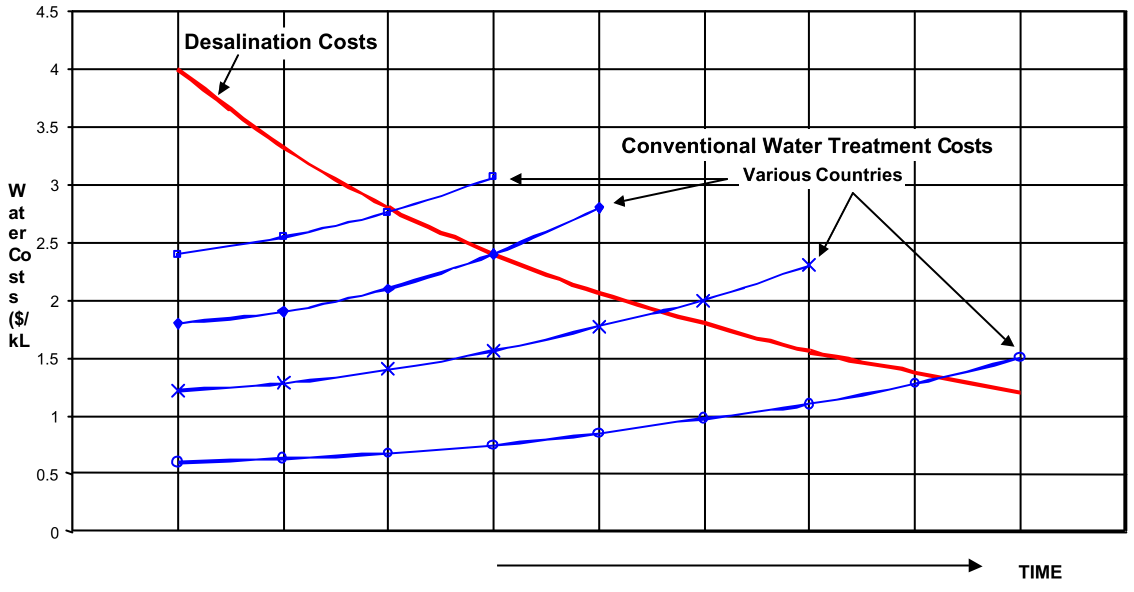

Figure 4-1 – Trends in Desalination Costs (adopted from Wagnick, 2002)

The desalination industry is relatively mature internationally. This experience assists in the development of cost estimates.

4.1.1 Capital Costs

Figure 4-2 summarises the capital costs of various desalination technologies. The RO capital costs have been derived from Australian suppliers and Queensland operators. The costs for other technologies have been derived from a number of sources including the IDA Worldwide Inventory and AFFA economic document.

The costing data should only be used to obtain indicative costs and care should be taken in interpreting the data. It is recommended that for preliminary costing purposes allowances for at least the following be added:

- Pre and post treatment costs
- Electrical works
- Delivery and discharge infrastructure
- Plant piping and valving
- Brine disposal systems
- Engineering
- Contingencies

For comparative purposes, indicative capital costs for conventional water treatment systems have also been provided. For compliance purposes conventional water treatment can be described as coagulation, sedimentation, filtration and disinfection.

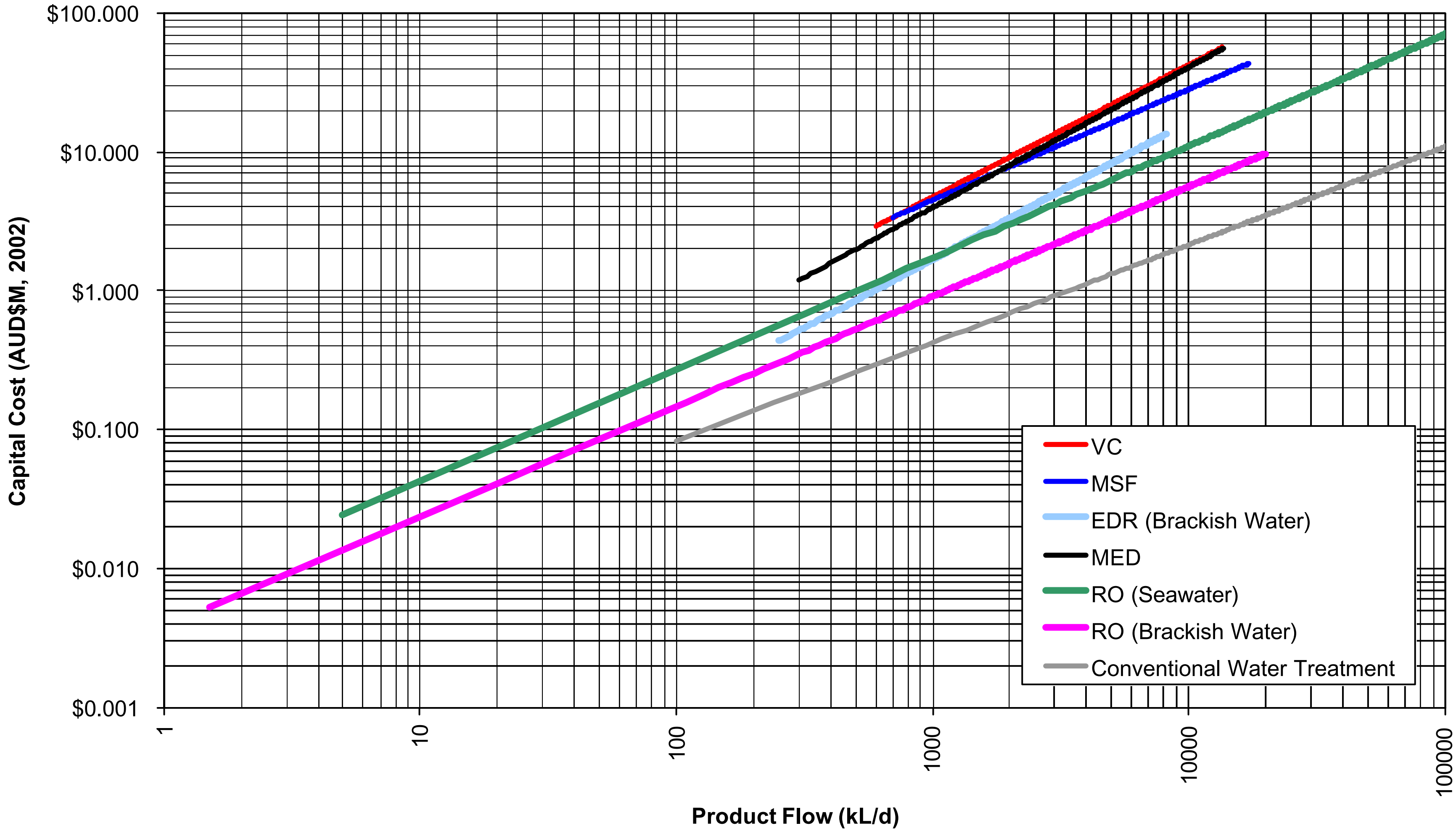

Figure 4-2 Capital Costs for Desalination Systems

4.1.2 Operating Costs

Operating and maintenance costs typically encountered in desalination facilities include:

- Energy
- Labour
- Membrane Replacement (in the case of RO and ED(R))
- Maintenance
- Chemicals

Typical operating costs for various desalination technologies are provided in Figure 4-3. The costing information for RO systems again has been derived from Queensland installations and Australian suppliers. Costing information for the other technologies has been derived from a number of sources including the economic report prepared by AFFA and the Western Australian Water Corporation report.

4.1.3 Opportunities for Cost Reduction

The cost of desalination in some instances have reportedly been off-set by:

- increasing utilisation rates
- co-generation/energy recovery
- Converting waste brine streams into a product with commercial value.

The impacts of utilisation rates on capital and operating costs are discussed further in Section 7.1.

The benefits of co-generation and energy recovery are discussed in more detail in Sections 4.2.1 and 4.2.2.

Opportunities for value adding to the waste brine stream are discussed in Section 4.6.2

4.2 Energy Requirements

All desalination technologies require some form of energy to separate the product water from saline feedwater. The form of energy available, the associated cost and the environmental constraints related to the energy source will play a role in the desalination technology selection.

Desalination technologies become more favourable when there is a cheap source of power (such as the use of a RO unit at Eraring Power Station in NSW) or where waste heat streams (such as steam) can be utilised for thermal applications. Within Queensland small electricity users are still subjected to a regulated market, where power can be purchased only from Energex (South East Queensland) and Ergon. Larger electricity and gas users however are able to purchase energy under contestable agreements. Generally electricity is purchased in bulk at a substantially reduced price.

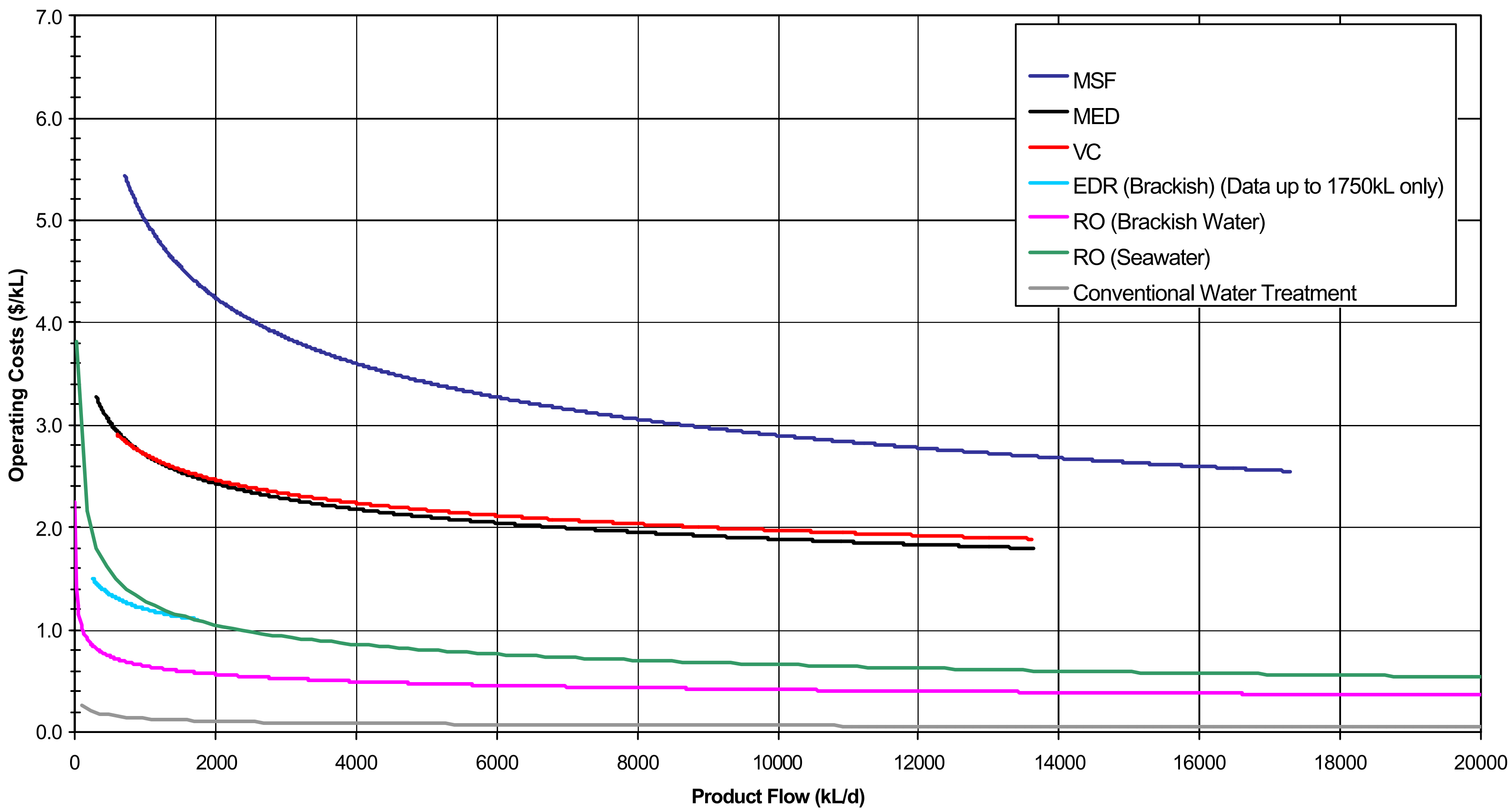

Figure 4-3 Operating and Maintenance Costs for Desalination Technologies.[1]

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[1] See section 4.1.1 for details on what is included and excluded in capital costs

4.2.1 Cogeneration

Energy consumption rates can be dramatically reduced for thermal desalination technologies if exhaust steam from steam turbine plants can be used. The energy requirements for thermal desalination plants that can take advantage of cogeneration are reduced by half to two thirds. The opportunities for cogeneration are generally limited to desalination plants that are constructed at the same time as the plant from which exhaust steam is being sourced.

4.2.2 Energy Recovery

Indicative energy usage for the different process is given in Table 4-1. Energy requirements can be reduced by careful design and process optimisation. For example through careful design and membrane selection, Dalby Council are predicting energy consumptions rates of less than 1kWh/kL for their new RO facility, which will treat low salinity water (TDS 2000 mg/L).

Energy consumption rates for desalination technologies can also be significantly reduced by using some form of energy recovery (refer to Table 4-1). Information was adopted from IDA, 2002.

Table 4-1 Energy Considerations for Membrane versus Thermal Technologies

Energy Consideration	Membrane Technology	Thermal Technology
Energy Consumption (kWh/kL) (adopted from IDA,2002)		
Electrical Consumption	1 – 2.5 (RO Brackish Water) 4– 7 (RO Sea Water) 1 (EDR, 1500 mg/L TDS)	1.5 - 3 (Distillation) 8 – 14 (MVC)
Thermal Consumption	N/A	6 – 21 (Distillation) N/A (MVC)
Total Consumption	1 – 2.5 (RO Brackish Water) 4 – 7 (RO Sea Water) 1 (EDR, 1500 mg/L TDS)	7.5 - 24 (Distillation) 8 - 14 (MVC)
Potential to use Alternate Energy Sources		
Waste Energy (Cogeneration)	Waste heat can be used to preheat feed water in some instances to achieve higher throughput in RO units (though salt rejection is reduced)	MSF and MED systems are commonly designed to use waste heat sources from gas turbines, industrial processes, solid waste incinerators etc.
Solar Energy	Used for small RO installations (<20kL/d) (Murdoch University has developed a solar powered RO unit capable of producing 400L/d of product water with a recovery ratio of 16 - 25%)	Used for small installations (<20kL/d)

Energy Consideration	Membrane Technology	Thermal Technology
Wind Driven	Not Applicable	Can be used to drive MVC processes – though the cost of producing energy can be prohibitive.
Geothermal Brine	Not Applicable	The use of warm water (80oC) from deep artesian bores may prove feasible in the future.
Energy Recovery	RO systems commonly designed with one of the following energy recovery devices: Recovery turbines - use pressure energy in Brine streams to rotate a turbine to produce electrical energy. Recovery turbochargers - propriety equipment that transfer pressure energy from the brine to other parts of the plant. Work exchange energy recovery Pressure exchanger recovery	Brine and distillate leaving the system is used to preheat feedwater.

4.3 Source Water Characteristics and Pre-Treatment

The key feedwater quality parameters that impact on desalination process design (including pre-treatment requirements) include:

- Salinity
- Turbidity
- Organic content
- pH
- Concentrations of scale forming salts and non-ionic fouling species
- Temperature.

Other issues to be considered include

- The location of the feed source relative to the desalination plant
- Environmental and construction issues associated with extracting feed waters.
- Extraction rates.
- Impact of brine disposal on feedwater source.

Potential feedwater sources for potable water applications include:

Traditional Sources

- Brackish surface/ground waters
- Seawater
- saline bore water

Alternative Sources

- Boiler blowdown water
- Coal Seam Methane water
- Tailings dam waters
- Process waters.

Water chemistry is complex, with many chemicals having synergistic affects when combined with other chemicals. It is often difficult to predict raw water behaviour when elevated levels of contaminants are present. Suppliers of desalination equipment therefore typically recommend the use of pilot plants to determine the pre-treatment requirements. The cost of pilot plants are easily justified if they identify out of the ordinary pre-treatment steps to avoid inappropriate and otherwise costly technology selection choices. The capital cost of a pilot plant reviewed in this study was $10,000. Information gathered from this pilot study was to be used in the design of a full scale facility with a capital cost of around $2.2 M Table 4-2 outlines issues for pre-treatment

Table 4-2 Source Water Considerations – Membrane versus Thermal Technologies

Feedwater	Membrane Technology	Thermal Technology
Source		
Seawater	For larger scale RO plants a cheap electricity source is required to compete economically against thermal processes. While there are a few EDR plants in the Middle East desalinating seawater, EDR plants are generally not economically feasible to treat seawater.	Thermal technologies are most commonly used for large installations or when a waste heat source is available.
Brackish water	RO is most commonly used Pilot plant trials are often recommended for brackish surface water sources. ED(R) is very effective where source water has TDS < 3000 mg/L and high scalant concentrations.	Thermal technologies only used for very large plants or where a waste heat source is available.
Saline bore water	RO is most commonly used. ED(R) is very effective where source water has TDS < 3000 mg/L and high scalant concentrations.	

Feedwater	Membrane Technology	Thermal Technology
Quality		
Salinity	Capital and operating costs are generally directly related to TDS concentrations.	Capital and operating costs are not dependant on salinity content.
Turbidity	High turbidity levels require pre-treatment	Generally not a concern
Temperature	Higher temperatures result in higher fluxes but also higher TDS levels in the product water. Rate increases of 3-5% per degree Centigrade have been reported (Wilf and Klinko)	Too hot and the feedwater can be a concern for MED processes.
Organic Content	High organic levels require pre-treatment.	Not a concern
pH	Poor pH control may reduce membrane life.	Poor pH control may lead to equipment corrosion.
Chlorine	Dechlorination prior to RO is essential.	Not applicable
Highly fluctuating feed water quality	Not well tolerated by RO systems. Membranes are designed for specific feedwater quality. A membrane designed for TDS levels between 1,000-5,000mg/L will fail if the TDS levels increase above 5,000mg/L. Change in silica, iron, manganese concentrations may exacerbate fouling and increase operational costs.	Highly fluctuating feedwater qualities are tolerated.
Pre-treatment Requirements		
Solids Removal	Media filtration followed by cartridge filtration or membrane filtration is generally required for RO. Filtration requirement is to 1 to 5 microns for RO and 10 microns for EDR.	Less rigorous filtration requirements. Filtration to 80microns generally sufficient.
Chemical conditioning	RO and ED(R) are very susceptible to scaling and fouling. Prevention measures required. ED(R) equipment is considerably less sensitive	Less extensive requirements for scaling prevention

More detailed discussions on pre-treatment requirements are provided in Appendix C.

4.4 Product Water

As desalination essentially removes most ions from the water, the product water often requires post-treatment to make it suitable for the intended end use. For drinking water supplies degassing, pH adjustment and alkalinity recovery are required for corrosion control. Blending with untreated surface water or brine is commonly carried out to reduce the overall water production costs. This is generally only feasible where there is a reasonably high quality water source available. Care must be taken when reblending with brine to ensure that no backwash contaminant or cleaning chemicals are present.

Thermal processes generally produce lower TDS waters (less than 10mg/L) compared with RO/ED(R) processes (generally less than 500mg/L). Water produced by thermal processes therefore requires higher post-treatment to minimise the corrosiveness of the product water.

More detailed discussions on post-treatment requirements are provided in Appendix D.

4.5 Geographical and Location Constraint

Availability of Skilled Operators

Skilled operators are generally required to operate and maintain desalination equipment. If operators are not available locally and need to be imported the cost of operating desalination plants will increase. The majority of desalination equipment suppliers will provide training as part of installation packages. It is assumed that an existing water treatment plant operator would have the ability to be trained up.

Skilled personnel are required to carry out detailed maintenance and repair activities. The cost of maintaining and repairing desalination equipment is dependant on the accessibility of and distance to skilled maintenance bases. The cost of maintaining and repairing remote desalination installations was evident during commissioning of a reverse osmosis plant on Murray Island. It was estimated that each trouble-shooting event cost in the order of $10,000 to resolve from a human resource point of view. It would be advantageous for plant operators to have access to a desalination specialist to act as a trouble shooter for the facility. This could reduce the level of maintenance required and hence the annual operating costs.

Land Availability

Desalination plants typically do not require large footprints, compared to conventional water treatment systems (including land requirements associated with dams).

Land availability is generally not a consideration for large plants as the required footprint is similar for membrane and thermal technologies. Both technologies require approximately 0.5ha for each 50ML/d production capacity. For smaller scale plants, RO facilities typically require less area than thermal plants.

The method adopted for brine disposal will significantly impact on the land requirements for desalination facilities. The disposal method requiring the largest land area is Salt Pond Evaporation. Salt pond evaporation is discussed furthering section 4.6.2.

Availability of Energy

As discussed previously, desalination technologies are high users of energy. Therefore it is important that an energy supply to the desalination plant can be economically provided.

4.6 Environmental Factors and Waste Disposal

4.6.1 Environmental Factors

The following environmental issues should be considered for any desalination technology:

- Construction phase impacts including the clearing of land for the desalination plant and the creation of cleared easements for pipeline and outfall facilities
- Energy consumption
- Atmospheric emission (air, noise and thermal)
- Chemical storage and handling
- Environmental impacts associated with water extraction
- Waste disposal: brine solutions, pre-filtration backwash waters and cleaning wastes require disposal.
- Aesthetic impacts of the facilities.

The majority of impacts can however be effectively mitigated through the use of current environmental protection measures and careful planning.

4.6.2 Concentrate/brine disposal

The aim of all desalination processes is to remove salt and other chemical impurities from water. The salt and other chemical solutions removed from the water is generally collected in a concentrated liquid form called brine.

The quantity and quality of brine produced will depend on the technology adopted and feedwater quality. Generally a thermal process will produce less brine than an RO process when desalinating seawater, the opposite is true for brackish waters.

The way in which brine is disposed will depend on site-specific issues but may include:

- Sewer disposal
- Disposal to ocean
- Groundwater injection
- Evaporation Ponds
- Crystallisation
- Livestock Watering
- Value-added options

The advantages and disadvantages of these disposal options are discussed further in Table 4-3, while value adding opportunities are discussed in more detail below.

Table 4-3 Advantages and Disadvantages of Brine Disposal Options

Disposal Method	Advantages	Disadvantages
Sewer disposal	Makes use of existing infrastructure. Dilution of TDS levels with domestic wastewaters may reduce impact on receiving environment.	Wastewater treatment plants are not designed to reduce TDS levels. High salt concentrations may impact on effluent disposal opportunities. Additional hydraulic load placed on treatment plant. Only economical where quantities are low and TDS levels are low.
Ocean disposal.	Discharging into a highly saline water. Large volume of water body aids in dilution.	Potential for localised impacts of brine stream due to high salinity. Temperature variations may exist between brine and receiving waters.
Groundwater Injection	Cost effective disposal option.	May not be environmentally acceptable – will depend on groundwater quality.
Evaporation ponds	Low tech solution. Provides storage until alternate disposal/reuse opportunities become available. Minimise impact to water bodies. Potential to combine with value added opportunities as discussed below.	Large areas are required. Favourable meteorological conditions are required. Salt water ponds very susceptible to forming a crust which reduces drying potential. Large volumes of salt produced over time that will require disposal. Minimal opportunities for reuse may exist
Crystallisation	Reduced impact on receiving environment. Generates a marketable product	Capital intensive option. Technically complex process. High operator input. Tendency to the formation of incrustation on the heat-exchanging surfaces.

Livestock Watering	Some livestock have high level of tolerance to waters containing TDS up to 5000mg/L. Provides an alternate water source.	Contaminants from backwash and cleaning may have negative impacts on the livestock

Business opportunities associated with brine wastes are discussed below:

Brine Wastes and Value Adding - Salt Harvesting

Brine disposal in many areas, where evaporation exceeds rainfall, is achieved by evaporation. Waste brine solutions are discharged into large ponds and as the water evaporates, a salt precipitate is left behind. This salt product can be harvested and used for a variety of beneficial uses including commercial salt sales, road base additives, dust suppressants, stock feed, medical and chemical uses.

For salt harvesting operations to be profitable, medium to large scale operations are generally required (AFFA 2002). Capital costs have been reported in the order of $20,000 per hectare of pond, with annual O&M costs associated with labour, salt harvesting, cleaning, packaging etc (AFFA, 2002). AFFA have also reported that good quality salt can be sold for between $25 and $250/tonne.

Brine Wastes and Value Adding - Aquaculture

Aquaculture is emerging as a potential beneficial reuse enterprise for brine disposal ponds. Suggested aquaculture ventures include fish, shrimp, algae and seaweed. Care must be taken that residual chemicals do not impact on these operations.

Brine Wastes and Value Adding – Energy Generation

Brine disposal ponds can be constructed as solar ponds, which uses the pond’s salinity gradient to collect and store solar energy.

A brine disposal pond would normally consist of three layers:

- An upper layer containing low levels of salinity
- A middle layer of increasing salinity
- A bottom layer of high salinity.

Solar radiation penetrating the pond is absorbed in the different layers and causes the temperature of each layer to increase. In a normal reservoir, convection currents would set up by the temperature differentials, causing hot water to float up to the surface. On coming to the surface, the hot water exchanges heat with the environment and cools back down. In a solar pond, the thermal convection process is suppressed by the unfavourable density gradient (the lower layers contain higher salinity levels and are therefore denser in nature). The hot layers therefore remain hot.

Heat extraction can be achieved by submerged heat exchangers, or alternatively the hot brine is circulated through an external heat exchanger and pumped back to the storage zone. A number of end uses can be successfully coupled to the solar ponds. These include: hot water production, drying, desalination of sea water or brackish water, air conditioning and refrigeration, bromine recovery, preheating for the production of magnesium chloride, and power generation (Adopted from The Energy and Resources Institute).

Brine Wastes and Value Adding – Salt Pond Evaporation

Evaporation ponds decrease brine concentrate volumes to the point of crystallization making it possible to handle the TDS precipitates as a solid material. However, brine ponds require vast amounts of land, and have limited capacity. Solids that accumulate in the ponds require periodic disposal. Deep well injection and mechanical evaporation are capital-intensive as well as having high operation and maintenance costs. Salt pond operations are very sensitive and must not be allowed to completely dry out, as the liner system will become damaged.

Salt Ponds may be able to be utilised as solar energy collectors. For these ponds to be effective in collecting solar energy, three differing zones of salt concentration is required which work together to trap and store heat originating from the sun. The surface zone the lightest in salinity allows the heat to travel down but not upwards and also acts as buffer to the second zone. The second zone prevents heat from returning to the surface. The third zone with the greater concentration of salinity acts as thermal storage and readily absorbing the solar heat rays.

Brine Wastes and Value Adding – Hypochlorite generation

Brine solutions can be used for on-site generation of hypochlorite. Hypochlorite generation is a well-established, commercially available technology that creates Sodium Hyperchlorite (NaOCl) by means of an electric current applied to a brine solution. Available hypochlorite generation equipment uses brines composed of water and food-grade salt; but the use of RO brine is under investigation to determine its suitability for replacing purchased salt. Initial comparisons show a 50% drop in operating costs by eliminating the use of purchased salt (http://www2.bv.com/news/articles/dec02/methods_brine_disposal.htm).

Brine Wastes and Value Adding – SAL-PROC

This approach is based on sequential extraction of a variety of salt minerals, slurries and liquid compounds by multiple evaporation and cooling of concentrated saline wastewaters, desulphation, reaction, crystallisation, washing and dewatering. The process is particularly suitable for brine with high levels of dissolved sulphate, potassium and magnesium salts that may be found in some industrial situations.

Associating the SAL-PROC with a desalination plant powered by a cheap energy source (e.g., waste heat energy from conventional power plants or solar energy generators) will improve SAL-PROC economics.

(http://www.desline.com/articoli/4012.pdf)

4.7 Ability to Upgrade in Future

Both membrane and thermal desalination technologies are typically manufactured in a modular nature. Therefore the ease at which plants can be upgraded in the future is similar.

4.8 Operational and Maintenance Issues

Skilled operators are required to effectively operate and maintain thermal desalination installations. The plants are often reported to have a degree of resilience to less than optimum maintenance regimes However, anecdotal evidence suggests that plants operated and maintained by highly skilled and motivated personnel perform best in terms of achieving consistently high quality product water and long term least cost operation (pers comm. Mr Terry Fagg).

Preventative maintenance requirements are similar for both thermal and membrane processes and will include:

- Instrument calibration
- Pump adjustment
- Chemical feed inspection and adjustment
- Leak detection and repair.

Less routine maintenance activities include:

ED(R) Technology	RO Technology	Thermal Technology
Cleaning of membranes (cleaning in place) Replacement of membranes (every 5 – 10 years) Replacement of electrodes (every 10,000 – 20,000 hours) (pers comm. Mr Terry Fagg) Pump overhauls etc	Cleaning of membranes (every 6 – 18 months) Replacement of membranes (every 3 - 5 years) Pump overhauls etc Replacement of pressure vessels (every 20 years)	Repairing damage to liners. Removing scale and marine growths in the tubes using high pressure sprayers. (every 6 –12 months for small/mobile units) Removing the vacuum system ejectors for cleaning, inspection, and replacement as necessary (every 3 - 4 years). Acid wash tubes every 10,000 – 20,000 hours. Pump overhauls etc.

Common to all technologies is the need to regularly maintain intake structures.

4.9 Mobile and Intermittent Operations

The issues associated with mobile and intermittent operations are discussed in Section 7.1.