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Brackish groundwater: a viable community water supply option?

NSW Public Works

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Waterlines

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Glossary of abbreviations and acronyms

ADWG	*The Australian drinking water guidelines 2004*
ANZECC	Australia and New Zealand Environment Conservation Council
CIP	Clean-in-place
CO_2	Carbon dioxide
DBNPA	2,2-dibromo-3-nitrilopropionamide
EC	Electrical conductivity
ECe or ECse	Electrical conductivity of a saturated extract
EDR	Electrodialysis reversal
EIA	Environmental impact assessment
HERO™	High efficiency reverse osmosis
HMI	Human-machine interface
ISD	In-situ desalination
MED	Multiple effect distillation
MEH	Multiple effect humidification
MF	Microfiltration
MSF	Multi-stage flash
NWC	National Water Commission
O&M	Operation and maintenance
PLC	Programmable logic controller
PV	Photovoltaic
REF	Review of environmental factors
RO	Reverse osmosis
ROSI	Reverse osmosis solar installation
RTU	Remote telemtry unit
SCADA	Supervisory control and data acquisition
SDI	Silt density index
SMS	Short message service
TDS	Total dissolved solids
UF	Ultrafiltration
USA	United States of America
UV	Ultraviolet
VSEP	Vibratory shear-enhanced processing membrane system
VWS&T	Veolia Water Solutions and Technologies
WTP	Water treatment plant

Units of measurement

a	annum (one calendar year)
d	day
g	grams
h	hour
L	litres
m	metre
S	siemens

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Executive summary

Australians rely heavily on groundwater sources, with around 4 million people dependent partially or totally on groundwater for domestic water supply. Groundwater varies in its concentration of dissolved salts. In many cases, the concentration is so high that the water is unsuitable for drinking without treatment to remove the salts.

There are a number of desalination technologies for removing salts from water. Reverse osmosis (RO) membrane desalination has gained popularity in Australia since 1980 following successful installations here and overseas. Brackish water desalination using RO membranes is used to produce drinking water for domestic purposes in a number of inland towns and communities where other water supply options are limited.

Desalination processes produce a waste stream of concentrated salty water called brine that must be disposed of appropriately. Water-supply managers face challenges when disposing of this waste in regional and rural areas, as disposal can harm the environment.

The most common brine disposal method is the use of evaporation ponds. Although effective, they are expensive to build, costing up to 50% of the capital cost of a desalination project. There are technology options for further processing brine, but these are more suited to industrial applications because of the cost of applying them to drinking-water supply.

Beneficial reuse of brine for agricultural purposes, such as stock-watering or crop irrigation is largely untried in Australia. Some crop varieties, however, tolerate brackish water and could be considered for Australian applications.

The level of tolerance of plants to brackish water is dependent on two key factors, the prevailing climatic conditions of the locality and the salinity of the water used for irrigation. This report presents scenarios using locations in Australia to illustrate differences in agricultural opportunities for differing climatic zones.

Water authorities considering brackish groundwater desalination as a water supply option can learn valuable lessons from towns and communities that already own and operate desalination plants. This report investigates six such locations around Australia and presents case studies on each.

Wowan in Queensland (Qld) and Yuelamu in the Northern Territory (NT) have recently decided to build desalination plants to provide most of their domestic water supply and are investigating design and procurement options. Yalata in South Australia (SA) and North Star in New South Wales (NSW) have been operating small desalination plants for about five years and maintain them through an ongoing agreement with the equipment supplier. Dalby in Queensland and Coober Pedy in SA own and operate larger desalination plants as part of their town’s domestic water supply and have since added another plant to increase treatment capacity.

Capital and operating costs for desalination are location-specific and can vary greatly between installations. This report presents an example of the costs that should be considered for a new installation and also provides indicative costs for a scenario.

The overall feasibility of a project is dependent on a number of considerations, particularly geographic location and raw water quality. Subject to these considerations, brackish groundwater desalination can be considered a viable community water supply option.

1. Introduction

1.1. Groundwater

Groundwater is a general term used to describe water in underground aquifers and aquitards of fractured rock or sand. Australia is richly endowed with vast amounts of groundwater, which has traditionally been exploited for drinking water, irrigation, leisure activities and by industry. About 30% of Australia's water use is derived from groundwater, with up to 4 million people partly or totally dependent on it for domestic supply.[1,2]

Groundwater varies greatly in quality, quantity and depth, depending on the host-rock type, the nature of the overlying soils, and rainfall. It has often been lying undisturbed in underground aquifers for tens, if not hundreds of thousands, of years. Over time, salts from the surrounding strata dissolve in it, leading to a higher concentration of salts in groundwater than in surface waters.

1.2. Desalination

Groundwater can be extracted from underground aquifers for useful purposes such as drinking water supply, agriculture, and industrial processing. In some cases it contains such a high level of salts that it is unsuitable for some purposes.

Desalination is the process of separating salts from water to produce water that is lower in salinity and suitable for its intended purpose, and a by-product waste stream. Desalination processes are numerous. The choice of technology is dependent on factors such as water end-use and the availability of energy and funds. Section 2 describes current technologies.

1.3. Salinity and groundwater quality

1.3.1. Brackish water

In simple terms, brackish water is water that has a higher salt content than fresh water but a lower content than seawater. As the term covers a large range of salinity, it is often broken down into smaller categories. Definitions of brackish are many and varied and are often refined to suit the prospective use of the water being described.

The Australian drinking water guidelines (ADWG) value for total dissolved solids (TDS) is 500 mg/L for drinking water, as this is considered the upper threshold of taste. Some Australian community water supplies have a TDS of up to 1500 mg/L, which is considered to be the maximum tolerable salinity.

There is no health-based guideline value for salinity, but patients suffering from severe hypertension or congestive heart failure should be aware, if the sodium level—the most common salt found in brackish water—is higher than 20 mg/L.

This study defines brackish water as having a TDS level between 500 mg/L and 30 000 mg/L. The table below shows some potential uses of water against differing levels of salinity.

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[1] NWC 2008
[2] AWA 2007

Table 1–1: Definitions and uses of saline waters

Description	*TDS (mg/L)*	*Potential use of water*
Fresh	<500	All purposes, limit of ADWG
Brackish	500–1500	Most purposes, objectionable taste if used for drinking
	1500–5000	Livestock, limited irrigation
	5000–7000	Most livestock
	7000–14,000	Some livestock (beef, cattle, sheep)
	14 000–30 000	Limited industrial uses, ore processing
Saline	30 000–50 000	Limited industrial uses, ore processing
Hypersaline	50 000–100 000	Limited industrial uses, ore processing
	>100 000	Brine production, ore processing

Source: Adapted from multiple sources, largely Australian Water Resources Council 1988.

1.3.2. Salinity and salts

The types of dissolved salt in groundwater are mainly common salt (sodium chloride), calcium and magnesium carbonates, chlorides and sulfates. Similarly, the most abundant dissolved ions in seawater are sodium, chlorine, magnesium, sulfate and calcium—although sea water is likely to have a higher proportion of sodium chloride. However, other salts (including some that may be considered toxic) can occur in significant concentrations in some locations. The term ‘salinity’ is used to describe dissolved salts in water. Salinity can be expressed as the amount of soluble salts in the soil or in water (commonly described as Total Dissolved Solids or TDS measured in mg/L) or as electrical conductivity (measured in µS/cm). Both measurements are commonly used to describe salinity but cannot be used interchangeably as they measure different parameters.

TDS is the most accurate description of salinity, as it is a measurement of the concentration of salts in the water. However, a TDS measurement requires laboratory analysis to identify and measure every cation and anion present in the water. Alternatively, a water sample can be evaporated and the remaining dry solids weighed.

Electrical conductivity, on the other hand is a simple measurement, requiring basic analytical instruments that can be used in the field or in process plants to give an instantaneous reading. For this reason, it is often used in industrial and agricultural applications.

There is no exact relationship between electrical conductivity as µS/cm and TDS as mg/L, as different salts in water have a different ability to conduct electricity. In water with a higher proportion of sodium chloride (e.g. sea water), a rule of thumb to convert conductivity readings to mg/L is to multiply the µS/cm reading by 0.5. For most other water (for example, in hydroponics solutions or sewage effluent), a factor of 0.67 or 0.7 is used. Although it is possible to calculate the conductivity for any electrolyte at any temperature and concentration, the exact contribution of individual ions is difficult to determine because of interactions between the ions.

Table 1–2 below illustrates the conductivities of some individual solutions.

Table 1–2: Relationship between TDS and conductivity for some common salts

Salt (0.01 mol/L)	*TDS (mg/L)*	*Conductivity (µS/cm)*	*TDS factor (TDS/cond.)*
$NaCl$	584	1156	0.51
$CaCl_2$	1110	2310	0.48
$NaHCO_3$	840	865	0.97

1.3.3. Other water quality issues

As well as salinity, groundwater often has other water quality issues that need to be considered when it is being used as a drinking-water source.

Groundwater can present health concerns if not properly treated. Toxic elements and ions, such as arsenic, chromium, iodide, fluoride and uranium, can all be found in groundwater in Australia. Supplies can also become contaminated with viruses and bacteria.

In addition to human consumption issues, other factors can affect the successful operation of a desalination process. High concentrations of barium, iron, manganese and silica can cause significant fouling in membranes.

1.4. Desalination in Australia

Water produced from desalination accounted for approximately 0.57% of water usage in 2009 and is expected to grow to 4.3% by 2013. The rapid increase is largely due to significant seawater desalination projects under construction in Melbourne, Adelaide and Western Australia.

By volume, seawater desalination accounts for 86% of desalinated water in Australia, dwarfing brackish water desalination, which makes up only 1.2% of installed capacity. This is not unexpected, though, because the brackish water market is traditionally located in small inland towns and villages with low treatment volumes. The remainder of desalination installations process industrial wastewater, such as water from mining.[3]

Brackish water desalination is becoming more popular for inland drinking-water supplies, with most installations using traditional reverse osmosis (RO) membrane technology. Electrodialysis reversal and high-efficiency RO are also used.

[3] Hoang M. et al 2009.

2. Desalination technologies

There are a number of different technologies suitable for separating salts from water to be used for drinking. Information about them has been widely published and will not be repeated here in detail. However, an overview is presented in the following sections.

The choice of technology depends on a number of factors, most significantly raw water quality and local availability of power sources. The large variation in these two factors has seen different technologies become popular in different parts of the world. Thermal distillation processes, for example, are more popular in Middle East nations with access to low-cost gas and petroleum resources, whereas in Australia RO membranes are the most popular because of access to electrical power. Research and development of desalination technologies has led to a number of proprietary technologies appearing on the market. While not all of these can be discussed in this report, some of the more notable have been included in this technology review.

2.1. Distillation processes

Desalination through distillation uses the principle of phase change to separate water molecules from raw water containing salts and other minerals. These processes are best suited to large installations in locations with a readily available heat source, such as a gas-fired power plant, and are most commonly used in the Middle East.

2.1.1. Multistage flash

The multistage flash desalination process passes heated feedwater through a series of heated chambers at varying pressure levels, from a low vacuum to a very high vacuum, where water evaporates and recondenses into fresh water. The feedwater—usually sea water—is first passed through the heating chambers where it helps condense the water vapour for collection through a heat-exchange mechanism. After this, the water enters the brine heater where a heat source is applied and flashing occurs.

The unflashed portion of feedwater contains more salt and is referred to as the brine. This passes through the series of differential pressure chambers. There, water is flashed and recondensed into fresh water with the aid of first-stage feedwater passing through the chamber via tubes. At each chamber the brine passing through to the next chamber becomes more concentrated and is eventually discharged.

2.1.2. Multiple-effect distillation

In multiple-effect distillation, steam produced from one heating chamber is transferred to the next chamber for boiling additional feedwater, which produces steam in a series fashion. The recycling of energy for evaporation at multiple stages provides energy savings.

The process requires a series of chambers that pass or spray feedwater (usually sea water) through a series of tubes carrying steam generated from the previous chamber. The heat exchange from the steam humidifies the passing feedwater as it recondenses, and is collected as fresh water from each chamber.

The chambers are maintained at decreasing levels of pressure and increasing levels of temperature. As the water evaporates in each chamber (effect) the salt from sea water is collected as brine at the bottom of the effect and finally discharged.

2.1.3. Vapour compression

Vapour compression distillation is a closed-loop process where the heat needed for the boiler and condenser is recycled. Water is first sent through a system of heated plates to bring it to boiling. This produces water vapour, which is then compressed to increase its temperature. The heated vapour is used to reheat more water and, as the heat dissipates, the vapour recondenses and is collected as fresh water.

Usually the process is complemented by a secondary heater to make up for any difference in the heat energy required from the actual heat energy of the compressed vapour. As the process continues in a closed loop the water reservoir becomes increasingly concentrated and is eventually discharged when it reaches a specific concentrate level.

2.2. Membrane processes

Membrane desalination uses the principle of separation by allowing only certain molecules in a solution to travel through the membrane. These processes are generally modular and much simpler to run on a small scale than distillation processes. They operate at ambient temperature, so are able to be run without external heat input, and can be powered by grid electricity, making them more suitable for locations where this is the only energy option.

2.2.1. Reverse osmosis

Reverse osmosis uses the principle of osmosis, whereby an ion is transported from an area of high ion concentration to an area of lower concentration until equilibrium is reached. When an ion-excluding membrane is placed between two ionic solutions, the pressure generated across the membrane by the solvent (often water) passes through the membrane to equalise the overall concentration. This is known as the osmotic pressure.

In RO a pressure greater than the osmotic pressure is applied to solution on one side of the membrane. This reverses the osmotic flow and forces the solvent to travel through the membrane from the solution of higher concentration into the less-concentrated solution. In the case of desalinising brackish or saline water, this effectively forces the water molecules out of a saline solution. The process has two products: a fresh water stream low in salinity and a highly concentrated ‘brine’ solution. The higher the percentage of fresh water produced, or the higher the concentration of salts in the feed, the higher the pressure forcing the feedwater needs to be.

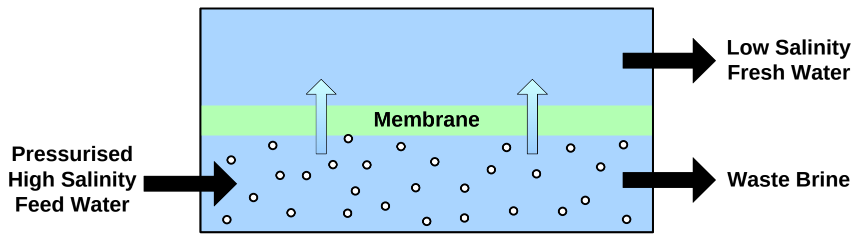


Figure 2-1: Reverse Osmosis Process

Recovery

'Recovery' describes the percentage of clean water produced from a given volume of raw water. As a general rule, there is more recovery as feed pressure increases and salinity decreases. The optimum recovery for a given process is determined during the design stage. Seawater RO desalination processes usually operate at a recovery of around 40% to 50% and return 50% to 60% of the raw water to the sea as concentrate. Inland brackish water installations can operate at between 50% and 75%, depending on the quality of the raw water. Some high-efficiency processes can increase recovery to above 90% but these often involve the use of additional chemicals.

Some RO installations operate using multiple pressure vessels to increase recovery. There is a distinction, however, between multistage and multipass RO systems. In multistage systems, permeate (clean water) is piped to storage and the concentrate (brine) is sent through additional membrane modules, sometimes interstage with pressure boosting, to recover additional permeate. In multipass systems the concentrate is piped to waste and the permeate sent through additional membrane modules operating at a lower pressure to further reduce salinity levels. Multipass systems are common in seawater desalination and ultrapure water applications.

2.2.2. Electrodialysis reversal

Electrodialysis reversal (EDR) employs the principle of ionic charge to separate ions in solution, using charged electrodes. In 'forward' electrodialysis DC current is applied to two electrodes, with positively charged sodium ions flowing towards the cathode and negatively charged chloride ions towards the anode. By applying layers of ion-selective membranes between the cathode and anode the water stream can be separated into desalinated and concentrated salt streams.

EDR operates in the same way, but the DC current flow is intermittently reversed to clear the membrane surface. This reduces the effects of fouling and scaling to increase membrane life. In some cases EDR can be comparable to RO for treating brackish water. The technology provides a number of benefits over RO but has the following limitations:

- EDR is able to treat high silica water. Water recovery is not limited by silica, as the process itself does not remove silica.
- EDR membranes are not as sensitive as RO membranes to turbidity, chlorine and silica.
- EDR is not effective in removing pathogens (~5% removal), is of varying effectiveness in removing radiological substances (50%–90%) and not effective in removing pesticides and volatile organic carbons (~5%).
- EDR typically has a lower unit cost for water than RO membrane processes because of lower construction and operating costs with the raw water source.
- Recovery from 80% to 94% is achievable with EDR, which produces less brine.
- Typically, EDR is not competitive for source water with TDS greater than 2000 mg/L.
- Scaling on EDR units is permanent.

Table 2–1: Water-quality limitations to EDR feedwater

Parameter	*Value*
Feed TDS	400–3000 mg/L
Soluble iron	<0.3 mg/L
Manganese	<0.1 mg/L
Hydrogen sulphide	<0.1 mg/L
Aluminium	<0.1 mg/L
COD	<50 mg/L
Total organic carbon	<15 mg/L
Oil and grease	<1 mg/L
Free chlorine	0.5 mg/L (30mg/L intermittently)
Turbidity	0.5 NTU (2 NTU intermittently)
Silt density index	10–12 (15 intermittently)

2.3. Emerging processes

2.3.1. Membrane distillation

Membrane distillation uses differences in temperature to remove fresh water from a saline feed through a hydrophobic membrane. As this is an emerging technology, there are still only a few commercial installations.

A benefit of membrane distillation technology is that it operates at atmospheric pressures, using heat as the energy source. For this reason, it is most appropriate where a source of waste heat is available. The process is limited by a low flux rate, requiring larger and more expensive installations than competing technologies. Research into the technology is continuing, with priority being given to increasing the flux rate to improve efficiency. Solar-heat energy is also being investigated for use as a heat source, which would make the technology more suitable for brackish groundwater applications in regional areas.

2.3.2. Solar multiple-effect humidification

Solar multiple-effect humidification employs the simple concept of heat transfer from direct sunlight using solar-absorbing materials to humidify raw water and recondense it into clean drinking water. The challenge is to design systems that maximise the heat and mass exchange using optimal surface geometries. It is also beneficial to reduce the temperature gap to harness most energy from the heat source.

Generally, the humidification and dehumidification chambers are separated. However, some commercially available portable systems use a single chamber for both water evaporation and recondensation. As thermal desalination is an energy-intensive process, the production volume of solar power-based systems is limited and generally suited for portable small-scale applications, unless large-scale concentrated solar reflective arrays are used.

2.4. Innovative desalination applications

2.4.1. Reverse osmosis solar installation[4]

Reverse osmosis solar installation (ROSI) combines the technologies of physical membrane filtration and RO desalination with photovoltaic (PV) solar-power generators as its power source. The system is designed for use in remote areas that have no permanent electricity

[4] Werner et al 2005

supply. Being portable, it is suitable for quick deployment and temporary installation. The system is capable of producing drinking water in the range of 100 L/d to 500 L/d from brackish groundwater sources.

RO desalination requires a large amount of power to operate because of the high pumping pressures needed. As solar PV systems generally are unable to deliver the power required for high-pressure pump operation, a separate battery system is needed to store energy and release it at as required. This adds bulk and expense to the system. ROSI overcomes this challenge by operating the desalination process at low pressures with a much lower recovery than a normal installation. Recovery in the system is around 10%, with the remaining 90% being rejected. The rejected water, however, is not wasted and is disinfected for use in non-potable activities such as cleaning and showering. Using the system in this way provides safe water for drinking and non-potable uses in areas where it is otherwise unavailable.

2.4.2. In situ desalination[5]

In situ desalination (ISD) is a proprietary concept that combines an RO membrane and a bore pump into a single unit. This is inserted directly into a borehole drilled into a brackish groundwater aquifer. Water is pumped from the aquifer through the membrane, with permeate being delivered up the borehole to the surface and waste brine remaining in the aquifer. The process is said to mimic the natural hydrological cycle of trees.

The technology has a number of benefits. The major difference from conventional water treatment is the minimal above-ground infrastructure. A single pumping source is used to treat and deliver water, reducing equipment and energy requirements. As only the product water is brought to the surface, there is no waste brine stream to dispose of, which can greatly lower operating and capital costs.

The major drawback is the limited control over the quality of the product water. An ISD unit comprises a single RO membrane and a fixed-speed pump, which gives the operator little control over the recovery of the desalination process. As permeate-water quality is determined by the quality of the groundwater in the aquifer, it will change if the salinity of the groundwater changes.

A thorough understanding of the aquifer's hydrology and water quality is needed to determine whether ISD is suitable. The unit removes water from an aquifer and leaves salt behind, which, depending on groundwater movement and aquifer recharge, could lead to local concentration of salt around the unit and increased salinity of the ISD feed. This, in turn, will result in higher salinity of the permeate. The ability to produce water with salinity below ADWG levels is therefore almost entirely dependent on the groundwater conditions.

2.4.3. High-efficiency reverse osmosis[6]

High-efficiency reverse osmosis (HERO™) is a patented technology where special pre-treatment removes certain contaminants and solids and increases the pH of water before RO is carried out. The technology was developed by Deb Mukhopadhyay, whose patents are licensed by several distributors, including GE and Aquatech.

The processes involve cation exchange for hardness removal, degasification for carbon dioxide (CO_2) removal and alkalinity removal by pH increase over 8.5. The enhanced pre-treatment process makes HERO™ suitable for applications where conventional RO would not be possible, such as groundwater with high silica content.

[5] Desaln8 2011
[6] Aquatech 2011

The high pH environment reduces the need to clean RO modules by reducing silica scaling, oil and grease fouling, and particulate and bio-organic fouling. HERO™ also provides a water-recovery rate of over 90% and is particularly suited for industrial feedwater systems. The high recovery also significantly reduces the volume of brine requiring further treatment.

The processes are more complex to operate and rely heavily on chemical dosing. They are generally considered only when conventional RO is not feasible because of high recovery requirements or poor feedwater quality.

3. Reverse osmosis for brackish groundwater desalination

RO and EDR are the most viable treatment options for brackish groundwater desalination in Australia at this time. Feedwater quality may also dictate which technology should be used and the pre-treatment requirements. In many cases, it may be beneficial to use a blending scenario to meet water-quality goals. These blending scenarios may also mitigate the need to post-treat or stabilise water before sending it to the distribution system.

Further detail about RO desalination is provided below, as this is currently the commonest technology for brackish water desalination in Australia.

3.1. Treatment and cleaning requirements

3.1.1. Pre-treatment

Pre-treatment before RO is an important step because of the sensitivity of RO membranes to suspended solids and organics in natural waters. These impurities can lead to fouling of the membranes, which can significantly compromise the membranes' performance and increase operating costs. Excessive fouling can also void a manufacturer's RO membrane warranty. Some issues related to fouling include:

Scaling

A detailed feedwater analysis is recommended to assess the scale-forming potential of the water source. Controls include antiscalants, water-softening and pH adjustment.

Colloidal particulate fouling

Fouling potential is based on a silt density index (SDI), which is a universally accepted test for measuring the fouling potential of the water source. Typically, 15-minute SDIs <5 (sometimes <3) for the feedwater are required by RO membrane suppliers to honour any warranty claims on the membrane. Controls include one or more of the following: coagulation, flocculation, filtration and cartridge filters. Membrane filtration (e.g. ultrafiltration and microfiltration) to replace coagulation and filtration is becoming more common.

Two commonly used SDI tests are the 15-minute SDI (SDI 15) and the three-minute SDI (SDI 3). The SDI 15 is used to test the quality of the RO feed, while the SDI 3 is the standard used to test the quality of the raw water. Some typical SDI 3 and SDI 15 values are shown in the following tables.

Table 3–1: SDI 3 (3-minute SDI test) test results

Typical SDI 3 range	*Description*
7–15	Good water quality, low fouling potential.
15–to 25	Moderate water quality, moderate fouling potential.
>25	Poor water quality and high fouling potential.

Table 3-2: SDI 15 (15-minute SDI test) test results.

Typical SDI 15 range	*Description*
>3	Acceptable water quality for RO, low fouling potential.

Organic and biological fouling

Natural organic matter can foul the membranes and is controlled through regular cleaning of the RO plant. Biological matter in the feed is seen as colloidal particulates because of their size.

3.1.2. Post-treatment

Because the RO treatment removes alkalinity species from the water, the product water is very corrosive. Therefore, post-treatment is used to condition and stabilise the permeate before introducing the water into the distribution system. For stabilisation, lime is used to add calcium hardness back to the water, along with CO_2 to reduce the pH without affecting the alkalinity.

For brackish water systems, stabilisation can sometimes be accomplished by using bypass blending where a portion of the feedwater is diverted around the RO system and re-blended with permeate. This process reduces the plant footprint and operating costs (chemicals, pumps, etc.). When treated water quality targets cannot be achieved with blending alone, sodium hydroxide is added to adjust pH to an acceptable range.

3.1.3. Maintenance wash, clean-in-place operations

With membrane systems, periodic maintenance washes and clean-in-place operations are needed to remove scale/biological growth that accumulates on the membrane surface over time. The duration and frequency of these cleans, and the required chemicals, are a function of the raw water quality and level of pre-treatment and are usually optimised over time. Depending on the disposal method, the resulting waste from these cleans may need to be neutralised (pH around 7) prior to disposal. A separate tank is usually required for the process. Neutralisation also requires additional chemical-dosing systems.

3.2. Operational complexity

3.2.1. Required skills

The RO treatment process is more specialised and technology-intensive than conventional water treatment and only in recent years has gained wider acceptance as a viable, cost-effective option. Well-operated RO systems can provide consistent and reliable service once the chemical dose rates and backwashing/chemical cleaning sequences have been optimised to suit the raw water quality.

Unlike granular media filters, membranes are often less forgiving of suboptimal operation, leading to poor performance and/or irreversible damage. In such a scenario, full restoration of the membrane’s original performance is unachievable and permanent reductions in capacity are the result. Replacement of the fouled membrane itself is also sometimes required to restore desired production rates. Because of this, well-trained operators are critical in deciding whether to pursue RO as a viable treatment option. However a service contract with the technology supplier can be a suitable alternative.

3.2.2. Number of personnel

The number of operators needed for a small RO water treatment plant (WTP) is assumed to be one. The number of actual staffing hours may be lower than a conventional WTP, depending on the level of pre-treatment, plant automation and remote access.

3.3. Reverse osmosis vendors

The number of vendors for RO desalination units in Australia is increasing. While there are differences in the treatment units and technologies provided by vendors, key services are offered in addition to the treatment plant itself

3.3.1. Vendor service capabilities

Vendor support/service capabilities are an important consideration for all types of plants. Since RO plants are much more automated than conventional plants there is the added concern of problems occurring that require specific technical knowledge of the unit itself (this could occur at any point in its operational life).

Some issues are difficult to resolve without the involvement or support of the manufacturer or their representative. As a result, the location of service staff relative to the WTP location should be an important factor in the selection of the preferred vendor.

3.3.2. Guarantees

With RO membranes, an important consideration is the vendor’s membrane guarantee outlining the product’s design life, if operated within specific operational parameters and raw water quality conditions. These terms and conditions are a key part of the contract and affect the plant’s long-term running costs.

3.3.3. Membrane supplies

Membranes in a brackish water desalination plant typically require replacement every 3–5 years of full time operation. The availability of membranes is another important consideration, as the membranes are not usually available through multiple outlets. More often, they must be sourced from the vendor. Some vendors may be able to guarantee more flexible delivery time frames, depending on how they handle warehousing for their Australian customers. This would be considered an important criterion for assessing the service capabilities of each membrane vendor if this is the preferred technology.

4. Brine handling, disposal and reuse

4.1. Background

A key issue in using desalination plants, particularly in areas some distance from the coast, is the disposal of a ‘brine’ waste product that is high in salt. The volume and concentration of salts in the brine differ, depending on the treatment process being used. For the purposes of this study, we will consider brine produced from RO desalination processes, as this is the most commonly used technology in Australia.

Traditionally, brine has been disposed of into the environment, but greater understanding of the role of salts in our ecosystems has led to problems being identified with this disposal method. The effects of discharging brine or brackish water into the environment are:

- salt build-up in receiving waters
- real and apparent toxicity of concentrated salts and trace contaminants
- potential salt build-up in soils and its impact on groundwater
- chronic and acute impacts on wildlife, livestock and agriculture.

The different methods of brine disposal range from simple evaporation, to aquaculture, to industrial reuse. Figure 4–1 below shows some of the factors to consider when choosing brine-disposal methods.

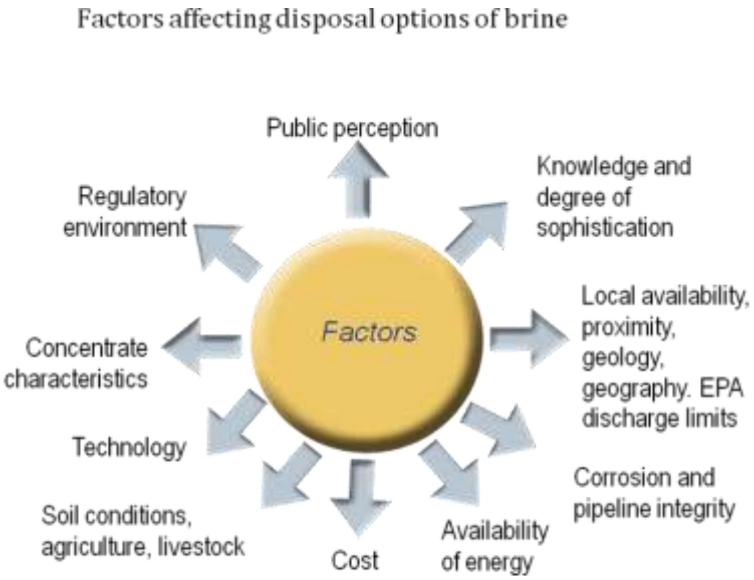


Figure 4–1: Factors affecting brine disposal options

This study has considered two broad areas for brine disposal: agricultural reuse and further processing, treatment and disposal. The two areas are discussed in the following sections.

4.2. Environmental considerations

The potential impacts of applying brine wastes to soil through crop irrigation or spray dispersal include increasing soil salinity and soil sodicity. A number of statutory requirements and guidelines address these issues.

4.2.1. Soil salinity

Salination results from:

- high levels of salt in the soils
- landscape features that allow salts to become mobile (movement of the water table)
- climatic trends that favour accumulation
- human activities such as land clearing.

Salinity from irrigation can occur over time wherever irrigation occurs, since nearly all water (even natural rainfall) contains some dissolved salts. When plants use the water, the salts remain in the soil and begin to accumulate. Since soil salinity makes it more difficult for plants to absorb soil moisture, the salts must be leached out of the plant root zone by applying additional water. This water in excess of plant needs is called the leaching fraction. Salination from irrigation water is also greatly increased by poor drainage and by using saline water to irrigate agricultural crops.

The consequences of salinity on crop and grasslands are:

- detrimental effects on plant growth and yield
- larger volumes of irrigation water required for plant growth
- damage to infrastructure (roads, bricks, corrosion of pipes and cables)
- reduction of local ground and surface water quality
- ultimately, soil erosion when crops are too strongly affected by the amount of salts.

Soil salinity can be reduced by leaching salts out of soil with excess irrigation water. In some cases where there is plenty of land and enough natural rainfall, an irrigation site can be temporarily abandoned until the salts leach from the soil.

High levels of soil salinity can be tolerated if salt-tolerant plants are grown. Sensitive crops lose their vigour in slightly saline soils, most crops are negatively affected by (moderately) saline soils, and only salinity-resistant crops thrive in severely saline soils.

4.2.2. Soil sodicity

In **saline soils**, sodium combines with chloride to form a salt. As described in the preceding section, salt in the soil reduces the availability of water to plants, reducing yield and, in high enough concentrations, can kill them.

In **sodic soils**, much of the chloride has been washed away, leaving sodium ions (sodium atoms with a positive charge) attached to tiny clay particles. As a result, the clay particles lose their tendency to stick together when wet, leading to unstable soils that may erode or become impermeable to both water and roots.

Sodic soils (with significant clay content) are likely to become waterlogged—if the soil comprises mostly sand there may be a little effect, as sand particles are relatively inert and will not stick together. This is a major concern if sodicity occurs at the surface (because water will not enter the deeper soil) or in the plant root zone (restricting the amount of air available for healthy root development).

If sodicity occurs below the root zones, its effect on crop productivity may be less apparent, but it can still cause significant problems in high rainfall areas as the sodic layer may not allow water to drain, leading to waterlogging at the surface. (However, in very dry climates this will be a minor issue).

Sodic soils erode easily.

4.2.3. Salinity/sodicity effects

Sodic soils that are also saline contain high concentrations of both sodium and sodium chloride. Such soils will usually not show symptoms of sodicity, because the sodium and chloride ions formed by the dissolved sodium chloride in the soil solution prevent the clay particles dispersing.

The amount of electrolyte required to prevent decline in soil structure and waterlogging is the 'threshold concentration'. However, this phenomenon should not generally be used to manage sodic soils, as any rainfall event (i.e. the uncontrolled application of a non-saline water source) will render the upper layers of the soil non-saline, inducing the damaging effects of soil sodicity.

Management of sodicity

Sodicity can often be treated. Most commonly, calcium-containing substances like gypsum are applied to the affected soil. Other substances are also effective, including the direct application of acid-producing chemicals such as sulfur, aluminium and iron sulfates or iron pyrite, all of which form gypsum in soils containing calcium carbonate. Gypsum is usually the cheapest and most effective treatment readily available for treating large areas.

Such additives may not always solve the problem in the long term. For example, large quantities of gypsum may be needed if the additions are to have anything more than a short-term effect. And subsoil sodicity may not be affected by the addition of gypsum at the surface unless the soils are also deep-ripped to aid penetration.

4.2.4. Statutory requirements and guidelines

The disposal of a waste product to the environment is addressed by individual state legislation. The principle involved in all legislation is that the disposal of a waste product must not downgrade the value of any resource. The resources at risk from a waste irrigation scheme are:

- surface waters
- ground waters
- soil
- nearby sensitive ecosystems.

Surface waters

The risks to surface waters are from run-off of waste product or contaminated groundwaters directly connected to surface water resources. These risks are primarily mitigated by 'buffers'. Buffers include allowing an irrigation-free zone between any irrigation area and the surface-water resource and by ensuring that soil-moisture deficits remain after an irrigation event. The latter allows natural rainfall to soak into the soil (even if it occurs soon after an irrigation event), diluting the effects of run-off or percolation.

Various state agencies provide guidelines on buffer zones, which usually vary between 30 and 50 m.

Groundwater

The risks to groundwater are reduced by ensuring that there is not enough movement of salt below the plant root zone to increase the salinity of the groundwater resource and affect its potential use. As salt must leach below the root zone (see section on soil below), the groundwater body must either be large enough so that the addition of more salt has no impact on its quality and/or constantly flowing so that the salt is gradually released to a safe end point (e.g. tidal waters or a fast-flowing river).

Various state agencies have guidelines on the minimum depth to a groundwater resource and/or the distance to a groundwater bore. With high-risk wastewaters, detailed investigations of groundwater resources below any beneficial reuse site are usually required.

Soil salinity

With regard to salt, the following principles apply:

- the irrigated plant soil system must reach an equilibrium salt concentration, otherwise salt will continue to accumulate
- at equilibrium, salt in equals salt out
- the salt concentration within the system depends on the ratio of the water volume in versus the water volume out
- the efficacy of the system depends on the salt concentration within it.

The key process is the rate of drainage below the plant root zone. If deep drainage is small then the equilibrium salt concentration in soil will be high and the soil salinity determines which species can be grown.

Statutory requirements may allow the soil to increase its salinity levels during irrigation as, in principle, once irrigation ceases the salt will ultimately leach out (however, this may present a risk to local groundwater). Some states take a simpler approach by mandating the upper level of salinity in the irrigation water (e.g. Queensland with regard to the beneficial use of coal-seam gas waters). However, the acceptable salinity of irrigation waters on a particular plant soil system is highly dependent on the prevailing climate and soil type.

Soil toxicity

Guidelines are available on the upper limits of known soil toxicants such as those provided for NSW by the former Department of Environment and Conservation, as shown in Table 4–1 below. These are used by state agencies when approving schemes involving recycled wastewaters. Unlike salt (which will ultimately leach from the soil given appropriate rainfall conditions), many of these toxicants bind to the soil permanently, rendering it unsuitable for human or animal food production.

Table 4–1: Maximum permitted concentrations of contaminants in topsoil

Contaminant	*Max. concentration in topsoil (mg/kg)*	*Contaminant*	*Max. concentration in topsoil (mg/kg)*
Arsenic	20	Zinc	200
Cadmium	1	DDT/DDD/DDE	0.5
Chromium VI	1	Aldrin	0.02
Copper	100	Dieldrin	0.02
Lead	150	Chlordane	0.02
Mercury	1	Heptachlor/hepta-chlorepoxide	0.02
Nickel	60	Lindane	0.02
Selenium	5	Hexachlorobenzene	0.02
PCBs	Non-detect		

Source: Adapted from NSW Dec. 2004

Sensitive ecosystems

If a waste product is being irrigated close to a sensitive ecosystem (such as a state park or national park) the potential impacts on the ecosystem need to be considered. These impacts could include (but not be limited to) spray drift (i.e. a drift of salt-laden waters onto a salt-sensitive plant) or the dispersal of a salt-tolerant (and usually robust) agricultural crop or turf from the brine-waste irrigation area to the natural environment.

4.3. Brine-processing technologies

4.3.1. Brine concentration

One of the biggest drawbacks of the RO membrane technology is the need to dispose of high-strength brine stream, which is four to five times more concentrated than the feed. RO product recovery for brackish water is typically 65–85% and the brine stream constitutes around 15–35% of the feedwater. In some instances, the recovery rate may be as low as 50%. Recovery rates are often lowered to increase the life of the membranes and reduce the cost of treatment.

Maintaining a high recovery rate can cause dissolved salts in the water to precipitate within the RO membrane, causing fouling. To mitigate this, pretreatment and scale inhibitors are needed to keep the low-solubility salts in solution. Moreover, in RO systems the other parameter limiting the recovery is the osmotic pressure exerted by the brine solution. With an increase in concentration of the brine solution, the osmotic pressure also increases. This, in turn, increases the driving-pressure requirements, which themselves are limited by the design of the membrane system. The increase in concentration factor with recovery is seen in Figure 4–2 below.

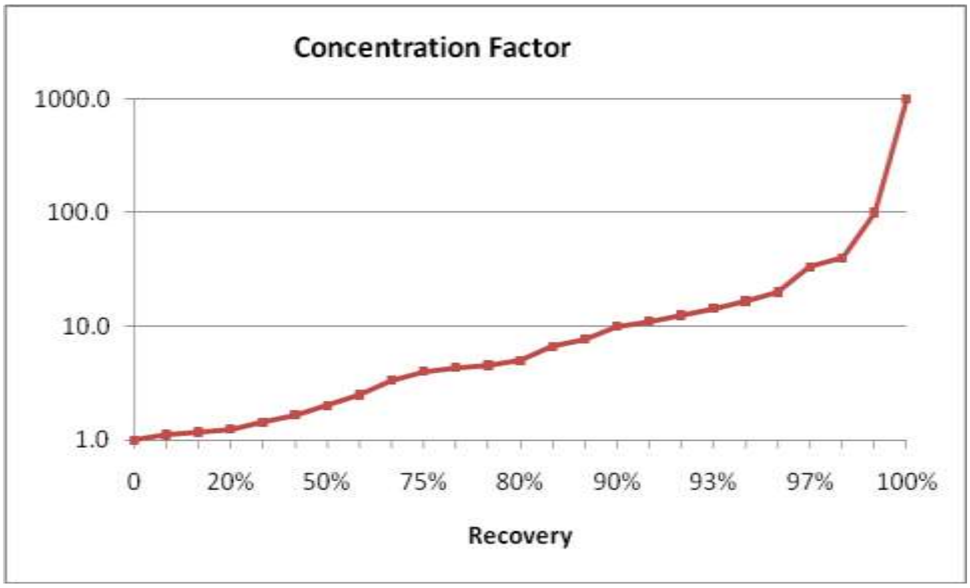


Figure 4–2: Increase in concentration with recovery rate

In addition to the volume of water being sent to waste, brine disposal becomes a challenge as part of the treatment program. High flows discharged to a small river can also create issues of poor mixing of the brine concentrate, resulting in a hypersaline layer that may harm aquatic and benthic life forms.

4.3.2. Brine disposal methods

The most common methods of brine disposal for all RO installations are shown in Figure 4–3 below.

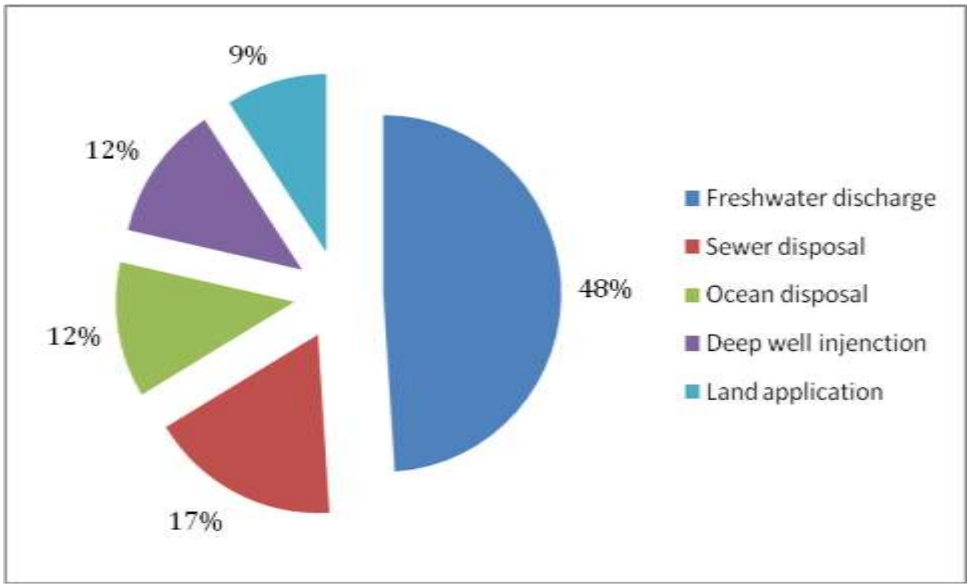


Figure 4–3: Common approaches to brine water management

In coastal plants, the brine stream can be easily discharged to the sea if the brine concentrate is diluted enough to minimise adverse effects. In inland plants, discharging to freshwater streams is problematic because of the reduced dilution effect. In South East Queensland, hundreds of small-scale plants have been approved. Individually, these plants may be miniscule, but in aggregate they may pose a significant threat to the receiving water environment[7]. Moreover, transport costs increase if there are no other means of disposal.

The most common disposal options for inland plants are discharge to the sewerage network or evaporation in ponds. Neither is sustainable in the long run, as larger quantities of brine are produced. Large evaporation ponds are expensive and do not reuse the water. Brine disposal to the sewer decreases the usable hydraulic capacity at the receiving wastewater treatment plant and is detrimental to the valuable effluent produced. Moreover, in Queensland, the Department of Environment and Natural Resources has banned evaporation ponds as a solution to brine water disposal from the coal-seam methane plants.

Brackish water management solutions need to be:

- cost effective
- energy efficient
- environmentally friendly
- implementable.

4.3.3. Brine disposal technologies

A number of brine disposal technologies are shown in the tables below and on the following pages. The tables present the key issues associated with each technology.

[7] Tripodi N, Ramsay I 2009

Table 4–2: Liquid brine disposal options

Brine concentrate disposal method	*Key Issues*
Blending with RO permeate feed	• Low capital cost • Technically easy to carry out • As long as the permeate conductivity does not increase over 1000 µS/cm for drinking water projects • If a two-pass process, then the first-pass reject is sent to the feed
Ocean/sewer	• Availability of discharge facilities with capacity • Environment habitat issues • Regulatory requirement/permits • Type of treatment available
Deep-well injection	• Land availability/seismic activity • Potential to use existing unused bores • Geologic/geohydrologic conditions • Potable water aquifers may get contaminated through leakage of wellhead due to corrosion • Need regulatory requirements/permits • Public perception/acceptance • Membrane brine concentrate compatibility • Need to condition the brine before discharge, and associated costs • Typically used for plants with capacity >4 ML/d • Uncertainty of wellhead life, which can only be estimated
Land application (spray irrigation)	• Land availability and cost of land • Can be applied on lawns, parks, golf courses • Percolation rates • Climate applicability • Salt drift • Water-quality tolerance of target vegetation to salinity • Aesthetic issues • Habitat issues if there is a large bird population • Long-term impacts on shallow groundwater

Table 4–3: Liquid concentrating and volume-reduction brine disposal options

Brine concentrate disposal method	*Key issues*
Natural treatment system—wetlands	• Low maintenance • Land availability/space requirements • Potential groundwater contamination • RO concentrate quality • Selection of appropriate vegetation/plant species • Vegetation not very effective at removing sodium chloride and sulfates
Electrodialysis (ED)/electrodialysis reversal (EDR)	• Complexity of equipment—requires trained operators • Energy power requirements • Variable transmissivity of the membrane • Cleaning and antiscalant chemicals • Produces a brine stream that requires disposal • Typical recovery rates 40–50%
Two phase RO with intermediate chemical precipitation	• Lime-soda softening • Coagulation and precipitation of salts and resulting sludge • Higher pressures required in the second-stage RO • Recovery can be as high as 95% • Footprint • Operator interaction
RO with high pH operation (HERO™)	• Two-phase RO with primary RO chemical pretreatment, ion exchange of concentrate from primary RO and high pH operation of secondary RO. • Requires significant chemical dosing • 90–95% recovery rates • More suitable for wastewater applications where organics are a problem
Vibratory shear-enhanced processing membrane system (VSEP)	• Small site footprint • Complexity of equipment—requires trained operators • Energy power requirements • Cleaning and antiscalant chemicals • Membrane replacement costs • Produces a brine stream that requires disposal
Membrane distillation	• Uses low grade heat • Largely limited to research. Commercial applications are few • Requires a heat source • Has been tried in remote locations with solar power
Mechanical evaporation—vertical-falling film brine concentrator	• Complexity of equipment • Mechanically intensive • Site specific • Capital and cost intensive • Exotic metallurgy • Height of system • Energy power requirements • >90% of water can be recovered

Table 4–4: Crystallisation brine disposal options

Brine concentrate disposal method	*Key Issues*
Evaporation ponds/mist sprays	• Land availability and cost of land • Climate applicability—limited to areas of dry, arid locations with high evaporation rates • Construction and maintenance requirements • Salt drift • Potential groundwater contamination from pond leakage—therefore require double lining with leakage-sensing probes • Aesthetic issues • Habitat issues if there is a large bird population • Disposal of crystallised salt • Excavating of salt without damaging liners
Wind-aided intensified evaporation	• Wind energy used to enhance evaporation • Small footprint compared to evaporation ponds by spraying the concentrate over vertical surfaces, thus increasing the evaporative area by a factor of 10 in comparison to evaporation ponds • Low energy costs • More suitable for climates with high natural evaporation
Forced circulation crystalliser	• Complexity of equipment • Mechanically intensive • Energy/power requirements • More suitable for power plants and other sites with a high degree of technical competence

Table 4–5: Other brine disposal options

Brine concentrate disposal method	*Key issues*
Salt production—SALPROC process	• Produces salts such as magnesium hydroxide, gypsum and calcium chloride • High capital costs • Not economically viable for most since operating and selling salts are not core business for water desalination plant operators
Aquaculture—shrimp farming	• Can offset the cost of the desalination plant
Energy production—solar ponds	• Still experimental and requires government subsidies • A 100-hectare solar-pond production cost of electricity is $0.30 /kWh which is around double the normal rate

Most of the options shown in the tables above require a high level of operator knowledge and cheap source of energy. High capital and operating costs make them unsuitable for remote locations where there is limited technical expertise.

4.3.4. Brine disposal costs

In general, the cost of desalination is determined by four factors:

- energy requirements for a chosen desalination process and energy costs
- the feedwater salinity level and water quality
- economies of scale
- operating and maintenance costs.

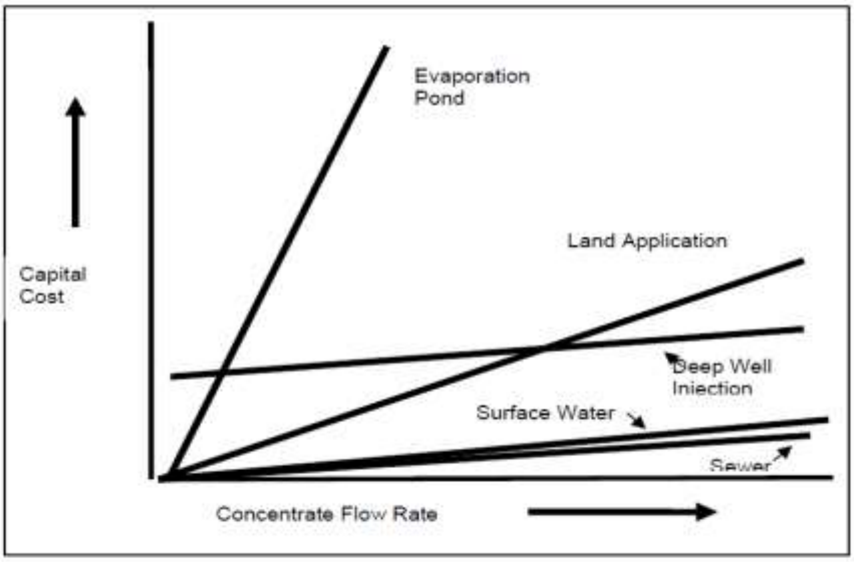
The following empirical formula can be used to evaluate the indicative cost per kL of brine.

$$P = \frac{C\,(e + i_m - dt)I_F/(1 - t)}{G}$$

where:

P – cost of brine disposal option ($/kL)
G – the water process rate (kL)
I_F – total capital cost of the project ($)
C – operation and maintenance cost ($)
t – tax rate (%)
d – depreciation rate (%)
e – capital recovery factor (%)
i_m – minimum acceptable rate of return (%)

Figure 4–4 below shows the cost of commonly available disposal options.



Source: Mickley M 2009

Figure 4–4: Relative capital costs of conventional disposal options

4.4. Agricultural brine reuse

4.4.1. Overview

Opportunities may exist for the beneficial reuse of waste brine for agricultural uses such as irrigation of salt-tolerant pastures or tree crops, hydroponics, aquaculture or as stock drinking-water.

If the brine is too salty for these purposes it can be diluted with the treated water to an acceptable level so that it can be reused. However, care is needed to prevent unintended impacts such as degradation of local ground and surface waters and/or contamination of important ecosystems, soil or crops.

The suitability of brackish waters for irrigated agriculture, including horticulture, has been the subject of a number of international, national, state and local research programs. This has led to the development of guidelines on the suitability of waters of various qualities for a range of uses.

The use of saline waters as stock drinking-water must take into account management practices such as the potential for water to evaporate in drinking troughs, thereby increasing the salinity to potentially unacceptable levels.

Similarly, while some fish species can tolerate a wide range of saline waters, aquaculture does not 'reuse' the product. Instead, it creates a wastewater that, in turn, must be disposed of. This could also be seen as an opportunity. For example, in Israel wastewater from aquaculture is reused as irrigation water.

The application of irrigation waters to crops and pastures changes the salinity of the soil. The salinity conditions in the soil primarily determine the performance of crops rather than the salinity of the irrigation water. While the salinity of irrigation water may be considered relatively constant, soil salinity will vary depending on:

- the drainage characteristics of the soil (these may change if, for example, a clay soil becomes sodic)
- the type and management of crops
- the prevailing weather
- the salinity of irrigation water as well as the type of salts in the irrigation water
- the method and frequency of irrigation .

Furthermore, at any one time soil salinity conditions will vary down the soil profile.

4.4.2. Water quality guidelines for stock-drinking

Water-quality guidelines provided by the NSW Department of Primary Industries for stock drinking-water are shown in Table 4–6 below. In using these guidelines, the likelihood that the water will evaporate in drinking-water troughs must be considered. In this case, the salinity will increase, depending on the time and prevailing weather that the water is stored in open troughs.

Table 4–6: Stock drinking-water guidelines

<table>
<tr><th>Animal</th><th>Consumption per day (L)</th><th>Desirable maximum TDS (mg/L)</th><th>Maximum TDS given other factors (mg/L)</th><th>pH</th></tr>
<tr><td colspan="2">Sheep</td><td rowspan="5">5000</td><td rowspan="5">10 000</td><td rowspan="13">6.5 – 8.5</td></tr>
<tr><td>Weaners</td><td>2–4</td></tr>
<tr><td>Grass fed adults</td><td>2–6</td></tr>
<tr><td>Saltbush</td><td>4–12</td></tr>
<tr><td>Ewes with lambs</td><td>4–10</td></tr>
<tr><td>Beef cattle</td><td>35–80</td><td>4000</td><td>5000</td></tr>
<tr><td colspan="2">Lactating cattle</td><td rowspan="4">2500</td><td rowspan="4">4000</td></tr>
<tr><td>Lactating cattle grassland</td><td>40–100</td></tr>
<tr><td>Lactating cattle saltbush</td><td>70–140</td></tr>
<tr><td>Vealers</td><td>25–50</td></tr>
<tr><td>Horses</td><td>40–50</td><td>4000</td><td>6000</td></tr>
<tr><td>Pigs</td><td></td><td>4000</td><td>6000</td></tr>
<tr><td>Poultry</td><td></td><td>2000</td><td>3000</td></tr>
</table>

Source: Adapted from NSW Department of Primary Industries.

Stock on dry pasture need more water. If saltbush is grazed stock require more low-salinity water. Animals' tolerance to salt decreases if they are in poor health. Too much salt can depress appetite and cause digestive upsets. Outside a pH range of 6.5 to 8.5 digestive upsets occur and water is usually rejected.

In addition to salinity considerations, significant concentrations of iron, magnesium, arsenic, lead, mercury, selenium and fluoride will lower livestock productivity. The appearance of blue-green algae (potentially present if water stored is open to sunlight) can be toxic to animals.

4.4.3. Water quality guidelines for aquaculture

The use of brines or brackish waters for aquaculture involves consideration of water quality parameters as described below. As noted previously, aquaculture will not reuse the brine wastes. Instead, a waste product will be generated that, in turn, must be disposed of sustainably. In Australia, this has necessitated locating aquaculture enterprises near large saline water bodies such as the ocean.

Salinity and temperature

Table 4–7 below was compiled to help fish farmers determine the salinity of their water and provide guidelines for the salt tolerance of species commonly aquacultured in Western Australia.

Table 4–7: Salinity and temperature guidelines for types of commercial aquaculture species

Species	*Salinity TDS mg/L (optimum range)*	*Temperature °C (optimum range)*
Artemia *Artemia salina*	31 300–340 000 (150 000)	6–35 (25–30)
Silver perch *Bidyanus bidyanus*	0–12 000	
Barramundi *Lates calcarifer*	0–40 000 (20 000–35 000)	16–35 (26–30)
Tropical black bream *Acanthopagrus berda*	<3000–40 000 (10 000–35 000)	12–36 (21–32)
Black bream *Acanthopagrus butcheri*	8000–35 000	8 –33 (24)
Grouper *Epinephelus coioides*	15 000–45 500	22–31 (24–28)
Marron *Cherax tenuimanus*	0–15 000 (<6000)	4–30 (20–24)
Milkfish *Chanos chanos*	500–>100 000	10–40 (28–32)
Sea mullet *Mugil cephalus*	0–75 000 (0–30 000)	3–35 (17–25)
Giant tiger prawn *Penaeus monodon*	<2000–<75 000	7–42 (27–34)
Rainbow trout *Oncorhynchus mykiss*	0–35 000	2–29 (10–22)
Greenback flounder *Pseudorhombus taparina*	0–40 000	8–25

Source: Adapted from Australian Water Resources Council 1988. Silver perch data from Guo R et al. 1995.

Alkalinity and hardness

Alkalinity refers to the amount of substances that release hydroxyl ions (OH–) when dissolved in water. These ions buffer the water against sudden changes in pH by absorbing hydrogen ions when the water is acid and releasing them when it becomes basic. Waters of low alkalinity (<20 mg/l) are poorly buffered and the removal of CO_2 during photosynthesis (i.e. if algae are present) results in rapidly rising pH. Waters with greater than 20 mg/l alkalinity have greater buffering capacity. Hardness is the concentration of metal ions (primarily calcium and magnesium) expressed in mg/l of equivalent calcium carbonate. Waters are often categorised according to degrees of hardness as follows:

- 0–75 mg/L—soft
- 75–150 mg/L—moderately hard
- 150–300 mg/L—hard
- over 300 mg/L—very hard

Desirable levels for fish culture generally fall within the range of 20–300 mg/L. If total alkalinity and total hardness are too low they may be raised by liming. However, there is no practical way to decrease alkalinity and hardness when they are above desirable levels. As a general rule, the most productive waters for fish culture have a hardness and alkalinity of about the same magnitude. The increased production results from the likelihood of higher concentrations of phosphorus and other essential elements that increase along with hardness and alkalinity.

4.4.4. Water quality guidelines for crops

Irrigation water-quality guidelines published by the Australian and New Zealand Environment Conservation Council act as a general guide for applying saline irrigation waters for relatively salt-tolerant crops. The guidelines do not consider the salt load in the soil, which is discussed in a later section. The tables below show the guidelines for salt-tolerant plants and upper limits for some heavy metals and elements.

Table 4–8: Irrigation water-quality guidelines for relatively salt tolerant plants

Parameter	*Guideline in irrigation water*				*Comment*
	Moderately tolerant		*Very tolerant*		
Salinity	3000 µS/cm–5000 µS/cm	Zucchini, beets, olive, dates, wheat, millet, sunflower, oats, kikuyu, fescue.	4000 µS/cm–7000 µS/cm	Barley, canola, cotton, Japanese millet, couch, Rhodes grass, buffalo, rye grass, phalaris, berseem clover puccinellia.	Some salts are plant nutrients (phosphates and nitrates). When brines have a significant concentration of nutrients the contribution of these to salinity can be discounted.
Alkalinity					High carbonates cause calcium and magnesium ions to form insoluble minerals, leaving sodium as the dominant ion in solution. Alkaline water could intensify sodic soil.
pH	6.5–8.5	Most crops and plants.	>8.5	Salt-tolerant plants usually grown in high pH soils.	
Chloride—leaf damage	355 mg/L–710 mg/L	Alfalfa, barley, corn, cucumber.	>710 mg/L	Cauliflower, cotton, safflower, sesame, sorghum, sugar beet, sunflower.	Drip or subsurface irrigation/irriga-tion at night will minimise risks.
Chloride—in water	710 mg/L–960 mg/L	Grapes.			
Sodium (SAR)	18–46	Clover, oats, tall fescue, rice.	46–102	Wheat, Lucerne, barley, tomatoes, beets, most grasses.	
Boron	2.0 mg/L–4.0 mg/L	Lettuce, cabbage, celery, turnip, bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash.	4.0 mg/L–6.0 mg/L	Sorghum, tomato, alfalfa, parsley, beets. Asparagus (6.0–15).	

Source: ANZECC 1992

Table 4–9: Upper limits for some heavy metals and elements in irrigation waters

Element	*Guideline (mg/L)*	*Comment*	*Element*	*Guideline (mg/L)*	*Comment*
Aluminium	5	Toxic in acid soils.	**Lead**	0.2	
Arsenic	0.1		**Lithium**	2.5	Citrus 0.075 mg/L.
Beryllium	0.1		**Manganese**	2	Acid soil limit to 0.2 mg/L.
Boron	0.5-6	See table 2.2.	**Mercury**	0.002	
Cadmium	0.01	Higher toxicity in acid soil.	**Molybdenum**	0.01	
Chromium	1.0	Limit chromium V1 to 0.1 mg/L.	**Nickel**	0.2	
Cobalt	0.05		**Selenium**	0.02	
Copper	0.2		**Uranium**	0.01	
Fluoride	1		**Vanadium**	0.1	
			Zinc	2	1 mg/L in sandy soil below pH 6.

Source: ANZECC 1992

4.4.5. Crop species and management for saline areas

Some grass and shrub species have been found suitable for growing in saline areas. A detailed list and description of these species is provided in Appendix B.

4.4.6. Other brine reuse options untested in Australia

Aquaculture in combination with agriculture

As shown in section 4.4.3, there is a fish species to suit any level of water salinity. However, fish-farming does not recycle brine wastes—it simply reuses the brine and creates a new waste product, probably containing increased concentrations of plant nutrients such as nitrogen and phosphorus. This waste product, with appropriate dilution, could then potentially be recycled onto agricultural land. The Israeli Consulate website advises that at Kadesh Barnea, a small moshav (cooperative farm settlement) on the Egyptian border, beef cattle are fed fodder grown with brackish water recycled from 'bubbles'—covered tanks for intensive fish cultivation. Similarly, at Kibbutz Revivim, water from fish tanks nourishes alfalfa for ostriches.

Irrigation with brackish groundwater in hydroponics

The use of brackish water in hydroponic systems for commercial crops has been practised in Israel, the Canary Islands, Sicily and North African countries for many years. When hydroponic water is saline, disturbances in plant development result primarily from nutritional disorders and hampered root environmental conditions rather than the salinity of the water. Hence there is potential for irrigating with a ‘balanced’ nutrient solution in highly saline water sources (TDS of 2500 to 3500 mg/L) in gravel and coarse sand culture method.

Studies undertaken in Avara, near the Dead Sea in Israel, suggest that higher nitrate and potassium levels are recommended and that phosphorus and iron levels should be lowered and added more frequently to reduce precipitation of ions.

4.5. Impacts of climate, soil drainage conditions and land management on soil salinity

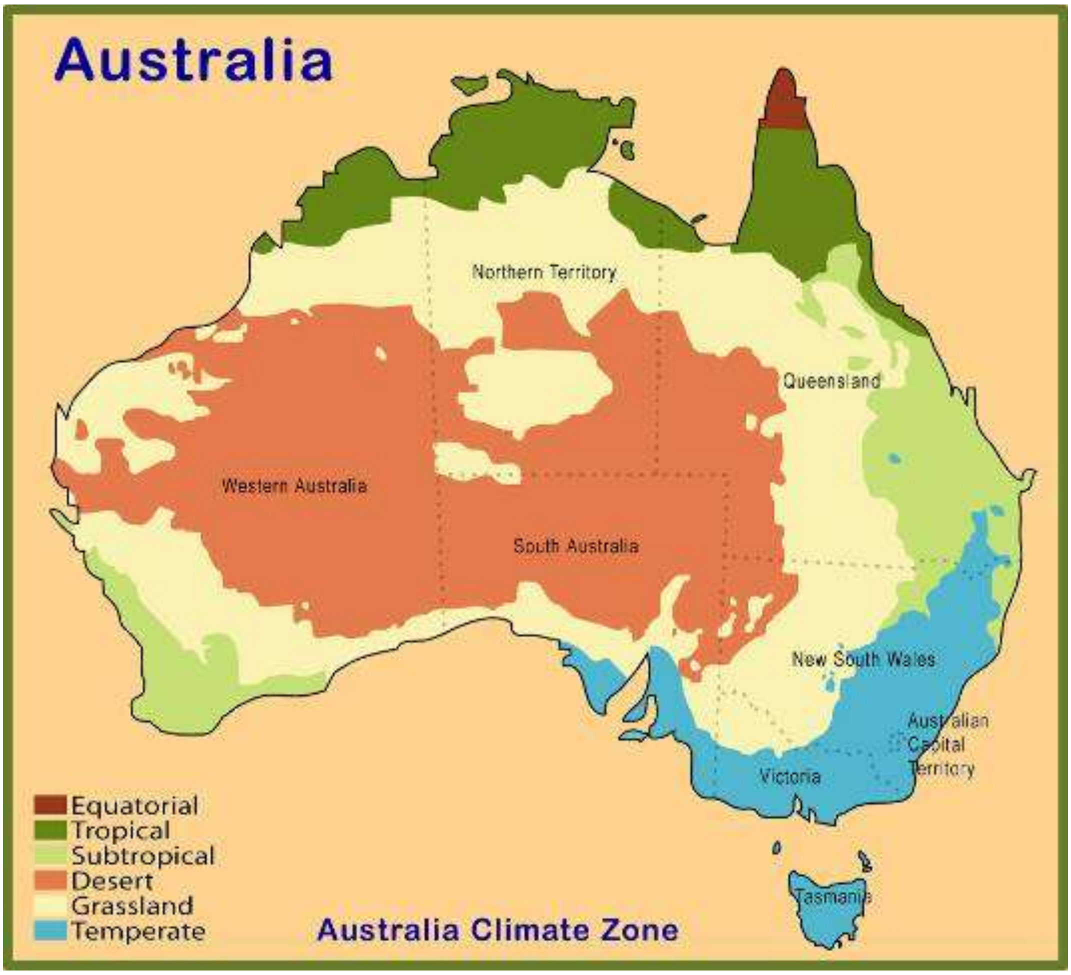
4.5.1. Background

Irrigation with brackish water

Continuous irrigation of agricultural land with brackish water can have a negative effect on the soil conditions that, over time, can impair the ability of the land to produce crops. This is true whether the source of the water is directly from a brackish bore, brine waste from a desalination process, or a blend of the two.

Climatic zones of Australia

Land and irrigation management relies heavily on the prevailing climatic zone of the region. Figure 4–5 below shows the various climatic zones within Australia, defined by a number of climatic parameters, but particularly rainfall and temperature.



Source: Adapted from Australian Bureau of Meteorology 1990.

Figure 4–5: Climatic zones of Australia

4.5.2. Salt balances

Four locations in Australia were chosen to carry out water and salt balances to show the effects of irrigation, using brackish water in a range of climates. Desert and low-rainfall locations were chosen, as these typically represent areas where brackish groundwater is more commonly used as a water supply.

A combination of water balance (using the H2OB model, developed by Dr John Murtagh of LanSci Management P/L), and salt budgets were used to estimate the soil salinity following irrigation using brine wastes of various salinities, as measured by the conductivity of the water.

- The water balances were used to estimate the deep drainage under a number of contrasting climates.
- The rates of deep drainage were then applied to salt budgets to estimate the likely soil salinity following irrigation with wastewater of varying salinities.

The water balances used long-term (1940–2010) daily rainfall records at the four locations to quantify the deep drainage in the various locations of Australia. Two crop types were investigated: a grass-based pasture with a moderate rate of water use and a tree crop that represented a crop with a high rate of water use. Two soil types were investigated, including a deep, well-drained soil and one with a heavy clay subsoil that restricted drainage.

The salt budgets were undertaken for irrigation water with conductivity of 1000, 1500, 2000, 3000 and 4000 µS/cm.

Locations

The four locations chosen for the salt balance were Dalby (Qld), Bourke (NSW), Flemington (Vic.) and Coober Pedy (SA). The table below presents the relevant properties of the four locations.

Table 4–10: Rainfall and potential evapotranspiration at four locations in Australia

Location	*Rainfall*			*Potential evapotranspiration*	*Climate zone (see Figure 4–5)*
	Mean (mm/a)	*Median (mm/a)*	*1/10-dry year (mm/a)*		
Dalby	678	673	472	1640	Subtropical
Bourke	361	336	186	1485	Grassland (hot dry summer, cold winter)
Flemington	644	630	465	943	Temperate
Coober Pedy	161	143	59	2739	Desert

Source: Australian Bureau of Meteorology

All locations used in the analyses below have average annual rainfalls of less than 700 mm. A relatively low-rainfall environment often indicates that access to rain-fed water supplies is limited and the likelihood of reliable long-term, low-salt river and bore water sources is reduced compared to areas with much greater than 700 mm of rain. Where the potential evapotranspiration is greater (e.g. in the northern hotter locations and desert environments) the situation is usually more severe.

In addition to the four specific salt balances, a general risk assessment for irrigation with brackish water in various climatic zones is included in Appendix A.

Assumptions

The balances used an irrigation strategy that applied 20 mm of irrigation water when the soil dried to a 40 mm soil-water deficit. This meant that irrigation was applied only when the soil was dry enough to absorb all the applied water. Because of the very dry conditions and the extreme evaporative demand at Coober Pedy, it was necessary to modify that approach by limiting the annual irrigation volume to 10 ML/ha/yr to avoid applying very large volumes of water, and hence salt.

The irrigation strategy represented a reasonable level of watering that would not, in its own right, significantly lower crop yields. It should be noted that applying less water per hectare **may** reduce soil salinity (and consequently increase the range of potential plants that could be grown), but this is likely to reduce potential crop yields. Soil salinity is estimated as the mean annual water uptake-weighted, root-zone salinity. The salinity measurement was the electrical conductivity of a saturated extract (ECe or ECse). The weighting procedure gave more emphasis to the salinity at shallow soil depths where plants absorb most water.

Because the soil salinity at any one time will vary depending on preceding rainfall, the models used calculated median conditions and those that would occur in the one-in-10 dry year. The values were calculated on the assumption that the equilibrium soil salinity would, with changing rainfall, be reached within a year (i.e. the modelled soil salinity effects occurred within a space of one year and were not influenced by the soil conditions in the previous year, which could have been very wet or very dry). For purposes of this study, the two values can be taken to indicate:

- the average soil condition over all years
- the one-in-10 dry year values that show the likely soil salinity in very dry years, or if there were a string of drier-than-average years in a row.

Because there is a high risk that any irrigation scheme may begin with (or encounter) a string of years drier than the median year, the dry year results shown below should be the main guide. However, if a string of years that were drier than the one-in-10 years occurred, then the soil salinities shown in the following table could be higher than predicted in this report. Median results are also given for the Dalby environment to show the 'average' soil condition over all years.

Results

The tables below use different colours to indicate the range of species that can tolerate the expected soil salinity and where toleration was defined as less than a 25% reduction in plant growth due to salinity. The key to the coloured bars is given below.

Table 4–11: Colour codes for salinity tolerances of various crops

Species that can tolerate soil salinity below the upper threshold	*Upper soil salinity threshold (µS/cm)*	*Risk table colour*
All species	1700	
Moderately sensitive and above	5400	
Moderately tolerant and above	9000	
Tolerant and above	13 000	
None or extremely tolerant species		

The threshold values are the means within the tolerance bands for each group of species, as given in the *National Water Quality Management Strategy guidelines (2000)*. It is emphasised that the results give a general depiction and that there is some variation around the thresholds for individual species. For instance, some sensitive species can tolerate higher soil salinity than 1700 µS/cm, and others cannot.

4.5.3. Dalby environment

The Dalby results represent a subtropical environment with a low average rainfall that has a summer-dominant distribution. The potential evapotranspiration is 1640 mm/yr. With irrigation that keeps the soil damp, the rainfall provides some deep drainage and hence some leaching of salt. This limits the build-up of soil salinity.

The tables below present the types of species, indicated by their colour code, which can tolerate irrigation with water of varying salinity in different environments. The species were classified whether they were high or medium water users, and whether they were growing on well- or poorly-drained soil. The first table applied to median wetness, whereas the other tables applied to dry conditions.

Table 4–12: Range of species that can tolerate irrigation with water of varying salinity with median wetness in the Dalby environment

Soil	*Plant water use*	*Conductivity of irrigation water (µS/cm)*				
		1000	*1500*	*2000*	*3000*	*4000*
Well-drained	Medium					
	High					
Poorly drained	Medium					
	High					

Salt accumulation was least with the medium water-use species on well-drained soil. Under these conditions, water with a salinity of 1000 µS/cm could be used on all species suited to the climatic conditions of Dalby. Even with salinity up to 3000 µS/cm most plants could be grown, except for those species that are highly sensitive.

However, with high water-use species on poorly drained soil, none of the tested conductivity concentrations could be used on the highly sensitive species, and water with a salinity of 4000 µS/cm was generally unsuitable for any species.

Under some circumstances, a crop can be overwatered to induce deep drainage that will remove some salt from the upper soil layers. However, that approach is not recommended when the irrigation water is quite saline in part because the additional salt may impact elsewhere (e.g. move downslope from the irrigation site, creating a saline outbreak).

Table 4–13: Range of species that can tolerate irrigation with water of varying salinity under dry conditions in the Dalby environment

Soil	*Plant water-use*	*Conductivity of irrigation water (µS/cm)*				
		1000	*1500*	*2000*	*3000*	*4000*
Well-drained	Medium					
	High					
Poorly drained	Medium					
	High					

Overall irrigation water with a lower salinity is required during drier-than-average periods. For example, under median rainfall conditions water with salinity of 3000 µS/cm could be used on medium water-use species on well-drained soil. However, under dry conditions the acceptable limit was 2000 µS/cm. At Dalby, it may be possible to use brine waste with salinity, even as high as 4000 µS/cm, provided very salt-tolerant species with only a ‘medium’ water requirement are used.

4.5.4. Bourke environment

The Bourke results represent a subtropical environment with an arid rainfall that has a slight summer-dominant distribution. The rainfall is only about 60% of Dalby's rainfall, but the potential evapotranspiration is 90% of Dalby's.

Table 4–14: Range of species that can tolerate irrigation with water of varying salinity under dry conditions in the Bourke environment

Soil	*Plant water-use*	*Conductivity of irrigation water (µS/cm)*				
		1000	*1500*	*2000*	*3000*	*4000*
Well-rained	Medium					
	High					
Poorly drained	Medium					
	High					

Table 4–14 above shows that under drier than average conditions much of the applied salt accumulates within the root zone. The resultant high soil salinity severely restricts the species that can be grown. Moderately tolerant species could be grown with water salinity of 1000 µS/cm. Only tolerant species were suited when water salinity was between 1000 µS/cm and 2000 µS/cm. Water with salinity of 3000 µS/cm or more was considered unsuitable for full irrigation. In Bourke, it is likely that irrigation application rates would need to be reduced and/or the brine diluted to between 1000 and 2000 µS/cm.

4.5.5. Flemington environment

The Flemington results represent a temperate environment with a low rainfall that is reasonably evenly distributed over the year. The rainfall is only a little more than that received at Dalby. The potential evapotranspiration is 943 mm/yr, less than 60% of Dalby's.

Temperate districts differ from the subtropical areas in that they have lower rates of evapotranspiration during the cooler months and more even distribution of rainfall throughout the year. As a result, more deep drainage is likely, subject of course to rainfall patterns.

Table 4–15: Range of species that can tolerate irrigation with water of varying salinity under dry conditions in the Flemington environment

Soil	*Plant water use*	*Conductivity of irrigation water (µS/cm)*				
		1000	*1500*	*2000*	*3000*	*4000*
Well-drained	Medium					
	High					
Poorly drained	Medium					
	High					

Table 4–15 above shows that more salt-sensitive species can be grown at Flemington with similar water salinity to Dalby's or Bourke's. Salt-tolerant species can be grown even with water with an EC of 4000 µS/cm.

4.5.6. Coober Pedy environment

The Coober Pedy results represent a temperate environment with an arid rainfall that is reasonably evenly distributed over the year. The mean potential evaporation rate of 2739 mm/yr is exceptionally high.

In undertaking the salt modelling, the irrigation volume was restricted to 10 ML/ha/yr, otherwise too much salt was applied even with water at a relatively low salinity.

Table 4–16: Range of species that can tolerate irrigation with water of varying salinity under dry conditions in the Coober Pedy environment

Soil	*Plant water-use*	*Conductivity of irrigation water (µS/cm)*				
		1000	*1500*	*2000*	*3000*	*4000*
Well-drained	Medium					
	High					
Poorly drained	Medium					
	High					

Because of the very dry climate, there was almost no deep drainage except in unusually wet years. In dry years, most of the applied salt accumulated in the root zone, resulting in high levels of soil salinity. The only acceptable salinity in irrigation water was of 1000 µS/cm, and even at that concentration only salt-tolerant plants would grow at acceptable rates.

5. Case studies: Brackish groundwater as a new supply source

Wowan in Queensland and Yuelamu in the Northern Territory are two small towns looking to upgrade their water supplies to improve both quality and security. Both towns have carried out initial water supply investigations, which identified brackish groundwater desalination as the preferred source of water. Both towns will be looking to procure and commission new WTPs in the near future.

The case studies below describe the process each town went through to reach the decision to pursue brackish water desalination.

5.1. Case study 1: Wowan, Qld

5.1.1. Background

Location

The town of Wowan is located in Queensland, in the Banana Shire. It is accessed by the Leichhardt Highway and is about 70 km north of Biloela, the council's administration centre. Wowan is about 90 km south of the city of Rockhampton, which is the closest regional airport. The shire is located in an area known as the Capricorn Coast Hinterland.

Coal mining, beef production, power generation, dryland cropping and irrigation cropping such as lucerne and cotton are the shire's major industries. Average rainfall is around 720 mm, with November through to February usually the wettest months.

Demographics

Wowan had a population of 338 at the time of the 2006 Census, of whom 3.8% were Indigenous and 94% were Australian citizens. About 50% were working-age (15 or older) and the unemployment rate was 4.8%.

Sheep, beef cattle and grain farming employed about one-third of the population, followed by education (6%) and coal mining (5%). The median household income was $579/wk.

5.1.2. Water supply

Overview

Water supplies in the Callide Valley, where Wowan is located, are generally considered to be overallocated. Groundwater levels around Wowan have been at historic low levels. There is currently a moratorium on establishing new bores in the valley.

Studies suggest local groundwater will continue to be the most cost-effective and least energy-intensive method of supplying water to the town as long pipelines would be required to connect Wowan to larger potable water supplies, many of which are already running at or are near capacity.

Wowan’s existing water supply consists of groundwater extraction, and chlorination before being pumped to the town’s storage tank. Town water is not usually consumed and rainwater tanks are the preferred supply for drinking water.

Banana Shire is investigating the feasibility of building a new RO desalination WTP to provide a robust, potable water supply for the town.

Water usage

The current daily unit consumption is around 300 L per person, which is affected by water restrictions. The present groundwater allocation is 100 ML/a, which can be cut during dry years; however, the current supply is considered reliable (including during dry years up to 2009 level).

Water quality

The groundwater source has a number of water quality parameters above the ADWG—high conductivity, chloride, sodium, sulfate, TDS and hardness. Quality is otherwise good, with low turbidity and colour and low dissolved metals.

The average TDS for Wowan is around 2000 mg/L, with a sodium level of around 200 mg/L and chloride and sulfate levels of 700 and 600 mg/L respectively.

Total hardness averages between 1300 and 1350 mg/L as $CaCO_3$, which significantly exceeds the ADWG of 200 mg/L.

Average pH is 6.8 to 7.4 with an alkalinity of around 200 mg/L, which is consistent with high alkalinity and hardness for bore water.

5.1.3. Water treatment plant

There is currently no WTP serving Wowan, with chlorine disinfection the only form of treatment. A 2010 planning report commissioned by the shire council investigated several supply options, of which a full-scale WTP was one option considered. Specific process units have only been estimated at this stage. The table below provides an overview based on available water quality data, of what processes would be required.

Table 5–1: Indicative WTP components

Process component	*Description*
Pre-oxidation	Aeration or prechlorination used for oxidation of iron and manganese and removal of any volatiles.
Filtration using mixed media	A media filter would be used to ensure removal of solids, including iron hydroxide, before the RO membranes. The existing systems should be assessed for suitability. If prechlorination is used, granular-activated carbon or sodium bisulfite dosing is also required to protect the RO membranes from chlorine.
RO system	The RO feedwater is pretreated by cartridge filters. Membrane elements are used for RO.
Cleaning system	This includes regular backwashing for the mixed-media filters and occasional acid/scale inhibitor cleaning of the RO unit.
Chlorination system	Disinfection and maintenance of correct chlorine residual to maintain water quality.
Brine disposal	Not yet investigated.

5.1.4. Costs

Capital costs

The costs of the WTP component alone for a 10 kL/h (approximately 0.25 ML/d) RO WTP for Wowan were estimated as shown in the table below.

Table 5–2: Capital cost estimate for a 10 kL/h RO WTP at Wowan

Component	*Cost*
Pre-oxidation system (if required)	$20 000
Raw water feed pumps	$10 000
Filtration system	$30 000
Control system, including programmable logic controller	$85 000
Chemical dosing systems	$30 000
RO feed pumps	$15 000
10 kL/h RO unit	$100 000
Permeate tank and treated water pumps	$10 000
Total treatment components	**$300 000**
15% contingency	**$45 000**
Subtotal	**$345 000**
Engineering—investigation, design and specification 15%	**$50 000**
Project management 10%	**$35 000**
Total	**$430 000**

The RO plant could require additional site works that have not been included in the cost estimate at this stage. They would usually be addressed during the concept-design phase and include:

- bores, pumps and delivery pipework
- connecting pipework to reticulation and storage tanks

- access road to the WTP site
- concrete slab
- air conditioner containers or prefabricated shed to house WTP
- site amenities
- power supply to site
- telemetry off site
- wastestream management
- modifications to existing chlorination plant
- perimeter security fence
- Contingency, engineering and project management on these items

The cost estimate developed is for the process technology only, for comparison with other processes. For a more detailed cost estimate of a full WTP based on this technology, refer to Chapter eight.

Operating costs

Operating costs shown in the table below were provided to the council as an indication rather than accurate cost information.

Table 5–3: Annual operating costs for a 10 kL/h RO WTP at Wowan

Component	*Cost*
Operator/maintenance based on 50% of an operator (based on $40 000 a year plus 50% on costs)	$30 000
Antiscalant and other chemicals	$5000
WTP power-use at 12 cents/kWh	$10 000
Maintenance (including membrane replacements and parts)	$10 000
Evaporation pan maintenance/salt disposal	$5000
Indicative annual cost ($/a)	**$60 000**

5.1.5. Discussion

The 2010 planning report commissioned by the council concluded that major external funding would be required to pursue advanced treatment options such as desalination because of the Wowan community's limited financial capability. Without funding, the present system of rainwater tanks was seen as the only option for the town. The report recommended that the council canvass the community to determine the level of service and water rates acceptable to it.

In the meantime, the report recommends continuing discussions with the Queensland Department of Environment and Resource Management, with a view to securing a 100% allocation for urban water supplies within the shire for all but the most severe dry periods. It also recommends implementing an effective water management plan (including leak detection and waste prevention) to strengthen its case with the department.

With groundwater seen as the only viable source of water in the short term, the report advises the council to take an interest in all land for sale with water allocations (provided it is near existing water supplies). To ensure groundwater remains a long-term source of supply, the report also advises the council to secure a bore with a paper allocation of around double the supply required, since reallocation of groundwater is likely to occur in the future because of overallocation in the area.

Since rainwater tanks provide most of the water used for human consumption in Wowan, the report advises a survey of rainwater tanks to assess any health risk and their condition and collection efficiency. Information on tank size, roof area and the number of occupants could also be collected at this time to allow the council to better estimate reliable yields. Upgrading or replacing old tanks, possibly with council-funded assistance, may be an effective, quick, low-cost option to a full-scale WTP.

5.2. Case study 2: Yuelamu, NT

Figure 5–1: Yuelamu Aboriginal Community—raw water tank

5.2.1. Background

Location

Yuelamu is an Aboriginal community in the Northern Territory, about 300 km north-west of Alice Springs. It is located on the Tanami Track, which runs from the Stuart Highway to Halls Creek in Western Australia. The long-term mean annual rainfall is 361 mm, with over half falling in the summer. There can be significant annual variation, with extended periods of low rainfall lasting many years.

The community is administered by a community council, which oversees local services and is part of the greater Central District Shire Council. The town has a number of community and government services and a small shop. Alice Springs is the nearest major centre.

Demographics

The town is entirely of Aboriginal heritage, the majority of residents identifying with the Anmatjere and Walpiri language groups.

The town's population is about 300, with over 70% under the age of 30. Many residents work within the community in service delivery and construction/maintenance. Sport, particularly Australian Rules, is popular, with a local team participating in regional competitions.

5.2.2. Water supply

Overview

Water is supplied to Yuelamu from a local dam. The water quality in the dam is good when the level is high, but when it drops, as it often does because of low and inconsistent rainfall, water cannot be supplied to the town. Residents are then supplied with bore water for non-potable uses and bottled water for drinking.

The NT's Power and Water Corporation is responsible for providing water supply services to Aboriginal communities. Yuelamu was identified as one of three priority communities and is being investigated for the building of a WTP supplied by local groundwater.

Building a new treatment plant at Yuelamu will have two major benefits. First, the town will have a stable and secure water supply. It has previously relied on intermittent rainfall and surface water collection. Second, water meeting the ADWG will be provided at all times from the domestic supply.

Water quantity

To limit the cost of water treatment and brine disposal, the Power and Water Corporation plans to incorporate water-saving measures into the new water supply system. Dual reticulation will be installed, with treated water provided for indoor potable use only and untreated groundwater for external use and toilet flushing. The corporation will also implement a community water-savings campaign to minimise overall groundwater extraction. Alternative sources of water will be sought for community uses such as sport and schoolfields watering.

Water quality

Groundwater has traditionally not been used as a water source at Yuelamu, as it exceeds AGWD levels for a number of parameters. Typical water quality is shown in the table below.

Table 5–4: Water quality vs. ADWG limits

Parameter	*Units*	*Value*	*ADWG*
Uranium	mg/L	0.2	<0.02
Fluoride	mg/L	4.5	<1.5
Nitrate	mg/L	190	<50
Hardness	mg/L	380	<200
Sodium	mg/L	550	<180
TDS	mg/L	2200	<500
Chloride	mg/L	560	<200
Sulfate	mg/L	370	<250
Silica	mg/L	60	–

With appropriate treatment, groundwater could be a suitable supply option.

5.2.3. Water treatment plant

Treatment technology

The new WTP is now being designed, with various processes being investigated for their suitability. The water quality provides a number of challenges that limit the available technologies.

As the salinity is too high for direct water consumption, a desalination process is required. Traditional membrane RO is unlikely to be effective in this case, as the high silica content of the water would cause rapid fouling of the membranes. For this reason, RO at high pH, such as HERO™, and electrodialysis reversal technologies may be considered.

The level of fluoride in the water is high enough to pose a health risk, and so may require additional treatment, depending on the desalination process chosen. Activated alumina could be used as an additional treatment step for this purpose.

Brine disposal

The existing sewerage system at Yuelamu uses large oxidation ponds for effluent disposal. The concept study found that the ponds were large enough to handle the increased inflow from the desalination plant waste, allowing brine to be discharged to the sewer. An advantage of using more advanced treatment methods, as previously discussed, is that the recovery of the processes is higher, leading to lower volumes of brine to be disposed of.

The Power and Water Corporation will monitor the operation of the ponds and sewage treatment system and may consider building evaporation ponds for brine waste, if required.

Plant monitoring and control

Because of the community's remote location and the large area of the corporation's operations, the corporation will require remote monitoring of the treatment plants by the supplier in the construction contract. The supplier will provide operational support to the corporation's staff, who will visit the plant regularly for basic checks and chemical refills.

The supplier will also be asked to provide an ongoing contract to carry out regular maintenance, instrument calibrations and any major work. The corporation has some experience with RO treatment but, as it has never operated an advanced treatment plant in a remote community, it will be relying on the supplier for operational support, ongoing advice and training.

5.2.4. Costs

As only order-of-cost estimates have been produced at this stage of the investigation, they cannot be presented in this report.

Power and Water Corporation provides water to Aboriginal communities as an essential service and does not charge residents for its use. Government agencies and their employees, and local businesses, are charged a set rate for water supply.

The cost for the new plants will be fully funded by the NT Government and will not result in an increase in water charges for paying users.

6. Case studies: Operating and maintaining a small desalination plant

Yalata in South Australia and North Star in NSW are small towns that have been operating brackish groundwater RO desalination treatment plants since about 2005. Both plants are maintained under contract from the original supplier.

The case studies below provide an overview of the WTPs, their integration with the town water supply systems and details of operations and maintenance practices.

6.1. Case study 3: Yalata, SA

Figure 6–1: Entrance to Yalata Aboriginal Lands

6.1.1. Background

Location

Yalata is an isolated Aboriginal community in South Australia. It is located on the Eyre highway, about 670 km west of Port Augusta, 280 km east of the Western Australian border. The highway is the major transport route between Adelaide and Perth.

The nearest services to the town are at a small service station/general store 50 km drive east. The nearest town, Ceduna, is a two-hour drive east. Ceduna is serviced by an airport, with Rex Air running daily commercial passenger services.

Demographics

Yalata Aboriginal Lands is a 458 000 ha area managed by Yalata Council, a recognised Aboriginal council. The one residential locality, known as Yalata, has some social and community services, including a health centre, school, community hall and swimming pool. The community has lived there since 1985.

The average population is estimated to be around 250, reducing to fewer than 100 in summer when residents leave the community for some time. The town's entire population is of Aboriginal descent, most being Anangu people originally from central South Australia.

There is little local industry or employment and most of the employed residents work in the community itself. A roadhouse and caravan park operated in the past have since closed.

Water supply

Annual rainfall in Yalata is quite low and there are no permanent surface water supplies in the region. Water has been supplied from bores located a few kilometres out of town since the establishment of the community. The bore water is too salty for direct consumption and an RO desalination plant was installed for local use. The ageing plant was replaced in 2005.

Water quality

Raw water for the treatment plant is drawn from three bores about 2 km from the community. The water is brackish with an electrical conductivity of around 13 000 µS/cm.

6.1.2. Water supply

Overview

The existing water supply scheme has been in operation since about 1985 and upgraded, but the still operates in the same way. The town uses a dual reticulation system to minimise the water requiring treatment.

Raw water from bores is pumped to raw-water tanks uphill from the town. Water for indoor drinking gravitates to the WTP and clear water is stored and disinfected with ultraviolet (UV) before entering the reticulation. Raw water gravitates directly to houses and is plumbed to toilets. There is no exterior use. The community council also uses raw water to water grounds.

The council operates the supply system but responsibility for the plant lies with SA Water, the agency responsible for supplying water to Aboriginal communities in South Australia.

Figure 6–2: Yalata raw water storage tanks

Water source

Raw water for the treatment plant is drawn from three bores located 2 km out of town. The water is brackish, with an electrical conductivity of around 13 000 µS/cm. Ongoing testing of the bore water salinity has found no increase in electrical conductivity since pumping began in 1985.

The bores are 40 m deep, drawing water from an aquifer above the Great Artesian Basin. The water is generally of good quality, with no concerning levels of metals or minerals.

6.1.3. Water treatment plant

Process description

The water treatment works consist of a single process line, with RO desalination and UV treatment, as shown in the diagram below.

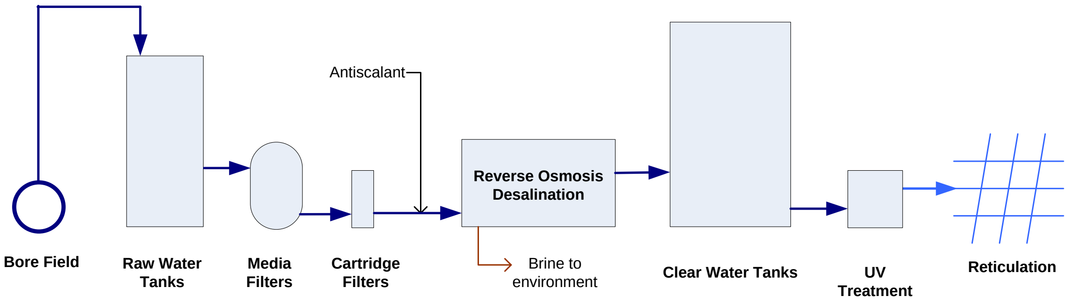


Figure 6–3: Process flow diagram of the water treatment process at Yalata

Raw water from the raw-water tanks gravitates to pressure sand-media filters, followed by cartage filters to remove any solids. Water is dosed with antiscalant and pumped through two-stage RO desalination. The water passes through calcite filters to remineralise and increase pH, and is then stored in one of three onsite clear-water tanks. A small, elevated header tank provides pressure from where water gravitates through a UV disinfection unit before entering the reticulation. Waste brine is piped to a local well for disposal to local groundwater.

The plant treats 100% of the process water, with no dilution or shandying with raw water. The process is operated at a 48% recovery rate over two stages.

The WTP was built and commissioned in 2005 by Osmoflo. The plant was built around two separate process trains, each capable of producing 80 kL/d. The two trains are usually run in duty/standby mode, but can be run in parallel if larger treatment volumes are required. Four-inch diameter spiral-wound membranes are used and produced by TriSep Corporation in the United States.

Brine from the plant is disposed to local groundwater through a small well on the site.

Plant control and monitoring

The plant is controlled locally by a programmable logic controller (PLC)-based control system, accessed by a touch-screen Human-machine interface (HMI) unit. The plant design incorporated online instrumentation for many parts of the process, including flow rate, conductivity, pH and pressure, all of which can be viewed from the HMI.

In addition to the local control, Osmoflo has included the capability for direct communication with the PLC control system from its head control room in Adelaide. As part of an ongoing service agreement, Osmoflo dials into the plant daily, inspects the process parameters and makes any necessary changes to process set points. Remote operators can monitor and control the plant as if they were using the HMI interface at the plant itself.

A small number of water supply system-wide parameters are also communicated to the head office of SA Water in Adelaide for monitoring purposes only.

6.1.4. Operation and maintenance

The plant is visited daily by a community council member who runs brief checks on pumps and equipment and inspects chemical levels and the HMI to ensure no serious problems have occurred. The visits rarely include any maintenance.

As mentioned, Osmoflo remote operators check the plant daily and adjust process parameters when required.

Osmoflo service technicians visit the plant every three months for routine maintenance as part of an ongoing maintenance agreement. They do a full plant check-up, top up chemical storages, test pumps and equipment and adjust instrumentation. The visits usually take a full day.

Once a year the technicians will carry out a two- or three-day visit which includes a full plant-shutdown and calibration of instruments, and other regular maintenance.

6.1.5. Discussion

Water treatment plant

The water treatment plant at Yalata has been running continuously since its commissioning in 2005 without any major service interruptions. SA Water and the Yalata community placed a high priority on continual availability of drinking water, and made a number of design decisions to ensure this.

Firstly, the clear water storage volume at Yalata is quite large, storing around three full days of water use for the community. In a chlorinated supply scheme, reservoirs this large provide a risk of losing chlorine residual and becoming ineffective at sanitising the water. The Yalata system does not use chlorine as a disinfectant, instead using a UV system downstream of the clear water reservoirs. This arrangement does not provide any residual disinfection, so care needs to be taken to ensure water does not become contaminated in the reticulation. The benefit of this arrangement however is that the clear water storage tanks can be sized to be quite large, providing a few days of water supply in the case of a water treatment system failure.

Additionally, the treatment plant itself has been designed with separate duty/standby RO trains. The plant automatically switches over to the standby train in the case of a fault. Due to the remote location of the plant and lack of locally qualified technicians, it may take more than 48 hours for an Adelaide-based technician to attend the plant for repairs. Having a standby allows the plant to continue to operate during this time.

Including such redundancy in the plant does incur a greater capital cost. The decisions made at Yalata were based on specific site conditions and requirements. Any water authority making a similar decision should weigh-up capital and operating costs over the plant's lifetime, along with operational considerations.

Brine reuse

The Yalata Aboriginal Lands are recognised by the National Wilderness Inventory as an area of important biodiversity. The soils on which much of this system stands are fragile and lie in shallow layers. Therefore some areas have been zoned 'no access areas' and are maintained as environment conservation zones. The high quality of this wilderness area is of national significance. This is complemented by the fact that the lands are bordered, on soil and sea, by neighbouring areas under state legislative protection.

Because of the protective legislation, any land-application scheme would need careful consideration of its potential impacts on the surrounding area. One possibility is to grow marine or salt-tolerant couch for turf on a local playing field. The establishment of these turf grasses is expensive but there would be a significant community benefit. Site-specific investigations are needed to determine the feasibility of this solution. Care would be needed to avoid couch grass extending beyond the boundaries of the irrigated area into the protected lands. This would be achieved by inserting barriers—probably needing to be at least 50 cm deep.

6.2. Case study 4: North Star, NSW

Figure 6–4: a) Typical street in North Star b) North Star water treatment plant

6.2.1. Background

Location

North Star is a small village in Northern NSW accessed from the Newell Highway. It is part of Gwydir Shire Council, west of the Great Dividing Range, and about 120 km north of Bingara, where the council's headquarters are based, and 45 km south of the border town of Goondiwindi.

North Star is the northernmost village in Gwydir Shire and, for travellers heading to central and far northern Queensland, lies on the main route north from Bingara. Moree, the nearest regional town and closest commercial rail and airline transport, is about 100 km southwest, with Tamworth about 160 km south.

Village facilities include a general store, hotel/motel, sports club, war memorial park, small caravan park, golf course, showground and polo ground.

Demographics

North Star's population at the time of the 2006 Census was 327, of which 4.3% were Indigenous and 91% Australian citizens. About 50% of the population was working age (15 or older) and the unemployment rate was 6%. Like many small regional farming towns in Australia, North Star has an ageing population and is struggling to retain its younger population and attract families to resettle in the area.

Agriculture and associated service facilities form the economic base for the area and are the main contributors to the regional economy. This means the effect of droughts and floods on the economic health of the local communities can be severe.

Sheep, beef cattle and grain farming employ about 60% of the population, with the next largest employment section, education, employing just 6%. The median household income is $814/wk.

6.2.2. Water supply

Overview

Groundwater supplemented with rainwater is the primary source of water for the shire. Groundwater in the area is slightly brackish, with desalination treatment considered a requirement. It is also characterised by high iron, high barium and high hardness.

The town water supply incorporates a bore and bore pump, a 180 m^3 raw-water storage tank, a 9 m^3 buffer tank, a WTP and a small, elevated header tank from which water gravitates to the reticulation.

Water usage

Average daily water demand is 100 kL/d, with a peak usage of 265 kL/d. Annual water usage is around 27.5 ML/a.

Anecdotal evidence suggests that the town water supply is generally used for gardening and outdoor purposes, with most residents using rainwater for drinking.

Water source

Water for the town supply is sourced from a bore about 130 m deep. There are no permanent surface water supplies in the area.

Groundwater quality is relatively consistent, with four parameters of concern shown in the table below.

Table 6–1: Water quality vs. ADWG limits

Parameter	*Units*	*Value*	*ADWG*
Barium	mg/L	0.8	<0.7
Iron	mg/L	0.4	<0.3
TDS	mg/L	580	<500
Total hardness	mg/L as $CaCO_3$	300	<200

These four parameters are only moderately outside the range recommended in the ADWG and easily accounted for in the WTP processes. Iron is specifically removed by the Birm filter to minimise its accumulation on the membrane surface, which can lead to premature membrane scaling. The subsequent RO process will remove barium, TDS and hardness.

6.2.3. Water treatment plant

Process description

The water treatment works comprising tanks and a WTP building are located on a single lot in the town. The WTP was supplied and constructed by Veolia Water Solutions and Technologies (VWS&T) in 2007 and comprises the following components:

Component	*Quantity*	*Details*
Aeration tank	1	Used to raise the dissolved oxygen concentration to oxidise soluble iron ahead of the Birm filter.
Birm feed pumps	2	Used to pump water through the Birm filter and provide low-pressure boosting pressure to the high-pressure pump.
Birm filter	1	Used to remove oxidised iron particulates.
Clean-in-place (Clean-in-place CIP)/flush pump	1	Used during the CIP process as well as for flushing the membranes with permeate water after a shutdown.
Cartridge filter array	7	Used to remove any particles in the feedline that can damage the internal components of the high-pressure pump.
High-pressure pump	1	Used to provide the high pressure that drives the RO separation process.
2-stage RO system	1	Two pressure vessels each with four membranes (brine from the first stage is filtered further in the second stage).
Antiscalant dosing system	1	Antiscalant is required to minimise scale formation on the RO membranes.
Soda ash dosing system	1	Soda ash is used to raise the pH of the treated water to ADWG levels.
Sodium hypochlorite dosing system	1	Sodium hypochlorite is used for primary and secondary disinfection.
CIP dosing system	1	Used for periodic chemical cleans of the RO membranes.

A flow diagram of the process is provided in Figure 6–5.

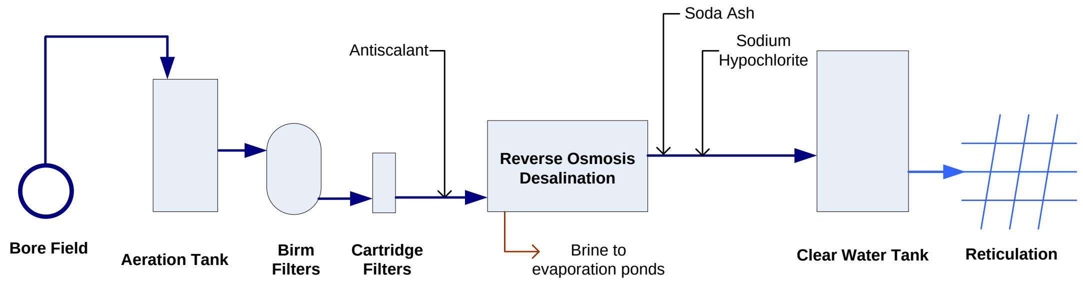


Figure 6–5: Process flow diagram of the North Star water treatment plant

Brine disposal

Evaporation ponds lined with plastic are used to store and dispose of brine generated in the desalination process. Beneficial reuse for irrigation was proposed but not approved by the NSW Office of Water, as the salinity of the brine was considered too high for land application.

6.2.4. Operation and maintenance

Daily operation

The plant is operated by the Gwydir Shire Council and visited once a day by council staff who:

- record meter readings
- check chemical levels
- check for any alarms
- check for leaks.

Council staff log a number of process parameters and investigate issues as they arise. Differential pressure and permeate conductivity are the primary indicators used to identify RO fouling. There is no remote monitoring of the WTP, although this is planned.

The staff have been trained to detect excessive scaling/fouling of the membranes. To monitor plant performance, operators take daily readings from the plant's online instruments. The readings are then faxed to the council and entered into a spreadsheet by the plant manager.

Regular maintenance

VWS&T has a contract with the council to service the plant every six months. This includes:

- 1 x organic CIP of the membrane (at high pH to remove biofilm)
- 1 x inorganic CIP of the membrane (at low pH to remove scale build-up)
- 1 x manual backwash of the Birm filter
- control-system check (valve operation, level-switch functionality, pressure-switch functionality, etc.)
- plant performance checks
- general checks.

Although council staff have been trained to perform a CIP (they are present during VWS&T service visits), the council has never had to do an additional CIP independently of those done by VWS&T.

To prevent the membranes from fouling during extended shutdowns, council staff are advised to run the WTP at least once every two days for an hour. This is the minimum time needed to fill the RO flush tank with permeate. After a shutdown, the WTP automatically performs a flush, which refreshes the water in the RO pressure vessels.

6.2.5. Costs

The approximate cost of the WTP and of operating and maintaining the plant are shown in the table below:

Table 6–2: Cost estimates.

Item	*Cost*
Capital cost WWTP alone WWTP + building + tanks	 $400 000 $750 000
Energy cost	$3000/a
Chemical cost	$4000/a
Maintenance cost (VWS&T)	$6855/a

Regarding staffing costs, the plant is attended once a day as it is located within the council depot and easily accessible. In addition to routine daily checks, operators are also responsible for grounds maintenance at the site. The council estimates that, if required, visits could be done weekly rather than daily, as the WTP currently requires little operator intervention.

The council is satisfied with its service contract with VWS&T and intends to continue with the arrangement.

The membranes are guaranteed for five years, but it is not uncommon for membranes to be used for much longer, provided the WTP is run conservatively and maintained on a preventative basis. The cost of replacing a membrane, at current prices, is about $1500. Although single membrane replacements are done, it is more common for all of them to be replaced at the same time. As each pressure vessel contains four membranes in two stages, the replacement cost would be $12 000

6.2.6. Discussion

The council seems satisfied with the operation and maintenance of the new WTP and, based on its experience, would recommend this approach for other areas, especially for remote sites where staffing can be a problem. While the ongoing maintenance fee is around half the operating costs of the WTP, the actual cost is quite low and likely provides a cost-saving over the life of the plant as a result of best-practice care of the membranes and other equipment.

7. Case studies: Operating and maintaining a large desalination plant

Dalby in Queensland and Coober Pedy in South Australia are large regional towns which have been operating brackish groundwater RO WTPs for some years. Both towns installed RO treatment plants for town-use and have since added another plant to increase supply capacity.

7.1. Case study 5: Dalby, Qld

Figure 7–1: Dalby RO water treatment plant #1

7.1.1. Background

Location

Dalby is located on the Warrego Highway in Queensland's Darling Downs region, about 200 km west of Brisbane. Commercial flights are available from Toowoomba, 90 km east. Dalby has a subtropical climate with a mean annual rainfall of 678 mm. The town is close to existing and potential coal-seam gas projects.

Demographics

The current population of Dalby is around 11 000, with the town growing at the rate 3–5% a year. The resident population is quite young, with about 40% under 25. The population is predominantly white Australian. About 6% identify as Aboriginal and 5% were born overseas.

Employment is spread across a number of professions, with technicians and trade workers the highest, at 17.6%. Unemployment is less than 3.5%. Farming is the most significant employment industry, and fuel and energy production are becoming increasingly popular.

Water supply

Dalby's water is supplied from a number of sources. Historically, most of the town's water came from a shallow groundwater aquifer. The rest was drawn from a weir on the Condamine River, from which water was extracted and treated in a conventional WTP.

The water level in the aquifer and subsequent bore yield were decreasing consistently, as a result of overuse from regional irrigation, forcing the local council to investigate other water supply options. Around 2000, the council decided to pursue RO desalination of brackish groundwater as the preferred future water-supply option.

In 2004, after lengthy pilot trials and investigations, a new desalination WTP was built and commissioned, providing up to 30% of the town's water needs. Water was sourced from a much larger and deeper aquifer. A second plant was commissioned in late 2010. The combined output of the two plants provides 60% or more of the town's water needs for most of the year. The river WTP is used during times of peak demand.

Water quality

Three bores drilled into the deep aquifer produce water of similar quality but with some variation due to differences in depth. The water in the shallower bore is of better quality but yields are poor.

The conductivity of the water ranges between 1200 µS/cm and 3400 µS/cm. Other parameters of concern are a fairly high level of silica, and of barium and sulfate.

7.1.2. Water supply

Overview

Most of the town's water is provided from two RO desalination WTPs, and a conventional treatment plant provides water when required. Water from the three treatment plants is sent to a combined clearwater tank for chlorination and then sent to a number of reservoirs in the town.

Water usage

Annual town water usage is around 1800 ML/a, with daily usage averaging 4 ML/d. This is covered by the two desalination plants, which produce about 2 ML/d each. On peak days in summer, town usage can reach 8 ML. Evaporative air-conditioners add an estimated 1 ML/d to the demand on hot days.

The newer treatment plant was built so that further membrane modules could be added to meet increased demand.

Water source

Raw water for the two treatment plants is drawn from the Condamine alluvium, a large aquifer at a depth of about 55 m. The aquifer is also used by other towns and irrigators in the region. The annual extraction is estimated to be around 60 000 ML.

Two bores are located within the grounds of the WTP and a third is located about 500 m east of it. A further three bores were drilled to the south and east to service the second desalination plant. Extraction is normally spread across at least three locations to limit local drawdown.

The water is generally of good quality, with only barium, sulfate, and silica concerning operators. Typical water quality is shown in the table below.

Table 7–1: Typical groundwater quality at Dalby

Parameter	*Units*	*Bore 1*	*Bore 2*	*Bore 3*
Bore depth	m	55	25	55
Conductivity	µS/cm	3340	1200	3370
TDS	mg/L	1810	721	1890
Total silica	mg/L	32	29	27
Sulfate	mg/L	117	37.5	113
Barium	mg/L	0.1	0.1	0.1
CO_2	mg/L	20.1	17.8	5.7

7.1.3. Water treatment plant

Process description

Both WTPs follow the same process and use similar equipment, as shown in the flow diagram below.

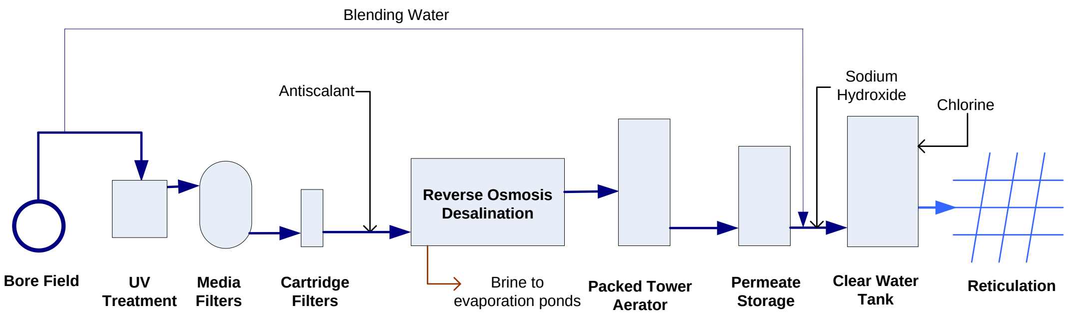


Figure 7–2: Process flow diagram of the water treatment process at Dalby

Raw water from the bores is pumped through a small UV unit to deactivate any bio-organisms that could foul membranes. It is then pumped through pressure-media filters, followed by two cartridge filters of 5 micron and 1 micron respectively. An antiscalant is dosed, and then water is pumped through two-pass RO filtration, yielding about 75% recovery. Permeate is aerated to remove CO_2. A turbine aerator is used in the older plant and a packed tower aerator in the newer plant. A small amount of sodium hydroxide is then dosed to increase the pH.

The water is then blended with raw groundwater at a ratio of about 5:1 to increase the alkalinity and hardness. Both plants produce a permeate with a TDS of around 120 mg/L, increasing to around 400 mg/L after blending. Finally, the mixed water is pumped to the combined clear-water storage for chlorine disinfection.

The first of the two plants was built in 2004 by Wendouree Water Treatment, a Queensland-based desalination provider, since taken over by Orica Watercare. The council worked closely with Wendouree to develop a design that included its major objectives.

During the first few years of plants' operation, the council made improvements to the first plant, including the upfront UV treatment. The evaporation lagoons, which were originally lined with locally sourced clay, were relined with plastic after the clay lining was found to be unsuitable.

The second plant incorporated these process improvements in its original design. This resulted in an almost identical treatment system. The new plant, built by Orica Watercare in 2010, included the more effective packed-tower aerator for CO_2 removal—a system that will be retrofitted to the older plant in the coming years.

Plant monitoring and control

Both plants incorporate full PLC-based control systems. Online instrumentation for conductivity and turbidity allows operators to monitor process parameters for successful operation of the plants. As plant operators visit the plant daily for data collection and process checks, remote monitoring is considered unnecessary. Process alarms have been set to alert operators by Short message service (SMS) if any alarm levels are reached.

The plant design included numerous sampling points throughout the treatment process, which are all brought back to a single sampling location within the plant. This allows the operators to monitor parts of the process quickly and efficiently and identify faulty process modules early and rapidly.

Brine disposal

The preliminary design identified options for brine disposal. Deep-well injection was considered the most suitable, but not enough was known about the local groundwater hydrology to allow this to happen. The council investigated reuse alternatives, including blending with raw water for use in irrigation, but there was little interest from local farmers.

The plant design allowed for using brine to backwash the media filters to increase process recovery. This caused some biofouling in the filters, which was controlled by dosing with a small amount of DBNPA biocide. As the backwashing requirements were much less than expected, the council switched to the simpler method of using raw water for backwashing.

Brine is currently disposed of in large evaporation ponds near the site, with an evaporation area of approximately 21 hectares. The ponds were initially constructed with a liner of locally sourced clay, and were subject to an environmental monitoring plan incorporating daily, weekly, monthly, yearly and five yearly testing of various parameters to monitor any impacts on local groundwater.

After a number of years of operation, brackish water was found in one of the groundwater monitoring bores, suggesting the clay liner was not working effectively. Council resolved that any risk of contamination to the local environment could be best mitigated by relining all the evaporation ponds with a polyethylene plastic liner.

The ponds are now lined with black plastic on the floor and white on the sloping sides. Figure 7–3 shows one of the evaporation ponds after the installation of new liners.

Figure 7–3: Dalby evaporation pond during relining with polyethylene lining

Council are currently investigating the option of installing a third reverse osmosis treatment plant designed purely for brine concentration, which will both increase the yield of drinking water from the bore extraction, and reduce the volume of water sent to the evaporation ponds.

7.1.4. Operations and maintenance

Daily operation is carried out by a team that looks after the entire water supply scheme. The operators previously looked after the conventional WTP and so had a good understanding of process plants and procedures. Wendouree Water Treatment provided training and supervision during the commissioning of the plant, which allowed the operational team to gain a full understanding of the plant's requirements.

The council's treatment manager supervises the team and provides long-term monitoring and technical support when required. Specialist resources may be called in for specific pieces of plant equipment such as the UV system. However, the council has found that its operations team can deal with almost any issue arising in the plant because of the knowledge the operators have gained after running the plant for the past seven years.

7.1.5. Costs

The capital cost of building the first desalination plant and evaporation ponds in 2005 was about $2.8 m, with about $1.2 m being for the treatment plant itself. This followed significant investment by the council in investigations and a pilot-plant trial. A further $2 m was spent in the following years on relining the evaporation ponds.

The total capital cost of the new treatment plant and associated works was around $6.5 m, with approximately $3.4 m for the treatment plant itself. This higher cost was due to the plant being designed for future expansion by making pipe and process-tank volumes larger than necessary and to incorporate improvements from the first plant into the initial design.

Operating costs for the first plant were conservatively estimated in 2005 to be about 30 c/kL. This estimate is for the ongoing cost of water production and does not incorporate the costs associated with the raw water supply, treated water distribution, asset depreciation and long-term salt disposal. It must be noted that any operating cost estimate is very site-specific because of labour requirements and the use of related infrastructure such as laboratories, chemical-dosing regimes and raw water quality. Any cost comparisons between sites should be treated cautiously, even when raw water quality appears to be similar.

Excluding additional capital works and increases in energy costs, the council has found the actual operating costs to be slightly lower than the original estimate because of efficiency improvements. Online monitoring and control of the permeate/raw water blending system have allowed the chemical dosing to be reduced, resulting in lower chemical costs. Conservative operation has also seen the filters and membranes exceed their design life. The membranes have been operating for almost seven years and do not appear to need replacing in the near future.

7.1.6. Discussion

The former Dalby Town Council (now Western Downs Regional Council) invested many years into investigating RO desalination to ensure it was a suitable long-term water supply option. The investigation involved staff visits to RO installations in the United States of America (USA) to meet with and learn from operators and managers. The staff look upon this as a valuable experience, with the benefits far outweighing the cost of the trips.

Following this, a pilot-plant trial was set up to determine the most suitable treatment process for a larger construction. This allowed council staff to develop a thorough understanding of the specific challenges posed by the water source, giving greater assurance of the level of pre-treatment required. This also allowed estimates of ongoing operation and maintenance costs, which were used to provide long-term costings to decision makers in the council.

The decision to reline the evaporation ponds with plastic came after concerns that the existing clay liner was not suitable for preventing leakage of waste brine to local groundwater. A comprehensive monitoring program detected a leakage soon after it occurred, and allowed Council to respond before there was any adverse impact on the environment. Council found that while the locally sourced clay lining may have been determined to be suitable in laboratory testing, there was difficulty in ensuring consistent construction and compaction over the large pond area of more than 20 hectares. Council decided that relining the ponds with plastic was the best option for mitigating any risk of further leakage.

The experience of Western Downs Regional Council and operators of the two Dalby RO WTPs is that maintaining the plant themselves has led to a good understanding of the issues associated with running it. This, in turn, has led to more efficient process operation, minimal down time and reduced maintenance costs.

7.2. Case study 6: Coober Pedy, SA

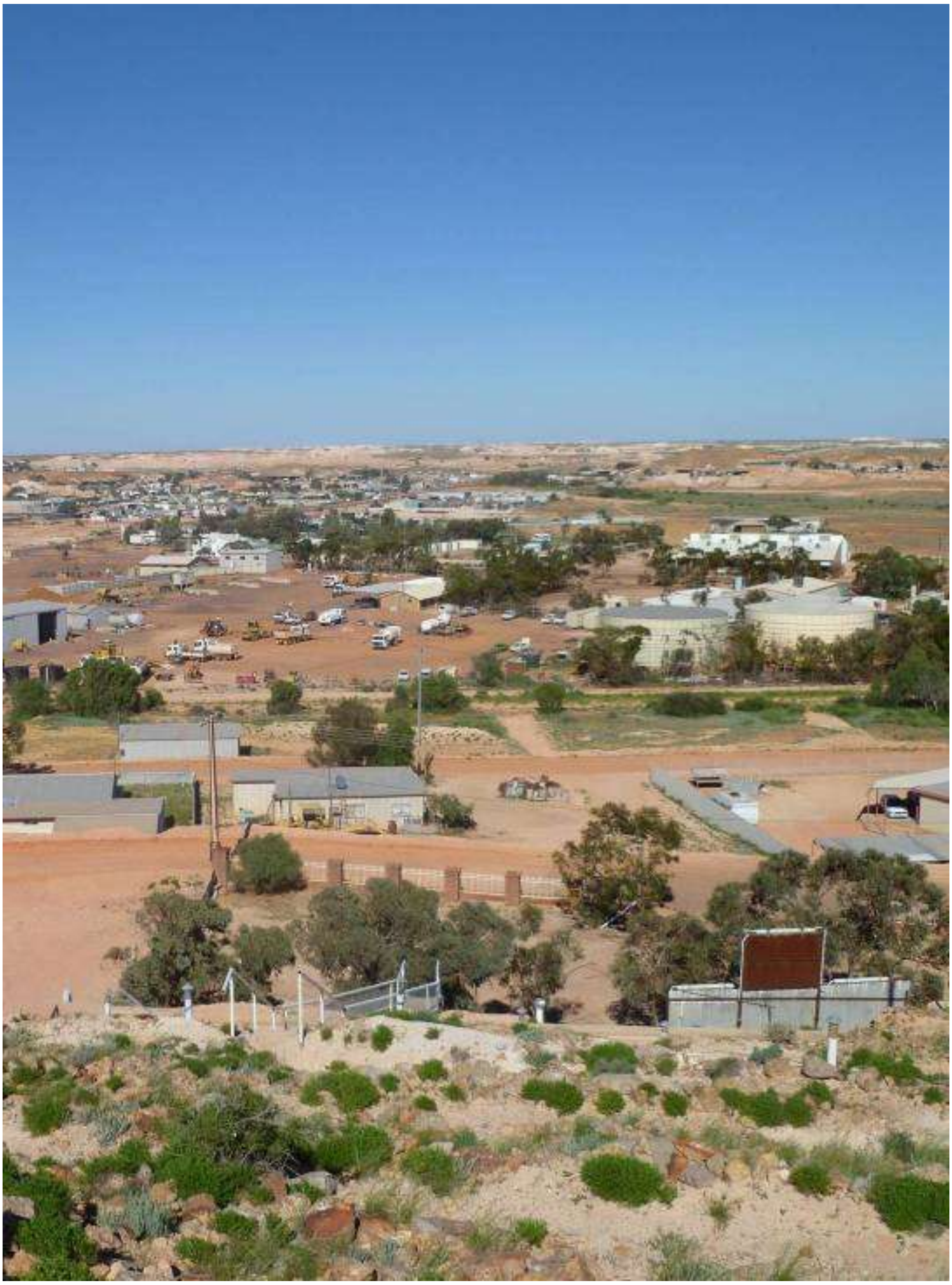


Figure 7–4: View of Coober Pedy from Lookout Hill

7.2.1. Background

Location

Coober Pedy is located on the Stuart Highway in central South Australia, about 550 km northwest of Port Augusta and 700 km south of Alice Springs. The highway is the major transport route for Central Australia, running from Adelaide in the south to Darwin in the north. Coober Pedy is also serviced by an airport, with Rex Air running daily commercial passenger flights.

Coober Pedy has an arid climate and typically low annual rainfall averaging 136 mm. The typical soil type is a red sodosol characterised by almost impervious hardpan at depth, restricting subsoil drainage. Temperatures can rise above 50°C in summer, which has led to some local residents and businesses building ‘dugouts’—underground dwellings bored directly into the earth.

Coober Pedy is not connected to the national electricity grid and sources power from a large diesel power generation facility in the town, operated by a private company.

Demographics

It is difficult to accurately estimate the population of Coober Pedy because of a significant tourist population and a large number of itinerant workers. The resident population is around 2000, with the maximum population said to be around 3500 at the peak of the tourist season.

The town is highly multicultural, with an overseas-born population of 33%. People from more than 40 nationalities are represented in the town. Most overseas residents emigrated from Europe in the 1960s and 1970s. The Aboriginal population is 17%, many living in the Umoona Aboriginal community on the outskirts of town.

The major industries are tourism, opal and other mining. Opals, including mining and sales, were the dominant industry after the town was settled in 1915, but the industry’s popularity is declining. Tourism is becoming increasingly popular and the town is also used as a transport hub for mineral mining operations in the region. There are no agricultural or farming activities, largely because of the extremely dry climate.

Water supply

A stable water supply has always been a significant issue for Coober Pedy. Different schemes have operated since the town was settled, including water carting, bore supply, solar desalination and, more recently, RO desalination. The first RO desalination plant, commissioned in 1971, piped water into the town from a bore.

A permanent water supply and reticulation were built in 1985 and operated by the newly incorporated town council. An RO desalination WTP commissioned at this time is still operating and in good working order, and provides most of the town’s fresh water needs. A second RO desalination plant was built in 2000 to supplement the growing town’s water usage.

Water quality

Raw water for the treatment plant is drawn from a number of bores located out of town. The water is brackish, and contains dissolved iron and manganese, which are removed during the treatment process.

7.2.2. Water supply

Overview

The water supply system has been operating with minimal changes since its construction in 1985.

Raw water is pumped from a bore to a small holding tank at the WTP site. Water is treated and disinfected, then stored in three large clear-water reservoirs before being pumped to the town reticulation.

Water usage

Annual town water usage is around 260 ML/a, with the plant producing 290 ML/a in 2010. The peak daily demand is around 1200 kL/d. Average daily demand in summer is 750 kL/d and 500 kL/d in winter. Despite the population being higher in winter, the larger water-use in summer is due to the use of evaporative air conditioners.

Most of the town water is used by households and businesses. A small amount is used to supplement reclaimed sewage effluent for watering the town football field. There is no raw water reticulation in the town.

Water source

Raw water for the treatment plant is drawn from a number of bores about 25 km out of town. The water is brackish, with an electrical conductivity of around 7500 µS/cm. Ongoing testing of the bore water salinity has found no increase in conductivity since pumping began in 1985.

The bores are 67 m deep, drawing water from an aquifer above the Great Artesian Basin. Bore pumps are located 35 m down the shaft. The water is generally of good quality, requiring only manganese and iron removal before desalination.

7.2.3. Water treatment plant

Process description

The water treatment works consist of two similar RO desalination WTPs. The process for both plants is shown in the flow diagram below.

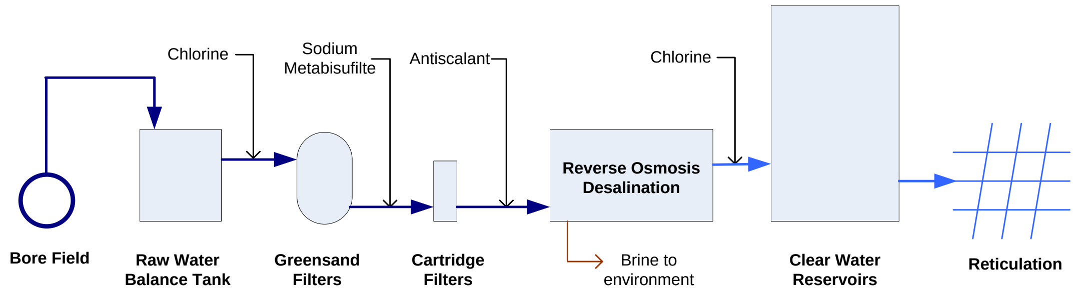


Figure 7–5: Process flow diagram of the treatment process at Coober Pedy

Raw water from the balance tank is dosed with chlorine before entering a greensand filter to remove dissolved manganese and iron. It is then dosed with sodium metabisulfite to remove any residual chlorine. Cartridge filters remove any remaining particulates. Water is then dosed with antiscalant and sent through two-pass RO desalination. Clear water is disinfected with chlorine before storage in one of three on-site clear water reservoirs. Waste brine is piped directly to a local creek for disposal to the environment, without further dilution.

Both plants treat 100% of the process water, with no dilution or shandying with raw water. The processes are operated at a 75% recovery rate.

The first of the two desalination plants was built in 1985 by NEI John Thompson and has a capacity of 900 kL/d. This plant runs continuously and provides most of the town's water needs. The second plant was built by Vivendi Water, now Veolia, in 2000 after population growth saw the demand for water increase beyond the capability of the first plant. The plant was designed to be as similar to the first plant as possible. Its installation followed the same process, except sodium hypochlorite was used instead of chlorine gas. This plant has a capacity of 600 kL/d and supplements the supply when required. Both plants use eight-inch-diameter membrane modules produced by Filmtec Corporation, a subsidiary of the Dow Chemical Company in the US.

The water produced by both plants is of similar quality, except electrical conductivity varies between 150 µS/cm and 400 µS/cm, depending on the age of the membrane modules. The modules in the newer treatment plant are due to be replaced in 2011 after 10 years of service. This longer-than-expected life span is likely due to the second plant being used only when required.

Plant monitoring and control

Both plants are fully automated and controlled through PLCs. A Citect supervisory control and data acquisition (SCADA) system installed on a PC in the control room gives operators access to all control and monitoring instruments at the plants. Operators also have a laptop with remote access to the SCADA system, allowing them to view and change parameters from anywhere with a mobile internet connection. The operators see this as a valuable feature, as plant status and alarms can be checked from home or another site without having to attend the plant.

Brine disposal

Brine produced by the plant is piped directly to a local creek. Because of the extremely low rainfall, the creek has no other flow, with the brine generally forming 100% of the flow. The creek runs out of the town into the local sandy desert.

7.2.4. Operation and maintenance

The plant is owned and operated entirely by the town council. A team of four operators and one manager look after the two plants as well as the town reservoirs and reticulation, bore field, sewage treatment plant and reclaimed-effluent systems.

Two operators do daily equipment checks at the plant and also check chemical levels, test the water quality and perform other general activities. Larger maintenance issues are dealt with as required. Having the flexibility of two plants allows the operators to isolate one plant and fix problems without interrupting the water supply. One operator is on call 24 hours a day, with plant alarms dialling out to a mobile phone. Most of the operations and maintenance work can be completed in-house, as all required trades are covered by council staff.

7.2.5. Costs

As the town council owns and operates the water supply system, the costs of producing water are fully recovered through usage charges. Charges for residents and commercial users are high relative to Australian water prices because of the high cost of producing water and the small number of consumers. High energy prices are the main contributor to the high water pricing because of the cost of using electricity produced from diesel generators. Water charges are shown in Table 7–2 below.

Table 7–2: Domestic water usage charges in Coober Pedy

Water usage	*Charges*
Residential access	$150/a
Less than 50 kL/a	$3.80/kL
51–300 kL/a	$4.70/kL
More than 301 kL/a	$5.70/kL

The SA Government is considering a proposed increase in the sale cost of electricity to the town. The town council estimates that the proposed higher electricity cost would see water rates also increase by around 20% to cover the cost.

7.2.6. Discussion

Coober Pedy has a robust and relatively ‘climate proof’ water supply system that produces drinking water of high quality but at a significant cost to the consumer. A lack of other viable water supply options has led to the development of an effective treatment system, which is operated efficiently and has had few problems over many years. The town’s remote location, low population density and high cost of electricity result in high prices for consumers. The high cost of water is believed to be a major factor in the absence of any high water-use activities. Town water is used almost entirely for internal use in houses and businesses, as only a handful of residents keep outdoor gardens.

Brine reuse

The extremely low rainfall and lack of any agriculture in the region restrict options for beneficial reuse in the short term. It is unlikely that farming will develop in the region in future.

A possibility worth investigating is the feasibility of using the waste brine to supplement the reclaimed effluent and potable water used to water the school oval and playing field. Provided the resulting mixture is of sufficiently low salinity not to hinder the growth of the grass surface, this would either reduce the town’s overall potable water use or make additional water available for the oval, with the bonus of eliminating brine waste discharge to the environment. Additionally, a staged introduction of a more salt-tolerant grass, such as marine couch, could allow more brine to be used for watering. A site-specific, cost-benefit analysis weighing up the cost of capital expenditures against future savings could determine the feasibility of these suggestions.

Plant operation

Plant operators and managers at Coober Pedy highly praise the desalination plant’s control and automation system. Water supply operators at Coober Pedy have a number of responsibilities. These cover water supply and storage, water treatment, reticulation, sewerage services and treatment and, in some cases, general maintenance, construction and repair. The ability to access and remotely operate the plant is of great benefit.

8. Costs and financial issues

The costs associated with brackish water desalination are a function of many variables and are very site-specific. They can vary significantly, depending on the source water quality, plant size, cost and availability of power, financing, geology and road access.

8.1. Capital costs

An indicative capital cost estimate for a typical 0.25 ML/d WTP producing potable water for domestic use is provided in Table 8–1 below. These costs are indicative and could differ significantly, depending on actual site/design requirements. The estimate has been developed for a raw water TDS of 2000 mg/L. Key assumptions include:

- project tendered out as a single package
- no existing equipment available (greenfield site)
- moderate level of pretreatment required
- brine disposal via brine evaporation ponds
- power to site available.

Table 8–1: Capital cost components for a typical 0.25 ML/d RO WTP

Component	*Cost*
Preliminaries, design and documentation	$25 000
Raw water feed pumps	$10 000
Site establishment cost	$50 000
Civil works (concrete slab and building)	$100 000
Pre-treatment system	$100 000
Control system (MCC) including PLC and instrumentation	$100 000
Chemical dosing systems (coagulant, cleaning and chlorination)	$200 000
RO feed pumps	$25 000
Neutralization system	$20 000
RO units	$375 000
Permeate tank and treated water pumps	$20 000
Bores, pumps and delivery pipework (at $100/m x 500m)	$50 000
Connecting pipework to reticulation and storage tanks ($100 x 500m)	$50 000
Laboratory equipment and start-up supplies	$10 000
Commissioning and O&M manuals, operator training	$30 000
WTP surrounds (fencing, landscaping)	$25 000
Utilities (power, lighting, compressed air, water)	$50 000
Salt evaporation pans	$50 000
Telemetry off-site	$20 000
Total capital cost	$1 310 000
Engineering and project management (20% of total capital cost)	$262 000
Contingency (20% of total capital cost)	$262 000
Total (ex GST)	**$1 834 000**

Items not costed in Table 8–1 but that need considering during the scoping/feasibility study phase include:

- pilot plant testing
- geotech and surveying
- land purchase
- Authority approval costs
- significant excavation and earth moving (significant site preparation)
- additional special painting or finishes on equipment
- additional site/WTP flooring requirements, handrailing, and access walkways
- lifting equipment (if large chemical deliveries are to be used)
- clear water pump station(s)
- provision of utilities to the site (power to site assumed to be already available)
- lightning protection
- client witness testing / inspection at manufacturing facility
- decommissioning/ removal of any existing facilities.

8.2. Operating costs

Indicative operating costs for a typical 0.25 ML/d RO WTP are provided in Table 8–2 below. The RO vendor, working with the local water authority, could supply more accurate costing details during the detailed design phase.

Table 8–2: Annual operating costs for a typical 0.25 ML/d RO WTP

Component	*Cost*
Membrane replacement cost (based on 10% of capital cost less contingency and external engineering over lifetime of 4 years)	$44 000
Operator/maintenance based on 50% of an operator (based on $52 000 per year plus 50% on costs)	$78 000
Antiscalant and other chemicals	$5000
Power use at 15 cents/kWh	$12 500
Miscellaneous	$2000
Evaporation pan maintenance/salt disposal	$5000
Indicative annual cost ($/year)	**$146 500**

The above costs do not include irregular waste disposal, such as:

- disposal of solid wastes, such as cartridges, membranes
- disposal of membrane cleaning chemicals
- disposal of solids generated during pre-treatment (screenings, sludge, and/ or solids from filter backwash water).

Chemical consumption

For a typical RO WTP, it can be assumed that, at a minimum, the following chemicals would be required:

- antiscalant
- acid (if pH adjustment required)
- post-treatment alkalinity adjustment
- chlorine
- fluoride.

Overall chemical consumption needs to be assessed for each site, based on the source water, and investigated before design begins. Modelling using actual water quality data from each site, as well as jar testing with typical raw water, would provide an accurate estimate of overall chemical consumption.

Staffing and labour requirements

Staffing is expected to be a significant issue, regardless of the technology chosen. As membrane systems are usually more automated because of the nature of their setup and operation, staffing requirements are expected to be slightly lower than for a conventional plant. Adequate staff outlay is a prerequisite for successful plant operation over the long term and can be a significant cost factor.

Maintenance

Maintenance concerns are again specific to the technology chosen but would include:

- spare parts, tools, lubricants
- consumables
- cartridge filters
- membrane modules (for membrane systems).

The major maintenance cost would be from RO membrane replacement which is typically every 3 to 5 years for brackish water. The level of pre-treatment and contaminants present in the raw water has a great impact on the operating life of RO membranes.

Energy consumption and wastewater handling

Energy consumption and wastewater handling costs depend heavily on system hydraulics and water quality. A technology supplier is usually able to provide an estimate of the process energy requirements during the design stage. More detailed analyses would be needed to fully determine costs.

9. Discussion

Brackish groundwater desalination may seem like a good idea for a water supply, but there are many issues to consider before jumping into the design of a new desalination treatment plant. Preliminary studies may seem expensive but are valuable, as they allow a water authority to make a judgement that balances the social, economic and environmental outcomes of any changes to an existing supply system.

9.1. Water supply

The first step in the process is to do a preliminary study of the water supply in general. This should provide enough detail to allow decision makers to select the most appropriate course of action and identify funding sources. An options or prefeasibility study, combined with the necessary specialist investigations, would be appropriate.

Does the water supply need improvement?

A water authority will generally have a good idea about the performance of its supply system. However, it should consider a more in-depth look at historical performances, individual incidents and community opinions when planning changes to the water supply.

The general issues that should be investigated include:

- **Water use**—What are the existing water-use patterns? What is the peak daily demand? Has demand-management been used successfully in the past?
- **Population**—What is the current population of the town? What are the long-term estimates and are they reliable? Are there any expected changes in local employment?
- **Water supply options**—What sources of water supply are available? Are there likely to be changes to surface and groundwater extraction limits in future? Can reclaimed effluent be sourced from a sewage treatment plant for non-potable use? Should dual reticulation be considered?
- **Water consumption**—Is household water consumption considered reasonable? What measures are in place to reduce household consumption? What factors contribute to major increases in water consumption, e.g. evaporative air conditioners? Are there any major non-domestic uses and can these be substituted?
- **Community opinions**—Has the community been consulted? Are there any special community water needs? How will any changes to the supply affect the community? How will any proposed changes be communicated?

Is brackish groundwater a viable source?

Many inland communities in Australia have access to groundwater sources, but this does not necessarily mean the groundwater will be suitable for use as a water supply source. If groundwater is being seriously considered, the water authority should do a detailed hydrogeological study for preliminary feasibility of its use, followed by test-bore drilling and flow testing, if suitable.

The major considerations in determining overall feasibility include:

- **Groundwater hydrology**—Are multiple aquifers available? What is the recommended pumping level? How many bores will be required?
- **Water quantity**—What flow volumes are achieveable? What effect does this have on the water level in the aquifer?

- **Other users**—How many other users extract water from the aquifer? What effect will a new water supply have on their existing systems?
- **Water quality**—What is the salinity of the bore water? How will the salinity of the bore water change if pumping continues for long time periods? What other water quality issues are present (e.g. iron, manganese, heavy metals, pesticides, radioactivity)? Is further testing required?
- **Regulatory issues**—Is there an extraction limit on the aquifer? What are the state regulations for extracting groundwater? What ongoing monitoring will be needed to meet any regulatory obligations?

Design considerations

If brackish groundwater is found to be a suitable water supply source, there are further areas to consider in the early stages of the investigation. To develop preliminary cost estimates, the following major cost items in a water supply project to the water authority should be investigated.

- **Location of borefield**—What is the distance of the borefield from the reticulation? Will a WTP be located near the town or near the borefield? What is the impact on system-wide pumping costs?
- **Integration with existing water supply system**—Will new pipelines be required? Will the system be single or dual reticulation? Is a new reservoir required?
- **Treatment technologies**—Is normal brackish desalination feasible? What other treatment will be required? What technology providers are available?
- **Brine disposal**—What method of brine disposal will be appropriate? (see further discussion in section 9.3).
- **Electricity requirements**—What is the average and peak power consumption of the new plant? Will the existing substation and/or network require upgrading?
- **Chemical risks**—Are any dangerous goods required to be stored on site? Are there specific delivery and storage requirements? Will there be further regularory requirements for hazardous chemicals? How will chemicals be cleaned up and disposed of in the case of a spill?
- **Environmental impacts**—Does a review of environmental factors/environmental impact assessment need to be carried out? Are there any local environmental issues that will affect the design? Is there concern about noise and odour?

9.2. Plant design, operation and maintenance

Package WTP or custom design?

Package water-treatment plants can have the benefits of being compact, having short construction lead times, being fully tested before delivery to the site and often having a lower capital cost than a custom design. On the other hand, because they can be smaller, this can make operations and maintenance more difficult and the plants tricky to upgrade or retrofit. The predesigned process design can also be less efficient than a customised plant.

Custom treatment plants can have the benefits of more space for operators, greater operational flexibility, an efficient treatment process and a longer lifetime. The major negatives are the longer design and construction times and higher capital cost, which can be prohibitive when funds are limited.

The choice is not clear-cut, as there are opportunities for combinations of both approaches such as partially customised plants in small containers and skid-mounted package treatment plants in a larger custom building. As RO treatment plants are limited to a few suppliers there will always be a trade-off between the package and custom options, and water supply managers need to carefully consider the decision. A net present value analysis of all associated costs and a trading-off exercise would be appropriate in this case.

In addition to capital and operating costs, key factors in determining the most appropriate design would include:

- **Operation and maintenance requirements**—What level of operator attendance is required? What automation is included in the plant?
- **Design redundancy**—What parts of the plant will operate in duty/standby? What equipment will have uninstalled spares? What level of downtime is acceptable?
- **Integration with existing telemetry/control system**—Can the new plant be integrated into existing telemetry and SCADA systems? Will RTUs require upgrading?
- **Quality of equipment and parts provided**—What is the design life of the plant equipment? What level of spares will be required? What regular maintenance and calibration will be required?
- **Use of proprietry equipment**—Can the equipment be replaced if it fails? Does the plant use easily available fittings and pipework? Is equipment sourced locally or from overseas?
- **Project timeframe**—How long is the plant-design period? How long will site- construction take? How much of the plant can be pre-assembled before delivery? What is the availability of the contractor?
- **Land area/space available for construction**—How large is the plant footprint? What size site is required for all associated works? Will land or easements need to be purchased? Is there vehicle access to the site?
- **Testing and commissioning**—What testing and commissioning period will be required? Where is testing to take place? Can the plant be tested before delivery?

Operator O&M or supplier O&M?

Many RO providers now offer ongoing maintenance contracts with their WTPs, sending service technicians to the plant regularly, often every three months. The service can be of great benefit to small water suppliers with limited operational experience, particularly those which have never had a filtered-water supply in the past.

In addition to ongoing maintenance contracts, some RO providers offer remote monitoring and control of their plants via a telephone connection between a control room and the plant's PLC control system. This service comes at an additional cost but can be useful for remote communities with no local operators, particularly when combined with an ongoing maintenance contract.

Water suppliers who do have an operational team with experience in water filtration or similar plants should be able to carry out plant operations and regular maintenance on the plant and its instruments. Operators can source help as needed for more difficult tasks such as changing membranes.

The most significant trade-off will usually be the cost of employing an operator versus the cost of an ongoing maintenance agreement. However, in addition to labour costs, the key factors in determining the most appropriate operation and maintenance regime would include:

- **Operational difficulty**—What experience does the water supply authority have in operating advanced WTPs? Can the current operational team manage the new plant?
- **Availability of skilled labour**—Are any current operators skilled enough to operate the plant? Who will succeed the proposed operator should he or she become unavailable? What incentives can be provided to keep an operator in the position?
- **Remote location of plant**—How far is the plant from the nearest water authority office or works depot? What transport is available to the site?
- **Supplier support**—What training is provided during commissioning? What ongoing support is available? What response time is offerred by service technicians?
- **Service and maintenance contract** – Is there a need to arrange a service and maintanance contract with the supplier? What should be included in the contract?
- **Communication systems**—Is phone coverage in the area suitable for wireless communications? Is a fixed phone line available? What is the condition of any existing control and monitoring systems for the water supply?

9.3. Brine disposal

One of the most critical decisions made by a water authority in a desalination design is the method of brine disposal. This can cost up to 50% of the plant's capital cost, and have major ongoing operational and environmental management requirements. For these reasons, brine disposal should be a key consideration in the overall water supply design, and should be investigated as early as possible in the design process.

Brine disposal and desalination processes

The expected salinity of the brine is a key factor which should be identified early in the design process, as different brine disposal methods have different process waste quality objectives. In some cases the brine disposal method dictates the desalination process itself. To optimise the operations and costs of the overall treatment process, brine disposal and desalination operations must be considered together.

For example, evaporation ponds aim to concentrate the waste stream by removing all remaining water from the brine. In this case, it would be beneficial to ensure the brine is as concentrated as possible before reaching the evaporation ponds, as this allows for a smaller pond area, and lower costs. This may lead to a desalination process designed to run at a higher recovery rate, or the inclusion of additional brine concentrating process steps.

Disposal to sewer may require lower salinity levels to avoid interfering with biological systems. In this case, running the process at a lower recovery rate may be the best alternative; however this needs to be looked at with reference to the total groundwater extraction.

Land application or beneficial reuse irrigation may require brine dilution to lower salinity to an acceptable level. In this case a source of water must be found for the dilution, and the costs and impacts of using this additional water should be compared to the benefits.

Environmental impacts

Many brine disposal methods will involve some type of environmental disposal, and so the environmental impacts of this disposal must be carefully considered. In addition to salts and water, brine often contains a number of other process chemicals, such as chlorine, aluminium, acids and alkalis, which can have harmful effects on local environments if not effectively dealt with. A risk management approach is the most suitable method for ensuring the safe disposal of any waste to the environment.

A water authority should first determine what options are available for brine disposal in their state. Different regulations apply to different types of users, particularly regarding aquifer recharge, land application, and pond evaporation. State government environmental regulators will have the most up to date information on what disposal methods are suitable.

Secondly, each of the alternatives should be considered in a risk framework, identifying the hazards associated with each disposal method, the likelihood of these hazards occurring, and the consequences of these hazards, should they occur. This will result in a risk profile for each disposal method, which can then be looked at in conjunction with operational and cost data to determine which is the most suitable for the process.

Once a brine disposal method has been chosen, a water authority should develop an operational and environmental monitoring plan to ensure the continuing successful operation of the scheme. This may include local groundwater quality monitoring bores, sampling and testing from local waterways, and chemical analysis of the waste itself. The monitoring program should include a response plan, indicating how the water authority should react to any adverse results, and who to contact should a contamination event occur.

Beneficial reuse of brine

This report has discussed a number of potential beneficial reuses of brine waste. The key factors to consider include:

- **Local grounds watering**—Are there opportunities for brine reuse on local school ovals or sporting fields? Could salt-tolerant grass or plant species be planted to allow use of brine for watering? Will there be any long-term salt accummulation in deeper soil or groundwater after prolonged brine irrigation?
- **Agricultural reuse**—What local agricultural activities are occuring? What existing water sources are used for local agriculture? Are there opportunities to substitute/supplement existing water sources with brine? Are there opportunities for new agricultural activities if a water source were made available?

Further brine treatment

As discussed in section 4.3, brine from a desalination plant can be further treated, generally with the dual purpose of increasing drinking-water recovery from the groundwater extracted and reducing the volume of brine requiring disposal. Further treatment is most suitable for situations requiring water disposal, such as evaporation ponds, and as discussed above, may not be required where there is beneficial reuse of brine. The issues to consider for further processing are similar to those of a desalination plant itself, as the technologies are similar.

Evaporation ponds

Evaporation ponds have been used for many applications in water and sewerage systems and are reasonably well understood by most water authorities. However, some design considerations must always be investigated. The major issues include:

- **Size of ponds**—What size ponds are required? Should they be oversized to cater for future increases in water usage? How regularly will solids require disposal?
- **Waste disposal**—How regularly will solids require disposal? Where will the solids be transported to for disposal? How long will the disposal process take?
- **Land availability**—Is there enough land for pond construction? Do land or easements need to be acquired? Is further land available for future construction? Where is this land located in relation to the borefield, WTP and reticulation? Is the land prone to flooding?

- **Pond lining**—Will the lining be clay or synthetic? Is suitable local clay available? What is the expected lifetime of the liner?
- **Monitoring**—What level of monitoring is required? What reporting is required to regulatory authorities? What labour will be required for monitoring?
- **Environment**—How would ecosystems and aquifers be impacted by leaks of brine from the evaporation pond?
- **Rehabilitation**—How will the pond be rehabilitated at the end of its lifetime?

9.4. Learning from others

A good way to start thinking about the decisions involved in a new water supply is to learn from other water supply authorities who have gone through similar processes. The six case studies presented in this report aim to give an overview of the different stages of the design process, and how local conditions affected design and operational choices. A number of the case study authorities had themselves spent time learning from others to help in making decisions about their own water supplies. Staff members from Dalby travelled overseas to find the people with the best knowledge of brackish groundwater desalination operations, and were very happy with their own outcomes as a result.

There are difficulties however in distilling another's information and making it suitable for a different context. The case studies found that the day-to-day demands of operating a regional water supply system is a difficult and time consuming task, and often doesn't leave time for longer term strategic planning. Long-term investigations into water quality, operation and maintenance costs, and research and development, often become neglected when the focus is on maintaining an aging supply system in a variable climate with a small operational team. Water supply authorities are encouraged to keep long-term data wherever possible, even if it isn't looked at regularly. This will enable them not only to make strategic decisions about their own water supplies, but also to assist other councils looking for help in deciding if brackish groundwater is a viable supply option for their community.

9.5. Conclusion

The use of brackish groundwater as a supply source for desalination treatment is technically feasible and established in Australia. The overall feasibility is dependent on a number of considerations, particularly geographic location and raw water quality. The high capital cost of constructing a desalination plant can be prohibitive for small communities, unless significant external funding is provided. Ongoing operational costs can generally be recovered through water charges. Subject to these considerations, brackish groundwater desalination can be considered a viable community water supply option.

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Appendix A—Brine land application risk assessment

The following table summarises the potential opportunities and risks for brine waters diluted up to 4000 µS/cm if applied to land. The preceding analysis has shown that brines with greater salinity than this are unlikely to have a beneficial use, except where exceptionally salt-tolerant plants, such as marine couch, is used. Aquaculture could be considered an exception to this rule. However, this use is not considered because aquaculture creates a waste product that would need to be beneficially reused. Hence, aquaculture wastewater would need to have (or be diluted to) an EC of less than 4000 µS/cm before it could be beneficially reused.

Table A1: Risk assessment for irrigation using brackish water with a conductivity of <1000 µS/cm

Climate zones	*Soil drainage*	*Range of plant types that can be grown*	*Other hazards*	*Risk*	*Potential preventative measures*
Moderate to wet rainfall (>800 mm/yr)	Well	Only very salt-sensitive species would be impacted. In unusually dry periods it may be necessary to leach out salt by overirrigating the site.	Soil sodicity	Low	Not required.
			Other toxins	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Select plant types with some salt tolerance and that are not significantly impacted by waterlogging.	Soil sodicity	Low–mod.	May require gypsum if SAR >6.
			Other toxins	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Subtropical to temperate low rainfall (400–800mm)	Well	Only very salt-sensitive species likely to be impacted. It may be necessary to leach out salt by overirrigating the site. If this leads to offsite impacts, then consider more salt-tolerant species.	Soil sodicity	Low	Not required.
			Other toxins	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only salt-tolerant species that are not significantly affected by waterlogging.	Soil sodicity	Mod.	Likely to require gypsum particularly if SAR >6
			Other toxins	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Tropical low rainfall (500–800mm)	Well	Some salt-sensitive species may be impacted. In drier than normal periods it will be necessary to leach out salt by overirrigating the site. If this leads to offsite impacts then consider more salt-tolerant species.	Soil sodicity	Low–mod.	May require gypsum if SAR <6 and the soil has more clay than sandy loam.
			Other toxins	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only salt-tolerant species that are not significantly affected by waterlogging.	Soil sodicity	Mod.	Likely to require gypsum particularly if SAR >6.
			Other toxins	Low–mod.	Likely to require gypsum if SAR >6 and the soil has more clay than sandy loam.
Dry (250–500 mm)	Well	Grow only salt-tolerant species.	Soil sodicity	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
			Other toxins	Mod.–high	Likely to require gypsum if SAR >6.
	Poor	Grow only very salt-tolerant species that are not susceptible to waterlogging.	Soil sodicity	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
			Other toxins	Mod.	Likely to require gypsum if SAR >6 and the soil has more clay than sandy loam.
Arid (<250 mm)	Well	Grow only salt-tolerant species. May need to restrict applications to less than 10 ML/year in very dry conditions.	Soil sodicity	Low	Undertake detailed analysis and determine maximum soil loading.
			Other toxins	Mod.–high	Likely to require gypsum if SAR >6
	Poor	Grow only species that are very salt tolerant. Restrict applications to less than 10 ML/year.	Soil sodicity	Low	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
			Other toxins	Low	Not required.

Table A2: Risk assessment for irrigation using brackish water with a conductivity of 1000–2000 µS/cm

Climate zones	*Soil drainage*	*Range of plant types that can be grown*	*Other hazards*	*Risk*	*Potential preventative measures*
Moderate to wet rainfall (>800 mm/yr)	Well	Grow only species with some salt tolerance except if rainfall >1200 mm/year. In unusually dry periods it may be necessary to leach out salt by overirrigating the site.	Soil sodicity	Low–mod.	May require gypsum if SAR>6 and soil is more clayey than sandy loam.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only species that are have some salt tolerance and can withstand waterlogging.	Soil sodicity	Mod.–high	Likely to require gypsum.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Subtropical to temperate low rainfall (400–800mm)	Well	Grow only species with some salt tolerance. In unusually dry periods it may be necessary to leach out salt by overirrigating the site. If this leads to offsite impacts then consider more salt tolerant species.	Soil sodicity	Low–mod.	Likely to require gypsum if SAR >6 and soil is more clayey than sandy loam.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only salt species that can withstand waterlogging.	Soil sodicity	High	Likely to require significant gypsum.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Tropical low rainfall (500–800mm)	Well	Grow only species with some salt tolerance. In unusually dry periods it may be necessary to leach out salt by overirrigating the site. If this leads to offsite impacts then consider more salt-tolerant species.	Soil sodicity	Low–mod.	Likely to require gypsum if SAR >6 and soil is more clayey than sandy loam.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only salt species and that can withstand waterlogging To avoid raising soil salinity. May need to restrict irrigation applications even when there is an irrigation demand.	Soil sodicity	High	Likely to require significant gypsum.
			Other toxins	Low–mod.	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Dry (250–500 mm)	Well	Grow only very salt-tolerant plant species. Leaching irrigations or resting the irrigation site for periods may be needed.	Soil sodicity	Mod.–high	Will require gypsum if SAR<6 and soil is more clayey than sandy loam.
			Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Only plants with very high salt tolerance and suited to waterlogged conditions will grow. Limit irrigation applications to avoid applying too much salt.	Soil sodicity	Very high	Will require gypsum if SAR <6. May need to acidify soil.
			Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Arid (<250 mm)	Well	Only plants with very high salt tolerance will grow. Limit irrigation to avoid applying too much salt.	Soil sodicity	Mod.–high	Likely to require gypsum if SAR <6 and soil is more clayey than sandy loam.
			Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Only plants with very high salt tolerance and suited to waterlogged conditions will grow, sto avoid applying too much salt.	Soil sodicity	Very high	Will require gypsum if SAR <6 May need to acidify soil.
			Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.

Table A3: Risk assessment for irrigation using brackish water with a conductivity of 2000–3000 µS/cm

Climate zones	*Soil drainage*	*Range of plant types that can be grown*	*Other hazards*	*Risk*	*Potential preventative measures*
Moderate to wet rainfall (>800 mm/yr)	Well	Grow only species with some salt tolerance. In unusually dry periods it may be necessary to leach out salt by overirrigating the site.	Soil sodicity	Low–mod.	May require gypsum if SAR >6 and soil is more clayey than sandy loam.
Moderate to wet rainfall (>800 mm/yr)	Well	Grow only species with some salt tolerance. In unusually dry periods it may be necessary to leach out salt by overirrigating the site.	Other toxins	Mod.–high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Moderate to wet rainfall (>800 mm/yr)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. May need to restrict irrigation in very dry years.	Soil sodicity	High	Will require gypsum if SAR >6. May need to acidify soil.
Moderate to wet rainfall (>800 mm/yr)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. May need to restrict irrigation in very dry years.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Subtropical to temperate low rainfall (400–800mm)	Well	Grow only species with salt tolerance. In dry periods it may be necessary to leach out salt by overirrigating the site.	Soil sodicity	Mod.–high	Likely to require gypsum if SAR >6 and soil is more clayey than sandy loam. May need to acidify soil.
Subtropical to temperate low rainfall (400–800mm)	Well	Grow only species with salt tolerance. In dry periods it may be necessary to leach out salt by overirrigating the site.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Subtropical to temperate low rainfall (400–800mm)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. Likely to need to restrict irrigation in very dry years.	Soil sodicity	High	Likely to require gypsum if SAR >6. May need to acidify soil.
Subtropical to temperate low rainfall (400–800mm)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. Likely to need to restrict irrigation in very dry years.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Tropical low rainfall (500–800mm)	Well	Grow only species with significant salt tolerance. In dry years restrict amount of water applied.	Soil sodicity	Mod.–high	Will require gypsum if SAR >6 and soil is more clayey than sandy loam. May need to acidify soil.
Tropical low rainfall (500–800mm)	Well	Grow only species with significant salt tolerance. In dry years restrict amount of water applied.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Tropical low rainfall (500–800mm)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. Restrict irrigation in very dry years.	Soil sodicity	High	Will require gypsum if SAR >6. May need to acidify soil.
Tropical low rainfall (500–800mm)	Poor	Grow only species with significant salt tolerance that are not prone to waterlogging. Restrict irrigation in very dry years.	Other toxins	Mod.–high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Dry (250–500 mm)	Well	Grow only extremely salt-tolerant species. Restrict volume of water.	Soil sodicity	High	Will require gypsum if SAR <6 and soil is more clayey than sandy loam. May need to acidify soil.
Dry (250–500 mm)	Well	Grow only extremely salt-tolerant species. Restrict volume of water.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Dry (250–500 mm)	Poor	Grow only extremely salt-tolerant species and restrict volume of irrigation water.	Soil sodicity	Very high	Will require gypsum if SAR <6. Will need to acidify soil.
Dry (250–500 mm)	Poor	Grow only extremely salt-tolerant species and restrict volume of irrigation water.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Arid (<250 mm)	Well	Extremely salt-tolerant species and restrict volume of irrigation water.	Soil sodicity	High	Likely to require gypsum if SAR <6 and soil is more clayey than sandy loam.
Arid (<250 mm)	Well	Extremely salt-tolerant species and restrict volume of irrigation water.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Arid (<250 mm)	Poor	Extremely salt-tolerant species and restrict volume of irrigation water.	Soil sodicity	Very high	Will require gypsum if SAR <6. Will need to acidify soil.
Arid (<250 mm)	Poor	Extremely salt-tolerant species and restrict volume of irrigation water.	Other toxins	High	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.

Table A4: Risk assessment for irrigation using brackish water with a conductivity of 3000–4000 µS/cm

Climate zones	*Soil drainage*	*Range of plant types which can be grown*	*Other hazards*	*Risk*	*Potential preventative measures*
Moderate to wet rainfall (>800 mm/yr)	Well	Grow only very salt-tolerant plants unless rainfall greater than 1500 mm.	Soil sodicity	Low–mod.	May require gypsum if SAR >6 and soil is more clayey than sandy loam. May require soil acidification.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only very salt-tolerant plants. May need to restrict amount of irrigation.	Soil sodicity	Very high	Will require gypsum if SAR >6. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis and determine maximum soil loading (Table x?).
Subtropical to temperate low rainfall (400–800mm)	Well	Grow only very salt-tolerant plants. May need to restrict amount of irrigation or use leaching irrigations.	Soil sodicity	Mod.–high	Likely to require gypsum if SAR >6 and soil is more clayey than sandy loam. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Grow only very salt-tolerant plants. Likely to need to restrict amount of irrigation.	Soil sodicity	Very high	Will require gypsum if SAR >6. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Tropical low rainfall (500–800mm)	Well	Grow only very salt-tolerant plants. May need to restrict amount of irrigation.	Soil sodicity	High	Will require gypsum if SAR >6 and soil is more clayey than sandy loam. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Extremely salt-tolerant species and/or restrict volume of irrigation water.	Soil sodicity	Very high	Will require gypsum if SAR >6. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Dry (250–500 mm)	Well	Likely to be unsuitable. Extremely salt-tolerant species and/or significant restriction volume of irrigation water.	Soil sodicity	High	Will require gypsum if SAR <6 and soil is more clayey than sandy loam. May need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Likely to be unsuitable. Extremely salt-tolerant species and/or significant restriction volume of irrigation water.	Soil sodicity	Extreme	Will require gypsum if SAR <6. Will need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
Arid (<250 mm)	Well	Not suitable unless irrigation restricted significantly.	Soil sodicity	High	Likely to require gypsum if SAR <6 and soil is more clayey than sandy loam.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.
	Poor	Not suitable unless irrigation restricted significantly.	Soil sodicity	Very high	Will require gypsum if SAR <6. Will need to acidify soil.
			Other toxins	Very high	Undertake detailed analysis of brine and soil to be irrigated and determine maximum soil loading.

Appendix B—Crop species and management for saline areas

The following grasses and shrubs are generally recommended for saline areas, usually without irrigation, and therefore are likely to be suitable under saline irrigation conditions.

Puccinellia

Puccinellia is a moderately salt-tolerant grass that is highly palatable and has a low-salt concentration in the leaves. It will tolerate waterlogging. It forms tussocks up to 40 cm high and wide and has long thin leaves. Its growing points are embedded in the base of the plant, which is compact and resistant to grazing. Puccinellia will shoot with the onset of cooler late autumn temperatures and respond to dew before the opening rains.

The plants grow from mid-autumn to spring and mature (hay-off) in November/December, remaining dormant over summer to early autumn. It has its highest grazing value in winter and spring while green and before flowering. Nutritive value declines as the plant flowers, matures and senesces, and further declines through summer and autumn even though it is still palatable. It changes from a high-quality, highly digestible feed capable of supporting high animal live-weight gains in spring to less than a maintenance ration in late summer/autumn.

Mature stands can be grazed after the opening rains (or irrigation), when they rapidly produce green feed, and/or ,more commonly, as dry feed in late summer–autumn, although at this stage some supplementation will be needed unless weight loss in the animals is acceptable. Leaving the grass feed standing over summer shades the soil, reducing the concentration of salts at the soil surface through evaporation.

Compared with the more salt-tolerant distichlis and marine couch (discussed below), these grasses have the great advantage of being available from commercial seed suppliers. As a precaution, do not apply heavy grazing pressure, particularly when young. Grazing in the establishment year is not recommended. Puccinellia is very slow to establish, particularly in tableland environments.

Tall wheatgrass

Tall wheatgrass (*Thinopyrum ponticum*) is a temperate perennial grass that tolerates soils of moderate subsoil salinity (4000–8000 µS/cm) without any significant yield reduction) and moderate waterlogging. It has been widely used as a saltland pasture in south-west Victoria and the upper south-east of South Australia, often in a shotgun mix with puccinellia and balansa and strawberry clovers.

Though a warm-season grower, tall wheatgrass is not a subtropical species, so it is not frost sensitive. This makes it well suited to southern Victoria and South Australia. Tall wheatgrass can produce significant biomass given sufficient summer moisture. It is strongly tussock-forming and, if not well managed, can quickly become clumpy and unpalatable to livestock. In addition, the clumps or tussocks can become so large as to make a paddock almost untrafficable. If allowed to run up to seed it can spread and colonise areas where it is unwanted, particularly along watercourses.

The two common tall wheatgrass cultivars, Dundas and Tyrell, have similar yields and salinity tolerance across a range of saline soils in western Victoria. Dundas is a selection from within Tyrell for enhanced leafiness and quality. Dundas is the recommended variety for reasons associated with quality for livestock, and for minimising the risk of spread as an environmental weed.

Research indicates that mature plants have relatively similar salinity tolerance but lower waterlogging tolerance than puccinellia. The lower persistence of tall wheatgrass at waterlogged sites in South Australia supports this theory, as shotgun mixtures of pasture seed segregate. Puccinellia persists on the lower-lying, waterlogged areas, while tall wheatgrass persists on the slightly higher ground and prevents undesirable species such as silver grass (*Vulpia spp.*) establishing. Tall wheatgrass is more persistent and productive at better-drained sites.

Distichlis

Distichlis, a native of the Americas, naturally occurs in brackish to saline marshes. It is highly salt tolerant and can stand significant waterlogging. It is a warm-season (C4) grass. The roots form air channels that enable gas exchange under waterlogged conditions. Distichlis grows well with soil salinities of 7000 to 28 000 µS/cm but can survive up to 80 000 µS/cm.

Establishment is difficult, as propagation requires transplanting established root material. However, once established, it is tolerant of heavy grazing. The vegetatively-established grasses are not salt accumulators and therefore likely to be nutritionally similar to their non salt-tolerant relatives

Distichlis has not yet been widely tested in Australia.

Marine and salt water couch

Marine couch and saltwater couch (*Sporobolus virginicus*) are extremely salt tolerant, widespread and therefore very adaptable. Marine couch has been observed growing under extreme saline environments. Studies by Aldous (2003) showed marine couch can be sustained at salt concentrations of 31 250 µS/cm, with growth beginning to decline at ~40,000 µS/cm, and rapid decline occurring at a salt concentration of 62 500 µS/cm.

Vegetative grasses can provide good groundcover and some grazing. However, seeds have poor germination ability. The vegetatively-established grasses are not salt accumulators and therefore likely to be nutritionally similar to their non-salt-tolerant relatives.

Actual levels of pasture production from these vegetative grasses have rarely been measured and little is known about the agronomic management (weed control, fertiliser use) of them. Animals will graze them, but animal performance levels have not been reported.

Because of the expense of establishing them, these plants tend to be used as turf grasses where the soil is saline or where only saline water is available for irrigation. A good example of this is the use of saltwater couch on a golf course in Western Australia where the ‘irrigation’ water is as salty as half-strength seawater. Under these conditions, saltwater couch has thrived. Marine couch has also been widely used in Queensland.

Kikuyu and Rhodes grass

Kikuyu (*Pennisetum clandestinium*) and Rhodes grass (C*hloris gayana*) are subtropical species that are widely grown in non-saline areas of southern Australia, including the Southern Coast of Western Australia, Kangaroo Island and Upper South East of South Australia and the South West and Gippsland Districts in Victoria. Kikuyu and Rhodes grass will grow well in soils of low salinity (2000–4000 µS/cm) and also into the moderate salinity (4000–8000 µS/cm) range.

Both are spreading grasses. Rhodes grass has runners (stolons), while kikuyu has both runners and rhizomes (underground runners). This spreading habit means they will spread vegetatively to fill in gaps, which is an advantage on saline sites as soil salinity can inhibit recruitment from seed. However, kikuyu's strongly creeping habit means that, over time, it can dominate mixed swards, and is often sown in non-saline situations without other grasses because of this. Rhodes grass is more suited to mixed swards.

New salt-tolerant varieties of Rhodes grass have been developed for the Middle East for irrigation with brackish water on well-drained soils, but the performance of these 'salt-tolerant' varieties has yet to be evaluated in southern Australia.

Barley

Barley will experience a 10% reduction in yield at soil salinity of 10 000 µS/cm and, consequently, is a potentially good solution for saline irrigation water. However, it will not tolerate waterlogged conditions and will only grow in the more temperate parts of Australia.

Salt-tolerant legumes

Legumes are usually much less salt tolerant than grasses, apparently because of their relative inability to exclude the toxic salts (ions) that disturb enzyme activity once taken up into the plant. Furthermore, for legumes to achieve their potential they must fix nitrogen, which means that not only does the legume need to be able to tolerate salinity, but that a salt-tolerant rhizobia is also needed, Finally, a 'salt-tolerant' symbiotic relationship between the legume and the rhizobia must be able to form in the hostile environment of a saline soil.

Clovers and medics underpin most Australian improved pastures on non-saline land, not only for their significant contribution to animal nutrition, but also on account of the nitrogen they can fix from the atmosphere, which later becomes available to grasses. Unfortunately, most common legumes have very low salt tolerance.

The most common legume species for saltland are (from most to least salt tolerant) burr medic, strawberry clover, lucerne and balansa clover. However, this ranking is only meaningful when set alongside waterlogging tolerance, which will often eliminate lucerne and burr medic from the choices.

Balansa is highly waterlogging-tolerant and may work if established after autumn rain (when it can experience quite low surface-soil salinity and early-flowering cultivars can set seed and avoid the high salinity levels over summer.

Local shotgun mixtures often include other subtropical species with lower salinity tolerances—for example, bambatsi panic seems to be a good bet for the hard-setting clays in northern NSW and is reputed to have some salt tolerance. Because legumes have only limited tolerance to salinity, in most saltland pasture situations the critical component is the salt-tolerant grass or shrub.

Saltbush

There is very little information is available about the irrigation of an old man saltbush plantation, but there is potential to irrigate the saltbush plants to boost plant growth and, in turn, increase biomass production per hectare.

Irrigated saltbush can potentially be used for[8]:

- grazing
- as a fodder reserve
- to stabilise eroded soils or soils at risk of erosion
- future carbon emissions trading schemes
- ‘clearing offsets’.

There are three commonly used saltbush species—old man saltbush (*Atriplex nummularia*), river saltbush (*Atriplex amnicola*) and wavy leaf saltbush (*Atriplex undulata*). Dense saltbush plantings are recommended for saltland sites with high summer salinity (subsoil values of 8000–16 000 µS/cm). Old man saltbush can endure soil water half the strength of seawater provided there is free drainage.

Cotton

Cotton is a subtropical climate crop grown in Australia over the summer months. It needs a soil with excellent water-holding capacity and aeration and good drainage, as it cannot withstand excessive moisture and waterlogging. The major groups of soil for cotton cultivation are alluvial, black, and red sand loam.

Cotton is a dual-purpose crop, widely used for fibre and oil purposes throughout the world. It is placed in the moderately salt-tolerant group of plant species with a salinity threshold level 7700 µS/cm. Its growth and seed yield is severely reduced at high salinity levels and different salts affect growth to a variable extent. However, inter- and intraspecific variation for cotton salt tolerance is considerable and can therefore be exploited through specific selection and breeding to improve salt tolerance of the crop.

Leucaena

Leucaena leucocephala is a species of small minosoid tree native to southern Mexico and northern central America. It is suited to the climate of northern Australia, with plantations reported as far south as Goondiwindi, Qld, and northern NSW. Minimum temperatures less than 15–20°C limit growth. *L. leucocephala* is used for a variety of purposes such as firewood, fibre and livestock fodder.

It has been considered for biomass production as its reported yield of foliage corresponds to a dried mass of 2000–20 00 kg/ha/year, and of wood to 30–40 m^3/ha/year, with up to twice those amounts in favourable climates. Leucaena is also efficient in nitrogen fixation at more than 500 kg/ha/year. It grows fast, young trees reportedly reaching a height of more than 6 m in two to three years. It has a similar hydrological impact as eucalypts (i.e. deep-rooted, potentially high water-using crop). It requires well-drained soils with pH above 5.5, or above 5.0 where aluminium saturation is very low. It is intolerant of soils with low pH, low P, low Ca, high aluminium saturation, high salinity and waterlogging. It is tolerant of moderate salinity and alkalinity.

During the 1970s and 1980s Leucaena was promoted as a ‘miracle tree’ for its multiple uses. It has also been described as a ‘conflict tree’ in that it is promoted for forage production but also spreads like a weed in some places. One of its drawbacks is its susceptibility to insect infestations. The seeds contain mimosine, an amino acid known to be toxic to non-ruminant vertebrates, but Leucaena provides an excellent source of high-protein cattle fodder.

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[8] *Inland Botanics* 2010.