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WaterSmart Pastoral Production™ Project Literature Reviews

Groundwater salinity, desalination equipment and practices applicable to the rangelands pastoral industry: A review

David de Vries

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Centre for Sustainable Arid Towns

CRC AUSTRALIA

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A review

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Key points

- There are significant gaps in information on groundwater quality in arid pastoral lands and in its accessibility for pastoralists. Interviews with pastoralists indicated that placement of new bores was based primarily on local knowledge (particularly of the bore drilling team) rather than use of a database.
- In interviews with pastoralists and equipment suppliers/installers/maintainers, the damage to pastoral infrastructure caused by salinity in water was not presented as a major problem.
- Decline in animal condition and health would be expected for water supplies containing total dissolved salts in the range 5–10 000 mg/ml for cattle and 10 000–13 000 mg/ ml for sheep.
- The key issue for reproductive success and growth in sheep reliant on saline drinking water is the survival of the 3–5 month old animal through the heat of the first summer.
- An important consequence of provision of saline drinking water through summer is that stock can graze only a very limited distance from watering points, resulting in adverse effects on stock food access and land degradation.
- No desalination systems are in use by the pastoral industry due to their prohibitive purchase costs and energy requirements.
- Hire of a reverse osmosis desalination system may be cost effective to enable a flock/herd to get through a dry summer.

Definitions

The Australian Natural Resources Atlas recognises two broad forms of salinity in Australia.

> *Primary or naturally occurring salinity is part of the Australian landscape, and reflects the development of this landscape over time. Examples are the marine plains found around the coastline of Australia, and the salt lakes in central and western Australia.*
>
> *Salts are distributed widely across the Australian landscape. They originate mainly from depositions of oceanic salt from rain and wind. Salt stored in the soil or groundwater is concentrated through evaporation and transpiration by plants. In a healthy catchment, salt is slowly leached downwards and stored below the root zone, or out of the system.*
>
> *Secondary salinity is the salinisation of land and water resources due to land use impacts by people. It includes salinity that results from watertable rises from irrigation systems (irrigation salinity) and from dryland management systems (dryland salinity). Both forms of salinity are due to accelerated rising watertables mobilising salt in the soil. There is no fundamental difference in the hydrologic process.*
>
> (Australian Natural Resources Atlas 2000)

This review focuses on the salinity of groundwater accessible by subterranean bores; that is, the water used for stock watering points.

Total salinity for the purposes of this review covers not only sodium chloride, but total salts, and may feature magnesium, calcium and other metals as well as their anionic pairs – carbonates, sulphates, etc.

In this review, salinity is expressed in two ways: total dissolved salts (TDS), expressed in units of mg/L or ppm; and conductance, expressed in units of milliSiemens/m or µS/cm. For example, the maximum permissible level of soluble salts for human consumption by World Health Organization standards is 1500 mg/L or about 270 mS/m (WHO 2006).

To convert the electrical conductivity of a water sample (µS/cm) to the concentration of total dissolved solids (TDS) reported in milligrams per litre (mg/L) in the sample, the conductivity must be multiplied by a factor between 0.46 and 0.9, depending on the unique mixture of dissolved materials. A widely accepted conversion factor is 0.55 for groundwater salinity of less than 7500 mg/L.

$$\text{TDS (mg/L)} = \text{Conductivity (µS/cm)} \times 0.55$$

Research from CSIRO commonly expresses salinity as a percentage: grams of NaCl per 100 ml; such that 1500 mg/L is equivalent to 0.15%. Note also that CSIRO research papers discussed in this review express % salt in feed as grams (g) salt per 100 g dried feed.

Introduction

This report summarises information about ground water salinity on pastoral lands, the associated problems and possible solutions. It also explores the potential for use of desalination technology to lessen the effects of saline water on stock. The report was commissioned to examine the following questions:

Question 1

Examine available maps of the extent of saline ground or surface water in relation to the pastoral industry across inland Australia and present consolidated picture of regions where there are likely to be saline water problems, where there are not, and where there are data gaps.

Question 2

Elucidate the damage to pastoral infrastructure (pumps, pipes, tanks) caused by salinity in water and estimate economic costs of the damage by interviewing some key pastoralists (suggested names as a starting point will be supplied), and equipment suppliers/installers/maintainers.

Question 3

Through interviews as noted above, determine what technologies exist to ameliorate these costs.

Question 4

Elucidate from literature the nature of the effect of salinity on the reproductive success and growth rate of sheep and cattle, and the growth rate of wool in sheep, and provide a synopsis of the problem and potential solutions.

Question 5

Identify from literature, the www, and interviews any existing commercially-available desalination systems for pastoral applications (i.e. that can reduce salinity to levels so that animal production efficiency improves), including manufacturers, product specifications, suppliers, maintenance requirements, known limitations and or faults; may include systems that are currently not used for or by the pastoral industry.

Question 6

If there are systems, estimate the number of users of the systems in rangelands and carry out some interviews with users in both cattle and sheep production regions to obtain first-hand testimonials of duration of use, perceived benefit, and problems encountered.

Groundwater salinity – problem regions for pastoral applications

The Bureau of Rural Services provides some useful resources for identifying the land available to the pastoral industry, such as the map below which shows grazing land use in tan.

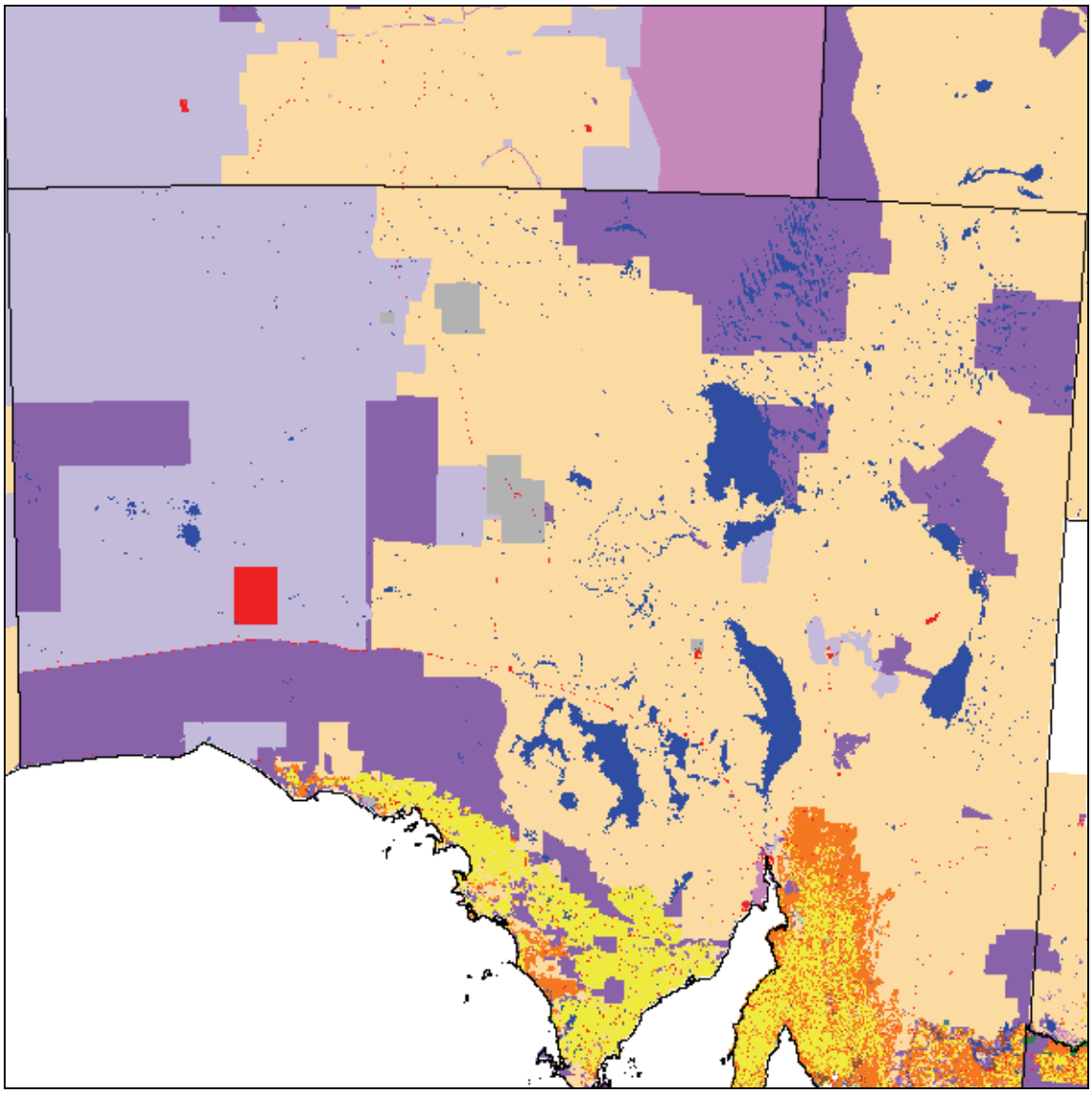


Figure 1: Land use map of south eastern SA (BRS)

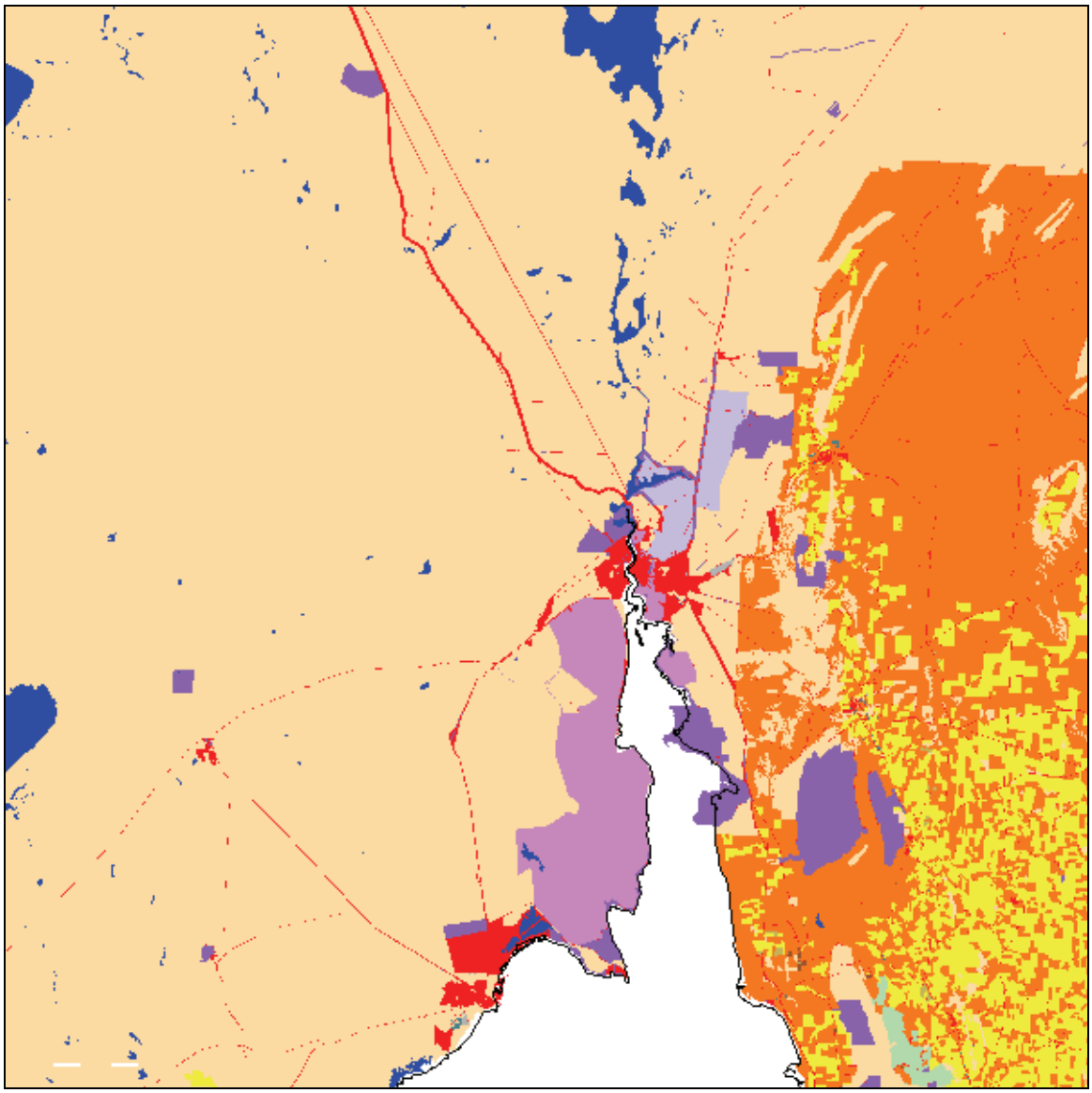


Figure 2: Land use map of south eastern SA (BRS)

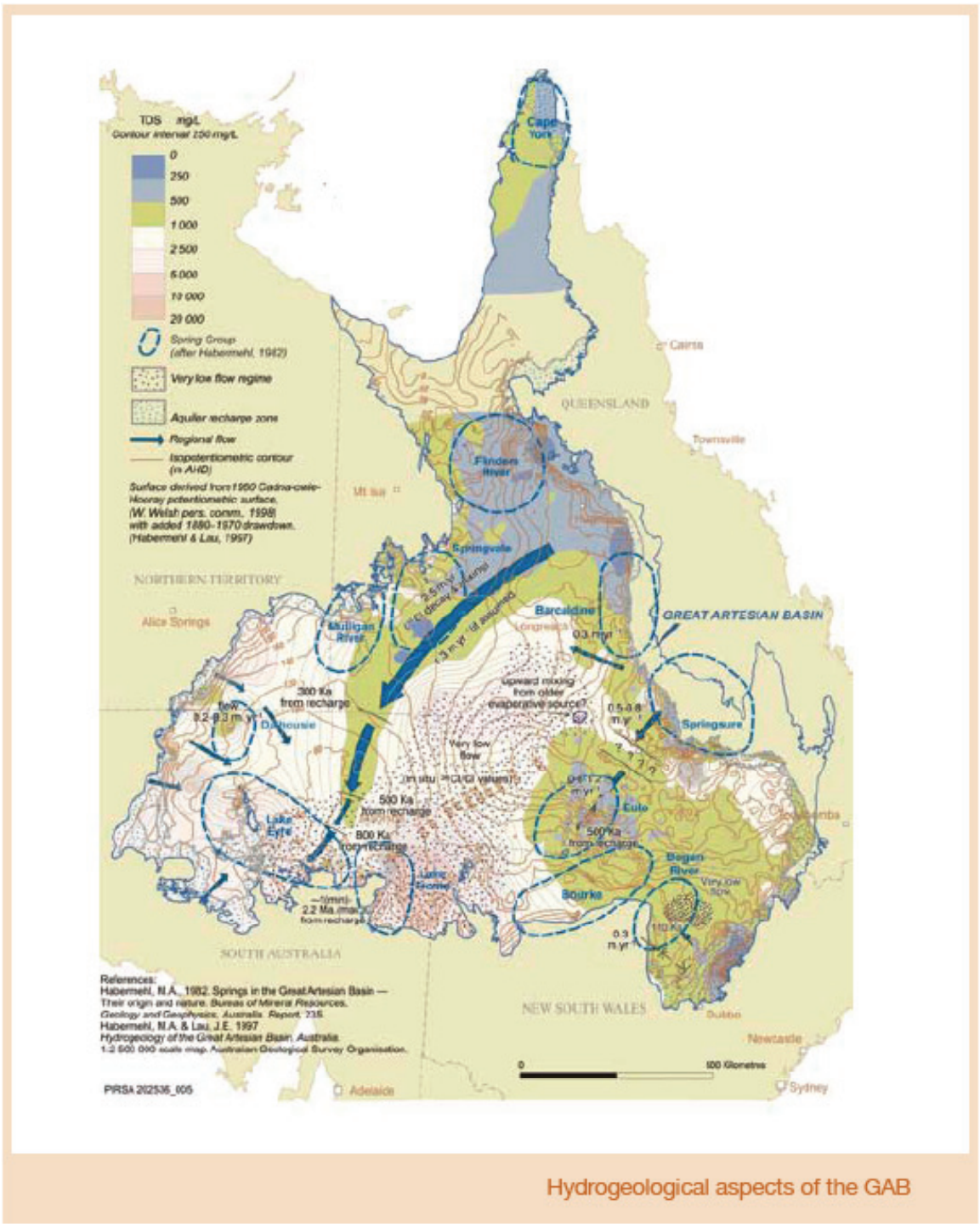
Measurements and observations from over 500 000 groundwater sites are stored in several databases across the country (BRS 1999). The BRS is endeavouring to set data standards and collate groundwater data:

> *Data about groundwater are collected and compiled by many organisations across Australia. The largest hydrogeological databases are maintained by State and Territory land and water agencies, supporting their role of managing the natural resources under their jurisdiction. These databases are populated by information derived from the registration of bores, as well as from monitoring programs initiated by the agency. Groundwater research or mapping agencies such as CSIRO, the universities and the Bureau of Rural Sciences (BRS) also actively collect groundwater data to achieve project outcomes. Organisations at a community level, such as Landcare and catchment groups, also routinely monitor their local groundwater system. Private consultants collect groundwater data in specific areas for their clients (Commonwealth of Australia 1999).*
>
> *A plethora of different databases makes the integration of data difficult for data users, particularly those involved in groundwater issues at a regional and national scale. This*

> *project will provide a distributed network of databases backed by an institutional framework that defines the policy and administrative arrangements for access to a clearing house network through which the data is made attainable (BRS nd).*

As we progress through this review, we note the limited nature of the data on groundwater salinity and its diverse storage.

The dominant aquifer for the continent is the Great Artesian Basin underlying 22% of the country, much of it pastoral inland Australia. Its salinity levels are usually acceptable, as outlined in Figure 3.



Hydrogeological aspects of the GAB

Figure 3: Hydrogeological aspects of the Great Artesian Basin (or GAB) including salinity expressed in TDS (SAAL 2006, p. 4.)

While the basin is subject to dramatic waste from unregulated bores and large demand from mines:

> *As long as we only use the compressed component of the stored water, and re-pressurisation occurs, the resource is generally considered sustainable in our time frame. In effect, limited abstraction of GAB water through artesian bores is farming pressure (as long as recharge occurs to re-pressurise the system). (SAAL 2006 p. 52)*

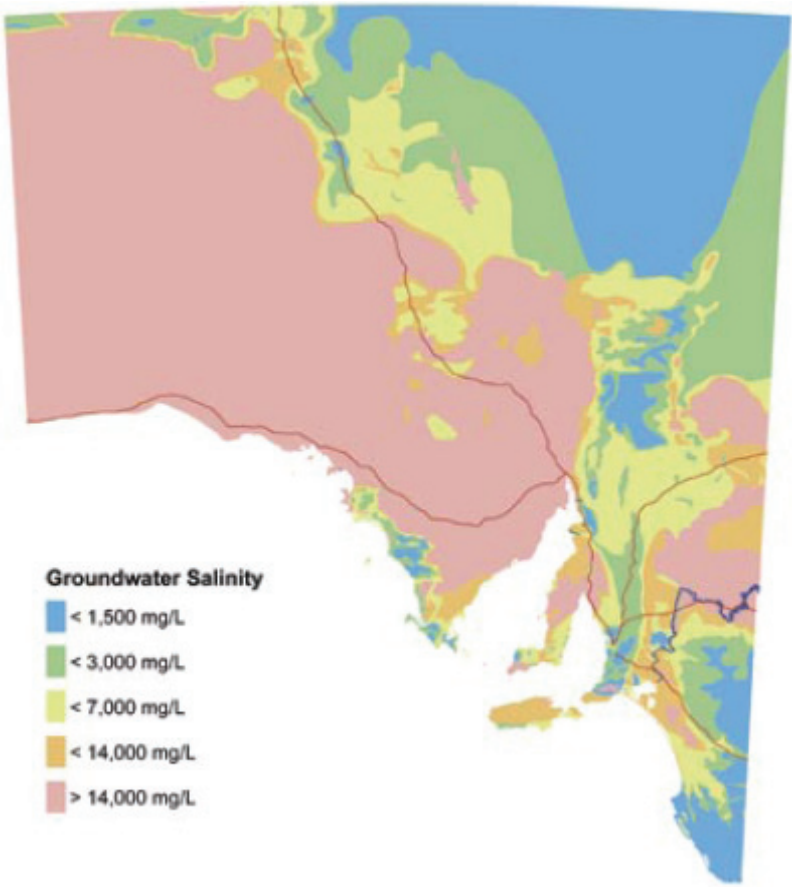


Figure 4: Distribution of groundwater salinity in SA
(Department of Water, Land and Biodiversity Conservation 2005)

In SA (see Figure 4), for other aquifers in arid areas:

> *There is a lack of understanding of the presence, extent and sustainable yield of shallow aquifer systems in the Arid Lands. Over extraction can deplete local aquifers and may draw in surrounding saline groundwater. (SAAL 2006, p. 54)*

In summary:

> *Very little long term monitoring in the Arid Lands has been undertaken in the past. The low population and vast distances in the SAAL (South Australian Arid Lands) Region means that monitoring is costly and difficult and because the resources are remote, they are easily overlooked. In some areas, even basic information about the presence or absence of water resources and dependent ecosystems remains rudimentary. What we do know is that the water cycle in the arid areas is one of boom and bust, and that one cycle occurs over decades. To provide meaningful information on water resources in the area, consistent and integrated monitoring needs to be undertaken for lengths of around 50 years. This information is not currently available. (SAAL 2006, p. 17)*

The poor state of groundwater studies in WA was recently reviewed (Australian Academy of Technological Sciences and Engineering 2005). Their report identified that:

> *No strategic groundwater exploration by Government has occurred since responsibility for such exploration was passed from the Geological Survey to the Water and Rivers Commission in 1996, then to the Department of Environment in 2001, and to the Department of Water in 2005.*
>
> *The Department of Water needs to reactivate strategic groundwater exploration, which will require the hydrogeology section to fully re-establish its former roles in:*
>
> - *groundwater exploration and resources assessment*
> - *hydrogeological mapping*
> - *maintenance of the groundwater database*
> - *publication of groundwater reports.*
>
> (Australian Academy of Technological Sciences and Engineering 2005).

For the NT a map of groundwater salinity is provided by the Department of Natural Resources, Environment and The Arts (DNRETA) on the internet (see Figure 5 below). A slightly more detailed version can be found in Figure 18 of the DNRETA report *Dryland Salinity Hazard Map of the Northern Territory* (Tickell 1994).

Very Fresh	Less than 500 mg/litre	Suitable for most uses
Fresh	500 to 1500 mg/litre	Suitable for most uses
Brackish	1500 to 3000 mg/litre	Unsuitable for human consumption
Saline	More than 3000 mg/litre	Suitable for limited stock and industrial uses

Figure 5: Northern Territory Groundwater Salinity
(Department of Natural Resources, Environment and The Arts 2007)

DNRETA also have a groundwater database with water quality information on many of the 30 000 water bores across the territory.

> *For example in some areas salinities may vary widely while in others they may be either consistently high or low. It is hard to generalise when looking at such a vast area as the arid zone of the NT.* (S Tickell 2006, pers. comm. 18 August)

A correlate of the patchy nature of groundwater data in arid Australia was obtained during interviews. Summarising these interviews, arid land pastoralists and researchers indicated that placement of new bores was based primarily on local knowledge (particularly of the bore drilling team) rather than use of a database (see interviews in Appendix 2).

These interviews also emphasised that hypersaline and relatively fresh water could be in very close proximity to each other, sometimes within a few hundred metres. At this resolution, broad scale groundwater data collection may never be effective in ensuring the water quality of a specific bore.

Problems and solutions to water salinity damage in pastoral equipment

In interviews with pastoralists and equipment suppliers/installers/maintainers the damage to pastoral infrastructure caused by salinity in water was not presented as a major problem. (Refer to interviews in Appendix 2).

To some extent this may be due to problems such as limited stocking rates and limited lifespan of equipment being accepted as a fact of life for the region. Choice of stainless steel pumps (relatively high cost) was seen as important in working with saline water.

Strategies used to deal with high salinity by some of the interviewees included:

Interviewee	Strategies and comments on high water salinity
Wool producer, Nullarbor Plain, WA.	Has severe problems with salinity. Uses antirust formulas and stabilisers for rust problems. Trialling rare earth and magnetic treatment on pipes to change characteristics of water.
Cattle producer, central Australia, NT.	'Salt' not an issue. Calcium build up biggest problem. Accumulates on floats and anything out of water. Some gal pipe better than others – forms holes and then rusts. Many bores run fine for 6–7 years, Mono bores (vertical helical rotor) last 10–12 years.
Pump equipment supplier, central Australia, NT.	Salinity 'not as big a problem as you might think'. Pipes cheap or sometimes he uses stainless steel. Pumps: If an issue, puts in a plastic pump and replace every three years. Also uses Grundfos quality stainless steels and others stainless steel pumps if dealing with water approaching high salinity levels.

A cattle producer in northern SA found that, counter to the accepted argument of high salinity being a problem, lower salt bores are more corrosive, and high salt bores form a protective layer.

Effects of water salinity on the reproductive success and growth rates of livestock

Most states offer similar information on the water needs for stock. For example, in NSW Robson and Curran (2003) undertook a review of livestock tolerance to water salinity levels.

Table 1: Tolerances of livestock to total dissolved solids (salinity) in drinking water (mg/L) (Markwick 2004)

Livestock	No adverse effects on animals expected	Animals may have initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production	Loss of production and decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually
Beef cattle	0–4000	4000–5000	5000–10 000
Dairy cattle	0–2500	2500–4000	4000–7000
Sheep	0–4000	4000–10 000	10 000–13 000[(a)]

The Agriculture Department of WA offer two good papers for farmers on stock and water salinity (Luke 1987, Department of Agriculture and Food 2004).

Water intake requirements

Livestock water requirements may be obtained primarily through green pasture, especially for sheep. However, in dryland conditions, cattle (dry stock, i.e. non-lactating, 400 kg) require 35–80 litres of water a day. Adult dry sheep require 2–6 litres of water a day on grassland and 4–12 litres of water a day on saltbush.

During drought, stock require more water as they are forced to select more fibrous and less digestible feed. This extra water is used to maintain the movement of the coarse feed in the gut. As drought worsens and stock become weaker, marginal waters may become unsuitable as the animals' tolerance of the salt decreases.

Feeding salt or salt-based licks or blocks during dry periods increases water intake. If water quality is marginal, this added salt intake may depress appetite and cause digestive upsets — the opposite of the supplement's purpose.

In pastoral areas, stock grazing saltbush or other chenopod plants require large quantities of relatively low-salinity water. This is because of the high level of salt in the diet and the need for a high water turnover to maintain the salt balance in the body (Thomas et al in press).

The effect of salinity on a range of parameters in sheep – including feeding, weight and wool growth – was studied in a series of papers from WA (Peirce 1959a,b,c,d,e; Wilson 1966, 1968; Wilson & Hindley 1970; Wilson & Leigh 1970) (see abstracts in Appendix 1). In summary, this research identified an interplay between water salinity, food salinity (halophytic plants such as saltbush) and drought conditions (availability of fresh growth). Adverse effects were observed at 1% water content of feed, which were exacerbated by high salt feed and lack of low salt pasture.

Wool growth was documented in a recent study looking at the impact of sodium and potassium in the diet (Masters et al 2005). While both salts had adverse effects on wool growth, weight gain and feed intake, curiously high sodium plus increased potassium were beneficial to wool growth expressed as mg/cm2. The abstract is included in Appendix 1.

Recent research at CSIRO Livestock Industries: Centre for Environment and Life Sciences and the Cooperative Research Centre for Plant-based Management of Dryland Salinity in Wemble, Western Australia, seeks to address the effects of high salt diets on feed selection and wool production (Thomas et al in press).

The key issue for reproductive success and growth in sheep reliant on saline drinking water is the survival of the 3–5 month old animal through the heat of the first summer (see Interviews 1, 4 and 5 in Appendix 2).

An important consequence of providing saline drinking water during summer is that stock can graze only a very limited distance from watering points, which results in adverse effects on stock food access and land degradation.

A possible way forward is to educate pastoralists about the sources of salt in their landscape and the role of careful management in avoiding excess salt load. High drinking water salinity may be alleviated by low salt feed. High salt feed may be compensated by good availability of low salinity water. The combination of halophytic feed, highly saline water and drought-induced loss of non-halophytic pasture should be avoided as it will adversely affect health and productivity.

Practical solutions for managing saline water and pasture include running mostly wethers, not ewes, to avoid summer losses (Interview 1 in Appendix 2), and careful management of non-saline water, non-saline perennials and stocking levels in summer (Interviews 4 and 5 in Appendix 2).

Commercially available desalination systems for pastoral applications

No desalination systems exist that are appropriate for general use by the industry. Indeed, no-one in the interviews expressed any optimism for this technological fix. While reverse osmosis technology is obviously applicable to desalinating water, it is not economically viable due to its high energy requirement. One producer of systems for remote human community use (Suntec, Interview 8) puts the value at ~$1/L when all expenses including power and maintenance are included.

The design requirements for a reverse osmosis (RO) system applicable to a pastoral watering point are different from other applications. These specific requirements are:

i. High salinity is acceptable (5000 ppm).

ii. Water required at 5–15,000 L/d per watering point e.g. 1000 sheep drinking 6 L/d = 6000 L/d.

iii. Water desalination not required all year. Only necessary when heat coincides with lack of surface water and low water content of saline feed; that is, summer in temperate areas, dry season in the tropics.

When this reviewer put these design requirements to two potential providers, it became apparent that the technology may be on the verge of affordability. Note, these comments are more informal thought experiments than research proposals, or fixed quotes.

1. Dr. Bryce Richards, Lecturer – School of Engineering and Physical Sciences, United Kingdom participated in the design of a Reverse Osmosis Solar Installation (known as ROSI) with Dr Andrea Schaefer from the University of Wollongong (also now in the UK). They demonstrated their prototype in Alice Springs in 2005. Importantly, this system was designed to achieve human drinking water standards and its output volume was far below that required for stock. Dr Richards described how an RO system could be built to provide 5000 L/d of 5000 ppm water using 500–700 W of photovoltaic panels. Such a system would be transportable and might be affordable. Further research and development is required for proof of this concept. See Interview 6.

2. A recent player in the RO market is Coates Hire. Indicative pricing is provided in Interview 11 for their smallest plant that produces 10 kL/d of water at human drinking quality. It costs ~$2200/wk, including rental and fuel, giving a price for the water of $5.50/kL. Other expenses include a truck to mount the plant, and tanks and an evaporation pond at each site. While expensive, this cost may dramatically undercut water haulage options. Such a plant would be mobile, capable of servicing 2 or 3 stock watering sites during a dry season, and also of value in supplying human water needs. See Interview 11.

The authors could find no instances of desalination systems being used in the rangelands to provide low salinity water for stock.

A Nullarbor group of pastoralists are looking at magnetic and rare earth devices as water conditioners for their saline bore water. They do not claim to change salinity but modify the chemical structure. Two conditioners are currently being tested by this group with controls and conditioners on neighbouring paddocks. Monitoring involves counting how many animals are at each water point. Also vegetation and dung counts for sheep and kangaroos are being undertaken. Trials are over 18 months. See Interviews 1, 4 and 5.

While this technology may be considered ‘fringe’, the group have received advice on designing controlled experiments and may get interesting results.

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Appendix 1: Abstracts of selected papers

Wilson AD 1966, 'The tolerance of sheep to sodium chloride in food or drinking water', *Australian Journal of Agricultural Research*, vol. 17, pp. 503–514.

Sodium chloride was added in different amounts to the diet or drinking water of Merino sheep. The food intake declined at the higher concentrations (10–20% in food, 1.5–2.0% in water) but the decline was not related solely to the amount of sodium chloride ingested. The water intake increased in relation to the amount of sodium chloride ingested, irrespective of diet or means of ingestion (food or water).

It is suggested that the acceptability or taste of food or water containing high levels of salt is a factor in determining the salt tolerance of sheep. The salt intake–water intake relationship is used to estimate the possible saving of fresh water to be derived from diluting it with saline bore water.

Wilson AD 1968, 'The effect of high salt intake or restricted water intake on diet selection by sheep', *British Journal of Nutrition*, vol. 22, pp. 583–588.

I. In three experiments sheep were offered a choice of two rations: one high in NaCl (7.5 or 15%) and one low in NaCI. The intake of each ration was recorded when fresh water was freely available, when increasing amounts of NaCl were added to the drinking water and when the amount of fresh water available was restricted.

2. Low levels of NaCl in the drinking water or mild restriction of available water did not effect the diet selected. At higher levels, total food intake was reduced and the reduction was sustained entirely by the high-salt ration. The intake of the low-salt ration remained the same or increased, so that the selected diet then contained an increased proportion of the low-salt ration. The effects of adding NaCl to the drinking water and of water restriction were similar.

3. It was concluded that sheep with a choice of high- and low-salt rations can partly avoid the stress of saline drinking-water or restricted water supply by changing the proportion of each ration eaten.

Wilson AD and Leigh JH 1970, 'Comparisons of the productivity of sheep grazing natural pastures of the Riverine Plain', *Australian Journal of Experimental Agriculture and Animal Husbandry*, vol. 10, no. 46, pp. 549–554.

The productivity of Merino sheep grazing on the semi-arid natural shrub (*Atriplex vesicaria*) and grassland (*Danthonia caespitosa-Stipa variabilis*, *D. caespitosa*, *S. variabilis*) pastures of the Riverine Plain was measured over three years. At 0.5 sheep to an acre, the sheep on *A. vesicaria* (bladder saltbush) community at first grew more wool than those on the grasslands, but wool growth rate declined in autumn to the same degree as on the grassland. In the second year, most of the *A. vesicaria* bushes did not recover from grazing and wool growth rate fell to half that on the grasslands. The sheep on *A. vesicaria* had to be removed in the second year, but on the grasslands there was no evidence that sheep could not be maintained indefinitely at that stocking rate. At 1.0 sheep to an acre, both the *A. vesicaria* and the *D. caespitosa-S. variabilis* grassland were incapable of maintaining the sheep for the duration of the experiment.

Wool growth of the sheep on the grasslands showed an annual rhythm, with high growth rate in spring (14 g per day) followed by a gradual decline in rate to 6–8 g per day in late summer and autumn. However, the extent of this decline was dependent on summer rainfall, as in one summer when rainfall was high, wool growth rate was maintained at near the spring rate. The mean annual rate of wool growth was found to be correlated ($r = + 0.92$, $P<0.01$) to summer rainfall (November–April). The weight gain of weaner sheep was best on *D. caespitosa*, and was equaled by that on *A. vesicara* only in the first year.

Growth was not influenced by the presence or absence of bushes of *Kochia aphylla*. Growth on *S. variabilis* was less than on *D. caespitosa*.

Wilson AD and Hindley NL 1970, 'Variations in the performance of sheep when introduced to saline drinking water', CSIRO Field STA REC. vol. 9, no. 1, pp. 45–53.

In two field experiments, gradual introduction (4 or 12 days) of sheep to an increasing concentration of dissolved salts in water to a maximum of 1.75% (1.45% NaCl + 0.3% MgSO4) did not reduce the number of deaths, when compared with the immediate introduction of saline water. The deaths occurred when the full concentration of dissolved salts was introduced at times of high ambient temperature. Six sheep with large and 6 sheep with small bodyweight losses in the above experiments were placed in individual pens indoors. When the saline water was given, either to drink, or as a fixed volume administered by drenching, there were only small variations in food intake between sheep. However, when the sheep that had been drenched with the saline water were given the water to drink, the water and food intakes of some sheep were low. Food intakes were correlated with their weight changes in the field experiments. Variations in food intake of sheep on saline water, both between sheep and between experiments, are attributable to variations in the intake of the saline water.

Peirce AW 1959a, 'Studies on salt tolerance of sheep – PART I. The tolerance of sheep for sodium chloride in the drinking water', *Australian Journal of Agricultural Research*, vol. 10, no. 5, pp. 725–735.

Four groups, each of six sheep, were fed in pens for 15 months on an adequate diet of chaffed lucerne and wheaten hays. One group was offered rainwater to drink, whereas the others were offered similar water to which sufficient sodium chloride had been added to give concentrations of 1.0, 1.5, or 2.0 % sodium chloride. The intake of water increased with concentration of sodium chloride, the mean daily intakes for the entire experiment being 2.0, 3.0, 4.4, and 3.0 1. for the groups whose water contained 0, 1.0, 1.5, and 2.0 % sodium chloride, respectively. It also increased in all groups with temperature, being 50–70 % higher in the hottest months than in the coldest months. The intake of sodium chloride by some sheep was very high; four of them consumed over 115 g (0.25 lb) daily for more than half the experiment, and 170–230 g daily for periods of 1–10 weeks. A concentration of 1.0 % sodium chloride in the drinking water had no adverse effects on the sheep, but 1.5 % is detrimental to a small proportion and 2.0 % was detrimental to all of the sheep. There was a decline in food consumption and body weight of the affected animals, and several receiving 2.0 % sodium chloride became very emaciated and weak and two were killed *in extremis*. The only other obvious sign was an occasional diarrhoea which occurred in most of the sheep receiving 2.0 % sodium chloride. Sodium chloride in the drinking water had no effect on the concentration of sodium, potassium, calcium, or magnesium in the blood plasma. It did, however, affect the chloride concentration; this was significantly higher, throughout the experiment, in the group which received water containing 2.0 sodium chloride.

Peirce AW 1959b, 'Studies on salt tolerance of sheep – PART II. The tolerance of sheep for mixtures of sodium chloride and magnesium chloride in the drinking water', *Australian Journal of Agricultural Research*, vol. 10, no. 5, pp. 725–735.

Seven groups, each of six sheep, were fed in pens for 16 months on a ration of chaffed lucerne and wheaten hays. One group was offered rainwater to drink, another group was offered 1.30 % sodium chloride, whereas the others were offered one of the following mixtures of sodium and magnesium chlorides : 1.27 + 0.02, 1.24 + 0.05, 1.18 + 0.10, 1.05 + 0.20, and 0.69 + 0.50 %. Many of the animals refused to eat or drink satisfactorily when the saline waters were first offered. If, however, the concentrations were increased gradually over a period of 3 weeks to the desired levels, satisfactory performance by most animals was obtained. The intake of water containing 1.30 % sodium chloride was higher than that of rainwater, and the intake increased with increasing concentrations of magnesium

chloride up to 0.10 %; the mean daily intakes for the entire experiment by the seven groups were 2.3, 3.9, 4.2, 4.8, 5.0, 4.3, and 3.5 1. respectively. The intake also increased in all groups with temperature, being 60–100 % higher in the hottest months than in the coldest months. A concentration of 1.3 % sodium chloride, and concentrations of up to 0.10 % magnesium chloride with 1.2 to 1.3 % sodium chloride had no adverse effect on the sheep, but 0.20 or 0.50 % magnesium chloride (with 1.05 and 0.69 % sodium chloride respectively) was detrimental to some of the sheep. The principal effect was a reduction in food consumption. The only other obvious sign in these last two groups was an occasional diarrhoea; this was more frequent on the higher concentration of magnesium chloride. The saline drinking waters had no effect on the concentrations of sodium, potassium, calcium, or chloride in the blood plasma. Magnesium, however, was significantly higher, throughout most of the experiment, in the plasma of the sheep which received 0.50 % magnesium chloride.

Peirce AW 1959c, 'Studies on salt tolerance of sheep – PART VI. The tolerance of wethers in pens for drinking waters of the types obtained from underground sources in Australia', *Australian Journal of Agricultural Research*, vol. 10, no. 5, pp. 725–735.

Seven groups, each of six wether sheep, were fed in pens for 15 months on a ration of chaffed lucerne and wheaten hays and were offered various solutions as drinking waters. These comprised: (1) rainwater (control group); (2) 1.30% sodium chloride; (3) and (4) synthetic waters containing salts in the proportions found in many underground waters in South and Western Australia (referred to in this paper as 'chloride waters'), with total concentrations of 0.65 and 1.30% respectively; (5) and (6) synthetic waters resembling those obtained in Queensland from the Great Artesian Basin ('bicarbonate waters'), with total salt concentrations of 0.20 and 0.50% respectively; and (7) seawater diluted with rainwater to a total salt concentration of 1.30%.

The intake of all saline solutions, except that of the bicarbonate water with a concentration of 0.20% salts, was higher than that of rainwater, the increases ranging from 80% for 1.30% sodium chloride to 15% for the more concentrated bicarbonate water. The intake also increased in all groups with temperature, being 40–90% higher in the hottest months than in the coldest months.

Compared with the control group, a significant decrease in wool production was observed only in the group receiving bicarbonate water with 0.50% total salts. These sheep also produced significantly less wool, for at least a portion of the experiment, than did those receiving the other synthetic mixtures of salts.

The concentrations of potassium, calcium, and chloride in the blood plasma were not affected by the saline drinking waters. The concentrations of sodium at times were higher in the plasma of the control group and lower in the plasma of group 2 (1.30% sodium chloride) than in that of the remaining groups. Magnesium concentrations at times were higher in group 7 (diluted seawater) and lower in group 2 than in the remaining groups.

None of the solutions used in the experiment had any adverse effect on general health, food consumption, or weight increase.

Peirce AW 1959d, 'Studies on salt tolerance of sheep – PART VII. The tolerance of ewes and their lambs in pens for drinking waters of the types obtained from underground sources in Australia', *Australian Journal of Agricultural Research*, vol.17, no. 2, pp. 209–218.

Groups of eight or 10 ewes were fed in pens on a ration of chaffed lucerne and wheaten hays and oats and were offered various solutions as drinking waters. In two experiments these comprised: (1) reservoir water (control group); (2) synthetic water containing salts in the proportions found in many underground waters in South and Western Australia ('chloride water') with a total salt concentration of 1.30%; or (3) synthetic water resembling the waters obtained in Queensland from the Great Artesian Basin

('bicarbonate water') with a total salt concentration of 0.50%. In a third experiment, the total concentration of salts in the chloride water was only 1.00%, that of the bicarbonate water again being 0.50%.

The ewes were mated, they lambed, and they reared their lambs on the experimental regime until the lambs were weaned at the age of approximately 10 weeks. The weaned lambs were continued on the treatment for a further 5 months, the total duration of each experiment being 13 months. The commencement dates of the experiments were separated by intervals of approximately 6 months; by this arrangement pregnant ewes, lactating ewes, and weaned lambs received, in at least one experiment, the saline waters during the months of high environmental temperatures, with the associated high water intakes.

There was some indication in one experiment of a poorer reproductive performance by the ewes receiving either chloride (1.30% total salts) or bicarbonate water as compared with the control group.

The intake of saline waters in all experiments was higher than that of reservoir water, the increases ranging from 20 to 50%.

The body weight increases during early pregnancy of the ewes receiving saline waters were identical with those of the corresponding control groups. Significantly lower body weights, as compared with the control group, were observed at one period only in one group of treated lambs receiving chloride water with a concentration of 1.30% total salts.

Reductions in the sodium, potassium, and chloride concentrations in the plasma occurred in some groups receiving saline water. No effect was observed on concentrations of calcium, while the effect on magnesium was variable. No adverse effects were observed on health, food consumption, or wool production of the ewes and lambs as a result of drinking any of the saline waters.

It is suggested that under the conditions of the experiment, ewes and their lambs could tolerate drinking water of either the chloride type with 1.00% total salts or the bicarbonate type with 0.50*#37; total salts.

Peirce AW 1959e, 'Studies on salt tolerance of sheep – PART VIII. The tolerance of grazing ewes and their lambs for drinking waters of the types obtained from underground sources in Australia', *Australian Journal of Agricultural Research*, vol. 19, no.4, pp. 577–587.

Groups of 50–60 ewes grazing sown pastures near Adelaide, SA, were offered various solutions as drinking waters. In two experiments these comprised: (1) reservoir water (control group); (2) synthetic water containing salts in the proportions found in many underground waters in South and Western Australia ('chloride water') with a total salt concentration of 1.30%; (3) synthetic water resembling the waters obtained in Queensland from the Great Artesian Basin ('bicarbonate water') with a total salt concentration of 0.50%. In a third experiment, one group received reservoir water and another group received a chloride water containing 1.00% total salts.

The ewes were mated, they lambed, and they reared their lambs in the paddocks while receiving the various waters. In at least one experiment, pregnant ewes, lactating ewes, and weaned lambs received the saline waters during the months of high environmental temperatures, with associated high water intakes.

The chloride water with a total salt concentration of 1.30% led to a reduction in the percentage of ewes that lambed in one experiment, but not in the other. It also led to decreased body weight gains of the lambs in both experiments, and in addition to diarrhoea and increased mortality in one experiment. Chloride water with 1.00% total salts led to decreased body weight gains and reduced wool production, without apparently adversely affecting the health of the lambs. Bicarbonate water with a total salt content of 0.50% had no adverse effect on the lambs in either experiment, but in one of these experiments it did lead to a reduction in the percentage of ewes that lambed.

The implications of the findings in relation to the use of saline drinking waters under field conditions are discussed.

Masters DG, Rintoul AJ, Dynes RA, Pearce KL and Norman HC 2005, 'Feed intake and production in sheep fed diets high in sodium and potassium', *Australian Journal of Agricultural Research*, vol. 56, pp. 427–434.

Salinity is a problem facing many crop and livestock producers in southern Australia. One management option is to revegetate with salt-tolerant plants suitable for animal production. These plants are often halophytic shrubs containing up to 30% ash, predominantly as sodium, potassium, or chloride.

This experiment examines the consequences of a high intake of sodium and potassium separately or together on feed intake, digestibility, liveweight change, and wool growth. Twelve groups of 6 weaner wethers were allocated to treatments according to a balanced 3 × 4 factorial design with 3 levels of added potassium (0, 0.38, and 0.77 mol/kg DM (dry matter) equivalent to 0, 15, and 30 g/kg DM) and 4 levels of added sodium (0, 0.87, 2.18, and 3.48 mol/kg DM, equivalent to 0, 20, 50, and 80 g/kg DM) as the chloride salts. The treatment diets were fed to sheep for 6 weeks.

Increasing sodium in the diet significantly decreased feed intake, digestibility, liveweight gain, and wool growth either as a main effect or through an interaction with potassium. Organic matter intake was reduced from 1.35 kg at the lowest levels of sodium and potassium to 0.67 kg at the highest levels. Comparing the same 2 groups, liveweight gain was reduced from 144 to 0 g/day, organic matter digestibility from 59.1% to 57.3%, and wool growth from 1.21 to 1.04 mg/cm2.day. The response surfaces indicate that production was depressed even at the lower levels of sodium, whereas high potassium depressed intake, digestibility, and liveweight gain at high levels of sodium only. The interaction between sodium and potassium was always negative at high levels of sodium, indicating that manipulation of the proportions of the 2 elements is unlikely to provide benefits for animal production when total salt levels are high. Although wool growth was depressed at high sodium and potassium, the efficiency of wool growth increased from 10.0 to 15.4 g/kg organic matter intake when the lowest and highest levels of the sodium and potassium were compared. This result may present significant opportunities for the use of saline land to grow fine wool.

Appendix 2: Relevant information from interview transcripts

Interview 1

Role in industry
Pastoralist (wool grower) Nullarbor Plain, WA.

Where are the gaps in information on identifying saline water?
Neighbours let each other know. Southern end more saline. Deeper water has less salinity. Water at 500 ft depth.

What affects does salinity have? What strategies or technologies are available to decrease these effects or the associated costs?
Productivity affected? Yes. To avoid summer losses they run mostly wethers, not ewes. This is less profitable. Wethers get urinary calculi and you see them leaving the trough with a body full of fluid.

For rust problems, use antirust formulas and stabilisers.

A Nullarbor group of pastoralists are looking at magnetic and rare earth devices as water conditioners. These do not change salinity but modify chemical structure. Two conditioners are currently being tested by this group over 6 months using observations with controls and conditioners on neighbouring paddocks. They are counting how many animals at each water point and also monitoring vegetation and dung counts for sheep and kangaroos. The trials are over 18 months.

Vivifier experiment where rare earth material wraps around inlets to troughs to change water molecules. Results (tomatoes which are no longer bitter and petunias doing better) suggest a positive effect.

Noel Sweeney is providing two rare earth devices and a magnet device for testing has lent two rare earth devices.

Commercially available desalination systems for pastoral applications?

Interview 2

Role in industry?
Pastoralist (cattle producer) central Australia

What resources are available to inform you about salinity on your property?
'Salt' not an issue.
Pastoralist has one good basin on east of property but west is patchy and more 'soda'.

Where are the gaps in information on identifying saline water?
Stab in the dark.

What effects of salinity on equipment and technologies are available to decrease costs?
Calcium build up accumulates on floats and anything out of water. Some gal pipes are better than others that form holes and then rust. Poor pipe bores are ok for 6–7 years but Mono bores last 10–12 years when the vertical helical rotor rubber ages and everything is replaced. They also use electric submersibles, such as Grundfos pumps.

Commercially available desalination systems for pastoral applications manufacturer?
Does not know of anyone using such a system; they are not viable and we need to look for alternative sources.

Interview 3

Role in industry?
Pastoral manager (cattle producing company) Qld and NT.

What resources?
For placement of bores, pastoralist uses a combination of bore drillers' knowledge, local knowledge and divining.

Where are the gaps in information on identifying saline water?
Only 2 bores have gone salty. If a new bore proves salty they go ahead and drill another.

Commercially available desalination systems for pastoral applications?
Not needed.

Interview 4

Role in industry
Agriculture adviser (WA government)

The practical 'managing salt' approach we are pursuing in the shrubland of the southern rangelands of WA covers the following strategies:

- Building the general awareness among pastoralists of the impact of salt on a ruminant animal (and pseudo-ruminants)
- Understanding how salt levels in ground water compound the effect of dietary salt intake of halophytic shrubs
- Understanding how these salt levels can be diluted for the ruminant by the low salt plant species (LSPS) (particularly the perennial forbs, shrubs and grasses in dry seasons)
- Understanding how grazing radii rapidly shrink when pastures dry and the supply of dietary intake from LSPS disappears
- Understanding how continuous grazing will often remove the LSPS from the landscape due to the heavy and continuous grazing pressure, particularly during dry seasons
- Understanding that maintaining seasonal stocking rates within carrying capacities of the management unit is a fundamental requirement for sustainable and profitable pastoralism.

Some producers are:

- Using their low salt sources of stock water to maximum advantage for their livestock
- Using rotation grazing to provide the necessary grazing control and rest to enable the LSPSs to regenerate and endure
- Planning the possibilities of capturing surface water in dams to dilute salty ground water and to provide the large water supply necessary when mobs of stock are amalgamated in order to implement 'rotation' grazing to enable the introduction of 'rest' to protect/regenerate the LSPS
- Investigating the options of using reverse osmosis to provide a low salt source of stock water (Peter McCafferty of the WA Chemistry Centre is investigating this possibility)
- Experimenting with products which claim to alleviate the effects of ruminants imbibing salt water (vivifiers etc).

Three research papers were provided covering relative tolerance of cattle and sheep to high salt diets, landscape dysfunction due to overgrazing and grazing management from a rumen ecology perspective.

Interview 5

Role in industry?
Technical advice to pastoral industry including water supplies (WA government)

What resources?
Hydrogeological surveys have been conducted but there is still no guarantee of water quality. The area from Kalgoorlie to Nullarbor saltbush/bluebush has problems with salinity or with no groundwater. Northern areas are better.

W and SW Nullarbor leases need to run pipelines long distances.

Where are the gaps in information on identifying saline water?
In saltbush/bluebush areas there are only occasional small freshwater pockets. Mineral exploration companies have been valuable in passing on water finds to pastoralists.

What effects of salinity on equipment and technologies are available to decrease costs?
High salinity decreases the life of pumps. For chenopod pastures (salt feed) in winter, salinity is not an issue as surface water, grasses and forbs are available. In summer, livestock rely on chenopod shrubs. There is a problem with decreased productivity close to water points, especially for weaners.

Effect of salinity on the reproductive success and growth rate?
Understand productivity discount – There is a decrease in reproductive rate from mating to first shearing due to the impact on the weaners. The lambs are ok but in summer there are losses. They need to get to half their potential weight (25 kg of 50 kg) by the beginning of summer. There is a loss of grazing area as sheep are restricted to water points.

Strategies for farmers described in attached Pastoral Memos

Commercially available desalination systems for pastoral applications?
See Interview 1 above.

Reverse osmosis is too expensive.

Interviewee suggested a good paper about the effect on stock of a combination of saline forage and saline water (Addison 2005).

Interview 6

Role in industry?
Research in voltaics and development of a solar powered RO system (researcher) in UK.

Dr Richards developed a Reverse Osmosis Solar Installation (known as ROSI) with Dr Andrea Schaefer from the University of Wollongong (also now in UK). They demonstrated their prototype in Alice Springs in 2005. The following points summarise initial questions and an email discussion that identified the potential for modifying the design to accommodate requirements for stock water points rather than human consumption.

Initial questions

Is ROSI applicable to standalone supply of water troughs?
I doubt it. Even if the water was only slightly brackish I don't think the economics would be that favourable. One advantage of ROSI over the diesel pumps that we encountered in central Australia is that it can operate autonomously, so does not require the time and cost of dragging fuel out to all these bores.

What would the maintenance period be for high tds low organics bore water?
I would guess once every 3 months (initially), aiming to extend that out to once every 6 months. We still need funding to determine the long-term system performance. The results of our field trip in central Australia in Oct–Nov 2005 were very encouraging, but the longest test we did on one bore was a week. We really need to leave a system running for a year.

Are there commercial companies looking at this application?
Not to my knowledge.

Discussion of possibilities

Background suggestions by author

Basic requirements for a system:

- Salinity 5000 ppm (original suggestion for 100 ppm mixed with 10 000ppm bore water rejected by researcher – better to design system for 5000ppm)
- Run for 4 summer months per year (10 hr/d sunshine guaranteed)
- Need 5 kL/d to cater for one stock water point
- If using a solar system for 10 hr/d output required is 250 L/hr.

Possible diesel model (not economically viable for the industry on a routine basis but may be relevant in a crisis/drought where you are faced with losing all your stock):

- Hire companies now provide a diesel+RO system that will do the job
- The smallest plant (includes a 16 kW generator/fuel tank) produces 10 kL/d of high quality water
- Costs are ~$700 /wk for the plant, 15 L/hr fuel. Note that the fuel costs more than the rental.

Possible photo-voltaic model:

- A solar system will need a lot of power e.g. 5 kW at $8,000 /kW = $40,000
- Pump + RO system = $40,000
- Total $80,000
- Equipment could be rented out for 40 weeks per year at $1,000 /wk
- Renter could make the capital outlay back in 2 years
- Customer would have desalinated water at 56 hrs/wk x 250 L/hr = 14 kL or $71/kL
- This is 10-fold more expensive than the diesel generator.

Researcher's response

For the photo-voltaic model, a 5kW PV array is definitely not portable (about the size of two average house roofs).

Characteristics of researcher's system and potential for pastoral use:

- Specific energy consumption of 2kWh/m3 of clean water produced
- Produces 1m3 per day using 300W of PV panels
- For 5kL per day then as a start we can multiply this by 5 to get 1.5kW of PV panels
- System is designed to produce drinking water, but if research showed the system could produce 5000ppm water using a different membrane then we could probably halve this
- This may mean only having 750W of PV; we currently have 600W on our trailer (which is portable), so the numbers are now becoming much more feasible
- You would qualify for a PV-grant (50% off cost of array) because you're no longer using diesel.

Author's response:

To produce water at 5000 ppm you estimate an efficiency of 1kWh/kL = 5kWh/5 kL and that ten hours of sun requires a 500 W system.

My guess for what such a system might cost in commercial production is $4500 in panels and $40,000 in RO. This becomes competitive with diesel powered RO.

Interview 7

Role in industry?
Geology Researcher SA

What resources?
Interviewee has sampled 140 bores in Gawler Ranges area where local pastoralists have problems with groundwater salinity. The best water is at the flanks of hills rather than in the valleys. The required detailed study is part of the Arid Lands NRM project.

Where are the gaps in information on identifying saline water?
There's still a bit of hit or miss in finding good water. The local drilling contractors are a good source of information. They are good at finding water but the quality may vary. Within 100 m distances there may be very different qualities and I cannot see a pattern yet.

Interview 8

Role in industry?
Manufacturer, installer and maintenance of RO systems for human consumption in central Australia.

What technologies are available to decrease these costs?

- A reliable, simple, stand alone, solar-powered system producing 1000 L/d would cost $30–35000.
- It is a unique system with no waste water. Other systems discharge 60% to waste.
- The system can take 6000 ppm water and produce 20 ppm.

Maintenance requirements?
First filter 3/yr, second filter 1/yr

Known limitations and or faults?

- Station owners don't like technology or maintenance
- Others suggest RO water is lacking micronutrients – need to be added back in
- Blending with other water results in costs of valves and monitoring.

Number of users of the system?

- Has been approached by several pastoralists but they invariably baulk at cost. ~$1/L when all expenses including power and maintenance are included
- 4 solar systems on Pitjantjatjara Lands ~1000 L/d for 7 years
- Hamilton Downs Youth Camp

Interview 9

Role in industry
Installer of tanks/pumps/systems in central and western NSW.

Comments
Several problem sites/bores
Causes loss of productivity of livestock
Equipment OK; important to use 316 stainless steel pumps
RO too expensive.

Interview 10

Role in industry?
Research, manufacturer, supplier, installer/maintainer of solar powered pumps, solar hybrid power systems and RO desalination systems in central Australia.

What is the extent of damage to pastoral infrastructure (pumps, pipes, tanks) caused by salinity in water?
Not as big a problem as you might think. Pipes are cheap or sometimes he uses stainless steel. If salinity is an issue for pumps, put in a plastic pump and replace every three years. Also use Grundfos quality stainless steel and other stainless steel pumps approaching this quality.

Use of desalination equipment:
There's a problem with lack of maintenance on Aboriginal communities as system is solar powered.

The system can't provide the volume for stock application.

Commercially available desalination systems for pastoral applications manufacturer?
Can provide a small unit producing 500 l/d for ~$15 000. Also need a tank and stand for ~$10,000.

Maintenance requirements?
Significant. Systems previously installed do not work due to lack of maintenance.

Known limitations and or faults?
Pastoralists need big systems (500 head on a bore use 25 kL/d) and this is prohibitive. It would be better to pipe water from elsewhere.

Interview 11

Role in industry?
Desalination equipment hire in WA

Review of interview:
Coates Hire supply Novatron (www.novatron.net.au) RO plants. They could provide a plant producing 10 kL/d of high quality water. The plant would include a 16 kW generator/fuel tank. The 2.5 t of equipment would be transportable on a 4 t truck. Costs would be ~$700 /wk for the plant, plus cost of fuel use at 15 L/hr.

Maintenance: weekly backflush and change of filters and engine oil once per month.

Additional costs would be the truck and provision of two tanks and an evaporation pond at each point of use.

This cost is less than cartage and offers health benefits in providing very high quality water.

The plant could be moved from point to point; e.g. two water points could be alternated. If there was a 20 kL tank at each point with an output to stock trough of 5 kL/day, both points could be maintained on alternate weeks with the saline bore water gradually salting before replenishment.

Litres/wk = 40kL. Therefore at $700 rent + $15 diesel/hr * 100 hrs = $2200/wk gives $5.50/kL.

Larger storage volumes would enable more points to be serviced by the same RO plant.

Interview 12

Role in industry
Pastoralist (cattle producer) in SA

Salinity
Not a big problem for equipment or stock.

Highest bore is 3500mg/L.

Finds that lower salt bores are more corrosive. Believes high salt forms protective layer.

DKCRC Partners

AIATSIS

Australian Government
Department of Families, Community Services and Indigenous Affairs

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A joint centre of Flinders University and Charles Darwin University

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CSIRO

Curtin
University of Technology

desert peoples centre

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Government of Western Australia

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