RURAL SOLUTIONS SA
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Investigation and Assessment of Mallee Dune Seepages

SAMDB Project 07690-9081

Chris Henschke and Rebecca Tonkin

Project Officer / Consultant

Chris.henschke@sa.gov.au

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

RURAL SOLUTIONS SA ABN 53 763 159 658
Level 16, 25 Grenfell Street, Adelaide SA 5000
GPO Box 1671, Adelaide SA 5001 DX 667
T 08 8463 3335 T 1300 364 322 F 08 8463 3336
E info@ruralsolutions.sa.gov.au W www.ruralsolutions.sa.gov.au

Government of South Australia
Primary Industries and Regions SA

SOUTH AUSTRALIA

Prepared by:

CJ Henschke

Rural Solutions SA

Office: (08) 8463 3335

Fax No: (08) 8463 3336

Email: chris.henschke@sa.gov.au

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1 Introduction

The term mallee dune seepage has been coined to describe the occurrence of seeps and freshwater soaks discharging at the base of sandy rises in mallee country under a broad acre cropping land use system.

Many farmers report that an early warning sign of seepage development is 'boggy' ground conditions where vehicles and machinery sink into waterlogged soil.

Some 12 land-holders have expressed concern about the development and expansion of seeps and soaks on their properties to the SA MDB NRM Board (B Lawson pers comm). This prompted the development of a scoping study to determine the extent of the problem and what can be done to remedy it.

A suitably qualified hydrogeologist will be engaged to undertake property visits on four affected properties, produce reports for each property and at a forum present the findings and an introduction to the hydrogeological processes for interested and affected farmers.

The project will be managed by the Land Management Program of the SA Murray Darling Basin Natural Resources Management (SA MDB NRM) and will target farmers who are directly affected by mallee seepages.

Project deliverables include the following:

- Meet with Team Leader Land Management to identify potential participants for property visits
- Undertake four property visits to collect historical site information including long and short term land use, siting and spread of the seepages and any remedial actions undertaken by the owner
- Produce property reports to include landscape assessment in relation to the location of the seep, soil type, soil condition, including soil tests
- Undertake desktop assessment of relevant literature and reports
- Present at a forum the results of the reports to assist farmers to understand the mallee seepages and management options available
- Produce a final report including recommendations for future management of each site, opportunities for farmers with mallee seepage (e.g. alternative crops, summer crops etc.).

At the conclusion of this scoping study an evaluation will be undertaken with farmers to determine the next stage if required.

Background Information

Statistics for dune seepage potential in the SA MDB NRM region are provided in Table 1. This information is provided by the Department of Environment, Water and Natural Resources (DEWNR) Soil and Land Program. The data indicates potential for 'dune seepages' by re-classifying soil landscape units in terms of:

- Proportion of swales in which clayey subsoils may force seepage water to the surface, and
- Proportion of sand dunes in the landscape

Eight dune seep classes are classified as indicated in the following table. The most relevant being classes 1 to 5 in terms of what might be seen on the ground.

Table 1. Dune seepage potential statistics, SA MDB NRM region

Dune Seep Class	Proportion of Swales Susceptible to Seepage	Proportion of Dunes in Landscape	Hectares	Percentage of Total
1 (red)	>60%	>30%	0	0
2	>30%	>30%	135,294	3.4
3	5 – 30%	>30%	313,514	7.9
4	>60%	10 – 30%	7,277	0.2
5 (yellow)	30 – 60%	10 – 30%	97,203	2.5
6	5 – 30%	10 – 30%	16,255	0.4
7		<10%	2,598,926	65.7
8 (green)	<5%		677,547	17.1
X	N/A	N/A	108,274	2.7
TOTAL			3,954,290	100

Class X is Not applicable (includes urban, reservoirs, lakes, quarries, evaporation pans)

The areas indicated in Table 1 are for the potential of land to be affected. The actual areas affected are expected to be far less than for what is indicated by these statistics. James Hall (pers comm) has indicated that the model used to generate this data could be 'tweaked' to create more realistic data.

The accompanying map (Figure 1) provides a statewide picture of dune seepage potential for each of the NRM regions. The SA MDB appears to have the greatest potential for dune seepage. The most impacted area in the mallee occurs between Murray Bridge and Pinnaroo with other areas adjacent to the River Murray between Murray Bridge and Morgan.

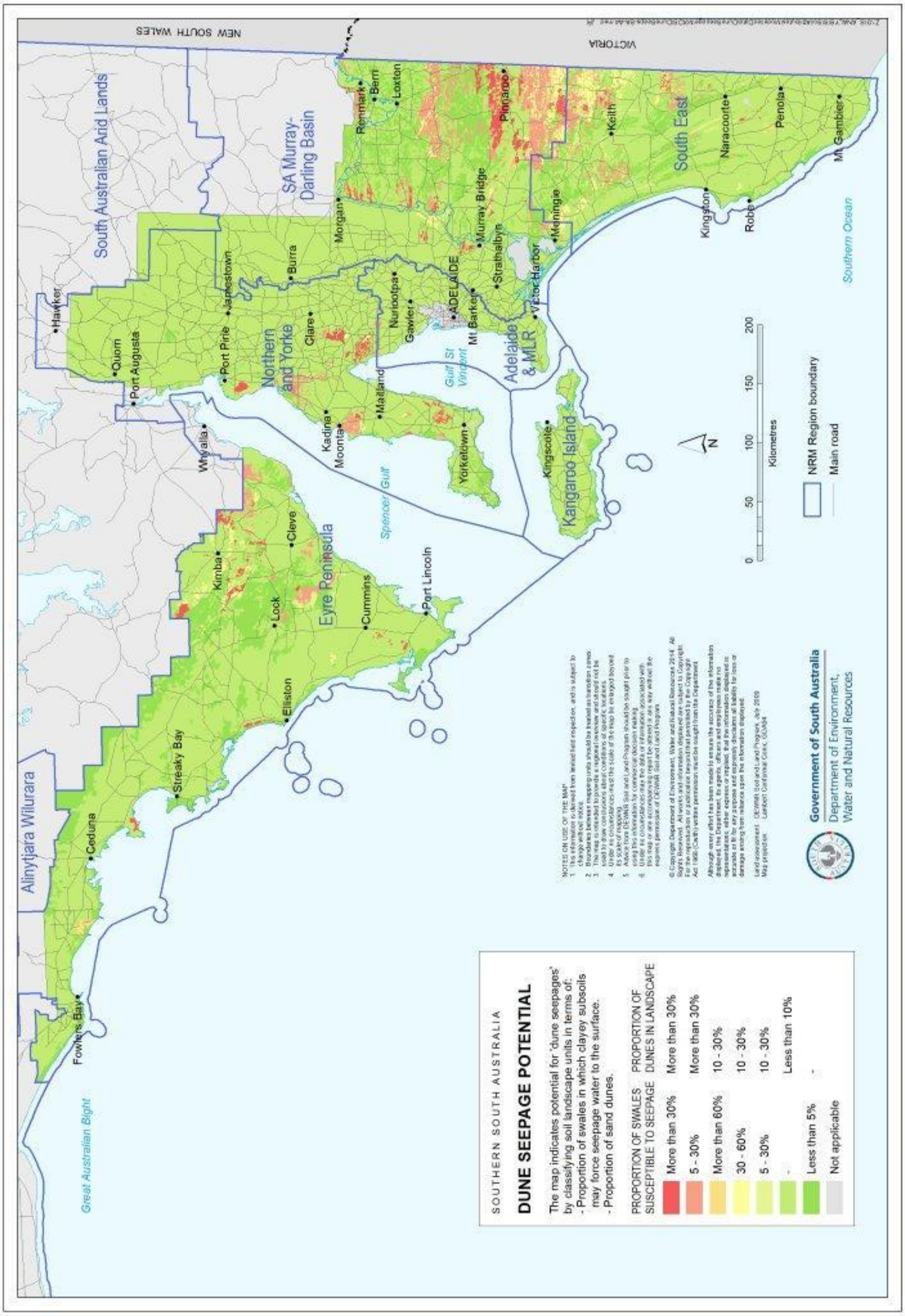


Figure 1. Map showing dune seepage potential in SA NRM regions

2 Case Studies

Case studies are provided from four farm sites in the SA mallee region where seepage is of concern. The sites were chosen based on interest expressed by the landholders and / or famers who are leasing properties with a seepage problem.

- Kevin Bond (Mannum)
- David Arbon (Wynarka, north)
- Peter Rose / Andy Thomas (Wynarka, west)
- Stuart Pope (Karoonda)

The four sites are located in the SA mallee region bounded by Mannum and Murray Bridge to the west and Karoonda to the east as indicated below on Google earth maps.

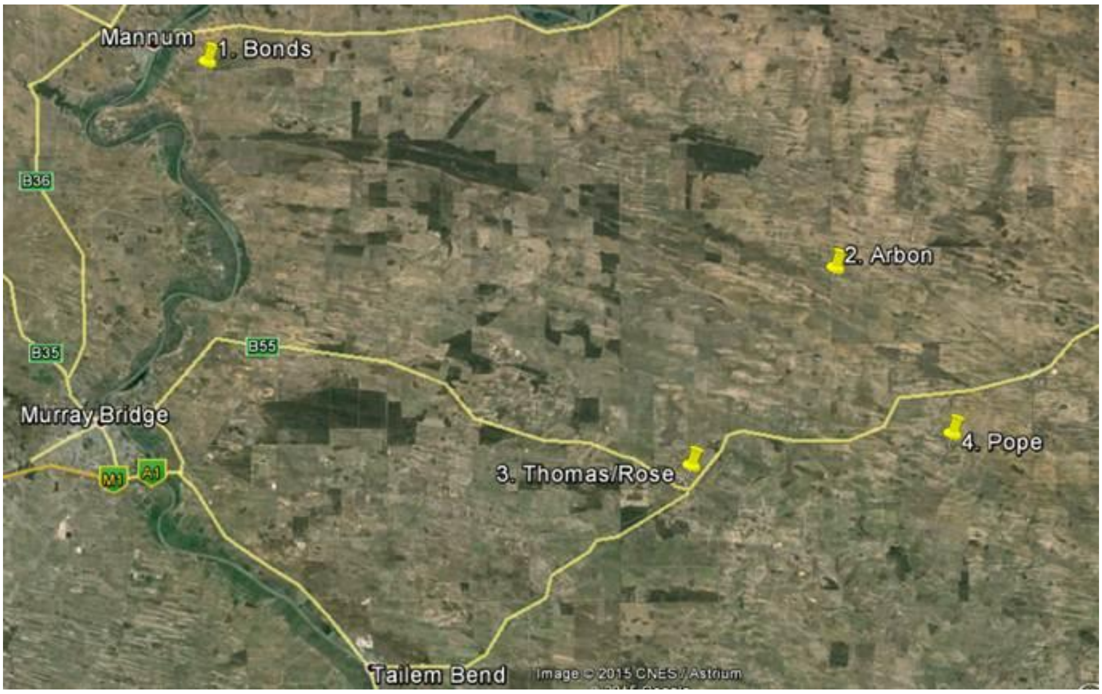


Figure 2. Location of the four mallee dune seep case study sites

Site inspections were conducted during visits to the properties and at field days held on these properties. Staff from SA MDB NRM Board, Rural Solutions SA and other private consultants were represented at the meetings with the landholders.

The following have assisted with the production of this report and are gratefully acknowledged:

- Bernadette Lawson (SA MDB NRM Board)
- Steve Barnett (DEWNR)
- James Hall (Juliet Creek Consulting)
- Brian Hughes (RSSA)
- Chris McDonough (RSSA)

2.1 Jeff and Kevin Bond, Mannum (east)

This property is located to the east of Mannum and is bounded by Cross Road and Burdett Road (Figure 3). A initial site inspection was carried out on 29/8/12 by R Tonkin (Rural Solutions SA), and B Lawson (SA MDB NRM Board). Another site inspection with NRM and RSSA staff was done on 3/2/15.

Figure 3. Location of Bonds dune seep case study site

The Bonds carry out continuous cropping (no-till) farming practices and includes mainly wheat in the rotation. High hills overlook the main central valley with long slopes of yellow sand. Smaller jumbled sand dunes of white sand occur on the lower slopes.

The seepage areas first appeared around 2005 and there is currently around 4 hectares of land affected. It began as a waterlogging problem but is now looking more like a dryland salinity problem with bare and scalded patches that are continuing to spread. Anecdotal information suggests that some soaks were already apparent in the 1950s and may be a reason why not all the trees were cleared in the main central valley.

The worst affected area is in the main central valley at the base of a long slope. Numerous smaller seeps / pockets of soaks / wet depressions occur in the lower landscape amongst the jumbled non-wetting sand dunes and at the break of slope adjacent to the main central valley. Wet boggy areas on lower slopes have resulted in the header becoming trapped in a wet area even at harvest time.

The water from the seeps accumulates in the main central valley. The depressions have an overflow point whereby when the fill-point is reached, they overflow to the next lowest level leaving eroded channels in the ground (Figure 5).

In previous years, the area had been prone to waterlogging but had fresh water and grew good crops. Salts are now being flushed from the more saline layers deeper in the soil profile, with increasingly concentrated mineral salts on the surface.

Figure 4. Photo of seep taken by K Bond (August 2012)

By 2010-11, the main seep area was unable to be sown with crops due to the wet and boggy soil. Cereal crops around the edge of the main seep had died off, probably due to waterlogging. The only plants able to grow near the seep were rye-grass and some thistles. The bare soil shows signs of crusting and white efflorescence (mineral salt accumulation).

Soil pits dug with a spade in August 2012 showed that the general profile consists of a dark grey-brown sandy loam in the topsoil (0-15 cm), showing anaerobic staining from waterlogging. This sandy layer has a crust which may contain mineral salts. This lies over a leached light brown/white sandy layer at 15-40 cm and is saturated with water. After 40cm, there is a mixture of light clay (becoming heavier with depth) and calcrete. The calcrete may be in large rocks or soft gravel. Water seeped into the pit as it was being dug (in late August 2012). Water continues to pond in the low-lying areas until summer.

Figure 5. Overflow point of the main seepage area at Bonds (August 2012)

Soil profiles examined during a site visit in February 2015 showed saturated clayey sands on top of calcrete. White efflorescence's noted on bare scalded patches are dominated by gypsum and carbonates with only small amounts of sodium chloride salts. A pit previously dug in a scald in the main central valley encountered red mottled heavy clay of the Blanchetown Clay (Figure 6).

The problem appears to be driven by summer and out of season rainfall events on non-wetting sands. There is currently poor water use on the white sand ridges lower in the landscape.

In the past, summer weeds used to use much of the out of season rainfall as they had deep tap roots. Changed farming practices mean that weeds no longer occur on the sand ridges. A new type of weed (Fleabane) has become more common in the mallee surrounding the seeps.

From a geomorphic point of view, this site is somewhat atypical of the mallee as the landscape is transitional from the Mount Lofty Ranges to the Murray Basin. Some of the largest hills may represent basement highs. The prominent valley in which the seeps occur may be part of a remnant palaeochannel. Because this site is somewhat atypical of the mallee it could be a site that is more suitable for a GRDC funded project.

A deeper groundwater system occurs in the area as indicated by old abandoned wells dug to 55m but having groundwater that is too saline for use. The deeper underlying groundwater system is not connected to the shallow flow system which is solely responsible for causing the dune seepage.

There may be multiple flow paths discharging to the main central valley with short flow paths (fresh water) from adjacent sand ridges and longer flow paths through the cores of the dunes originating from topographic highs. Over time, the cores of sand dunes can become saturated and provide a store of water for continuing discharge to seepage areas (Hall, 2015).

Figure 6. Scald in main central valley with exposed Blanchetown Clay from pit (Feb 2015)

Management Options

At Kevin Bond's property, it is probable that unless action is taken, the area will continue to expand and remain saline. Salinity is already evident, and mineral salts will continue to wick up from lower layers if the topsoil remains bare and water is drawn up and evaporated from the surface.

There are a number of options to prevent more water being added to the site and to use up water already present:

Increasing water use efficiency of crops grown will help to reduce recharge to the perched watertable. It may be necessary to use a summer cover crop such as millet around the seep to soak up excess water. Deep rooted perennial species such as lucerne would be able to access more moisture than annuals, however the continuous cropping rotation would have to be changed and this may not be profitable.

Treating the water repellent sand to reduce recharge is also likely to help. Clay spreading may be difficult if there is no clay source nearby. Not very much clay spreading has been carried out in this area due to a lack of suitable clay.

Delving is not an option as the sand is too deep. Spading or inverting the deep sand may overcome the water repellence, but has high risks of wind erosion initially. Other options may be changing tine configuration or sowing down existing crop rows. Trials are underway in the Coomandook area looking at non-clay options for dealing with water repellent sands.

This site would be ideal for a lucerne demonstration trial. A strategic block of lucerne (for hay) should effectively intercept midslope moisture flows and dry out the soaks in the main valley and developing seeps at the break in slope. A wetting agent would be required to get better establishment of lucerne in the non-wetting sands.

Using more water on the actual seep by revegetating the site with salt / waterlogging tolerant perennial species is likely to be successful. This may require a gradual approach, planting at the edges of the saline waterlogged area and moving in as the area becomes drier and less salty. Once plants have established and roots have accessed the deeper moisture, they should do well. Any salts that have accumulated on the ground surface should leach away over time with normal rainfall.

2.2 David Arbon, Wynarka (north)

This site is located north of Wynarka on the property of David Herrmann, now David Arbon (see Figure 7). The property is located at Durdin Rd / Hundred Rd intersection. Rainfall is 325mm meaning all of the winter rainfall would be used by crops except on poorly productive sandhills.

Figure 7. Location of the Arbon dune seep case study site

The farm is continuously cropped with wheat/barley rotations and some legumes (lupins) also being grown. Being continuously cropped now for almost 20 years has meant much better control of summer weeds since the mid-1990s. The plan is to run sheep on the stubble in the future.

Larger sand dunes are oriented in a north west to south east direction. Some dunes have patches of limestone and there are stony flats in low lying areas. The better loamy soils are located in the hollows where there is more available water for plants.

Seep areas started to show up after the wet summer in 2010. Summer storms can produce 20+mm in less than an hour and this produces surface runoff into hollows. These then become bog holes over the next 6 months and this can often be the precursor of an eventual soak. The location of the seeps appears to be totally unpredictable with small seeps breaking out around the sides of a large sandhill. Seeps appear to occur where the clay/limestone base intersects the soil surface.

One seepage areas have developed they have thick cover of ryegrass but become bare and scalded over time. In winter the subdued depressions become almost un-trafficable. The concern is that they will expand in size. Of interest is the high productivity surrounding the seep, usually thick rye grass and phenomenal crop growth. The thick ryegrass surrounding the seeps is difficult to control, probably because of resistance to spraying.

Soil profiles comprise soft sand over clay on the slopes. The sand here is non-wetting and rainfall tends to puddle on top but eventually soaks down into the soil. There is no visible white salt efflorescence's at the soil surface in bare areas at this site.

Examination of the soil profile in the seep (Figure 8) showed brown sand to 30cm, with moist sandy loam at 30-60cm. A red light clay with small amounts of calcrete occurs at 60cm then grading to a wet heavy clay. A light sodic clay (saturated) occurs at around 1m depth.

Figure 8. Arbon dune seep demonstration site (Feb. 2015)

Management Options

It is expected that the closest sandhill rather than higher and more distant sandhills is the main contributor of water to the seepage area. Treatments should therefore be targeted to the closest sandhill to the seep.

Summer cropping (sorghum) although rarely attempted in this area, could have potential in areas of the landscape with moist subsoils. The New Horizons program is looking at trials to increase the productivity of deep sandy soils and outcomes should be applicable to this site.

A sand ridge will be selected for a trial to establish a belt of trees with the idea of demonstrating different treatment options at each of the four focus sites. A paired trial means that one site is treated and the other is left as a control.

Strategic tree planting will be aligned with existing fencelines to intercept midslope moisture flow and dry out soaks from forming downslope.

2.3 Peter Rose / Andy Thomas, Wynarka (west)

The property on which this seepage occurs is located around 7km south west of the township of Wynarka (Figure 9). It is currently being leased by Peter Rose. Seepages also occur on an adjoining property, previously leased by Peter Blackett and now leased by Andrew Thomas.

Figure 9. Location of Thomas / Rose dune seep case study site

The seepage problem first appeared around 2005. Up until about 2008 this area grew good crops although tending to be boggy. By 2011 the area was too wet to drive on and gradually turned saline. Currently the ground is bare and scalded with visible mineral salt crystals (Figure 10). The surrounding area is too soft for machinery to be driven over for most of the year and so cannot be sown to crops or pasture. No plants are growing on the most severely affected areas. Rye-grass, brome, and thistles grow prolifically on the fringes of the scald.

Figure 10. Scald caused by seepage, P Rose, Wynarka (Feb 2015)

The site was cleared between 1905 and 1910 and in classical dryland salinity situations with rising groundwater tables, seeps may have expected to become apparent by the 1950s. However this seep only became noticeable in 2005. This indicates that the cause of the seep is the changed farming practices under no-till farming and soil moisture conservation. Previously, summer weeds used up the excess moisture caused by out of season rainfall events. Dunes comprise non-wetting white sandy soil and currently poorly productive crops on these soils are not using up all of the subsoil moisture.

The main seep on this property is characterised by a surface crust and white efflorescence at the soil surface. There is some black anaerobic staining as well. The white efflorescence's are possibly composed of gypsum, carbonates and minor sodium chloride. It is possible that in older seeps, some of the calcrete has dissolved over time (James Hall, pers comm). The swale area may be part of an historical watercourse as is the situation at Bonds (James Hall, pers comm).

Soil pits dug with a spade in the seep in October 2011 showed that the general profile consists of a dark grey-brown sandy loam in the topsoil (0-15 cm), showing anaerobic staining from waterlogging (Figure 11). There is a surface crust which contain mineral salts. The soil becomes moist below 10cm. This lies over damp reddish brown sandy light clay (15-30 cm). Below 30cm, there is a mixture of light clay (becoming heavier with depth) and calcrete. The clay varies from reddish-brown at about 30cm to cream/yellow/grey further down the profile as more lime is mixed with the clay. The calcrete may occur as stones and rocks on higher ground or as soft gravel in the scalded area.

The watertable was 0.6m below the surface in November 2011 (Figure 11). Because of the wetness of the profile, even in summer, only small amounts of rain (e.g. 10mm) is enough to saturate the seep and surrounding land.

Figure 11. Shallow watertable exposed in scald at Wynarka (Oct 2011)

Soil samples taken from the 0-10cm and 40-50 cm layers in the profile in October 2011 showed relatively high salinity in the topsoil, but much lower salinity at around half a metre (Table 2). This indicates that mildly saline water has been wicked up from the lower layers in the soil and the water evaporated, leaving increasingly concentrated mineral salts on the surface.

Table 2. Soil salinity test results from a pit in seepage area

Depth (cm)	EC1:5 (mS/cm)	Texture	Texture Conversion Factor	ECe estimated (mS/cm)	Severity of Salinity
0-10	2.30	SL	9.5	21.8	High
40-50	0.34	SCL	6.5	2.2	Low

Where: EC1:5=Electrical conductivity of the 1:5 Soil:Water extract, ECe= Electrical conductivity of the saturation extract, S = Sand, L=Loam, C=Clay

There may be multiple water flow paths with a shallow fresh flow system in the shallow sand over light clay and a somewhat deeper and slight more saline flow system through the core of the sandhill. Cores of sand dunes can become saturated over time, providing an increased store of water for discharge to seeps (Hall, 2015). These shallow systems are underlain by the much deeper regional limestone aquifer. The presence of windmills in the area suggests that historically, farmers tried to tap into the deeper system for a stock water supply, but it was often too saline to be used. It is highly likely that the deep aquifer is not connected with the shallow seepage issue.

There is a developing seep on the other side of the sandhill on property leased by Andy Thomas. The profile in this developing seep comprises brown sandy loam over red moist light clay at 20-50cm and underlain by carbonate rubble. The seepage area is currently covered with thick rye grass.

Management Options

At the property leased by Peter Rose, it is probable that unless action is taken, the area will continue to expand and remain saline. Salinity is already evident, and salt will continue to wick up from lower layers if the topsoil remains bare and water is drawn up and evaporated from the surface.

As with the other focus sites, the issue of non-wetting sands needs to be addressed using techniques of clay spreading and/or delving. Deep ripping of the subsoil sodic yellow clay could help to break up the impermeable layer allowing perched water to drain down to the deeper aquifer. This yellow clay is Loxton/Parilla sand and not Blanchetown Clay (Hall, 2015 mentions that Loxton/Parilla sand does have clay layers). Sometimes the surface of the clay is impermeable and ripping it could make it more permeable (J Hall pers comm). Note that calcrete is not really an impermeable layer, but it is the clay under the calcrete that holds up the water (J Hall pers comm).

A demonstration trial is supported at the Wynarka site as shown in Figure 12. This site has an infertile sand hill adjacent to a mature seepage area on one side of the hill and a developing seep on the other side of the hill. Currently soil moisture and rainfall are being monitored at this site.

This demo site could be a site for more intensive monitoring with some drilling and installation of piezometers / observation wells / monitoring bores. The bores could be sited adjacent to soil moisture probes and automatic rain gauges. They could be fitted with dataloggers to relate rainfall and soil moisture storage to changes in watertable levels overtime.

Another option is to excavate an interception trench around the perimeter of the seepage area and fill it with permeable material such as stones or organic matter.

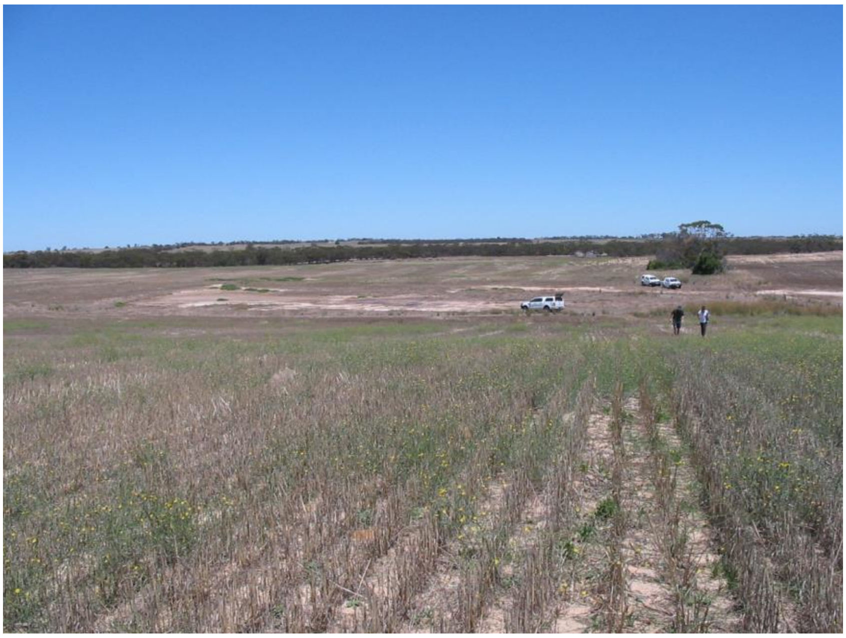


Figure 12. View of demonstration site at Wynarka showing sandhill and seepage area (Feb 2015)

Revegetating the site with salt-tolerant species is likely to be successful as long as plants are placed in soil which is not too saline. This may require a gradual approach, planting at the edges of the saline waterlogged area and moving in as the area becomes drier and less saline. Once plants have established and roots have accessed the deeper moisture, they should do well.

2.4 Stuart Pope, Karoonda

This property occurs south west of Karoonda and south of Pope Road (Figure 13). The land use has changed from grazing of sheep on annual pastures to continuous cropping with wheat / lupin rotations. After changing to continuous cropping, the control of summer weeds seemed to exacerbate the problem. Winter crops do not use all of the rainfall on the infertile sands.

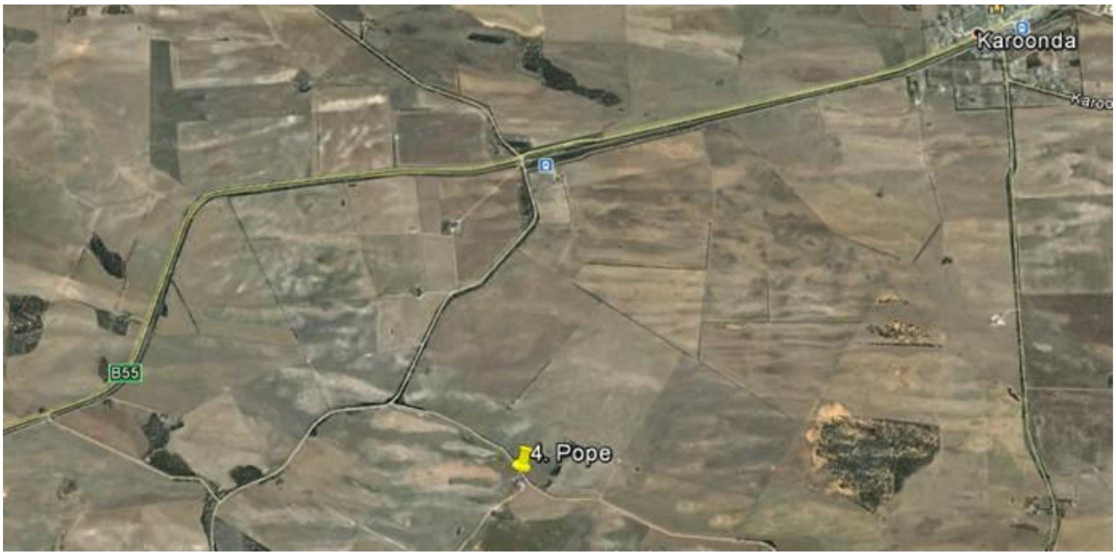


Figure 13. Location of Stuart Pope dune seep site

A number of seepage areas have been developing around the sides of large sandhills on this property. One example of a mid-slope scald is shown in Figure 14. A dam downslope of the scald became saline over time due to concentration by evaporation and then silted up due to erosion of the scalded area. The highly eroded seep is still continuing to spread back up the slope. Features of this severely degraded area include a fluffy surface due to flocculation, white efflorescence and crusting, black organic staining and unusual bright green organic tinges in the sand just below the surface.

Figure 14. Dune seepage, S Pope, Karoonda

There are a number of land-locked wet depressions at the base of a large sand dune along Pope Road. The problem got worse after depressions filled with water after a wet summer. Symptoms of waterlogging include black reducing (anaerobic) soils and poor germination of a barley crop in the depression. Lush crop growth is observed surrounding the wet depression at the break of the slope where the crop has most likely tapped into a fresh perched watertable. There is currently no visible expression of salt in this seepage area (soil samples were taken in October 2011 to confirm this). Currently the problem here is a seasonal waterlogging issue.

Soil profiles in affected areas comprise of sandy loams with a dark anaerobic staining indicating waterlogged conditions. The topsoil is underlain by pale brown saturated sand, containing water which appears to be quite fresh. The perched watertable overlays red slightly mottled calcareous light to medium silty clay at 30 to 40cm.

Small developing hillside seeps occur upslope from the farmhouse on a long slope sandhill. Profiles in the small seeps comprise saturated sand over yellow clay. These hills supported summer weeds including skeleton week and paddy melon years ago. Clay was spread at this site at 70t/hectare a few years ago. This sporadic scalding off of crops may have been called 'magnesia' in years gone by (J Hall pers comm). Salinity not associated with a saline watertable is also called 'dry saline land' or transient salinity (Hall, 2015). Ephemeral fresh perched watertables may also play a role in these types of saline land.

Wet pans are also noted to be developing on neighbouring farms.

It is the infertile sands that appear to be generating the seeps. Overall the area impacted by seeps is less than 10 hectares over the whole property but there is concern that they are still spreading.

A well dug to 6 m near Stuart Pope's farmhouse many years ago was fresh enough to be used as a domestic water supply. This indicates that fresh perched watertables have always been a feature of the mallee landscape. Deeper bores have also been drilled in the past and have tapped the deep regional groundwater system. A bore drilled to the south of this property had a waterlevel that rose from 28m to 6m from the surface. This indicates the deeper aquifer is under artesian pressure.

Management Options

At Stuart Pope's, seepage areas may be sustained by future out-of-season large rainfall events.

There is a strong case for making the infertile non-wetting sands more productive. Clay spreading and clay delving trials have previously been carried out on this property. This was not very successful as the clay had not been very well incorporated. Follow up trials with spading and discing produced better results.

A soil amelioration trial upslope of the seepage area shown in Figure 14 should see benefits as the seep has a well-defined recharge area. The New Horizons program provides demonstrations such as deep ripping and organic matter placement to increase the productivity (and hence water use on sands). There are still issues to address including how best to get organic matter down into the soil and what are the cost/benefits of doing this. It was suggested that an off-set disc be used to incorporate material such as manure deeper into the soil.

Another suggestion that has been raised is to drill a drainage bore down into the deep regional limestone aquifer and allow the shallow water drain down into this aquifer. It is doubtful that this would be affective and the legalities of doing this would need to be investigated.

Currently the site is instrumented with soil moisture probes and an automatic rain gauge.

3 Hydrological Processes

This section describes the soil and landscapes of the mallee and the hydrogeological processes that drive mallee dune seepage.

3.1 Landscape Geology and Soils

The landscape of the mallee reflects the underlying geology. The Tertiary sediments (sands and clays) produce a generally broad flat land surface. Quaternary aeolian sediments overlying the plains produce an undulating land surface of remnant calcrete benches / ridges and sandhills. Figure 15 shows a typical sequence of soils and geology in the mallee.

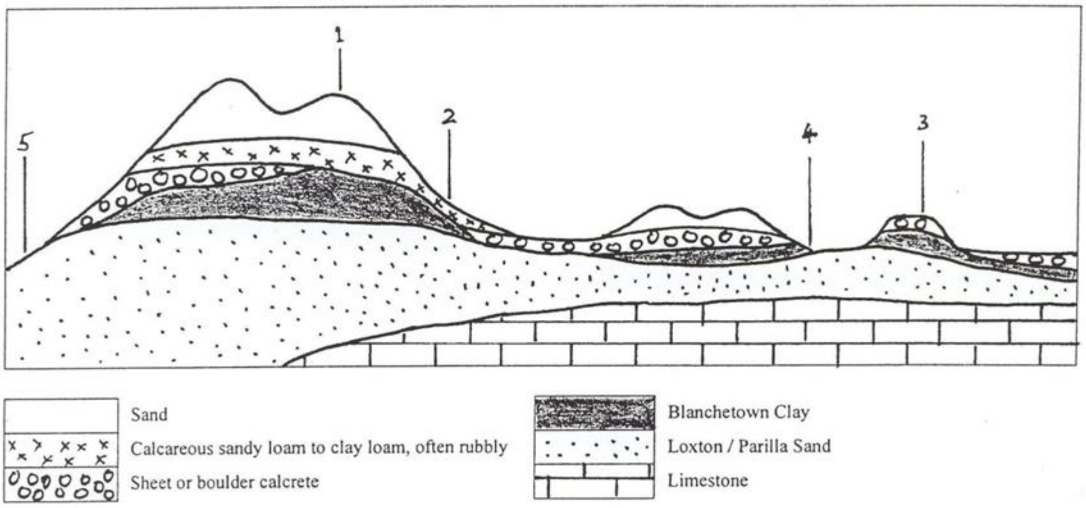


Figure 15. Typical sequence of soils and geology in the mallee

The key landscape features for the mallee are documented in Table 3. This includes sand dunes (codes 1 and 2), rocky rises (code 3), Blanchetown Clay (code 4) which is not continuous but occurs as lenses. Loxton Parilla Sand (code 5) occurs everywhere and this formation can be a sandy clay in places.

Table 3. Profile descriptors for Figure 15

Diagram code	1	2	3	4	5
Geology	Molineaux Sand	Bakara Soil	Ripon Calcrete	Blanchetown Clay	Loxton / Parilla Sand
Landscape	Sand dune	Footslope	Rocky rise / outcrop / bench	Swale	Flat / slope
Soils	Deep sand	Calcareous sandy loam	Skeletal soil on calcrete	Loam on clay	Gradational sandy loam
Crop water use	Low	Moderate	Low	High	Moderate

Land Systems

The following land systems are mapped where mallee dune seepage is experienced. The descriptions are taken from DWLBC (2007).

Burdett Land System
This land system occurs to the east of Mannum and Bonds farm occurs in this system. The system is formed on sheet calcrete and windblown *Molineaux Sand* which has been reworked into sand dunes in places. The dunes comprise of brown to yellowish-red sand over orange soft clayey sand. The profile then grades into rubbly calcareous sandy clay loam. The sands are often water repellent. *Blanchetown Clay* may occur beneath the calcrete. Figure 16 is a generic cross-section of the Burdett land system taken from McCord, where Qsm=Molineaux Sand, QCa=Calcrete, TQlb=Blanchetown Clay and Tpp/Tpl= Loxton Parilla Sand.

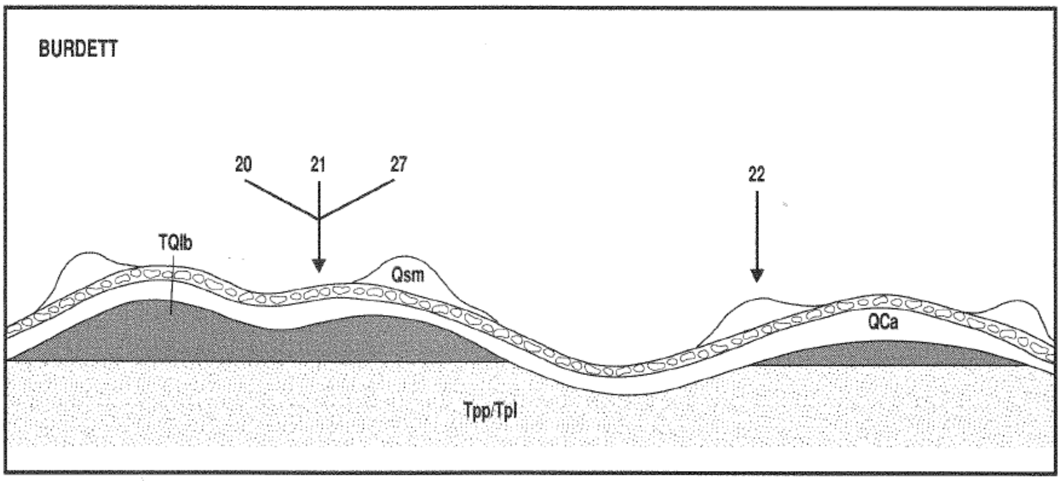


Figure 16. Geological cross-section of the Burdett Land System (after McCord)

Wynarka Land System
The landscape (Figure 17) is characterised by undulating rises and flats with rounded sandhills. It occurs in the Wynarka to Karoonda area and both the Rose and Pope farms are located in this land system. The flats are underlain by *Blanchetown Clay* or sediments of the *Loxton*/*Parilla Sand*.

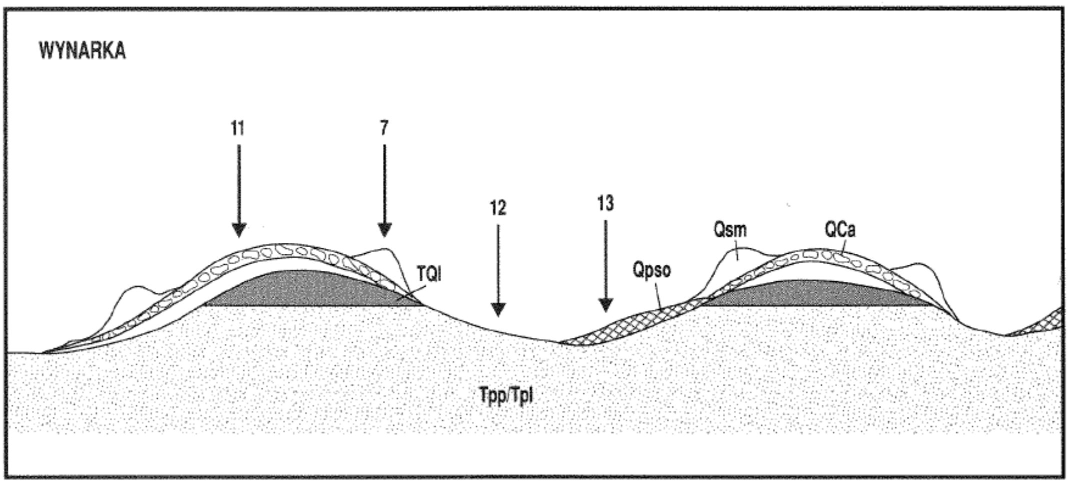


Figure 17. Geological cross-section of the Wynarka Land System (after McCord)

The slopes and rises are comprised of rubbly calcareous sandy loams. Remnants of an old calcreted land surface occur. The sandhills comprise brown loose sand over red clayey sand, often as lamellae in a sandier matrix. The key in Figure 17 includes Qpso (colluvium).

3.2 Hydrology

Rainfall water not used by plants eventually finds its way into the groundwater system, or is trapped below the root zone (e.g. by a clay or hardpan layer). Recharge is the rainfall that flows down through the soil to join the watertable. Rainfall may also infiltrate the dune in places and seep along the clay interface, eventually discharging into land-locked depressions ('pans') at the base of the dune. The amount of recharge depends on soil, vegetation and climatic characteristics. Soils that limit plant growth and water use increase the potential for recharge to occur. Non-wetting sands tend to focus rainfall infiltration into preferred channels. Sand dunes characteristically contain non-wetting sands and this promotes surface runoff. Water concentrates into hollows and depressions at the foot of the dune. Subtle depressions often occur at the break in slope of sand ridges and it is speculated as to how these depressions form. One theory is that surface runoff from heavy rainfall accumulates at the base of the dune and this results in bare soil due to ponded water. Bare sandy soil is vulnerable to wind erosion and blowouts can result in forming a deflation hollow.

Soil type and plant growth affects the movement of water into and through the soil. The higher the clay content the higher the soil water holding capacity and the lower the rate of recharge downwards as indicated in the following table (Murray Mallee LAP, 2001).

Table 4. Effect on soil texture on water holding capacity

Amount of clay in top 50cm of soil profile (%)	Soil texture	Water holding capacity (mm)	Recharge rate (mm/year)
0 - 5	S	30	35
5 - 15	LS	40	10
15 - 20	SL	55	5
20 - 30	SCL	70	0 - 5

S = Sand, L = Loam, C = Clay

Regional groundwater flow systems occur in deep limestone aquifers across the mallee at depths of 20 to 50 metres below the surface. The deep systems can be overlain by local shallow perched flow systems in aeolian sediments. There is limited interaction between shallow local watertables and the deeper limestone aquifer.

Research in the WA wheatbelt found that recharge to the deep aquifer was occurring beneath the sandplain seep (George, 1992). This was causing the development of a groundwater mound in the deeper system which may enhance saline groundwater discharge. It is not known if a similar situation could occurr in the SA mallee.

In the mallee, topography is defined by dunes and swales and not by discrete catchments. This needs to be taken into consideration when trying to define boundaries on local groundwater flow systems. The most likely scenario is for perched watertables to develop in aeolian sands overlying clay layers. McAuley and Robinson (1994) mention that perched watertables can also occur within sandy layers of the Blanchetown Clay.

3.3 Hydrogeological Research

A study from the wheatbelt of WA where drilling and installation of observation wells was carried out to define the extent of the sandplain perched aquifer system. This was done to assess its hydraulic and chemical properties so that the effects of management strategies could be assessed at the research site. A groundwater flownet and hydrogeological cross-section through the seep (George 1992) is shown in Figure 18.

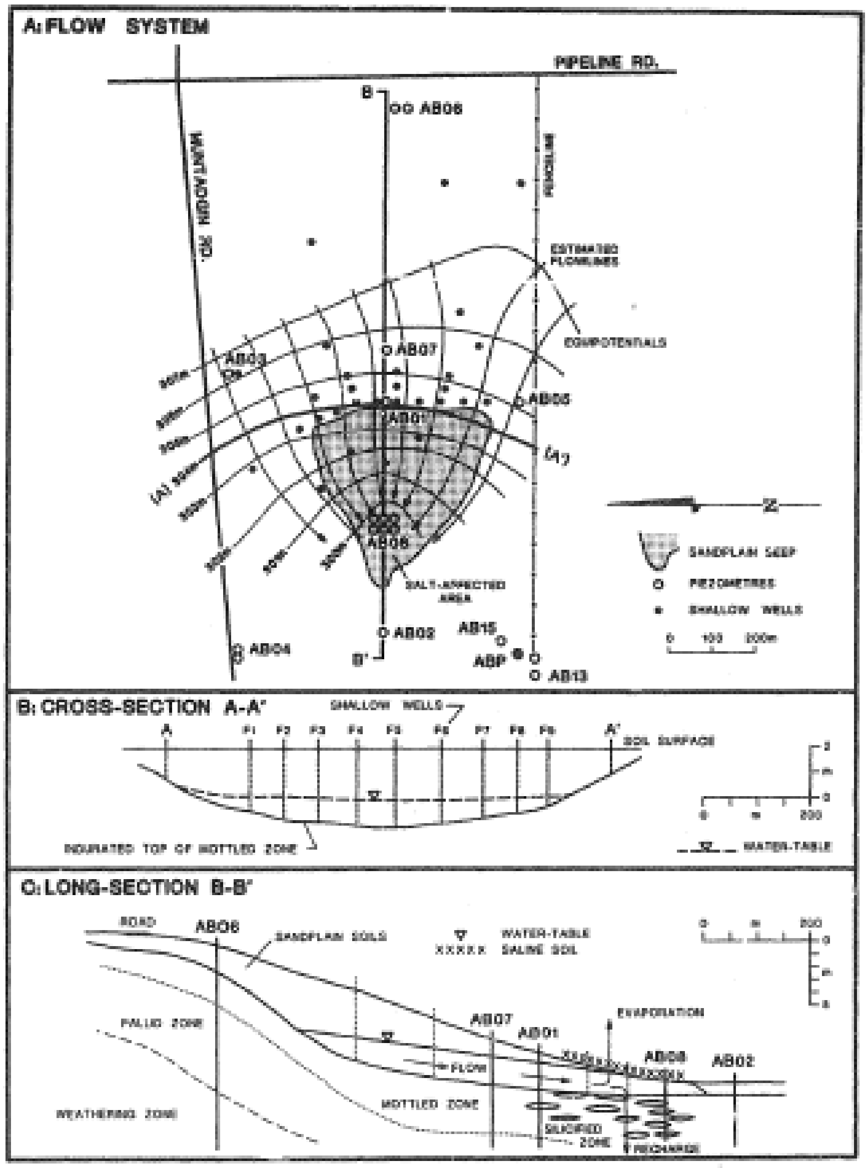


Figure 18. Flow system in a shallow perched aquifer (after George, 1992)

Reclamation demonstrating trials were also conducted involving both drainage schemes and block tree planting. Tree belts were found to be successful in reclaiming the seeps. Trees were planted immediately upslope of the seepage area and planted on the contour across the full width of the seep. Plantings occurred at a density of 400-600 stems/ha with 6-10 rows at 4-5m spacings.

Drainage with wells pumps and trenches was found to be expensive and therefore not cost-effective.

An investigation was carried out by Barnett and Berens (2003) to determine the cause of a salinized area which appeared in the year 2000 on grazing land 2.5km southwest of the township of Parilla. It was initially thought that the problem could be irrigation related and so a research project was undertaken by the then DWLBC. Geophysical surveys, drilling and water chemistry and isotope analysis showed that a perched watertable resulting from intense summer storms caused the seep.

An analysis of rainfall patterns at Parilla indicated a number of episodic out of season rainfall events contributing rainfall recharge to groundwater. This includes a large daily fall of 74mm in December 1999 followed by wet months in February and April 2000. As noted by the authors, this intensive rainfall event would have caused significant recharge to the perched watertable. The 1999 event was followed up by another intensive rainfall event in February 2003 with almost 100mm falling in two days.

Of particular interest is anecdotal evidence suggesting that seepages had previously been activated in very wet years (such as 1955 – 1956) and that landholders planted trees around the seepages in an effort to dry them out.

Five shallow boreholes were drilled at Parilla in March 2003. Geological logs were compiled and sediment cores collected for analysis. All drillholes bar one intersected perched water.

The cross- section (Figures 19) shows the various units, and the position and extent of the perched groundwater. It shows the extensive red-brown stiff clay underlying younger sediments of calcareous silt, sand and sandy clay. Dunes comprised of deep sand are up to 10m thick.

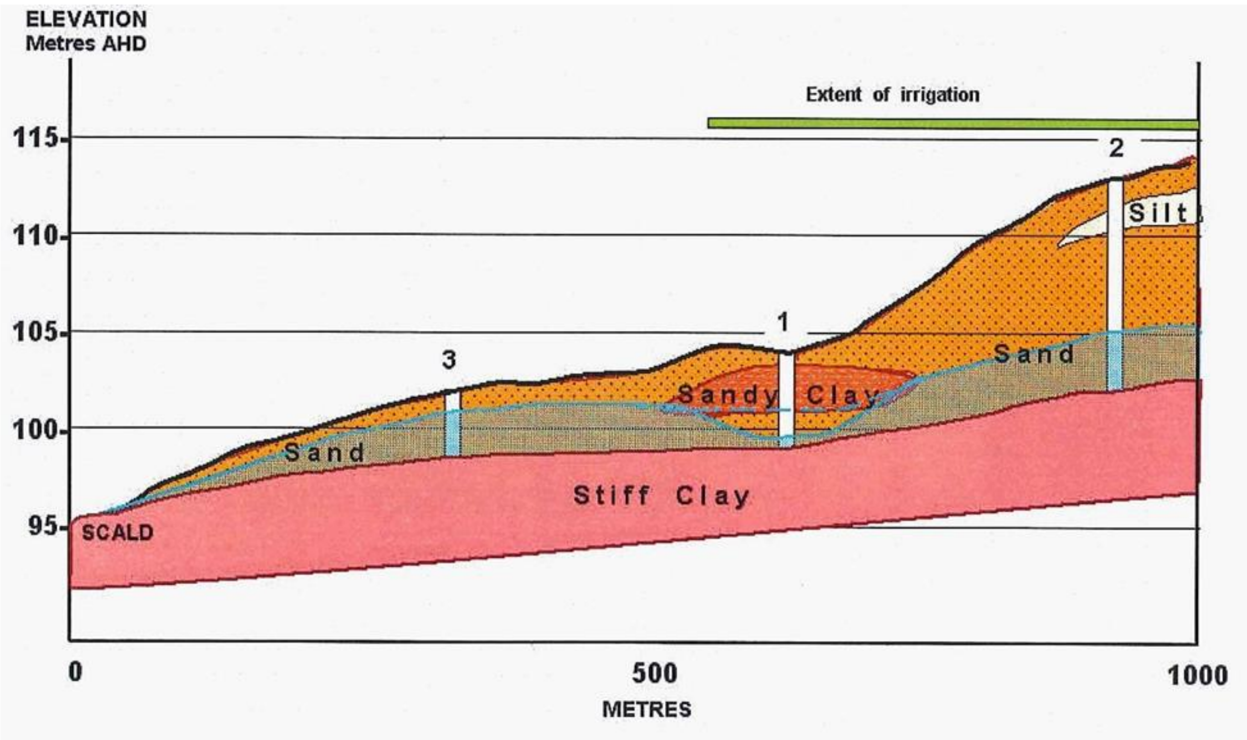


Figure 19. Hydrogeological cross-section for wells 1,2 and 3 at Parilla (after Barnett and Berens, 2003)

Figure 19 shows the location of the perched watertable which was intersected in wells 1 2 and 3. The watertable (blue line in the figure) is perching in the sand on top of stiff clay. At well #5 (not shown in Figure 19) located at the top of the sand dune, a perched watertable occurs at almost 6m below the surface. The watertable is depressed in well #1, possibly due to a lens of sandy clay which has slowed the downward percolation of rainfall. The authors indicate that this well may eventually recover to a position shown by the dashed line at the base of the sandy clay lens.

Although irrigation was occurring via a centre pivot at sites 1 and 2, it was concluded by Barnett and Berens (2003) that the scald area downslope was not the result of irrigation but from rainfall induced recharge.

Salt Sources in the Mallee

The potential sources of salt are from rainfall and from inherent storage of salt in clay soils and sediments. While the input of salt is ~350kg/ha/yr at the coast, this decreases to ~35kg/ha/yr some 250km from the coast. Even with very small amounts of salts, water can concentrate via evaporation. For example the electrical conductivity (EC) of rainwater is <100 microSiemens while perched water in seepage areas will have concentrated to 1000+ microSiemens.

Clay profiles in the mallee have small amounts of stored salts including Boron. The salts stored in sub-soil clays and sediments and sand dune cores can be remobilized by subsurface water flows.

Subsoil boron and salinity is indicated in the Calcic Red Chromosol soils of the mallee and hence it is possible that salt may begin to "wick-up" the from the deeper saline subsoil clays in the future if these areas remain wet and bare. These soils are typically sandy loams over red calcareous sandy clays at 30cm over Blanchetown Clay or clayey Parilla/Loxton sand at 80cm. The Blanchetown Clay is almost universally impermeable while the clay component of the Parilla/Loxton sand is generally sodic.

The scalds at the mallee focus sites are showing signs of salinity which is not sodium chloride dominated but appears to be a mix of gypsum ($CaSO_4$), carbonate (CO_3) and chloride salts (NaCl). An XRD analysis would help to confirm the actual composition of the mineral salts.

4 Management of Dune Seepage

Areas affected by dune seepage are usually not very large and appear to reflect a local waterlogging issue. If the problem is transient (i.e. comes and goes depending on seasons), it may not be necessary to do anything in some cases. However, where the landscape becomes unproductive due to vehicles becoming bogged and failed crops it then becomes necessary to do something. A cost-benefit analysis of any treatment needs to be considered as the cost and effort of imposing a treatment may far outweigh any benefits.

Management decisions need to address the following questions:

- provide a cover on bare areas
- prevent the seepage area from spreading
- reclaim the seep back to its former land use

If seepage areas are affecting productivity and are expanding they can be managed both on-site by revegetation with perennials and off-site by improving water use on the sand dune immediately upslope of the discharge site.

Clay spreading, clay delving and spading are all techniques currently being trialled to improve productivity on sand dunes. Improved productivity and water use should result in less water ending up in the land-locked depressions on the flats. More trials are underway in the SA MDB looking at ways to deal with water repellence that do not require clay.

The New Horizons program provides techniques to carry out soil amelioration.

Options for management and control of seepage can include both engineering and agronomic / plant based solutions.

4.1 Engineering Solutions

Construction of graded interceptor drains may be effective where the depth of sand over clay is relatively shallow (<1m). The banks / drains are used to collect seepage water and divert it away from the problem area.

Perched systems are generally fresh to brackish and suitable for a stock water supply. Intercepted water can be harvested and stored in dams, ponds or tanks. Harvesting of shallow brackish groundwater has been used in the eastern wheatbelt of WA and on the Upper EP of SA.

Interception at point sources needs further examination and would be highly site specific. The Department of Water WA (2007) describe several options to develop sand seeps as water supplies. These include using a bore or series of bores, well liners / well liners with feeder drains or excavating a soak within the seepage area. McAuley and Robinson (1994) indicate that low cost engineering options such as wind and solar pump systems may aid in protecting and/or rehabilitating areas of land affected by shallow watertables.

4.2 Plant-based Solutions

Increasing the landscape water using deep rooted perennials plant is a favoured option on deeper sands over clay underlain by a perched watertable. Perennials include lucerne and fodder shrubs.

Lucerne pastures can control groundwater recharge when used periodically in farming systems on aeolian soils of the Murray Basin (Murphy and Val, 1994). This could be part of a phase farming system where following much higher than normal rainfall, a lucerne pasture is established to dry out the soil profile before resuming annual cropping .

On the Great Plains of the USA, alfalfa (lucerne) was shown to be effective in drying up the perched watertable and reclaiming land lost to saline seeps (Brown et al., 1983). Continuous cropping of the affected area was resumed after a number of years. The perched watertable was occurring at depths of 4m to 8m in the recharge areas. It was noted at the time that cropping farmers were reluctant to move to perennials and so demonstration areas were set up to convince famers to move to a flexible cropping system.

Block planting with lucerne surrounding seepage areas will help dry these areas out. When seeps are expanding it means that there is no capacity of the soils to absorb moisture and hence the area becomes waterlogged and boggy.

It is important to prevent the soil for becoming bare of plant cover. In the short term a cover of mulch (old hay, chaff, straw, manure, wool dags) will help to reduce evaporation and concentration of mineral salts at the soil surface.

4.3 Demonstration Trials

A funded project will trial some key strategies at the four mallee seepage focus sites. Options to be trialled include any of, or a mix of the following:

- Perennial high water use plants (e.g. lucerne)
- Perennial salt tolerant shrubs and pastures (e.g. puccinellia)
- Strategic tree planting (e.g. eucalyptus)
- Summer cropping (e.g. veld)

Treatments to contain or control the spread of mallee dune seepage needs to be practical for the farmer especially with modern farming machines and systems. The question to consider is "what fits in with your farming system that will manage the issue"? On-going research is to be encouraged as this will help decide where best to target treatments in the landscape. The main focus at each of the four sites is anticipated to be along the following lines:

1. Bonds - A strategic block of lucerne (for hay) should effectively intercept midslope moisture flows and dry out the soaks in the main valley and developing seeps at the break in slope
2. Arbons - Strategic tree planting will be aligned with existing fencelines to intercept midslope moisture flow and dry out soaks from forming downslope
3. Thomas/Rose – intense soil testing, soil pits, strategic piezometer sites, establish cover on bare areas, assess the effects of summer weed control vs not controlling summer weeds on sandhills
4. Popes – improving growing season crop water use efficiency on sands to reduce infiltration, involving strategic soil amelioration techniques to address water repellence (the effects of existing clay spreading and delving trials could be assessed).

All sites will have plans to establish soil moisture monitoring and rainfall collection data. This is required to best assess the differences between treated and non-treated areas. EM38 surveys are being carried out in 2015 at each of the four sites followed by soil testing. Ground truthing with deep soil pits will include soil texture and electrical conductivity (ECe) analysis. Contour elevation mapping will also be undertaken.

5 Summary and Conclusions

Perched watertable induced seepage occurs in dune-swale landscapes where seeps and freshwater soaks discharge at the base of sandy rises. Groundwater discharge causing seepage typically occurs in low lying / depression areas which may be landlocked. Discharge can also occur on hillsides and at break-in-slopes.

Local shallow perched flow systems in aeolian sediments are the principal driver. These are caused by an aquifer which has developed on top of a confining / clay layer. The watertable may be transient / ephemeral if the aquifer is thin (<1m) or may be permanent if the watertable is some metres thick. Where a depth of sand over clay is small, shallow ephemeral perched watertables can develop during winter and dry up in late spring. For greater depths of sand (>1m), a more permanent perched groundwater system may form.

Wetter seasons and/or large episodic rainfall events, means that more water infiltrates to shallow groundwater systems resulting in the initial development and/or expansion of seepage areas. Hence unused rainfall recharges shallow perched watertables resulting in waterlogged areas downslope that may become saline over time due to evaporation.

Mallee dune seepage is a transient or cyclical phenomenon driven by episodic out of season extreme rainfall events and concurrent poor water use in rapidly draining or non-wetting sandy soils. Seepage areas will contract in drier seasons unless the land has become salinized, scalded or eroded due to lack of plant cover for long periods of time. Wet depressions may have always been in these landscapes.

Anecdotal evidence suggests that this problem has been increasing in recent years. It appears that wetter seasons in 2010 and 2011 with large out of season rainfall events in 2014 have seen a re-emergence of dune seepage in some mallee landscapes.

The occurrence is unpredictable, but is based on complex interactions between local soil-landscape /climate-rainfall / and land-use interactions. Hydrogeological processes will be more likely occurring at a hillslope or paddock scale rather than at a catchment or regional scale.

Because watertables are fresh to brackish in dune seepage situations, soil/plant indicators suggest waterlogging rather than salinity as the cause of the bare/scalded/degraded area. While affecting only very small areas of the mallee it is a cause of concern to farmers on whose properties it occurs. It greatly inconveniences with their cropping programs due to bogging of machinery.

It is most unlikely that deeper regional groundwater systems are involved. Some salt storage is apparent in clay layers and dune cores and is a likely source of salt if water is able to wick up to the surface from a deeper level.

This scoping study has highlighted the extent and size of the problem across the SA mallee region. The focus areas are along the river (e.g. Mannum, Bowhill) and between Murray Bridge and Pinnaroo (e.g. Karoonda-Wynarka area).

In the four focus areas investigated, all the seeps are surrounded by sandy slopes, some being long slopes and some seeps have short adjacent slopes. All seeps appear to occur in a depression and/or at a break in slope. However, in some cases, some seeps occur on long slopes with no apparent break in slope or depression. Some of the soaks seep water all year around even during summer, while others dry out in summer or after long dry spells. Even when dry at the surface (as in Feb 2015) there is saturated soil not far below the surface. This suggests a fairly extensive storage of subsurface water.

Hall (2015) notes that it is the very large sand dunes that are more likely to cause problems in the longer term. Over time the dune cores will become saturated and store water for subsequent delayed discharge.

In seepage areas the crop suffers from 'wet feet' and the 'pans' become bare due to lack of cover. The landholders also mentioned that summer weeds used to inhabit these areas and so would help to dry them out. This is no longer the case with more effective chemical weed control and hence these areas tend to remain bare as the excess water is no longer being used up in the 'pans'.

The poor drainage in the landlocked depressions means that water has nowhere to go, being constrained by the surrounding sand dunes and by the sub-soil clay. There is minimal vegetative cover in the 'pans' to use up the excess water.

Research carried out in other areas (WA and Canada) suggest that groundwater mounds may build up beneath seepage areas which means that paradoxically they can also act as recharge areas!

A broad strategy for areas affected by freshwater seepage is to use more water in the area immediately surrounding the seepage zone. Being very localised and with processes occurring at a paddock scale rather than a catchment scale, it should be much easier to find solutions that work.

Future Action

A survey of the areas around Wynarka and Karoonda could be done to see if this is an increasing problem in the area. A desk-top study using GIS is possible, or a land-holder survey.

Increased landholder awareness could prevent increasing problems in the future.

Promotion of NRM activities/grants to combat salinity, waterlogging and association problems could assist farmers to treat these problems.

To fully understand and manage mallee dune seepage into the future, it recommended that further investigation and monitoring be carried out on at least one of the case study sites in the mallee.

Funding is currently being sought to carry out further research into the causes and management of mallee dune seepage. Components would include:

- Research – causes, mechanisms and processes
- Investigation – set up demonstration trials
- Monitoring and evaluation
- Communication of best practice management

Some project initiatives would include the following activities:

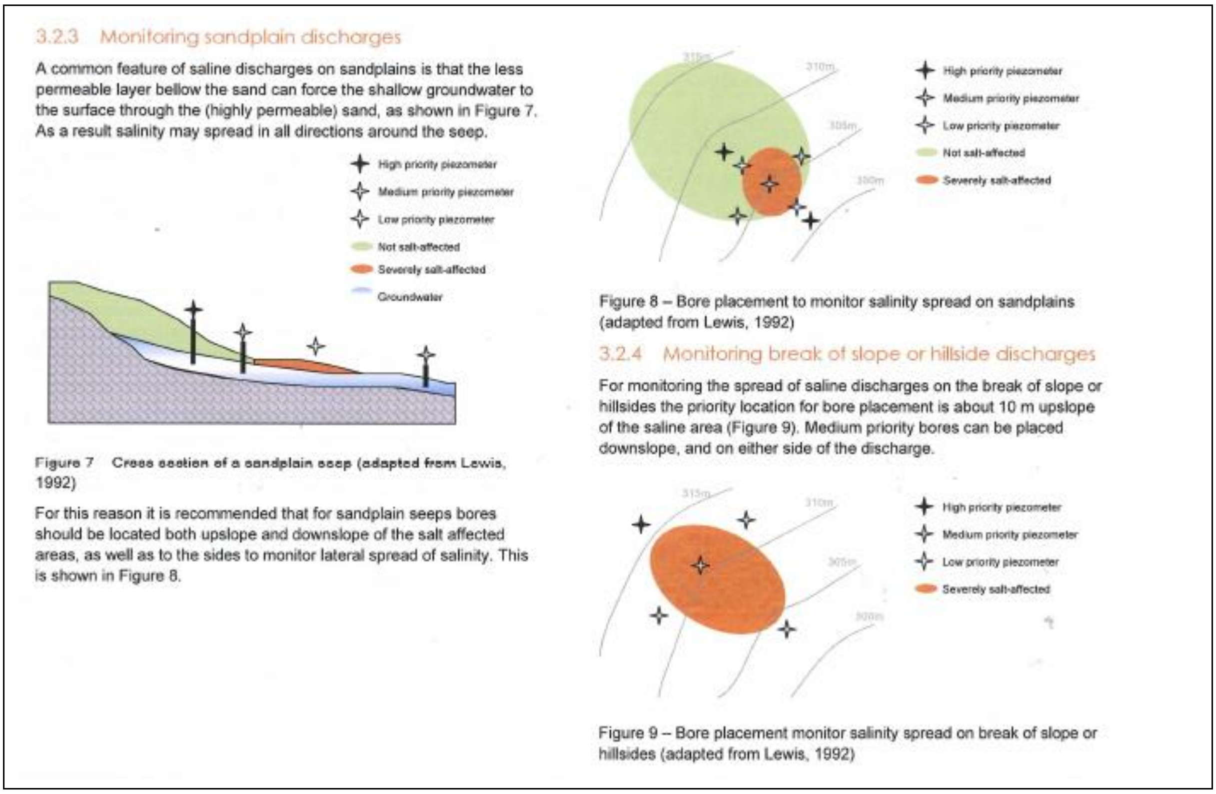
- Analysis of historical aerial data and land management practice to document changes to seepage boundaries over time
- Remote sensing and geophysical mapping including EM (electromagnetic surveys) to map extent and depth to clay
- Installation of piezometers / observation bores (see Figure 18) and instrumented with water level dataloggers to determine response of groundwater to rainfall events and changed land management practices; these can be linked in with soil moisture probe monitoring activities
- Paddock scale demonstration trials of innovative approaches to land management (such as summer cops, perennials and geo-engineering such as rock drainage and interception points)

- A link with a research centre (CSIRO, Universities etc.) to include student resources, learning and research expertise (collect climatic data, historical air photo interpretation etc.)

Geophysical surveys and some drilling would help to confirm the location of underlying clay layers.

Before selecting a management strategy it is important to gain an understanding of the extent, nature and risk of the problem. It is vital to understand the source of the flow of water causing the problem. Interpretation of geological, landscape soil and climatic and hydrological data will help to define the boundaries and characteristics of the flow system. Management systems can then be built based on this understanding.

Figure 20 provides a bore placement network design for monitoring groundwater discharge in hillside, break of slope and soak/seepage situations. It is recommended that monitoring bores (piezometers) be positioned both upslope and downslope of the discharge area as well as to either side of the seep. A nested piezometer site should be located within the discharge area with a shallow well to around 1.5m and a deeper piezometer to the base of the zone of saturation (base of the perched aquifer).


3.2.3 Monitoring sandplain discharges

A common feature of saline discharges on sandplains is that the less permeable layer bellow the sand can force the shallow groundwater to the surface through the (highly permeable) sand, as shown in Figure 7. As a result salinity may spread in all directions around the seep.

Figure 7 Cross section of a sandplain seep (adapted from Lewis, 1992)

For this reason it is recommended that for sandplain seeps bores should be located both upslope and downslope of the salt affected areas, as well as to the sides to monitor lateral spread of salinity. This is shown in Figure 8.

Figure 8 – Bore placement to monitor salinity spread on sandplains (adapted from Lewis, 1992)

3.2.4 Monitoring break of slope or hillside discharges

For monitoring the spread of saline discharges on the break of slope or hillsides the priority location for bore placement is about 10 m upslope of the saline area (Figure 9). Medium priority bores can be placed downslope, and on either side of the discharge.

Figure 9 – Bore placement monitor salinity spread on break of slope or hillsides (adapted from Lewis, 1992)

Figure 20. Bore network design for monitoring seepage discharges (after Department of Agriculture Fisheries & Forestry, 2009)

The estimated cost of contract drilling is $100 per metre (this is an all up cost include mobilisation, accommodation and consumables). A minimum of six monitoring wells is recommended with depths expected to range from around 2m up to 8m. A budget of $2,500 to $3,000 would be required to carry out this work. Additionally the cost of a downhole waterlevel datalogger should also be budgeted for.

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