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Perched Watertable Induced Seepages in Dune-Swale Landscapes of SA's Agricultural Lands

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1 Introduction

Perched watertable induced seepage is a relatively widespread phenomena occurring in dune-swale landscapes where freshwater seepage or soaks discharge at the base of sandy rises. The terms seep, seepage and soaks are used synonymously. The occurrence of dune seeps is highly unpredictable and can appear in the landscape without any apparent cause.

In texture-contrast soils, rainwater can collect and perch on top of low permeability subsoils (i.e. clays) and form a zone of seasonal saturation in the profile. This mainly results in transient seasonal waterlogging. In this case we are dealing with shallow groundwater rather than soil water *per se*. Hence the problem is perennial rather than seasonal with fresh water discharge occurring even during summer.

Anecdotal evidence suggests that this problem has been increasing in recent years. It appears that wetter growing seasons in 2010 and 2011 with large "out of season" rainfall events in 2010, 2011 and 2014, have seen an emergence or re-emergence of dune seepage in some areas. Farmers are also being affected by the inconvenience and disruption of machinery becoming bogged in wet areas, especially when seeding but also while spraying and even at harvest time.

The farmers who appear to be the most affected are ones who are intensively cropping their land and rigorously controlling weeds. Those who have a rotational crop/ pasture system to cater for livestock enterprises do not appear to be as affected. In a grazing system, animals will affect plant growth and eventually annual plants die off, but the plants continue to use soil moisture while they are alive. It is suggested that effective weed control stops weeds from using soil moisture and this unused water is draining rapidly through the deep sands of the dunes. This forms a shallow fresh watertable on top of, or within clayey subsoils. The clay subsoils may be sodic which reduces their infiltration capacity.

Examples of sand dune seepage across South Australia have not been well documented or studied apart from mapping by the Soil and Land Program during the 1980s and 1990s. Anecdotal information has largely been relied upon to compile this report.

This scoping study provides a State-wide overview of the situation regarding the extent and severity of shallow perched watertables due to seepage in dune-swale cropping situations and the significance of the issue from a natural resource management perspective. It attempts to identity if seepage caused by perched watertables is a significant enough issue from both a natural resource management and sustainable agriculture perspective to warrant investment in treating it.

A related project titled "Investigation and Assessment of Mallee Dune Seepages" (Henschke and Tonkin, 2015) is being managed and funded by SA Murray-Darling Basin Natural Resources Management (SAMDB NRM). A report has been produced for this project covering four focus farms in the Mannum, Karoonda and Wynarka areas of the Mallee. Demonstration trials are being set up at each site to trial some key strategies at the four focus locations.

At the time of writing this report, further funding has become available to carry out research into the causes and mechanisms of perched watertable induced seepage. This has included electromagnetic (EM) mapping of soils, soil pit descriptions and the installation of watertable monitoring wells at a number of locations.

2 Hydrological Processes

Local shallow perched flow systems in aeolian sediments are the principal drivers of induced seepages in dune-swale landscapes. Water draining from the aeolian soils has collected within and on top of lower permeability (confining) clay layer (such as Blanchetown Clay or its equivalents). Figure 1 is a schematic diagram showing the hydrological processes that can occur in dune-swales.

The occurrence of Blanchetown Clay or its equivalent in the landscape seems to be a pre-requisite for the formation of perched watertable discharge. This clay is named after the type area (Blanchetown in the mallee) and represents a type of clay that is relatively heavy in texture, high in boron and salt, and widely distributed across SA. It was formed in an ancient lake (lacustrine) environment and is a greenish-grey to mottled red-brown clay sediment.

According to research conducted by Cook *et al*., (2001) in the Mallee, perching of water on the Blanchetown Clay occurs mainly in irrigation areas and in higher rainfall areas. They have indicated a figure of some tens of millimetres per year for vertical hydraulic conductivity (permeability) of the Blanchetown Clay.

Watertable discharge causing seepage typically occurs in low lying depressions which may be landlocked. Discharge can also occur as seeps on hillsides and at break-in-slopes. Anecdotal evidence suggests that wet depressions have always been a natural feature in dune- swale landscapes. The expansion and contraction of seepage areas is a cyclical phenomenon exacerbated by large rainfall events outside of annual plants' growing season and changing farming practices.

During wet seasons and/or large episodic rainfall events, more water infiltrates to shallow groundwater systems resulting in the initial development and/or expansion of seepage areas. Unused rainfall recharges shallow perched watertables resulting in waterlogged areas in lower-lying areas. These bare areas might become saline over time due to evaporation and accumulation of salt drawn from the soil profile at the soil's surface.

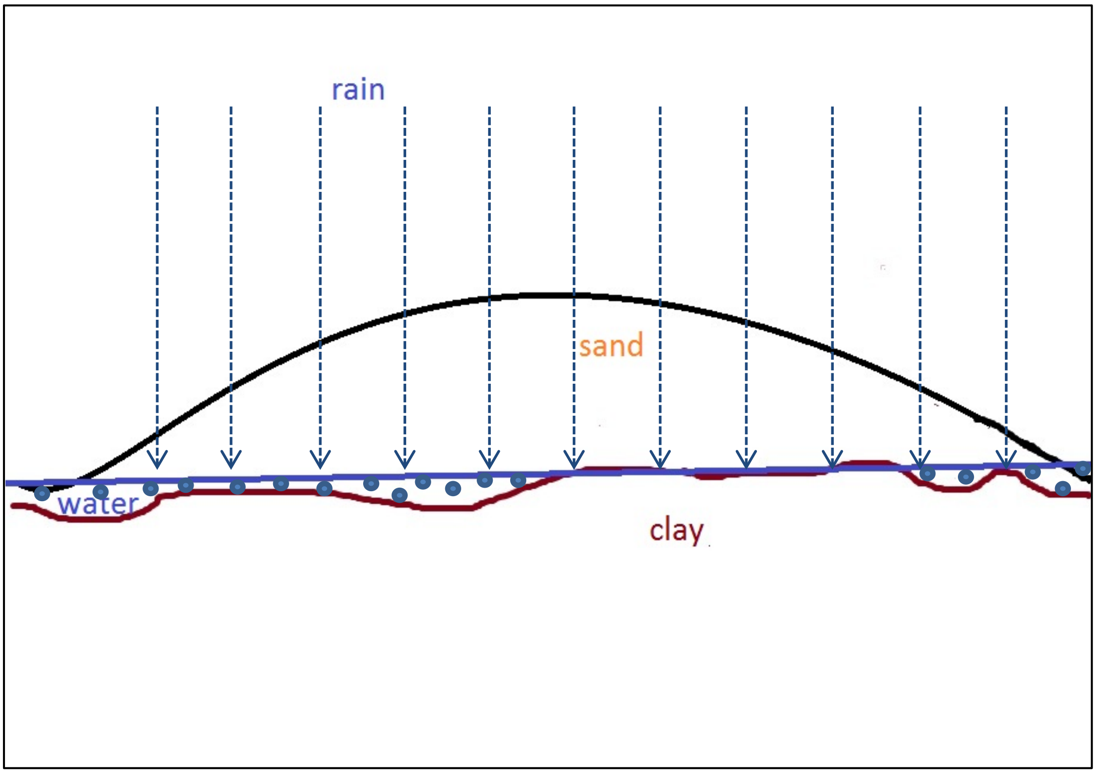

Figure 1: Schematic of dune-swale hydrological processes

Interaction between shallow local watertables and deeper regional aquifer systems is site specific. In some cases the two systems join together resulting in much more severely salinized land. The discharge zone becomes much more difficult to reclaim once it is salinized. This could well be the scenario on the Yorke and Eyre Peninsulas, but not so apparent in the Mallee where the regional saline groundwater aquifer is much deeper.

Research carried out in other areas (Western Australia and Canada) suggest that groundwater mounds may build up beneath seepage areas which means that paradoxically they can also act as recharge areas to deeper groundwater systems.

Poor surface drainage in landlocked depressions means that water has nowhere to flow to, being constrained by the surrounding sand dunes and by the sub-soil clay. Common indicators of perched watertable discharge include:

- Changes in vegetation communities (weeds begin to dominate)
- Free water or dampness at the ground surface (boggy soils)
- Bare soil and/or changes in soil structure (e.g. 'fluffy' or 'oily' surface)
- Appearance of white crystalline crusting (mineral salts) and/or 'soil blackening' (organic matter)

Groundwater or watertable discharge results in waterlogged or salinized areas in the landscape. Saline groundwater discharge is referred to as dryland salinity. While perched watertable induced seepage is not termed as dryland salinity, the processes and mechanisms can be similar. The main difference is that dryland salinity is caused by increased recharge to groundwater systems through the removal of perennial, high water-use plants in the landscape, causing the usually highly saline groundwater to rise closer to the soil surface. Perched watertable seepage is more of a waterlogging issue.

Non-watertable induced salinity (also termed dry saline land or commonly known as "magnesia patch") is caused by the natural presence of high levels of salts in the soil profile (Kennewell and Young, 1997). The salts can migrate up and down through the soil profile with drainage of rainfall or capillary rise and evaporation of soil water.

3 Occurrence on SA's Agricultural Lands

A map of showing dune seepage potential on the State's agricultural lands provided by the Department of Environment, Water and Natural Resources (Figure 2), indicates potential for 'dune seepages' by classifying soil landscape units in terms of:

- Proportion of swales in which clayey subsoils are close enough to the soil surface to cause seepage water to appear on the surface
- Proportion of sand dunes in the landscape.

The map in identifies eight dune seep classes shown in Table 1.

Table 1: Dune seepage potential, South Australian agricultural lands (DEWNR State Land and Soil Information)

Dune Seep Class	Proportion of Swales Susceptible to Seepage	Proportion of Dunes in Landscape	Hectares	Percentage of Total
1 (red)	>60%	>30%	1006	0.0
2	>30%	>30%	242,315	1.7
3	5 – 30%	>30%	574,917	4.1
4	>60%	10 – 30%	49,594	0.3
5 (yellow)	30 – 60%	10 – 30%	248,254	1.8
6	5 – 30%	10 – 30%	108,093	0.7
7		<10%	11,402,643	80.9
8 (green)	<5%		2,176,512	15.4
X	N/A	N/A	152,712	1.1
TOTAL			14,088,214	100

Class X includes urban land, reservoirs, lakes, quarries, evaporation pans

The sequence of classes 1 through to 8 is determined by the frequencies of both swales and dunes. This ensures that landscapes with greater frequency of dunes and swales in combination are rated as having higher risk than those swales or plains which are not associated with high dune frequency.

The categories in the legend show that as the Dune Seep Class increases from 1 to 8, the likelihood of seepage occurring in the swales decreases, due to the lack of proximity of dunes adjacent to swales. The inherent risk due to permeability of the soils and substrates within swales has already been accounted for.

Figure 2 shows dune seepage potentially occurring in the NRM regions of:

- Eyre Peninsula
- Northern and Yorke
- SA MDB

The occurrence is relatively minor in the other regions, although the South East is not well documented and there may be occurrences north east of Keith.

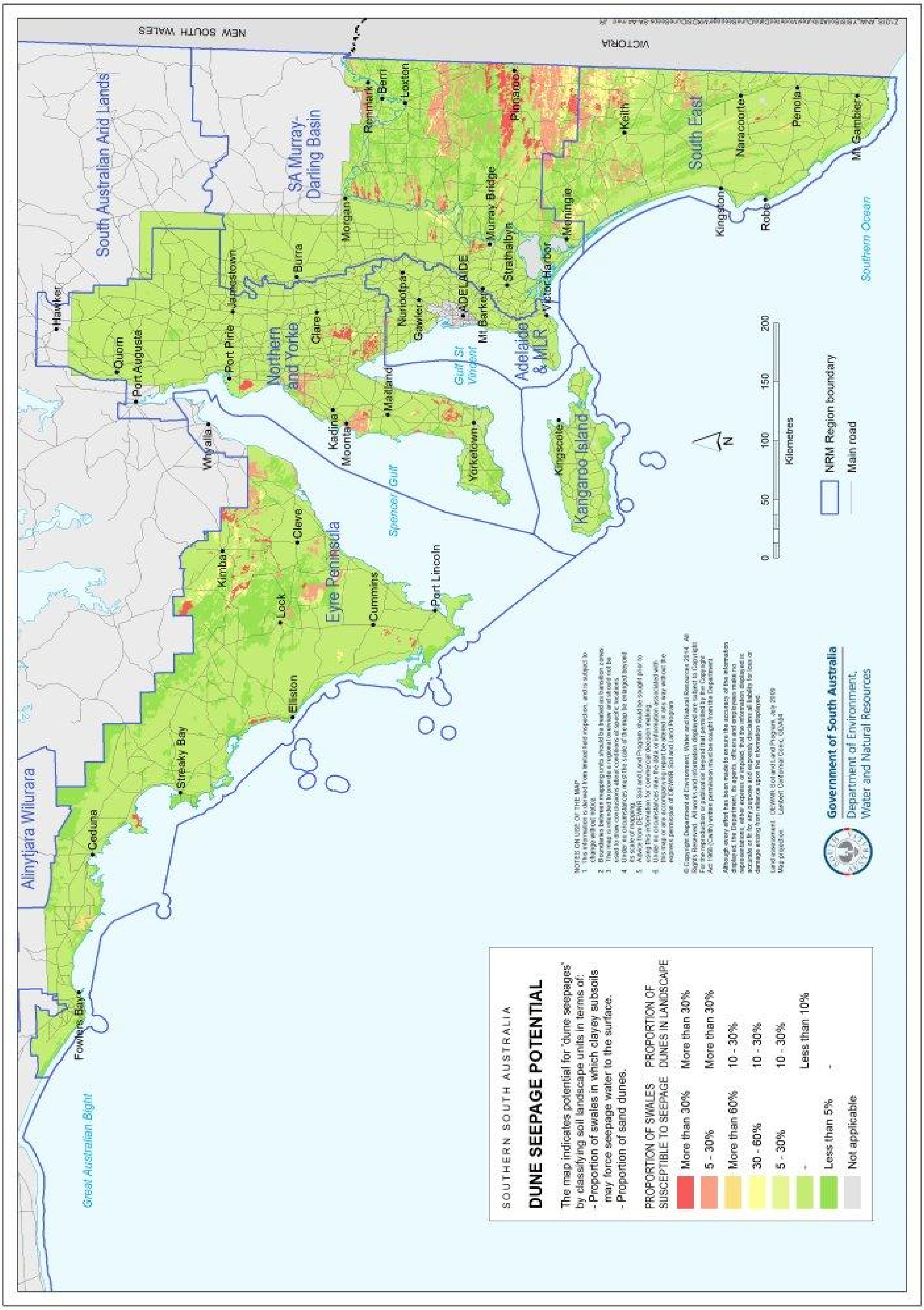

Figure 2: Map showing dune seepage potential in SA NRM regions

4 Regional Occurrences

4.1 Eyre Peninsula

The following table estimates the potential for dune seepage to occur in the Eyre Peninsula NRM region and is based on inherent soil properties and topography. It does not take into account climate or land management factors. The actual area affected is expected to be less than the potential area.

Table 2: Dune seepage potential, Eyre Peninsula Region (DEWNR State Land and Soil Information)

Dune Seep Class	Proportion of Swales Susceptible to Seepage	Proportion of Dunes in Landscape	Hectares	Percentage of Total Area
1 (red)	>60%	>30%	0	0
2	>30%	>30%	51,219	1.1
3	5 – 30%	>30%	69,027	1.5
4	>60%	10 – 30%	18,533	0.4
5 (yellow)	30 – 60%	10 – 30%	47,309	1.0
6	5 – 30%	10 – 30%	29,983	0.6
7		<10%	3,533,571	75.7
8 (green)	<5%		920,334	19.7
X	N/A	N/A	116	0
TOTAL			4,670,092	100

Class X includes urban land, reservoirs, lakes, quarries, evaporation pans

The main areas identified as having the greatest potential for dune seepage in the region occur on eastern Eyre Peninsula between Cleve and Kimba and south of Lock. Other areas include the Cummins-Wanilla Basin and the far west coast, especially north of Elliston.

Many of the parallel sand dunes on the Eyre Peninsula have remnant vegetation left on them, unlike the SAMDB and N&Y regions. This could explain why the occurrence of perched watertable seepage is not as common in some dune/swale areas of this region as there is less recharge from sandhills due to the presence of this perennial vegetation.

Sand dune seepage occurs at a number of sites north of Cleve (B Hughes pers. comm.), especially in spillway sands that occur in the Mangalo area. Spillway sands are the infill between rocky outcrops and comprise deep white sands to loamy sands with occasional groundwater discharge (fresh seepage) towards the lower end of the slope.

A trial in the 1980s (B Hughes pers. comm.) was conducted on an area of 20-25ha which was fenced off and was planted to lucerne in 1983. A site on the Hannemann property in the Cleve Hills near Mangalo was revegetated in July 1986 with salt tolerant species including *Casuarina glauca*, flat topped yate, swamp mallet, salt tolerant red gums and *Melaleuca halmaturorum*. Figure 3 is a recent aerial view of trees on the seep.

Figure 3: Trees growing on seepage site between sandhills, Mangalo (GoogleEarth™, 2015)

In the Cleve uplands there are occurrences of lenses of fresher water in sands overlaying a saline regional groundwater flow system in the crystalline basement rocks. Rainfall recharge keeps the shallow system relatively fresh (i.e. EC[1] is less than 3000 µS/cm), but as the saline watertable rises due to clearance of native vegetation, more saline water mixes with the fresher water and causes the shallow system to become saline.

The geology underlying dune-swale systems on the Eyre Peninsula is very different from the Murray Basin and Pirie Basin and could suggest why seepages tend to become saline over time. Dunes in the Cleve-Cowell hills are draped over a granitic landscape where fractured rock aquifers discharge highly saline groundwater in the valleys. In the Basins there is a deep sedimentary sequence and the deep groundwater aquifer is much deeper.

Developing saline areas indicate that a deeper saline groundwater system is connecting with the perched watertable resulting in severely salt-affected land. It is possible that in the early days of farming, these seeps were fresh and provided a reliable water resource for stock use and for irrigation (e.g. vegetables and fruit trees). Some of the fresh water soakage areas have been used for stock water resources utilising cement well liners. Over time, the deep groundwater has risen to within a couple of metres of the ground surface providing a source of salt, thus rendering the fresh seepage water unsuitable for irrigation and general use.

[1] EC = Electrical Conductivity, micro-Siemens per centimetre (µS/cm)

4.2 Northern and Yorke

There are a number of different types of land salinity occurring in the Northern and Yorke district. This has been summarized in Liddicoat (2005) and Harding et al. (2008). The groundwater system in the Wokurna area has generally deep watertables with higher land elevation so the likelihood of perched watertables connecting with more saline deeper groundwater is low. While perched watertable seepage has occurred in the past and landholders have taken action such as planting perennial species on seepage areas, in more recent times (and perhaps with a newer generation of farmers who have not seen it before) it has been raised as a problem affecting productive land.

Table 3 estimates the potential for dune seepage to occur in the Northern and Yorke NRM region and is based on inherent soil properties and topography. It does not take into account climate or land management factors. The actual area affected is expected to be less than the potential area.

Table 3: Dune seepage potential, Northern and Yorke Region (DEWNR State Land and Soil Information)

Dune Seep Class	Proportion of Swales Susceptible to Seepage	Proportion of Dunes in Landscape	Hectares	Percentage of Total Area
1 (red)	>60%	>30%	1006	0
2	>30%	>30%	42,043	1.3
3	5 – 30%	>30%	60,346	1.9
4	>60%	10 – 30%	10,616	0.3
5 (yellow)	30 – 60%	10 – 30%	8,974	0.3
6	5 – 30%	10 – 30%	3,852	0.1
7		<10%	2,952,697	92.4
8 (green)	<5%		97,494	3.1
X	N/A	N/A	19,971	0.5
TOTAL			3,193,999	100

Class X includes urban land, reservoirs, lakes, quarries, evaporation pans.

In this region, the main areas inherently at risk of dune seepage occur south east of Port Wakefield (Long Plains-Avon area) and on the plains north of Balaklava. Smaller areas are south of Port Broughton and south of Moonta. There are also occurrences in the Minlaton-Ramsey area and south of Port Pirie. Some seepage areas are also noted in the Long Plains–Avon area.

During the last five years (since around 2010), there has been increasing reports from growers in the Wokurna and Bute districts of productive land in dune-swale systems being taken out of production due to waterlogging and inability to pass over seepage sites with machinery. There were also reports of machinery getting bogged unexpectedly in wet patches in paddocks (Stefan Schmitt, pers comm).

The Wokurna Land System (as defined by DWLBC, 2007) is predominantly dune-swale country. The dunes have deep, low-fertility, rapidly drained soils with a high recharge potential. The soils are deep sandy soils of Aeolian origin. Hall et al (2009) have classified these soils as a Calcic Calcarosol – deep siliceous sands. The swales tend to be of sedimentary substrates containing carbonate material and clay. The clays can be highly impermeable and sodic.

Figure 4: Ponded water in depression in cereal crop, Wokurna, September 2014

Seepage has been known to occur in the area before and in some situations seepage areas have been sown to perennial, salt-tolerant plant species such as saltbush. These have tended to be on "break of slope" areas, not in the lowest-lying areas where water accumulates and ponds.

Landholders had hoped that the problem would correct itself with a return to more normal seasons after a number of wet years but now believe the expansion of affected areas is continuing. There were reports of "lakes as big as football fields" in a number of paddocks which was particularly frustrating during the last few years when dry spring conditions have prevailed and crops adjacent to the ponds suffered moisture stress. Apart from the lost production and problems caused by not being able to sow, spray or harvest the wet sites, the areas can also become havens for weeds and pests.

Figure 5: Seepage area burnt presumably to control weeds and make it easier for tillage equipment to work through, March 2015.

Seepages are reported to be widespread in the Alford area particularly on the more continuously cropped / no-till farms with effective summer weed control (Wayne Johns, pers. comm.). In the Agery-Weetulta areas on the northern Yorke Peninsula, PPK (1994) recognised perched watertables as a hydrological process causing seepage to develop in sandy country.

Figure 6 is a typical example of a seepage at the break-of-slope of a major sand dune in the Alford area. The seepage area occurs immediately downslope of a significant dune system at the break in slope of the dune. The seep has been colonized by weeds such as buckbush and potato weed (the green area in middle of seep).

Figure 6: Example of break of slope dune seepage in the Alford area

The Johns at Alford have observed that small seeps or boggy areas have started to develop where they were not a problem 10 years ago. It is believed that this is related to their continuous cropping and better summer weed control systems. They observe that neighbouring farmers with less intensive cropping systems (e.g. pasture phases with minimal summer weed control) are not having the same problems of seep development.

Management of the seepages have been attempted by a number of landholders in the Alford area. The Johns are trying methods to improve the productivity and reduce recharge on the sandhills. For example, in the 2014-15 summer they sowed sunflowers which germinated following the January rains. Mr Johns is considering undersowing wheat with a winter-dormant lucerne in the coming year.

Some farmers have planted saltbush in wet areas that have begun to become bare. On the property of Wayne Johns some seepages are thought to have always been present (noted as far back as the early 1970s when they bought the property). Their 'swamp' area was planted around the edges of the seep with 3 ha of saltbush that is now 1 – 2m high.

In some areas on the Yorke Peninsula, the perched watertable has connected with the underlying groundwater flow system resulting in severely salt-affected land. It is possible that in the early days of farming, these seeps were fresh and provided a reliable water resource for stock use and for irrigation (e.g. vegetables and fruit trees). Over time, the deep groundwater rose to within a couple of metres of the ground surface providing a source of salt, rendering the fresh seepage water unsuitable for irrigation.

This appears to be the case south of Minlaton (Treloar property) where water harvested from depressions and swales between sandhills was fresh enough to be used as a stock water supply in the 1930s. By the 1970s this water had become too saline for use due to the rising deep highly saline groundwater (McCarthy, 1991).

Piezometers were installed in the Treloar catchment at Minlaton in August 1990 as part of a statewide dryland salinity research program. Table 4 is a geological log of a sandhill profile where seepages occur downslope around the edge of the swampy depression which is now highly saline. The drilling profile shows sand and clay layers are encountered in the core of a sand dune which is up to 20m in height. Water can be stored and transmitted through the more permeable layers in the dune core. Note that some of the clay layers are mottled. Mottling can sometimes indicate periodic waterlogging in a soil profile, suggesting that the layers have poor drainage.

Table 4: Dune core soil profile at Minlaton

Depth (m)	Description of material
0.0 – 0.5	Grey loamy sand
0.5 – 4.0	Yellow brown mottled sand clay with limestone concretions
4.0 – 5.0	Pale brown clayey sand
5.0 - 6.0	Orange sandy clay
6.0 – 8.0	Sand
8.0 - 9.0	Cream clayey sand
9.0 – 13.0	Tight grey mottled plastic clay
13.0 16.0	Clay with sandy bands
16.0 – 21.0	Grey mottled sandy clay

The following groundwater flow systems were recognised during the drilling and piezometer installation program in this catchment:

- Regional highly saline groundwater flow in deep glacial sand aquifers, discharging to terminal lagoons and salt lakes
- Local saline flow in sandy clay aquifers causing dryland salinity in valley flats
- Perched watertables discharging as freshwater seeps below sandhills.

Freshwater seeps were occurring higher up in the landscape at the break in slope of large sandhills. These seepages had not become saline because the regional groundwater is much deeper in the higher part of the landscape. Sand dunes were revegetated with tagasaste in the 1990s and this has assisted in drying out the perched watertables.

4.3 South Australian Murray-Darling Basin

Estimates of the potential for dune seepage to occur in the South Australian Murray-Darling Basin NRM region, based on inherent soil properties and topography, are provided in Table 3. They do not take into account climate or land management factors. The actual area affected is expected to be less than the potential area.

Table 5: Dune seepage potential, South Australian Murray-Darling Region (DEWNR State Land and Soil Information)

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 includes urban land, reservoirs, lakes, quarries, evaporation pans.

The SAMDB region has the greatest area of dune swale systems with potential for dune seepage in SA. The areas most at risk in the region occur between Murray Bridge and Pinnaroo with other areas adjacent to the River Murray between Murray Bridge and Morgan. Other significant areas occur between Pinnaroo and Keith, and south of Loxton.

Case studies from four farm sites in the SA mallee region are documented in a separate report by Henschke and Tonkin (2015). The sites are located at Mannum, Wynarka and Karoonda. Demonstration trials are being set up to demonstrate key strategies with a mix of options to be tested. The sites are also having electromagnetic (EM) surveys carried out to investigate if it is possible to map clay as an indicator of where seeps are likely to occur in the landscape.

5 Case Study Farms

Situations where seepages were reported to have increased in recent years were inspected and discussed with farmers and advisers. While there were reports of increased areas of seepage from Eyre Peninsula, these appear to have some connection to dryland salinity or were not necessarily associated with dune-swale systems.

5.1 Hewett property, Wokurna

The Hewett property near Wokurna has several examples of seeps or soakages that are appearing in the dune-swale country in the region. GoogleEarth™ images from 2010 to 2013 show the appearance of these areas during that period. Seep 1 and seep 2 (Figure 8) are areas that have been the subject of observation and investigation in 2015.

The Hewetts have been continuously cropping their property for a number of years and do not run livestock. They have a rigorous weed control programme which includes controlling the growth of any weeds that are germinated by summer rains. Couch had been established on sandhill country a number of decades ago to stabilise the rises and prevent them from drifting; this was eradicted around 2010.

While the western end of seep 1 has been evident in the landscape for a number of years, in more recent times the area inundated has become larger and the inundation period has grown longer. Seep 2 varies from being completely under crop to inundated then completely devoid of plant growth. Figure 7 shows seep 1 in September 2014.

Figure 7: Ponded water in seep, 10th September 2014

The Hewetts, along with other farmers in the area, also report instances of striking "boggy" patches in paddocks where machinery will start to sink and occasionally become bogged in wet patches on otherwise sandy soil on rising land. These patches are not obvious and cannot be detected by different soil colour or crop growth. Wheel marks left by machinery are the main indicator of these areas. Machinery has been bogged at various times of the year during summer weed control through to harvesting operations and the greatest cost associated with these areas is the time lost and inconvenience in retrieving bogged machinery at busy times of the year.

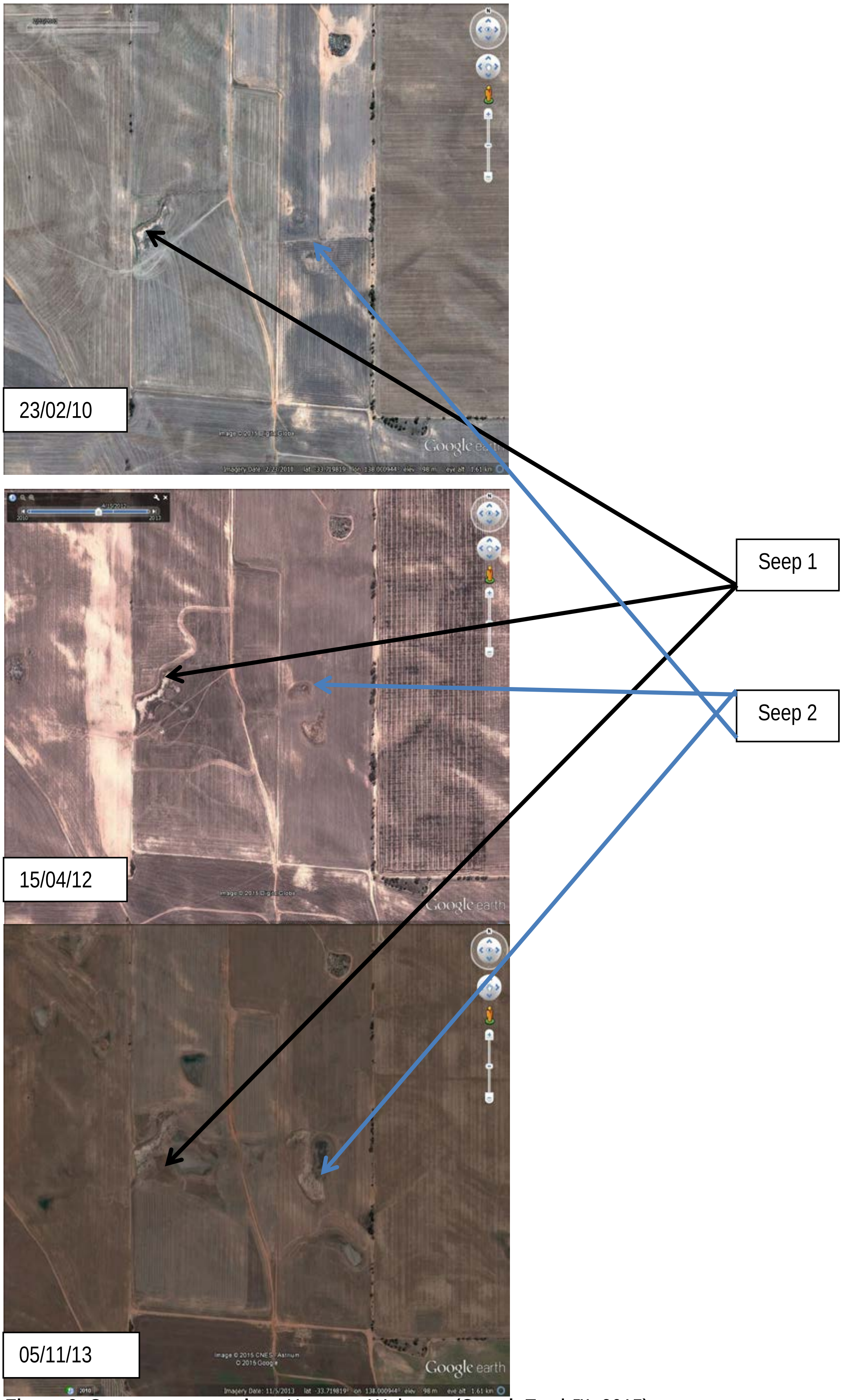

Figure 8: Seep areas over time, Hewetts, Wokurna (GoogleEarth™, 2015)

Observation of these areas in November 2014 found that all ponded surface water had either drained into the soil profile or had evaporated. Seepage was evident in some places. The areas were devoid of plant growth except near seepage where salt-sensitive plants such as ryegrass and milk thistle (*Sonchus oleracens*) grew. Wheat plants just above seepage on seep 1 were well grown and out in head with very full heads of grain.

Figure 9: Western edge of seep 1, November 2014

Figure 10: Vigorous crop and weed growth on seepage

A slight ridge at the western edge of this seep suggests a geomorphological structure running in an approximate south west to north east direction and it is possible that this structure has intercepted the watertable, forcing seepage to emerge at the surface higher in the landscape.

The surface appearance of the dried seep comprised a mix of colours. White non-crystalline deposits reacted to dilute hydrochloric acid indicating it is calcium carbonate. It is believed this has resulted from dissolution of calcium carbonate in the soil profile. Darker soil is associated with organic material accumulated under anaerobic conditions during periods of waterlogging.

Seep 2 was an area of bare land approximately 300 m^2 with seepage channels evident on the western side of the area.

In autumn 2015, seeps 1 and 2 had dried out sufficiently to enable the Hewetts to cultivate most of the areas.

Figure 11: Seep 2, November 2014

Figure 12: Seepage western side of seep 2

Figure 13: Seep 2 mostly cultivated except for active seepage area, May 2015

In January 2015, a backhoe was used to dig a pit on a “boggy” patch on Hewett’s property. A site was selected that was not an obvious soak or depression, but observed to be boggy when driving machinery over it. The site was mid-slope of a sandhill.

Figure 14: Looking up slope from soil pit site

Figure 15: Looking down slope from soil pit site

On commencement of digging, water immediately began to seep into the pit. At the time of describing and collecting soil samples from the soil profile, the water was 80 cm below the soil surface. The salinity of the water was approximately 3,950 EC units or 2,500 mg/L Total Dissolved Salts.

Figure 16: Perched water table below soil surface

Description of the soil profile shows a sandy loam textured soil overlying a layer of calcrete rubble, which is above a sandy loam and then light to medium clay from about 60 cm beneath the soil surface (Figure 17). The soil was highly sodic throughout the profile.

Depth (cm)	Description
0-15	Dark reddish brown, highly calcareous sandy loam with sub-angular blocky structure, weak consistence.
15-30	Yellowish red (bleached), highly calcareous sandy loam with sub-angular blocky structure, weak consistence
30-45	Calcrete rubble with more than 80% fragments
45-65	Massive strong brown, sandy clay loam, sub-angular blocky structure, very highly calcareous with more than 50% hard carbonate fragments
65-80	Reddish yellow, massive, highly calcareous light clay with many calcrete fragments
80-110	Red, light medium clay with sub angular blocky structure with firm consistence and 15% hard calcrete fragments
110-150	Red, medium clay, with angular blocky structure, strong consistence, with soft carbonate present and many medium ferromanganiferous fragments

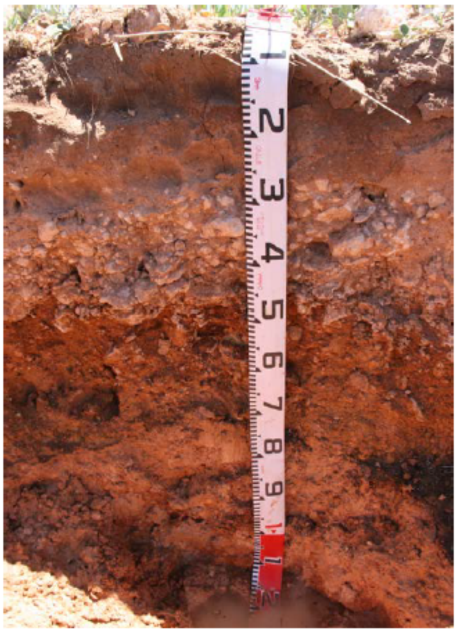

Figure 17: Soil description and profile of soil in "boggy" patch

In contrast, a soil profile description for a sandhill on an adjacent property, shows the complete absence of clay and free drainage properties of the sand (Figure 18).

Soil Description:

Depth (cm)	*Description*
0-4	Orange loose sand. Abrupt to:
4-38	Yellowish red friable loamy coarse sand. Diffuse to:
38-69	Yellowish red soft moderately calcareous sand. Gradual to:
69-90	Yellowish red soft highly calcareous sand. Clear to:
90-113	Red friable massive coarse sandy loam with 10-20% fine carbonate segregations. Clear to:
113-139	Yellowish red soft very highly calcareous loamy sand. Clear to:
139-180	Orange soft very highly calcareous sand.

Figure 18: Soil description DEWNR Soil and Land Information Soil Characterisation Site CM004

These observations support the suggestion that rainfall is draining through the sands and collecting above and within clay layers in the soil. Where the clay layer is close to or at the soil surface, ponds of water appear on the land. The relatively low salinity of the water and the presence of salt sensitive plants growing on and adjacent to seeps indicates that there is not a connection to deeper, highly saline groundwater. It is more likely that plant growth is affected by waterlogging, rather than by salinity.

While the Hewetts are growing high yielding crops, it appears that there is “unused” water draining through the profile. Some of this is from “out of season” rainfall and it is also possible that losses are occurring from early growing season rainfall, when young plants have small root systems.

Examination of rainfall data from Mundoora shows that summer and early autumn rainfall events of over 50 mm occurred in December 2010; February, March and December 2011; March 2012 and February 2014 (Figure 19). While a series of drier years (indicated by a downward trending line) from about 2000 to 2009 is suggested by the cumulative deviation from the average of annual rainfall in Figure 20, the cumulative deviation from the average for the December to March period indicates a series of wetter summers since the early ‘90s and particularly since around 2006 (Figure 21).

Figure 19: Monthly rainfall 2010 - 2014, Mundoora station (Source: Bureau of Meteorology)

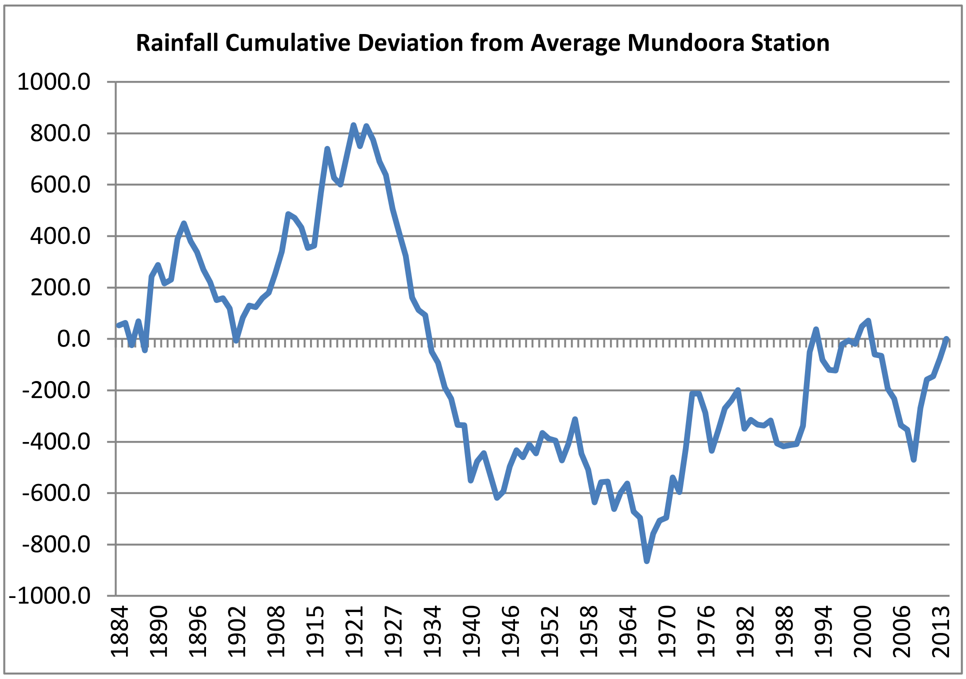

Figure 20: Indication of series of wetter and drier years, annual rainfall Mundoora (Source: Bureau of Meteorology)

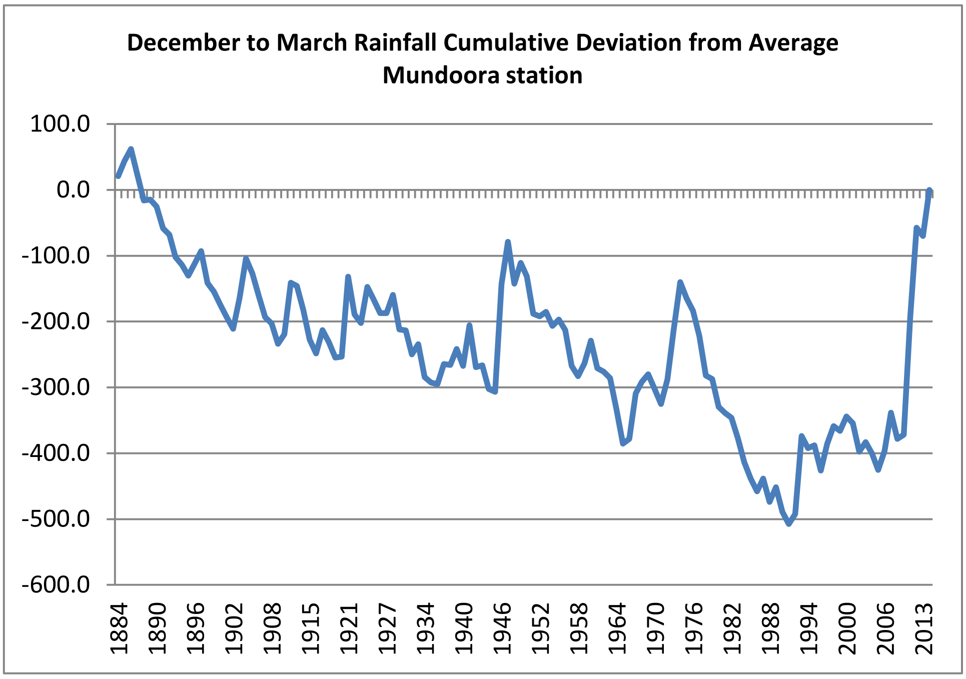

Figure 21: Indication of series of wetter and drier summers, December to March rainfall, Mundoora (Source: Bureau of Meteorology)

This period of above average summer rainfall, combined with rigorous control of summer growing plants, suggests a sustained accumulation of unused water in the soil profile.

While the waterlogged and boggy areas do cause economic losses through lost production, time losses and weed problems, the area affected is not significant. The greatest cost is the lost opportunity to utilise the water to grow profitable crops.

5.2 Rose Property, Wynarka

This site was one of four investigated as part of a project conducted for the SAMDB (Henschke and Tonkin, 2015). A property leased by Peter Rose located around 7 km south west of Wynarka, was first noticed to have seepages around 2005. An adjacent property leased by Andrew Thomas also has seepage areas.

Google™ satellite images show the area in 2006 and 2013 (Figure 22).

Figure 22: Satellite imagery showing seep development between 2006 and 2013 (GoogleEarth™, 2015)

The seepage areas were reported to be growing good crops although tending to be boggy until about 2008. By 2011, the area had become too wet to drive on and gradually turned saline. In early 2015, the ground was bare with mineral salt crystals evident (Figure 23). The surrounding area is too damp to be driven over by machinery most of the year so cannot be sown to crops or pastures. No plants are growing on the most severely affected areas. Salt-sensitive ryegrass, brome and thistles grow prolifically on the fringes of the bare area.

The seepage area shown in Figure 23 is characterised by a surface crust and white efflorescence, possibly gypsum, carbonates and some sodium chloride, with black staining indicating waterlogged conditions.

Figure 23: Bare area caused by seepage, Rose's, February 2015.

Exposure of the soil profile to a depth of approximately 60 cm showed a dark grey-brown sandy loam to 15 cm, overlying a damp, reddish-brown sandy light clay to 30 cm. Below this is a mixture of light clay which becomes more clayey with depth, and calcrete. As the carbonate becomes more dominant, the colour of the clay changes from reddish brown at 30 cm to a yellow-grey further down the profile (Figure 19).

Soil samples taken from the 0-10 and 40-50 cm depths in October 2014 showed relatively high salinity in the topsoil but much lower salinity at around half a metre (Table 6). This indicates that the mildly saline water has risen through capillary action from lower layers in the soil and evaporated at the soil surface leaving the salts concentrated at the soil surface.

Table 6: Soil salinity of soil under bare 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

Figure 24: Shallow watertable exposed underneath bare area, Wynarka October 2011

The land was cleared between 1905 and 1920 so typical evidence of groundwater-driven salinity would be expected to have become apparent in the 1950s. However, this seep only become evident in the mid-2000s which suggests it is not dryland salinity.

Examination of cumulative deviation from the average of annual and December to March rainfall recorded at Karoonda indicates a run of wetter years from 2001 to 2011, then a series of drier years from 2011 to 2014 (Figure 25). Summer rainfall during this period was generally above average (Figure 26).

Monthly rainfall data shows falls of over 50 mm during the December to March period in December 2010, February and March 2011, and February 2014 (Figure 27).

The rainfall data suggests that the seeps have occurred as a result of accumulation of rainfall unused by plants draining through the soil profile.

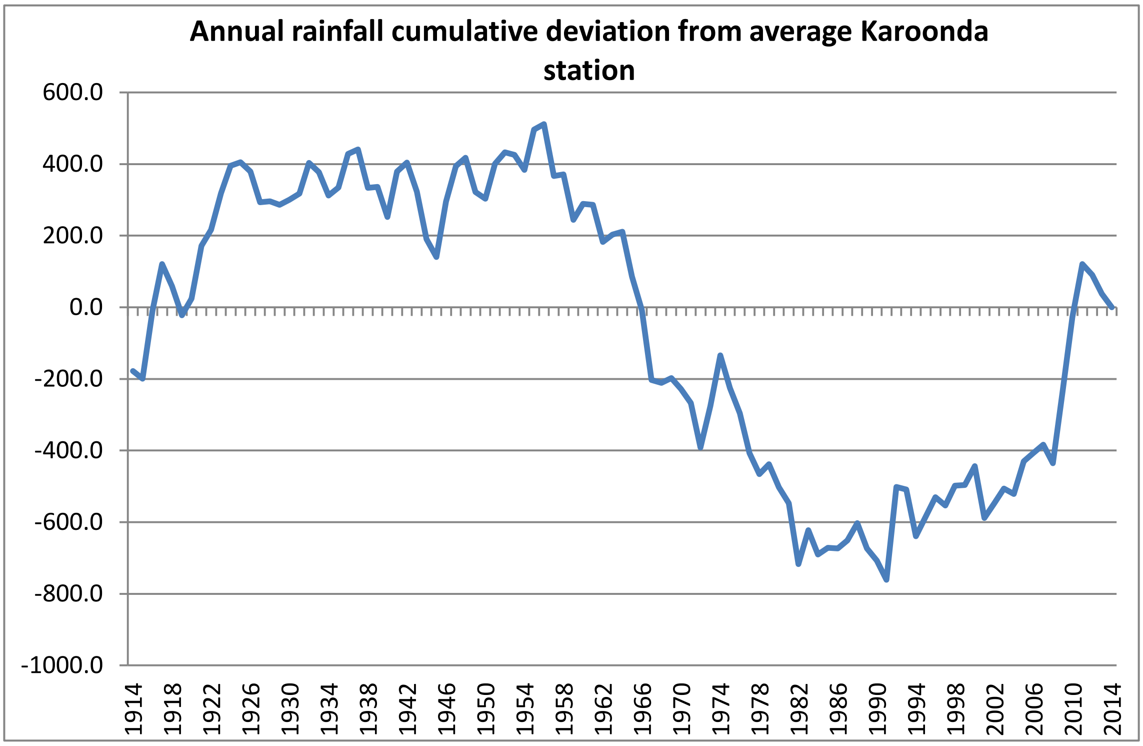

Figure 25: Indication of series of wetter and drier years, annual rainfall Karoonda (Source: Bureau of Meteorology)

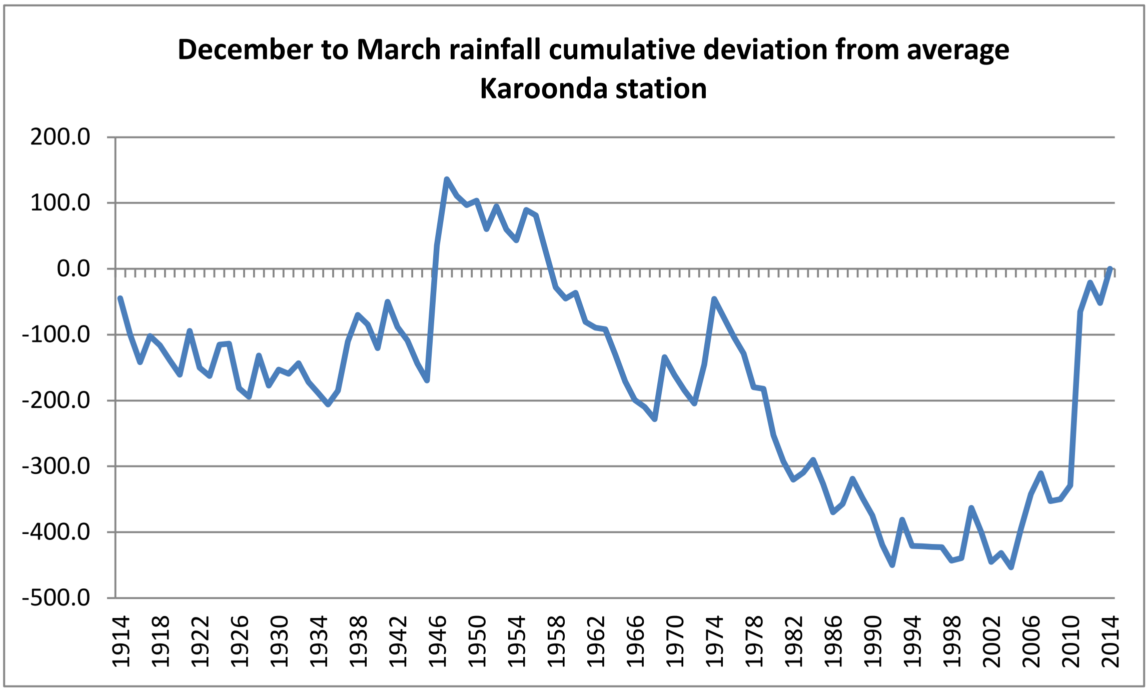

Figure 26: Indication of series of wetter and drier summers, December to March rainfall, Karoonda (Source: Bureau of Meteorology)

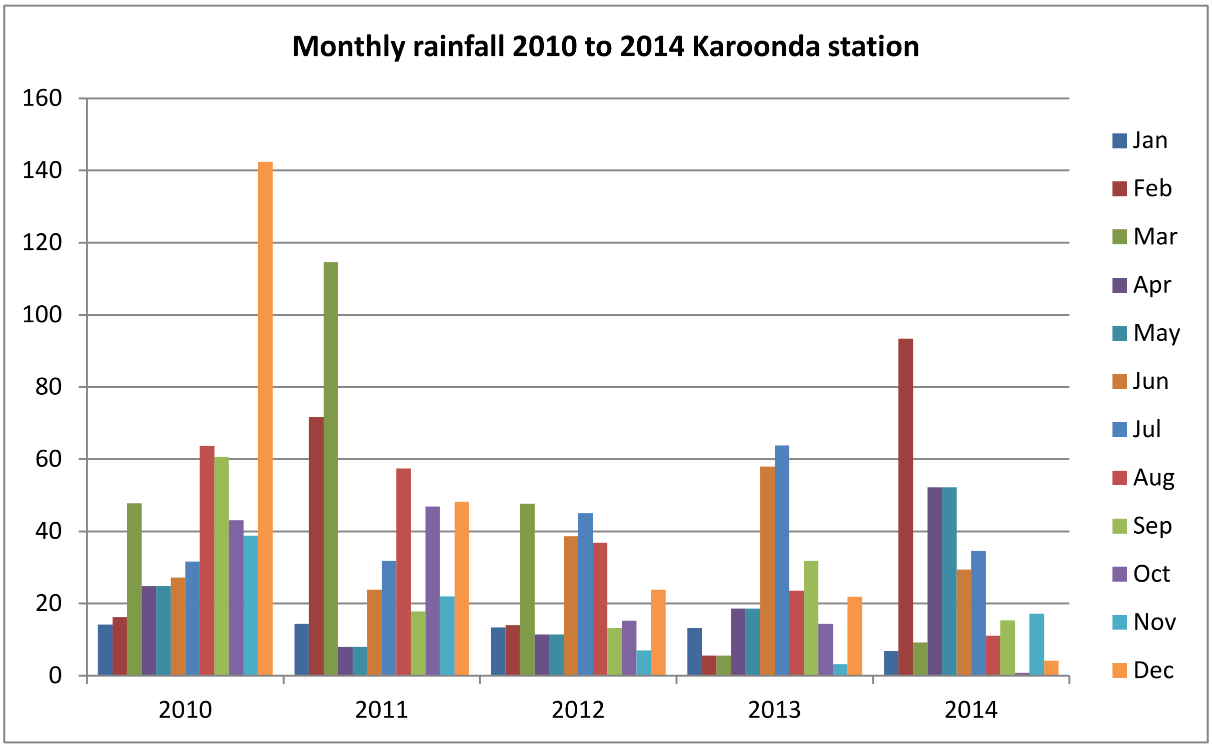

Figure 27: Monthly rainfall 2010 to 2014, Karoonda (Source: Bureau of Meteorology)

6 Implications for natural resource management

Where deeper, groundwater systems are not connecting with shallow perched watertables, the soil is not being degraded significantly by salinization through the drawing up of salt from deep in the soil profile or very saline water.

Some salinization of the soil surface is occurring through the drawing of salts from somewhat saline clay subsoils to the soil surface through evaporation of soil water. As with dry saline land, this salt movement up and down through the soil profile is transport of “in situ” salt, that is, salt that was already present in the profile.

The greatest, but not significant, land degradation risk posed by the development of waterlogged areas is the erosion risk from exposure of the bare soil remaining after surface water has evaporated off or drained into the subsoil, to wind erosion. Even though these soils are bare, while they are damp they require higher energy / velocity wind flows to entrain soil particles than dry soils do. The area of bare soil resulting from seepage is minor – less than a few hectares in a paddock and less than the area of surrounding sandhills that are at much greater risk of erosion.

Greater gains in protection from degradation of the soil resource will be made from increasing the water use on the sand hills to grow more biomass which becomes protective soil surface cover. This could entail growing summer-active plants or improving the ability of the sand to hold water in the root zone of plants, rather than draining down through the profile. Clay and organic matter are key factors in a soil’s water holding capacity so adding these materials to sandy soils can increase its ability to hold water in the root zone.

As a water resource, the moderate salinity of water in the perched water tables renders it suitable for some agricultural purposes such as stock water. While there would be costs associated with capturing, storing and reticulating the water, it could perhaps take pressure off other water resources used in the area (such as reticulated River Murray water).

As the problem mostly affects agricultural production, its treatment will be driven by cost effectiveness.

7 Management of Perched Watertables

The management of seepage areas caused by relatively shallow and fresh perched watertables will be based on a number of factors including the following:

- Size of seepage area and rate of expansion;
- Loss of cover making the area vulnerable to erosion and invasion by weeds;
- Salinization of the soil surface through evaporation of water from the soil profile;
- Trafficability of land within and adjacent to the seep;
- Land use of the surrounding land e.g. cropping, grazing;
- Cost of production losses and / or inconvenience caused by seepage.

In some cases, doing nothing may be the most cost effective approach. 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.

There are 4 broad strategies that can be considered in managing perched watertables in dune-swale systems:

1. Reduce recharge to the watertable in the sand dunes

Utilising the rain when it falls is difficult in farming systems based on annual plants, which most temperate-season agricultural plants are. "Out of season" rainfall and even early growing season rainfall when root growth is shallow, can drain rapidly through sandy soils. Perennial plants with well-established root systems can use rainfall throughout the year but the range of perennial agricultural plants that can persist through a series of dry summers is limited. Incorporating perennial plants into an annual cropping program is particularly difficult.

Increasing the water holding capacity of sandy soils by adding materials such as clay and to a lesser extent, organic matter, will hold water for longer in the soil profile. However, the amount of clay materials to effectively increase the clay proportion in the sandy soil, requires clay application rates of 150 – 200 t / ha. Assuming a suitable clay source is locally available, adding clay to a 20 ha sandhill would require around 3000 – 4000 m^3 of clay. An excavation pit to source this clay would be in the order of 30x60 m^2 in area which could well be greater than the area of the land affected by seepage.

2. Utilize groundwater where it is within reach of plant roots without waterlogging them

"Soaking up" the seepage water before it reaches the soil surface is a tactic already used by farmers as evidenced by the plantings of saltbush in some of these areas. As these seeps are relatively fresh, salt-tolerant species are not required but perennial, high-water-use ones are.

Most perennial agricultural plants are used for grazing so for farmers without grazing enterprises, there are few perennial crop options.

3. Treatment of discharge areas

Little can be done in these areas while they are wet and untrafficable. Consideration could be given treating these areas as large dams and using the water; for example, collecting, storing and reticulating it for stock water or other purposes.

Once these areas have dried out, the risk of salinization of the soil surface through capillary rise and evaporation of groundwater could be reduced by covering the soil surface with a mulch which could be stubble residues, old hay or even sand. The size of the area to be covered might render this treatment impractical. Appropriate weed and pest control measures should also be carried out as these can affect surrounding land.

4. Do nothing / minimize losses

All of the treatment options listed above would most likely cost more than the losses the producer is bearing. As these seeps are not resulting in permanent degradation of the soil resource, there are no imperatives, apart from economic ones, driving producers to treat the problem.

Through monitoring of watertable depths and rainfall, and knowing the depth to clay, it might be possible for farmers to anticipate when seepage areas are likely to appear and avoid sowing these areas. This would save some seed, fertilizer, fuel, chemical and labour costs.

8 Summary

Perched watertable induced seepage occurs in dune-swale landscapes where freshwater seepages or soaks discharge at the base of sandy rises. In seepage areas, crop suffer from 'wet feet' and the 'pans' become bare due to lack of cover. Summer weeds used to grow on sandy rises and use up some of the water in the soil but this is no longer the case with more effective chemical weed control in intensive cropping systems.

The appearance of seepage areas is a cyclic phenomenon with expansion following large or "out of season" rainfall events. Seepage areas will contract in drier seasons unless the land has become salinized or eroded due to a loss of plant cover.

Seeps appear to be increasing due to a number of factors including summer or early autumn rainfall events, with increasing herbicide use to get rid of resultant weeds. Increasing recharge in sand dune areas is draining through the sands and collecting on top of impermeable clay layers.

The perched watertables are generally fresh to brackish in dune seepage situations and soil and plant indicators suggest waterlogging rather than salinity as the cause of the degraded area. While affected areas are usually only small they can inconvenience a farmer's cropping program due to bogging of machinery.

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. Deeper regional groundwater systems sometimes connect with the shallow perched watertables resulting in more salinized land.

Recommendations

Where seepages are occurring, consideration should be given to the connection to the underlying groundwater system to check that the seepages are not a result of the groundwater system. Where there are connections to the deeper system, there is potential for salinization of land to increase. In a number of saline catchments in the agricultural lands of South Australia, the causes of salinity have been investigated and management strategies to address salinity suggested. Key to the understanding of groundwater induced salinity is the ongoing monitoring of groundwater depths to ascertain if these are rising or falling.

The freshwater seepages that are reported to have increased in area in recent years appear to be a result of rainfall not used by plants draining through the soil profile and perching within and above an impermeable clay layer. Where the clay is close to or at the ground surface, the perched water table is within the rooting depth of plants or ponds on the soil surface, waterlogging plants and rendering these areas untrafficable by machinery. While a treatment strategy would be to use this water before it reaches and accumulates at the impermeable layer, this is not cost effective in most situations. Farmers might be able to reduce their losses through understanding when and where the seeps are likely to occur by monitoring rainfall and knowing at what depth the clay layer is from the soil surface in their dune-swale soils. Wetter years or periods of "out of season" rainfall are believed to increase recharge so avoiding sowing areas prone to waterlogging following these events might reduce losses for farmers. Installation and monitoring of observation wells in strategic locations will also indicate the depth to the perched water table and how likely it is to cause waterlogging problems at the ground surface.

There is little information regarding the soils of swales in dune-swale systems, or the soil layers below the 1.5 metres depth used for soil description. Electromagnetic (EM) mapping is being tested in dune-swale systems in the SAMDB and N&Y regions to ascertain its effectiveness in identifying clay layers in the soil profile but this is subject to confusion by presence of soil water in the profile and is also limited to the top metre of the soil. Deeping drilling of soil profiles to characterise soil to greater depths would provide a greater understanding of subsoil properties and the movement of water in dune-swale systems.

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