Mallee Dune Seeps

Soil Characterisation and Land Unit Mapping

Pope Subcatchment

In fulfilment of the contract between Natural Resources South Australian Murray–Darling Basin and Juliet Creek Consulting Pty Ltd (NRSAMDB Agreement for Services 1418C).

February 2016

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Government of South Australia
South Australian Murray-Darling Basin Natural Resources Management Board

Australian Government

National Landcare Programme

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Acknowledgements

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February 2016

Introduction

Mallee dune seeps are areas of excessive wetness in mallee dune–swale environments. Over the last decade a number of seep areas have appeared across the South Australian Murray Mallee, probably largely owing to changed farming practices. When these areas become too wet, they are no longer arable – causing some of the most productive farmland in mallee environments to be lost to production.

Dune seeps are caused by excess water moving through sandy soils beyond the plant root zone which then forms 'perched water tables' upon deep layers of low permeability clay. This low permeability clay has been determined to be the geological layer known as the Blanchetown Clay (see Hall et al 2009) – which is common across the Mallee. The perched water then seeps laterally and can appear in the landscape where restrictive clay layers occur at shallow depth, especially in lower-lying areas adjacent to sand dunes.

It is suspected that effective control of summer weeds on sand dune areas – as a result of the use of modern farming techniques and herbicides – within continuous cropping systems, has created excess water in these low rainfall farming environments. Anecdotal evidence suggests that most dune seep areas have appeared since these technology changes have occurred – although older seep areas are known to exist, one of which exists in the subcatchment reported here. In addition, seeps are known to enlarge over time, typically expanding upslope.

Once seeps have developed, and are wet enough to be non-arable, they are prone to degradation because of bare soil. Erosion is common; while bare areas become more saline with time. Once seeps are degraded, they are very difficult to rehabilitate (see **Figure 2**). Surface cover should be maintained at all times to prevent land degradation.

Natural Resources SA Murray–Darling Basin and the National Landcare Program are supporting investigations into the processes involved, as well as mitigation, prevention and rehabilitation of seeps.

Several subcatchments have been examined via soil characterisation investigations, land unit mapping and drilling (see **Figure 1**). A major report has been produced for Natural Resources SA Murray–Darling Basin on two of these subcatchments (Hall 2015a), which also incorporates the work of an earlier report produced for Rural Solutions SA (Hall 2015b). The report herein documents the outcomes of soil characterisation investigations and land unit mapping at the Pope subcatchment near Karoonda in the South Australian Murray Mallee. Drilling investigations are also planned for the subcatchment.

In addition, soil modification trials are being conducted within this subcatchment to investigate the potential for reducing dune seepage through increasing crop water use and productivity.

The overall aim of these studies is to gain a better understanding of the processes involved in the development of dune seeps to support the development of management solutions.

This subcatchment has been investigated via:

- characterisation of sites and soil profiles along a strategic toposequence above a severe dune seep area
- stereoscopic air-photo-interpretation (API) of overlapping aerial photographs and the development of land unit maps.

Owing to the limited level of soil investigation, however, soil maps have not been developed.

The locations of the investigated soils are shown in **Figure 6** in Appendix 1.

A key question has been whether a topsoil dominant water-flow system (upon the subsoil surface), or a much deeper water-flow system (or both), is involved in the development of dune seeps. It has been shown at previously investigated subcatchments that a deep 'perched water table' is present. This has implications for the selection and placement of plant species designed to utilise ground water.

Final conclusions at this site cannot be given until drilling is complete, however, initial conclusions have been made (see 'Findings and interpretations' and 'Summary' sections). It is also known that regional groundwater is not a casual factor, as this occurs at considerable depth (many tens of metres) over most of the Murray Mallee.

The investigations of this and previous projects, and subsequent better understanding of processes have enabled development of initial recommendations for Murray Mallee subcatchments affected by dune seepage (see Mallee Sustainable Farming 2016).

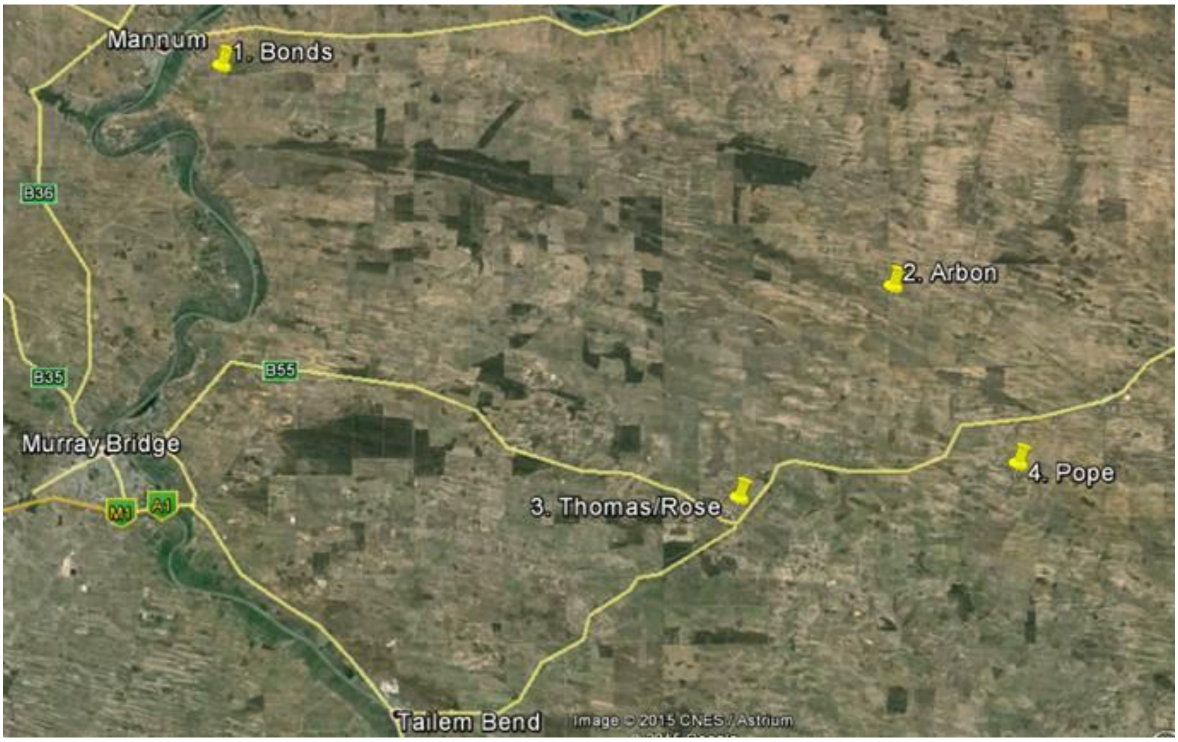

Figure 1 Locations of subcatchments in the SA Murray Mallee within which dune seep processes have been investigated and/or trial work looking at increased plant water use has been established.

Figure 2 Scene of the severe dune seep below the investigated toposequence. Note bare scalded surface and barley crop in background. Seep area is expanding upslope.

Methods

This report is based upon initial investigations at the Pope subcatchment near Karoonda in the South Australian Murray Mallee (see Appendices 1–2) – work which has been funded by Natural Resources SA Murray-Darling Basin and the National Landcare Program.

Soil characterisation has been undertaken to investigate the possible existence of near-surface lateral flow of water along subsoil surfaces. Soil characterisation helps to determine the extent of downward movement of water via assessment of the vertical distribution of soluble substances and the nature of specific physical indicators. Moreover, soil characterisation is undertaken to investigate representative soils in detail so that impediments to root and plant growth and production can be better understood to support the development of management solutions.

The siting of soil investigations has been carefully considered, with key considerations being that:

- main segments of the landscape are selected (e.g. dune crests, lower slopes, low-lying land)
- sites define a particular toposequence (a down-slope sequence of landform sites)
- that it is clear that sites along the toposequence are directly interconnected in terms of water processes within the subcatchment system
- the location of field trial treatments.

Soil morphological description has been conducted according to national standards (NCST 2009). Moreover, comprehensive chemical analyses have been performed on samples from each described soil layer, again to national standards (Rayment & Lyons 2010). These physical and chemical data help with understanding of land and soil processes, allowing interpretations to be made of soil, landscape and agronomic systems and interactions – such as water movement, storage and use.

Chemical analyses of soil samples have been performed at CSBP Laboratories in Western Australia (a nationally accredited soil laboratory).

Land units have been defined to show the extent of various landscape features, including seeps (see **Figure 6** and **Figure 7** in Appendix 1).

Land unit mapping shows the nature and extent of particular landscape areas, giving insights into topography, geomorphology, geology, soils, as well as land and soil conditions (such as wetness and salinity). This is based on expert stereoscopic air-photo-interpretation (API) using the most recent and highest resolution aerial photograph stereo pairs (2001 from Mapland). However, as few seeps were evident in 2001, aerial photos from 2013 were used to assess the extent of seepage. Unfortunately, no stereo pairs from these years are available. It should also be understood that land unit mapping is based on an extremely limited number of on-ground investigations.

Land unit mapping can be utilised to calculate the actual areas of seeps (hectares and percent of subcatchment), overall productivity losses owing to seepage, the productivity changes arising from management systems that reduce seepage, as well as in water balance models.

Soil unit mapping is more useful and accurate for making such calculations, but soil maps can only be produced once a full soil survey is conducted.

Findings and interpretations

The investigated toposequence consists of a long hillslope overlain with sand deposits. A severe dune seepage area is present at the base of the slope (see **Figure 2**).

All soils investigated exhibited 'sand over clay' profiles (see Appendix 2): with very low fertility sandy topsoils that commonly display water repellence and contain a bleached subsurface layer. Some topsoils are thick enough (>100 cm) to be considered deep sands (see Hall et al. 2009). Subsoils consist of whole-coloured or mottled fine sandy clay loam to light clay. All deeper layers exhibit mottling, which is indicative of seasonal wetness. It is thought that sandy topsoils and sandy clay loam subsoils are all part of the same depositional sequence, although there has been much reworking and post-clearing movement of sand, during pre- and post-European settlement, respectively.

Chemical and physical data from soil characterisation site profiles indicate that the majority of water that moves beyond the rootzone moves vertically thought the subsoil. Nonetheless, there are indications that a not insignificant proportion of water travels laterally along sandy clay loam subsoils.

It appears that water 'perches' upon deeper low permeability clay layers, and dune seeps form where this layer comes close to the land surface, and adjacent to sand dunes. This clay is the geological layer known as Blanchetown Clay (see Hall et al. 2009). Blanchetown Clay -like material was viewed and textured within the severe dune seep area (see **Figure 2**). It is expected that proposed drilling will confirm the presence of Blanchetown Clay and deep 'perched water tables'; while the installation of peisometer tubes will enable monitoring of water table levels.

These results are similar to those of the two previously investigated subcatchments in the Murray Mallee with surface manifestation of dune seepage.

Mid-slope (site MDS-P02)

On the mid-slope of a long slope and at the highest point of the investigated toposequence (see Appendix 2). The profile is a thick sand topsoil (55 cm) with a bleached subsurface layer and a subsoil of fine sandy clay loam, which is slightly dispersive and mottled in the lower part. Chemical and physical indicators show an excessively leached topsoil within which even phosphorus has leached. Soluble substances have mostly leached within the sandy clay loam layer to the middle and lower subsoil and below. Indications are that drainage waters mostly move vertically through the profile, although water movement along the subsoil surface would not be insignificant.

Middle part of lower slope (sites MDS-P03A,B and P04)

These sites are situated on the lower slope of a long slope, forming the middle section soils of the investigated toposequence (see Appendix 2). The three sites are located where different soil treatments were applied within a field trial in 2015 season:

P03A   spading of the soil to 40 cm (see **Figure 3**)
P03B   standard cultivation: control treatment (see **Figure 4**)
P04   spading of the soil to 40 cm + chicken manure (see **Figure 5**).

The benefit of the spading of the soil and added chicken manure can be clearly seen in the additional root growth evident in Figure 5.

All profiles have very thick sand topsoil (from around 100 cm to 120 cm) with a bleached subsurface layer underlain by fine sandy clay loam, which is slightly dispersive and mottled below the upper subsoil. The original soil surface is overlain by approximately 50 cm of sand deposited since initial clearing.

Chemical and physical indicators show an excessively leached topsoil within which even phosphorus has leached. Soluble substances have mostly leached within the sandy clay loam layer to below the upper subsoil. Indications are that drainage waters mostly move vertically through the profile, although water movement along the subsoil surface would not be insignificant.

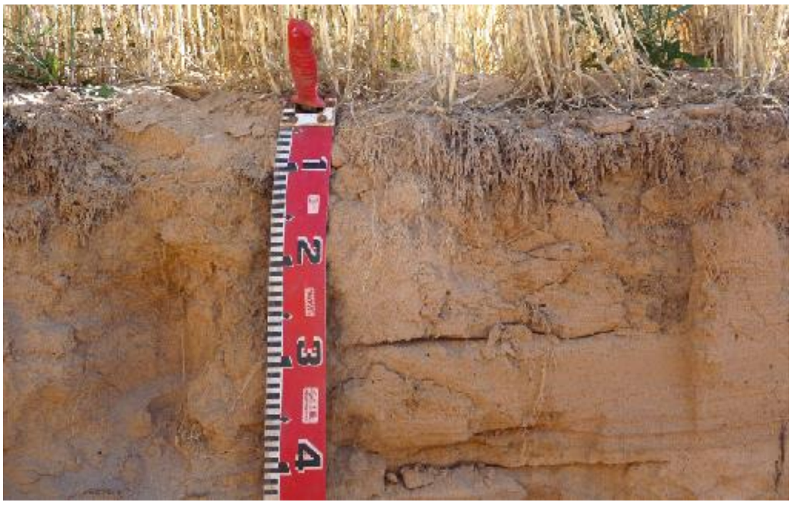

Figure 3 Topsoil of site P03A showing the effect of spading to 40 cm.

Figure 4 Topsoil of site P03B showing the effects of standard cultivation (control treatment).

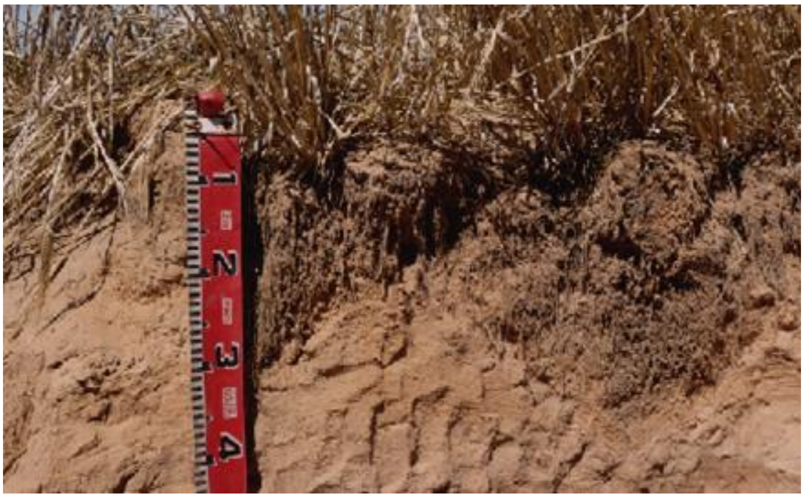

Figure 5 Topsoil of site P04 showing the effects of spading to 40 cm + chicken manure.

Lower part of lower slope (site MDS-P01)

On the lower part of the lower slope segment of the long slope. This is at the lowest point of the investigated toposequence (see Appendix 2), not far above the severe dune seep (see landscape image at site P01 in Appendix 2). The profile is a very thick sand topsoil (80 cm) with a bleached subsurface layer underlain by fine sandy clay loam, which is mottled below the upper subsoil. Chemical and physical indicators show an excessively leached topsoil within which even phosphorus has leached (phosphorus has even leached into the upper subsoil). Soluble substances have mostly leached within the sandy clay loam layer to the lower subsoil. Indications are that drainage waters have in the main moved vertically through the profile, although water movement along the subsoil surface would not be insignificant. In addition, seepage waters were observed at the base of the profile (approximately 10 cm of water was observed in the base of the pit after one day), presumably perched upon a low permeability layer of Blanchetown Clay.

Summary

It has been established from drilling and soil investigations at several other subcatchments in the SA Murray Mallee (see Hall 2015a) that deep drainage, and deep perched water tables and lateral flows upon low permeability clay, are the major processes contributing to the formation of mallee dune seeps in those subcatchments. Although deep drilling is yet to be undertaken in this subcatchment, the soil and landscape investigations reported herein support similar processes being active.

These seepage systems are localised water flow systems with a base of Blanchetown Clay. Seeps arise where Blanchetown Clay has a near surface presence in low-lying areas. Seepage from unused water that accumulates below neighbouring sandy soil profiles supplies the water. Dune cores may also act as reservoirs and sources of water throughout the year.

These findings and conclusions have impacts for the development of management solutions to control and reduce seepage and seep areas, and making better use of available water and land (see Hall 2015a, Mallee Sustainable Farming 2016, McDonough 2015, Liddicoat & McFarlane 2007, Stirzaker et al. 2000).

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Appendix 1 – Maps

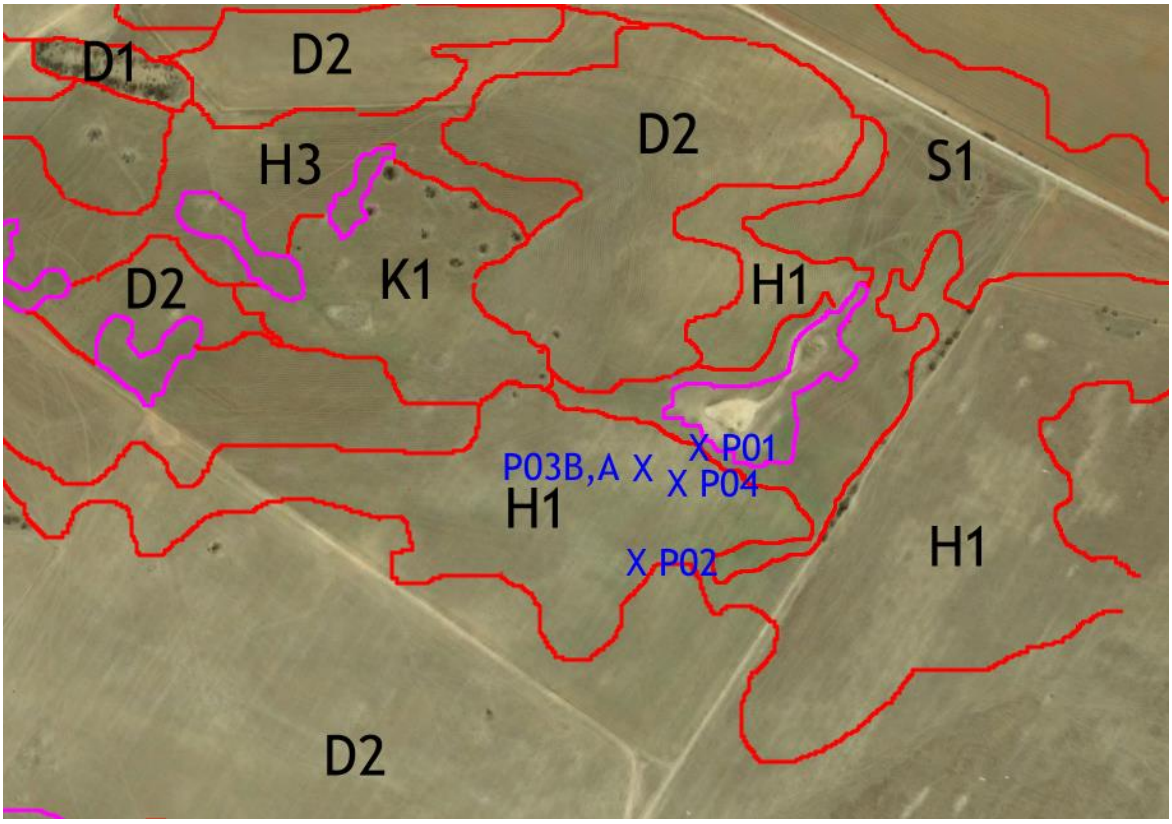


Figure 6 Pope subcatchment (Karoonda) in the South Australian Murray Mallee: showing sites investigated via soil characterisation along a toposequence and on different field trial treatments. (Approximate positions with a composite of 2001 and 2013 aerial photographs as background.) Land units are also shown: see Figure 7 for details. The scalded area of the severe dune seep can also be seen.

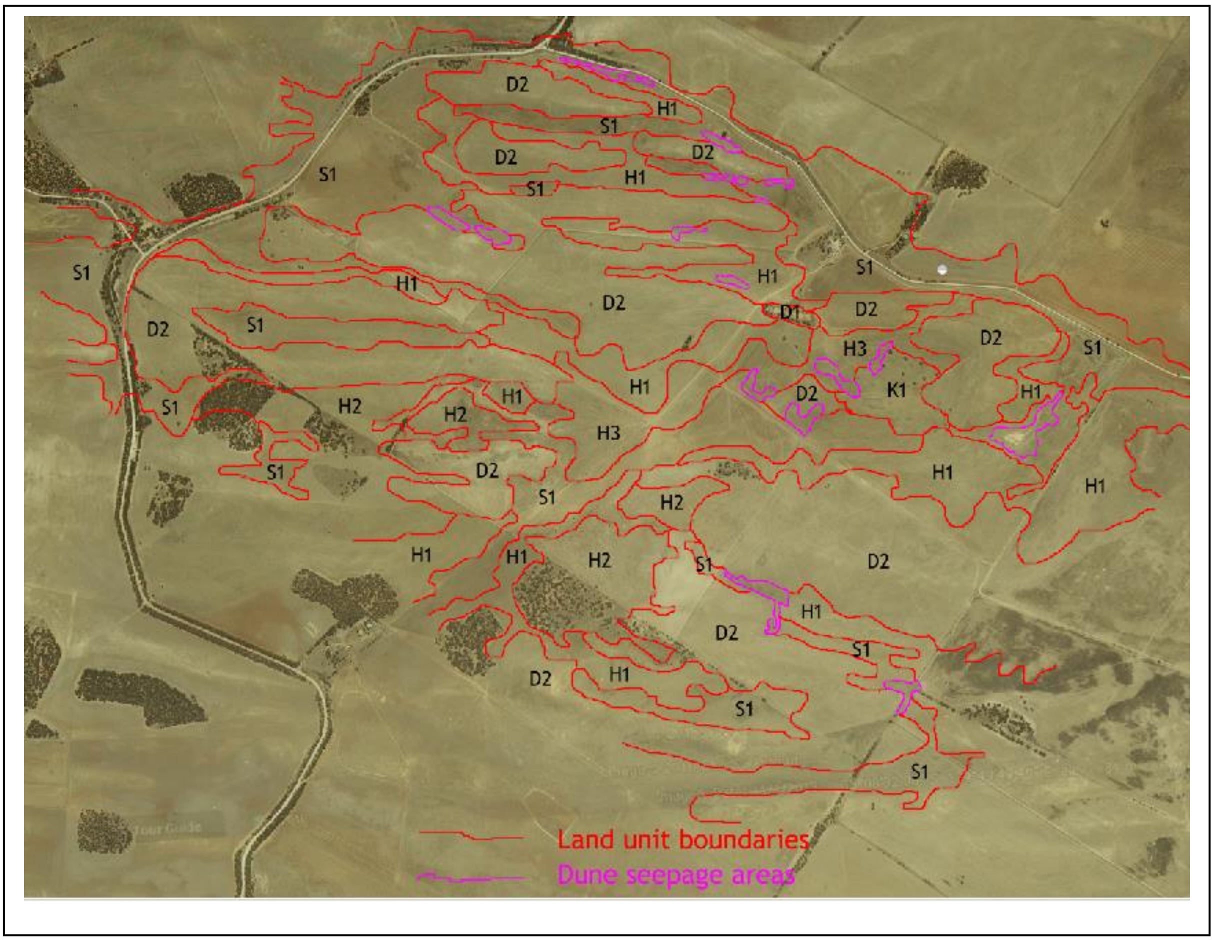


Figure 7 Pope subcatchment near Karoonda in the South Australian Murray Mallee: showing land units. A 2001 aerial photograph is shown as background. Stereoscopic air-photo-interpretation (API) was performed to define land units, using the latest available 1:40,000 scale overlapping photo pairs (2001) from Mapland. More recent aerial imagery (2013) was used to map dune seepage areas, however, stereo pairs are not available. Subcatchment boundaries are not shown as the subcatchment is larger than the area displayed.

Land unit development is based on stereoscopic air-photo-interpretation (API) of 2001 aerial photographs, an interpretation of 2013 aerial photographs (non-stereo), a very limited number of on-ground investigations, and State Land & Soil Mapping Program descriptions of the area (Soil & Land Program 2007).

D1 = sand dune (non-arable)

D2 = sand dunes and sand-covered slopes, rises & low hills

H1 = lower slopes

H2 = plains and undulating land (upper-level)

H3 = plains (lower-level)

K1 = calcreted plain

S1 = low-lying areas (depressions), including dune seepage areas (shown in pink)

Appendix 2

SAND OVER SANDY CLAY LOAM

Very thick sandy topsoil with a bleached subsurface layer over fine sandy clay loam with carbonate and seepage at depth.

Subgroup soil	Soil G2 (bleached sand over sandy clay loam) (Hall et al. 2009)
	Rises overlain by a dunefield
Substrate	Mottled fine sandy clay loam
Vegetation	-
Position	Lower slope of a long slope, 40 m above severe dune seep scald
Site	Pope subcatchment:

Site No:	MDS-P01	1:50 000 mapsheet:	6827–1 (Karoonda)
Hundred:	Hooper	Easting:	394 053
Section:	-	Northing:	6110 420
Date:	3/12/2015	Annual rainfall:	340 mm

Soil Description

Depth (cm)	Description
0–20	Loose, repellent, dark yellowish brown, heavy loamy sand with single grain structure. Abrupt boundary to:
20–60	Dark yellowish brown and brownish yellow, sporadically bleached, coarse loamy sand with single grain structure. Clear boundary to:
60–80	Brownish yellow, bleached, light coarse loamy sand with single grain structure. Sharp boundary to:
80–110	Highly calcareous, yellowish brown and brownish yellow, heavy fine sandy clay loam with weak structure. Gradual boundary to:
110–145	Highly calcareous, yellowish brown, yellowish red and light olive brown, heavy fine sandy clay loam with weak structure. Gradual boundary to:
145–190	Slightly calcareous, yellowish red, yellowish brown and light olive brown, fine sandy clay loam with weak structure, >50% hard carbonate nodules (20–60 mm) and seepage of water.

Australian Soil Classification

Bleached-Sodic, Calcic, **Brown Chromosol**; very thick, non-gravelly, sandy / clay loamy, deep.

Summary of Properties

Drainage The soil profile as a whole is moderately well drained. Some restriction to downward water movement occurs at the topsoil–subsoil interface; however, the sandy topsoil itself is rapidly drained, with leaching of phosphorus evident. Mottled subsoil is an indicator of restricted drainage and seasonal wetness. Seepage water is evident at the base of the profile.

pH Soil pH is acidic in the surface soil, neutral in the subsurface soil, and alkaline to strongly alkaline in the subsoil.

Rooting depth Barley roots were observed to 110 cm, with most in the top 20 cm.

Barriers to root growth

Physical There are no significant physical barriers to root growth in the top metre.

Chemical Chemical barriers to root growth occur in the form of low inherent fertility in the sandy topsoil, and possible seasonal perched water on the subsoil, and high pH in the subsoil.

Waterholding capacity Plant Available Waterholding Capacity (PAWC) is estimated to be approximately 60 mm (moderately low). [Workings: 0.2x120 + 0.4x0.5x70 + 0.2x0.5x60 + 0.3x0.5x110].

Seedling emergence Moderate. There are no physical barriers; however, the surface soil is affected by water repellency which could result in reduced seedling emergence. There is also potential for sand-blasting of seedlings.

Workability Good.

Erosion potential

Water Low.

Wind Moderate. Maintenance of surface cover is required to minimise erosion.

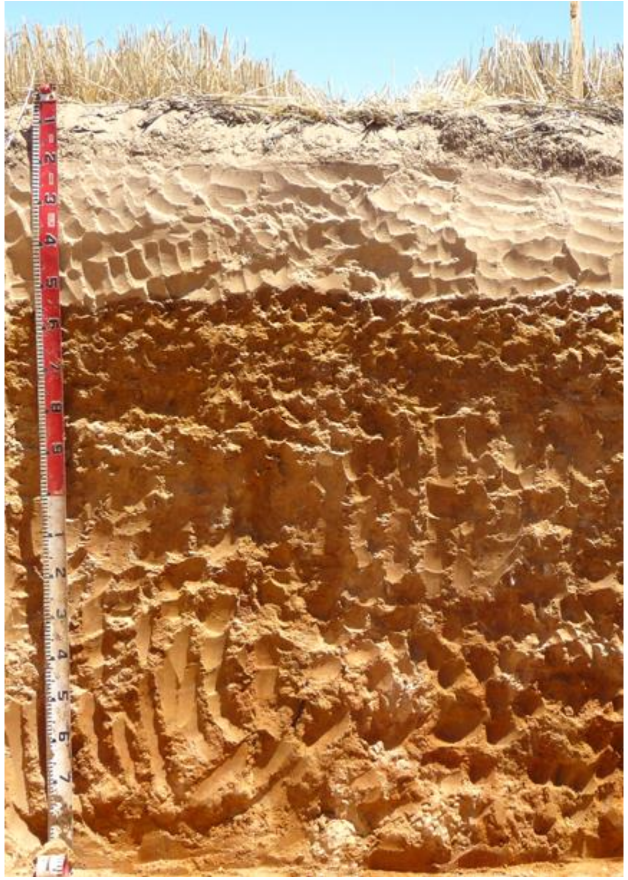
Laboratory Data – MDS-P01

Hori-zon	Depth cm	Texture	N $NH4^+$ mg/kg	N $NO3^-$ mg/kg	pH H2O	pH CaCl2	CO3 %	EC 1:5 dS/m	ECe dS/m	Org C %	P Avail. mg/kg	P Buff Index	K Avail. mg/kg	S (KCl) mg/kg	Boron mg/kg	Trace Elements mg/kg (DTPA)				Sum cations meq/ 100g	Exchangeable Cations meq/100g					ESP
																Cu	Fe	Mn	Zn		Ca	Mg	Na	K	Al	
A11	0–20	ls+	2	3	6.3	5.2	0.21	0.014	0.25	0.47	24	11.5	69	2.4	0.27	0.25	26.3	2.12	0.85	1.72	1.23	0.26	0.03	0.15	0.05	1.7
A2j	20–60	kls	<1	3	7.3	5.9	0.22	0.014	0.18	0.13	11	9.7	47	2.2	0.23	0.18	37.7	1.80	0.13	1.21	0.82	0.15	0.03	0.12	0.09	2.5
A2e	60–80	kls-	<1	2	7.4	6.9	0.25	0.019	0.26	<0.05	9	10.6	48	1.1	0.23	0.46	7.14	0.54	0.36	1.35	0.90	0.22	0.03	0.12	0.08	2.2
B21	80–110	fscl+	<1	2	9.2	8.1	1.13	0.114	0.50	0.06	6	64.6	523	2.5	3.25	0.24	7.03	0.52	0.21	13.31	7.43	3.84	0.61	1.27	0.16	4.6
B22	110–145	fscl+	<1	3	9.4	8.3	3.07	0.164	0.92	<0.05	<2	61.1	407	4.2	3.74	0.25	5.76	0.71	0.13	12.53	6.91	3.47	0.95	1.04	0.16	7.6
B23	145–190	fscl	<1	2	9.6	8.1	0.28	0.098	0.50	<0.05	<2	41.6	422	7.3	7.07	0.17	5.41	0.63	0.13	7.89	1.93	3.31	1.36	1.08	0.21	17.2
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	<0.7–1.85	<4–8	>1–2	>25–35	100–200	>80–120	>6–8	1–15	>0.2	>2.5	>1–2	>0.5–1.0	>15	75% CEC	20% CEC	<6% CEC	5% CEC	<5% CEC	<6

Note: (1) Sum of Cations approximates the Cation Exchange Capacity (CEC), a measure of the soil's capacity to store and release major nutrient elements.
(2) Exchangeable Sodium Percentage (ESP) is derived by dividing the exchangeable sodium value by the CEC, in this case estimated by the Sum of Cation

SAND OVER SANDY CLAY LOAM

Thick sandy topsoil with a bleached subsurface layer over fine sandy clay loam with minor carbonate at depth.



Subgroup soil Soil G2 (bleached sand over sandy clay loam) (Hall et al. 2009)

Rises overlain by a dunefield

Substrate Mottled fine sandy clay loam

Vegetation -

Position Mid-slope of a long slope

Site Pope subcatchment:

Site No:	MDS-P02	1:50 000 mapsheet:	6827–1 (Karoonda)
Hundred:	Hooper	Easting:	394 717
Section:	-	Northing:	6110 264
Date:	3/12/2015	Annual rainfall:	340 mm

Soil Description

Depth (cm)	Description
0–18	Loose, strongly repellent, dark yellowish brown, heavy loamy sand with single grain structure. Abrupt boundary to:
18–55	Very pale brown, bleached, coarse sand with single grain structure. Sharp boundary to:
55–85	Slightly dispersive, Yellowish brown, fine sandy clay loam with weak structure. Gradual boundary to:
85–130	Highly calcareous, slightly dispersive, yellowish brown, fine sandy light clay with weak structure, fine carbonate segregations between aggregates and 10–20% hard carbonate nodules (>60 mm). Gradual boundary to:
130–190	Slightly calcareous, slightly dispersive, yellowish brown, yellowish red and light brownish grey, fine sandy clay loam with weak structure and 10–20% fine carbonate segregations.

Australian Soil Classification

Calcic, Subnatric, **Brown Sodosol**; thick, non-gravelly, sandy / clay loamy, moderate.

Summary of Properties

Drainage The soil profile is moderately well to well drained. Some restriction to downward water movement occurs at the topsoil–subsoil interface and owing to the sodic–dispersive subsoil; while the sandy topsoil shows signs of excessive drainage with some leaching of phosphorus below the surface soil. Mottled lower subsoil is an indicator of seasonal wetness in this layer.

pH Soil pH is neutral in the topsoil, and strongly alkaline in the subsoil.

Rooting depth Roots were observed to 55 cm, with most in the top 18 cm.

Barriers to root growth

Physical The sodic–dispersive subsoil forms a moderate physical barrier to root growth.

Chemical Chemical barriers to root growth occur in the form of low inherent fertility in the sandy topsoil, and probable seasonal perched water on the subsoil, and high pH in the subsoil.

Waterholding capacity Plant Available Waterholding Capacity (PAWC) is estimated to be approximately 40 mm (low to moderately low). [Workings: 0.18x120 + 0.20x60 + 0.17x0.5x60].

Seedling emergence Moderate. There are no physical barriers, however, the surface soil is affected by strong water repellency and likely resulting reduced seedling emergence. There is also potential for sand-blasting of seedlings.

Workability Good.

Erosion potential

Water Low.

Wind Moderate. Maintenance of surface cover is required to minimise erosion.

Laboratory Data – MDS-P02

Hori-zon	Depth cm	Texture	N NH_4^+ mg/kg	N NO_3^- mg/kg	pH H2O	pH CaCl2	CO3 %	EC 1:5 dS/m	ECe dS/m	Org C %	P Avail. mg/kg	P Buff Index	K Avail. mg/kg	S (KCl) mg/kg	Boron mg/kg	Trace Elements mg/kg (DTPA)				Sum cations meq/100g	Exchangeable Cations meq/100g					ESP
																Cu	Fe	Mn	Zn		Ca	Mg	Na	K	Al	
A	0–18	ls+	2	<1	7.2	6.1	0.25	0.03	0.23	0.40	18	10.1	40	4.1	0.38	0.31	25.5	1.66	1.29	1.5	1.07	0.25	0.10	0.03	0.05	6.7
Ae	18–55	ks	<1	<1	7.4	6.5	0.25	0.02	0.19	<0.05	7	5.9	44	1.3	0.20	0.16	11.0	0.49	0.06	0.96	0.63	0.17	0.11	0.02	0.03	11.5
B21	55–85	fscl	<1	<1	9.5	8.3	3.74	0.21	1.24	0.07	<2	63.0	526	2.2	7.97	0.25	6.7	0.54	0.17	14.22	5.93	5.12	1.68	1.35	0.14	11.8
B22	85–130	fslc	<1	<1	10.1	8.4	5.36	0.32	2.45	<0.05	<2	90.2	496	7.1	12.8	0.25	7.2	0.58	0.09	14.73	4.97	4.87	3.51	1.25	0.13	23.8
B23	130–190	fscl	<1	<1	10.0	8.3	5.62	0.43	0.59	0.05	<2	75.1	502	12.0	14.2	0.22	6.9	0.60	0.12	15.28	4.93	4.66	4.25	1.29	0.15	27.8
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	<0.7–1.85	<4–8	>1–2	>25–35	100–200	>80–120	>6–8	1–15	>0.2	>2.5	>1–2	>0.5–1.0	>15	75% CEC	20% CEC	<6% CEC	5% CEC	<5% CEC	<6

Note: (1) Sum of Cations approximates the Cation Exchange Capacity (CEC), a measure of the soil's capacity to store and release major nutrient elements.
(2) Exchangeable Sodium Percentage (ESP) is derived by dividing the exchangeable sodium value by the CEC, in this case estimated by the Sum of Cations

DEEP BLEACHED SILICEOUS SAND

Deep siliceous sand with a bleached layer; underlain by fine sandy light clay with minor carbonate.

Subgroup soil	Soil H3 (bleached siliceous sand) (Hall et al. 2009)
	Rises overlain by a dunefield
Substrate	Mottled fine sandy clay loam
Vegetation	-
Position	Lower slope of long slope, approximately 150 m above severe dune seep scald
Site	Pope subcatchment [Soil treatment: spading to 40 cm]:

Site No:	MDS-P03A	1:50 000 mapsheet:	6827–1 (Karoonda)
Hundred:	Hooper	Easting:	394 750
Section:	-	Northing:	6110 400
Date:	3/12/2015	Annual rainfall:	340 mm

Soil Description

Depth (cm)	Description
0–30	Loose, repellent, light yellowish brown and dark yellowish brown, loamy sand with single grain structure. Gradual boundary to:
30–50	Light yellowish brown, loamy sand with massive structure. Clear boundary to:
50–62	Yellowish brown, loamy sand with massive structure. Abrupt boundary to:
62–120	Very pale brown, bleached, coarse sand with massive structure. Sharp boundary to:
120–140	Hard, highly calcareous, slightly dispersive, yellowish brown, fine sandy clay loam with weak structure and fine carbonate segregations between aggregates. Clear boundary to:
140–160	Yellowish brown, yellowish red and olive yellow, fine sandy light clay with weak structure.

Australian Soil Classification

Calcic, Subnatric, **Brown Sodosol**; very thick, non-gravelly, sandy / clay loamy, deep.

DEEP BLEACHED SILICEOUS SAND

Deep siliceous sand with a bleached layer, underlain by fine sandy light clay with minor carbonate.

Subgroup soil	Soil H3 (bleached siliceous sand) (Hall et al. 2009)
	Rises overlain by a dunefield
Substrate	Mottled fine sandy clay loam
Vegetation	-
Position	Lower slope of long slope, approximately 150 m above severe dune seep scald
Site	Pope subcatchment [Soil treatment: standard cultivation]:

Site No:	MDS-P03B	1:50 000 mapsheet:	6827–1 (Karoonda)
Hundred:	Hooper	Easting:	394 750
Section:	-	Northing:	6110 400
Date:	3/12/2015	Annual rainfall:	340 mm

Soil Description

Depth (cm)	**Description**
0–12	Loose, dark yellowish brown and light yellowish brown, loamy sand with single grain structure. Clear boundary to:
12–35	Light yellowish brown, loamy sand with massive structure. Clear boundary to:
35–52	Light yellowish brown, loamy sand with massive structure. Abrupt boundary to:
52–58	Yellowish brown, loamy sand with massive structure. Abrupt boundary to:
58–120	Very pale brown, bleached, coarse sand with massive structure. Sharp boundary to:
120–140	Hard, slightly dispersive, yellowish brown, fine sandy clay loam with weak structure and fine carbonate segregations between aggregates. Clear boundary to:
140–160	Highly calcareous, slightly dispersive, yellowish brown, yellowish red and olive yellow, fine sandy light clay with weak structure.

Australian Soil Classification

Calcic, Subnatric, **Brown Sodosol**; very thick, non-gravelly, sandy / clay loamy, deep.

Summary of Properties [Soil Characterisation Sites P03A & P03B]

Drainage Soil profiles are well drained. Some restriction to downward water movement occurs at the interface between the deep sand and the underlying sandy clay loam material. The sandy topsoil shows signs of excessive drainage with some leaching of phosphorus evident. Mottled underlying layers indicate seasonal wetness.

pH Soil pH is acidic in the upper sandy layers, neutral in the lower sandy layers, and strongly alkaline in the underlying sandy clay loam.

Rooting depth Profile P03A: roots were observed to 120 cm, with most in the top 30 cm. Profile P03B: roots were observed to 120 cm, with most in the top 35 cm.

Barriers to root growth

Physical There are no significant physical barriers to root growth in the top metre. Sodic–dispersive underlying layers would be restrictive.

Chemical Chemical barriers to root growth occur in the form of low inherent fertility in the sandy layers, and possible seasonal perched water on the underlying sandy clay loam. High pH and boron levels in the underlying layers would be restrictive.

Waterholding capacity Plant Available Waterholding Capacity (PAWC) is estimated to be approximately 65 mm [P03A] and 60 mm [P03B] (moderately low). [Workings P03A: 0.30x120 + 0.32x0.5x80 + 0.58x0.5x60. Workings P03B: 0.12x120 + 0.23x80 + 0.23x0.5x80 + 0.62x0.5x60].

Seedling emergence Moderate. There are no physical barriers, however, these soils have potential for water repellency. There is also potential for sand-blasting of seedlings.

Workability Good.

Erosion potential

Water Low.

Wind Moderate to moderately high. Maintenance of surface cover at all times is required to minimise erosion.

Laboratory Data – MDS-P03A

Hori-zon	Depth cm	Texture	N NH4⁺ mg/kg	N NO3⁻ mg/kg	pH H2O	pH CaCl2	CO3 %	EC 1:5 dS/m	ECe dS/m	Org C %	P Avail. mg/kg	P Buff Index	K Avail. mg/kg	S (KCl) mg/kg	Boron mg/kg	Trace Elements mg/kg (DTPA)				Sum cations meq/100g	Exchangeable Cations meq/100g					ESP
																Cu	Fe	Mn	Zn		Ca	Mg	Na	K	Al	
1A11	0–30	ls	1	<1	6.9	6.4	0.28	0.03	0.23	0.21	13	11.4	45	1.8	0.37	0.23	23.6	1.57	0.43	1.42	0.96	0.24	0.03	0.12	0.07	2.1
1Ae	30–50	ls	<1	1	6.4	5.8	0.20	0.04	0.38	<0.05	7	9.2	61	3.7	0.24	0.15	9.7	1.45	0.08	1.28	0.79	0.18	0.04	0.16	0.11	3.1
2A	50–62	ls	<1	<1	7.5	6.6	0.31	0.02	0.19	0.15	3	8.2	53	0.8	0.29	0.24	9.4	1.20	0.06	1.91	1.49	0.19	0.02	0.14	0.07	1.0
2Ae	62–120	ks	<1	<1	7.8	7.2	0.25	0.02	0.25	0.09	<2	6.6	20	0.9	0.24	0.23	8.2	0.42	0.09	1.12	0.88	0.11	0.02	0.05	0.06	1.8
2B21	120–140	fscl	<1	4	9.4	8.3	1.98	0.23	1.12	0.13	3	52.9	408	10.0	4.87	0.25	8.8	0.54	0.13	13.05	6.16	4.31	1.35	1.05	0.18	10.3
2B22	140–160	fslc	<1	8	9.5	8.4	7.23	0.31	1.54	0.07	<2	106	639	20.0	10.1	0.33	7.1	0.62	0.12	18.45	8.09	6.38	2.17	1.64	0.17	11.8
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	<0.7–1.85	<4–8	>1–2	>25–35	100–200	>80–120	>6–8	1–15	>0.2	>2.5	>1–2	>0.5–1.0	>15	75% CEC	20% CEC	<6% CEC	5% CEC	<5% CEC	<6

Note: (1) Sum of Cations approximates the Cation Exchange Capacity (CEC), a measure of the soil's capacity to store and release major nutrient elements.
(2) Exchangeable Sodium Percentage (ESP) is derived by dividing the exchangeable sodium value by the CEC, in this case estimated by the Sum of Cations

DEEP BLEACH SILICOUES SAND

Deep siliceous sand with a bleached layer; underlain by fine sandy light clay with minor carbonate.

Subgroup soil	Soil H3–G2 (bleached siliceous sand – sand over sandy clay loam) (Hall et al. 2009)
	Rises overlain by dunefield
Substrate	Mottled fine sandy clay loam
Vegetation	-
Position	Lower slope of long slope, approximately 150 m above severe dune seep scald
Site	Pope subcatchment [Soil treatment: spading to 40 cm + chicken manure]:

Site No:	MDS-P04	1:50 000 mapsheet:	6827–1 (Karoonda)
Hundred:	Hooper	Easting:	394 784
Section:	-	Northing:	6110 368
Date:	4/12/2015	Annual rainfall:	340 mm

Soil Description

Depth (cm)	Description
0–30	Loose, strongly repellent, dark yellowish brown, loamy sand with single grain structure. Clear boundary to:
30–45	Yellowish brown, loamy sand with massive structure. Abrupt boundary to:
45–58	(Darker) yellowish brown, loamy sand with massive structure. Abrupt boundary to:
58–98	Bleached, light yellowish brown, sand with massive structure. Sharp boundary to:
98–112	Hard, yellowish brown, heavy fine sandy clay loam with massive structure. Gradual boundary to:
112–140	Highly calcareous, slightly dispersive, yellowish brown, heavy fine sandy clay loam with weak structure and fine carbonate segregations between aggregates.

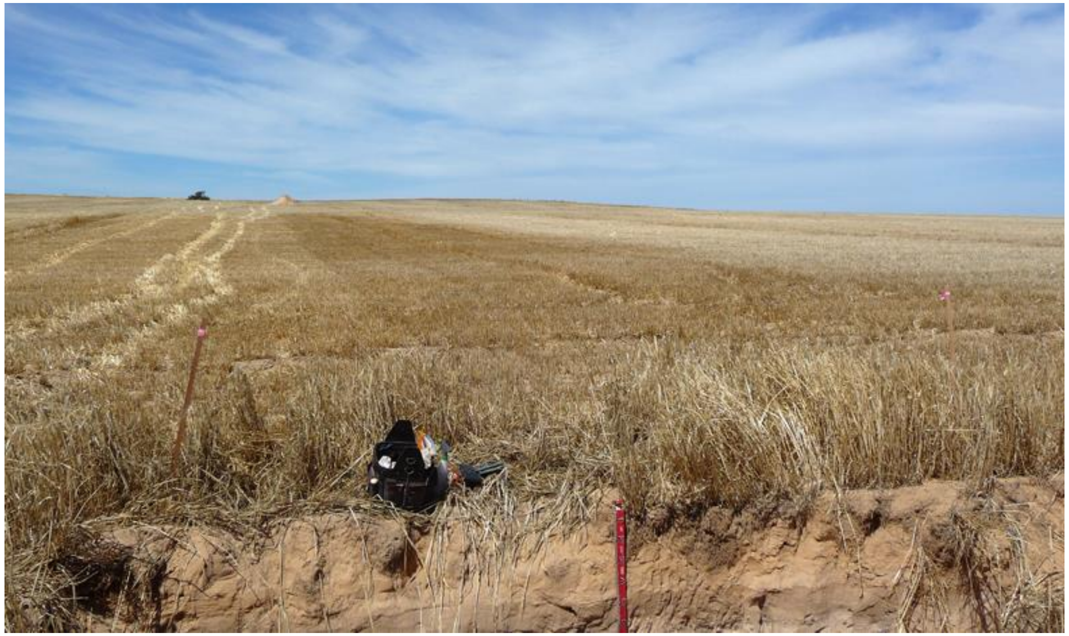
Australian Soil Classification

Sodic, Calcic, **Brown Chromosol**; very thick, non-gravelly, sandy / clay loamy, deep.

Summary of Properties

Drainage The soil profile is well drained. Some restriction to downward water movement occurs at the interface between the deep sand and the underlying sandy clay loam material. The sandy topsoil shows signs of excessive drainage with leaching of phosphorus evident.

pH Soil pH is acidic in the upper sandy layers, neutral below this, and alkaline to strongly alkaline in the underlying sandy clay laom.



Rooting depth Roots were observed to 112 cm, with most in the top 45 cm.

Barriers to root growth

Physical There are no significant physical barriers to root growth in the top metre.

Chemical Chemical barriers to root growth occur in the form of low inherent fertility in the sandy layers, and possible seasonal perched water on the underlying sandy clay loam. High pH below 112 cm would be restrictive.

Waterholding capacity Plant Available Waterholding Capacity (PAWC) is estimated to be approximately 70 mm (moderately low to moderate). [Workings: 0.3x120 + 0.15x80 + 0.13x0.5x80 + 0.4x0.5x60 + 0.14x0.5x110].

Seedling emergence Moderate. There are no physical barriers, however, strong water repellency could reduce emeregence. There is also potential for sand-blasting of seedlings.

Workability Good.

Erosion potential

Water Low.

Wind Moderate to moderately high. Maintenance of surface cover at all times is required to minimise erosion.

Laboratory Data – MDS-P04

Hori-zon	Depth cm	Texture	N NH_4^+ mg/kg	N NO_3^- mg/kg	pH H2O	pH CaCl2	CO3 %	EC 1:5 dS/m	ECe dS/m	Org C %	P Avail. mg/kg	P Buff Index	K Avail. mg/kg	S (KCl) mg/kg	Boron mg/kg	Trace Elements mg/kg (DTPA)				Sum cations meq/ 100g	Exchangeable Cations meq/100g					ESP
																Cu	Fe	Mn	Zn		Ca	Mg	Na	K	Al	
1A11	0–30	ls	3	<1	6.5	5.8	0.30	0.03	0.34	0.33	39	15.4	50	3.8	0.38	0.55	23.4	2.41	1.72	1.65	1.10	0.34	0.04	0.12	0.05	2.4
1A12	30–45	ls	<1	1	6.5	5.9	0.27	0.04	0.45	<0.05	10	10.0	65	3.8	0.21	0.55	10.1	1.37	0.31	1.25	0.74	0.23	0.04	0.16	0.08	3.2
2A1	45–58	ls	<1	<1	7.5	6.7	0.27	0.03	0.25	0.13	7	9.5	57	2.1	0.23	0.49	9.07	1.22	0.31	1.89	1.40	0.25	0.02	0.15	0.07	1.1
2Ae	58–98	s	<1	<1	7.8	7.2	0.23	0.02	0.24	0.05	4	6.6	33	1.3	0.18	0.25	8.89	0.54	0.13	1.23	0.90	0.14	0.02	0.09	0.08	1.6
2B21	98–112	fscl+	<1	<1	8.5	7.1	0.29	0.04	0.36	0.08	<2	39.2	237	1.3	2.51	0.24	10.4	0.48	0.13	9.55	4.31	4.00	0.42	0.61	0.21	4.4
2B22	112–140	fscl+	<1	3	9.4	8.2	21.4	0.16	0.67	0.21	<2	147.5	274	6.4	4.95	0.45	7.70	0.60	0.19	16.43	9.87	5.01	0.71	0.70	0.14	4.3
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	<0.7–1.85	<4–8	>1–2	>25–35	100–200	>80–120	>6–8	1–15	>0.2	>2.5	>1–2	>0.5–1.0	>15	75% CEC	20% CEC	<6% CEC	5% CEC	<5% CEC	<6

Note: (1) Sum of Cations approximates the Cation Exchange Capacity (CEC), a measure of the soil's capacity to store and release major nutrient elements.
(2) Exchangeable Sodium Percentage (ESP) is derived by dividing the exchangeable sodium value by the CEC, in this case estimated by the Sum of Cation