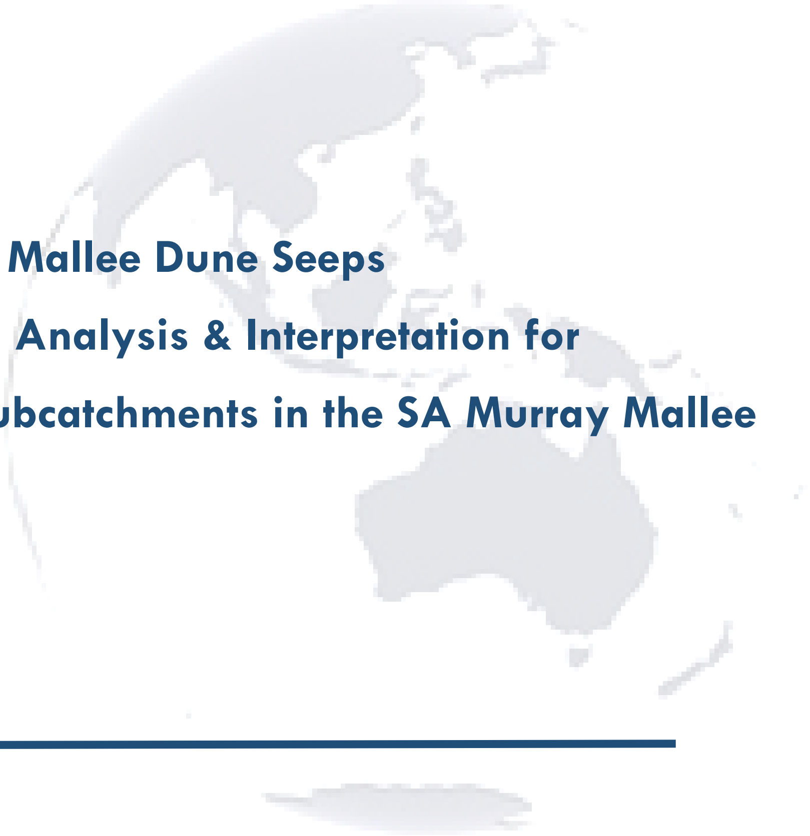

Mallee Dune Seeps
Deep Soil Analysis & Interpretation for All Investigated Subcatchments in the SA Murray Mallee

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A report produced for Natural Resources South Australian Murray–Darling Basin by Juliet Creek Consulting Pty Ltd in part fulfilment of Goods & Services Agreement 1556C.

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Solutions in Natural Resource Management

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Contents

List of Figures

List of Tables

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Mallee Dune Seeps
Deep Soil Analysis & Interpretation for All Investigated Catchments in the SA Murray Mallee

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June 2017

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1 Introduction

Mallee Dune Seepage is a phenomenon that occurs in dune-swale landscapes where excess water moves through sandy soils, and then laterally as groundwater seepage. Seepage waters can appear as discharge in lower-lying areas and downslope of sand dunes, forming semi-permanently to permanently waterlogged areas known as seeps. Seep areas are lost to production and can become severely degraded over time through erosion and salinisation.

Attention has been drawn to this issue because the majority of investigated and observed seeps in the South Australian Murray Mallee have appeared since after the year 2001. Many seeps are also growing in size. It is thought changed farming practices have caused this.

The presence of seepage waters in these landscapes indicates a wider problem of sub-optimal water use and lost productivity. The extent of excess and unused rainfall is surprising given that these are areas where rainfall is considered low to moderate for rainfed annual cropping. The amount of rainfall lost to production via seepage and deep drainage, however, is unknown, but it is likely to be significant. The extent of economic loss is also unknown, but is likely to be considerable.

A range of field observations and investigations, trials, monitoring, analyses of landscape processes, interpretations of data, and evidence-gathering from farmers have been conducted or made in a number of subcatchments to determine the nature and best management of Mallee Dune Seepage (see Hall et al. 2016, Hall 2016, McDonough 2016a, McDonough 2016b, Hall 2015, Henschke 2015, McDonough 2015, Henschke & Young 2015, Henschke & Tonkin 2014, McDonough 2014a, McDonough 2014b). Information has also been provided to land holders and others via conference and workshop presentations and various media (print media, factsheets and a video production).

Soil investigations at sites along toposequences (transects from high ground and dune crests to lower-lying seeps) have been conducted at three subcatchments (Wynarka, Mannum East and Karoonda). These investigations have included full soil descriptions and comprehensive chemical analyses of all soil layers to determine barriers to crop water use and root growth, as well as to determine the nature of water movement and storage within soils (see Hall 2015 and Hall 2016).

In addition, the three subcatchments have been investigated via deep drilling to assist with understanding of processes and the provision of recommendations. All materials brought to the surface via drilling have also been described (see Hall 2015, Henschke 2015 and Hall et al. 2016), while selected samples were taken for laboratory analyses. Comprehensive chemical analyses were conducted on samples, matching the comprehensive analysis performed on soil samples from excavated characterisation sites in the same subcatchments. Monitoring wells (piesometers) have also been installed at drilling sites – for details see Hall 2015, Henschke 2015 and Hall et al. 2016.

A major discovery has been that the soil and deeper geological layer known as Blanchetown Clay Formation forms the restrictive layer (aquatard) upon which perched water lies, and is a major cause of seepage and seeps. Excess soil water becomes deep drainage where Blanchetown Clay is absent (see Hall 2015, Hall 2016 and Hall et al. 2016 for more details). It has also been discovered that the main water movement through investigated soils is downward, with lateral movement along subsoil surfaces usually relatively minor.

Having matching comprehensive chemical analyses and descriptions from both soil layers and deep soil samples provides a unique set of data that can be evaluated to better understand potential root exploration in soils as well as at depth (e.g. for deep-rooted perennials), to better understand the nature of water movement (via an examination of chemical and physical indicators), and to assess the potential for land use and management change to more fully utilise incident rainfall.

The comprehensive chemical analyses undertaken match those conducted on 1100 soil characterisation sites across the state by the State Land & Soil Mapping Program (see Hall et al. 2009 and https://data.sa.gov.au/data/dataset/soil-characterisation-sites), as well as more recent soil characterisations undertaken by Juliet Creek Consulting.

This report provides interpretations of regolith (deep soil) as well as soil profile physical and chemical data in terms of indicator chemical levels, physical barriers, indications of water movement and storage, and the potential for root growth. General recommendations are also made (see the 'Main Findings & Recommendations' section below) about how best to improve water use and productivity. Report findings are summarised in the 'Conclusions' section.

2 Method

This study presents unique data, providing the opportunity to evaluate deep drill-hole samples for assessment of deep chemicals/nutrients and water movement, the presence of toxic accumulations of substances, as well as the potential for new farming systems and deep-rooted plants.

Three representative subcatchments and toposequences from across the SA Murray Mallee (Wynarka, Mannum East and Karoonda) were investigated via soil excavation and characterisation, subcatchment watershed boundary and land unit mapping, interpretations of soil and landscape processes utilising soil physical and chemical data, EM mapping, and deep drilling.

32 deep soil samples from all drilling sites in the three subcatchments were described, collected, dried, stored and submitted for chemical analyses – see below. For more details see Appendix 2.

2.1 Drilling Sites – Deep Soil Samples

2.1.1 Rose-Thomas Subcatchment (Wynarka)

Site MDS-R01 – dune crest (drilling 10/6/2015)

Sample MDS-R01 D1 (0.7 m)
Sample MDS-R01 D2 (6 m)
Sample MDS-R01 D3 (9.5 m) (Blanchetown Clay Formation)

Piesometer installed | adjacent to soil characterisation site MDS-R01

Site MDS-R02 – lower dune slope (drilling 10/6/2015)

Sample MDS-R02 D1 (3.5 m)
Sample MDS-R02 D2 (4 m)
Sample MDS-R02 D3 (5–6 m) (Blanchetown Clay Formation)

Piesometer installed | adjacent to soil characterisation site MDS-R02

Site MDS-R04 – upper dune slope (drilling 11/6/2015)

Sample MDS-R04 D1 (3.5 m)
Sample MDS-R04 D2 (5.5 m) (Blanchetown Clay Formation)

No piesometer installation | no adjacent soil characterisation site

Site MDS-R05 – seep edge (drilling 11/6/2015)

Sample MDS-R05 D2 (2.5 m) (Blanchetown Clay Formation)

Piesometer installed | corresponding to nearby soil characterisation site MDS-R03

2.1.2 Bond Subcatchment (Mannum East)

Site MDS-B01 – valley/depression/flat (near seep) (drilling 17/6/2015)

Sample MDS-B01 5 (2.5 m)
Sample MDS-B01 6 (3 m) (Blanchetown Clay Formation)
Sample MDS-B01 10 (5.5 m)
Sample MDS-B01 14 (8.5 m)
Sample MDS-B01 18 (11 m)

Piesometer installed | adjacent to soil characterisation site MDS-B01

Site MDS-B02 – upper dune slope superimposed upon the lower slope of a very long hillslope (drilling 18/6/2015)

Sample MDS-B02 5 (2.5 m)
Sample MDS-B02 8 (4 m)
Sample MDS-B02 11 (5 m)
Sample MDS-B02 12 (6.5 m) (Blanchetown Clay Formation)

Piesometer installed | adjacent to soil characterisation site MDS-B02

Site MDS-B03 – high-level sandy plateau (drilling 18/6/2015)

Sample MDS-B03 7
Sample MDS-B03 10
Sample MDS-B03 16

No piesometer installation | adjacent to soil characterisation site MDS-B03

2.1.3 Pope Subcatchment (Karoonda)

Site MDS-P05 (Paddock A) – upper slope (drilling 12/2/2016)

Sample MDS-P05 11 (4.5–5 m) (Blanchetown Clay Formation)

Piesometer installed | no adjacent soil characterisation site

Site MDS-P06 (Paddock A) – mid slope (drilling 12/2/2016)

Sample MDS-P06 12 (5 m)
Sample MDS-P06 13 (5.5–6 m) (Blanchetown Clay Formation)

Piesometer installed | corresponding to nearby soil characterisation site MDS-P02

Site MDS-P07 (Paddock A) – within seep; lower slope near upper seep edge (12/2/2016)

Sample MDS-P07 2 (0.5 m)
Sample MDS-P07 5 (2 m)
Sample MDS-P07 7 (3–3.5 m) (Blanchetown Clay Formation)

Piesometer installed | adjacent to soil characterisation site MDS-P01

Site MDS-P08 (Paddock B) – sand dune crest superimposed on upper slope (15/2/2016)

Sample MDS-P08 9 (3.5 m)
Sample MDS-P08 10 (4 m)
Sample MDS-P08 15 (7–7.5 m) (Blanchetown Clay Formation)

Piesometer installed | no adjacent soil characterisation site

Site MDS-P09 (Paddock B) – within seep; lower slope near edge of a large seep in a swale area (15/2/2016)

Sample MDS-P09 4 (1.5–2 m)
Sample MDS-P09 5 (2–2.4 m) (Blanchetown Clay Formation)

Piesometer installed | no adjacent soil characterisation site

Analyses and interpretation of the physical and chemical data from both deep samples and soil profiles will help support land use, farm and catchment planning for improved water use and productivity as well as improved management of seeps.

3 Discussion

An interpretation of soil and regolith (deep soil) physical and chemical characteristics follows, with a particular focus on impediments to root growth. This should help determine the potential and suitability of deep-rooted perennial plants to increase the utilisation of soil and regolith moisture and so improve paddock water use efficiency.

3.1 Rose-Thomas Subcatchment (Wynarka)

3.1.1 Site MDS-R01 – Dune crest

Soil Profile (0–165 cm): as discussed in Hall 2015, this dune crest soil consists of a loamy sand to sandy loam topsoil to 90 cm, and sandy clay loam subsoil with a maximum accumulation of fine carbonate below 110 cm. High pH and the carbonate accumulation indicate that drainage is not excessive. Indications are that wetting fronts commonly extend below 1 m. More easily leached materials such as salt (as measured by ECe), sodium (as measured by ESP) and boron show no zone of accumulation in the top 165 cm. This and other indicators show that soil profile drainage within the dunecrest is neither excessive nor greatly restricted, but is well-drained. In-field consistence assessment (moisture content and strength as a function of clay content) revealed no saturated soil layers, with the highest moisture content in the 14–60 cm zone at the time of description. There are no physical or chemical indications that lateral movement of water along the subsoil surface is significant, meaning that excess soil water moves downward rather than laterally. Roots were observed to 90 cm and soil plant-available waterholding capacity was estimated to be 45 mm. There are no significant physical constraints to root growth (although the soil is relatively hard below 110 cm). The only chemical constraints to root growth are low fertility, and high to very high pH below 60 cm.

Regolith (deep soil) (to 10.5 m): Blanchetown Clay was encountered at 7 m, with a likely saturated layer above this from about 6–7 m. Based on the assessment of drilling samples (see Hall 2015), there are no obvious significant physical barriers to root growth above the Blanchetown Clay, save for the saturated layer. Chemical data (see Appendix 2) indicates moderate salinity levels, very high pH, and very high sodium levels. It is unlikely that deeper-rooted perennial agricultural plants could access moisture in deep layers or tap into the perched watertable.

The most likely way to increase annual water use by productive plants would be to have plants growing and utilising water all year round, either via more perennials in the landscape or through the introduction of both summer and winter cropping. Consideration of matching land use to land type would also benefit water use.

3.1.2 Site MDS-R02 – Lower dune slope

Soil profile (0–170 cm): as discussed in Hall 2015, this lower slope soil consists of sandy topsoil (to 80 cm) over clayey subsoil. The presence of clayey subsoil as well as thin calcrete lamellae and dispersive clays results in somewhat restricted drainage. The existence of a bleached topsoil is confirmation of this. Chemical analyses reveal a maximum fine carbonate accumulation from 98–120 cm, together with very high pH, a build-up of boron and sodium, and a slight build-up of salt below this. Accumulation of excessive sodium in the subsoil results in dispersive soil that restricts drainage. The results of chemical analyses indicate that wetting fronts commonly extend below 1 m. Assessment of consistence when the soil was described revealed that the wettest layers were the lower topsoil and the underlying upper subsoil. The lower topsoil, while not saturated, was at approximately field capacity, indicating the likelihood of some lateral movement of water when the layer is saturated. Profile internal drainage is moderate. It is likely that significant amounts of soil water within the profile move laterally, as well as downward. Roots were observed to 60 cm and soil plant-available waterholding capacity was estimated as 52 mm. There are no significant physical restrictions to root growth above 98 cm, below this the soil is slightly dispersive and relatively hard. The subsoil also contains a series of discontinuous, thin calcrete lamellae, which present a barrier to roots. It is also likely that seasonal perched water in the lower topsoil restricts root growth to subsoil layers. Chemically, general topsoil infertility is likely to limit root growth, as will strong alkalinity below 120 cm.

Regolith (deep soil) (to 6 m): Blanchetown Clay was encountered at 5 m, with a saturated layer above this. Based on the assessment of drilling samples (see Hall 2015) there are no obvious significant physical impediments to root growth above the Blanchetown Clay, save for the saturated layer of possibly 1 m thickness perched on this clay. Chemical data (see Appendix 2) indicates very high pH and very high sodium levels. It is unlikely that deeper-rooted perennial agricultural plants could access moisture in deep layers or tap into the lower perched watertable.

The most likely way to increase annual water use by productive plants would be to have plants growing and utilising water all year round, either via more perennials in the landscape or through the introduction of both summer and winter cropping. Consideration of matching land use to land type would also benefit water use.

3.1.3 Site MDS-R04 – Upper dune slope

Soil profile: no soil was excavated or characterised at this site, although drilling revealed a deep sandy soil with a bleached layer from approximately 150–200 cm.

Regolith (deep soil) (to 5.5 m): Blanchetown Clay was encountered at 4.5 m, and no saturated layer was observed above this. Based on the assessment of drilling samples (see Hall 2015), other than a calcrete layer at approximately 250–300 cm, there is no obvious significant physical impediment to root growth above the Blanchetown Clay. Chemical data (see Appendix 2) indicates strong alkalinity and high sodium at 3.5 m, however, it is likely that no chemical impediments to root growth (other than low fertility) occur in the sandy material to 2.5 m depth.

Matching land use to land type on this deep sandy soil – with species that can access all sandy layers to 2.5 m depth – would benefit water use and productivity.

3.1.4 Site MDS-R05 – Seep edge

Soil Profile (0–115 cm): Characterisation site MDS-R03 is a nearby corresponding soil also on the seep edge. This wet soil consists of sandy loam topsoil (to 47 cm) over clay loam subsoil. It is calcareous below 15 cm and has an abundant accumulation of hard carbonate fragments in the lower topsoil. The profile has very restricted drainage owing to a combination of depth to Blanchetown Clay and position in the landscape. Salt levels (as measured by ECe) reach their maximum in the subsurface layer (a moderate level of 7.3 dS/m at 15–28 cm), but are relatively low below this (<2.5 dS/m). These data confirm that this is a ‘freshwater’ seep, but where salts can accumulate over time owing to evaporative processes, especially in areas with no vegetative cover. There are a number of indications from chemical and physical analyses that demonstrate the seep has not been wet for a great number of years. Firstly, the soil lacks high organic carbon content in the surface soil and, secondly, the nature of the mottling of the subsoil does not indicate excessive wetness, and is similar to that of the lower slope and dunecrest sites. Of interest is that no layer was seen to be saturated (on the day of description), although water was evident on the land surface in the scalded part of the seep a few metres away. The layer from 47–62 cm (the upper subsoil) was the wettest, and all layers were at field capacity or greater. When the site was excavated, water began to trickle in from the top of the clay layer just upslope, while some water entered via a crack in the pit face at a depth of about 1 m. After one day the excavated hole was half-full. The site has very poor to poor drainage, indicating the presence of a restrictive layer that holds up drainage at relatively shallow depth (confirmed by drilling as Blanchetown Clay at 2 m). Although all soil layers are dispersive and highly sodic, there are no serious physical impediments to root growth. Chemical barriers to root growth are significant: including strong alkalinity, raised salinity levels, and high sodium levels – this is largely owing to an accumulation of substances with seepage waters.

Regolith (deep soil) (to 3 m): Blanchetown Clay was encountered at 2 m depth, and the whole soil profile above this was saturated. Chemical analyses of the Blanchetown Clay layer (see Appendix 2) showed strong alkalinity, high boron, and very high sodium levels.

Specialised waterlogging-tolerant, and moderately salt tolerant, plants are required to provide cover to prevent degradation. However, if whole-of-catchment measures to reduce seepage are successful, this area should once again become highly productive farmland.

3.2 Bond Subcatchment (Mannum East)

3.2.1 Site MDS-B01 – Valley/depression/flat (near seep)

Soil Profile (0–140 cm): as discussed in Hall 2015, this wet soil consists of sandy loam topsoil (to 52 cm) over light clay to clay loam subsoil. Drainage is poor, owing to the seepage/overflow of water from the nearby seep into this area. Salinity levels are moderate to moderately low, with the highest in the 22–52 cm zone (an ECe of approximately 6 dS/m). The clay loam subsoil does not constitute a significant barrier to drainage. Deep drilling revealed a highly restrictive layer to drainage at approximately 2.5 m depth, which is only about 50 cm thick at this site. This is tight, mottled, heavy clay (Blanchetown Clay Formation). It is known that this layer is much thicker slightly up-slope where the main seep area occurs. It is certain that the presence of the seep in this area is a function of the relatively shallow Blanchetown Clay layer, which restricts deeper drainage of subcatchment seepage waters that accumulate in this low-lying area. Of interest is the absence of signs of seepage waters just slightly down-catchment from this site, which indicates the likely absence of the Blanchetown Clay layer and the capacity for excess water to drain directly downwards. The discontinuous nature of the Blanchetown Clay corresponds to its formation in discontinuous lake environments as well as more recent dissection of landscapes. There are indications from chemical and physical analyses that the seep has not been wet for a great number of years. For example, there is no substantial accumulation of organic matter in the surface soil, and the subsoil is whole-coloured rather than mottled. Roots were observed to 52 cm, and soil plant-available waterholding capacity was estimated to be 50 mm. The soil profile contains no significant physical barriers to root growth. Profile wetness presents a barrier to roots. Chemical constraints to root growth are significant and include strong alkalinity, high boron and sodium, and moderate salinity levels.

Regolith (deep soil) (to 11 m): Blanchetown Clay was encountered from 2.5–3 m, with a saturated/seepage layer above this. The Blanchetown Clay layer becomes thinner from the nearby seep to this point. It is likely that it is no longer present only a short distance away, as seepage waters are no longer observable – presumably they drain to depth because of the absence of Blanchetown Clay. The physical barrier of the Blanchetown Clay, plus strong alkalinity, very high sodium levels, and moderate salinity levels (below the Blanchetown Clay) suggest that the roots of agricultural plants would be unable to reach any great depth (see Appendix 2).

Although wet, this site is still able to be cropped. The addition of perennial plants into the farming system, or a more consistent use of incident water via the utilisation of both winter and summer cropping would provide more productivity and water use in this area. Given the amount of reasonable quality soil water entering this area, a plantation of tree species or other high-water use species with moderate salinity tolerance would probably thrive, as suitable plants should be able to utilise the shallow excess water in these soils.

3.2.2 Site MDS-B02 – Upper dune slope superimposed on the lower slope of a very long hillslope

Soil Profile (0–175 cm): as discussed in Hall 2015, this sand dune soil consists of sandy topsoil (to 50 cm) over sandy subsoil (to 130 cm), which is underlain by light sandy clay material. The profile is excessively drained to about 68 cm, with some slight restrictions below this. Wetting fronts commonly reach to well below 1 m, indicated in part by the beginnings of fine carbonate accumulation from 130 cm. There is no evidence of lateral water movement, and no saturated layers were encountered in the soil profile. It is clear at this site that soil water that is not stored in the soil profile or used by growing plants moves directly downward rather than laterally. Roots were observed to 68 cm, while soil plant-available waterholding capacity is estimated to be 69 mm. There are no physical barriers to root growth; general low fertility is the only chemical barrier.

Regolith (deep soil) (to 6.5 m): drilling revealed Blanchetown Clay at 6 m, with a bleached and saturated sandy clay loam layer of approximately 1 m thickness above this. Based on the assessment of drilling samples (see Hall 2015), there are no obvious significant physical barriers to root growth above the Blanchetown Clay – there may however be a calcrete layer, but this is likely to be relatively thin with cracks, thereby allowing roots to penetrate. The saturated layer itself would be a barrier to root growth for most species. Bleaching of this layer indicates considerable water movement over time. Chemical data (see Appendix 2) indicates strong alkalinity at depth, such that it is unlikely that the roots of deep-rooted agricultural species could access moisture below the sandy layers (below 2 m).

The most likely way to increase annual water use by productive plants in this deep sandy soil would be to have plants growing and utilising water all year round, either via more perennials in the landscape or through the introduction of both summer and winter cropping. Consideration of matching land use to land type – by selecting species that could tap into all sandy layers to 2 m – would also benefit water use. Increasing seasonal crop water use by improved agronomy or soil modification would also be beneficial.

3.2.3 Site MDS-B03 – High-level sandy plateau

Soil Profile (0–160 cm): as discussed in Hall 2015, this deep sandy loam consists of light sandy loam topsoil (to 52 cm) over sandy loam subsoil that becomes calcareous below 77 cm. The lower subsoil has high pH below about 77 cm, while fine carbonate accumulation is significant below 160 cm – indicating that drainage is restricted to a minor degree, but that wetting fronts commonly reach to well below 1 m. Soil data show no signs of lateral water movement at this site. No saturated layers were encountered in the soil profile, with the highest moisture content in the 77–125 cm zone. It is clear that soil water that is not stored in the profile or used by growing plants moves downward rather than laterally. In the profile roots were observed to 52 cm, while soil plant-available waterholding capacity was estimated to be 58 mm. The soil profile contained no physical impediments to root growth, and no obvious chemical restrictions, other than relatively low general fertility throughout, plus very high pH below 77 cm.

Regolith (deep soil) (to 9.5 m): drilling revealed no Blanchetown Clay or saturated layers, although a firm to very firm medium clay was encountered in the last several metres of the drill hole. Based on the assessment of drilling samples (see Hall 2015), no layers significantly restrict drainage, however, the medium clay in the lower part of the hole is moderately restrictive. Chemical analyses (see Appendix 2) reveal deep layers with strong alkalinity, very high sodium levels, and moderately high salinity levels. It is unlikely that the roots of deep-rooted agricultural plants would be able to access these deep layers.

This means that to increase annual water use by productive plants mostly involves improved agronomy for existing winter crops, soil amelioration, the utilisation of both summer and winter cropping, and/or more perennials in the farming system and landscape. Even though deeper-rooted perennials are unlikely to utilise water and nutrients from very deep layers, they are, however, likely to extract water from soil layers that most annual roots will not reach, and will also utilise rainfall all year round (e.g. see Figure 2).

3.3 Pope Subcatchment (Karoonda)

3.3.1 Site MDS-P05 (Paddock A) – Upper slope

Soil Profile: no soil was excavated or characterised at this site, although drilling revealed a sandy topsoil over a sandy loam subsoil with calcrete and sandy clay loam below this.

Regolith (deep soil) (to 4.7 m): Blanchetown Clay was encountered at 4.4 m, and a bleached moist to wet layer in sandy light clay material was observed on this – which is likely to be seasonally saturated. Based on the assessment of drilling samples (see Hall et al. 2016), other than some calcrete, there is no obvious significant physical impediment to root growth above the Blanchetown Clay. Only the Blanchetown Clay was chemically analysed (see Appendix 2). Based on this, as well as testing of fine carbonate in the field, it is likely high to very high pH, plus very high sodium levels, are the main impediments to root growth in the layers below the soil and above the Blanchetown Clay.

Use of perennials, summer and winter cropping, soil amelioration, and/or improved agronomy will improve water use, however, it is unlikely even the roots of deeper-rooted perennial plants would reach much beyond 1.5–2 m to access deep water and nutrients.

3.3.2 Site MDS-P06 (Paddock A) – Mid slope

Soil Profile (corresponding to nearby soil characterisation site MDS-P02) (0–190 cm): as discussed in Hall 2016, this 'sandy over clay' soil consists of sandy topsoil with a bleached subsurface layer (to 55 cm) over sandy clay loam subsoil, 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 laterally along the subsoil surface would not be insignificant. Roots were observed to 55 cm, while soil plant-available waterholding capacity was estimated to be 40 mm. The sodic-dispersive subsoil forms a moderate physical barrier to root growth. Chemical barriers to root growth occur in the form of low inherent fertility in the sandy topsoil and very high pH in the subsoil.

Regolith (deep soil) (to 6.2 m): Blanchetown Clay was encountered at 4.7 m, and a bleached wet layer in light medium clay material was observed above this. Based on the assessment of drilling samples (see Hall et al. 2016), the slightly dispersive clay above the Blanchetown Clay from about 2–4.7 m is likely to be a moderate physical impediment to root growth. Based on laboratory analyses (see Appendix 2), the main chemical barrier is likely to be very high pH and very high sodium levels in all deep (below-soil) layers.

Use of perennials, summer and winter cropping, soil amelioration, and/or improved agronomy will improve water use, however, it is unlikely that the roots of perennial agricultural plants would reach these deeper layers to access deep water and nutrients.

3.3.3 Site MDS-P07 (Paddock A) – Lower slope near upper seep edge

Soil Profile (adjacent to soil characterisation site MDS-P01) (0–190 cm): as discussed in Hall 2016, this 'sandy over clay' soil consists of sandy topsoil with a bleached subsurface layer (to 80 cm) over sandy clay loam subsoil, which has mottled colours in its 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 lower subsoil. Indications are that drainage waters have in the main moved vertically through the profile, although water movement laterally along the subsoil surface would not be insignificant. In addition, seepage waters were observed at the base of the profile at the time of description (approximately 10 cm of water was observed in the base of the pit one day after it was opened), presumably perched and seeping upon a low permeability layer of Blanchetown Clay (this was subsequently confirmed by drilling). Roots were observed to 110 cm, while soil plant-available waterholding capacity was estimated to be 60 mm. No significant physical barriers to root growth were observed. Wet soil at the base of the profile may limit roots. Chemical barriers to root growth occur in the form of low inherent fertility in the sandy topsoil and very high pH in the subsoil.

Regolith (deep soil) (to 3.5 m): Blanchetown Clay was encountered at 2.6 m, with saturated subsoil above this. Based on the assessment of drilling samples (see Hall et al. 2016), the dispersive subsoil, the calcrete layer from about 0.9–1.5 m, and the wet soil below about 1.5 m are likely to form a significant physical impediment to root growth. Chemical analyses (see Appendix 2) reveal strong alkalinity, very high sodium levels and moderate salinity in below-soil layers – which will impede root growth.

The P01 site, although wet, still supports cropping, while nearby P07 drilling site is on the margin of the scalded (bare) seep. For the P01 site, the addition of perennial plants into the farming system, or a more consistent use of incident water via the utilisation of both winter and summer cropping would provide more productivity and water use in this area. Given the amount of reasonable quality soil water entering this area, a plantation of tree species or other high-water-use species with moderate salinity tolerance would probably thrive, as suitable plants should be able to utilise excess soil water. The P07 site, however, requires specialised waterlogging-tolerant, and moderately salt tolerant, plants to provide cover to prevent degradation. Nonetheless, if whole-of-catchment measures to reduce seepage are successful, these seep margin areas should once again become productive farmland.

3.3.4 Site MDS-P08 (Paddock B) – Dune crest

Soil Profile: no soil was excavated or characterised at this site, although drilling revealed a sandy topsoil over a light sandy loam subsoil with sandy loam below this.

Regolith (deep soil) (to 7.5 m): Blanchetown Clay was encountered at 7 m, and a wet layer in sandy light clay material was observed above this, probably from 6–7 m. Based on the assessment of drilling samples (see Hall et al. 2016), there is no obvious significant physical impediment to root growth above the Blanchetown Clay. Chemical analyses (see Appendix 2) show strong alkalinity in the deep layers above the Blanchetown Clay, which is likely to impede root growth. The wet layer would also restrict roots.

Better matching of land use to land type would improve water use and productivity at this site. This is a deep sandy site that would be ideal for deeper-rooted perennials. The site would also benefit from soil amelioration (e.g. with clay and/or organic matter). Having plants growing all year round would greatly improve water use (e.g. utilising both summer and winter cropping).

3.3.5 Site MDS-P09 (Paddock B) – Lower slope on edge of seep area

Soil Profile: no soil was excavated or characterised at this site, although drilling revealed a light sandy loam topsoil over a wet sandy clay loam subsoil with some calcrete in lower soil layers.

Regolith (deep soil) (to 2.4 m): Blanchetown Clay was encountered at about 2 m, and a wet subsoil of sandy clay loam material was observed above this. Based on the assessment of drilling samples (see Hall et al. 2016), there is no significant physical barrier to root growth above the Blanchetown Clay other than some calcrete. Saturated layers would, however, restrict roots. Chemical analyses (see Appendix 2) reveal very high pH as the main chemical impediment to root growth.

Specialised waterlogging-tolerant, and moderately salt tolerant, plants are required to provide cover to prevent degradation. However, if whole-of-catchment measures to reduce seepage are successful, this area should once again become productive farmland.

4 Main Findings & Recommendations

4.1 Dune soils and sandy paddock soils not adjacent to seeps

In these areas perched watertables occur more than about 2.5 m below the surface, with the Blanchetown Clay itself at more than roughly 3.5 m depth (see Figures 1 & 2 and Tables 1 & 2). These sites possess a significant regolith layer between the bottom of the soil profile (at about 1 m depth) and the underlying Blanchetown Clay. The growth of annual crops at these sites is generally not directly impacted by the perched groundwater.

The regolith layer above the Blanchetown Clay is generally a sandy clay loam to sandy clay. It does however sometimes include firm clay layers in its lower parts, and sometimes calcrete.

The regolithic sandy clay loam to sandy clay layers do not generally possess toxic accumulations of substances such as boron and salt (as measured by ECe) (see Appendix 2), however, high to strong alkalinity is ubiquitous, and it is likely that this is enough to restrict deep root growth. (The State Land & Soil Mapping Program has extensive data showing that few to no roots grow in soil layers with a pH_{H2O} above 9.2 or pH_{CaCl2} above 8.5 – see Hall et al. 2009.) Sodium levels are also usually very high (with levels of exchangeable sodium that are detrimental to plant roots). Although obvious physical barriers to root growth – other than some calcrete and some firm clays – were not revealed by drilling, these regolithic layers do consist of densely-packed soil particles with few cracks and little to no openings for roots to explore, as expansive (shrink-swell) clay minerals are absent, and old root channels are rare.

Saturated layers perched on Blanchetown Clay present a barrier to most plant roots – while the Blanchetown Clay itself is both physically and chemically hostile to plant roots.

4.1.1 'Sand over Clay' Soils

In the 'sand over clay' soil situation (see Table 1 & Figure 1) (also see sites R01, R02, B05, P02, P04, P05 & P06 in Appendix 2 and/or Hall 2015, Henschke 2015, Hall 2016 & Hall et al. 2016), where sandy clay loam to sandy clay subsoil layers occur within the top 1m, the roots of annual agricultural plants generally do not access layers beyond 1 m (quite often very few roots occur below 50–60 cm).

Table 1 Investigated sites that can be categorised as 'sand-over-clays' in 'dune soils and sandy paddock soils not adjacent to seeps'.

Site	Soil Character -isation	Drilling	Position in the Landscape	Depth to Watertable (m)	Depth to Blanchetown Clay (m)
MDS-R01	√	√	dune crest	~6	7
MDS-R02	√	√	lower dune slope	~4	5
MDS-B05	√	X	lower slope of a very long hillslope	>1.9	>1.9
MDS-P02	√	X	mid-slope of a long hillslope	>1.9	>1.9
MDS-P04	√	X	lower slope of long hillslope	>1.4	>1.4
MDS-P05	X	√	upper slope of long hillslope	~4	4.4

MDS-P06	X	√	mid-slope of a long hillslope	~3.5	4.7

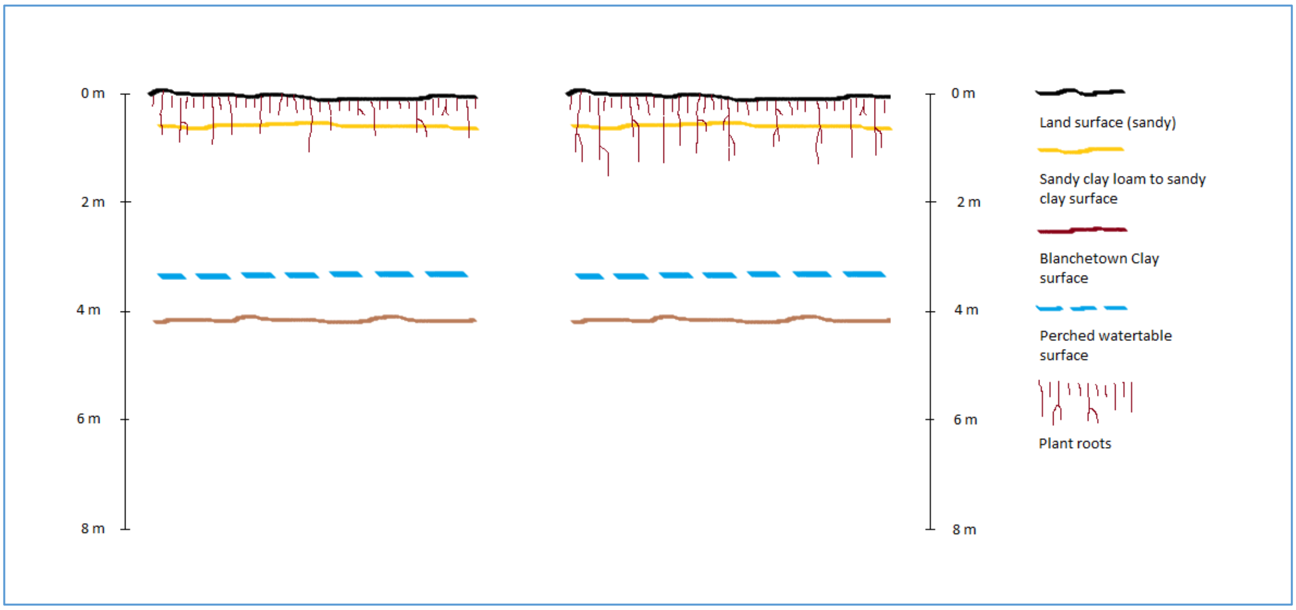

Figure 1 The ‘sand over clay’ situation where sandy clay loam to sandy clay subsoil occurs within a depth of 1 m. The left diagram shows the likely root-growth situation with annual crop plants. The right diagram shows the likely root-growth situation with deeper-rooted perennial agricultural plants. [Juliet Creek Consulting]

4.1.2 ‘Deep Sands’

In the ‘deep sand’ situation that often occurs on dunes (see Table 2 & Figure 2) (also see sites R04, B02, B03, P03 & P08 in Appendix 2 and/or Hall 2015, Henschke 2015, Hall 2016 & Hall et al. 2016), where sandy layers can be more than 2 m thick, the roots of annual agricultural plants can access greater depths. In sandy layers general infertility is the greatest restriction to root growth.

Table 2 Investigated sites that can be categorised as ‘deep sands’ in ‘dune soils and sandy paddock soils not adjacent to seeps’.

Site	Soil Character -isation	Drilling	Position in the Landscape	Depth to Watertable (m)	Depth to Blanchetown Clay (m)
MDS-R04	X	√	upper dune slope	none	4.5
MDS-B02	√	√	upper dune slope (superimposed on the lower slope of a very long hillslope)	~5	6
MDS-B03	√	√	high-level sandy plateau (actually a deep light sandy loam)	>9.5 (if present)	>9.5 (if present)
MDS-P03	√	X	lower slope of long hillslope	>1.6	>1.6
MDS-P08	X	√	dune crest (superimposed on the upper slope of a hillslope)	~6	7

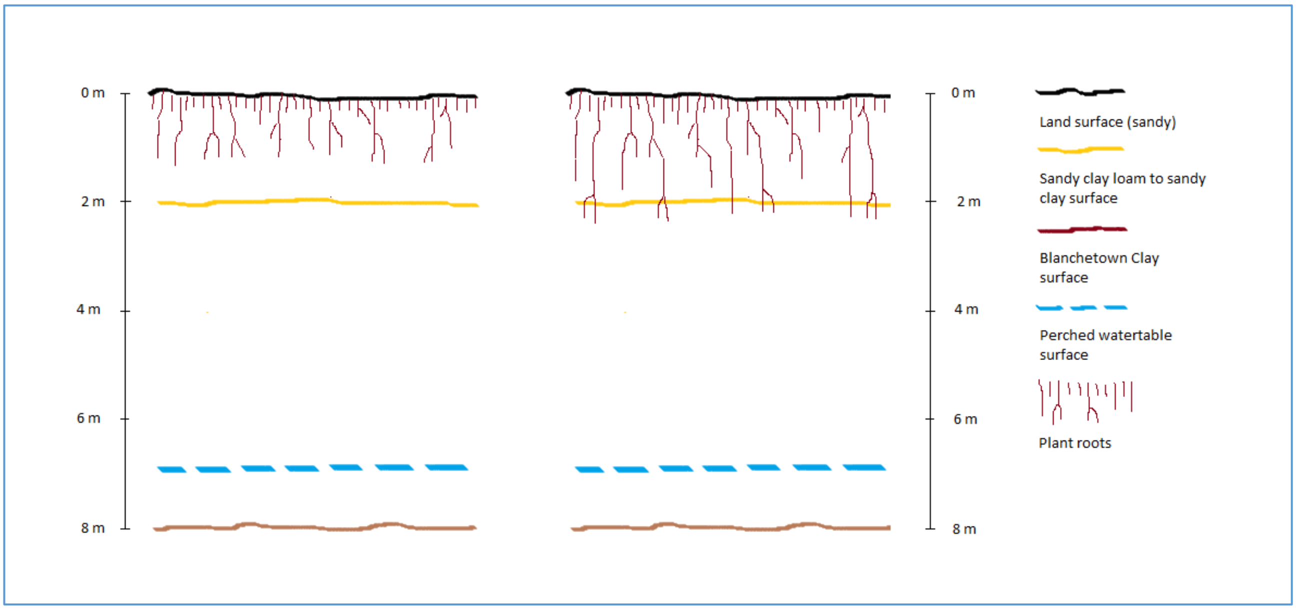

Figure 2 The 'deep sand' situation where the sandy clay loam to sandy loam layer is below 1 m. The left diagram shows the likely root-growth situation with annual crop plants. The right diagram shows the likely root-growth situation with deeper-rooted perennial agricultural plants. [Juliet Creek Consulting]

4.1.3 Best-Bet Options for Improving Productivity & Water Use and Reducing Seepage

- moving to a summer and winter plant growth farming regime (thereby increasing water use by having productive plants growing all year round)
- adding deeper-rooted perennial agricultural plants (e.g. lucerne) into the farming system (see Figures 1 & 2)
- matching land use to land type (i.e. farming to land type rather than having the same land use and management regime across all land types within a rectangular paddock)
- soil modification and amelioration (e.g. clay spreading, delving, spading, adding organic matter)
- improved agronomy (e.g. improved nutrition, management of water repellence, rotations)
- strategic tree-planting.

The additional of perennials into these landscapes is likely to result in a relatively small increase in rooting depth and exploration, but a significant increase in plant available water and potential water use (see Figures 1 & 2). Except where sands extend to depth, relatively chemically unfriendly soils limit root growth potential.

The greatest benefit to water use and productivity, however, is likely to come from having productive plants growing all year round, and so extracting soil moisture all year – through adding perennials to the landscape, but through shifting to a summer and winter crop and pasture growth model and farming regime.

Engineering solutions such as interceptor drains are unlikely to be successful in these sandy paddock soils because lateral flow of water across subsoil surfaces is generally not sufficient to feed water into constructed drains, and many subsoils are too deep. Most water in these soils moves directly downward through subsoil layers to depth, where its downward movement is impeded by Blanchetown Clay (when present). Even if viable, drain construction and maintenance are unlikely to be cost effective. Drains require the construction and maintenance of stabilised waterways, plus the development of sacrifice areas where drained waters accumulate (not unlike the seeps themselves!). Drains also interfere with paddock operations.

4.2 Seep soils and soils adjacent to seeps

In these areas crops are directly affected by perched groundwater derived from Mallee Dune Seepage. Or in the case of seeps themselves, crop plants will not grow or survive, and land surfaces are either scalded (bare), or are covered with moisture-loving plants.

4.2.1 Soils Adjacent to Seeps

In soils adjacent to seeps (see Table 3 & Figure 3) (also see sites B01, B04 & P01 in Appendix 2 and/or Hall 2015, Henschke 2015, Hall 2016 & Hall et al. 2016), where perched groundwater occurs at less than about 2.5 m depth and Blanchetown Clay occurs at less than roughly 3.5 m, wet soil occurs in subsoil layers, and crop production may even be boosted by the relatively shallow perched water.

Table 3 Investigated sites that can be categorised as 'soils adjacent to seeps'.

Site	Soil Character-isation	Drilling	Position in the Landscape	Depth to Watertable (m)	Depth to Blanchetown Clay (m)
MDS-B01	√	√	on a flat adjacent to a seep	~1	2.5–3
MDS-B04	√	X	on a flat/very lower slope adjacent to a seep	~1	>1.4
MDS-P01	√	X	lower slope about 40m from seep edge	~1.5	>1.9

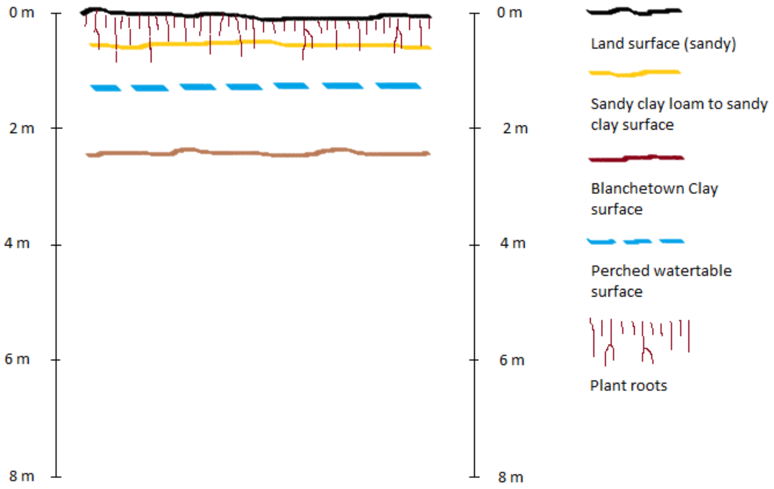

Figure 3 The 'soils adjacent to seep' situation where the soil and crops are affected by perched water. The likely growth of annual crop roots is shown [Juliet Creek Consulting]

4.2.2 Best-Bet Options for Improving Productivity & Water Use and Reducing Seepage

- better matching of land type with land use and management by farming areas adjacent to seeps differently to the main paddock areas to make best use of available perched groundwater
- selecting plant types that can best utilise perched water (e.g. water-loving tree species with moderate salt tolerance)
- moving to a summer and winter plant growth farming regime (thereby increasing water use by having productive plants growing all year round)
- soil modification and amelioration (e.g. clay spreading, delving, spading, adding organic matter)
- improved agronomy (e.g. improved nutrition, management of water repellence, rotations).

Implementation of whole-of-subcatchment measures listed in 4.1.3 should decrease overall seepage and lessen the severity of perched water in these areas.

Engineering solutions such as interceptor drain construction are unlikely to be viable in these areas as the low permeability clay – which would form the base of the drains – is too deep. Stabilised channels, waterways and sacrifice areas (similar to the seeps themselves!) would need to be constructed and maintained. These are unlikely to be cost effective and would impede farming operations.

4.2.3 Seep Soils

In the seeps themselves (see Table 4 & Figure 4) (also see sites R03, R05, P07 & P09 in Appendix 2 and/or Hall 2015, Henschke 2015, Hall 2016 & Hall et al. 2016), the whole soil profile, or the soil profile to just below the surface soil is semi-permanently to permanently saturated, and normal agricultural plants cannot be established or do not grow owing to excessive soil wetness.

Table 4 Investigated sites that can be categorised as 'seeps'.

Site	Soil Character -isation	Drilling	Position in the Landscape	Depth to Watertable * (m)	Depth to Blanchetown Clay (m)
MDS-R03	√	X	vegetated seep margin	~0.5	>1.15
MDS-R05	X	√	vegetated seep margin	~0.5	2
MDS-P07	X	√	scalded (bare) seep margin	~0.5	2.6
MDS-P09	X	√	scalded (bare) seep margin	~0.5	2

* or depth to saturated soil

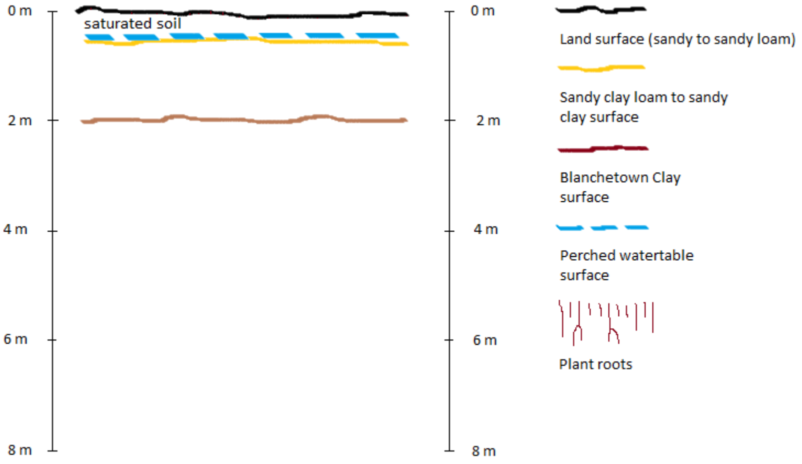

Figure 4 The 'seep soils' situation where there is no crop growth owing to saturated soil [Juliet Creek Consultng].

4.2.4 Best-Bet Options for Managing Seeps

- manage seeps separately from other areas (matching management and use to land type) and ensure plant cover at all times to minimise degradation via erosion and salt accumulation (e.g. through plantings of puccinellia, tall wheat grass or saltbush).

Implementation of whole-of-subcatchment measures listed in 4.1.3, as well as those listed in 4.2.2, should decrease overall seepage and lessen the extent and severity of seep wetness. Many seep areas may even revert back to the highly productive cropping land they once were.

There is a case that engineering solutions could benefit seep areas. It is possible that the fresh to brackish water that accumulates in seeps could be pumped and used at other locations (e.g. for livestock or irrigation). Cost-benefits would need to be examined. It is also possible at some locations (e.g. the main seep at Mannum East) that a drainage channel could be constructed to drain seep water to nearby areas not underlain by Blanchetown Clay, where deep drainage could occur. The capacity of end-point areas to accept and drain water would need to be determined.

5 Conclusions

In this report subcatchment areas have been separated in the 'Main Findings and Recommendations' section into four main zones:

Dune soils and sandy paddock areas not adjacent to seeps:

1. 'sand over clay' soils
2. deep sands

Seep soils and soils adjacent to seeps

3. soils adjacent to seeps
4. seep soils

These can be viewed as separate land management zones that would benefit from land use and management that takes account of their specific land types and conditions. The benefits would be greater productivity and overall farm water use, protection of seep areas from degradation and, eventually, rehabilitation of most seep areas back to productive farmland.

An analysis has been given of the physical and chemical nature of regolith (deep soil) materials. It has been concluded that it is unlikely that the roots of deeper-rooted plants will access deep layers of sandy clay loam and clay – mostly because of very high pH, very high sodium levels, and their tightly-packed natures. More vigorous roots are, however, likely to penetrate slightly further than those of normal annual crops, enabling these plants to access significantly more soil moisture (see Figure 1). Moreover, there is an opportunity to fully exploit deep sandy soils, where the sandy layers present much less of a barrier to the roots of deeper-rooted plants (see Figure 2).

Because it is unlikely that the roots of any newly utilised more vigorous plants will penetrate very much deeper than currently utilised plants – except most probably in the case of deep sands – it seems clear that farming systems that integrate productive plants growing all year round will be most successful in increasing overall farm water use – the focus being on having plants growing all year, whether perennials, or annuals as part of a combined summer/winter cropping system.

In land management zones 1 and 2, the low permeability Blanchetown Clay layer is at more than roughly 3.5 m depth, and the growth of annual crop plants is not directly affected by the perched groundwater situated on the clay. Even productive deeper-rooted perennial plants are unlikely to be able to directly 'tap-into' or benefit from the perched groundwater. (See Figures 1 & 2).

In these zones, the greatest benefit to water use and productivity is likely to come from having productive plants growing in the landscape and utilising soil moisture all year round, either through more perennials or the implementation of farming systems utilising both summer and winter crops. Improving the productivity of current systems is also important, especially on the deep sands that seem to be the main source of seepage waters (i.e. they can be considered the main recharge areas).

The greatest opportunity for greater root penetration exists with the deep sands (>1 m), where it is likely that more vigorous deeper-rooted plants (predominantly perennials) will extend roots to the full depth of sand (see Figure 2). The main issue with these sandy layers is their general infertility.

The changes required to farming systems to increase productivity and water use are not, however, insubstantial or necessarily easily implemented.

In land management zones 3 and 4, the low permeability Blanchetown Clay is at less than roughly 3.5 m depth, and annual crops or other plants are directly impacted by the perched groundwater.

In land management zone 3, the underlying perched groundwater may often have a beneficial effect on growth (see Figure 3). Plants are likely to be able to derive water from the capillary zone of wetness above the saturated zone of perched groundwater. Depth to groundwater is a crucial factor – if too shallow crop growth is likely to be impeded.

In land management zone 4 – the seeps themselves – soils are too wet for normal crops (see Figure 4). Wetland agronomy is the focus in these areas. Plantings of useful water-loving plants should be established to minimise degradation by erosion and salinisation. Utilisation of the fresh to brackish water from these areas is a possibility. Drainage of seep water via channels is also a possibility in some cases. The best solution is, however, to increase productive water use across whole subcatchments to reduce seepage and revert seeps back to productive farmland.

Final Note

This revised edition of this report contains amended chemical data (shown in blue in the tables of chemical analyses in Appendix 2). This is because the original exchangeable calcium test figures were much higher than expected – which also affected the sum of cation and exchangeable sodium percentage (ESP) results. The original exchangeable cations analysis was done using the ammonium acetate test (Method 15D3 in Rayment & Lyons 2010). After presentation of evidence and prolonged discussions, it was agreed that the laboratory would retest the deep soil samples using the barium chloride/ammonium chloride exchangeable cation method (Method 15E1 in Rayment & Lyons 2010). This resulted in much more realistic exchangeable cation figures (e.g. up to 10 meq/100g less than previously measured), and hence sum of cation and ESP results. Exchangeable magnesium, sodium and potassium figures showed no significant difference between the two test methods. It seems method 15D3 was also measuring some free calcium carbonate as exchangeable calcium in these mostly highly calcareous soils. In samples with no to slight free calcium carbonate, there was much less difference between the two test methods. The laboratory is now implementing a pre-screening process so that samples with free calcium carbonate are tested using a suitable method.

Free calcium carbonate was also retested for all deep soil samples, but with no significant difference from previous results in the vast majority of cases.

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Appendix 1 Maps

Appendix 1.1 Rose-Thomas Subcatchment (Wynarka)

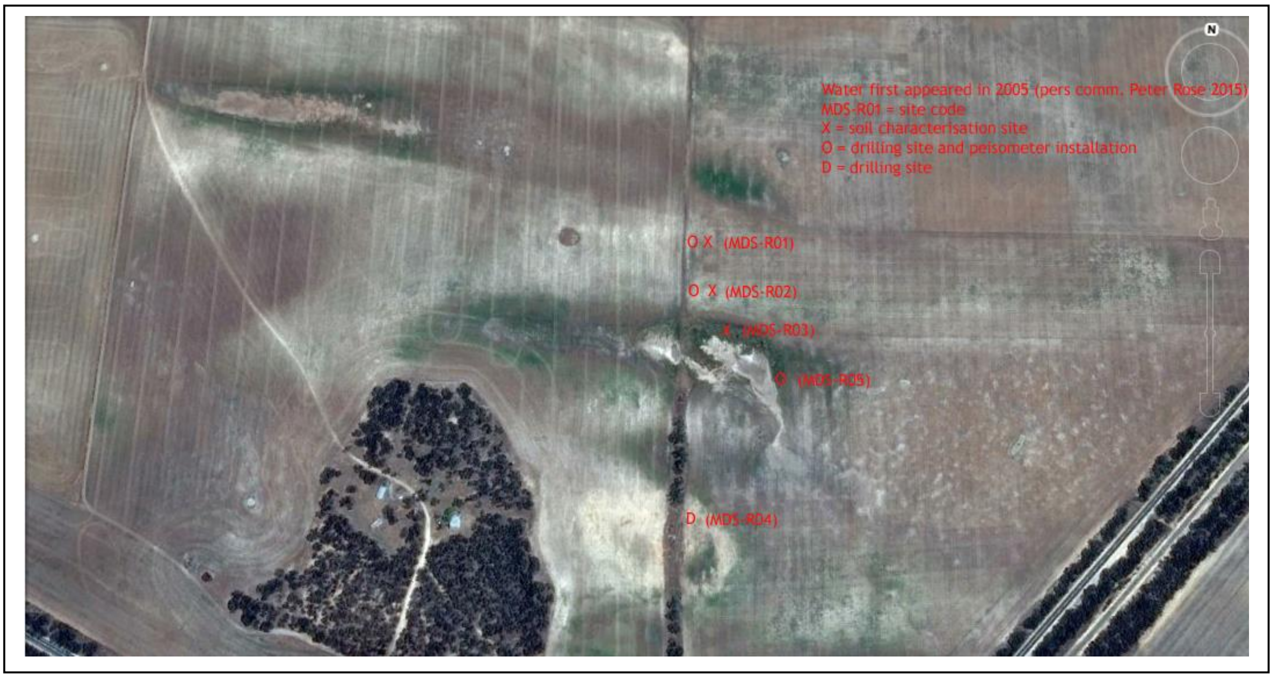

Figure 5 Rose-Thomas subcatchment at Wynarka (Kulde) in the South Australian Murray Mallee: showing sites investigated via soil characterisation (marked with an 'X') and drilling (marked with a 'D', or an 'O' where a piesometer or monitoring well has been installed). A 2013 aerial image is used as background. [Annotation Juliet Creek Consulting | imagery Google Earth]

Appendix 1.2 Bond Subcatchment (Mannum East)

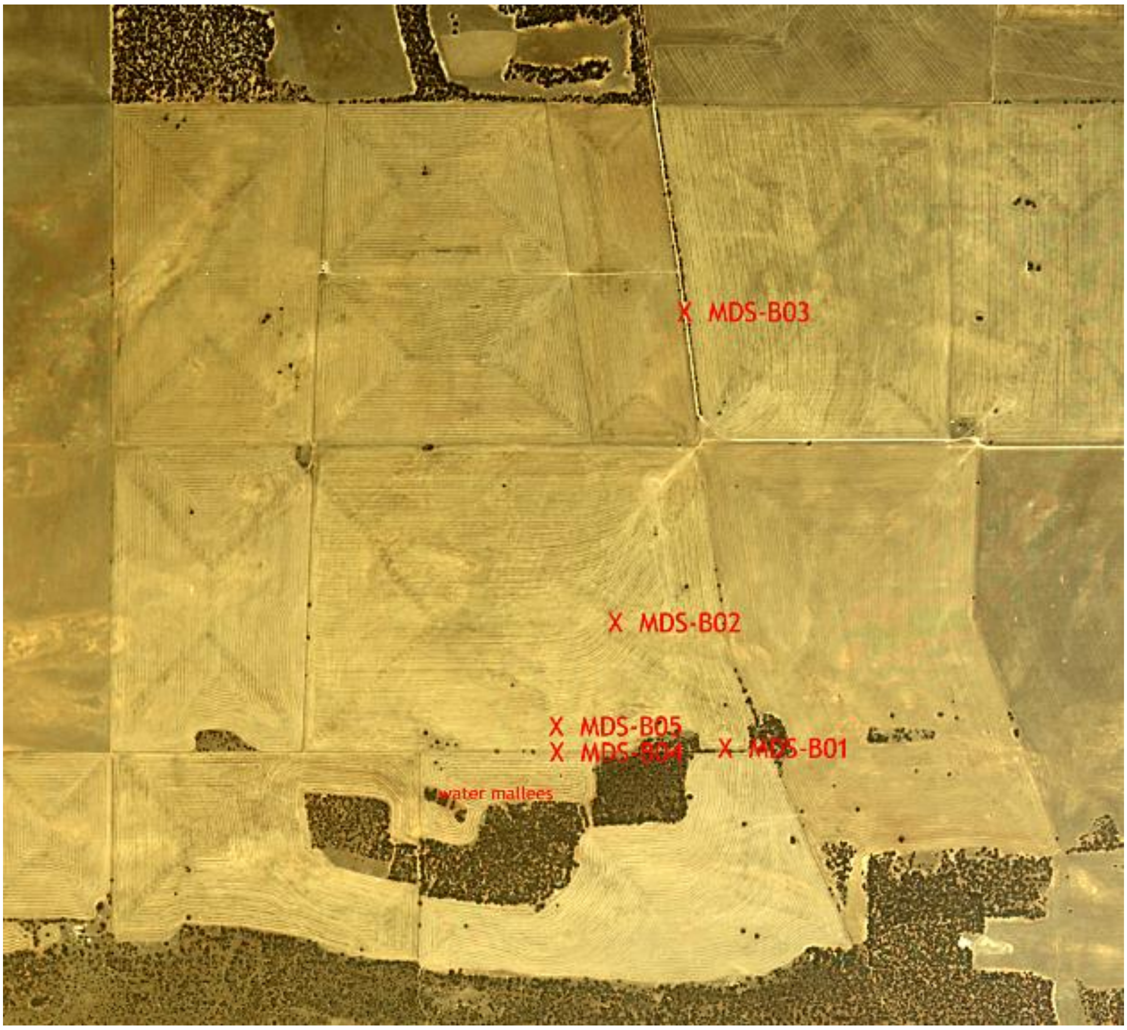

Figure 6 Bond Subcatchment at Mannum East in the South Australian Murray Mallee: showing sites investigated via soil characterisation and drilling. A 2001 aerial photograph is used as background. [Annotation Juliet Creek Consulting | imagery Mapland]

Appendix 1.3 Pope Subcatchment (Karoonda)

Figure 7 Pope subcatchment near Karoonda in the South Australian Murray Mallee showing approximate locations of soil characterisation sites (in blue – see Hall 2016) together with drilling and well establishment sites (in green). Sites P05, P06 and P07 are situated within 'Paddock A', with drainage from P05 toward P07 and the main farm seep; while sites P08 and P09 are situated within 'Paddock B', with drainage from P08 to P09. A 2001 aerial photograph merged with a 2013 photo is shown as background. Seeps show as bare or darker areas in the landscape. [Annotation Juliet Creek Consulting | imagery Mapland and Google Earth]

Appendix 2 Laboratory Data for Deep Soil Samples

Appendix 2.1 Rose-Thomas Subcatchment, Wynarka (Kulde)

For details of subcatchment and soil characteristics, drill site positions and geographic coordinates, as well as the physical and morphological natures of each deep sample, see Hall 2015 and Henschke 2015.

2.1.1 Site MDS-R01 (drilled and sampled 10/6/2015 | dune crest – northern | adjacent to a soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered at a depth of approximately 7 metres – there was a likely saturated layer above this in sandy clay material. Total drilling depth was 10.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH_4^+ mg/kg	N NO_3^- mg/kg	pH H_2O	pH $CaCl_2$	CO_3 %	CO_3 eff.	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	
D1	0.7	loamy sand	<1	3.2	9.9	8.3	20	-	0.52	1.8	0.07	<5	233	343	33	5.98	1.24	5.1	0.53	0.88	17.2	7.83	3.62	4.78	0.97	0.0	27.8
D2	6	sandy clay	1.2	4.6	9.4	8.3	32	-	1.2	5.1	0.09	7	177	612	251	13	0.68	4	1.68	0.35	29.6	9.88	6.30	11.61	1.75	0.0	39.3
D3	9.5*	heavy clay	1.4	3.2	9.8	8.3	10	slt	0.42	4.6	0.03	8	107	859	289	13.6	0.74	5	1.48	0.23	42.6	9.88	11.36	18.83	2.51	0.0	44.2
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk (*).
(4) Heavy clay is Blanchetown Clay Formation material.

It seems that drilling sample MDS-R01 D1 is from greater depth than 0.7 m, as chemical analyses (e.g. calcium carbonate percentage, ECe and sum of cations) indicate it is highly unlikely to be from topsoil layers. Owing to this, the laboratory sample was assessed and was found to be a highly calcareous heavy sandy clay loam, and the sample is likely to be from the highly calcareous subsoil layer between 110–165 cm (see Hall 2015).

2.1.2 Site MDS-R02 (drilled and sampled 10/6/2015 | lower dune slope – northern | adjacent to a soil characterisation site | piesometer installed –

perched watertable monitoring site)

Blanchetown clay was encountered at a depth of approximately 5 metres – there was a saturated layer above this in sandy light clay material. Total drilling depth was 6 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
D1	3.5	sandy light clay	<1	5.9	9.9	8.4	26	-	0.49	1.4	0.09	<5	167	481	29.3	10.5	0.67	4.6	0.3	0.43	17.3	7.29	4.30	4.48	1.18	0.0	26
D2	4	sandy light clay	<1	7.2	9.8	8.4	28	mod	0.57	1.6	0.07	<5	150	546	42.3	10.8	0.49	3.4	0.3	0.35	20.5	7.88	4.81	6.22	1.57	0.0	30
D3	5–6*	heavy clay	2	2.5	9.5	8.7	14	-	0.83	1.6	0.06	7	98	914	55.8	14.1	0.82	4.5	5.6	0.32	35.0	7.04	10.29	15.14	2.49	0.0	43
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk (*).
(4) Heavy clay is Blanchetown Clay Formation material.

2.1.3 **Site MDS-R04** (drilled and sampled 11/6/2015 | upper dune slope – southern | no adjacent soil characterisation site | no piesometer installed)

Blanchetown clay was encountered at a depth of approximately 4.5 metres – no saturated layer was encountered. Total drilling depth was 5.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
D1	3.5	heavy sandy loam	<1	5.9	9.8	8.6	13	mod	0.35	1.3	0.11	<5	149	266	7.9	6.3	0.18	3.4	0.56	0.11	13.3	5.74	3.73	3.04	0.82	0.0	22.8
D2	5.5*	heavy clay	2.3	2.7	7.6	6.6	0.5	mod	0.28	2.3	0.04	<5	84	453	163	3.6	0.68	13.2	0.3	0.29	27.1	1.37	11.44	13.01	1.32	0.0	47.9

Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk (*).
(4) Heavy clay is Blanchetown Clay Formation material.

2.1.4 Site MDS-R05 (drilled and sampled 11/6/2015 | seep edge | nearby corresponding soil characterisation site MDS-R03 | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered at a depth of approximately 2 metres – the whole soil profile above this was saturated. Total drilling depth was 3 metres.

Sam-ple	Depth metres approx.	Texture	N NH4+ mg/kg	N NO3- mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
D2	2.5	heavy clay	1.9	3.3	9.5	8.5	16	mod	0.95	3.3	0.06	<5	99	557	98	15.6	0.52	3.8	1.86	0.35	29.9	6.39	8.81	10.27	1.47	0.0	38.1
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk (*).
(4) Heavy clay is Blanchetown Clay Formation material.

Appendix 2.2 Bond Subcatchment, Mannum East

For details of subcatchment and soil characteristics, drill site positions and geographic coordinates, as well as the physical and morphological natures of each deep sample, see Hall 2015 and Henschke 2015.

2.2.1 Site MDS-B01 (drilled and sampled 17/6/2015 | valley/depression/flat (near seep) | adjacent to a soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 2.5–3 metres – there was a likely saturated layer above this in light medium clay material. Total drilling depth was 11 metres.

Sam-ple	Depth metres approx.	Texture	N NH4^{+} mg/kg	N NO3^{-} mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
5	2.5	light medium clay	<1	5.2	9.7	8.4	38	mod	0.71	2.8	0.1	<5	168	419	67	14.3	0.41	2.3	2.55	0.36	18.3	6.54	4.20	6.57	1.02	0.0	35.8
6	3	heavy clay	<1	2.3	9.6	8.8	2.3	mod	0.81	1.8	0.04	<5	58	467	58	15.9	0.39	2.1	0.94	0.11	23.0	2.91	7.62	10.96	1.48	0.0	47.7
10	5.5	medium clay	1.2	4.3	9.4	8.5	2.5	nil	0.86	3	0.05	<5	62	289	173	4.8	0.47	4.6	0.45	0.31	16.9	4.73	4.43	7.05	0.73	0.0	41.6
14	8.5	silty clay loam	<1	4.1	9.2	8.5	1.0	nil	0.79	6	0.04	<5	46	201	130	4.5	0.25	3	0.37	0.10	12.1	2.22	3.29	6.09	0.47	0.0	50.4
18	11*	silty clay loam	<1	3.8	9.4	8.6	1.7	nil	0.89	7.2	0.06	<5	43	217	111	4.8	0.23	3.7	0.56	0.09	13.4	3.89	3.18	7.87	0.49	0.0	43.8
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.

2.2.2 Site MDS-B02 (drilled and sampled 18/6/2015 | upper dune slope superimposed upon the lower slope of a very long hillslope | adjacent to a soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 6 metres – there was a bleached, saturated layer above this in sandy clay loam material. Total drilling depth was 6.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH4^{+} mg/kg	N NO3^{-} mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	

5	2.5	sandy clay loam	<1	1.4	9.3	8.5	10	high	0.12	0.77	0.11	<5	378	219	4.8	1.55	0.17	2.2	0.71	0.11	12.3	7.68	3.84	0.15	0.61	0.0	1.2
8	4	sandy clay loam	<1	2.3	9.7	8.7	1.9	slt	0.21	0.89	0.02	<5	140	432	5.2	5.84	0.22	2.7	0.99	0.27	8.7	3.94	2.69	1.05	0.98	0.0	12.1
11	5	sandy clay loam	<1	7.6	9.8	8.4	43	slt	0.43	1.8	0.1	<5	385	449	17.7	7.31	0.57	2.4	1.49	0.39	12.7	5.99	2.53	3.08	1.10	0.0	24.3
12	6.5*	heavy clay	1.3	2.5	9.3	8.6	5.4	-	0.9	1.6	0.06	7	83	817	95.7	19.6	1.24	2.2	1.33	0.86	23.0	3.17	7.31	10.31	2.24	0.0	44.8
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.

2.2.3 Site MDS-B03 (drilled and sampled 18/6/2015 | high-level sandy plateau | adjacent to a soil characterisation site | no piesometer installed

No Blanchetown clay was encountered. No saturated layer was encountered. Total drilling depth was 9.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
7	3.5	sandy clay loam	<1	26.7	9.8	8.6	14	high	1	7.6	0.15	<5	386	497	70	10.0	0.37	3.4	0.96	0.23	15.8	6.19	2.58	5.87	1.15	0.0	37.2
10	5	sandy loam	<1	6.7	9.6	8.4	29	high	1.2	12.7	0.2	<5	411	421	104	8.71	0.34	2.6	1.73	0.38	17.4	7.73	2.26	6.35	1.06	0.0	36.5
16	9*	medium clay	<1	1.7	9.2	8.5	31	mod	2.3	13.8	0.09	6	281	645	173	10.3	0.65	4.2	4.72	0.37	26.9	5.69	5.10	14.1	1.95	0.0	52.6
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.

Appendix 2.3 Pope Subcatchment, Karoonda

For details of subcatchment and soil characteristics, drill site positions and geographic coordinates, as well as the physical and morphological natures of each deep sample, see Hall 2016 and Hall et al. 2016.

2.3.1 Site MDS-P05 (Paddock A) (drilled and sampled 12/2/2016 | upper slope | no adjacent soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 4.4 metres – there was a bleached, moist to wet but not saturated layer above this in light sandy clay material (all indications are that this layer is seasonally saturated). Total drilling depth was 4.7 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
11	4.5–5*	medium clay	1.1	7.8	9.2	8.2	9.2	high	0.82	2.4	0.06	<5	191	721	118	9.7	0.24	1.5	0.72	0.17	22.8	5.54	5.98	8.48	1.81	0.0	37.2
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) The medium clay is Blanchetown Clay Formation material.

2.3.2 Site MDS-P06 (Paddock A) (drilled and sampled 12/2/2016 | mid slope | corresponding to nearby soil characterisation site MDS-P02 | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 4.7 metres – there was a bleached, saturated layer above this in light medium clay material. Total drilling depth was 6.2 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	

12	5	light medium clay	<1	9	10.1	8.4	55	mod	0.7	1.8	0.1	<5	428	625	17.7	11.6	0.27	2.8	1.08	0.13	15.7	6.09	1.54	6.44	1.62	0.0	41.0
13	5.5–6*	heavy clay	<1	6.8	9.5	8.7	8.9	nil	1.3	4.3	0.03	5	159	1196	210	20.7	0.61	3	0.59	0.23	27.7	4.32	5.63	15.14	2.61	0.0	54.6
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.

2.3.3 **Site MDS-P07 (Paddock A)** (drilled and sampled 12/2/2016 | on edge of seep; lower slope near upper seep edge | adjacent to soil characterisation site MDS-P01 | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 2.6 metres – there were saturated layers above this in sandy clay loam material. Total drilling depth was 3.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH_4^+ mg/kg	N NO_3^- mg/kg	pH H2O	pH CaCl2	CO3 %	CO3 eff.	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	
2	0.5	loamy sand	<1	10.4	9.7	8.9	1.1	nil	0.4	4.2	0.08	6	12.5	84	20.3	2.8	0.13	4.2	0.31	0.23	3.7	0.85	0.56	2.11	0.15	0.0	57.0
5	2	sandy clay loam	<1	2.8	9.7	8.4	27	high	0.7	5.5	0.11	<5	226	299	32.2	6.2	0.27	6.3	0.99	0.22	15.1	7.34	3.05	3.95	0.77	0.0	26.1
7	3– 3.5*	heavy clay	1.1	1.1	9.3	8.6	4.7	nil	0.9	1.5	0.09	5	73	578	40.4	2.8	0.99	10.8	0.93	0.26	25.5	3.96	9.79	9.92	1.79	0.0	38.9
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.

2.3.4 Site MDS-P08 (Paddock B) (drilled and sampled 15/2/2016 | sand dune crest superimposed on upper slope | no adjacent soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 7 metres – there was a bleached, saturated layer above this in sandy light clay material. Total drilling depth was 7.5 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
9	3.5	sandy clay loam	<1	1.9	9.3	8.4	7.6	high	0.13	0.67	0.06	<5	311	293	6.4	1.9	0.17	3.6	0.8	0.12	13.1	8.18	3.82	0.38	0.74	0.0	2.9
10	4	sandy clay loam	<1	2.5	9.6	8.6	13	high	0.69	1	0.05	<5	176	692	29.7	12	0.45	3.7	0.43	0.15	21.3	5.44	6.42	7.61	1.86	0.0	35.7
15	7–7.5*	heavy clay	<1	4.5	9.9	8.4	25	-	0.53	0.88	0.04	<5	387	591	9.7	11.6	0.19	3.9	0.66	0.09	16.3	5.59	4.09	5.05	1.53	0.0	31.0
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.

2.3.5 Site MDS-P09 (Paddock B) (drilled and sampled 15/2/2016 | within seep; lower slope near edge of a large seep in a swale area | no adjacent soil characterisation site | piesometer installed – perched watertable monitoring site)

Blanchetown clay was encountered from approximately 2 metres – there were saturated layers above this in sandy clay loam material. Total drilling depth was 2.4 metres.

Sam-ple	Depth metres approx.	Texture	N NH4$^+$ mg/kg	N NO3$^-$ mg/kg	pH H2O	pH CaCl 2	CO3 %	CO3 eff.	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	
4	1.5–2	sandy clay loam	<1	5.2	9.7	8.4	48	high	0.38	1.8	0.13	<5	152	240	19	6.2	0.55	3.4	1.53	0.41	16.0	7.53	4.82	3.04	0.54	0.0	19.1

5	2–2.4*	heavy clay	<1	4.4	9.7	8.5	23	slt	0.67	1.1	0.07	<5	115	357	31.8	13.3	0.49	4	1.99	0.27	23.4	5.99	7.82	8.39	1.15	0.0	35.9
Approx. Critical/Ideal Values			-	-	6–8	5.5–7.5	0	nil	<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.
(3) All depths are approximate, except those marked with an asterisk.
(4) Heavy clay is Blanchetown Clay Formation material.