Soils of the Audalia Medcalf area

Investigations into the soils on which *Marianthus aquilonaris*, *Eucalyptus rhomboidea* and *Stenanthemum bremerense* grow - for use in defining critical habitats

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Summary

Soil investigations were conducted in April and August 2019 within and around the Medcalf Project mining tenement (M63/656) to determine the range of soil types on which *Marianthus aquilonaris* (MA), *Eucalyptus rhomboidea* (ER) and *Stenanthemum bremerense* (SB) grow. Seventy four soil profiles located both within and outside populations of MA, ER and SB were described and samples were taken from representative soil horizons for laboratory analysis.

Five main soil groups were identified:

1. Alkaline red shallow loamy duplex
2. Loamy gravel
3. Shallow gravel over indurated mottled zone
4. Stony soils
5. Shallow gravel

A large number of soil observation sites were dug within and surrounding the populations of MA that had been mapped by Botanica Consulting. The soil survey showed that MA grows on gravelly, shallow loamy soils with an indurated, mottled zone layer that occurs within 30 cm of the soil surface ('Shallow gravel over indurated mottled zone' soil). These soils are almost always located on a low ridge that typically have outcrops of limonite. The soil pH is acidic. The soils in the areas that surround these ridges of shallow soils are quite different. They are deeper colluvial soils, do not contain outcrops of limonite and typically have a neutral or alkaline pH. The 'Shallow gravel over indurated mottled zone' soil is a very minor soil type in the district.

Areas of 'Shallow gravel over indurated mottled zone' soil were mapped. The MA populations that were mapped independently by Botanica Consulting occur within this soil map unit. Areas of 'Shallow gravel over indurated mottled zone' soil were found in areas away from the MA populations. The map of the 'Shallow gravel over indurated mottled zone' soils may assist in determining the boundaries of the critical habitat for MA.

The soils on which *Eucalyptus rhomboidea* was growing were examined and described at twenty one sites. This species grows on a range of soil groups at a range of positions in the landscape. This species was found growing on 'Alkaline red shallow loamy duplex' soils that occur on the lower, mid and upper slopes. It was found growing on 'Loamy gravel' soils on the lateritic plateau at the top of the landscape and on the mid slopes. It was also found growing on 'Shallow gravel' soils, below a breakaway. The 'Alkaline red shallow loamy duplex' and 'Loamy duplex' soils are common soil groups in the district.

The soils on which *Stenanthemum bremerense* was growing were examined and described at twenty sites. All sites contained a high percentage of ironstone gravels and were classified as the 'Loamy gravel' soil group. SB was found on the lateritic plateau at the top of the landscape and

on areas of gravelly rises on the mid to lower slopes. The 'Loamy gravel' soil is a common soil group in the district

Aim

Soil information is required to support the Environmental Impact Assessment for the proposed Medcalf Project. In particular, soil data is required to assist with defining the habitat of *Marianthus aquilonaris* (MA), *Eucalyptus rhomboidea* (ER) and *Stenanthemum bremerense* (SB).

The four aims of this study are to:

1. Describe the major soil types that occur in the Medcalf Project tenement area.
2. Determine and describe the soil types on which MA, ER and SB grow.
3. Accurately map the extent of the 'Shallow gravel over indurated mottled zone' soils that are associated with the MA populations.
4. Survey readily accessible areas of the tenement and adjacent regional land for other areas of 'Shallow gravel over indurated mottled zone.' Map these areas.

Method

Defining the properties of the soils on which MA, ER and SB grow

The soils, landform type and vegetation were described at seventy four sites that were located within and adjacent to the populations of MA, ER and SB.

The GPS coordinates from the Botanica Consulting vegetation survey were used to locate populations of the three species. A subset of these coordinates was selected for conducting the soil descriptions. Sites were chosen to sample the full range of soils present across all populations and landscape types.

A spade, pick and hand auger were used to excavate the soil (rather than a backhoe) to prevent damage to the vegetation.

Soil parameters that were described at each site included; the depth of each soil horizon, soil texture (hand assessment), soil structure, colour, percentage of coarse fragments including gravel (field sieving), field pH and electrical conductivity. The soil profiles were described using the terminology of McDonald et al (1990). Soil colours were described according to standard Munsell colour chart notation. Estimates of plant available water of representative sites were calculated based on soil texture, percentage of coarse fragments and estimated rooting depth.

Eighty one soil samples of the different soil horizons from 38 sites that represented the range of soil groups encountered in the soil survey were sent to the Chem Centre for physical and chemical analysis. These samples were analysed for:

- Percentage of stones
- pH_{water}
- pH_{CaCl}
- EC

A sub set of samples from each soil group were submitted to a more comprehensive suite of analysis which is listed below:

- ESP
- BSP
- Ca, K, Mg and Na
- CEC
- Organic carbon
- N
- % of clay, silt and sand
- Mehlich suite (Al, P, K, Ca, Na, Mg, B, S, Cu, Fe, Mn, Mo, Cd, Ni, Pb, Zn, Se)

Mapping areas of 'Shallow gravel over indurated mottled zone' soils on which the populations of MA occur

East west lines at intervals of 30 metres were drawn on aerial photographs over areas within and adjacent to the MA populations. Initially the soil surveyor walked along these transects digging holes until the boundary of the 'Shallow gravel over indurated mottled zone' soil was identified. It was found that it was quicker and of similar accuracy for the soil surveyor to map the boundary on the 'Shallow gravel over indurated mottled zone' soil by using the presence of outcrops of mottled zone (limonite), so this approach was used instead. Way points were entered into the GPS at distances of approximately 20 metres as the surveyor walked around the areas of 'Shallow gravel over indurated mottled zone' soils. The boundaries were checked against the soil profile descriptions, and by digging observation sites to confirm the soil type.

Mapping of other areas of 'Shallow gravel over indurated mottled zone' in and adjacent to the tenement area on which no MA has been found

Access to much of the tenement area is limited due to the lack of tracks and the long distances that have to be covered by walking through bushland. There are four roads that radiate from the camp (SE road, SW road, NE road and NW road). The soil surveyors searched on foot for approximately 250 metres on either side of these roads looking for outcrops of limonite that indicate the presence of the 'Shallow gravel over indurated mottled zone' soil. When areas of 'Shallow gravel over indurated mottled zone' soils were found the soil surveyors used a GPS to mark way points around the soil boundary.

Because of difficulties with access only a small percentage of the area in and around the tenement was searched for the presence of the 'Shallow gravel over indurated mottled zone' soil.

Background information

Existing broadscale soil mapping

The following link shows soils and landform information that is available for Western Australia on the DPIRD website. https://www.agric.wa.gov.au/resource-assessment/nrinfo-western-australia

The only information that is available for the Lake Metcalf area is the Atlas of Australian Soils mapping that was completed at the very broad scale (1:3000000). The whole of the Audalia tenement area is shown as one soil/landscape unit (266DD13) with the major WA soil groups being listed as 'Calcareous loamy earths', 'Red deep loamy duplex', 'Red shallow loamy duplex' and 'Loamy gravel'.

This information is of too broad a nature to be of use in identifying the soils that the three plant species (MA, ER and SB) grow on.

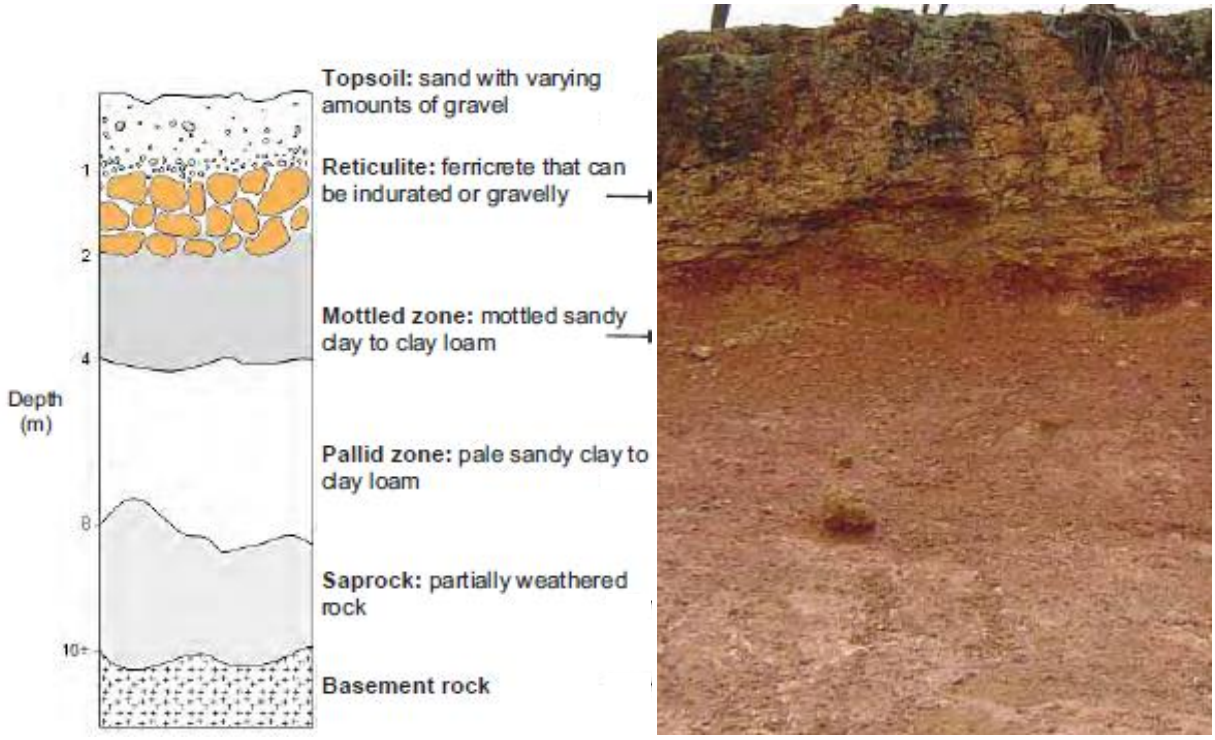
Geology and physiography

The Medcalf deposit is located on the Lake Johnston Greenstone Belt area. The Medcalf layered sill, which is comprised of gabbro, pyroxenite and amphibolite has intruded into the enclosing basalt.

The upper surface of these rocks has undergone laterization. The lateritic profile can be seen at the top of the landscape at Medcalf. It consists of a gravelly sandy loam overlying ferricrete (duricrust) and lateritic boulders. Beneath the ferricrete layer is the mottled zone, which in turn overlies saprolite and then sap rock.

Figure 1 shows a diagram of a typical lateritic profile (left) and a photograph of the ferricrete layer and underlying mottled zone (right). The parent material at Medcalf is mafic rock which results in a darker red, more loamy topsoil than indicated in the diagram in Figure 1, and the pallid zone was absent or not seen.

Figure 1. Typical lateritic profile in the south west of Western Australia (from Moore, 2011 (left) and Sawkins, 2011 (right)).



The lateritic material and the underlying mafic rock provide the parent material for the soils at the Medcalf site. The extent of dissection of the lateritic profile has a large influence on what soils are formed. Different soils develop in different parts of the landscape. Soil types follow a sequence down the slope (catena) with:

- Gravelly lateritic soils developing over ferricrete or ironstone boulders at the top of the landscape.
- Below the breakaway face shallow gravelly soils develop over the mottled zone.
- Where the underlying mafic rocks have been exposed on the upper and mid slopes these rocks generally weather to form loam over clay (duplex) soils.
- Deeper loamy surfaced duplex soils develop as a result of colluvial movement on the mid and lower slopes.
- Salt lakes occur at the bottom of the landscape.

Results

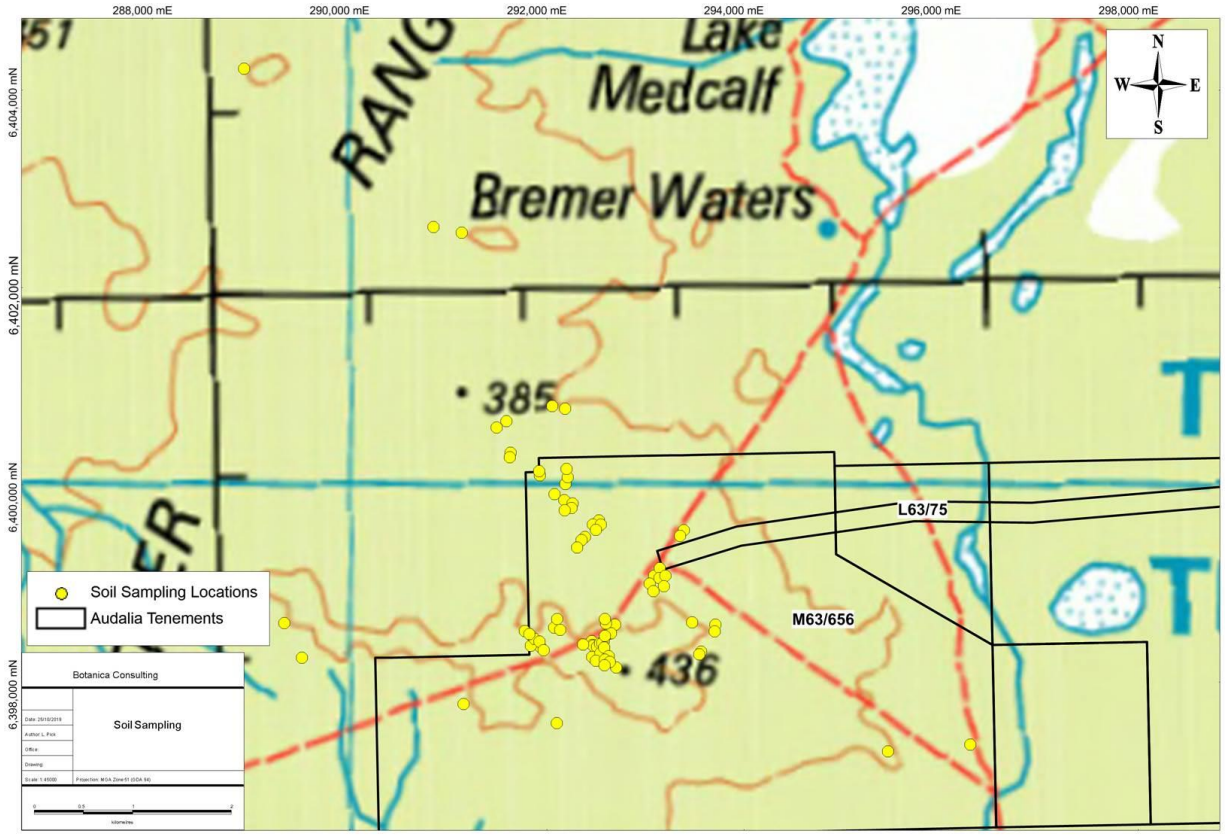
Soil descriptions

Seventy four soil profiles were sampled and described in and adjacent to the MA, ER and SB populations. The location of the soil profiles is shown in Figure 2. Additional observations sites of the surface soil texture and vegetation type were also made at locations outside of the Medcalf mining tenement to gain an understanding of the regional distribution of the soils.

The soils at these sites can be classified into five soil groups:

1. Alkaline red shallow loamy duplex
2. Loamy gravel
3. Shallow gravel over indurated mottled zone
4. Stony soils
5. Shallow gravel

Figure 2. Location of the soil profile description sites and the Medcalf mining tenement.



Alkaline red shallow loamy duplex

Location and position in the landscape

This is a major soil group within the Medcalf mining tenement and surrounding areas. In the sequence of soils in the landscape (catena) this soil group occurs below the gravelly lateritic plateau and extends towards the valley floor. It can be found on the upper, mid and lower slopes.

The soil surface usually contains a scree of dark lateritic gravels, particularly on the upper slopes where they may cover up to 70 % of the soils surface. Outcropping of mafic rocks is not common but can occur particularly on the upper slopes where the depth to bedrock is often shallower.

Soil description

This soil group contains a range of red coloured, loamy duplex soils with the soil properties at each site being influenced by the geology of the parent material and position in the landscape.

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown sandy loam. A dark reddish brown or dark red clay sub soil generally occurs within 40 cm. In some examples of this soil there is an intermediate sandy clay loam layer between the topsoil and the clay.

The soil has a moderate, sub angular blocky structure.

The soil profile contains between 0 and 60 % dark angular ironstone gravel and rocks. In some profiles, fragments of the underlying mafic rocks are found in the subsoil. When these soils occur on the mid and lower slopes they generally contain less rock.

The topsoils have a neutral to alkaline pH (pH_{water} = 7 to 8.5). The subsoil is alkaline (pH_{water} = 8.5 to 9) and often contains lime nodules.

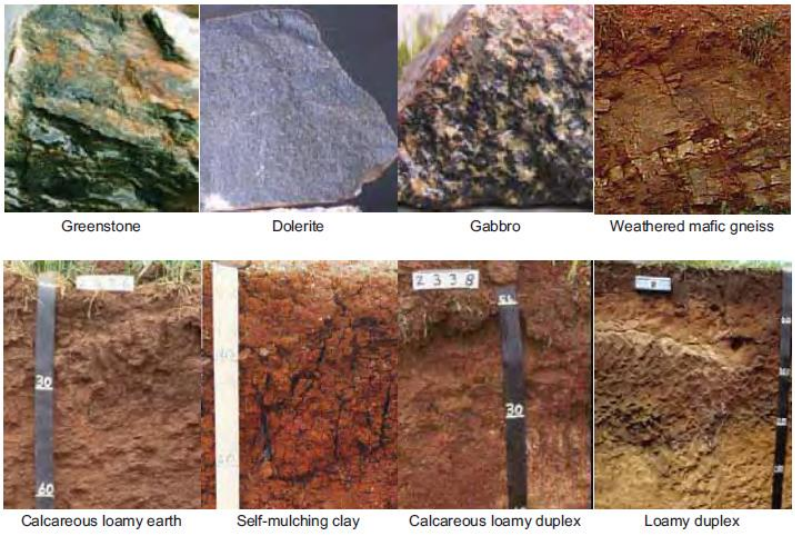
The salinity of this soil is generally low. However, the sub soil can be saline, particularly on sites that are located lower in the landscape.

Areas of similar soil with a greater depth to the clay subsoil (‘Alkaline red deep loamy duplex’) and similar soils with a more brown or grey colour or with a deeper loamy topsoil (‘Calcareous loamy earths’) can also be found. These soils are less common than the ‘Alkaline red shallow loamy duplex’ and all have similar chemical and physical properties so they have not been separated in this study.

Plant growth considerations

Plant roots can grow deep into the subsoil as this soil has no impeding layers and is moderately well structured. The water holding capacity of this soil is high due to the loamy to clay textures. The plant available water in the effective root zone of this soil group is high, however on examples of this soil with a high percentage of gravels, the water holding capacity is reduced.

Figure 3. Photographs of an 'Alkaline red shallow loamy duplex' soil at Medcalf showing roots of the native Eucalyptus species growing into the clay subsoil (left and below). Photographs showing a range of soils formed from different mafic rocks (right from Sawkins, 2011)



2. Loamy gravel

Location and position in the landscape

This is a major soil group within the Medcalf mining tenement and surrounding areas and it is found at many positions in the landscape. It occurs on the lateritic plateau at the top of the landscape, and on the upper, mid and lower slopes.

The soil surface contains a scree of dark lateritic gravels and they may cover up to 70 % of the soils surface. Ironstone rocks often occur on the soil surface, particularly on the upper slopes.

Soil description

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown, gravelly loamy sand to sandy loam. This surface horizon grades into a dark reddish brown sandy loam to sandy clay loam which extends to depths of greater than 50 to 80 cm. The percentage of gravels generally increases from about 20 to 50 % in the topsoil to over 60 % in the subsoil. A clay layer may be encountered at depth.

The pH throughout the soil profile is close to neutral (pH_{water} = 6.5 to 7.5).

This soil is not saline.

Plant growth considerations

This soil has no impeding layers that limit root growth. The water holding capacity of this soil is reduced by the high percentage of gravels. The plant available water in the effective root zone of this soil group is moderate.

Figure 4. A photograph of a 'Loamy gravel' soil at Medcalf.

3. Shallow gravel over indurated mottled zone

The soil investigation showed that MA grows only on this soil type. 'Soil groups of Western Australia: a simple guide to the main soil groups of Western Australia' Schoknecht and Pathan (2013) contains a general soil group called 'Shallow gravel'. As the soil requirements of MA are so specific it was necessary in this study to subdivide this soil group and create a separate soil type for those soils that contain shallow indurated mottled zone in the sub soil.

The mottled zone in these soils has been hardened by the addition of iron and it is referred to by geologists as limonite. Limonite is an iron ore consisting of a mixture of hydrated iron (III) oxide-hydroxides. The limonite at Medcalf is believed to have formed from weathered basalt. In this report I refer to the soil layer as the 'indurated mottled zone'.

Figure 5. A photograph of the surface of this soil group showing the high percentage of limonite rock on the surface (left) and the shallow depth to the indurated mottled zone (right).

Location and position in the landscape

This soil is a minor soil group within and on the land surrounding the Medcalf mining tenement area. It occurs on the upper slopes below the lateritic plateau. It is usually found on ridges that are often only one to two metres higher than the surrounding area. It can occur on spurs that lead down from the lateritic plateau.

Figure 6. A photograph showing MA vegetation in the foreground growing on a rocky ridge of 'Shallow gravel over shallow mottled zone' soil, and in the background Eucalyptus species growing on the deeper soil that occurs off the ridge.

Between 70 and 90 % of the soil surface is covered with a scree of dark lateritic gravels and fragments of limonite rock. Limonite outcrops are common and in areas may compose up to 50 % of the soils surface.

This soil group can contain areas where water erosion has removed some of the topsoil to expose the underlying indurated mottled zone. The impermeable subsoil and limited plant growth make this soil more prone to erosion by water.

Soil description

The topsoil is generally about 10 to 15 cm thick and is a dark reddish brown sandy loam. In most examples the dense, indurated mottled zone occurs directly below the topsoil (at less than 15 cm deep). In some cases, a sandy clay loam subsoil layer can occur below the topsoil, with the indurated mottled zone occurring at depths of no greater than 30 cm.

The soil contains between 10 and 50 % dark angular ironstone gravel.

Topsoils and subsoils are generally acidic, with a pH_{water} between 4.5 and 7.

The salinity of this soil is generally low.

Figure 7. A photograph of a 'Shallow gravel over indurated mottled zone' soil at Medcalf showing the shallow loamy topsoil and an indurated mottled zone occurring at 15 cm deep. The pick had difficulty penetrating the indurated mottled zone.

Plant growth considerations

No plant roots were seen penetrating the indurated mottled zone. This layer appears to be continuous, which is quite different to the 'Shallow gravel' soil group where ironstone rocks and boulders are found within a soil matrix.

The effective rooting depth of plants is likely to be limited to the soil above the indurated mottled zone. The plant available water in the effective root zone of this soil group is likely to be very low. The acidity of the soil may limit the growth of some species.

Figure 8. A photograph of a track showing the continuous nature of the mottled zone that occurs below the topsoil. *E. livida* which grows on this soil can be seen in the background.

4. Stony soils

Location and position in the landscape

This is a minor soil group within the Audalia tenement that is found in association with outcrops of mafic rocks. It usually occurs higher in the landscape.

The soil surface contains rocks that may cover up to 90 % of the soils surface. The bedrock may outcrop in places.

Soil description

The topsoil is generally about 10 to 25 cm thick and is a dark reddish brown, rocky loamy sand to sandy loam. The percentage of gravels and rocks in the topsoil can be as high as 90%. This topsoil overlays bedrock.

The pH is close to neutral (pH_{water} = 7 to 7.5).

This soil is not saline.

Plant growth considerations

The water holding capacity of this soil is greatly reduced by the very high percentage of gravels and rocks. However, plant roots can explore the soil matrix between the rocks in the subsoil. The plant available water in the effective root zone of this soil group is low.

Figure 9. A photograph of a 'Stony soil' at Medcalf.

5. Shallow gravel

Location and position in the landscape

This is a minor soil group within the Audalia tenement. This soil is often found at the top of the landscape adjacent to the breakaway face.

The soil surface contains a scree of dark lateritic gravels and rocks that may cover up to 90 % of the soils surface. Ironstone cap rock (ferricrete) may outcrop in places.

Soil description

The topsoil is generally about 10 to 25 cm thick and is a dark reddish brown, gravelly loamy sand to sandy loam. The percentage of gravels and rocks in the soil can be as high as 90%. This topsoil overlays ironstone boulders or lateritic cap rock.

The pH is close to neutral (pH_{water} = 7 to 7.5).

This soil is not saline.

Plant growth considerations

The water holding capacity of this soil is greatly reduced by the very high percentage of gravels and rocks. However, plant roots can explore the soil matrix between the ironstone rocks in the subsoil. The plant available water in the effective root zone of this soil group is low.

Figure 10. A photograph of a 'Shallow gravel' soil at Medcalf.

Laboratory analysis

The results of the laboratory analysis are shown in Attachments 1 and 2.

Summary of significant results

Percentage of stones (> 2mm)

All the soils generally contained a high percentage of stones in the topsoil (between 20 and 50 %), with some soils containing up to 80 % stones. The clayey subsoil layers typically contained less than 25 % stones.

pH

The 'Alkaline red shallow loamy duplex' typically had neutral soil pH's in the topsoil and were strongly alkaline in the subsoil with the pH_{water} ranging from 8.0 to 9.3.

The 'Loamy gravel' and 'Shallow gravel' soils had pH's that were close to neutral throughout the soil profile (the pH_{water} ranged from 6.3 to 7.6).

The 'Shallow gravel over indurated lateritic zone' soil had an acidic to neutral pH (the pH_{water} of this soil ranged from 4.0 to 6.9).

Electrical conductivity

Electrical conductivity is a measure of the salinity of the soil. The laboratory analysis showed that a number of the sites contained soil that had a high salinity.

The sub soils of 'Alkaline red loamy shallow duplex' soils which were located lower in the landscape often had elevated salinities (100 to >300 mS/m). It is likely at these locations that the regional saline groundwater table was influencing the salinity of the subsoil.

One 'Shallow gravel over indurated lateritic zone' soil (Site 16) had an elevated salinity (230 mS/m) in the topsoil. This site was located immediately below a small breakaway and the area was bare of vegetation.

Percentage of clay, silt and sand

The particle size analysis conducted by the laboratory (shown in Attachments 1 and 2) agreed well with the hand textures described in the field during the soil survey (see Appendix 1). The topsoil of all soil groups contained a similar percentage of each particle size fraction and generally had a sandy loam texture.

Organic carbon

The topsoil of all soil groups contained moderate to high levels of organic carbon (1.2 to 2.8 %).

Exchangeable sodium percentage (ESP)

Sodic soils are prone to dispersion which can reduce water infiltration and root penetration. A soil with an ESP of greater than 6 is regarded as sodic and if the ESP is greater than 15 is regarded as strongly sodic.

None of the topsoils of the soils that were analysed were sodic. However, all of the sub soils were sodic or strongly sodic. The two samples of indurated mottled zone (sample 10 C and sample R) were sodic or strongly sodic.

Composition of the indurated mottled zone (limonite)

A sample of the indurated mottled zone which occurs in the subsoil of the 'Shallow gravel over indurated mottled zone' soil was analyzed for its composition. The results are shown in Table 1.

Table 1. Composition of the indurated mottled zone (limonite)

Composition	Percentage
SiO_2	45
Fe_2O_3	17
Al_2O_3	12
CaO	11
MgO	7
TiO_2	3
Na_2O	1.8
K_2O	1.1

Soil and vegetation relationships

In the south of Western Australia there is often a close relationship between the soil type and the native vegetation. Farmers use vegetation as a method of describing soil types, for example, Salmon gum clay, York gum/Jam loams, Morrel loams and Banksia sands. Soil types (and vegetation) vary over short distances and often there is an intergrade of soils (and vegetation) at the margins.

Many species grow on a range of different soil types, but some species grow only on a specific soil type and are good 'indicator species' for that soil type. The information in this section demonstrates that there is a very good correlation between soil type and the presence of MA and SB. On the other hand, ER grows three soil groups that occur at three locations in the landscape.

Appendix 1 gives a summary of soil, landform and vegetation descriptions at the 74 sites.

Moisture holding characteristics

The moisture holding capacity of a soil depends on soil depth, soil texture and the percentage of inert material such as gravel. Deep, well-structured soils allow roots to access water at greater depths in the soil profile. Loams hold more water than sands. Gravels do not hold moisture and a high percentage of this material will limit the soils water holding capacity.

Table 2 gives estimates of plant available water stored over the depth of the effective root zone for a typical example of each soil group. The figures are derived from a soil moisture calculating spreadsheet developed by Department of Primary Industries and Regional Development staff.

It can be seen that the 'Alkaline red shallow loamy duplex' has the highest plant available water within the root zone while the 'Shallow gravel over indurated mottled zone' has a very low plant available water.

Table 2. The estimated effective rooting depth and plant available water for typical examples of the five soil groups.

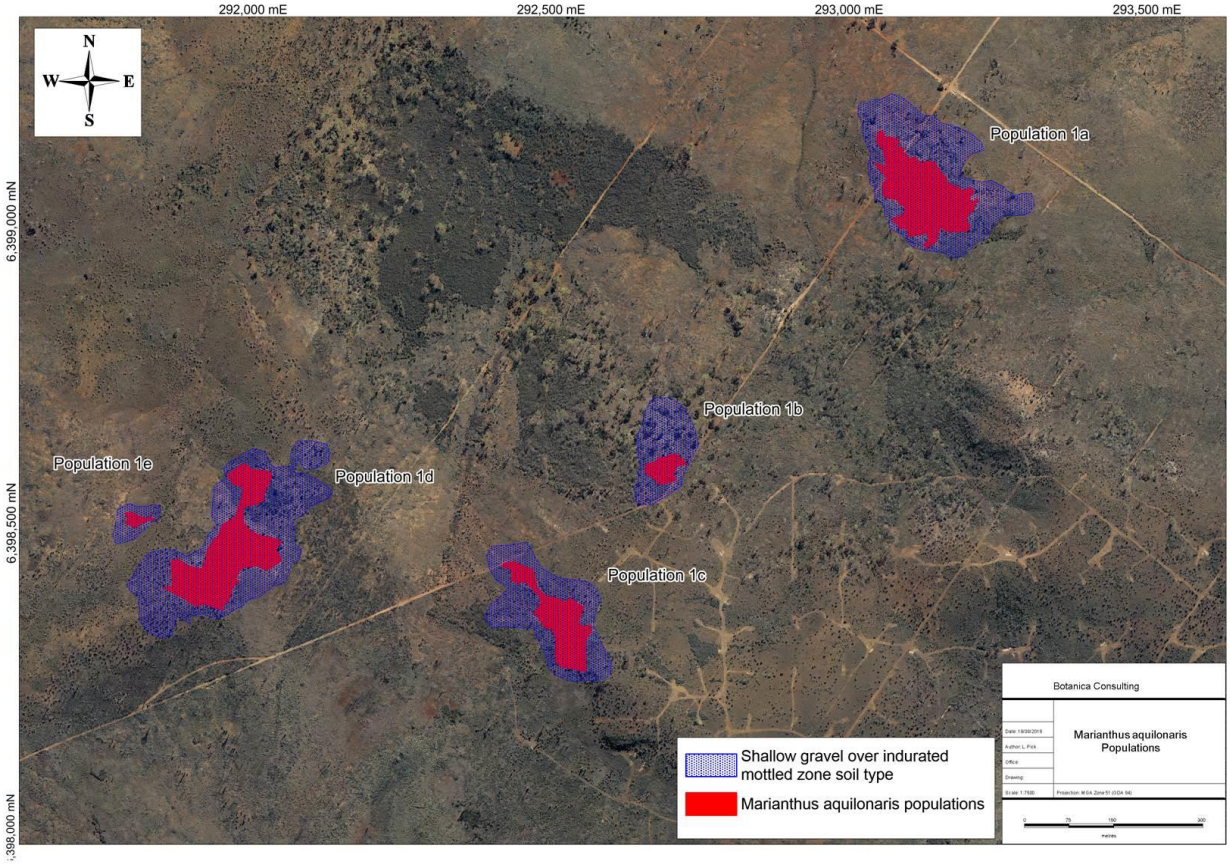
Soil group	Estimated effective rooting depth (cm)	Plant available water (mm)
'Alkaline red shallow loamy duplex'	100	80
'Loamy gravel'	100	40
'Shallow gravel over indurated mottled zone'	15	6
'Shallow gravel'	30	10
'Stony soils'	30	10

Marianthus aquilonaris (MA)

MA grows on the 'Shallow gravel over indurated mottled zone' soils. Of the 18 sites that were described adjacent to MA populations, 17 of these were 'Shallow gravel over indurated mottled zone' soils and one location had a soil type that was borderline in being classified as this soil.

The areas of the MA populations are superimposed on top of the map of the 'Shallow gravel over indurated mottled zone' soil in Figure 11. It can be seen that MA was only found on this 'Shallow gravel over indurated mottled zone' soil type.

Figure 11. Areas of 'Shallow gravel over indurated mottled zone' soils and the MA populations as mapped by Botanica Consulting



Appendix 1 shows that depth to the indurated mottled zone, presence of limonite outcrop and low soil pH are very well correlated with the presence of MA.

The soil survey indicated that MA does not grow on other shallow soils that contain subsoil layers of lateritic duricrust (ferricrete) or decomposing mafic rocks.

The indurated mottled zone appears to be continuous, with no cracks (Figure 8) and plant roots may not be able to penetrate this layer. On areas of 'Shallow gravel' soils that have ferricrete in

the subsoil, and on soils with decomposing igneous rock in the subsoil there are usually gaps between the rocks which contain soil into which plant roots can grow.

At the Medcalf mining tenement, the only place in the landscape where water holes were found was on soils with an indurated mottled zone, indicating that this layer is probably quite impermeable. However, the presence of water pools was rare and the excavated soil profiles did not show subsoil moisture above the indurated mottled zone. It is likely that following rainfall water flows sideways off these ridges along the top of the shallow indurated mottled zone and into the deeper soils on the margins of this soil type. This is supported by the evidence of water erosion in some areas.

There was no difference in the soil properties between the different MA populations (Populations 1a, 1b, 1c, 1d and 1e).

Plants, such as MA, which grow on the 'Shallow gravel over indurated mottled zone' soils must be well adapted to long periods of low water availability. MA does not grow in the areas of deeper soils that have a higher water holding capacity, possibly because it is outcompeted by other species.

There is a strong relationship between soil pH and the presence of MA. Appendix 1 shows the field pH measurements and Attachment 1 shows the pH of the soil samples submitted to the laboratory. The pH_{CaCl} of the 'Shallow gravel over indurated lateritic zone' is acid (pH_{CaCl} = 3.8 to 6.3). Many of these soils had a pH_{CaCl} of less than 4.5.

The pH of the soil affects the availability of nutrients. Phosphorus, molybdenum, magnesium and calcium become less available to plants at a low soil pH. Aluminum and manganese may reach levels that become toxic to plants. Aluminum concentrations increase rapidly and become toxic for most crop and pasture species at a soil pH_{CaCl} of less than 4.5.

It is possible that the low soil pH of the 'Shallow gravel over indurated mottled zone' is a determinant of what species grows on the soil. MA is obviously tolerant of low soil pH. The tolerance of native species to aluminum toxicity has not been well researched.

Microbial activity in the soil is affected by soil pH with most activity occurring in soils with a pH of 5 to 7.

The areas of 'Alkaline red shallow loamy duplex' soils and 'Loamy gravels' that surround the MA populations have very different soil characteristics.

Factors other than soil type (such as pollinator species, surface drainage and aspect) may determine the critical habitat. However, in this case it appears that soil, and in particular the presence of a shallow indurated mottled zone layer, is a dominant consideration.

Eucalyptus rhomboidea (ER)

ER was found growing on three soil groups. The largest population of ER is on the 'Alkaline Red Shallow Loamy Duplex' soils. These soils can be found on the lower slopes near the creek lines and on the mid and upper slopes. ER was also found on the plateau surface growing on the 'Loamy Gravels' and just below the breakaway face growing on the 'Shallow gravels'. The 'Alkaline Red Shallow Loamy Duplex' and 'Loamy Gravels' are common soil groups in the district.

All 27 soil profiles that were excavated at ER populations occurred on these three soil groups.

Figure 12. A photograph of *E. rhomboidea* growing with other eucalyptus species on an 'Alkaline red shallow loamy duplex' adjacent to a creek line on the lower slope

Stenanthemum bremerense (SB)

SB grows on 'Loamy gravels'. All the 26 sites that were dug adjacent to the SB plants were located on 'Loamy gravels'. The 'Loamy gravel' soil is a common soil group in the district.

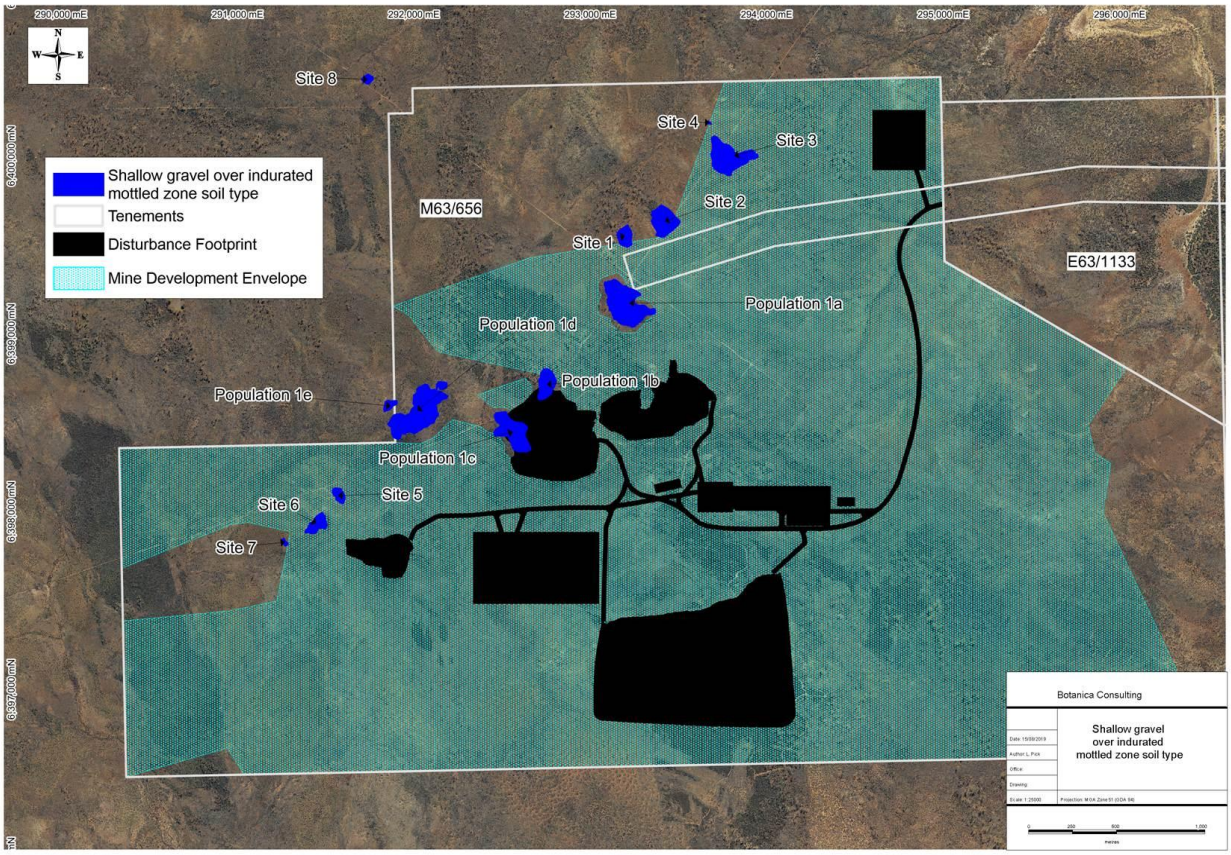
Figure 13. *Stenanthemum bremerense* growing on a deep 'Loamy gravel'

Mapping areas of the ‘Shallow gravel over indurated mottled zone’ soil

A map of areas of the ‘Shallow gravel over indurated mottled zone’ soil was produced (Figure 14). The areas of this soil type that contained MA populations were accurately mapped (Populations 1a to 1e), while areas of this soil that contained no MA populations (Sites 1 to 8) were mapped with less accuracy.

There could be other areas of ‘Shallow gravel over indurated mottled zone’ soil within the Audalia tenement and in the surrounding area. Only land within 250 metres of these four roads, and the tracks within the proposed mine site, was surveyed due to difficulties with accessing other areas.

Figure 14. A map showing locations of the ‘Shallow gravel over indurated mottled zone’ soil in an around the Metcalf mining tenement.



The number of hectares in each area identified in Figure 14 is given in Table 4. There are 14.4 hectares of ‘Shallow gravel over indurated mottled zone’ soil that contain MA populations and 7.7 hectares of ‘Shallow gravel over indurated mottled zone’ soil that have no MA present. The

currently identified areas of the 'Shallow gravel over indurated mottled zone' soil type make up about 1% of the total land area within the Medcalf mining tenement.

Table 4. Number of hectares in each area of the 'Shallow gravel over indurated mottled zone' soil in and adjacent to the Metcalf tenement

Feature	Area (ha)
Population 1a	4.35
Population 1b	1.36
Population 1c	2.76
Population 1d	5.24
Population 1e	0.35
Area of 'Shallow gravel over indurated mottled zone' with MA populations	**14.4**
Site 1	0.82
Site 2	1.98
Site 3	3.12
Site 4	0.03
Site 5	0.48
Site 6	0.87
Site 7	0.11
Site 8	0.28
Area of 'Shallow gravel over indurated mottled zone' with no MA populations	**7.7**
Audalia Tenement M63/656	1853.9

Areas of 'Shallow gravel over indurated mottled zone' soils near Maggie Hayes

A significant area of 'Shallow gravel over indurated mottled zone' soil was found about 10 kilometers south of the Maggie Hayes mine site. The soils occurred in an area near the salt lakes where erosion of the lateritic profile had resulted in breakaways and areas of exposed mottled zone. A GPS coordinate within this area is 51H Easting 269035 and Northing 6426661. This area of 'Shallow gravel over indurated mottled zone' soil was not mapped.

Figure 15. A photograph of a 'Shallow gravel over indurated mottled zone' soil in the Maggie Hayes area.

Sites identified by DBCA as possible potential habitat for *Marianthus aquilonaris*

The Department of Environment and Conservation Interim Recovery Plan 303 for *Marianthus aquilonaris* identified six sites in the Bremer Range where the species might occur. The sites were identified from a desk top assessment using geology maps.

The GPS coordinates of the six sites are:

GPS coordinates	**Soil sample identification**
51 H 288927 6404218	WP1
51 H 292185 6400773	WP 3
51 H 291138 6402558	WP 5
51 H 290849 6402615	WP 7
51 H 289337 6398599	WP 10
51 H 289514 6398248	WP 11

In October 2019 soil was collected from the six sites and the samples and submitted to the Chem Centre for laboratory analysis. The results from the laboratory analysis are shown in Attachment 3.

None of the six sites contained 'Shallow gravel over indurated mottled zone' soils. The soil survey of the existing MA populations has shown the excellent correlation between this soil type and the presence of MA. The was no outcropping of limonite at the six sites. It is therefore unlikely that these locations are critical habitat for the species.

Maps of the underlying geology are generally of limited value in predicting soil type in the south west of Western Australia.

References

Botanica Consulting (2018). Marianthus aquilonaris landform monitoring: Spring 2018

Macdonald *et al* (1990). Australian Soil and Land Survey Field Handbook. Inkata Press, Melbourne and Sydney.

Moore, G A. (2001), *Soilguide* (Soil guide): a handbook for understanding and managing agricultural soils. Department of Agriculture and Food, Western Australia, Perth. Bulletin 4343.

Sawkins, D. N. (2011). Landscapes and soils of the Lake Grace district. Department of Agriculture and Food, Western Australia. Bulletin 4825.

Schoknecht, N.R. and Pathan, S. (2013) 'Soil groups of Western Australia: a simple guide to the main soil groups of Western Australia.' 4th edition. Department of Agriculture and Food, Western Australia. Report 380.

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Appendices

Appendix 1. Summary of soil properties for the 74 sites

Sites highlighted in yellow are 'Shallow gravel over indurated mottled zone' soils.

Sites highlighted in red are 'Alkaline red shallow loamy duplex' soils.

Sites highlighted in green are 'Loamy gravel' soils.

Sites highlighted in grey are 'Stony soils'.

Sites highlighted in brown are 'Shallow gravels'.

Site No.	Landform	Soil Group	Depth to indurated layer	Limonite outcrop	pH of topsoil	MA, SB or ER present?
1	Ridge below plateau surface	Shallow gravel over indurated mottled zone	15 cm	Yes	6	MA
2	Edge of ridge on upper slope	Alkaline red shallow loamy duplex	Not encountered	No	7	
3	Ridge below plateau surface	Shallow gravel over indurated mottled zone	30 cm	Yes	6.5	MA
4	Ridge below plateau surface	Shallow gravel over indurated mottled zone	12 cm	Yes	6	MA
5	Ridge below plateau surface	Shallow gravel over indurated mottled zone	10 cm	Yes	6	MA
6	Edge of ridge on upper slope	Loamy gravel	Not encountered	No	7	
7	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	7.5	
8	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	7	

Site ID	Landform	Soil group	Depth to indurated layer	Limonite outcrop	pH of topsoil	MA, SB or ER present?
9	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	8	
10	Ridge below plateau surface	Shallow gravel over indurated mottled zone	15 cm	Yes	7	MA
11	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	7.5	
12	Upper slope near ridge	Loamy gravel	Gravel stops digging at 20 cm	No	6.5	
13	Mid slope	Shallow gravel over indurated mottled zone	12 cm	Yes	5.5	MA
14	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8.5	
15	Mid slope	Stony soil	Not encountered	No	7.5	
16	Upper slope. Next to breakaway	Shallow gravel over indurated mottled zone	25 cm	Yes	4.5	MA
17	Mid slope. Off ridge	Alkaline red shallow loamy duplex	Not encountered	No	6.5	
18	Crest	Shallow gravel over indurated mottled zone	5 cm	Yes	6	MA
19	Mid slope. Off ridge	Alkaline red shallow loamy duplex	Not encountered	No	8.5	
20	Adjacent to crest	Shallow gravel over indurated mottled zone	30 cm	Yes	7	MA
21	Crest	Shallow gravel (over duricrust)	25 cm	No	7	
22	Mid slope. Off ridge.	Loamy gravel	Not encountered	No	7.5	

Site ID	Landform	Soil group	Depth to indurated layer	Limonite outcrop	pH (field) topsoil	MA, SB or ER present?
23	Edge of ridge on mid slope	Shallow gravel over indurated mottled zone	20 cm	No	6	MA
24	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8	
25	Plateau surface	Loamy gravel	Not encountered	No	7	ER
26	Plateau surface	Loamy gravel	Not encountered	No	6.5	
27	Plateau surface	Loamy gravel	Not encountered	No	7	ER and SB
28	Plateau surface	Loamy gravel	Not encountered	No	7	ER
29	Upper slope	Loamy gravel	Not encountered	No	7	
30	Mid slope ridge	Shallow gravel over indurated mottled zone	5 cm	Yes	6	MA
31	Mid slope ridge	Alkaline red shallow loamy duplex	Not encountered	No	7	
32	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8	
33	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	8	ER
34	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	8.5	ER
35	Lower slope	Loamy gravel	Not encountered	No	7	SB
36	Lower slope	Loamy gravel	Not encountered	No	7	SB
37	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	8	ER

Site ID	Landform	Soil group	Depth to indurated layer	Limonite outcrop	pH (field) topsoil	MA, SB or ER present?
38	Upper slope. 20 m below Breakaway	Shallow gravel	Not encountered	No	7.5	ER
39	Mid slope ridge	Shallow gravel over indurated mottled zone	10 cm	Yes	7	
40	Mid slope ridge	Shallow gravel over indurated mottled zone	10 cm	Yes	6	
41	Mid slope ridge	Shallow gravel over indurated mottled zone	10 cm	Yes	5.5	MA
42	Mid slope	Loamy gravel	Not encountered	No	7.0	SB
43	Gravelly rise on mid slope	Loamy gravel	Not encountered	No	7.0	SB
44	Mid slope	Loamy gravel	Not encountered	No	7.0	SB and ER
45	Top of a drainage line in mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8.5	ER
46	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	7	ER
47	Crest on mid slope	Loamy gravel	Not encountered	No	7.0	SB
48	Crest on mid slope	Loamy gravel	Not encountered	No	7.0	SB
49	Upper slope	Alkaline red shallow loamy duplex	Not encountered	No	6.5	ER
50	Upper slope	Loamy gravel	Not encountered	No	7.0	SB
51	Upper slope	Loamy gravel	Not encountered	No	7.0	SB
52	Upper slope	Loamy gravel	Not encountered	No	7.0	SB

Site ID	Landform	Soil group	Depth to indurated layer	Limonite outcrop	pH (field) topsoil	MA, SB or ER present?
53	Upper slope	Loamy gravel	Not encountered	No	7.0	SB
54	Mid slope	Loamy gravel	Not encountered	No	6.0	SB
55	Below breakaway	Alkaline red shallow loamy duplex	Not encountered	No	7.0	ER
56	Mid slope	Loamy gravel	Not encountered	No	7.0	SB
57	Rise on mid slope	Loamy gravel	Not encountered	No	7.0	SB
58	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	7.0	ER
59	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8.0	ER
60	Upper slope	Shallow gravel over indurated mottled zone	Not encountered	Yes	7.0	MA
61	Mid slope	Alkaline red shallow loamy duplex	Not encountered	No	8.0	
62	Mid slope	Shallow gravel over indurated mottled zone	10 cm	Yes	6.5	MA
63	Mid slope	Shallow gravel over indurated mottled zone	10 cm	Yes	6.5	MA
64	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	8.0	ER
65	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	8.0	ER
66	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	7.5	ER

Site ID	Landform	Soil group	Depth to indurated layer	Limonite outcrop	pH (field) topsoil	MA, SB or ER present?
67	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	7.5	ER
68	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	8.0	ER
69	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	7.0	ER
70	Mid slope crest	Loamy gravel	Not encountered	No	6.0	SB
71	Mid slope crest	Loamy gravel	Not encountered	No	6.5	SB
72	Mid slope crest	Loamy gravel	Not encountered	No	7.0	SB
73	Lower slope	Loamy gravel	Not encountered	No	7.0	SB
74	Lower slope	Alkaline red shallow loamy duplex	Not encountered	No	7.0	ER