Mapping soil properties for irrigation development in the Riverland of South Australia using the EM38

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Abstract
A program of electromagnetic mapping (EM38) has been completed over a vineyard in South Australia's Riverland and results compared with soil profile descriptions collected from inspection pits. This paper investigates the application of EM38 as a tool for mapping soil characteristics for irrigation developments and the use of these maps as a substitute for inspection pits or as guide for selecting pit locations. The results show that distinctly different profiles can have the same electromagnetic properties, such that, on a property scale, the use of EM38 is not recommended. The study also examines the use of EM38 on a single block where soil profile changes can be expected to be less dramatic. Here, the EM system appears to effectively map short-range soil profile variability; variability that is reflected in plant vigour and productivity.

Key Words
Electromagnetic Induction**,** Mallee Soils, Readily Available Water

Introduction
The South Australian Department of Water, Land and Biodiversity Conservation (DWLBC) have completed an assessment of the application of electromagnetic induction surveying for mapping the variation of soil characteristics. The assessment was undertaken in the Riverland of South Australia, where extensive irrigated viticulture projects have been established on the region's Mallee soil.

The trial, which was completed in a large established vineyard, compared the results of EM38 electromagnetic surveying to the results of an extensive soil pitting program. The pitting was completed prior to vineyard establishment and consisted of 1368 sample sites excavated on a square 75 metre grid.

Two EM mapping approaches were tested. The first investigated the short-range variability within individual vineyard blocks, approximately 10 hectare single variety management units, where remote sensing imagery products and yield mapping had defined significant crop variations. The second mapped the entire vineyard using a much wider EM line spacing.

This paper examines the relationship between the soil pit data and the geophysical mapping.

Site characteristics
The vineyard has been established on Mallee soil in the Loxton area in South Australia's Riverland. The site has a maximum elevation of around 55 metres and a minimum elevation of approximately 48 metres. The western end of the site is 1 kilometre east of the River Murray. The river has an elevation of 13 metres.

Mallee soil is defined (Northcote 1971) as solonized brown soil, characterised by large amounts of calcareous material in the profile, both in the fine-earth fraction and as soft and hard segregations. The carbonates are calcium and magnesium with calcium normally dominating. A typical Mallee soil shows gradual texture change down through the profile, becoming finer with depth. The soils show an increase in carbonate in the subsoil and a change in colour, becoming less red with depth. These soils become increasingly alkaline with depth. Subsoil pH values may rise to 9 or 10, and soluble salt contents may increase to considerable amounts. Some dark manganiferous segregations may occur in subsoils.

A typical Mallee soil will consist of grey-brown, brown or red-brown sand, loamy sand, sandy loam, less commonly clay loam, which varies from less that 0.3 metres to over 1 metres thick before it merges with the horizons of maximum carbonate concentration, in the upper part of which nodules, or pans, either weakly or strongly cemented may appear.

Texture gradually become finer downward although rarely do clay contents rise to 50%, even at depth; a clay content of 30% is considered high and the clay content is normally below this. Commonly the soils are non-pedal.

The physiography of the site is dominated by east-west aligned narrow dunes; features that can be traced for over 1000 metres. This fabric has developed over a landscape with north-northwest aligned, shallow valleys.

A useful introduction and data compilation that described the development of the vineyard was available (Robinson 1999).

Methods

Survey methodology

Soil pitting programme

The site has a total of 1368 soil pits excavated on a square 75 metre grid, Figure 1. The vineyard was developed in five stages and the soil surveying was completed in four campaigns between 1995 and 1997. The results of all the surveys are described in four reports (Wetherby 1995a; Wetherby 1995b; Wetherby 1996; Wetherby 1997).

The soil surveying methodology is described in Wetherby (1992).

The soil profile data used in this study were the depth to the top and base of each horizon and the horizon's texture and fragment percentage

Rootzone Available Water (RAW) values were calculated for the upper 0.35 and 0.70 metres of the soil profile found in each pit providing a quantitative soil value that could be interpolated. RAW is the amount of water that can be easily extracted and used by plants and is expressed in millimetres per metre for the depth of profile nominated. It is a function of the texture of the soil and the percentage of fragments. The value is generally calculated over the estimated depth of the rootzone of a nominated plant, however here it has been calculated to predetermined depths across the site.

EM surveying

The EM surveying was undertaken in two stages using a Geonics EM38 instrument operated in vertical dipole mode and a Differential Global Positioning System.

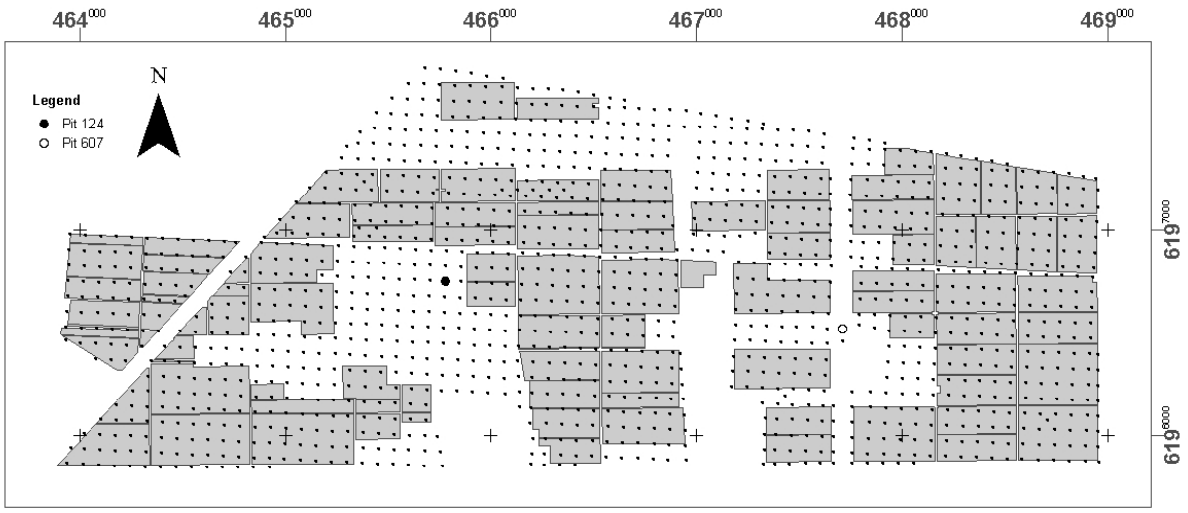

Figure 1. Soil pit grid.

Stage 1 surveying

Seven blocks were selected for detailed surveying. The EM38 was towed behind a four-wheeled motorbike at approximately 10 kilometres per hour. The EM38 and the DGPS were set to record

automatically at 20 and 1 Hertz, respectively, resulting in a sample spacing of 3 metres. Every third inter-row was surveyed creating a line spacing of approximately 8 metres (Figure 2).

Stage 2 surveying
The EM38 was again towed behind the motorbike at 10 kilometres per hour, but for this survey the headings and property tracks were used as a 'grid'. The major access tracks were avoided as these tend to be surfaced with crushed limestone (Figure 3).

Data processing
Soil pitting programme

A soil profile map was created from the profile descriptions by calculating RAW (Equation 1), an index based on horizon thickness, texture, and fragment content.

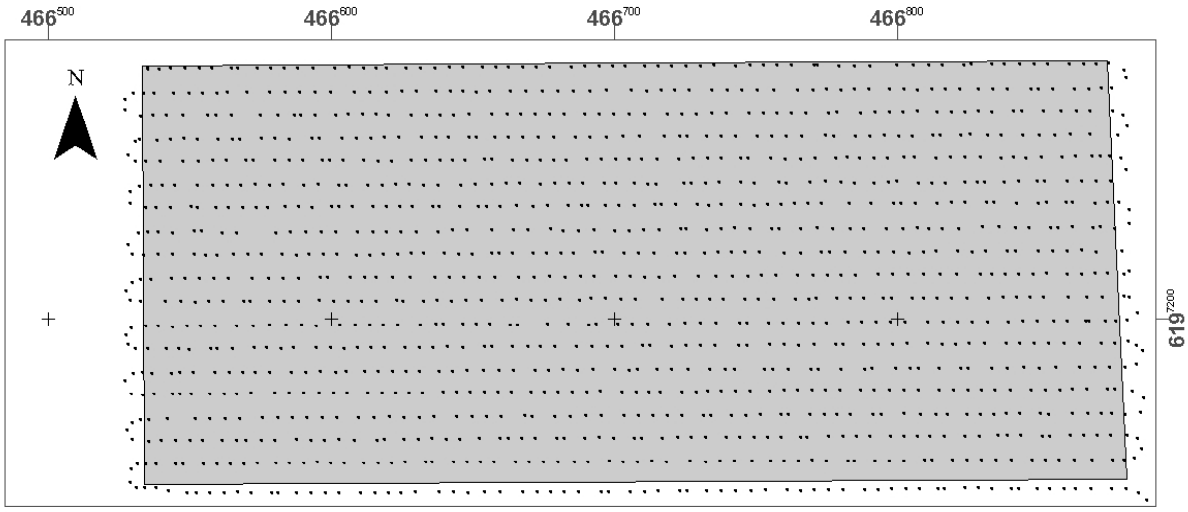

Figure 2. Individual vineyard block survey; close-spaced EM survey data points (Scale: 100m grid lines).

Figure 3. Complete vineyard survey, wide-spaced EM survey data points (Scale: 1000m grid lines).

Equation 1. Readily Available Water (RAW) formula
Total RAW to depth A = Sum of slices to depth A of (Thickness x Suction value[a] x Soil volume factor[b])
[a] Suction value for the specified pressure in the specified texture
[b] Soil volume factor is (100 - % of fragments)/100
RAW is typically calculated over the expected depth of rooting of a nominated crop and at the root suction pressure of that crop. For this project, RAW was calculated to arbitrary depths of 0.35 and 0.7

metres as the EM38's penetration was not limited to a nominated rooting depth. In order to calculate RAW to any depth, the soil profile database was first 'sliced' into 0.05 metre thick sub-layers, with RAW calculated for the sub-layers. These values were summed to provide a RAW for the selected depth. RAW was not calculated for depths exceeding 0.70 metres as a significant number of the pits did not extend past this depth and the coverage becomes relatively sparse in areas.

Continuous surfaces of RAW at 0.35 and 0.7 metres were interpolated across the site and compared to the EM mapping.

2. EM surveying

The located averaged EM values were used in an interpolation of a soil conductivity surface across the area surveyed, either the individual block or the entire property.

The two disparate survey geometries necessitate the application of two different interpolation approaches; the individual block data are collected on a close-spaced relatively regular grid whereas the survey across the complete site used a much wider spacing.

A number of interpolations techniques were applied to the regular grid data for the block the results compared visually. The product was found to be relatively insensitive to the interpolation method using a 2 metre cell size (Figure 4).

With the wide-spaced lines, a number of interpolation routines were used. Results were visually compared against the topographic model. The interpolation that produced the best result used a strongly anisotropic search ellipse oriented east-west, the direction of the sand dune ridges. This ellipse had a major, east-west axis of 400m and a minor, north-south axis of 25m (Figure 5). Universal Kriging was used as the interpolator and validation returned a coefficient of determination, r^2, of 0.9986.

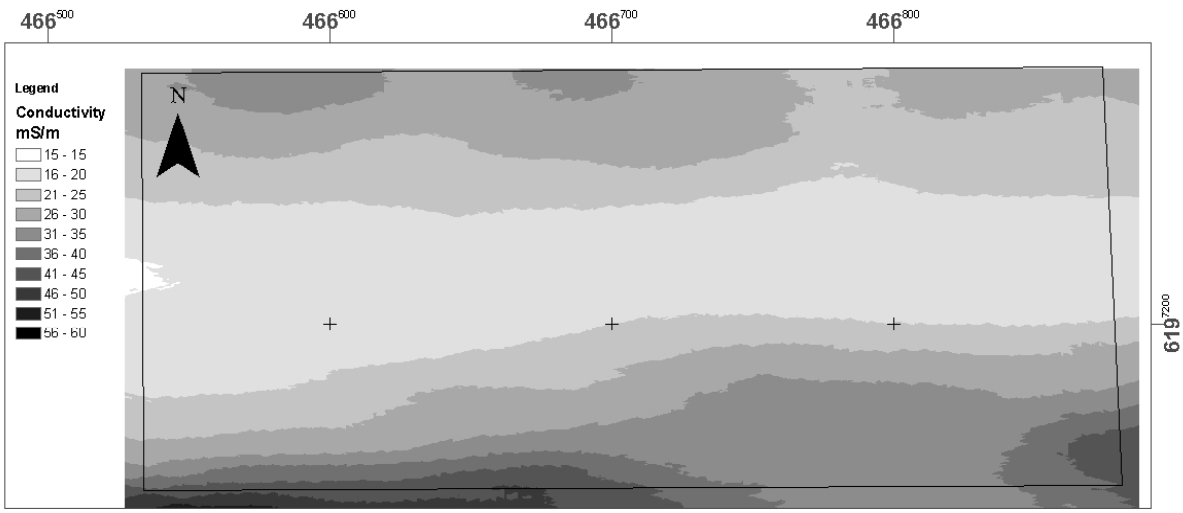

Figure 4. Conductivity (EMv), close-spaced survey lines (Scale: 100m grid lines, darker areas are resistive).

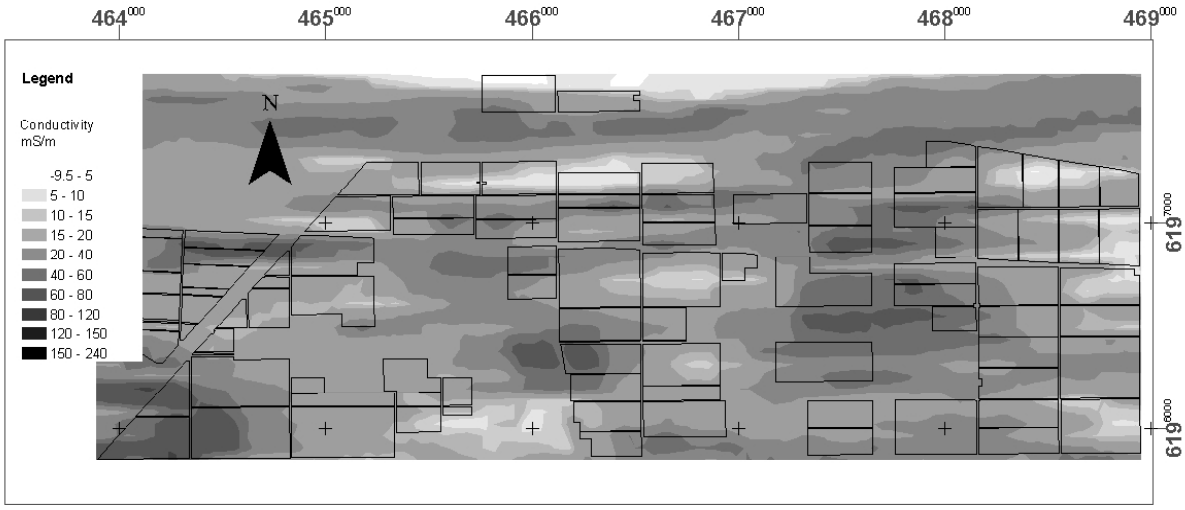

Figure 5. Conductivity (EMv), wide-spaced survey lines (Scale: 1000m grid lines, individual block highlighted, darker areas are resistive).

Other data

A detailed topographic model was available with a cell size of 30m. This elevation data was collected during a low-level, close-spaced airborne electromagnetic survey using a laser altimeter. This model defined the physiographic characteristics of the site such as east-west sand ridges and north-northwest drainage courses (Figure 6).

The site's GIS incorporated the individual block yield data and the remote sensing images.

Results

The calculated RAW indices for each of the pits, and the interpolated surface derived from these data, does not correlate well with the EM mapping either at the individual block scale or across the site. To provide a statistical measure of the degree of correlation, EM readings were interpolated to the pit locations. Conductivity (EMv) has been plotted against the RAW to 0.7 metres and RAW to 0.35 metres (Figure 7) values each of the pit locations across the complete site.

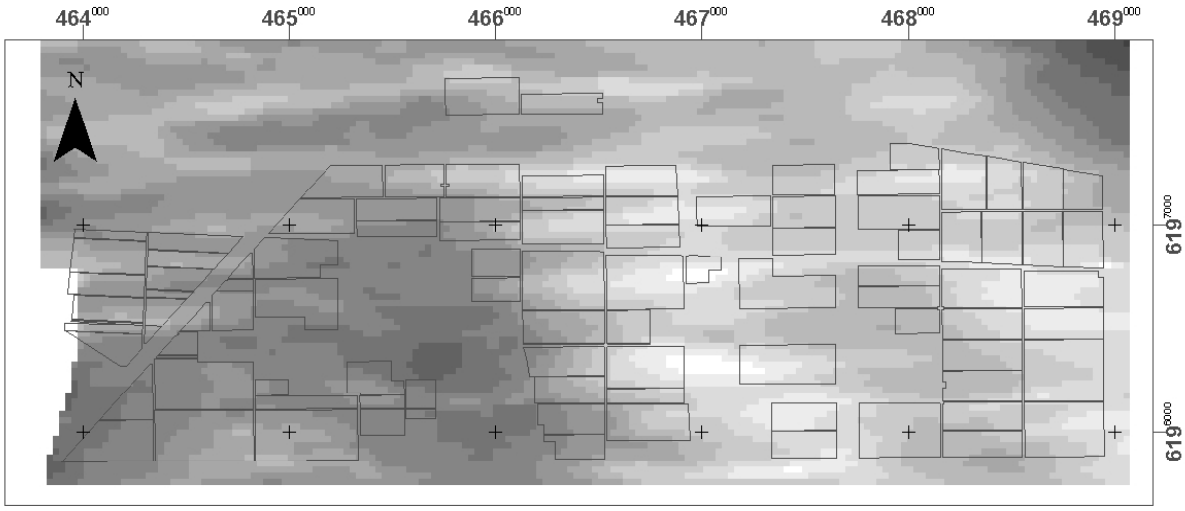

Figure 6. Topographic model, 30m grid (Scale: 1000m grid lines).

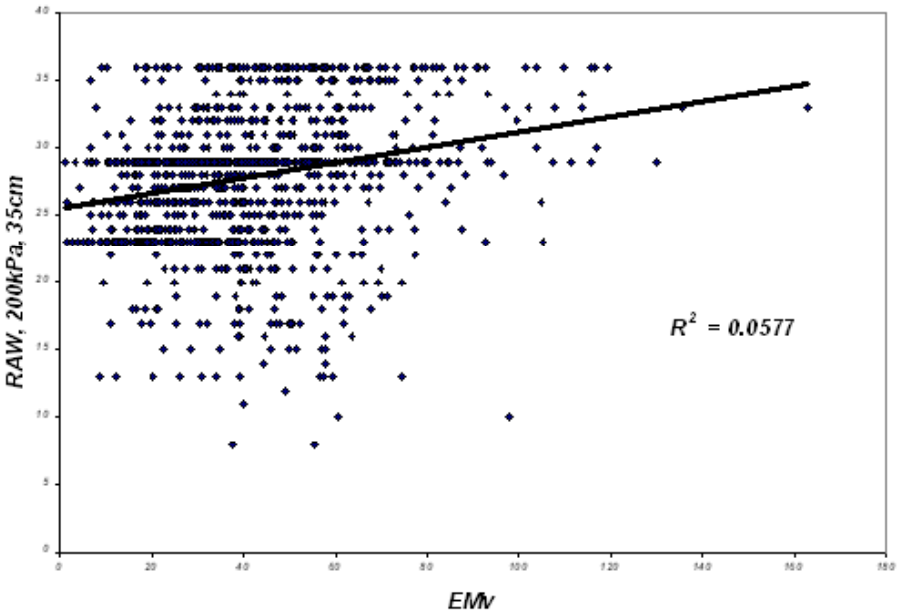

Figure 7. Conductivity (EMv) vs RAW (0.35 metres).

A plot of conductivity against RAW to 0.70m confirms this finding, the coefficient of determination, r^2, for both depths are given in Table 1.

Table 1. Coefficient of determination, r^2, between EM and RAW at the pit locations .

Survey	r^2 for RAW 0.35 metres	r^2 for RAW 0.70 metres
Individual blocks	0.2038	0.0652
Complete site	0.0577	0.0033

Discussion

The poor correlation between the EM mapping and the pit profile data suggests that the two data groups are measuring different variables.

The soil profile data records observations, depth from and depth to, and determinations, texture measurement through 'hand-texturing' and fragment percentage estimation.

The EM38 is measuring the electrical conductivity of the soil profile at each recording station. The electrical conductivity at these points is determined by one or more of the following parameters (McNeill 1980):

a) Clay content and clay type;
b) Moisture profile with depth;
c) Moisture salinity;
d) Moisture temperature.

Of these, the moisture profile is considered to be the most complex (McNeill 1980) and includes, (i) the porosity, (ii) the extent to which the pores are filled with water, and, (iii) the number, size and shape of the interconnecting passages, all of which vary with depth.

As an illustration, two conductive zones were selected across the site. These zones are known to have distinctly different soil profiles, one dominated by a shallow carbonate hard-pan that makes the location unsuitable for cultivation, Pit 124, and the other at a site with deep, relatively clay- rich, soil, Pit 607. Diagrammatic representations of these profiles are presented in Figure 8.

The shallow hard-pan present in Pit 124 extends under an area of approximately 0.25 square kilometres. The hard-pan, which is 0.40 metres thick, and its associated profile, is a distinct conductive feature on the EM map for the complete site. The conductivity at the pit site is 59 mS/m.

The profile at Pit 607 has a similarly high conductivity, 87 mS/m, and at this location the profile is dominated by thick clay from 0.35 metres to the base of the pit at 1.80 metre. The carbonate accumulation is less dramatic, rising to a maximum of 60% in Layer 2 between 0.35 metres and 0.65 metres.

Both sites are within the upper 20% of conductivity across the site, however their soil profiles are distinctly different. This suggests that it may be unwise to use an EM38 survey as a data input when selecting the sites for soil profile excavation.

Although EM surveys conducted over the complete site should be viewed with care as the relationship between an EM value and a particular soil profile is not unique, the data from individual blocks may have potential to map short-range subtle changes in soil properties. This judgment is, however, unproven at this stage and additional pitting is required to define the exact nature of the soil variations that are being mapped by EM.

Within an individual block of approximately 10 hectares there would be between 15 and 20 pits at the 75 metre grid spacing. Establishing short-range variation of the soil properties within the block using EM38 surveying has demonstrated that soil variability contributes to variations in harvest yield and canopy development, as established by airborne remote sensing imagery. Understanding the causes of this variation may prove valuable as a management tool and efforts to understand the nature of the soil variation through additional pitting may be justifiable. The soil conductivity map would control the locations of these additional pits.

Conclusions

The EM38 has the potential to provide a high-resolution data set that can be used to rapidly map the conductivity across relatively large areas. This study suggests that reliance on EM mapping for the location of a limited number of soil profile excavations may not result in a satisfactory outcome.

A greenfields development of a high-value irrigated crop justifies a soil profile excavation density of no less than 2 pits/hectare, as recommended by the Australian Soil and Land Survey Handbook (Gunn 1988). At this density the soil survey probably represents between 0.5 and 1% of establishment costs for irrigated viticulture (not including land acquisition). Reducing the number of pits on economic grounds therefore is difficult to justify. This study suggests reducing the number and locating them using EM mapping is dangerous.

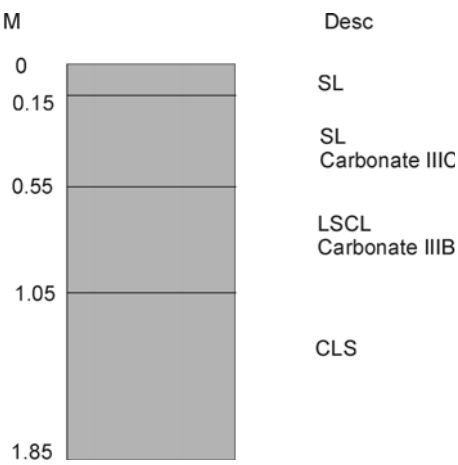

Figure 8a. Soil profile at Pit 124.

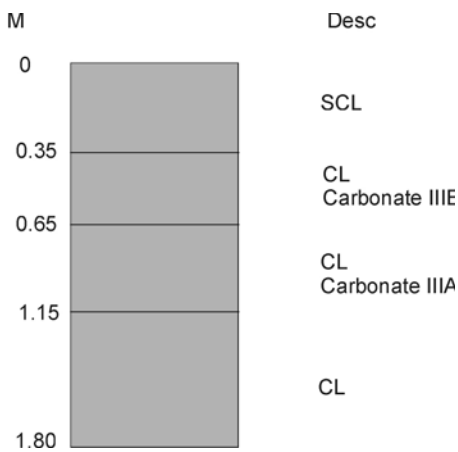

Figure 8b. Soil profile at Pit 607.

For less capital intensive agricultural activities, property scale EM mapping is justifiable. The value of the EM map product is likely to be significantly increased if the methodology employed and the findings of the survey are recorded and made available to a suitably skilled soil surveyor.

The value of additional data when undertaking the interpolation of the property-scale EM data should be emphasised. High quality topographic data is of great value and could be used both to plan an appropriate distribution of soil pits and to control how the EM data is interpolated.

When considering short-range variability within established high-value crops, EM surveying offers the opportunity of developing high-resolution soil variability maps, however additional soil profile examination would still be required before determining the cause of this variability.

Acknowledgements
The author wishes to acknowledge the cooperation of Tim Smythe and Phillip Goodes of McGuigan Simeon Wines; both contributed to the field program and have made useful comments.

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