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Standards for Electromagnetic Induction mapping in the grains industry

GRDC
Grains Research & Development Corporation

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Executive summary

A workshop to establish a protocol for electromagnetic mapping applications in the grains industry was held in Mildura on 3-4 November 2004. The workshop developed a framework and four working groups completed the detail. This protocol consists of ten sections, intended to provide guidance for the standard measurement, recording and interpretation of soil conductivity data; particularly for third parties that might receive the data for subsequent analyses and development of recommendations. The ten sections are:

1. EM survey objectives
2. EM survey design
3. Instrument set-up
4. Best management practise
5. Fundamental data set
6. Data management and processing
7. Presentation & reporting
8. Soil testing
9. Recommended statement of ethics
10. Opportunities for future working groups

Background

Electromagnetic induction technology (EMI or EM) and other soil conductive technologies (e.g. resistivity) have been used for decades to map ground conductivities in mineral exploration (Keller and Frischknecht 1966). Until the advent of global positioning systems (GPS) in the early 1990's, its application in agriculture was mainly limited to salinity management in irrigated systems (De Jong et al. 1979; Williams and Baker 1982; Cook et al. 1992). There is now great interest from dryland farming enterprises, particularly the grains industry, where the management of crops at a greater spatial resolution is now achievable (Corwin and Lesch 2003a; O'Leary et al. 2004; Whelan and McBratney 2003).

EM sensors only measure bulk soil electrical conductivity (ECa). Other soil properties of interest may be inferred using EM data but only if these are well correlated to ECa. For each and every variable of interest, calibration against observed data is necessary. For agricultural applications the most common variables that have been found to correlate well with ECa are: soil water content, soil clay content and soil salinity (Johnson et al. 2001). Unfortunately, temperature (air and soil) effects make universal calibrations complex. Additionally, the mineral type and content of the soil will also affect the calibration. As a result, universal calibrations, whilst theoretically attractive, prove very difficult in practice (Corwin and Lesch 2003a).

The lack of a workable universal calibration to relate ECa to other soil properties makes it necessary to establish these correlations for each individual survey site. This may be achieved through analysis of soil cores taken at the same time as the soil conductivity survey (Corwin and Lesch 2003a). Other variables, like potential rooting depth, that are functions of water, clay and salt content may also be applicable in some places. The detection of specific elements or compounds (e.g. phosphorous) can only be accommodated to the extent of the strength of the ECa co-correlation with water, salt and clay (Kitchen et al. 2000). Other variables like drainage cannot be measured directly with EM because of the complex relationship between other components of the water balance equation and time. Thus, customised calibrations must be derived after a survey to establish what can and can not be measured with EM sensors. It is very much site specific (Kitchen et al. 2000).

As a result of the complexities involved in collecting and calibrating EM data, US scientists, Corwin and Lesch (2003b), have recently developed a protocol for characterising soil spatial variability using soil electrical conductivity methodology. Their report details the theory and practice of EM mapping. However, their protocol was developed by scientists for use by other scientists. As a result of this, it is unlikely to be of direct use in Australia's broadacre EM industry.

In addition to the grains industry, other Australian agricultural industries are also interested in the use of EM technologies to assist growers in making better management decisions. The Australian viticulture industry has already developed a protocol for the mapping of spatial yield data (Bramley and Williams 2004). This has the potential to be adapted to include spatial soil data derived from conductivity maps. EM surveying has been adopted by the Australian rice industry of southern New South Wales in a protocol for identifying land suitable for ponding during rice growing (McLeod and Shaw 2001).

Questions relating to more precise management of crops and farmland are now being raised and EM technology is being used to map various soil properties that are correlated to soil electrical conductivity (EC) (Sudduth et al. 2001). This correlation of soil EC and various soil properties is the basis for the use of electromagnetic induction technology in agricultural resource management. This protocol for the grains industry does not discuss in detail the different technologies for measuring soil conductivity, instead it concentrates on how EM data should be collected and presented in a way that is useful for agricultural interpretation.

A proposal to develop an Australian industry standard for EM data collection was put forward by Ormesher and Dale at the 2001 conference "Electromagnetic Techniques for Agricultural Resource Management", held by the Riverina Branch of the Australian Society of Soil Science at Yanco, NSW. Significant interest was shown by a number of participants and a draft standard was developed. This draft included EM38 operating guidelines as well as some standards for data presentation. Unfortunately, Dennis Ormesher has since sold his business and the document was never completed. However, the issue remains as relevant as ever.

The fundamental problem is that EM data collection and interpretation can be a complex process and EM contractors collect and process data with varying quality and procedures. Whilst there is no question that different quality and standards (e.g. in spatial resolution) may be required for particular exercises, what is frequently lacking is clear documentation regarding data collection and accuracy. Furthermore, some contractors only provide coloured maps, without access to the actual EM data, which limits subsequent analysis by third-party consultants. It is apparent that the EM mapping industry should agree to some basic standards or best practice guidelines.

The Grains Research and Development Corporation (GRDC) was concerned about this because the issue was Australia-wide. Consequently, GRDC, as part of its Precision Agriculture and Subsoil Special Initiatives, funded a workshop for the development of a grains industry standard for EM mapping.

Workshop summary

Twenty-nine delegates attended the first day and thirty attended on the second day. Rohan Rainbow, from Rainbow and Associates, was employed to facilitate the meeting. On Day 1 Alan Mayfield (GRDC) gave an introductory talk explaining the GRDC's interest in a Manual for best EM practice for the grains industry, with particular emphasis on the need to achieve this as a team effort. Speakers with EM mapping experience from grains and non-grains industries were also invited. Their task was to highlight the essential elements that should be included in an EM mapping protocol. The invited speakers were:

- Dennis Ormesher - the history behind the development of his original EM protocol;
- Rob Bramley - experience of the need for an EM protocol in the viticultural and horticultural industries;
- Geoff Beecher - the benefits of an existing EM protocol in the rice industry;
- John Triantafilis - his experience with EM work in the cotton industry;
- Rod Davies - experience of an EM protocol from a soil surveying perspective under a two-part Code and Guidelines structure in South Australia; and
- Martin Peters - his experience from the perspective of an EM contractor.

All speakers were very focused and proceeded to quickly address the objectives of the workshop.

After these presentations, four groups were formed to summarise key elements of an EM protocol for the grains industry. Two groups reflected a service provider's perspective and two reflected a user's/farmer's/agronomic consultant's perspective. All groups highlighted the need for an EM protocol to define the objective of the proposed EM survey as the number one item. It was acknowledged that different objectives require a different level of detail in application and accuracy.

On Day 2, four different groups were formed to add detail to the various components of the proposed EM protocol. The composition of these groups was aligned with the expertise of participants and formed the basis of four working groups to develop the protocol.

Opportunities for the future

Over the coming years workshops will be developed to progress EM training and accreditation for EM contractors. It is hoped that members of the EM surveying community will participate fully and improve the practice of EM mapping in the grains and other interested industries.

Acknowledgments

We would like to thank the participants of the workshop listed below for their ideas and helpful debate on various aspects of the protocol. We would also like to thank the working group members who brought this to a conclusion. Ken Bates, Geoff Beecher, Rob Bramley, Rod Davies, David Lamb, Neil Meadows, Jo Peters and Phil Price also provided helpful comments on an earlier draft. It is not possible to please everyone, but there was broad agreement that a protocol needed to be established and promoted by the EM industry. The Grains Research and Development Corporation together with CSIRO Land and Water and the Victorian Department of Primary Industries and all the companies, agencies and individuals represented here contributed significantly to this protocol. The challenge is to make it work and improve on it after a period of practical application and testing in the industry.

Workshop participants:

Ken Bates, Geoff Beecher, Nigel Bodinnar, Ian Boothey, Rob Bramley, Tristan Campbell, Peter Cousins, Jim Cunningham, Rod Davies, Terry Evans, Mick Faulkner, Vincent Grinter, Iain Hume, Kym Luitjes, David Malinda, Ian Maling, Alan Mayfield, Neil Meadows, Al Mitchel, Shane Norrish, Garry O'Leary, Dennis Ormesher, Martin Peters, Jo Peters, Rohan Rainbow, Paul Rampant, John Triantafilis, George Truman, Michael Wells, Mike Wong.

Working groups:

1. Survey design and instrument set-up (Martin Peters - Working group chair, Michael Wells, Ken Bates, Mick Faulkner and Tristan Campbell)
2. Objectives of EM survey and metadata (Ian Maling - Working group chair, Iain Hume and Garry O'Leary)
3. Data management, presentation and reporting and soil testing (Ian Boothey - Working group chair, Nigel Bodinnar and Rob Bramley)
4. On-going review, education and accreditation - (Geoff Beecher - Working group chair, George Truman, John Triantafilis and Rohan Rainbow)

1. EM survey objectives

The objective of an EM survey defines the level of detail and accuracy required. It is important to document this to prevent misunderstanding by third parties or even the contracting landholder. The objective is the heart of the mapping report document. Each survey report should, therefore, define the objectives of the EM survey.

This section of the report should contain a background statement identifying: e.g.

- background to the survey;
- issues to be investigated;
- purpose of the survey;
- choice of instrument (e.g. Geonics EM38 or Veris);
- required accuracy (< 1 m or < 2 cm etc…) and, therefore,
- type of GPS signal to be employed (e.g. AGPS, DGPS, WAAS or RTK); and
- potential limitations of the survey (e.g. calibrations against soil properties should be made that are not compromised by changes that might occur during a survey, e.g. water content could be affected by rainfall during a survey).

It is suggested that all EM mapping reports include the 7 sections shown above, with as much detail as possible recorded for each section. Appendix B provides an example of pages from an actual EM survey with objectives, maps and data description.

2. EM survey design

The basic characteristics of an EM survey should be determined from the objectives, as described in Section 1 above. The crucial components to be considered when planning the survey are described below.

2.1. Type of instrument

2.1.1. Choice of conductivity instrument

The choice and combination of different types of conductivity instrument will also depend on the survey objectives. The depth of penetration of the EM signal is a major consideration. There are a couple of options available for undertaking root zone surveys:

- The EM38 (Geonics Ltd, Canada) has a maximum sensitivity at a depth of approximately 0.4m if oriented in the vertical mode (effective depth range: 1.5m). When used in the horizontal mode maximum sensitivity occurs at the surface (effective depth range: 0.75m). Therefore, the vertical mode is more useful for subsoil investigations. Furthermore, the vertical mode will be less sensitive to surface changes in water content that might occur from light rainfall during a survey. A dual dipole EM38 provides simultaneous measurements from both the horizontal and vertical modes. As a result, some contractors provide both data sets at no extra cost.
- The Veris (Veris Technologies, USA) also measures ECa at 2 depths simultaneously (shallow mode: 0-0.3m and deep mode: 0-0.9m).

For survey interests below the root zone of most crops, the deeper penetrating Geonics EM31 (depth to 6m) is often used (e.g. rice industry).

2.1.2. Choice of GPS

The choice of GPS will depend on the required accuracy for the survey, as determined by the survey objectives. Differential GPS should be considered as the minimum level of accuracy for EM surveys. If accurate topographic information is required for the survey area, RTK GPS should be used to collect the elevation data while conducting the EM survey. It should be noted that manufacturers usually quote GPS error for elevation data as being 2-3 times the error in the horizontal. Consider the stated accuracy of GPS hardware when assessing suitability for job. Be aware that some GPS manufacturers quote pass-to-pass accuracy, while others quote absolute accuracy. Operators should also note the difference between the accuracy of a stationary GPS receiver using repeated measurements and the accuracy of a moving receiver using single measurements. It may be necessary for operators to test the stated accuracy by an independent method to make sure that the survey objectives will be met.

2.2. Transect spacing

Transect spacing primarily depends on the end use of the information. The following spacings have been suggested as a guide:

- Broad acre dry land: <60 m
- Irrigated: <30 (for rice < 20 m (maximum))
- Precision Agriculture: <3 times harvest width

The irrigated and precision agriculture applications are included to illustrate the point that as the level of investment per unit area increases, then the transect spacing reduces. This is not meant to indicate that the grains industry recommends the application of EM surveying in these cases.

2.3. Speed of operation

The speed of operation will affect the distance apart of individual readings. Additional factors to be aware of are inaccuracies and errors that increase with speed. Appendix C discusses possible ways to minimise speed errors. A maximum speed of 20km/h is recommended as a guide.

When undertaking an EM survey, operators should be careful to ensure that:

- speed remains constant where possible;
- the EM unit remains at a constant height above the ground (no bouncing). If different heights are used between surveys this will be a source of variance between the surveys. To overcome this, the EM data should be calibrated against soil measurements by regression analyses (see reference to regression analyses in Section 8: Soil testing).
- Speed is slow enough to maintain minimum required distance between readings
- (minimum may be equal to required transect spacing).
- Speed is safe for the ground conditions.

2.4. Soil water content

Recurrent EM surveys of an area can produce conductivity maps showing similar spatial patterns. The bulk conductivities can change across the season and the principal dependent variable is likely to be the soil water content. Consideration of this variability is required when planning and reporting surveys.

The following issues should be taken into account when deciding on the optimum timing for EM surveys:

- At very low water content (below permanent wilting point) conductivity pathways are interrupted and correlation with clay content may be poor. If profiles have impermeable layers, water content can vary widely; the upper profile may be saturated overlaying a dry deeper layer.
- At very high water content (above field capacity and at saturation) the correlation with soil EC from a saturated extract (ECe) will be poor due to dilution effects. EM surveys for salinity mapping should avoid soil conditions above field capacity.
- Best correlations with soil physical and chemical properties will occur when the majority of the survey area is between field capacity and the permanent wilting point.
- Surveying immediately post harvest (at minimum soil water content) can identify variation in water use by crops.

The rationale for the timing of the survey should be recorded as part of the 'Objectives' section of the mapping report.

2.5. Cropping phase

The survey design should ensure that due consideration is given to cropping phase. The survey timing should minimise damage to crops; ideally this is between harvesting one crop and establishing the next. There is often a trade-off between preferred soil water and the potential for crop damage. However, surveying growing crops is sometimes unavoidable, and should be done at the discretion of the landowner. Cereal crops generally suffer no long-term damage if flattened before stem elongation commences.

In addition to the physical practicalities related to cropping phase, care should also be taken when comparing EM surveys from paddocks with different management histories. For example, deep rooting crops, and pasture plants such as lucerne will draw soil water from deep down the soil profile and can show a residual effect for several years after they are replaced.

3. Instrument Set-up

3.1. Warm up

The instrument should be allowed to stabilise for a warm-up period before surveying commences. Typically 15 minutes is adequate, but refer to manufacturer's instructions.

3.2. Nulling

If absolute ECa readings are required, it is vital that the unit is zeroed using the procedure described in the operator's manual. The location of the nulling should be carefully recorded (use GPS coordinates) to allow for calibration checks during the day, and consistency with subsequent surveys.

3.3. Drift management

The following table summarises causes and minimisation techniques for instrument drift.

Cause of drift	Notes	Management technique
Battery voltage variation	As the supply battery discharges, the output voltage may drop, affecting the calibration of the sensor.	Keep battery at or above minimum output voltage recommended by manufacturer. Supply power from external stabilised source (subject to manufacturer's approval)
Temperature and temperature variation	Geonics EM equipment is temperature compensated (up to 40°C), but this relies on uniform temperature across the unit. Exposure to direct sunlight will result in temperature differential within the instrument, and unpredictable calibration changes.	Maintain a uniform temperature across instrument by shading or (ideally) enclosing it. Do not operate when air temperature is 40°C or above.
Coil / electrode spacing variation	Not relevant on fixed coil units such as EM38 and EM31, or fixed tine ground-engaging units such as Veris, but must be considered on remote coil devices such as EM34	Ensure coils are kept precisely spaced throughout the survey, as specified in the operator's manual.
Data collection hardware inconsistencies	Changes in the physical surroundings of the sensor can result in changes in calibration.	Ensure the instrument cannot move on the carrying device. Ensure power and data cables cannot move relative to the instrument. Maintain a constant distance between instrument and prime mover.

Table 1: Causes of drift and techniques to minimise drift

Procedures should be put in place to allow the data to be checked for instrument drift, options include:

- Real-time confirmation by revisiting a known control station. As a MINIMUM this should be done at the start and once during a survey. For large areas consider numerous observations, e.g. once an hour. The instrument should be adjusted if the ECa reading at the control station varies by more than 3 mS/m or 5%, whichever is greater (Appendix D provides an example data sheet for recording instrument drift).
- Post processed checking can be used if a known point is repeatedly crossed during the survey period. However, this does not allow for early detection and correction of problems.
- Control lines or strips are best suited to post processed analysis, but may be used to adjust data for instrument drift after the survey through use of post process analysis.
- Examination of the ratio between vertical and horizontal dipole can enable identification of drift or changes in one dipole when no drift occurs in the other dipole.

3.4. Survey operation

3.4.1. Coverage

It is important to ensure even coverage of the survey area. Random driving patterns do not provide good survey data. Use of a hardware or software guidance system ensures good coverage. Straight transect lines, orientated with the longest boundary, are typically the most efficient method to cover the survey area. When paddock features (such as contour banks or open drains) do not allow this, the best practical solution is to follow the path taken during normal farming operations.

3.4.2. Local reference points

Wherever possible the location of paddock features such as dams, trees, posts etc should be included on the map to make orientation easier for the end user.

3.4.3. Interference

It is important to be aware of the presence of any factors that could interfere with the EM instrument. The main factors to be aware of are:

- Metal objects can strongly influence the EM signal. To minimise this, do not wear steel-capped boots. Do not use metal (such as nails and tyres with wire beads) in the construction of a carrying device. Be aware of the location of metal posts in the vicinity of the survey. Mark these on the map and take these into account when interpreting the survey data. Soil samples for calibration should be taken in representative places where the EM signal cannot be unduly biased because of metal objects. (e.g. mid-way between steel posts).
- The vehicle towing the EM can interfere with the EM signal. Tow the EM at least 2-3m behind the vehicle and maintain a constant distance.
- Proximity to devices transmitting electromagnetic radiation, such as Television Transmitters, may cause interference (anecdotal evidence shows that interference with EM38 readings may even occur at a distance of 1km from a TV transmitter).

It is important to document details of any potential sources of interference if these are outside the control of the operator.

3.5. GPS

3.5.1. Receiver placement

It is unlikely that the GPS antenna can be located exactly over the EM sensor, but it is preferable to align the antenna with the centre line of the EM sensor because calculating the offset is particularly prone to miscalculation if it is offset to the side and the back or front.

3.5.2. Interference

It is possible that electrical interference from vehicles (especially ATVs) can degrade GPS accuracy. In order to test for this, GPS quality should be compared with the engine running and with it stopped. If a problem is identified, it can often be reduced or eliminated by simply relocating the GPS receiver and antenna. However, it may sometimes be necessary to install an electrical noise filter.

3.6. Offset and lag

The true position of an EM reading can be effected by two key factors:

- Offset - distance between EM sensor and GPS antenna
- Time Lag - time from when the EM sensor takes a reading to when the data logger records it.

If the degree of error is outside an acceptable range then there are two methods of correcting it. An acceptable error might be 3m for broad acre crops - see article on transect spacing (O'Leary et al. 2004).

- Post processing. The recorded position is adjusted by various algorithmic methods. For example, by a constant offset distance value. If using this method it is crucial that the data is collected at a constant speed. For greater accuracy, offset distance and error due to time lag can also be corrected with known calibrations. Alternatively, statistical methods may also be employed (e.g. block kriging using large blocks typically greater than 3 times the transect width).
- Real time. The data logger is programmed with values for both time lag and offset. Corrected values are recorded in the raw data file.

3.7. Calibration recording sheets

Calibration recording sheets are useful as standard forms for documenting EM drift during surveys. They can be incorporated into general survey documentation or be separate. An example is provided in Appendix D.

4. Best management practice

Best management practice for EM operations requires consideration of a number of factors, including: occupational health and safety, paddock hygiene and quarantine relating to weed, and disease issues. Whilst these are not unique to EM operations they are considered essential and should be accounted for by all operators of EM equipment. The following checklist is indicative of the items that need to be considered and acted upon.

4.1. Occupational health, safety and work practices

- Occupational health and safety legislation
- Quad-bike training - competency based training
- Safety equipment and procedures - roll bar, helmet, canopy, EPIRB, phone-in procedure
- Procedures for working in remote areas

4.2. Paddock hygiene

- State / region / property level
- Crop damage
- Fire risk and preparedness

4.3. Hygiene between properties

- Wash down / clean up / foot baths

4.4. Weeds & disease

Weeds and disease are a quarantine issue, examples include:

- Broom rape, Bathurst burr, noxious weeds
- Cotton - Fusarium
- Vines - Phylloxera

5. Fundamental data set

Recording of fundamental data is important to maximise the value of the data. The recommended elements of this data are listed below. An annotated example is given in Appendix A with an actual example given in Appendix B.

- Dataset (Title, Custodian, Jurisdiction)
- Description (Abstract, Purpose, Search word(s), Geographic extent (Names), Geographic extent (polygons)
- Data currency (Beginning date, End date)
- Data set status (Progress, Maintenance and update frequency)
- Access (Stored data format, Available format types, Access constraints)
- Data source (Hardware, Data acquisition software)
- Data quality (Lineage, Positional accuracy, Attribute accuracy, Completeness, GPS settings, Instrument settings, Conduct of survey, Data handling, Ground-truthing)
- Contact information (Contact organisation, Contact person, Mail address, Locality/suburb/place, State,
- Country, Postcode, Telephone, Facsimile, Email address)
- Survey date
- Additional information (Data, Notes)

6. Data management and processing

The data processing stage is an important component of EM surveys. Whilst the fundamental data set described in the previous section provides the main data description, the following list of key information should be considered and documented during data processing.

6.1. Archiving & naming protocol

- Raw data should be preserved.
- Use logical and informative names. We recommend “site-crop-year-attribute” format for file and directory names, after SPAA protocol (Bramley 2004).
- Metadata defined as fundamental data set above.

6.2. Correcting data for antenna offset

Document antenna set up and record data correction method applied to raw data.

6.3. Data lag

Document any data lag present and record data correction method if any was applied to the raw data.

6.4. Correcting raw GPS data

- Document GPS set up (including co-ordinate system used to collect raw data).
- State differential source.
- Document any post-processing of raw position data to correct to real world co-ordinates.
- Document co-ordinate system used in processed data set.

6.5. Interpolation & Kriging

Prior to interpolating data sets, it is important to remove any data known to be erroneous. Kriging is the recommended interpolation method. There are three main reasons why kriging is recommended:

- Kriging provides a kriging variance that can be mapped to give an ‘attribute accuracy map’.
- The mean kriging variance can be used as a test of statistical significance between clusters, if the EM data layer is later clustered with other data (e.g. yield) to produce management zones.
- The mean kriging variance can also be used to determine whether the legend categories used in the raw map are real (i.e. is dark red really different to light red?). This is not possible with other interpolation routines and standard tests of significance (e.g. t-test) are not appropriate for such large data sets.

6.6. Comma delimited output

- The agreed file format to transfer data is in comma delimited ASCII text (csv).

7. Presentation & reporting

All EM operators should prominently acknowledge in all their communications, verbal, advertising and reporting, that an EM conductivity map is not a soil map. Recommendations for the presentation of EM data and predicted soil properties as maps are given below.

- Legends should not contain more than 12 colours, after SPAA protocol (Bramley 2004);
- A monochrome legend based on red should be used for ECa. Increasing intensity should correspond to increasing ECa.
- Use of other monochrome colours schemes is recommended for derived soil variables to reduce confusion with usually multi-coloured yield and NDVI maps.
- The data range should be stated (minimum, maximum, median).
- The data range for ECa data should normally be expressed in relative terms because the range will change according to soil type, condition or location, but this will depend on the objective.
- Maps/legends should provide details of the units of measurement used for each variable being displayed. See Appendix E for more information on preferred SI units.

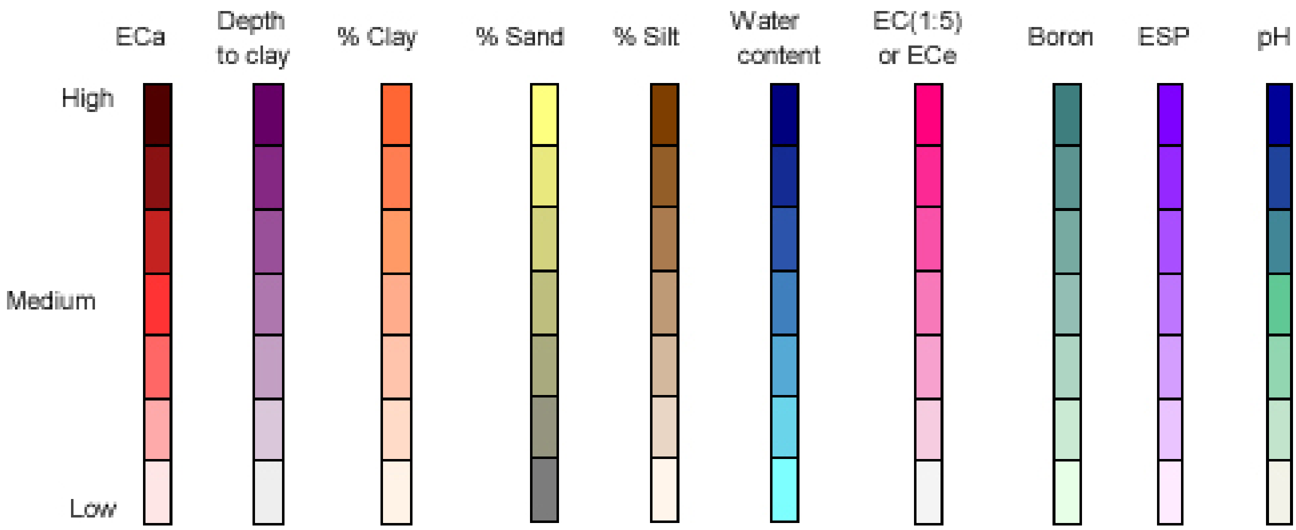


Figure 1: Example of colour schemes

8. Soil testing

An electrical conductivity map is not a soil map. An EM conductivity survey will establish the bulk electrical conductivity at sampling points beneath the instrument across the survey area. The map is an interpolation of these point measurements. It should be recognised that the electrical conductivity of the soil profile is never governed by a single soil property; rather by a combination of the following properties in varying proportions:

- clay content, clay type or depth to clay in duplex soils,
- soil water profile with depth,
- soil water salinity, and
- soil water temperature.

Collection and subsequent analysis of soil samples is essential for accurate calibration of the EM data. The soil samples should ideally be collected at the same time that the EM survey is conducted to avoid complications resulting from potential differences in soil temperature and water content. The survey objectives determine the number of samples and subsequent analysis required. Some of the key aspects to consider in the planning and execution of this sampling are outlined below.

8.1. EM data calibration basics

The most complex of the factors contributing to soil conductivity is soil water profile. The soil water profile describes the way in which the following factors vary horizontally and with depth:

- the porosity,
- the extent to which the pores are filled with water, and
- the number, size and shape of interconnecting passages.

The soil water profile is, therefore, affected by soil material type, topography, compaction and season. Furthermore, the depth over which this conductivity is measured is not constant. It is governed by the overall conductivity and the conductivity's profile with depth.

The spatial variation described by EM conductivity maps can represent the variability of a range of soil properties providing that a correlation can be demonstrated between the property and the EM value at a statistically representative number of locations. This is achieved using regression analysis and it is performed between a soil property measured at a particular location and the EM value at the same location.

8.2. EM data calibration uncertainty

In order to produce a true soil property map the correlation must, by definition, be perfect. Given that the correlation will never be perfect, there will always be a degree of uncertainty associated with each soil property map. It is the appreciation, definition and management of this uncertainty that should be of interest to the EM industry, farmers and the soil surveyor. The definition of an acceptable level of uncertainty will be related to the intended use of the survey results and the risk associated with using incorrect data. Enterprises with low investment per hectare can arguably make decisions with datasets having lower levels of confidence. For intensive agriculture where an incorrect decision can have expensive consequences a significantly lower level of risk is desirable.

8.3. Management decisions based on predicted soil property maps

Another important element of this style of analysis is that the single soil property map must be represented as such; a single variable in a complex natural system. Any management decision based on information relating to a single variable must be made with the knowledge that any changes made to that variable may have unforseen consequences for the complex natural system that is the soil profile. For an informed decision to be made, a manager would need to understand the methodology applied to develop the soil property map from the EM data, have some knowledge of the uncertainty introduced through the regression procedure and appreciate the consequences of any intervention that is chosen. In most circumstances the EM contractor would be wise to refer the manager to a suitably qualified soil specialist or agronomist.

8.4. The need for soil sampling

A soil conductivity map without any soil analysis has a low value. A soil conductivity map with a number of soil samples taken across the survey area from a range of EM values has a higher value. A soil property map of an analysed variable created through regression analysis with EM data potentially has a high value. However, there is also a risk associate with this, as described above.

For a manager requiring information concerning critical soil properties, the intensive effort required to provide models of soil properties with an acceptable level of uncertainty might make regression analysis of the EM data an inappropriate selection. At this point an assessment of the soil characteristics by a suitably qualified soil specialist would be warranted. However, the EM conductivity map would still provide a useful tool in guiding the investigations of the soil specialist.

It is arguable whether there is a broad enough knowledge base within the agricultural sector to allow informed decisions regarding these matters. A Code of Practice should recognise this and the onus should be placed on contractors to correctly represent their technology and the data produced.

8.5. Regression analyses for EM-soil calibrations

Statistically, the number of soil sampling points required to adequately represent a typical arable paddock will depend on the spatial variance. There is at least one software package available (ESAP95, USDA) that assists in selecting a sampling regime which provides a balance between an economic number of samples as well providing representation of the variation within the paddock. An alternative method of identifying sample locations is to choose one to two points in each decile of data provided they represent large areas of the field. One to two sample points per decile per 100-200 ha should provide sufficient points for typical grain paddocks. Ultimately, it depends on the accuracy required. Appendix F shows typical errors obtained from 50-100 ha fields from the Murray Mallee region (G.J. O'Leary, unpublished data, 2004). The standard regression approach to calibrating ECa data against known soil parameters is to fit a straight line through the data. This can be done in Excel or many other statistical packages. However, not all ECa data are best described linearly and, in some instances, curves may provide a better option. This is because ECa and the true ECe or EC(1:5) are near linear at low ECa (<1 dS/m) but become curved beyond that range. Furthermore, regressions against soil water content are often curved (convex) while relationships with salt levels (e.g. soil Cl) can curve in the opposite direction (concave). A common feature of ECa calibration curves is that they nearly always pass through zero. Polynomials are also useful but beware that their nature (multiple maxima and minima) can result in spurious extrapolations in some data sets. Polynomials also need more data points than linear functions to maintain adequate degrees of freedom. To indicate uncertainty in regression analyses operators should at least quote the accuracy (e.g. Root Mean Squared Error (RMSE)) either of the original data set (sometimes called the training set) or an independent data set.

8.6. Selection of soil sampling points check list

- The survey objective should determine the required detail of the sampling regime.
- Sample locations should cover the full range of map readings.
- Paddock history should be considered when designing a sampling regime. More samples will be required if paddocks are fragmented with different histories.
- The location of samples should be confirmed to establish relationships between soil characteristics and EM data.
- All samples should be correctly labelled.
- Samples taken for soil water content should be sealed in the field immediately.
- Depending on analyses to be conducted, soil samples should be stored under refrigeration. Temperatures of less than 4°C should provide stable samples for many months.

9. Recommended statement of ethics

The working groups discussed the importance of a code of ethics and agreed to adopt a code based on the 'Code of ethics for soil surveyors amended to suit EM service providers as follows:

Members of the soil conductivity service industry (commercial providers, researchers and data users) recognise that a professional approach is founded upon integrity, competence and provision of appropriate service. This concept shall guide their conduct at all times. In this way, each person's actions will enhance the reputation and status of the industry.

The soil conductivity surveying industry will build it's reputation on the basis of merit of the services performed or offered by individuals.

Members of the industry are aware that technologies and interpretations are evolving and improving as knowledge increases so communication of advances across the industry is very important.

Each person who is engaged in the use, development and improvement of soil conductivity mapping services should accept these principles as a set of dynamic guides for conduct. It is an inherent obligation to apply oneself to one's industry with all diligence and in so doing to be guided by this Code of Ethics.

Accordingly, each person in the soil conductivity mapping services industry shall have full regard for achieving excellence in the practice of the surveying and interpretation and of maintaining the highest standards of ethical conduct in responsibilities and work for an employer, all clients, colleagues and associates and society at large, and shall:

1. Be guided in all professional activities by the highest standards and be a faithful trustee or agent in all matters for each client or employer.
2. At all times function in such a manner as will bring credit and dignity to the soil conductivity mapping industry.
3. Strive to apply appropriate technology and approaches to deliver a quality product that meets the requirements of clients
4. Not compete unfairly with anyone who is engaged in the mapping sciences profession by:
   - Advertising in a self-laudatory manner;
   - Monetarily exploiting one's own or another's employment position;
   - Publicly criticising other persons working in or having an interest in the soil conductivity mapping industry; and/or
   - Exercising undue influence or pressure, or soliciting favours through offering monetary inducements.
5. Work to strengthen the soil conductivity mapping industry by:
   - Personal effort directed toward improving personal skills and knowledge;
   - Interchange of information and experience with other persons interested in and using a soil conductivity mapping approach, with other professions, clients and the public;
   - Seeking to provide opportunities for professional development and advancement of persons working under his or her supervision; and
   - Promoting the principle of appropriate compensation for work done by persons in their employ.
6. Undertake only such assignments in the use of soil conductivity mapping services for which one is qualified by education, training, and experience, and employ or advise the employment of experts and specialists when and wherever clients' or employers' interests will be best served thereby.
7. Give appropriate credit to other persons and/or firms for their professional contributions.
8. Recognise the contributions and rights of others.

10. Opportunities for future working groups

A further opportunity that the EM mapping industry could consider is the potential to develop some form of competency standards, leading to an industry accreditation program. The topic is beyond the scope of this manual, but could be investigated by a small working group of interested people. Some background information and an example of an accreditation scheme in the field of soil science are provided in Appendix G.

Further reading

ANON (2004). Global positioning system handbook. GPS data collection for integration with

geographic information systems. Standards, specifications and best practice field Guide. Department of Sustainability and Environment and Department of Primaries Industries, Victoria.

BEECHER, HG (ed.) (2001). Electromagnetic Techniques for Agricultural Resource

Management. Proceedings of the Riverina Branch conference, ASSSI. Yanco

Agricultural Institute, Yanco, New South Wales. July 3-5, 2001.

PRECISIONAGNEWS (2003). The Magazine of the Southern Precision Agriculture

Association. 2 (1) Winter 2003. (http://www.spaa.com.au/downloads/SPAAwinter2003.pdf).

PRECISIONAGNEWS (2004). The Magazine of the Southern Precision Agriculture

Association. 2 (3) Summer 2004. (http://www.spaa.com.au/downloads/SPAAsummer2004.pdf).

References

BRAMLEY R (2004) Some tips on map production for PA. PRECISIONAGNEWS. The Magazine of the Southern Precision Agriculture Association. 2 (3) Summer 2004 56-58. (http://www.spaa.com.au/downloads/SPAAsummer2004.pdf).

BRAMLEY, R. AND WILLIAMS, S. (2004). A protocol for the construction of yield maps from data collected using commercially available grape yield monitors. Cooperative Research Centre for Viticulture. 21p. Victoria. http://www.crcv.com.au/research/programs/one/CRCVProtocolBkfinal.pdf)

COOK, P.G., WALKER, G.R., BUSELLI, G., POTTS, I. AND DODDS, A.R. (1992). The application of electromagnetic techniques to groundwater recharge investigations. J. Hydrology 130 201-229.

CORWIN, D.L. AND LESCH, S.M. (2003a). Application of soil electrical conductivity to precision agriculture: theory, principles and guidelines. Agronomy Journal 95 455-471.

CORWIN, D.L. AND LESCH, S.M. (2003b). Survey protocols for characterising soil spatial variability with apparent soil electrical conductivity. USDA-ARS Salinity Laboratory.

DE JONG, E., BALLANTYNE, A.K., CANERON, D.R. AND READ, D.W. (1979). Measurement of apparent electrical conductivity of soils by an electromagnetic induction probe to aid salinity surveys. Soil Sci. Soc. Am. J. 43 810-812.

JOHNSON, C.K., DORAN A.W., DUKE H.R., WIENHOLD B.J., ESKRIDGE K.M. AND SHANAHAN J.F. (2001). Field-scale electrical conductivity mapping for delineating soil condition. Soil Sci. Soc. Am. J. 65 1829-183

KELLER, G.V. AND FRISCHKNECHT, F.C. (1966). Electrical methods in geophysical prospecting. Chapter 1. Pergamon Press, N.Y.

KITCHEN N.R., SUDDUTH K.A AND DRUMMOND S.T. (2000). Characterizing soil physical and chemical properties influencing crop yield using soil electrical conductivity. Presented at: Second International Geospatial Information in Agriculture and Forestry Conference, Lake Buena Vista, Florida 10-12 January 2000.

MCNEIL, J.D. (1980). Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6. Geonics Limited. 15p.

MINASNY, B., MCBRATNEY, A.B. AND WHELAN, B.M. (1999). VESPER V1.0. Australian Centre for Precision Agriculture.

http://www.usyd.edu.au/su/agric/acpa/vesper/vesper.html

O'LEARY, G.J. (2003). How to speed-correct EM data collected with mobile data loggers. PrecisionAg News - The Magazine of the Southern Precision Agriculture Association. 2 (1) Winter 2003 9-11.

O'LEARY, G.J., GRINTER, V.T. AND MOCK, I.T. (2004). Optimal transect spacing for EM38 mapping for dryland agriculture in the Murray Mallee. Proceedings of the 4 th International Crop Science Congress. Brisbane, Australia, 26 September - 1 October 2004. http://www.cropscience.org.au/icsc2004/poster/1/6/493_olearyg.htm

ORMESHER, D. AND DALE, M.O. (2001). EM38 operating standards and practices - a workshop discussion for practitioners. In Electromagnetic techniques for agricultural resource management. Proceedings of the Australian Society of Soil Science, Riverina Branch conference. ASSSI. Yanco Agricultural Institute, Yanco, New South Wales, July 3-5 2001. 175-179

MCLEOD, G. AND SHAW, C. (2001). Commercial applications of EM31 for differentiating areas suitable for rice growing in the NSW Murray Valley. In Electromagnetic techniques for agricultural resource management. Proceedings of the Australian Society of Soil Science, Riverina Branch conference. ASSSI. Yanco Agricultural Institute, Yanco, New South Wales, July 3-5 2001

SUDDUTH, K.A., DRUMMOND, S.T. AND KITCHEN, N.R. (2001). Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Computers and Electronics in Agriculture 31 239-264

WHELAN BM AND MCBRATNEY AB (2003). Definition and interpretation of potential management zones in Australia. . In Solutions for a better environment. Proceedings of the 11th Australian Agronomy Conference. 2 - 6 February 2003, Geelong, Victoria. Australian Society of Agronomy. ISBN 0-9750313-0-9

http://www.regional.org.au/au/asa/2003/c/15/oleary.htm

WILLIAMS, B.G. AND BAKER, G.C. (1982). An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Aust. J. Soil Res. 20 107-118

Appendices

- Appendix A: Example of the fundamental data
- Appendix B: Example objectives, maps and fundamental data set
- Appendix C: Minimisation of speed errors
- Appendix D: Example worksheet to record electronic drift at calibration points.
- Appendix E: Units of measurement
- Appendix F: Typical errors obtained for calibration of EC against various soil variables from 50-100 ha fields in the Murray
- Appendix G: Example of an accreditation scheme in the field of soil science
- Appendix H: Acronyms and abbreviated terms

Appendix A: Example of the fundamental data

This provides an annotated example of the fundamental data set that is recommended for all EM surveys. Example fundamental data set [Word doc, 85kb] Example fundamental data set [Excel doc, 24kb]

EM DATA CATEGORY	CORE DATA ELEMENT	DESCRIPTION
DATASET	Title	USE SPAA NAMING CONVENTION (Bramley 2004) www.spaa.com.au
	Custodian	e.g. Golddog Solutions Pty Ltd
	Jurisdiction	Not applicable
DESCRIPTION	Abstract	Define saline prone areas in the lower landscape on Boomdock Farms
	Purpose	Define saline prone areas in the lower landscape on Boomdock Farms
	Search word(s)	e.g. Electromagnetics, EM38, EM, EM31, Pine Ridge, New South Wales
	Geographic extent name(s)	e.g. New South Wales
	Geographic extent polygon(s)	Map Projection: Geographic Datum: WGS84 Minimum longitude 150.467214 E Minimum latitude: 31.514786 S Maximum longitude: 150.476115 E Maximum latitude: 31.530658 S
DATA CURRENCY	Beginning date	11 August 2004
	Ending date	11 August 2004
DATASET STATUS	Progress	Complete
	Maintenance and update frequency	Not applicable.
ACCESS	Stored data format	Comma-delimited text files (*.csv)
	Available format types	
	Access constraints	Approval of client required
DATA SOURCE	Hardware	e.g. Veris
	Data acquisition software	Specify settings

Lineage	Data was acquired by: SoilEM Services Pty Ltd, PO. Box 12345, Mount Gambier, SA 6001. The further we get from the raw data developing derived products the more important lineage becomes.	
Positional accuracy	Not specified.	
Attribute accuracy	Not specified.	
Completeness	Complete.	
GPS settings	Signal source	
	Set up	
	Antenna offset	
Instrument settings	Instrument	e.g. EM38 dual dipole
	Mounting	e.g. 1m high on quad ATV
	Orientation	V, H or V+H
	Battery strength	Start/End
	Warm-up period	E.g. 20 minutes
	Transmitter coil	Zero/Initial/Adj
	Functional checks	In Phase - After Adj Comp- ECa, Init & Adj Phase- Init & Adj
	Signal drift management	Method used
	Std site check	Value (Time)
	Vertical reading	
	Horizontal reading	
	Standard site location	co-ordinates
Conduct of survey	Crop/soil condition	e.g. vigorous wheat growth stage 5 e.g. cloddy ploughed fallow
	Air temperature	Start/End
	Soil wetness	0 1 2 3 4 5 An educated guess is all that is needed here
	Transect spacing	e.g. 20m
	Speed	<15km/hr, >15km/hr, ( )km/hr
	Signal recording	1/sec

Appendix A: Example of the fundamental data

Appendix A: Example of the fundamental data (continued)

EM DATA CATEGORY	CORE DATA ELEMENT	DESCRIPTION	
DATA QUALITY	Data handling	Corrections	Bad data points: used ESAP95 to filter out anomalous data
			Data density:
			Instrument drift:
			Speed: e.g. equation used
	Ground-truthing	Sample location method	e.g. ESAP 95 software
		Sample date	
		Number of samples	
		Sample depths	
		Sample type	e.g. undisturbed core
		Lab used	
CONTACT INFORMATION	Contact organisation		
	Contact person		
	Mail address		
	Locality /suburb/place		
	State		
	Country		
	Postcode		
	Telephone		
	Facsimile	(03) 9361 0977	
	Electronic mail address	Info@silverfox.net.au	
EM DATE	EM survey date	31 August 2004	
ADDITIONAL EM DATA	Additional EM data		

Appendix A: Example of the fundamental data

Appendix B: Example objectives, maps and fundamental data set

This provides example pages from an actual EM survey including:

- survey objectives,
- ECa map,
- soil sample map,
- calibration statistics
- maps of predicted soil water and salinity, and
- fundamental data set

Example EM survey objectives [Word doc, 23kb]

1. Background

This survey is the first of several surveys to be undertaken at the site. Subsequent surveys will be conducted at different levels of soil water. This survey will be conducted over canola stubble, prior to seeding. Significant recharge of the soil profile has occurred between harvest and the planned survey date.

2. Issues

Water levels and sub-soil sodicity are key properties of interest in this study. Topographic data is not required since this was collected during a previous survey.

3. Purpose

The electromagnetic survey will be conducted to provide data for a research project into the evaluation of subsoil constraints to broad acre cropping in the area. The survey aim is to identify variation in soil properties across the paddock, focussing on variation with depth. Particular emphasis will be placed on assessing subsoil properties that might limit crop growth and development.

4. Choice of instrument

Dual dipole EM38 was chosen for this survey because the use of data from both dipoles allows a better understanding of the variation of soil properties with depth.

5. Accuracy required

◘ < 2cm ☑< 1m ◘ < 2m ◘ < 5m ◘ < 10m

Sub-metre GPS accuracy will be sufficient as topographic data is not required. However, a cm-accurate RTK GPS is available and will be used for this survey.

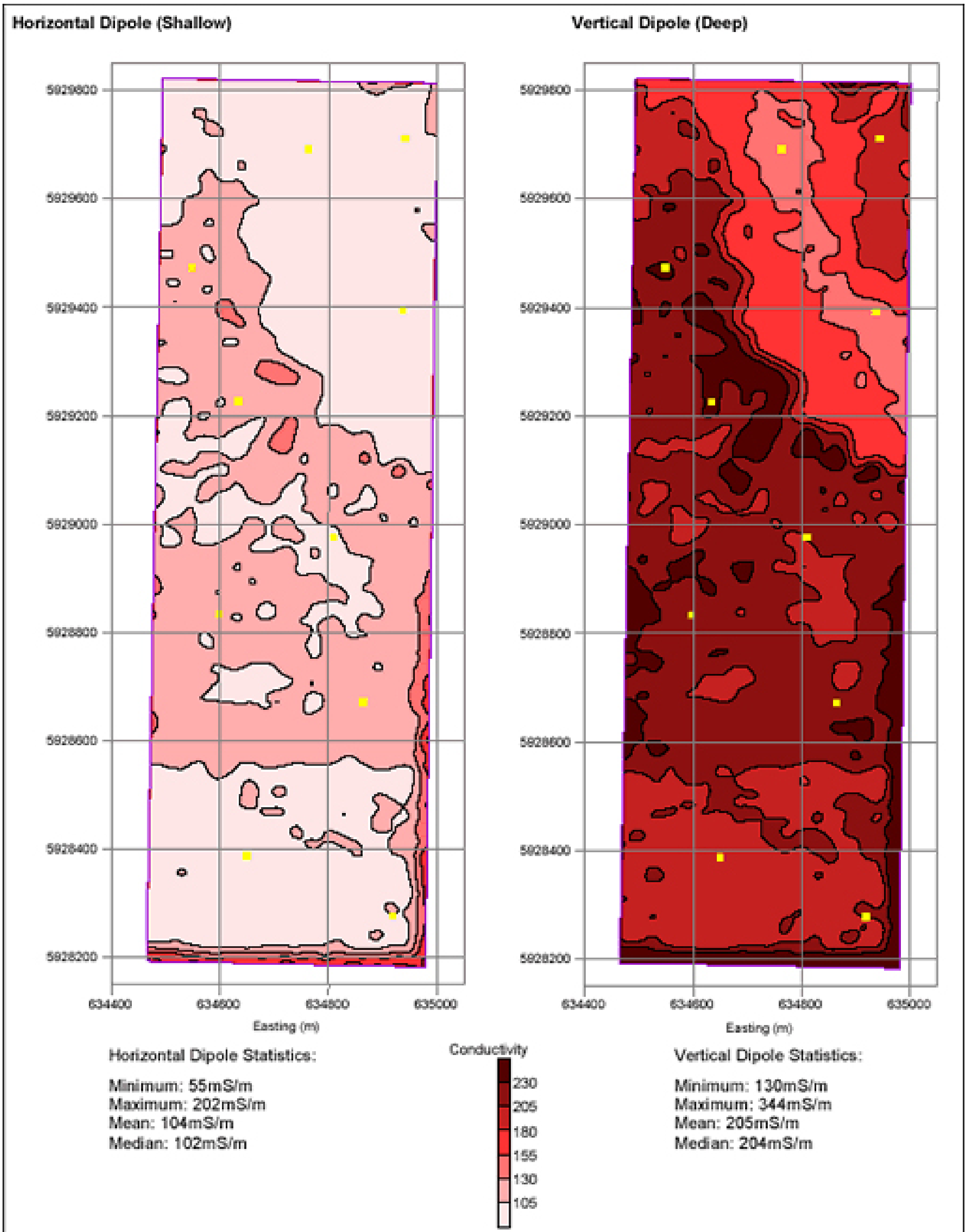
6. Type of GPS signal to be used

◘ AGPS ◘ DGPS ◘ WAAS ☑ RTK

7. Limitations

As soil water is of importance to this study, soil samples will be taken as soon as possible after the survey.

The site does not have any specific hygiene requirements (such as a plant hygiene certificate). In accordance with standard procedure, all equipment will be thoroughly cleaned and inspected for soil and plant material prior to entering and leaving the site.



Map showing apparent electrical conductivity of the soil. Dark areas (high conductivity) indicate heavier/wetter soil, buckshot, compaction or salinity. Map requires calibration with soil samples to determine cause of variation.

Site ID: My Paddock
Example Soil Conductivity Map

My Farm Mapped with Geonics EM38DD

Soil sample location

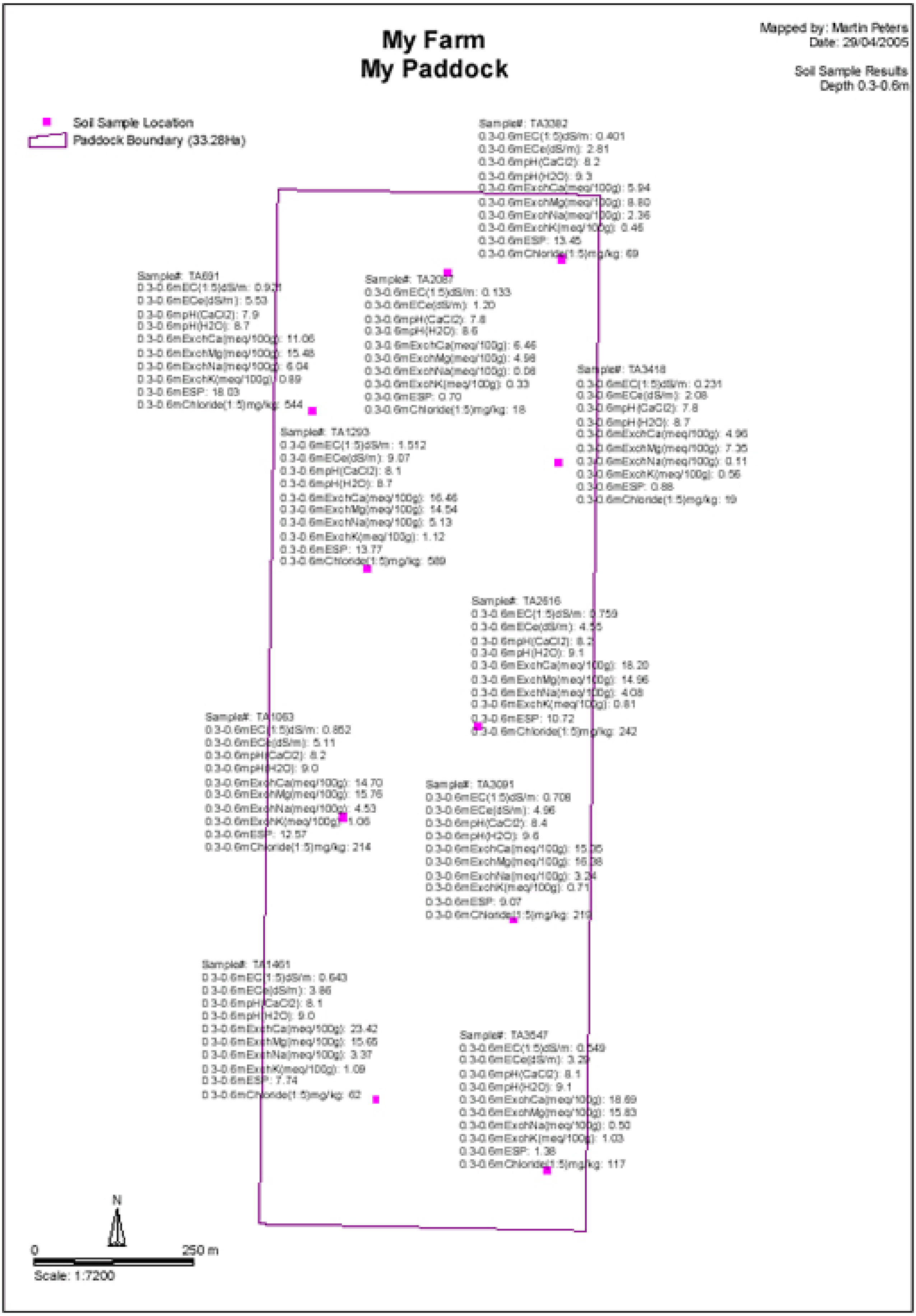
Scale 1:9,000
0 100 200 300 400
Map Grid Australia (GDA94) Zone 54

www.acmepa.com.au

Mapped By: Martin Peters
Drawn By: Jo Peters

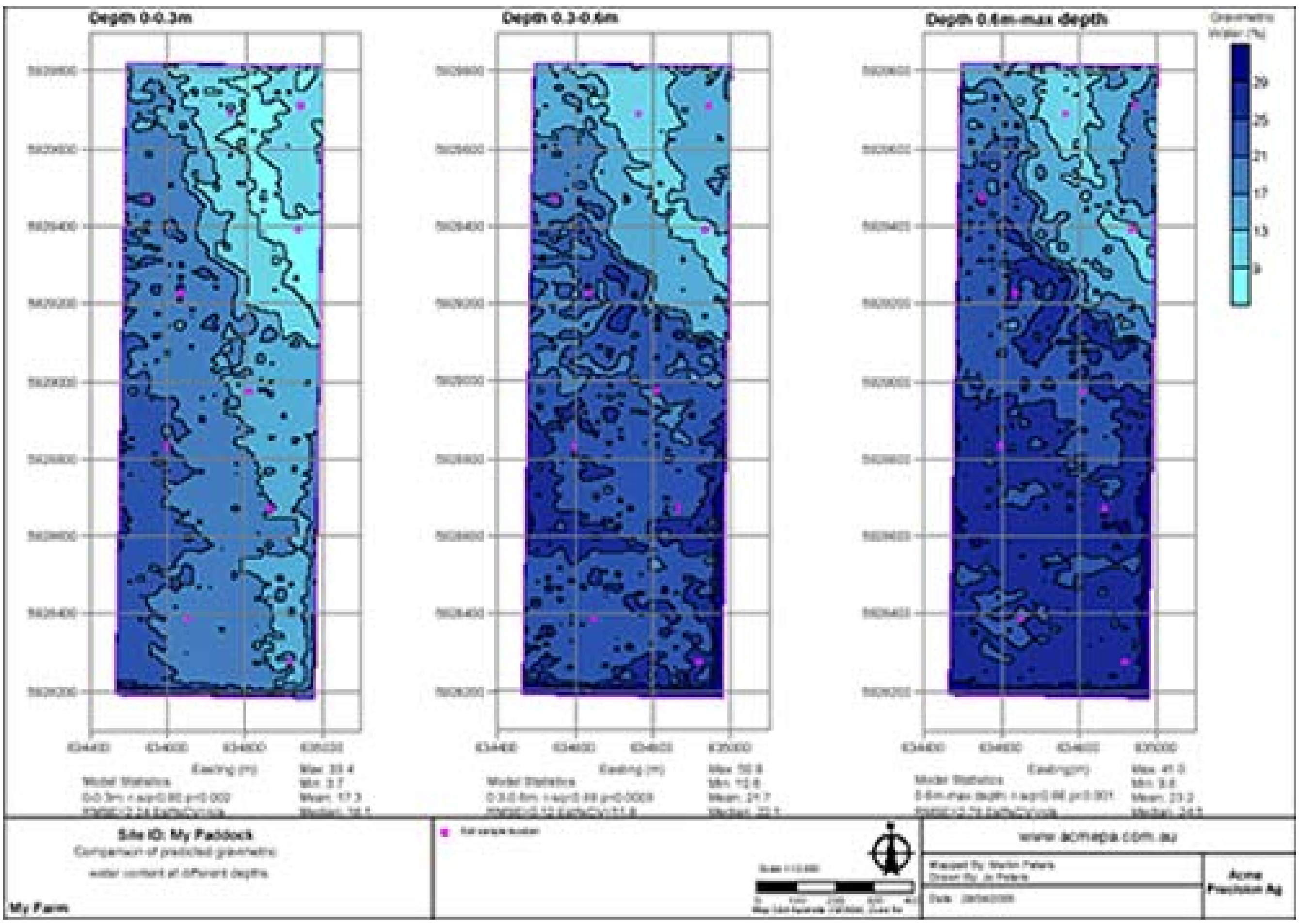
Date : 29/04/2006

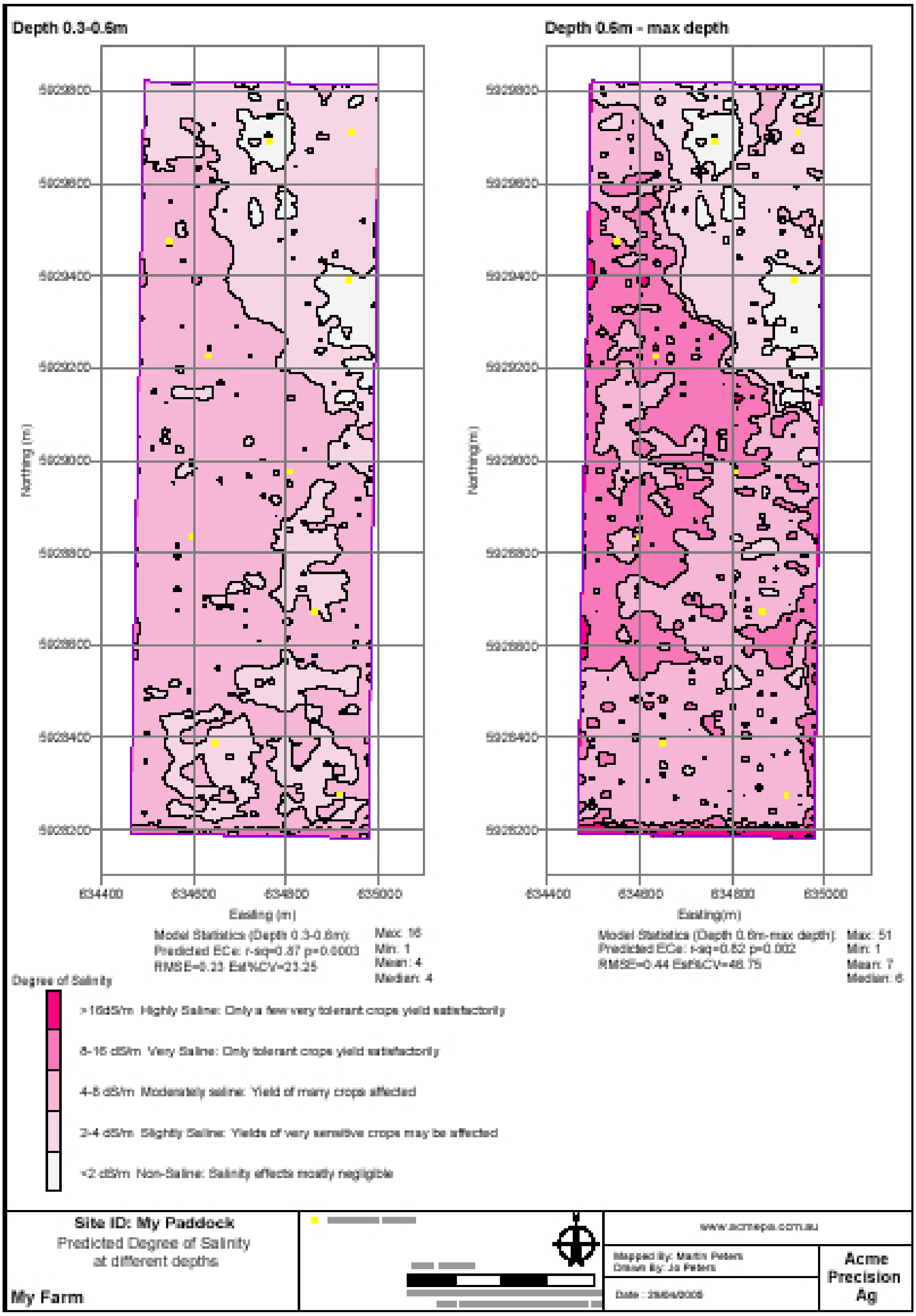
Acme Precision Ag


My Farm
My Paddock
Mapped by: Martin Peters
Date: 29/04/2005
Soil Sample Results
Depth 0.3-0.6m
Soil Sample Location
Paddock Boundary (33.28Ha)
Sample#: TA3082
0.3-0.6mEC(1:5)dS/m: 0.401
0.3-0.6mECe(dS/m): 2.81
0.3-0.6mpH(CaCl2): 8.2
0.3-0.6mpH(H2O): 9.3
0.3-0.6mExchCa(meq/100g): 5.94
0.3-0.6mExchMg(meq/100g): 8.80
0.3-0.6mExchNa(meq/100g): 2.36
0.3-0.6mExchK(meq/100g): 0.46
0.3-0.6mESP: 13.45
0.3-0.6mChloride(1:5)mg/kg: 69
Sample#: TA691
0.3-0.6mEC(1:5)dS/m: 0.921
0.3-0.6mECe(dS/m): 5.53
0.3-0.6mpH(CaCl2): 7.9
0.3-0.6mpH(H2O): 8.7
0.3-0.6mExchCa(meq/100g): 11.06
0.3-0.6mExchMg(meq/100g): 15.48
0.3-0.6mExchNa(meq/100g): 6.04
0.3-0.6mExchK(meq/100g): 0.89
0.3-0.6mESP: 18.03
0.3-0.6mChloride(1:5)mg/kg: 544
Sample#: TA2087
0.3-0.6mEC(1:5)dS/m: 0.133
0.3-0.6mECe(dS/m): 1.20
0.3-0.6mpH(CaCl2): 7.8
0.3-0.6mpH(H2O): 8.6
0.3-0.6mExchCa(meq/100g): 6.46
0.3-0.6mExchMg(meq/100g): 4.98
0.3-0.6mExchNa(meq/100g): 0.08
0.3-0.6mExchK(meq/100g): 0.33
0.3-0.6mESP: 0.70
0.3-0.6mChloride(1:5)mg/kg: 18
Sample#: TA3418
0.3-0.6mEC(1:5)dS/m: 0.231
0.3-0.6mECe(dS/m): 2.08
0.3-0.6mpH(CaCl2): 7.8
0.3-0.6mpH(H2O): 8.7
0.3-0.6mExchCa(meq/100g): 4.96
0.3-0.6mExchMg(meq/100g): 7.35
0.3-0.6mExchNa(meq/100g): 0.11
0.3-0.6mExchK(meq/100g): 0.56
0.3-0.6mESP: 0.88
0.3-0.6mChloride(1:5)mg/kg: 19
Sample#: TA1293
0.3-0.6mEC(1:5)dS/m: 1.512
0.3-0.6mECe(dS/m): 9.07
0.3-0.6mpH(CaCl2): 8.1
0.3-0.6mpH(H2O): 8.7
0.3-0.6mExchCa(meq/100g): 16.46
0.3-0.6mExchMg(meq/100g): 14.54
0.3-0.6mExchNa(meq/100g): 5.13
0.3-0.6mExchK(meq/100g): 1.12
0.3-0.6mESP: 13.77
0.3-0.6mChloride(1:5)mg/kg: 589
Sample#: TA2616
0.3-0.6mEC(1:5)dS/m: 0.759
0.3-0.6mECe(dS/m): 4.55
0.3-0.6mpH(CaCl2): 8.2
0.3-0.6mpH(H2O): 9.1
0.3-0.6mExchCa(meq/100g): 18.20
0.3-0.6mExchMg(meq/100g): 14.96
0.3-0.6mExchNa(meq/100g): 4.08
0.3-0.6mExchK(meq/100g): 0.81
0.3-0.6mESP: 10.72
0.3-0.6mChloride(1:5)mg/kg: 242
Sample#: TA1063
0.3-0.6mEC(1:5)dS/m: 0.852
0.3-0.6mECe(dS/m): 5.11
0.3-0.6mpH(CaCl2): 8.2
0.3-0.6mpH(H2O): 9.0
0.3-0.6mExchCa(meq/100g): 14.70
0.3-0.6mExchMg(meq/100g): 15.76
0.3-0.6mExchNa(meq/100g): 4.53
0.3-0.6mExchK(meq/100g): 1.06
0.3-0.6mESP: 12.57
0.3-0.6mChloride(1:5)mg/kg: 214
Sample#: TA3091
0.3-0.6mEC(1:5)dS/m: 0.708
0.3-0.6mECe(dS/m): 4.96
0.3-0.6mpH(CaCl2): 8.4
0.3-0.6mpH(H2O): 9.6
0.3-0.6mExchCa(meq/100g): 15.95
0.3-0.6mExchMg(meq/100g): 16.08
0.3-0.6mExchNa(meq/100g): 3.24
0.3-0.6mExchK(meq/100g): 0.71
0.3-0.6mESP: 9.07
0.3-0.6mChloride(1:5)mg/kg: 219
Sample#: TA1461
0.3-0.6mEC(1:5)dS/m: 0.640
0.3-0.6mECe(dS/m): 3.86
0.3-0.6mpH(CaCl2): 8.1
0.3-0.6mpH(H2O): 9.0
0.3-0.6mExchCa(meq/100g): 23.42
0.3-0.6mExchMg(meq/100g): 15.65
0.3-0.6mExchNa(meq/100g): 3.37
0.3-0.6mExchK(meq/100g): 1.09
0.3-0.6mESP: 7.74
0.3-0.6mChloride(1:5)mg/kg: 62
Sample#: TA3547
0.3-0.6mEC(1:5)dS/m: 0.549
0.3-0.6mECe(dS/m): 3.29
0.3-0.6mpH(CaCl2): 8.1
0.3-0.6mpH(H2O): 9.1
0.3-0.6mExchCa(meq/100g): 18.69
0.3-0.6mExchMg(meq/100g): 15.83
0.3-0.6mExchNa(meq/100g): 0.50
0.3-0.6mExchK(meq/100g): 1.03
0.3-0.6mESP: 1.38
0.3-0.6mChloride(1:5)mg/kg: 117
N
0
250 m
Scale: 1:7200

Regression models predicting soil properties from conductivity

Soil Property	r-sq	p	Root MSE	Est. %CV		
%Sand 0-0.3m	0.35	0.07	9.92	n/a	%Sand = 37.2 -6.4(z1)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%Sand 0.3-0.6m	0.7711	0.0057	0.0848	8.4939	ln%Sand = 3.3 - 0.06(z1) + 0.94(x)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%Sand 0.6-0.9m	0.4158	0.0441	6.1578	n/a	%Sand = 32.3 - 4.3(z1)	z1=a1(lnemv-mean[lnemv]) + a2(lnemh-mean[lnemh]
%Silt 0-0.3m	0.5762	0.0109	4.1015	n/a	%Silt = 12.9 - 4.0(z1)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%Silt 0.3-0.6m	0.6748	0.0036	0.2896	29.58	ln%Silt = 2.2 - 0.37(z1)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%Silt 0.6-0.9m	No valid model					
%Clay 0-0.3m	0.5542	0.0135	0.2922	29.85	ln%Clay = 3.8 + 0.29(z1)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%Clay 0.3-0.6m	0.7625	0.001	0.1089	10.93	ln%Clay = 4.0 + 0.16(z1)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%Clay 0.6-0.9m	0.3056	0.0974	0.277	28.24	ln%Clay = 3.9 + 0.16(z1)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%Gravel 0-0.3m	No valid model					
%Gravel 0.3-0.6m	No valid model					
%Gravel 0.6-0.9m	No valid model					
%GravWater 0-0.3m	0.9035	0.0019	2.2384	n/a	%GravWater = 25.3 + 2.94(z1) - 29.7(x) - 6.1(y)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%GravWater 0.3-0.6m	0.8984	0.0003	0.1175	11.79	ln%GravWater = 3.3 + 0.21(z1) - 0.5(y)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%GravWater 0.6-0.9m	0.8608	0.001	2.78	n/a	%GravWater = 27.8 +4.3(z1) - 9.1(y)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%VolWater 0-0.3m	0.6323	0.006	0.2528	25.69	ln%VolWater = 3.0 + 0.27(z1)	z1=a1(lnemv-mean[lnemv]) + a2(lnemh-mean[lnemh]
%VolWater 0.3-0.6m	0.8937	0.0012	0.0781	7.8199	ln%VolWater = 3.5 + 0.11(z1) - 0.4(y)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
%VolWater 0.6-0.9m	0.7043	0.0024	6.1233	n/a	Vol%Water = 32.6 + 8.32(z1)	z1=(1/std.dev[lnemh])(lnemh - mean[lnemh])
%Water rel to Field Capacity 0.3-0.6m	0.9441	0.0004	0.0623	6.2348	ln%MrelFC = 4.2 + 0.11(z1) + 0.07(z2) - 0.3(y)	z1=a1(lnemv-mean[lnemv]) + a2(lnemh-mean[lnemh] z2=a3(lnemv-mean[lnemv])-a4(lnemh-mean[lnemh])
%Water rel to Field Capacity 0.3-0.9m	0.7668	0.0009	0.1411	14.1816	ln%MrelFC = 4.2 + 0.21(z1)	z1=(1/std.dev[lnemv])(lnemv - mean[lnemv])
Bulk density 0-0.3m	0.7969	0.0038	0.0962	n/a	BulkDensity = 1.1 - 0.13(z1) + 0.3(y)	z1=(1/std.dev[emh])(emh - mean[emh])
Bulk density 0.3-0.6m	0.9383	0.0019	0.0654	n/a	BulkDensity = 1.2 - 0.13(z1) - 0.05(z2) + 0.3(y)	z1=a1(emv-mean[emv]) + a2(emh-mean[emh]) z2=a3(emv-mean[emv])-a4(emh-mean[emh])
Bulk density 0.6-0.9m	0.5859	0.0457	0.1764	17.7832	lnBulkDensity = 0.3 + 0.13(z1) - 0.13(z2)	z1=a1(lnemv-mean[lnemv]) + a2(lnemh-mean[lnemh] z2=a3(lnemv-mean[lnemv])-a4(lnemh-mean[lnemh])
ECe 0.3-0.6m	0.8728	0.0007	0.2294	23.2464	lnECe = 1.4 + 0.37(z1) + 0.20(z2)	z1=a1(lnemv-mean[lnemv]) + a2(lnemh-mean[lnemh]
ECe 0.6-0.9m	0.8212	0.0024	0.4446	46.7534	lnECe = 1.8 + 0.59(z1) + 0.33(z2)	z2=a3(lnemv-mean[lnemv])-a4(lnemh-mean[lnemh])
ESP 0.3-0.6m	0.6773	0.0034	3.6711	n/a	ESP = 9.6 + 4.97(z1)	z1=(1/std.dev[emv])(emv - mean[emv])





Modelled using 10 soil samples. Sample locations identified using EM data.

emv=vertical dipole reading, emh=horizontal dipole reading Note: all trend surface parameters shown above (if any) have been estimated using centred and scaled location coordinate data

Raw Location Co-ordinates: u and v, Scaled Location C-ordinates: x and y (x=(u-min[u])/k y=(v-min[v])/k k=the greater of: (max[u]-min[u]) or (max[v]-min[v])

EM DATA CATEGORY	CORE DATA ELEMENT	DESCRIPTION
DATASET	Title	example_em+predictions.csv
	Custodian	Acme Precision Ag Co
	Jurisdiction	Not applicable
DESCRIPTION	Abstract	Filtered geophysical data comprising: EM38 dual dipole data and associated predictions of soil properties as one comma-delimited text file (.csv). The following fields are available in sample_em+predictions.csv: ESAP ID, Easting (m), Northing (m), GPSQuality, Speed(km/h), Heading, Transect Spacing(m), Vertical Dipole(mS/m), Horizontal Dipole(mS/m), 0-0.3m%sand, 0-0.3m%silt, 0-0.3m%clay, 0-0.3mTexture, 0-0.3mDry Bulk Density(gcm-3), 0-0.3mGrav Moisture%, 0-0.3mVolMoisture, 0.3-0.6m%sand, 0.3- 0.6m%silt, 0.3-0.6m%clay, 0.3-0.6mTexture, 0.3-0.6mBulk Density(gcm-3), 0.3-0.6mGrav Moisture%, 0.3-0.6mVolMoisture, 0.3-0.6m%H2O rel to Field Capacity, 0.3-0.6mECe(dS/m), 0.3- 0.6m Exchangeable Sodium Percentage, 0.3-0.6mChloride 1:5(mgkg-1), 0.3-0.6m_pHH2O, 0.6- 0.9m%sand, 0.6-0.9m%clay, 0.6-0.9mTexture, 0.6-0.9mBulk Density(gcm-3), 0.6-0.9mGrav Moisture%, 0.6-0.9mVolMoisture, 0.6-0.9m%H2O rel to Field Capacity, 0.6-0.9mECe(dS/m), 0.6- 0.9m Exchangeable Sodium Percentage, 0.6-0.9mChloride 1:5(mgkg-1) Associated data sets: 'example_em_raw.csv' (raw data), 'example_soil_sample_results.csv' (results of soil sample analysis), 'example_model_statistics.csv' (statistics from models of EM with soil properties), 'example_base_log.dat' (GPS log file recorded by RTK base station) 'example_AusPos_report.pdf' (report generated by GeoScience Australia from base station log and used to post-process GPS data to real world co-ordinates) Associated files: 'example_em_report.pdf' (report containing maps, sample results, models and predictions
	Purpose	Identify variation in soil properties across paddock, focussing on variation with depth. Particular empahsis on subsoil properties that might limit crop growth and development.
	Search word(s)	Electromagnetics, EM38, EM, My Farm, VIC
	Geographic extent name(s)	My Paddock, My Farm, Western Victoria
	Geographic extent polygon(s)	MGA 94 Zone: 54 Maximum Northing: 5929819.64 Datum: GDA94 Minimum easting: 634462.94 Minimum northing: 5928185.18 Maximum easting: 634999.89

DATA CURRENCY	Beginning date	29-Apr-05
	Ending date	29-Apr-05
DATA SET STATUS	Progress	Complete
	Maintenance and update frequency	Not applicable.
ACCESS	Stored data format	Comma-delimited text files
	Available format types	Arc View Shape file, Autocad dxf file, Manifold map file, Farm Works client project/ archived layer
	Access constraints	Approval of client required
DATA SOURCE	Hardware	Geonics EM38 dual dipole
	Data acquisition software	Site Mate VRA (Farm Works): setup to account for fact that GPS antenna is 2m in front of EM38DD (GPS readings correspond to actual location of EM data).
DATA QUALITY	Lineage	Data was acquired, processed and modelled by: Acme Soil Mapping Services, My Town, VIC
	Positional accuracy	Collected with RTK GPS (cm accurate), Base location determined using autonomous GPS, Base (and rover) positions corrected for real world co-ordinates using AusPos service from GeoScience Australia. Base GPS file logged for 2.5hrs.
	Attribute accuracy	ECa +/- 5%
	Completeness	Complete.

Appendix A: Example of the fundamental data

EM DATA CATEGORY	CORE DATA ELEMENT	DESCRIPTION	
DATA QUALITY	GPS settings	Signal source	Trimble RTK GPS
		Set up	Original base location determined using autonomous GPS and post processed to correct to real world co-ordinates
		Antenna offset	Vertical: 1.75m, Horizontal: 2m (offset handled by software)
	Instrument settings	Instrument	Geonics EM38 dual dipole
		Mounting	0.1m high on wooden sledge 2m behind quad ATV
		Orientation	V+H
		Battery strength	Not applicable, run from stabilised 9 volt power supply unit
		Warm-up period Transmitter coil	17 minutes
			Not zeroed for this survey - only require relative readings
		Functional checks	In Phase - After Adj Comp-ECa, Init & Adj Phase- Init & Adj
		Signal drift management	Used control station method
		Standard site check	Start time: 15:45, Mid time: 17:00, End time: 18:15
		Vertical reading:	Start: 319, Mid: 321, End: 319
		Horizontal reading:	Start: 200, Mid: 197, End: 198
		Standard site location	Easting (m): 634924.92 Northing (m): 5928203.45
	Conduct of survey	Crop/soil condition	Canola stubble
		Air temperature (oC)	Start: 17, End: 16
		Soil wetness	Average grav moisture from samples: 19.5
		Transect spacing	30m
		Speed	Average speed: 19km/h
		Signal recording frequency	1/sec
	Data handling	Corrections	Bad data points: used ESAP95 to filter out anomalous data
			Data density:
			Instrument drift: no correction required
			Speed: no speed correction required (data collection software setup for this)

	Ground-truthing	Sample location method	ESAP95 software
		Sample date	29-Apr-05 No rainfall between EM survey and sampling
		Number of samples	10
		Sample depths	0-0.3m, 0.3-0.6m, 0.6-0.9m
		Sample type	Undisturbed core
		Sample type Lab used	Acme soil lab, VIC

CONTACT INFORMATION	Contact organisation	Acme Precision Ag Co
	Contact person	Not applicable
	Mail address	1 Acme Way
	Locality / suburb/place	My Town
	State	Victoria
	Country	Australia
	Postcode	3333
	Telephone	
	Facsimile	
	Electronic mail address	info@acmepa.com.au
EM DATE	EM survey date	29-April 2005
ADDITIONAL INFORMATION	Data	
	Data Notes	

Appendix A: Example of the fundamental data

Appendix C: Minimisation of speed errors

Speed induced positional errors in EM data collection can be minimised by four basic methods. The first is to collect the data at a very low speed (<5 km/hr). The second is to measure the error and post-correct the data. The third, is to measure the error and correct the data in real time. And the fourth is to statistically lower the error by averaging large numbers of points over a specified area, for example by using block-kriging. No preferred method is suggested but a reprinted article by Garry O'Leary (2003) from the SPAA Newsletter shows how the error can be measured and post correction applied. This would be useful in the application of the second and third methods.

How to speed-correct EM data collected with mobile data loggers

Garry O'Leary
CSIRO Land and Water, Mallee research Station, Walpeup Vic. 3507

The idea that EM data collected with mobile data loggers has a position error directly proportional to the speed of the data logger has been surprising to many EM practitioners in the industry. Some operators dismiss this idea as being too fussy since the error is normally much less than the size of management units, but what is useful to one client may not be useful to another. This is particularly a problem when you want to return to an interesting position to take soil samples of special interest. Sub-meter accuracy gained with Differential and Real Time Kinematic GPS may be totally destroyed without this correction. The need to apply speed corrections is well known among scientists (Sudduth et al. 2001; O'Leary et al. 2003).

The position error arises from two components. The first is the physical displacement of the GPS antenna from the EM sensor and the second is the result of a time lag for the EM sensor data to be saved into the data logger's memory. The first component error is well understood but the second is not largely appreciated because operators assume that the logging electronics record data instantaneously. In actual practice an acquisition time can be measured for each EM sensor/logger configuration. This lag can be typically around 0.5 seconds that translates to a 2 m error at 15 km/hr and over 4 m at 30 km/hr. A greater lag time results in larger error.

Speed error can be seen in maps made from parallel transects in opposite directions where contours seem to zigzag in response to the direction of travel (Figure 1). Where data is collected in a more random way spatially the errors will not be so obvious, but still present.

Operators should consider the benefits of speed-correcting their EM data. It's not difficult to apply and can be done in a simple spreadsheet calculator. The following correction steps are given as a guide to a simple method to apply to maintain sub-meter accuracy in mobile EM data.

Correction of mobile EM data
A simple linear correction method for mobile collected EM data is suggested. The correction is linear because it assumes that the sensor has moved in a straight line between two logged points (Figure 2). This is a good assumption for most applications, but where the sensor takes a curved path such as turning at the end of a run the method will be inaccurate, but more accurate than the uncorrected data. The method is not valid when the ground speed is zero and for practical reasons where the ground speed is below the resolution of the GPS employed. In practice this should be in the range of the calibration (e.g. 1 to 10 m/sec or 3.6 to 36 km/hr). Data should be excluded where speeds are outside this nominal range.

The objective here is to determine the antenna offset correction (AOC). This is given by:
AOC = a + b (gs)
where, AOC has units of m and gs is the ground speed (m/s). The distance the antenna is in front (or behind) of the EM sensor is the constant a (m) and the logger acquisition time is denoted by b (sec).

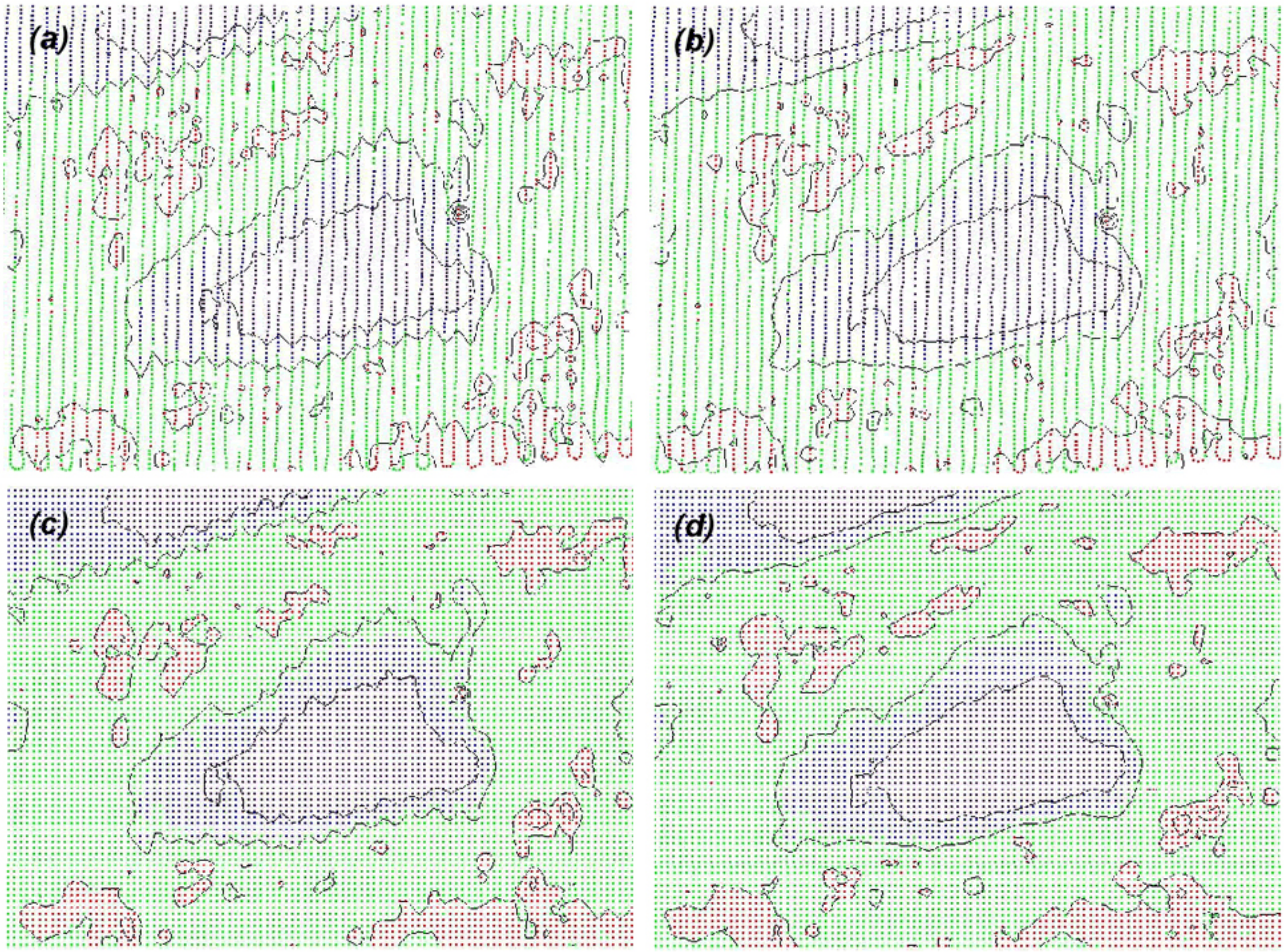


Figure 1. EM38 10 m-spaced transect data plotted without (a) and with (b) speed correction and point-Kriged 5 m grid without (c) and with (d) speed correction. Note the marked zigzag contour boundaries between the zones in the uncorrected data (a, c) corresponding to the direction of data collection.

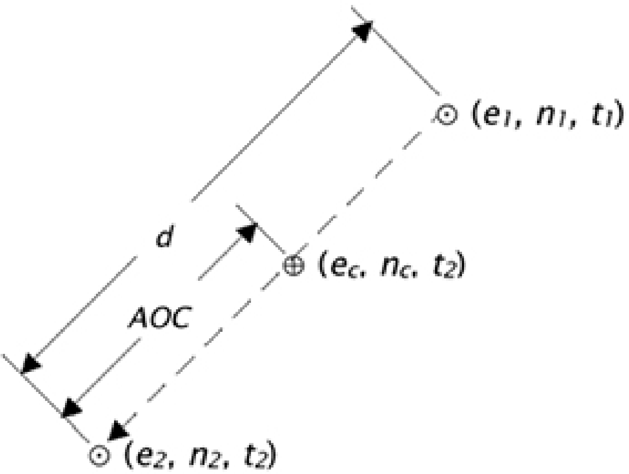
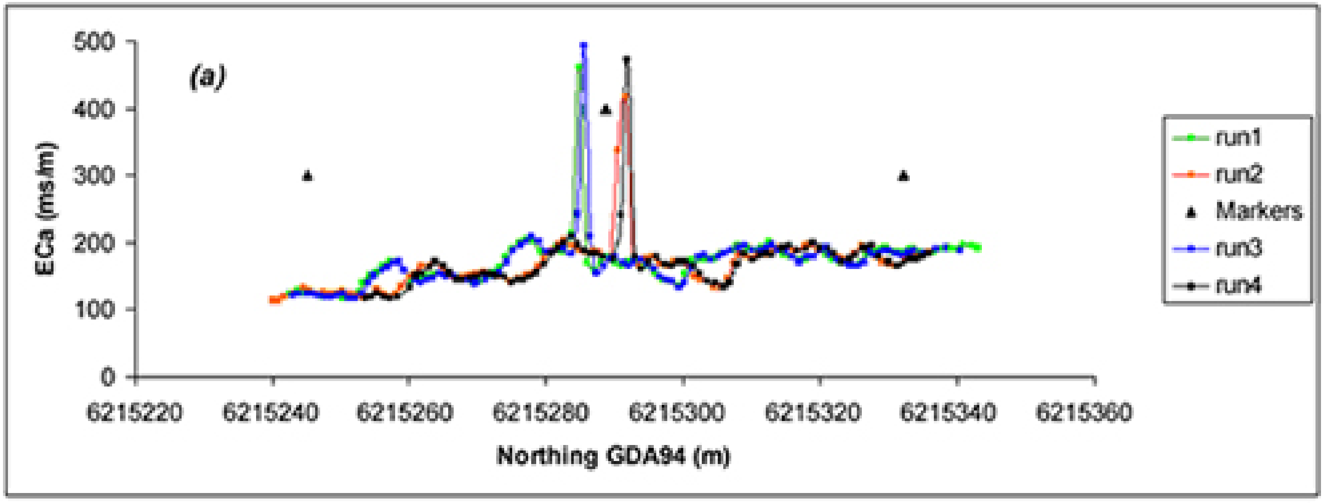


Figure 2. Diagrammatic illustration of the key dimensions of a linear correction for mobile EM data showing logged GPS positions (□) and corrected EM position () at time (t2). Positions are defined by easting (m), northing (m) and time (sec) denoted (e1, n1, t1) and position 2 likewise (e2, n2, t2) where the GPS antenna has moved from position 1 to 2. The corrected EM position is denoted (ec, nc, t2).

Step 1: Obtaining the Antenna Offset Correction calibration coefficients

The AOC coefficients should be determined from a speed calibration. This can be done by selecting a track of about 100 m in a field with known variation in EM. The greater the variation the better. It is also best to bury some highly conductive material (lump of iron etc…) in the centre of the track so that the EM signal will be spiked high when the sensor passes over it. A series of measurements are made over the 100 m track at various speeds for which the calibration is to be valid (Figure 3). This would normally be up to 30 km/hr because despite claims that data collection aims to be at a constant speed (say 15 km/hr) it rarely is and typically varies from near 0 km/hr to well over 20 km/hr especially in hilly terrain.

For this data the error of position (true displacement of the EM signal from known position) can be plotted against the mean speed and the calibration coefficient b determined by simple regression (Figure 4). The error of position can be measured from Figure 3a, which shows a typical plot of EM against distance (in this case northing) without the correction. Four runs were made, two in each direction (Figure 3a); the position of the spike material is also shown. This process is repeated at a range of speeds to enable the regression of offset correction against ground speed to be made (Figure 4). The coefficient a can either be measured directly with a tape measure or from the y-axis intercept of the calibration graph (Figure 4).



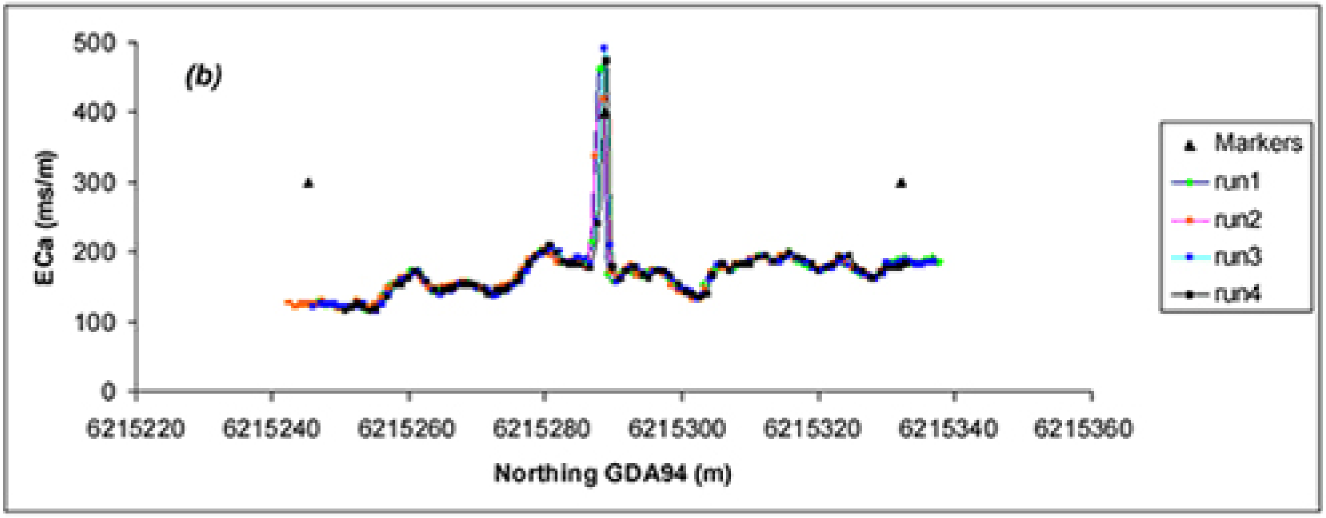


Figure 3. EM measurement (Apparent electrical conductivity, ECa) collected at 4 km/hr without (a) and with (b) correction over a 100 m run. In order to determine the Antenna Offset Correction (see Figure 4), a plot like that

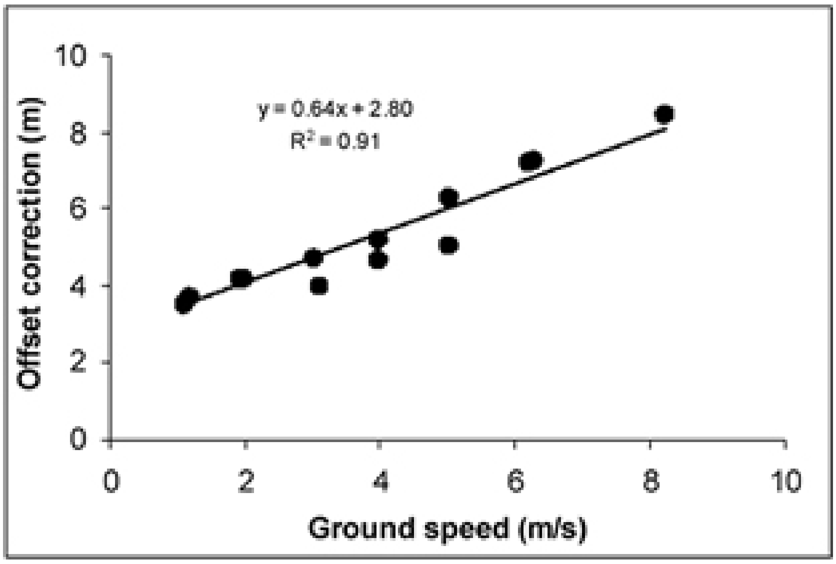


Figure 4. Example speed calibration showing the regression equation with a 0.64 second acquisition time and a zero-speed offset of 2.8 m behind the

GPS antenna (the Y-axis intercept).

Step 2: Applying the correction

The simple linear correction can be applied to the position data as follows, where the logged position 1 is defined by easting (m), northing (m) and time (sec) denoted (e1, n1, t1) and position 2 likewise (e2, n2, t2). The corrected position is denoted (ec, nc, t2).

The distance (d; m), time (t; sec) and ground speed (gs; m/sec) between the logged points are calculated as follows:

$$d = \sqrt{\left[(e_2 - e_1)^2 + (n_2 - n_1)^2\right]}$$

$$t = t_2 - t_1$$

$$gs = \frac{d}{t}$$

The corrected position at time t2 (ec, nc, t2) for the EM sensor is then calculated by

$$e_c = e_2 - AOC(e_2 - e_1)/d$$

$$n_c = n_2 - AOC(n_2 - n_1)/d$$

Acknowledgments

The GRDC, CSIRO and Victorian Department of Primary Industries funded this work. We thank our collaborating EM contractors Dennis Ormesher, Ken Bates and Michael Wells and farmers Alan Buckley, Howard and Alex Hillerman, Adrian and Colin Stoeckel and Kevin and Trudy Ryan for supplying data and unrestricted access to their farms for this work.

References

O'LEARY, G.J., ORMESHER, D. AND WELLS, M. (2003). Detecting subsoil constraints on farms in the Murray Mallee. In. Solutions for a better environment. Proceedings of the 11th Australian Agronomy Conference, 2 - 6 February. 2003, Geelong, Victoria.

Australian Society of Agronomy. ISBN 0-9750313-0-9.

http://www.regional.org.au/au/asa/2003/c/15/oleary.htm

SUDDUTH, K.A., DRUMMOND, S.T. AND KITCHEN, N.R. (2001). Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Computers and Electronics in Agriculture 31 239-264

Appendix D: Example worksheet to record electronic drift at calibration points.

EM 38 calibration sheet

Date:__________

Client:______________________

Address:____________________

Transect width __________m

EM units (mS/m or dS/m?) __________

		Battery (V)		Survey	EM reading B4 cal		EM reading after cal		
Date	Time	Reading	Old or new	Dipole V or H	Vertical	Horizontal	Vertical	Horizontal	Comments

Weather conditions

Date	Time	Temp	Wind	Ground conditions	Rain events	Comments

Appendix E: Units of measurement

Electrical conductivity has SI units of Siemens per meter (S/m or S m -1) often expressed as deci-siemens per meter (dS/m or dS m -1). What are Siemens? This is not well known, but can be more easily remembered as the inverse of electrical resistance (ohms -1), which is Amps per Volt. Thus S/m is equivalent to Amps/Volt/m with dimensions of kg -1 m -3 s 3 A 2 . That is, EC is a measure of the current per unit electrical potential difference (or electrical "pressure") per unit distance. Another important unit to understand is the unit of the soil property under study. This is particularly important when it comes to deciding if a volumetric or gravimetric unit is to be employed. Volumetric units are those expressed in terms of volume (e.g. soil bulk density mg m -3), whereas a gravimetric measure would be expressed in terms of mass or weight (e.g. mg kg -1 or ppm). The unit of the denominator defines its volumetric or gravimetric status. Chemical laboratories often report soil analyses in gravimetric units, but many soil parameters can be expressed in both units. Volumetric units are preferred for all EM and crop based analyses because the EM sensor measures ECa from a volumetric basis. Additionally, crops extract water and nutrients from the soil on a volumetric basis. Gravimetric units can be converted to volumetric units by multiplying the gravimetric unit by the density of the medium (e.g. dry soil bulk density for soil chemical analyses).

Appendix F: Typical errors obtained for calibration of ECa against various soil variables from 50-100 ha fields in the Murray Mallee region

Site	# of soil samples	EC(1:5) dS/m		Water (mm/m)		Chloride (g/m 3)		Boron (g/m 3)	
		Accuracy	Error	Accuracy	Error	Accuracy	Error	Accuracy	Error
Balranald	15	96	0.15	93	20	95	248	67	3.1
Hopetoun	6 (12) A	12	0.12	17	25	-	-	45	3.3
(Sowing)									
Hopetoun	10	88	0.08	64	35	77	108	77	3.7
Lascelles	10	69	0.09	0	36	82	101	15	2.8
Loxton	8	99	0.04	93	18	99	105	79	4.9
(Sowing)									
Loxton	10	99	0.04	83	14	99	86	29	6.1
Manangatang	10	98	0.04	64	54	99	39	88	2.3
Sea Lake	10	71	0.13	95	8	95	69	41	2.4
Speed	10	21	0.11	62	45	17	10	6	3.3
Swan Reach	11	44	0.06	61	16	71	35	55	1.2
Waikerie	10	86	0.11	66	19	78	156	82	2.3
Walpeup (Pasture)	22	86	0.09	88	22	93	92	83	2.5
Wemen year1	15	83	0.10	95	15	-	-	71	1.9
Wemen year2	10	98	0.05	96	10	99	41	75	2.4
*A 12 samples used for soil water calibration									

Appendix F: Typical errors obtained for calibration of ECa against various soil variables from 50-100 ha fields in the Murray Mallee region

Table 1. Accuracy (coefficient of Determination; R 2 *100) and error (Root Mean Square Error of the residuals) for weighted calibration of ECa in the vertical mode for soil EC(1:5), water, chloride and boron content for a range of Mallee locations after harvest (except where indicated). The weighted calibration takes into account the effect of depth on ECa sensitivity. Weighting for depth generally provides more accurate calibrations. However, the gains are often small and a non-weighted calibration is of more practical use (G.J. O'Leary, unpublished data, 2004).

Appendix G: Example of an accreditation scheme in the field of soil science

Accreditation of EM services

Accreditation of EM service providers and users is seen as a means of providing standardisation and a clear indication of competency. As described by Rod Davies during the workshop, the Australian Society of Soil Science Incorporated (ASSSI) offers a program for certified Professional Soil Scientist.

The Australian Society of Soil Science Inc. was established to work toward the advancement of soil science in the professional, academic and technical fields. The Society aims to advance soil science and provide a link between soil scientists and members of kindred bodies within Australia and in other countries.

The objectives of the Society are:

- to promote the field of soil science;
- to further the expertise in soil science of members;
- to provide a forum for discussion on soil science;
- to increase government and community awareness of the importance of soil science;
- to liaise and cooperate with other organisations in support of mutual interests;
- to encourage research and extension in soil science; and
- to promote wise management of the soil resource throughout Australia.

The Australian Society of Soil Science Inc. provides its members with an opportunity to gain accreditation under the Certified Professional Soil Scientist Scheme. Members of the Australian Society of Soil Science Inc. can apply for and maintain professional accreditation within the field of soil science with the Certified Professional Soil Scientist (CPSS) accreditation scheme.

A CPSS is a professional who has achieved the Professional Standards set jointly by the Australian Society of Soil Science Inc. and the Australian Institute of Agricultural Science and Technology. Integral to CPSS accreditation is an on-going commitment to keeping up to date with new knowledge, technology and industry developments.

CPSS's are recognised by their professional body as professionals who continually expand their knowledge and skills throughout their career, by seeking professional development opportunities. The CPSS process has an existing mechanism for the provision of indemnity insurance on an individual basis. A panel setup within the ASSSI reviews applications for CPSS by members of the ASSSI. The review process takes place as required. The CPSS process has a number of levels through which an applicant can progress as their experience and knowledge increases.

Other groups such as the Association of Commercial Soil Surveyors are undertaking a review of accreditation and standards including aligning with the ASSSI CPSS.

Having the CPSS imprimatur does not necessarily mean that the person undertakes the survey as required by the GRDC EM protocol.

Additionally many of the current operators of commercial EM services may not wish to; or be sufficiently academically qualified to achieve the CPSS recognition. On-the-job training may be way forward for such operators.

Training in EM services

An alternative means of seeking to achieve a cross industry standardisation and assurance of competently conducted surveys and interpretation and product quality could be through provision of competency based training courses. This subject was discussed and presented at length at the workshop by Geoff Beecher.

The workshop explored the need for accreditation and training in EM service provision. The model used in the Rice industry was presented and is outlined here.

The development of an appropriate training course for EM surveying/interpretation could be undertaken within a registered training organisation (RTO) that could be specific to the grains industry or it could be a more general and flexible; allowing coverage of a range of industries.

The existing EM surveying of rice fields course has been revamped to be more general in nature. The EM course covers 3 units of competency in the spatial information services area (ANTA 2001):

- (PRDSIS06A) Plan data collection and validation
- (PRDSIS07A) Capture new data
- (PRDSIS19A) Collate and interpret data

Provision of training services

Courses can be delivered by any RTO, such as universities, technical and further education colleges, agricultural colleges or commercial provider colleges, if these institutions have such a course on their “scope”. Their “scope” means that each RTO has the approval of the accreditation body in their State to deliver a particular course.

RTOs can apply to the registration board or accreditation board in their state showing that they have staff with the technical qualifications to deliver the course (the person with the technical expertise could be a guest trainer with hands on experience in undertaking the activity that needs to be studied).

Getting a course onto the Scope of an RTO in another state can be achieved in 2 ways:

- The initiating RTO can act as an umbrella organisation. For example, Murrumbidgee College of Agriculture could develop a Memorandum of Understanding with RTOs in other states, where funds are exchanged; or
- Having developed a course, Murrumbidgee College of Agriculture could contact RTOs in other states and ask them to put the course on their scope. (i.e. The interstate RTO applies to the registration board in their state to register to deliver such course with its associated costs).

Recognised prior learning

Recognition of current competencies (or RCC) the acknowledgment of competencies currently held by a person, acquired through training, work or life experience. More commonly known as recognition of prior learning.

Recognition of prior learning (or RPL) the acknowledgment of a person’s skills and knowledge acquired through previous training, work or life experience, which may be used to grant status or credit in a subject or module.

If a suitable course were developed then the opportunity for existing EM/Veris service providers to request recognition of prior learning would exist.

References

AUSTRALIAN NATIONAL TRAINING AUTHORITY (ANTA). (2001). PRD01 Property development and management training package. Volume 2 - Spatial information services sector. Australian Training Products Ltd, Melbourne, Victoria. ISBN 0 642 80382 X

http://www.ntis.gov.au/Default.aspx?/trainingpackage/PRD01/volume/PRD01_2/download

Appendix H: Acronyms and abbreviated terms

Acronyms	Abbreviated terms
AGPS	Autonomous GPS - GPS without differential correction (manufacturer quoted accuracy in the range 10-15m).
AOC	Antenna offset correction
ASSSI	Australian Society of Soil Science Incorporated
ATV	All terrain vehicle - 4 wheel motorbike or quad bike.
CPSS	Certified Professional Soil Scientist Scheme
DGPS	Differential GPS - incorporates a number of methods for improving an autonomous GPS position. The concept is relatively simple in that a 'differential' correction is one that is received and computed at a 'fixed' site and applied to the 'rover' GPS receiver. The differential correction is a determination of the atmospheric affects on the GPS signal, which is applied directly to the rover. DGPS methods include amongst others Real Time Kinematic (RTK), Real Time Differential (RDGPS), Kinematic and Static.
EC	Electrical conductivity - a measure of how well a medium conducts electricity.
ECa	Apparent electrical conductivity - bulk soil electrical conductivity, as measured by various methods.
ECe	Electrical conductivity of a saturated soil paste extract - a measure of soil salinity.
EM/EMI	Electromagenetic induction - a non-destructive method of measuring bulk soil electrical conductivity.
EPIRB	Emergency position indicating radio beacon - a small device which is used in emergencies and which indicates its position by means of a radio transmission.
ESAP95	Software written by USDA Salinity Lab specifically for handling EM data.
ESP	Exchangeable sodium percentage
GPS	Global Positioning System - The Global Positioning System is a satellite-based timing, navigation and positioning service designed, implemented and maintained by the United States Department of Defense. Whilst being intended primarily for military applications, many of the system's capabilities are also made available for civilian use. The GPS satellite constellation comprises a number (currently 27) of high-orbit satellites in six orbital planes providing 24 hour global coverage. Satellites transmit various signals and message information that can be accessed by users to obtain positioning accuracies ranging from ±20 m for a single receiver to centimetre level accuracy in a relative (differential) mode.

GRDC	Grains Research & Development Corporation
NDVI	Normalized Difference Vegetation Index - NDVI provides an estimate of vegetation health and a means of monitoring changes in vegetation over time.
RCC	Recognition of current competencies - the acknowledgment of competencies currently held by a person, acquired through training, work or life experience.
RMSE	Root mean-square error - statistical measure of residual variation
RPL	Recognition of prior learning - the acknowledgment of a person's skills and knowledge acquired through previous training, work or life experience, which may be used to grant status or credit in a subject or module.
RTK	Real-Time Kinematic GPS - provides cm accurate position information in real time.
RTO	Registered training organisation
SPAA	Southern Precision Agriculture Association
WAAS	Wide Area Augmentation System - free GPS differential correction available in the US (accurate to 3m). Currently NOT available in Australia. Other similar systems around the world are EGNOS in Europe and MSAS (a Japanese system that is still in testing, but may be available to Australia in the future).

Appendix H: Acronyms and abbreviated terms

For more information, please visit:
www.grdc.com.au