DEPARTMENT OF
PRIMARY INDUSTRIES

THE SALINITY MONITORING SITE NETWORK IN VICTORIA, STANDARDS AND PROCEDURES

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The salinity monitoring site network in Victoria, standards and procedures

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Abstract

Monitoring is being conducted to collect data on the extent and severity of dryland salinity across Victoria.
The monitoring will enable trends in salinity to be detected, and at paired sites, will indicate whether or not treatment is having an effect.

Salinity is documented using a variety of techniques, and this report details the standard method and procedure adopted in Victoria. The standard enables anyone to conduct monitoring and produce results directly comparable to their peers, both now and in the future.

The assessment of the extent of the discharge at the site is conducted using electromagnetic induction, vegetation analysis and soil sampling.

The method has been used in Victoria for 10 years and has proven to be reliable.

Keywords: salinity monitoring, discharge areas, electromagnetic induction assessment, EM38, dryland salinity

1 Introduction

Dryland salinity is a major soil and water problem in Victoria. In order to provide data to landholders and land managers, dryland salinity mapping and monitoring is being conducted to collect data on (i) the area and severity of dryland salinity, and (ii) soil salinity trends across Victoria.

Mapping has been conducted at a broad scale and recorded on the dryland salinity database held by the Department of Primary Industries (DPI).

More detailed monitoring to identify both trends and the effectiveness of recharge control options is conducted using approximately 50 strategically located discharge monitoring sites (see Map 1).

This report focuses on the discharge monitoring site network. It details the methods used to select and establish a monitoring site, and the re-assessment protocol. It is proposed that these procedures are to be used as the standards for the dryland salinity monitoring network in Victoria.

1.1 Dryland salinity

The term dryland salinity refers to the build-up of salt in the soil and groundwater systems. In many cases this is thought to result from the clearing of deep-rooted, native vegetation and its replacement with shallow-rooted, low water-using plants common in pasture and cropping enterprises. Salinity has long been recognised as a problem in Victoria. Robertson (1898) referred to the appearance of saline springs on the Dundas Tablelands in Western Victoria in 1853 shortly after European settlement commenced.

Allan (1994) identified two types of dryland (non-irrigation) salinity:

1. Primary (or natural) salinity, which existed long before European settlement and is held to be the result of natural environmental processes.
2. Secondary (or induced) salinity has occurred since European settlement and is considered to be the result of changes in land and water management practices.

This project focuses on monitoring changes in the area and extent of secondary dryland salinity in Victoria.

1.2 History of dryland salinity assessment

In the 1950s, after dryland (non-irrigated) salinity was acknowledged to be a major environmental problem in Victoria, government agencies began to assess the size of the problem and monitor its progress. The first surveys were confined to specific regions and assessment criteria varied from region to region. It was recognised that a piecemeal approach to the problem would not be in the best interests of the community.

As a consequence, a project was funded by the National Soil Conservation Project to develop a standard method for identifying, assessing and recording dryland salinity in Victoria (Matters & Boruvka 1987). The field guide for identifying salt-tolerant plants, *Spotting Soil Salting* (Matters & Bozon 1989) also resulted from this work.

In 1989 a statewide salinity initiative project was established to map all known (but previously unrecorded) dryland salinity sites and, as far as possible, locate and record newly emergent and previously unknown sites. In addition, information was to be collated on expansion rates. The Salinity Discharge Monitoring and Salinity GIS Project is an ongoing project undertaken by the Department of Primary Industries, Bendigo. Although primarily developed to monitor changes in dryland salinity, this project has been expanded to include some areas where irrigated and dryland agriculture exist side by side in the landscape.

1.3 Salinity Discharge Monitoring and Salinity GIS project

The statewide project is funded by the Catchment and Water Division in the Department of Sustainability and Environment. It has two main aims:

1. Mapping salinity across Victoria.

The methodology described by Allan (1996) has been used to identify, assess and map salinity across Victoria. Historical surveys were also utilised; any significant variation with the standard criteria described in this report was noted. The first comprehensive account of dryland salinity across Victoria was presented in Allan (1994). Salinity mapping is ongoing and updates are maintained on Victorian Resources Online <www.dpi.vic.gov.au/vro>.

Due to the small size of most of the salt-affected sites (50% are less than 2 ha in size) the standard scale adopted for recording data is 1:25 000. A mapping scale of 1:25 000 offers several advantages. It provides sufficient detail to be useful to landholders and government agencies to plan and monitor the effectiveness of onground works at farm or subcatchment scale. These maps can also be used as a basis to develop policy across regions and catchments by economists and planners. Dryland salinity data is stored as a layer on the GIS database maintained by DPI Bendigo.

2. Monitoring changes in salinity across Victoria.

As a complement to mapping salinity across the state at 1:25 000 scale, a network of strategic salinity monitoring sites was established across Victoria (see Map 1). These sites are monitored at relatively large scales (1:10 000 is the minimum scale but some sites are mapped at 1: 1000) and reassessed every three to five years to provide reliable data about the rate of change of the area and severity of salinity in a catchment, and the effectiveness of recharge control options. Data collected in individual catchments will be collated to develop a statewide appreciation of the rates of change in the extent and severity of soil salinity.

1.4 Distribution of discharge monitoring sites across Victoria

In the course of this project, the statewide framework used to manage soil salinity has changed as our understanding has become more sophisticated and our knowledge of the factors affecting soil salinity has deepened. The following section provides a brief overview of the statewide management approaches employed since the project commenced.

In 1988, the Victorian State Government developed a strategy for managing land and water salinity in Victoria which divided the state into nine catchment-based salinity control regions (now superseded by catchment management regions). It also defined a need for 20 sub-regional salinity management plans (SMPs) or regional salinity control strategies (SCSs) to cover irrigation and dryland areas that were affected by salinity or contributed to salinity damage within Victoria, or downstream effects within the Murray Darling Basin (Salinity Bureau 1994).

The Salinity Discharge Monitoring and Salinity GIS Project has established over 50 key saline sites across the salinity regions (see Map 1) although not all of these sites have been reassessed due to both climatic and financial constraints. The statewide discharge monitoring project funded around two-thirds of the sites with the remainder to be funded by salinity regions.

Because monitoring site establishment is costly and labour intensive the number of sites was limited. Sites were usually allocated across salinity regions on the basis of region size and the extent and costs to the community of salinity.

Most SMPs were subdivided into land management units (LMU) or priority subcatchments. LMUs were commonly used by agricultural, natural resource, land capability and socio-economic planners to provide a broad planning framework and concise summary of technical salinity information for each plan (Day undated). LMUs in Victoria were generally derived at a 1:250 000 scale and were defined by Day (undated) as 'a grouping of areas which share common hydrogeology and salinity processes. Commonly sharing similar landform, soils and climatic conditions, the same suite of salinity control options are likely to apply across the one unit.'

In 2000 there was a move to refine the salinity management framework and prioritize subcatchments based on the ability to bring about positive biophysical and socio-economic outcomes by targeting community resources. Prioritisation was based on criteria including mapped salinity discharge, salt loads, depth to groundwater, and recharge risk using a decision support tool known as the Integrated Catchment Salinity Risk and Prioritization (ICSRP) tool. The prime output from ICSRP was a map of priority subcatchments. In 2003 the decision making process was refined to explicitly incorporate assets and the decision support tool upgraded to accommodate the focus on assets. The new decision support tool GSHARP (Geospatial Salinity Hazard and Asset Risk Prediction) outputs an asset risk intensity map. This data is combined with expert knowledge of surface subcatchments, groundwater flow systems and socio-economic analysis to produce a map showing priority areas centred around areas of high asset risk.

The majority of discharge monitoring sites were selected under the SMP/LMU framework, but future site selection will be made using the current decision making framework.

2 Salinity monitoring site methodology

This section sets out the method and criteria used to establish and assess the monitoring sites.

2.1 Site selection

There are two main functions that discharge monitoring sites fulfil:

1. Sites placed in high priority salinity areas can be used to monitor change in the extent and severity of salinity in critical areas within a catchment.
2. A pair of sites may be established to assess the effectiveness of a salinity control option within a catchment. One site should be established in a subcatchment where the recharge and/or discharge zone (or parts thereof) have been treated to reduce accessions to the groundwater system, and a second control site located where the recharge and discharge zones are expected to remain untreated. It is important that apart from the treatment, the pair of sites are comparable in all other respects.

Sites were selected after consultation between DPI hydrogeologists and field staff, landholder groups and individuals, and CMA staff. Selection was based on a combination of technical and social factors, as not only is the site hydrogeologically representative, but the landholder has agreed to commit to the life of the project (expected to be more than 30 years).

The first step in the consultative process was to ascertain the priority areas in each catchment management authority (CMA) area. Within the priority areas the critical salinity processes, forms of salinity, and recharge treatment options were identified. Further monitoring sites may be added to the network and the following checklist is provided to aid their selection:

1. Is the site representative of the critical form of salinity in this priority area?
2. Is this site representative of the critical salinity process in this priority area?
3. Is this site representative of the critical recharge treatment in this priority area?
4. If a pair of sites is being chosen, are they truly comparable?
5. Is the landholder aware of the long-term nature of the monitoring and committed to the project?
6. Will this site provide a good extension tool for the local community?
7. Is there a piezometer network already in place at the site?
8. Can the site be used to assess discharge treatment options?
9. Can the site be used to assess saline agriculture options?
10. Is the site history known?
11. Will the site add to the technical understanding of the community and extension staff in this region?

Once these criteria have been addressed it should be possible to choose a suitable monitoring site. It is important that everyone involved in the selection process retains a clear view of the prime reasons for establishing the sites i.e. to monitor changes in salinity in critical regions, or to assess the effectiveness of recharge control options.

3 Recording field data at the monitoring site

The following section briefly describes ancillary data collected to aid in the site interpretation, and the methodology used to map the extent and severity of soil salinity at the monitoring site.

3.1 Geology

The geology at and adjacent to the site (particularly recharge areas) is determined by discussion with a hydrogeologist and/or by reference to the available geology maps. Consultation with a hydrogeologist will yield a more accurate description and some understanding of the groundwater system and the dominant processes operating in the area.

3.2 Climate

Rainfall data is rarely collected on site. The Bureau of Meteorology collects reliable and regular rainfall records at numerous sites across Victoria. Records for the closest comparable site are used in conjunction with the site's groundwater hydrographs to develop an understanding of the groundwater processes at each monitoring site. Additional long-term climate data is available from the Bureau of Meteorology.

As an alternative, Queensland's Natural Resource of Mines department has developed a model that estimates rainfall across Victoria based on records from all available stations. The output from this model is grid data with a spatial resolution of 5 km. Background information and a list of papers discussing the data and methodology can be found at the website <http://www.nrm.qld.gov.au/silo/>.

3.3 Site history

Site history is collected from the landholder to determine the timing of events that may have either had a significant impact on the site, or reflect significant changes at the site. Some of the critical factors are:

- the time when soil salinity was first noticed
- observed changes in the extent and severity of soil salinity
- observed changes in the plant community
- observed changes in groundwater levels (old bores, wells etc.) and spring activity
- changes in the area of bare soil
- changes in soil texture
- topsoil loss from the site
- the nature of the original vegetation cover
- the date of tree clearing in the catchment
- changes in site productivity.

3.4 Land use and management

Land use and management information is collected from the landholder. Changes in land use and management practices impact upon soil salinity at a site. For this reason historic land use and land management practices (and their timing) at and around the site are recorded. These may include factors such as:

- type of farming enterprise
- stocking rates and type of grazing management
- frequency of fertiliser application and application rates
- pasture/cropping rotation
- pasture mix that was sown, and time of sowing
- crop yield
- water management, including drainage.

3.5 Visual record

Photographs of the landscape are taken from known points so that scenes can be repeated on subsequent visits. In addition, photographs of dominant or significant plant species peculiar to that site are also captured.

3.6 Mapping the extent and severity of salinity

There are three techniques employed for documenting salinity levels at a discharge monitoring site:

1. vegetation assessment
2. electromagnetic induction (EMI) survey using an EM38 instrument
3. soil sampling.

In the site establishment phase of the project, all three methods are used wherever possible. However, due to seasonal and spatial variability, labour demands and cost, there is generally less emphasis placed on soil sampling.

After the initial assessment is complete, and the physical features and groundwater processes causing discharge at a monitoring site are understood, it may not be necessary to continue to conduct both vegetation assessment and EMI surveys.

Some sites, particularly in high rainfall areas, irrigated areas, or where cropping is the dominant land use, do not lend themselves well to vegetation assessment and then the EMI survey becomes the main form of salinity assessment. However, at sites where the natural magnetic field is extremely strong (this may be due to high concentrations of ironstone in the soil profile) it may not be possible to conduct an EM38 survey, in which case salinity assessment relies on the vegetation assessment supplemented by an extensive soil survey.

In general, the EMI survey tends to be the preferred method of reassessment because:

- it is not influenced by changes in land use and land management
- it is inherently more objective than vegetation assessment
- it is able to quantify soil salinity levels
- it is easily repeatable, subject to seasonal conditions

However, it is essential that survey protocols are strictly adhered to (see later section). In particular, soil must be saturated down to 60 cm for an accurate reading to be obtained. The aim of the mapping exercise is to identify any trends in the way that soil salinity changes over time and, if possible, relate this to changes in watertable depth. Many environmental factors can affect the expression of soil salinity at a site at any given time and it is important that a number of regular observations are taken to establish a reliable trend.

Vegetation assessment

A method has been developed to quickly and accurately assess the level of soil salinity using the presence of salt-tolerant vegetation and some soil based indicators, and the decline or absence of salt-sensitive plant species. This method is described in more detail in Allan and Clark (in prep). A summary of the method follows.

Salt-tolerant plants

Based on previous knowledge and field observations coupled with soil sampling, Matters and Boruvka (1987) classified a number of plant species common in Victoria as either salt-sensitive or salt-tolerant.

Common salt-tolerant and salt sensitive-plants in Victoria are listed in Appendix 1.

Within the group of plants known to be salt-tolerant there are two divisions — species that require salinity for growth (obligate halophytes), and species that can grow in both saline and non-saline conditions (facultative halophytes). For the purposes of mapping, further division was made based on the level of tolerance of each plant (Matters & Boruvka 1987; Matters & Bozon 1989). Four salinity classes have been applied (see Table 1) that rate each plant species based on its apparent tolerance of soil salinity as determined by saturation extract measurements (EC_e). Appendix 2 gives the typical characteristics of low, moderate, high and severely affected saline sites.

Table 1. Technical definition of soil salinity classes

Salinity severity class	Relative soil salinity level	Growth characteristics	Soil EC_e (dSm^{-1} at 25°C)
1	Low	Some effect on sensitive plants	2–4
2	Moderate	Growth/ yield restrictions for many plants	4–8
3	High	Only tolerant plants grow/yield satisfactorily at the low end of this range	8–16
4	Severe	Only a very few plants grow/yield satisfactorily	>16

These classes are based on widely accepted standards developed by the United States Department of Agriculture (USSLS 1954), and are indicative of relative plant tolerances only, as each species has a specific salt tolerance range. Soil testing results are also classified using this system (see Section 3.6, Mapping the extent and severity of salinity: soil sampling).

Species that are facultative halophytes can only tolerate lower levels of soil salinity (Class 1 or 2 soils). These species, like salt-sensitive species, are liable to show signs of salinity stress, such as reddening or stunting of plants, at the upper limits of their tolerances. Included in this group are some of the more common salt indicator plants such as sea barley grass (*Critesion marinum*), buck's horn plantain (*Plantago coronopus*) and spiny rush (*Juncus acutus*).

It is important to understand that sites should not be classified as saline solely based on the identification of one or two of the species known to be facultative halophytes. These plants can grow well in both saline and non-saline environments, and are not reliable indicators of salinity on their own. If salt-sensitive plants are decreasing in number (and the remaining plants are showing some signs of stress) and some of the soil-based indicators of salinity coincide with an increase in species from the facultative halophyte group, then it may by concluded that soil salinity is occurring.

Variation in the composition of the plant community compared to the surrounding area is a key factor in identifying a salt-affected site. When traversing a site from non-saline soil to inside the discharge zone, the number of salt-tolerant plants will tend to increase and the number of salt-sensitive plants will tend to decrease.

Obligate halophytes, as the name implies, require saline conditions for optimum growth. These plants are adapted to saline conditions and, characteristically, most have succulent leaves and stems. Some examples are beaded glasswort (*Sarcocornia quinqueflora*), Australian salt grass (*Distichlis distichophylla*), water buttons (*Cotula coronopifolia*) and streaked arrow grass (*Triglochin striata*). White (1981) considered this group of plants to be reliable indicators of soil salinity.

Surveying and mapping the site

At each site soil salinity is mapped based on the distribution of salt-tolerant and salt-sensitive vegetation at a minimum scale of 1:10 000. The extent of each class of plants with respect to their specified salt tolerance (see Matters & Bozon 1989) is mapped by traversing each class boundary with a GPS instrument and differentially correcting the data. As the method is based on identifying salt-tolerant and salt-sensitive plants, all surveys should be undertaken at a time when plants are easily identified. Across much of Victoria, this period is in late spring or early summer when plants have made their annual growth and commenced flowering.

Where feasible, at the time of the initial survey, topographic data is collected. This allows development of an understanding of the relationship between topography, the watertable, and the extent and severity of the saline areas. Spatial resolution of the survey will depend on the survey area and topographic variation at the site. Suffice to say that sufficient positions should be located that will allow the site to be accurately characterised. Relative accuracy in the vertical dimension will depend on the degree of variation inherent at the site i.e. at a relatively flat site 10 cm may be critical, whereas at a steeply dissected site +/- 1 m may be sufficient. If possible the digital elevation model (DEM) should be linked to the Australian Height Datum (AHD). This is particularly useful at paired sites established to monitor the effectiveness of recharge and discharge control options, and also allows the extrapolation of changes at the monitoring site to areas covered by the groundwater monitoring network within the same subcatchment.

Electromagnetic induction (EMI) assessment

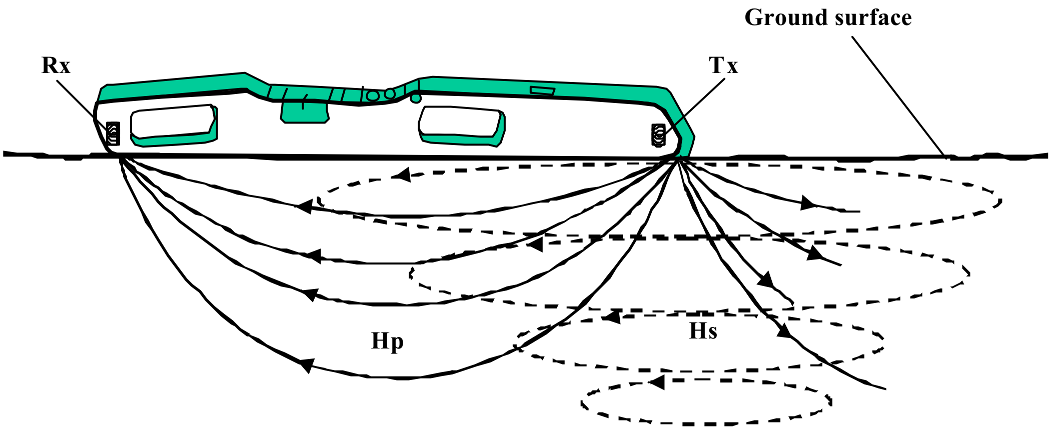
At the time of site establishment, an EMI survey is carried out at the site using an EM38 instrument to complement the vegetation-based assessment and soil salinity testing. The EM38 is well suited to mapping saline discharge sites. It is able to assess soil salinity in the likely root zone (this is assumed to be a soil depth of 60 cm at the monitoring sites) quickly and accurately by measuring the conductivity of the undisturbed soil profile (Norman 1990). EMI techniques provide the most practical means of estimating soil salinity levels where the vegetation community has been significantly altered by management practices (e.g. cropped paddocks or rehabilitated discharge sites). They are inherently more objective than vegetation assessments and more efficient and cost-effective than soil sampling.

At each monitoring site, a series of EM38 surveys are used to determine if there are any significant changes in the relative level of salt in the soil profile over time and not the absolute quantity of salts at any one time. A standard procedure (documented in this paper) has been developed for collecting EM38 data so that any variation between assessments will be due to changes in the soil salinity. It is essential that succeeding surveys adopt the standard procedure and correspond to the prescribed survey area so that changes in the extent and severity of soil salinity over time at a site can be readily identified.

One disadvantage of using the EM38 as the prime method of salinity assessment is the requirement for a saturated soil profile down to at least 60 cm. In dryland farming areas this means that EM surveys are restricted to the time when soils reach field capacity. In years of below average rainfall, reassessment of the monitoring site may not be possible until sufficient rain falls to saturate the soil profile.

What is an EM38?

The EM38 is a hand held instrument that measures soil electrical conductivity without actual soil to electrode contact. The ability to measure soil electrical conductivity without direct soil to electrode contact has dramatically improved the efficiency of mapping soil conductivity compared to previous technology. The instrument consists of transmitter and receiver coils, a power supply and circuitry capable of measuring both the electromagnetism transmitted and received by the instrument (see Figure 1). Measurements can be taken in two modes, the horizontal dipole or the vertical dipole. In the horizontal mode, sensitivity is greatest at the surface (see Figure 2) and declines as depth increases with 65% of the cumulative response coming from the top 60 cm of the soil profile (see Figure 3). By comparison, the vertical dipole has a low sensitivity to surface material, but this increases with depth, to a maximum at 40 cm, decreasing slowly thereafter as depth increases (see Figure 2). In the vertical mode only 36% of the cumulative signal comes from the top 60 cm of soil profile (see Figure 3). Depth of measurement is directly related to the separation between the transmitter and receiver coils and specifications provided by the instrument maker (Geonics Limited, undated) suggest that 1.5 m is the effective depth of exploration for either dipole.



Tx is the transmitter coil
Rx is the receiver
Hp is the primary magnetic field
Hs is the secondary magnetic field

Figure 1. A schematic of the EM38 and the electromagnetic fields generated by the instrument (Norman 1990)

What does the EM38 measure?

The EM38 measures the electrical conductivity of both the solid soil material and the soil water and such measurements are known as apparent electrical conductivity (EC_a) measurements (Slavich unpublished). Norman (1990) states that the instrument has been designed so that current flow is horizontal and not influenced by current flow at any other depth (see Figure 1) and different depths independently contribute to the cumulative readings of the total soil profile. However, the horizontal (EM_h) and vertical (EM_v)dipole readings are not simple depth weighted averages of conductivity down the soil profile, but averages weighted according to their respective depth response functions (McNeill 1980 cited in Slavich and Pettersen 1990).

A number of environmental factors (see the section below) can affect the ability to infer soil salinity levels from average conductivity data and it is important to take account of their influence when measuring soil electrical conductivity.

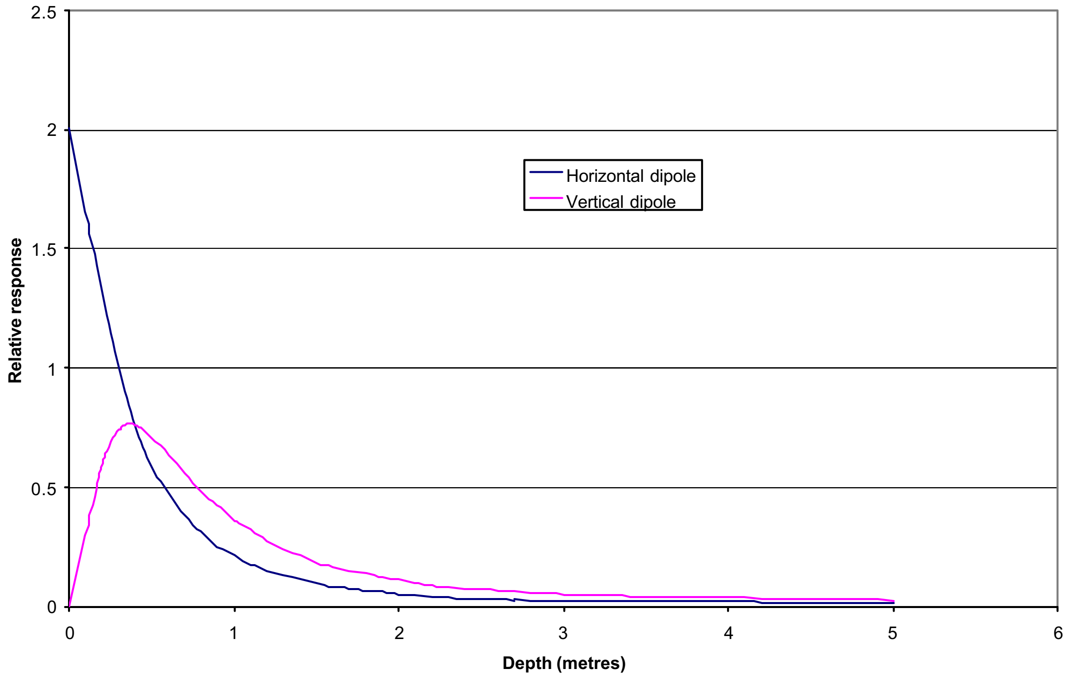


Figure 2. Relative response of the EM38 (horizontal and vertical dipole) v. depth in metres (after Geonics Limited undated)

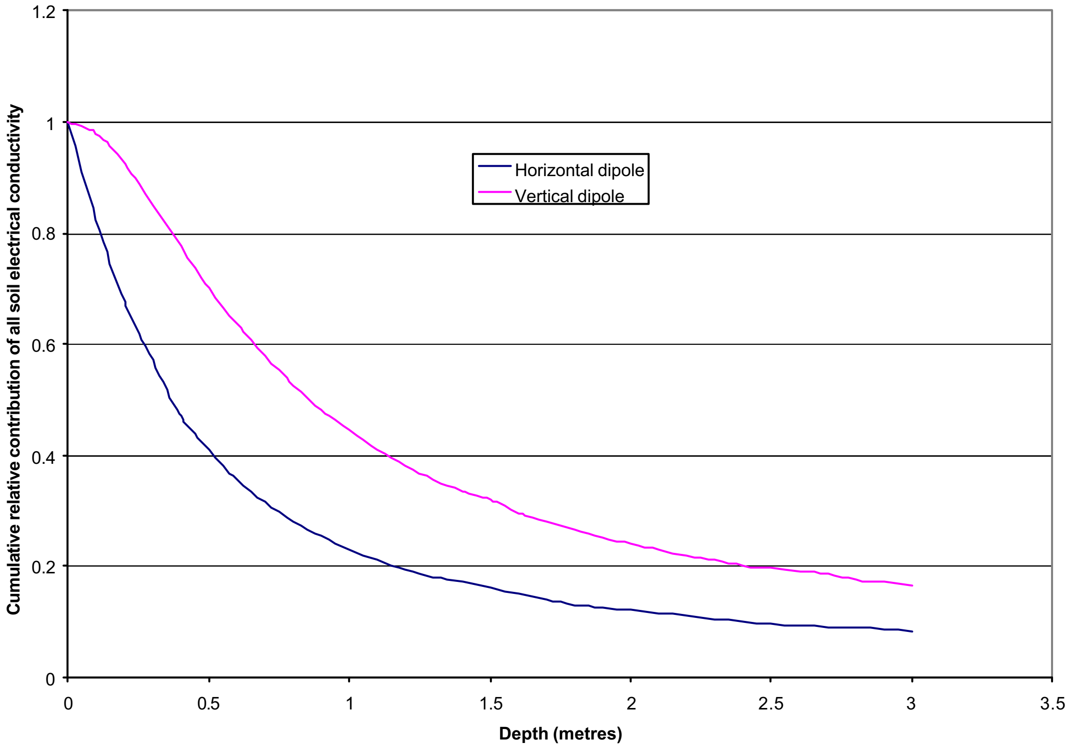


Figure 3. Cumulative response of the EM38 (horizontal and vertical dipole) v. depth in metres (after Geonics Limited undated)

Factors affecting the apparent electrical conductivity (EC_a) readings

Many soil minerals are poor conductors, and current flow in saline soil is primarily through the soil moisture existing between soil peds and to a lesser extent across the charged surface of clay particles. Apparent electrical conductivity is a function of all the properties of the soil profile.

Some of the more significant soil properties that may influence EM38 measurements include:

1. Soil salt concentration

The amount of soluble salts present in the soil profile directly influences the conduction of electrical current. This is the variable to be determined.

2. Soil moisture content

As current flow is primarily through soil moisture, the extent to which soil pores are filled with moisture will affect the current flow. For a given level of salt concentration in the soil water, EC_a will increase as moisture levels increase until field capacity is reached. Norman (1990) stated that regression relationships between EC_a and EC_e were not significantly different for gravimetric moisture levels between 20% and 25% and greater than 25%. He recommended that for clay soils (i.e. > 40% clay in the top 30 cm) gravimetric moisture content of the soil profile should be greater than 20% to allow actual soil salinity values (EC_e) to be accurately derived from observed EC_a data. Sands generally achieve field capacity at a lower level of moisture content than clays and it is possible to derive reliable EC_e values for lighter textured soils when the gravimetric moisture content is lower than 20%.

The procedure for determining the average gravimetric moisture content of the soil profile is described in Appendix 3.

3. Soil porosity (this relates to the bulk density)

The shape and size of the pores, and the number, size and shape of the interconnecting passages directly affect the ability of the soil medium to conduct a current (Norman 1990).

4. Amount and composition of colloids (this will affect the surface charge carried by the clay particles)

Clays consist of alumino-silcate layer minerals of less than 2 μm size, which tend to exhibit a negative charge (colloids). During weathering, positive ions (cations) are adsorbed onto the surfaces of these particles and with the addition of water , the cations can partially dissociate themselves from the clay particles and become available for ionic conductivity (Norman 1990). If all other soil properties are equal, a soil with a higher clay content will record a higher EC_a reading than a soil with a lower clay content due to the relatively greater ionic conductivity across the surface of the soil particles.

Colloidal content and composition are often related to the soil texture. Soil texture classes are determined using the system developed by Northcote (1984) and are defined in Appendix 4.

5. Soil temperature

The temperature of the soil will affect both the viscosity and the phase state (i.e. vapour or liquid) of the soil water, which in turn influences the mobility of salts. To allow for the varying effect of temperature on individual conductivity readings, all readings are normalised to 25°C.

The electrical conductivity at 25°C (EC_{25}) is calculated as

$EC_{25} = EC_t * Ft$ (Equation 1)

Where EC_t = EC in milliSiemens/ metre (mSm^{-1}) measured at the temperature (t).
Ft is the temperature correction value.

Norman and Sait (1992) specify that soil temperature should be recorded every two to three hours throughout the day while collecting EM38 measurements.

Appendix 5 lists the temperature correction (Ft) values calculated for a range of soil temperatures.

6. Magnetic minerals

The presence of magnetic minerals in the soil profile can have a significant affect on the conductivity of the soil profile e.g. the ferro-manganiferrous nodules of the volcanic plains.

How the EM38 measures apparent electrical conductivity (EC_a)

When an electric current is passed through a transmitter coil at one end of the EM38, a magnetic field known as the primary magnetic field is generated which in turn induces a relatively weak secondary magnetic field in the soil profile. A receiver coil at the other end of the instrument directly measures both the strong primary field and the weaker secondary field (see Figure 1). The ratio of the secondary field to the primary field is known to be linearly proportional to the soil electrical conductivity (McNeill 1980) and the strength of the secondary magnetic field is a function of the conductivity of the soil profile.

Instrument calibration

Before the EMI survey can begin it is important that the instrument be calibrated on site to ensure that the instrument is functioning correctly and reduce instrumental error (Geonics Limited undated). Heislers (1994) documented a number of instrumental checks and procedures that must be applied prior to and during a field survey. To collect reliable and accurate EC_a data, it is essential that these procedures be followed. It is also important that the instrument be calibrated annually against a standard 'Q coil' to ensure that there has been no instrument gain caused by the electronics. Appendix 6 describes all calibration procedures.

Observation spacings

Norman and Sait (1992) state that the distance between observations should not exceed 80 m and suggest that in general, the most efficient grid spacing for mapping soil salinity using the EM38 is 60 m x 30 m. In some instances this may not be the most suitable spacing, but is considered a good rule of thumb to work from. Significant changes in either horizontal or vertical dipole readings may make it desirable to take observations at a closer spacing, or collect observations from a series of transects rather than a grid spacing. In summary, the sampling pattern should be designed to accurately capture the character of the site as efficiently as possible and the maximum distance between measurements should not exceed 60 m.

Collecting and recording data

Once the instrument has been calibrated and the sampling pattern determined, the survey can commence. Early EM38 surveys were set out using a compass, a 100 m tapemeasure and an optical square. However, experience has shown that there are considerable gains to be made by using Global Positioning System (GPS) technology to locate and record the soil conductivity data. The GPS instrument should be capable of recording attribute data (horizontal and vertical dipole readings) at each location. The attribute data may be automatically attached or manually entered into the GPS at each data point.

To achieve the minimum standard of 1:10 000 scale site maps, the horizontal positional error for the GPS data should not exceed +/- 5 m. To achieve this level of accuracy, it is essential that position data are differentially corrected either in real time or by post-processing. The procedure for collecting EMI data with the EM38 is described in Appendix 6.

Data preparation

The first step in data analysis is to convert the raw EM38 readings from units of mSm^{-1} to the more common units of dSm^{-1} by dividing the readings by 100 (see Appendix 7). Following this, a temperature correction is then applied to normalise all readings to 25^0C (see Appendix 7).

Calculating average apparent electrical conductivity (EC_a) from EM38 measurements

To transform raw EM38 measurements into estimates of the average apparent conductivity for the likely plant root zone, Slavich (unpublished) developed a model incorporating regression equations that use both the horizontal (EM_h) and vertical (EM_v) dipole measurements. Slavich's model produces a single value that represents the average apparent conductivity values for the soil profile to a depth of 60 cm ($EC_{a(0\text{–}60\ cm)}$). Both Norman (1990) and Slavich (unpublished) suggested that any changes in the concentration of salts down the soil profile may have a significant effect on these regression equations. Changes in soil salt concentrations down the soil profile are characterised by calculating the ratio of the EM_h measurement to the EM_v measurement. Where $EM_h > EM_v$, salts are concentrated in the upper section of the soil profile and the profile is described as inverted. Where $EM_h < EM_v$ the salts are concentrated in the lower section of the soil profile and the profile is said to be leached. Norman (1990) stated that if only one relationship was developed for leached profiles, the predicted $EC_{a(0\text{–}60\ cm)}$ value for an inverted profile would be significantly underestimated.

The regressions developed by Slavich are:

For an inverted profile where $EM_h > EM_v$

$$EC_{a(0\text{–}60\ cm)} = 1.87 * EM_h - 0.7 * EM_v \quad \text{(Equation 2)}$$

For a leached profile where $EM_h < EM_v$

$$EC_{a(0\text{–}60\ cm)} = 1.24 * EM_h - 0.05 * EM_v \quad \text{(Equation 3)}$$

Appendix 7 gives an example of apparent conductivity calculations using the Slavich model.

Converting point data to a continuous surface

When monitoring change, grid surfaces are often easier to interpret visually, interrogate and analyse than point data. To assist in monitoring change at the saline sites, the point observations are converted to form grid data.

When the temperature corrected EM38 data for each point in the survey area has been converted to apparent conductivity values at each observation point, a continuous apparent conductivity surface for the top 60 cm of the soil profile is constructed by interpolating intermediate values between the observed point data. This surface is composed of a continuous array of grid cells. Each cell has the same dimension and is square in shape. There are a number of methods that may be used to interpolate between point data. But, as long as the same method is used for subsequent assessments, any change in the modelled surface will be due to changes in the EM38 measurements and not the method used to convert the point data to a continuous surface. To date the Inverse Distance Weighted (IDW) interpolator has been used to create the grided surface (Cell size = 2 m, Fixed radius = 70 m, Power = 2).

Classifying average apparent electrical conductivity values

Once the continuous surface has been constructed, each grid cell is assigned to a salinity class. Slavich (unpublished) developed a classification system based on a model proposed by Rhodes et al. (1989). In this model, current flow through the soil is a function of current flow across the surface of the solid soil particles and current flow through the soil water held in both the large and fine pores.

Table 2 lists a rating of $EC_{a(0-60\ cm)}$ ranges for different soil texture groups (see Appendix 8). The categories in Table 2 (low, medium, high and very high) are based on classes developed by United States Salinity Laboratory staff in 1954 (USSLS 1954) which used the saturation extract (EC_e) method to determine soil salt content. In contrast to the texture specific $EC_{a(0-60\ cm)}$ classes, the EC_e classes take into account varying soil texture. The EC_e classes reflect the effect that soil root zone salinity levels are likely to have on plant yield and performance across soils exhibiting a range of soil textures and water holding capacities (Shaw 1999).

Table 2. Salinity status indicated by apparent electrical conductivity values for soils of different texture at field capacity

Soil texture and saturation (percentage)	Apparent electrical conductivity EC_a (dSm^{-1})			
	Low	Medium	High	Very high
Sand – sandy loams (25–35%)	<0.4	0.4–0.7	0.7–1.3	>1.3
Loams (35–45%)	<0.7	0.7–1.1	1.1–1.9	>1.9
Clay loam – light clay (45–55%)	<1.0	1.0–1.5	1.5–2.5	>2.5
Medium – heavy clays (55–70%)	<1.25	1.25–1.9	1.9–3.0	>3.0

Note: Low (little effect on most vegetation) ≡ $EC_e < 2\ dSm^{-1}$
Medium (some effect on sensitive vegetation) ≡ EC_e 2–4 dSm^{-1}
High (growth restrictions for many species) ≡ EC_e 4–8 dSm^{-1}
Very high (only tolerant species grow satisfactorily at the low end of this range, at the upper end of this range very few species grow satisfactorily) ≡ $EC_e > 8\ dSm^{-1}$.

Interpreting EM38 survey data

After each grid cell has been allocated to a salinity class, the total area belonging to each class (see Table 2) is calculated and the percentage of the survey area in each class is determined. For reassessments, the percentage of each class at the site will be calculated and compared to the percentages obtained from previous assessments. To allow easy comparison between assessments, all subsequent surveys should conform to the spatial arrangement and area of the original survey as closely as possible.

Following classification it is useful to compare the soil analyses of samples collected at the time of survey and the vegetation assessment with the interpolated and classified surface. If there does not seem to be reasonable agreement between the EM38 data and the other assessments it is worth re-examining the soil texture data to determine if the optimum class boundaries based on interpreted average soil texture were applied (see Table 2).

Generally, EM38 classifications have shown a good correlation with the pattern of soil salinity obtained by mapping the distribution of salt-tolerant plants, and Heislers (1994) stated that the EM38 is a useful tool for estimating the salinity response in the uppermost 1.5–2 m of the soil profile. However, EC_a measurements do not absolutely define soil salinity levels, and care should be used when making a comparison to soil salinity assessments derived from the standard vegetation criteria. Heislers (1994) and Norman (1990) both agree that only absolute saturated extract (EC_e) measurements can be directly related to plant behaviour.

In summary we can say that apparent electrical conductivity classes derived from the EM38 surveys are often similar in magnitude and pattern to soil salinity classes inferred by the vegetation assessment, and it can be suggested that EC_a measurements collected during EM38 surveys measure the soil salt store. The soil salt store is known to be a significant factor in determining the characteristics of plant growth on these soils.

Soil salinity assessments based on EM38 surveys may appear to vary with vegetation based assessments and there are a number of factors which may account for this apparent variation:

- Assumptions made in the EM38 calibration process.
- The ability of the EM38 to measure soil conductivity to a depth of 1.5 m down the soil profile and determine soil salinity trends in advance of visual assessment of salt-tolerant and sensitive vegetation.
- The EM38 data consists of measurements made at isolated points and, therefore interpolation is required between points of known values.
- Masking of 'true' vegetation by land use (i.e. cropping or grazing).
- Adverse seasonal conditions that have altered the typical vegetation at the site.
- The interpretation made by the person undertaking the vegetation assessment.

Soil sampling

Soil sampling provides a third method of determining soil salinity. Soil samples are not used extensively to identify and classify soil salinity at monitoring sites as they are time consuming and costly to collect and process. In addition, collection of data at individual points means that the soil survey has a limited ability to reflect the spatial variability and distribution of soil salts. However, they are used to classify EM38 survey data and to validate the results of the vegetation assessment or EM38 survey data. Many studies have related the soil salinity classes derived by vegetation assessment to EC_e values (see Table 1).

Soil salinity levels can be sensitive to seasonal variation and this is related to the movement of water through the soil profile. In a non-irrigated environment, soil salts are leached downwards through the soil profile when rainfall exceeds evapotranspiration. Conversely, soil salts are concentrated in the upper layers of the soil profile when evapotranspiration rates exceed rainfall.

Soil salinity is commonly measured by determining the electrical conductivity of a prepared soil-water solution, and various laboratory procedures have been developed to ensure that the laboratory analyses correlate well with actual plant growth/yield *in situ* (Shaw 1999). Fertiliser and gypsum applications can have the effect of apparently increasing soil salinity levels, when in reality, plant growth/yield may not be adversely affected as inferred by the conductivity measurement.

The soil sampling procedure used at monitoring sites is:

1. When used in conjunction with an EM38 survey, select five to ten soil sample points that are likely to represent the range of conditions at the monitoring site. At sites where it is not possible to conduct an EM38 survey, 20 to 40 representative sample points are selected.
2. At each point, collect samples from the 0–15 cm, 15–30 cm, and 30–60 cm depths. Each of these samples will be analysed separately, i.e. three depths will be tested for each point.
3. To determine the salinity level of soil samples, analyse each sample using the standard test for EC of 1:5 soil/water extract (see Appendix 9).
4. Determine the texture of each sample using the standard classification developed by Northcote (1984). When the soil texture of all samples collected at a monitoring site has been determined, an average texture group for the top 60 cm of the site soil profile is assigned (the texture groups are defined by Northcote (1984)). The texture group is used to select the appropriate soil salinity status classes (see Table 2) to assist in the analysis of the EM38 survey data. At some sample points, the texture group may not be uniform down the profile, but change as depth increases. The texture group may initially be assigned for that sample point, based on the depth of profile for each group. If the texture group varies between sample points across the site one alternative is to decide to stratify the site, or in some cases, one texture group can be applied across the whole site.
5. Convert $EC_{1:5}$ values to estimates of EC_e values by applying the correction factor appropriate for the texture of each sample (see Table 3).

$$EC_e\ (dSm^{-1}) = EC_{1:5}\ (dSm^{-1}) \times \text{multiplier factor} \quad \text{(Equation 4)}$$

Table 3. Converting $EC_{1:5}$ values for specific soil texture classes to estimates of EC_e values

Soil texture	Multiplier factor
Loamy sand, clayey sand, sand	17
Sandy loam, fine sandy loam, light sandy clay loam	11
Loam, loam fine sandy, silt loam, sandy clay loam	10
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	9
Light medium clay	8
Medium clay	7
Heavy clay	6

Following processing of the EM38 data the output classification should be checked against the soil analyses for each sample point. If results correlate poorly, the texture groups (see step 4 above) should be re-examined to determine if there is a valid reason for altering the initial group assignment. If so the classification should be re-run using the new texture groups and reassessed against the soil analyses.

3.7 Groundwater data

Monitoring piezometers are used to determine the nature of the groundwater system feeding the discharge site, and to monitor changes in groundwater levels. Changes in groundwater levels may be linked to changes in the extent and severity of soil salinity.

Groundwater systems may be local, intermediate or regional in scale. A hydrogeologist should be consulted to determine which type of system is present at a site. Local systems are characterised by discharge that tends to expand up-slope towards the area of recharge, which typically occurs within 5 km of the discharge. On the other hand, discharge areas associated with regional groundwater systems are usually located more than 50 km from the main recharge areas, and generally expand in all directions. Elevated areas tend to be unaffected in a regional system. Understanding the groundwater system is important when analysing changes in the extent and severity of soil salinity at a discharge monitoring site.

4 Data analysis

The initial survey at a monitoring site is used to set a benchmark and successive surveys aim to identify any change in the extent and severity of soil salinity at a site. To develop a meaningful trend, the site should be reassessed every three to five years.

The minimum dataset to be gathered for reassessments comprises:

1. Repetition of either or both the vegetation assessment or the EM38 survey. The decision to use either or both of these techniques will depend on the physical characteristics of the site.
2. A continuous monitoring record of the piezometers.
3. A continuous record of rainfall data.
4. An updated site photographic record.
5. An updated record of land management practices.
6. An updated land use record.

This is the minimum dataset, however other site data may be reassessed if required.

Site maps showing the pattern and extent of soil salinity inferred from vegetation cover, physical conditions and EM38 data are used to create a picture of salinity distribution and severity at a site at the time of assessment. Soil salinity trends are developed by collating this data.

When long-term soil salinity trends have been established, the aim is to determine how these changes relate to any recorded variation in groundwater levels, climate, land use or land management practices.

5 Conclusion

The documented monitoring methodology provides a rigorous method of identifying change in the extent and severity of salt affected soil at selected priority monitoring sites and enables anyone to conduct monitoring and produce results directly comparable to their peers, both now and in the future.

Several techniques for mapping soil salinity are documented. However, EM38 surveys are the preferred method of mapping change in soil salinity as they provide the most rigorous and repeatable method of mapping soil salinity. The methodology links the soil salinity data to data quantifying and describing change in climate, depth to groundwater and landuse/ land management at the site. The methodology provides a means to report on change in condition of priority sub–catchments or to assess the effectiveness of land management options designed to reduce soil salinity by monitoring paired treated and untreated sites.

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Glossary

Field capacity	The water content of the soil two days after heavy rain or irrigation in the absence of evaporation.
GPS	Global Positioning System. An instrument that can be used to determine the user's location on the surface of the earth.
Gravimetric moisture content	The mass of water lost in an oven at 105 °C expressed as a percentage of the oven dry mass.
Ironstone	A nodule of iron rich material that may be magnetic. This material has the potential to influence EM38 readings.

Appendix 1 Salt-tolerant and salt-sensitive plants

Below is a list of salt-tolerant and salt-sensitive plant species which may be used to identify saline soils in Victoria. Salinity classes (see Table 1) are only known for some plants. They have been taken from Matters and Boruvka 1987; Matters and Bozon 1989 or estimated by DPI salinity officers located in Kerang based on their field experience.

Life cycle key A - Annual B - Biennial P - Perennial ? - life cycle not known

* Exotic species

Life cycle	Scientific name	Common name	Salt class
Salt-tolerant grasses			
* (?)	*Agrostis avenacea*	silvery hair-grass	
(A)	*Aira caryophyllea*	common blown grass	
(P)	*Austrodanthonia caespitosa*	white top wallaby grass	1-2
(P)	*Austrodanthonia eriantha*	wallaby grass	1
(P)	*Austrostipa tuckeri*	spear grass	
* (A)	*Briza maxima*	large quaking grass	
* (A)	*Bromus rubens*	red brome	
* (P)	*Chloris gayana*	Rhodes-grass	
(A/P)	*Chloris truncata*	windmill-grass	1-2
* (A)	*Critesion marinum*	sea barley grass	1-2
(P)	*Cynodon dactylon*	couch	1-2
(B/P)	*Diplachne fusca*	brown beetle grass	
(P)	*Distichlis distichophylla*	Australian salt grass	2
(?)	*Enteropogan acicularis*	curly windmill grass	1-2
(P)	*Eragrostis australasica*	cane grass	
(P)	*Eragrostis setifolia*	bristly love grass	
* (A)	*Hainardia cylindrica*	common barb grass	
(?)	*Lachnagrostis filiformis*	common blown grass	1-2
* (A)	*Lolium rigidum*	Wimmera rye grass	1
* (P)	*Lophopyrum elongatum*	tall wheat grass	1-2
* (A)	*Parapholis incurva*	coast barb grass	
* (A)	*Parapholis strigosa*	slender barb grass	2
* (A)	*Poa annua*	annual meadow grass	
* (P)	*Poa bulbosa*	bulbous meadow grass	
* (A)	*Polypogon monspeliensis*	annual beard grass	2
(?)	*Puccinellia ciliata*	Australian saltmarsh grass	3-4
(A)	*Puccinellia stricta*	Australian saltmarsh grass	1-2
(P)	*Sporobolus caroli*	yakka grass	
(P)	*Sporobolus mitchelli*	rat's tail couch	1-2
(P)	*Sporobolus virginicus*	salt couch	
(P)	*Tripogon loliiformis*	rye beetle grass	
* (A)	*Vulpia bromoides*	squirrel-tail fescue	
Salt-tolerant small plants			
(?)	*Angianthus preissianus*	salt angianthus	1-2
* (?)	*Aptenia cordifolia*	heart-leaf ice-plant	3
(P)	*Atriplex lindleyi*	eastern flat top	2-4
(P)	*Atriplex semibaccata*	creeping saltbush	1
(A/P)	*Atriplex suberecta*	lagoon saltbush	1-2

Appendix 1 continued next page..

Appendix 1 Salt-tolerant and Salt-sensitive plants (continued)

Life cycle	Scientific name	Common name	Salt class
* (P)	*Carpobrotus aequilaterus*	angled pigface	
(A)	*Centaurium spicatum*	centaury	1-2
* (A)	*Cotula bipinnata*	ferny cotula	
(A/P)	*Cotula coronopifolia*	water buttons	2
(P)	*Disphyma crassifolium* ssp. *clavellatum*	rounded noon-flower	2-3
(?)	*Einadia trigonos*	lax goosefoot	
(?)	*Lawrencia glomerata*	clustered Lawrencia	
* (?)	*Medicago minima*	little medic	
* (?)	*Medicago polymorpha*	burr medic	1-2
* (?)	*Melilotus alba*	Bokhara clover	1-3
* (?)	*Melilotus indica*	Hexham scent	1-3
(?)	*Mesembryanthemum crystallinum*	common ice-plant	2
(?)	*Mesembryanthemum nodiflorum*	small ice-plant	2-4
(P)	*Mimulus repens*	creeping monkey-flower	2
(A)	*Myosurus minimus*	mousetail	
(?)	*Osteocarpum salsuginosum*	bonefruit	3
* (P)	*Plantago coronopus*	buck's horn plantain	1-2
(P)	*Rhagodia spinescens*	thorny saltbush	1-4
(P)	*Samolus repens*	creeping brookweed	2
(P)	*Sarcocornia quinqueflora*	beaded glasswort	2 - 3
* (?)	*Sarcozona praecox*	sarcozona	
(?)	*Selliera radicans*	selliera (swamp weed)	1-2
(P)	*Spergularia marina*	salt sand-spurrey (lesser sea-spurrey)	
* (?)	*Spergularia media*	coast sand-spurrey (greater sand-spurrey)	1-2
* (A/B)	*Spergularia rubra*	red sand-spurrey	
(P)	*Suaeda australis*	austral sea-blite	2-3
* (?)	*Trifolium arvense*	hare's-foot clover	
* (A)	*Trifolium campestre*	hop clover	
* (P)	*Trifolium fragiferum*	strawberry clover	1-2
(P)	*Wilsonia rotundifolia*	roundleaf wilsonia	2
(A)	*Zygophyllum crenatum*	notched twin-leaf	
(A)	*Zygophyllum iodocarpum*	violet twin-leaf	
Salt-tolerant rushes			
(?)	*Isolepis congrua*	club rush	
(A)	*Isolepis hookeriana*	club rush	
* (A)	*Isolepis hystrix*	awned club rush	
(A)	*Isolepis victoriensis*	club rush	
* (P)	*Juncus acutus*	spiny rush	1-2
(A)	*Juncus bufonius*	toad rush	1-2
(P)	*Triglochin striatum*	streaked arrowgrass	2
Salt-tolerant trees and shrubs			
(P)	*Acacia stenophylla*	eumong	0-4
(P)	*Atriplex leptocarpa*	slender-fruit saltbush	
(P)	*Atriplex nummularia*	old-man saltbush	
(A)	*Atriplex pseudocampanulata*	fan saltbush	

Appendix 1 continued on next page…

Appendix 1 Salt-tolerant and Salt-sensitive plants (continued)

(P)	*Atriplex vesicaria*	bladder saltbush	
(P)	*Enchylaena tomentosa*	ruby saltbush	
(P)	*Eucalyptus largiflorens*	black box	0-4
(?)	*Halosarcia pergranulata*	samphire (blackseed glasswort)	
(P)	*Maireana aphylla*	leafless bluebush	
(P)	*Maireana brevifolia*	short-leaf bluebush	
(?)	*Maireana georgei*	satiny bluebush	
(?)	*Maireana humillima*	bluebush	
(P)	*Melaleuca ericifolia*	swamp paperbark	1-2
(P)	*Melaleuca halmaturorum*	salt paperbark	
(P)	*Melaleuca lancelata*	moona	1-3
(P)	*Muehlenbeckia cunninghamii*	lignum	0-4
(P)	*Nitraria billardierei*	dillon bush	
(?)	*Osteocarpum acropterum*	babbagia	
(P)	*Sclerochlamys brachyptera*	short-winged saltbush	
(P)	*Sclerolaena diacantha*	grey copperburr	
(P)	*Sclerolaena divaricata*	tangles copperburr	
(?)	*Sclerostegia tenuis*	slender glasswort	
Salt-tolerant agricultural plants			
(A)		Wheat (agricultural varieties)	0-2
(A)		Barley (agricultural varieties)	0-2
Salt-sensitive grasses			
(P)	*Antoxanthum odoratum*	sweet vernal grass	
(P)	*Austrodanthonia carphoides*	short wallaby grass	
(A)	*Briza minor*	shivery grass	
(P)	*Deyeuxia* sp.	creeping bent grass	
(P)	*Holcus lanatus*	Yorkshire fog grass	
(A)	*Hordeum leporinum*	barley grass	
(P)	*Lolium perenne*	perennial rye grass	
(P)	*Romuea rosea*	onion grass	
(P)	*Themeda triandra*	kangaroo grass	
Salt-sensitive rushes			
(P)	*Juncus articilatus*	jointed rush	
(A/P)	*Juncus planifolius*	broad-leaf rush	
(P)	*Juncus subsecundus*	finger rush	
Salt-sensitive small plants			
(A)	*Arctotheca calendula*	capeweed	
(A)	*Erodium sp.*	heron's-bill	
(P)	*Leontodon taraxacoides*	hairy hawkbit	
(A/B)	*Spergularia diandra*	small sandspurrey	
(A)	*Trifolium dubium*	suckling clover	
(A)	*Trifolium tomentosum*	woolly clover	
Salt tolerant agricultural plants			
(A)	*Brassica napus*	canola	0-1
(A)	*Cicer arietum*	chickpeas	0-1
(P)	*Trifolium repens*	white clover	0-1
(A)	*Trifolium subterraneum*	sub clover	0-1
(A)	*Zea mays*	maize	0-1

Appendix 2 Typical characteristics of slightly, moderately and severely saline soils

Soil salinity class	Typical symptoms
S1 (Low) Soil salinity (EC_e) ranges from 2 – 4 dSm^{-1}.	Salt-tolerant species such as sea barley grass are often abundant. Salt-sensitive plants in general show a reduction in number and vigour and salt-sensitive legumes (e.g. white and sub–clover, soybeans, chick pea, etc.) in particular show a noticeable reduction in vigour and number. At the upper end of the range, grasses and shrubs may be prominent in the plant community. There are no bare saline patches and no salt stain/crystals are evident on bare ground.
S2 (Moderate) Soil salinity (EC_e) ranges from 4 – 8 dSm^{-1}.	Salt-tolerant species begin to dominate the vegetation community and all salt-sensitive plants are markedly affected by soil salinity levels. At the upper end of the range, some slightly tolerant species disappear and are replaced by others with higher salt tolerance. Legumes are almost non-existent as the plant community is dominated by grasses, shrubs and flat weeds. Small bare areas up to 1 m^2 may be present and salt stain/crystals may sometimes be visible on bare soil at the upper end of the range.
S3 (High) Soil salinity (EC_e) ranges from 8 – 16 dSm^{-1}.	Salt-tolerant species like sea barley grass and buck's horn plantain may dominate large areas and only salt-tolerant plants remain unaffected. In low rainfall areas it is unlikely that any improved species will be present and trees may be showing some effect i.e. dieback and stagginess. Large, bare saline areas may occur showing salt stains or crystals (on some soils a dark organic stain may be visible), or the top soil may be flowery or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas. At the upper end of the range, halophytic plants may dominate the plant community and some species may show a reddening of the leaves.
S4 (Severe) Soil salinity (EC_e) is greater than 16 dSm^{-1}.	Only highly salt-tolerant plants survive and the community is typically dominated by 2 or 3 species. Moderately and highly salt-tolerant species may show a reddening of the leaves and at the upper end of the range even highly salt-tolerant plants may be scattered and in poor condition. Trees will be dead or dying. Extensive bare saline areas occur with salt stains and or crystals evident (on some soils a dark organic stain may be visible). Top soil may be flowery or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas.

Appendix 3 Determining the average gravimetric content of the soil profile

Soil moisture levels can be reliably determined by measuring the average gravimetric water content of the soil profile to a depth of 60 cm. An average gravimetric reading can be calculated by sampling soil moisture in the profile at 0 – 30 cm and at 30 – 60 cm, and averaging the readings. Soil samples should be collected and stored immediately in airtight tins to prevent moisture loss. Weigh the moist samples in the tin before drying, then oven dry the samples at 105° C for at least 24 hours. After drying, weigh the dry soil in the tin. Remove the dry soil from the tin, grind it and pass the sample through a 2 mm sieve. Weigh the empty tin and any gravel greater than 2 mm in diameter. To calculate the soil moisture content apply the following formula,

[(wet soil in tin)- (dry soil in tin)] / [(dry soil in tin) - (tin + gravel > 2 mm diameter)] x 100

Appendix 4 Soil texture characteristics defined by Northcote (1984)

Texture grade	Behaviour of moist bolus	Approx. clay content %
Sand (S)	Coherence nil to very slight; cannot be moulded; single sand grains adhere to fingers.	Always < 10 and commonly < 5
Loamy sand (LS)	Slight coherence; can be sheared between thumb and forefinger to give minimal ribbon of about 6 mm; discolours fingers with dark organic stain.	5 – 10 (some organic matter present)
Clayey sand (CLS)	Slight coherence; sticky when wet; many sand grains stick to fingers; will form minimal ribbon 6 – 13 mm; discolours fingers with clay stain.	5 – 10 (little or no organic matter)
Sandy loam (SL)	Bolus just coherent but very sandy to touch; will form ribbon of 1.3 – 2.5 cm; dominant sand grains are of medium size* and are readily visible.	10 – 15
Fine sandy loam (FSL)	Bolus coherent; fine* sand can be felt and heard when manipulated; will form ribbon of 1.3 – 2.5 cm; sand grains are clearly evident under hand lens.	10 – 20
Light sandy clay loam (SCL)	Bolus strongly coherent but sandy to touch; sand grains dominantly medium size* and easily visible; will form ribbon of about 2 – 2.5 cm.	15 – 20
Loam (L)	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or "silkiness"; but may be somewhat greasy to the touch if much organic matter present; will form ribbon of about 2.5 cm.	about 25
Loam, fine sandy (Lfsy)	Bolus coherent and slightly spongy; fine sand can be felt and heard when manipulated; will form a ribbon of about 2.5 cm.	about 25
Silt Loam (SiL)	Coherent bolus, very smooth to silky when manipulated; forms ribbons of about 2.5 cm.	about 25, and with silt 25% or more
Sandy clay loam (SCL)	Strongly coherent bolus sandy to touch; medium size sand grains visible in finer matrix; will form ribbon of 2.5 – 3.8 cm	20 – 30
Clay loam (CL)	Coherent plastic bolus; smooth to manipulate; will form ribbon of 3.8 – 5 cm.	30 – 35
Silty clay loam (SiCL)	Coherent smooth bolus; plastic and silky to the touch; will form ribbon of 3.8 – 5 cm.	30 – 35, and with silt 25% or more.

Appendix 4 continued next page ..

Appendix 4 Soil texture characteristics defined by Northcote (1984) (continued)

Texture grade	Behaviour of moist bolus	Approx. clay content %
Fine sandy clay loam (FSCL)	Coherent bolus; fine sand can be felt and heard when manipulated; will form ribbon of 3.8 – 5 cm.	30 – 35
Sandy clay (SC)	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form ribbons of 5 – 7.5 cm.	35 – 40
Silty clay (SiC)	Plastic bolus; smooth and silky to manipulate; will form ribbons of 5 – 7.5 cm.	35 – 40, and with silt 25% or more.
Light clay (LC)	Plastic bolus; smooth to touch; slight resistance to shearing between thumb and forefinger; will form ribbons of 5 – 7.5 cm.	35 – 40
Light medium clay (LMC)	Plastic bolus; smooth to touch, slightly greater resistance to ribboning shear than light clay; will form ribbon of about 7.5 cm.	40 – 45
Medium clay (MC)	Smooth plastic bolus, handles like plasticine and can be moulded into rods without fracture; has some resistance to ribboning shear; will form ribbon of 7.5 cm or more.	45 – 55
Heavy clay (HC)	Smooth plastic bolus; handles like stiff plasticine; can be moulded into rods without fracture; has firm resistance to ribboning shear; will form ribbon of 7.5 cm or more.	>50

NOTE: By definition sand grains in soils range from 2 mm to 0.2 mm diameter with an arbitrary separation of coarse and fine sand at 0.2 mm particle diameter.

Appendix 5 Temperature correction factors

Field conductivity measurements should be referenced to 25°C using the correction factors given in Table 4. To reference the field measurement to 25°C use the following formula:

$EC_{25} = EC_f \times Ft$

where EC_{25} = the field measurement referenced to 25°C

EC_f = the field measurement recorded at the field temperature

Ft = the correction factor calculated to reference all field measurements to 25°C

Table 4. Temperature correction factors to reference EC_a measurements to 25°C

Recorded field temperature	Correction factor (Ft)	Recorded field temperature	Correction factor (Ft)	Recorded field temperature	Correction factor (Ft)
6.0	1.5713	12.5	1.325	21.5	1.0738
7.0	1.5455	12.75	1.31	22.0	1.0625
8.0	1.5	13.0	1.3077	22.5	1.0517
8.5	1.478	13.5	1.2913	23.0	1.0408
8.75	1.467	14.0	1.275	23.5	1.0304
9.0	1.457	14.5	1.2594	24.0	1.02
9.25	1.447	15.0	1.2439	24.5	1.01
9.5	1.437	15.5	1.2291	25.0	1.0
9.75	1.427	16.0	1.2142	26.0	0.9808
10.0	1.417	16.5	1.2	27.0	0.9623
10.25	1.4075	17.0	1.186	28.0	0.9445
10.5	1.398	17.5	1.1725	29.0	0.9273
10.75	1.388	18.0	1.1591	30.0	0.9107
11.0	1.378	18.5	1.1462	31.0	0.8947
11.25	1.369	19.0	1.1333	32.0	0.8793
11.5	1.3602	19.5	1.121	33.0	0.8644
11.75	1.351	20.0	1.1087	34.0	0.85
12.0	1.3421	20.5	1.0969	35.0	0.8361
12.25	1.3412	21.0	1.0851	36.0	0.8226

Appendix 6 EM38 field procedure

9.1 Metallic Items

Remove any jewellery, watches, boots with metal toe caps and attempt to avoid large metal objects in the field (e.g. fences, powerlines). Note the location of metallic features in notebook.

9.2 Battery test .....daily check

- Turn on/off switch to 'Batt'.
- Switch range switch to 1000.
- Check that the reading (the absolute value) is greater than 720. If not, then two new AA size batteries are necessary.

9.3 Phasing of the instrument .....at start of a new survey

This is an equipment functional check.

- Set the mode switch to 'Q/P'.
- Set the range switch to '1000'.
- Lift the instrument to 1.5 m in the horizontal dipole position.
- Rotate the I/P coarse zero control knob clockwise one step, note reading, then return knob to original position.
- If the readings are different, adjust the phase control screw a small amount in one direction and repeat exercise until no change in reading occurs by rotating the I/P coarse zero control knob.
- Check I/P coarse zero control is in original position by checking the instrument null (i.e step 9.5).

9.4 Check instrument sensitivity .....at start of a new survey

Another functional check to ensure correct equipment operation.

- Set the mode switch to 'IP'.
- Set the range switch to '1000'.
- Lift the instrument to 1.5 m in the horizontal dipole position.
- Rotate the I/P coarse zero control knob clockwise one step. The needle should change between 100 and 200.
- Return the I/P coarse zero control to original position.

9.5 Nulling of the primary field .....every hour or soil change

The aim of this is to cancel or null the large primary field that is sensed by the receiver . Nulling of the primary field also helps to reduce overload on the electronic circuitry and increases sensitivity of the instrument over areas of different salinity.

- Turn on/off switch to 'on'.
- Set the mode switch to 'I/P'.
- Set the range switch to '1000'.
- Lift the instrument to 1.5 m or greater (i.e. above eye level) in the horizontal dipole position.
- Adjust reading to zero using the I/P zero control knobs.
- Repeat the above procedure with the range switch set to '100' A reading within 10 mSm^{-1} is an acceptable zero.

9.6 Instrument zero .....every hour or soil change

This adjustment ensures that the instrument reads zero when, in theory, it is raised high enough that the ground has negligible effect on the reading.

- Set the mode switch to Q/P.
- Lift the instrument to a height of 1.5 m or greater (above eye level) in the vertical position.
- Set the range switch to the '100' mS/m scale (so as to give a reading approximately somewhere mid-scale). If the conductivity is too high switch to '1000'.
- Without changing the height of the instrument rotate it to the horizontal position and note the new reading.
- If $E_v=2E_h$ then the machine is set correctly. Otherwise the Q/P zero knob must be adjusted until this relationship is achieved.
  - * If during the survey ground conductivity becomes low, recalibrate on '100' scale (if not already) for greater accuracy.

* If zeroing over resistive ground it is even more important to ensure that metallic objects are remote.

9.7 Removal of remnant magnetic field .....every half an hour or soil change

Natural magnetism due to soil susceptibility (compared to the induced magnetic fields) can create an additional signal in the receiver. The following procedure cancels this unwanted field.

- Turn the mode switch to 'IP'.
- Set the range switch to '1000' mSm^{-1}.
- Place the instrument on the ground in the horizontal dipole position.
- Adjust the scale to zero using both the coarse and fine IP zero control knobs.

9.8 Routine EM measurement

- Turn the mode switch to 'Q/P'.
- Take two horizontal and vertical readings perpendicular to each other (say E-W and N-S) and average readings for both planes (they should be similar)
- Readings are conventionally written as EMv/EMh

* In laterally uniform ground the EM38 should read the same regardless of the direction of the log axis (E-W or N-S). Any significant difference in the reading (>10%) suggests a significant lateral disturbance (e.g. a pipe) - the measure point should be moved.

* If unsure about the effect of metallic objects in clothing or on the body, remove them and observe any affect on reading. If no change then there isno problem.

* Powerlines can sometimes have an effect. Check to see whether the same reading is registered on both scales. If the reading is significantly different then there is instrumental overload. Use the '1000' scale in this case for this will be the accurate measurement.

9.9 Instrument gain ....once a year

Periodically it is necessary to ensure that the EM38 meter is standardised; that is, there has been no instrument gain caused by the electronics. If the EM38 is standardised using a 'Q coil' then the EC_e results obtained are able to be adjusted to that of a 'standard tool', to allow for differences in the actual machine used. It is recommended that this check be carried out annually. Currently this service is provided by staff at the Institute of Sustainable Irrigated Agriculture at Tatura and the instrument suppliers at Geoterrex-dighem Pty Ltd in Sydney.

Appendix 7 Calculating the average apparent conductivity from EM38 measurements

Sample calculation

EMv = 120 mS/m
EMh = 90 mS/m
Soil temperature 14°C
Soil type average texture for the depth 0 – 60 cm = clay loam to light clay

1. Convert EM readings from mSm^{-1} to dSm^{-1} by dividing by 100.
   EMv = 120/100 = 1.2 dSm^{-1}
   EMh = 90/100 = 0.9 dSm^{-1}
2. Normalise EM readings to 25°C by applying the temperature correction factor listed in Appendix 5 for 14°C (=1.275).
   EMv^{25} = 1.2 x 1.275 = 1.53 dSm^{-1}
   EMh^{25} = 0.9 x 1.275 = 1.15 dSm^{-1}
3. Calculate the average apparent soil conductivity using Slavich's regression equations.

EMv > EMh therefore use Equation 3.

$EC_{a(0\text{-}60cm)}$ = 1.24*1.15 - 0.05* 1.53
= 1.35 dSm^{-1}

4. Classify $EC_{a(0\text{-}60cm)}$ using Table 2

for average texture Clay loam to light clay
1.0 dSm^{-1} -1.5 dSm^{-1} = **medium salinity status**

Appendix 8 Soil texture groupings

Texture groups	Texture grades
Sands	Sand; loamy sand; clayey sand
Sandy loams	Sandy loam; fine sandy loam; light sandy clay loam
Loams	Loam; loam, fine sandy; silt loam; sandy clay loam
Clay loams	Clay loam; silty clay loam; fine sandy clay loam
Light clays	Sandy clay; silty clay; light clay; light medium clay
Medium-heavy clays	Medium clay; heavy clay

Appendix 9 Methodology for standard $EC_{1:5}$ soil analysis

The $EC_{1:5}$ test offers a standard means of comparing the electric conductivity of various soil samples. $EC_{1:5}$ values cannot be directly related to the effect of soil salinity levels on plant growth.

The following methodology, taken from Rayment and Higginson (1992), describes standard practices for preparing and testing a solution produced from a subject soil sample.

Prepare a 1:5 soil-water suspension. For example, weigh 20.0 g air dry soil into a suitable bottle or jar and add 100 ml of de-ionised water. Mechanically shake at 25°C for one hour to dissolve soluble salts. Allow around 20 – 30 minutes for the soil to settle. Calibrate the conductivity cell and meter in accordance with manufacturer's instructions, and by using the potassium chloride reference solution at the temperature of the suspensions.

Dip the conductivity cell into the supernatant, moving it up and down slightly without disturbing the settled soil. Take the cell reading with the cell stationary when the system has stabilised. Rinse the cell with de-ionised water between samples and remove excess water. Complete EC measurements within three to four hours of obtaining the aqueous supernatant.

Report EC (μScm^{-1}) at 25°C on an air dry basis.