Book 3 Dryland Salinity: Investigating and Assessment Techniques

Introduction

Each catchment and each property has a unique combination of landform, soil, hydrological, climatic and management features. Good land managers learn as much as they can about these characteristics and the way they interact on that property, to anticipate and correct problems so that agricultural production is more sustainable.

In the case of dryland salinity, site specific information helps land managers make informed decisions. It can be used to identify the primary causes of saline outbreaks and improve understanding of the physical or chemical limitations of the landscape.

Studying the distribution and concentration of salt in soil across a saline outbreak site helps determine limitations affecting management. Study methods may include measuring soil electrical conductivity (EC se), pH, nutrients, organic matter, cation exchange capacity (CEC) and toxicity.

Techniques that can be used to investigate and assess salinity include direct techniques, indirect techniques and remote techniques. A definition of these different approaches is provided later in this Booklet.

In selecting which method to use for assessing salinity, the following questions should be considered:

1. Who will be using the information, for example, specialist technical and research staff, regional/catchment planners or land managers?
2. What type of information is required, for example, does it need to be compatible or comparable with data already collected?
3. What is the size of the area under investigation, because some techniques are more expensive than others?
4. What type of investigation techniques are both available and suitable for use in the particular area?
5. Will the selected techniques answer the questions asked by the intended audience?
6. Is the scale of the investigation appropriate to the selected techniques, for example, is information required from a small area, whole property, subcatchment, catchment or an entire region?
7. What level of accuracy or density of information is required?
8. How much will it cost to collect the required information?

This booklet provides an overview of the issues that need to be considered when investigating and assessing salinity, and should be read in conjunction with other booklets in the Dryland Salinity series. It also provides a description of the various techniques for assessing salinity and gives a more detailed description of how some of these techniques are used.

Staff of the Department of Primary Industries and Catchment Management Authorities in different regions around the State may be contacted for advice and assistance in the application and relevance of the different techniques for salinity investigation and assessment in your local area.

What scale of investigation is required?

Many individuals and organisations have an interest in salinity including farmers, local communities, catchment groups and regional authorities. Their interest may stem from the desire to understand the current extent and degree of a salinity problem or the potential for salinity to develop given the presence of hazard and risk factors, as well as choice of suitable management options.

Before choosing the appropriate techniques for investigation and assessment of salinity in a particular location, it must first be decided what scale of investigation is required. Salinity investigations and assessments may occur at many scales, including at the paddock, farm, sub-catchment, district, catchment or regional levels for local monitoring and management purposes. Larger scale investigations and assessments of salinity may also be undertaken, for example, at the state, interstate and national levels for long term planning and monitoring purposes and to guide and coordinate cross border initiatives.

*What is **data density** and how does it affect selection of the scale for the investigation?*

Different types of planning require different levels of detail in the information used. Choice of the appropriate scale for salinity investigation and assessment activities is determined by the data density required in the final product or output such as a map or a plan.

Farm management plans usually require detailed information to direct on-ground works. The specific location, number and spacing of trees to be planted at a recharge site need to be identified.

Regional management plans require less detailed information but at a much larger scale, for instance when recommending revegetation of recharge sites across a sub-catchment.

The remainder of this section lists a series of questions for each scale depending on the data density required in the final product. These questions may be used to guide selection of the salinity investigation and assessment tools to ensure that the final product, such as a property, catchment or regional salinity plan or map, contains adequate and relevant information.

Investigations and assessments at the property or individual scale

Farmers have immediate, personal and business-related interests in salinity and its management. They may have some knowledge of the extent of salinity on their own farm or within the community but require further information to help them manage salinity at the paddock scale.

Useful scales to investigate salinity at the paddock level are those less than 1:7000.

(1 mm = 7 m and 1 square mm = 0.01 of a hectare).

Table 1 lists the questions that should guide the choice of investigation techniques at the property level.

Table 1: Questions to Guide the Choice of Investigation Techniques at the Property Scale.

Questions	Investigation techniques	Comments
Are there any indicators of salinity on my land?	Visual inspection – plant, soil and water indicators of salinity Ground based EMI Aerial photographs	Farmers might know where salt scalds are located, but may not understand the extent of potentially affected areas.
If so, what is the extent of the problem? Is it likely to get worse?	Ground based EMI Monitoring bores – watertable depth and quality	Assess what activities have caused rising watertables and salinity in adjacent or similar catchments
Is salinity damaging my assets or reducing productivity?	Visual inspection – crops, machinery, pumps and other infrastructure	An annual stocktake and visual assessment can help identify how much damage salinity has caused over time.
What are the future risks of salinity?	Ground based EMI Monitoring bores – water table depth and quality (changes over time)	Education and training may be needed to answer this question. Whole farm planning is the most effective action.

What can I do to stop it?	Further mapping (deeper EMI) may determine pathways of surface and groundwater flow and identify areas requiring remediation. Basic geology and soil review	Develop grazing and farming practices that use water more efficiently. Talk to neighbours or catchment management authorities about options.

Investigations and assessments at the sub-catchment scale

A local community group of ten to twenty neighbouring farms with similar soils and topography located within a sub-catchment may decide to pool their resources for planning purposes. This approach will improve coordination of management actions across the sub-catchment and allow land managers to gain economies of scale in their implementation.

A useful scale to investigate at the community or sub-catchment level, typically representing more than 10 whole farms, would be less than 1:25,000 (1 mm = 25m and 1 square mm = 0.06 of a hectare).

Table 2 lists questions to guide the choice of an appropriate investigation and assessment technique for the sub-catchment level. The questions are similar to those asked at the property scale, but are more likely to consider community benefits.

Table 2: Questions to Guide the Choice of Investigation Techniques at the Sub-Catchment Scale

Questions	**Investigation techniques**	**Comments**
What is the nature and extent of the salinity problem ?	Airborne and ground based EMI Rapid stream surveys Time-lapse satellite or aircraft remote sensing images	
How much salinity are we likely to get and when?	Soil and vegetation mapping Hydrology and water table trends Regional studies from adjacent areas (including geology) Monitoring bores – water table depth and quality	Understanding the relationship of the sub-catchment to surrounding areas and changes in land use is crucial
What can we do to stop it?	More detailed analysis of mapping products as well as modelling for prediction	Prevention and remediation measures require sound understanding of landscape and hydrological processes before action is taken
Is there anything we need our neighbours to do?	Historical information	
Is there anything I can do to prevent me making it worse for our neighbours?	Social and economic studies for groups or whole communities	The causes of salinity and the economic impacts rarely remain confined to farm boundaries. The costs and benefits of remediation also cross boundaries. Social and policy considerations are important.

Investigations and assessments at the catchment or district scale

Catchment management groups often have the responsibility of developing an integrated catchment management plan. Local councils are also responsible for managing many types of local infrastructure and community assets and need to consider salinity in conjunction with other natural resource management issues in their planning, development and maintenance of such assets.

An appropriate scale for this level of activity is 1:100,000 (1 mm = 100 m and 1 square mm = 1 hectare).

Table 3 lists the types of questions that may be asked at this level of planning to guide the choice of investigation and assessment technique.

Table 3: Questions to Guide the Choice of Investigation Techniques at the Catchment or District Scale

Questions	**Investigation techniques**	**Comments**
What is the overall level of the problem in this district or catchment?	Visual inspection Hydrology and water table trends Bore hole measurements Airborne and ground geophysics Remote sensing Rapid stream survey Vegetation and soil survey	An integrated approach is required for the entire area, to understand landscape effects on water movement. Detailed borehole and ground based information is needed.
How do managers ensure they adopt the most effective measures for addressing salinity and are educated about the management solutions available, their relative cost effectiveness and success rates?	Modelling (for prediction) requires good ground based information (monitoring bores, stream surveys)	Robust assessment of risks and benefits using risk management approaches. Modelling. Socio-economic considerations may extend outside the catchment planning area into adjacent areas.
Where are the best locations for on-ground actions (pastures, trees, soil works, management schemes) to achieve salinity targets in the most cost-effective way?	More extensive mapping using a suite of techniques is required. Survey design should focus on clear definition of the question to be addressed, and have a suite of methods chosen accordingly.	An even higher level of expertise is required to ensure benefits are maximised.
What information is needed to make sound investment decisions at this level? What is the best way to invest funds to maximise benefits from mapping, modelling, research and development, and on-ground works?	Farm or group historical information, social and economic studies for groups or whole communities.	Social and economic investigations and modelling (triple-bottom-line). Tailored research and investigation in landscapes for suitable management techniques

Investigation and Assessment at the Regional, State and National Scales

At the national and state levels, information is primarily used by planning and regulatory staff to develop government policy and provide direction to parliament and other state or national departments. Useful scales for this level of investigation include 1:500,000 or 1:1,000,000 scale where whole regions or states can be compared.

The types of questions used to guide investigation and assessment techniques will be similar to those asked at the catchment level.

Choosing an assessment technique

A range of techniques are available to investigate and assess saline outbreaks. These techniques are grouped into the three categories explained below.

Direct techniques

Salt is used to describe mineral salts such as sodium, potassium and calcium chlorides and sulphates. Direct methods for mapping salt refer to techniques that measure the actual level of salt directly.

Very few salinity assessment techniques measure salt directly. The techniques available include visual inspection of saline outbreaks, or taking a sample to measure total soluble salts in water or soil *in situ* , or for laboratory analysis of soil or water samples.

Indirect techniques

A wide variety of indirect techniques are available to measure salinity. These approaches measure parameters that are *indicators* of salt. From this information, the existence of salinity and the level at which it is present may be inferred.

Indirect methods are often used for mapping salinity in soil, water and the subsurface when funds are limited. They can be used to assess large areas of land at a minimal cost and generally employ non destructive technology to provide a representation of the characteristics of a given saline outbreak.

Examples of indirect techniques used to measure surface and subsoil salinity include resistivity and magnetics surveying, electromagnetic conductivity mapping (ground based EMI, or EM31 and EM38), oil map and geology map assessment and borehole conductivity logging.

The use of indirect techniques requires the support of other techniques to achieve an accurate understanding of the distribution of salts throughout an outbreak.

Remote techniques

Remote techniques for measuring soil and water salinity refer to direct or indirect methods applied at a remote location to measure parameters that indicate the presence of salt. Lillesand and Keifer (1979) have defined remote sensing as ‘obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon'.

Aerial photograph interpretation is the oldest remote sensing technique for broad acre mapping, combining the mapping of visible surface salt (direct method) and other indicators such as vegetation and water patterns (indirect method) from which salinity may be inferred. It is not on its own a useful tool for predicting where salt might occur in the future.

Other remote techniques are airborne and satellite radar imaging, airborne imaging spectroscopy and airborne EMI and radiometrics. Of all the airborne geophysical techniques, only electromagnetics have a signature closely related to salinity that is the results of an EMI investigation and the actual level of salinity are closely correlated so the former is a reliable indicator of the latter.

Each of these techniques has specific advantages and limitations. Selection of a particular technique for salinity investigations and assessments may be guided by the following questions:

1. Who is the intended audience?
2. What type of information is required?
3. What is the size of the area under investigation?
4. What type of investigation techniques will be used?
5. Will the selected techniques answer the questions asked by the intended audience?
6. Is the scale appropriate?
7. What level of accuracy (or density) of the information is required?
8. How much will it cost to collect the required information?

The multi-layered approach

It is unlikely that a single method for investigating or assessing salinity will be able to address all concerns. Using a multi-layered approach enables an investigation and assessment to accommodate different levels of understanding and accumulate a range of data sets to improve the accuracy of the conclusions.

The following format explains how to apply a multi-layered approach. The assessments featured range from those that are low in cost and easy to carry out to the more costly and complex techniques. Using investigation and assessment techniques in conjunction with local knowledge of the area enables a multi-layered approach to be applied at a farm or sub-catchment level.

For example, gathering historical information and local knowledge can comprise a combination of:

- direct techniques - knowledge of waterlogged areas which stay wet in summer and where vehicles get bogged, or a change in soil colour and type; and
- indirect techniques - livestock camps, change in paddock management, sites of lightning strikes and ameliorant (lime and gypsum) dumps.
- This collection of local information may then be followed by the application of investigation and assessment techniques, direct, indirect and/or remote, as listed above to affirm and refine the accuracy of the results.

Plate 1: A targeted, multi-layered assessment of salt affected land assists in the selection of vegetation species that can tolerate saline conditions and return productive outcomes.

Techniques should be used in an integrated approach to work out the geological and hydrological properties of the landscape, including characterisation of soils, salt content and subsurface flow pathways.

Validation and interpretation of results

When conducting a salinity investigation it is important to consider what the information will be used for, how accurate it is and if there is enough.

The validation and interpretation of information are important issues to consider when determining the quality control and quality assurance of data.

Validation ensures that the techniques used to collect data are sound. Typically, information is checked to ensure the quality and accuracy of information derived from a particular investigation. The information used to validate data should come from a different source and use a different technique to the one being validated.

Local knowledge of an area can be used to validate information collected during investigations at the farm scale and interviewing local land managers may be an effective and concise way to validate information.

The information collected is often very complex and requires a high level of technical expertise to interpret and explain the meaning of the results. An experienced technician should be able to provide plausible reasons for any anomalies within data sets and to determine whether the information is consistent with field observations.

When choosing an assessment technique, clients should consider:

- Who will validate the data and what should it involve?
- Who will interpret the data collected and how long will it take?
- What is the cost to complete the activities?

Investigation and assessment techniques - a comparison

Tables 4 – 6 compare and contrast available investigation and assessment techniques (Spies and Woodgate (2003)).

Table 4: Direct Investigation and Assessment Techniques

Techniques	Application	Cost	Comments
VISUAL INSPECTION	Through direct observation of salt scalds or by observing stressed vegetation. Then drawing the boundaries on a map.	Subject to the ordinary cost of labour.	Useful technique for mapping small areas (paddocks). Essential as a checking method for maps prepared from satellites, aircraft, or ground-based surveys.
LOCAL KNOWLEDGE	Through farm and local community social and economic assessments	Depending on cost of expert advice.	Used as a secondary validation tool. Also helps to benchmark status of community or farm unit.
FIELD MEASUREMENTS OF EC and ACIDITY	Electrical conductivity of a soil ($EC_{1:5}$) and water is a common and useful field procedure.	Cost - landholder time and cost of basic EC and pH meters.	Needs to be calibrated for solute type (laboratory analyses). Not all salt measured affects vegetation.

LABORATORY MEASUREMENTS OF ELECTRCIAL CONDUCTIVITY and ACIDITY	Analytical chemical analysis of evaluating soil and water salinity. Determines salt type and concentrations.	Moderately expensive if many samples are needed. Cost -variable	Laborious; days or weeks needed to obtain results. Salinity often varies greatly laterally and vertically, so samples may not be representative of large area.
RAPID STREAM SURVEY (requires EC and flow meters)	Measures EC and stream flow of sub-catchments at stream, creek or river intersections. Measures salt load and EC of a given stream.	Subject to cost of labour and good environmental equipment.	Can take days to survey major catchments. Need to assess differences between high and low flow.
GROUNDWATER MONITORING and SAMPLING	Examines groundwater chemistry, groundwater levels and responses to recharge spatially and in three dimensions. Also good for understanding groundwater pathways	Cost - variable	Bore holes should be logged as a matter of routine. Important to map salinity profile for calibration of surface and airborne systems.
HISTORICAL RECORDS (groundwater, rainfall)	Ideal method for identifying trends in data sets over time.	Cost - variable	Useful to help identify time scale reactions to climatic changes.
OTHER METHODS	Vegetation condition - dry matter assessments and random sampling. Preliminary review Hydrogeological data - water supply bores (GW levels and EC), EC of surface waters, examination of the geology of the area.		

Table 5: Indirect Investigation and Assessment Techniques (Ground Based)

Techniques	**Application to Assessment**	**Cost**	**Comments**
ELECRO-MAGNETIC INDUCTION TECHNIQUES (EMI) (eg: Geonics â EM31, EM39, EM34-3, Protem, Smartem)	Useful in mapping salt stores beneath root zone to various depths (eg EM31 to 6 metres or EM39 to 1.5 metres).	Cost - variable	Cannot resolve conductivity changes in root zone - use in conjunction with shallow probing EMI.
ELECTRICAL RESISTIVITY PROBING (ABEM (Terrameter, GeoMetrics, Ohm Mapper…)	Capable of improved resolution of vertical variations in conductivity from surface to bedrock.	Cost - variable	Requires use of electrodes in ground. Robust automated inversion software available

GROUND BASED MAGNETICS	To help define structural influences to groundwater movement and storage from the geology.	Cost-effective contribution to salinity management.	Best suited to mapping factors contributing to groundwater movement. Requires specialist interpretation.
GROUNDBASED GAMMA-RAY SPECTROMETRY (RADIOMETRICS)	Mapping of soil types is sometimes correlated with salinity.	Less than $1 per hectare. Usually acquired simultaneously with magnetics.	A demonstrated technique for broad area soil mapping. Requires specialist analysts for interpretation. Experts differ in respect of the usefulness of this technique for mapping surface salinity.
OTHER GROUND BASED SYSTEMS	Resource information surveys that measure geophysical attributes - gravity, magnetics, seismic etc.	Cost - variable	

Table 6: Remote Investigation and Assessment Techniques (Airborne and Satellite)

Techniques	**Application to Assessment**	**Cost**	**Comments**
AERIAL PHOTO INTERPRETATION	Through direct mapping of salt scalds or indirectly through mapping of stressed vegetation.	Air photos cost around $50 each. An experienced interpreter can map 3 - 6 photos per day.	A well-established technique. Can be slow to cover large areas but reliable for mapping in the root zone.
Multi-spectral Satellite Mapping (LANDSAT, SPOT, IKONOS, EARTHWATCH etc.)	Allows mapping of vegetation status and health. Useful in change detection.	Cost variable.	Good resources for a rectified image to record land management activities, land use changes and accurately record resource information.
AIRBORNE GAMMA-RAY SPECTROMETRY (RADIOMETRICS)	Mapping of soil types is sometimes correlated with salinity.	Less than $1 per hectare. Usually acquired simultaneously with magnetics.	A demonstrated technique for broad area soil mapping. Requires specialist analysts for interpretations. Experts differ in respect of the usefulness of this technique for mapping surface salinity.
AIRBORNE MAGNETICS	To help define structural influences of groundwater from geology.	Less than $1 per hectare. Cost-effective contribution to salinity management.	Best suited to mapping factors contributing to groundwater movement. Requires specialist interpretation.
OTHER AIRBORNE and SATELLITE METHODS	Radar Satellite Mapping (RADARSAT) Airborne Video - Mapping of vegetation growth for small areas.	Cost - variable	

	Airborne EMI (Tempest, Dighem, Resolve) - conductivity mapping for large flat areas.		

Description of common investigation techniques

Salinity investigations and validated interpretations can provide information for products used for higher-level planning at the catchment and regional scales, but also for lay land managers and professional resource managers. The results of salinity investigations can be integrated with a variety of local and historical information to help direct salinity interventions on the ground.

The following examples of assessment techniques are commonly used in salinity investigations, but the information should only be used as a guide to the application and limitations of the techniques.

Electro-Magnetic Induction (EMI) surveys - Salinity based investigations

EMI surveys are widely used for estimating the severity and magnitude of salinity outbreaks. They are also used for determining the distribution of particular soil types within an area (Plate 1).

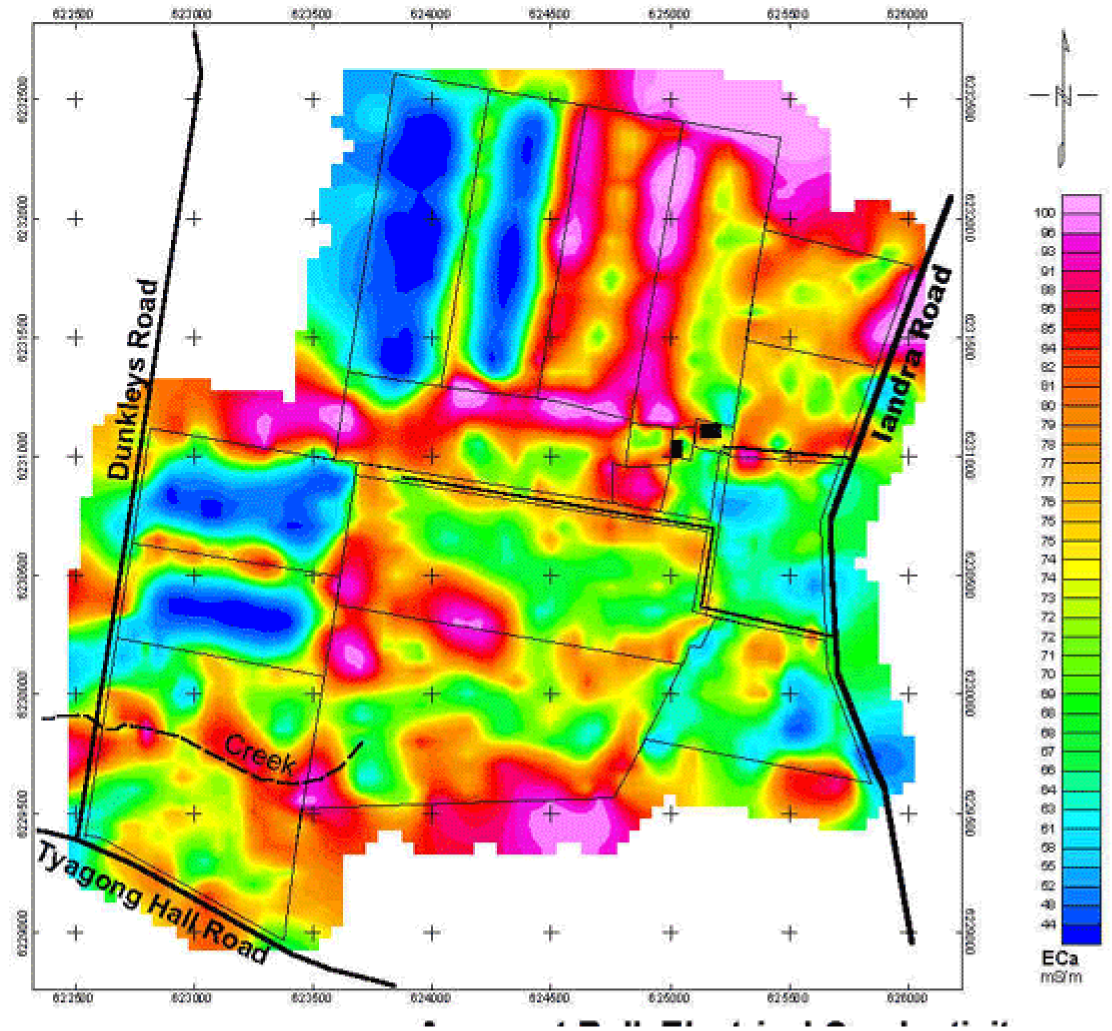
EMI measures soil conductivity. An EMI sensor (such as Geonics â EM31, EM38, EM34) measures this as the apparent bulk electrical conductivity (EC a) of the ground. The advantage of EMI surveys is that they are non-invasive, meaning that they require no disturbance of the ground. The surveys are accurate to ± 1m with position locations and ± 3m for height from sea level data when used with common GPS equipment.

Three main factors affecting the EC_a are related to soil texture (amount of sand, silt and clay in soil), soil moisture and cyclic salts of given depth of ground. These factors can be related to the specific characteristics of different soil types. EMI sensors are sensitive to changes in these soil factors and the EC_a readings expressed by the sensors usually vary between two extremes:

High conductivity readings can be expected where a heavy clay soil is seasonally waterlogged with saline ground water (red to pink colours on an EMI survey map); and

Low conductivity readings can be expected in dry, sandy soils (or gravel), with little clay and almost no salt (blue to green on an EMI Survey map).

Example of an EMI Survey Map



Types of EMI surveys **-** Ground based EMI surveys are usually applied at either a large or small scale. The size of an area to be surveyed and the density of the data points to be collected are the main differences between the two scales. Both approaches are non invasive requiring no disturbance of the ground during the survey.

EMI 31 Survey all terrain vehicle

Large area surveys (whole farms or groups) are usually conducted with the Geonics EM31 covering areas of up to 50,000 ha and measuring the soil conductivity to a maximum of 5 m when mounted on an ATV motorbike. The conductivity units used for the EM31 are in milliSiemens per centimetre (mS/cm) with resolution at ± 0.5%. The set-up of the EM31 on an ATV can cover up to 700 ha in a day for a catchment scale survey or around 100 ha per day for more saturated surveys.

General EMI 38 Survey

Small area surveys (research sites or paddocks) are usually carried out with EM38 covering areas of up to 50 ha and measuring the soil conductivity to a maximum of 1.5 m. The main use of the EM38 is to differentiate between highly conductive layers and nonconductive zones in the root zone. The sensor is primarily hand held having a capacity to cover 50 Ha per day for soil type surveys, but can also be set up in a similar fashion to the EM31 on a 4WD motorbike to enable areas to be surveyed much faster.

Limitations and validation of EMI surveys - EMI surveys cannot indicate how far down a saline layer will occur, or how far down there will be water and are not useful for determining where to sink stock or domestic bores. Highly conductive layers (anomalies) in the ground tend to influence most EMI readings. Examples of ‘anomalies' include electrical fencing, under-ground conductors (large pipes and drums) and magnetic geological features also affect survey results, so site visits are needed to validate the survey maps and data collected.

Validation of EMI surveys consists primarily of visual identification of salinity symptoms and correlation with historical information collected from an individual farmer or community group. To validate these surveys further, more detailed information needs to be collected by other methods and applied to the EMI survey products.

Aerial photo interpretation - Dryland salinity outbreak mapping

Aerial photo interpretation is the oldest remote sensing technique for broad acre mapping and involves the systematic acquisition of photos from precision cameras mounted on aircraft. The technique is likely to give an indication of the surface or root zone expression of salt where specific vegetation types can indicate the presence of salt. It is therefore a reliable mapping technique for existing surface or near surface salt when interpreted by an experienced operator. It is not, on its own, a useful tool for predicting where salt might occur in the future.

Salinity related mapping usually involves the detection of visible salt on the surface, or the identification of other factors such as vegetation or water bodies that might suggest salinity. Interpreted information can then be recorded onto topographic maps and digitised into a spatial database for distribution.

Mapping of saline outbreaks might also involve some form of validation or site visits. This allows information recorded with aerial photo interpretation to be checked to determine whether the boundaries and attributes describing each site have been accurately recorded.

Monitoring bore sampling and assessment - Groundwater investigation and modelling

Monitoring bores in saline discharge areas confirms whether a site has a groundwater problem or not. Groundwater levels need to be measured at least monthly, especially if water levels are changing rapidly. There is no point installing monitoring bores unless the water level is measured regularly (Plate 2).

If possible, monitoring should be done after major storms, steady rain or floods. This will give an indication of how fast groundwater levels respond to rain and what effect large rainfall events have on the groundwater system.

Longer term changes in groundwater levels due to climate, seasons and weather also interact with local landscape features to affect salinity levels. The results of this interaction are further influenced by the type of land use because of the varying impact of different land uses such as forestry, cropping and grazing, on local groundwater systems. Management choices, for example, pasture varieties, stocking numbers and crop rotation, also affect groundwater levels.

Small daily changes in groundwater levels also occur due to the earth's rotation, where changes in solar radiation cause variations in evapotranspiration, and the moon's gravity causes 'groundwater tides'.

Plate 3: Monitoring groundwater levels

Equipment Needed to Sample Monitoring Bores - The following items are essential for measuring groundwater levels from a monitoring bore:

- 30 metre tape with a bell shaped cylindrical 'plopper', reflecting the distinctive sound it makes when it touches the water surface;
- a clean container for testing samples;
- a bailer - a piece of pipe (copper or brass) approximately 0.5 metres in length with a flap at the bottom to collect water from monitoring bores; and
- an electrical conductivity meter.

When a monitoring bore is being sunk the removed core can provide information on the soil or rock profile and the depth of the groundwater (Plate 3). A bore log showing a salinity profile (laboratory salinity measurements at each metre) shows where the salt is concentrated.

Measuring water and salinity levels over time provides information on general trends (Plate 4). Readings should be taken over a number of years so it is important to keep them in a safe place. After water levels have been recorded over three or more years, seasonal trends will become evident.

Individual monitoring bore sites should be selected to represent various parts of the landscape. The following factors may be considered:

- changes in slope, where saline discharges often occur or expand;
- changes in rock type, because rock types vary in their groundwater characteristics; and
- different types of land use, for example, it may be useful to know what effect trees or perennial pastures are having on the groundwater system.

Upper groundwater levels may have higher salinity levels than deeper ones in recharge areas after significant rainfall, indicating downward water movement or recharge. Also, water levels in shallow monitoring bores often rise and fall sharply after rainfall, indicating rapid downward movement of water.

Plate 4: Auger sampling and monitoring bore installation

Plate 5: Bailing bore and sampling EC

Types of monitoring bore networks - If more detailed information is required, it is common practice to install a row of monitoring bores both along and across a representative sub-catchment (Plate 5). Direction of groundwater flow is indicated by water levels in the monitoring bores. Generally groundwater flows from a higher elevation to a lower elevation.

Nests of monitoring bores located in two transects will provide a thorough picture of what is happening at each site, across and down the catchment. Monitoring bores must be surveyed to compare water level height differences between bores in each transect. Groundwater contours can then be drawn up after surveying two or more transects.

A complete picture of the groundwater system can be drawn up after drilling in a grid formation. A three dimensional contour map of the groundwater system is the most comprehensive level of information available. However, the cost is usually excessive for the level of information needed. It is important to understand the level of detail required in the information before undertaking a drilling program.

Plate 6: Drilling and sampling monitoring bores

Satellite imagery usage - Land use mapping

Land use can be mapped using satellite imagery, which measures the reflected sunlight in the visible, infrared and thermal zones of the electromagnetic spectrum to create images of the earth's surface. These measurements can be made from aircraft or satellites and can cover large areas at high resolution. By measuring the reflected signals from the earth's surface it is possible to see vegetation types and predict their health.

This technique is particularly useful to identify patches of vegetation that are adversely affected by the presence of dryland salinity in the root zone. Accepted validation techniques for satellite imagery are aerial photo interpretations (API), site visits and farmer interviews for specific areas within a mapped region.

Glossary of terms

Air photo interpretation (API)	The act of examining photographic images for the purpose of identifying objects and judging their significance (Wolf, 1974). API may involve mapping the features of interest from a single photo or from two photos (known as a stereo pair), in which case the interpreter has the benefit of seeing the features in three dimensions. API is both an art and a science, and in general the more experienced the interpreter the better the result. When used for salinity mapping API is seeking to map direct evidence of salt at the surface, or is seeking to infer its presence in the root zone through signs that the vegetation is suffering or through signs that salinity has actual changes in the type of vegetation.
Biodiversity	Biodiversity is the variety of all life forms – the differing plants, animals and micro-organisms, the genes they contain and the ecosystems of which they form a part (State of the Environment Australia 1996). Australia 's biodiversity is a critical asset and is directly under threat from expanding salinity.
Dryland Salinity	The following description is taken from the Australian Dryland Salinity Assessment 2000 of the National Land and Water Resources Audit 2001. Two broad forms of salinity are recognised in Australia :
	Primary or naturally occurring salinity is part of the Australian landscape and reflects the development of this landscape over time. Examples are the marine plains found around the coastline of Australia and the salt lakes in central and western Australia . Salts are distributed widely across the Australian landscapes. They originate mainly from depositions of oceanic salt from rain and wind. Salt stored in the soil or groundwater is concentrated through evaporation and transpiration by plants. In a healthy catchment, salt is slowly leached downwards and stored below the root zone, or out of the system.
	Secondary salinity is the salinisation of land and water resources due to land use impacts by people. It includes salinity that is from watertable rises caused by irrigation systems, irrigation salinity, and from dryland management systems, dryland salinity. Both forms of salinity are due to accelerated rising watertables mobilising salt in the soil. There is no fundamental difference in the hydrologic process. Where the water balance has been altered due to changing land use (for example, clearing of native vegetation for broad acre farming or grazing) the excess water entering the watertable mobilises salt which then rises to the land surface. Movement of water drives salinisation processes and may move the stored salt towards the soil surface or into surface water bodies. It is the combination of the effects of salt and its movement by water through the landscape that leads to the creation dryland salinity.
EMI	Electro-magnetic Induction is the use of electrically generated magnetic fields to measure the conductivity (how well electricity can move through an object) of given sample of soil (see also Soil Conductivity).
Geophysics	The study of the earth by quantitative physical methods, such as magnetics, electro-magnetics, gamma ray spectrometry (radiometrics), and specific gravity.
Geophysical interpretation	The study of geological bodies within the subsurface of the earth crust to determine the location, size, geometry and depth from the surface. Spatial measurements of a geophysical field such as magnetics, electromagnetics and gravity are used to help infer this. Multiple interpretations are often made based on different assumptions depending on the type of model. Interpretations should be constrained by known information from ground observations or drill hole data, and may utilise computer-based inversion techniques.
Hydrogeology	A branch of geological studies determining occurrence, distribution, & effect of groundwater within geological structures. Groundwater is important in salinity studies as it controls the mobilisation & movement of salt through the landscape.

Hydrology	The scientific study of the properties, distribution and effects of water on the earth's surface, in the soil and underlying rocks and in the atmosphere.
Information product	A map-based product that provides information for immediate use in decision-making. Information products are derived from a range of data that may be in map form, developed through a process of expert analysis. A typical information product may be a whole of farm map and plan that shows the location of assets such as productive pasture and the presence of salt somewhere below it.
Landscape processes	The complex interactions between the natural cycles of the environment and the impact of human land use. The natural cycles, including hydrological, climatic and solar cycles, shape such critical processes and events as the movement of water, solar irradiation, climate, weather (including droughts and floods) and plant and animal growth. Human land use includes the cultivation of land, construction of build assets such as roads and dwellings, irrigation, management of national parks, forestry and other activities. It is the interaction of human activities and the natural processes that have increased the occurrence of dryland or secondary salinity in Australia .
Mapping methods	In this report a salinity mapping method is any technique on its own, or in combination with another, that can be used to detect the presence, concentration, location and extent of salinity at the time at which the techniques are applied. The extent is best defined by considering the breadth, width, and depth (the primary axes of an extant feature; the x, y and z axes) of a patch of salinity of consistent concentration. Salinity mapping methods range from soil sampling to measure salt concentrations to the use of satellite-based techniques for mapping vegetation patterns that indicate the presence of salt in the root zone. Soils, groundwater, regolith, vegetation and other spatial data can also be mapped using similar methods.
Model	A concept from which to deduce effects in comparison to observations. The "model" may be conceptual, physical or mathematical. Models are essential in any **interpretation** or **inversion** .
Modelling	Used in its broader context, modelling can refer to both the use of interpolating techniques that help produce a continuous picture by working with point-based data (put simply ‘the joining of the dots'), and for forecasting into the future the likely extent, location and amount of the feature that is the subject of the mapping. In this report modelling is specifically used in the latter context; as a forecasting technique for the likely location and concentration of salinity in the future. Therefore modelling introduces the fourth dimension, time, into the forecasting technique.
Remote sensing	Remote sensing involves obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand and Keifer, 1979).
Salinity	The presence of mineral salts such as sodium chloride (NaCl), potassium chloride (KCl), lime (calcium carbonate or CaCO3), gypsum (calcium sulphate or CaSO4), either in solution or as solids. (See also **Dryland Salinity**)
Scale	Scale is the ratio of the dimensions of objectives in real life as represented on maps.
Sodicity	A measurement of amount of exchangeable sodium (ESP) ions in the soil. High sodicity weakens soil structure and increases erodibility.
Soil Conductivity	Soil conductivity or EC is the measure for how well electricity can flow through soil, like clay and moisture content with amount of salts will influence results. High levels of clay and salt present in soil will give a high conductivity result. EC can be measured in various ways to get estimates, exact or inferred readings.

	These readings can be expressed as:
	EC a – apparent electrical conductivity of bulk soil using an electro-magnetic induction sensor (EM31, EM38, Protem, Smartem etc.).
	EC e – estimated electrical conductivity of a 1:5 (soil and water) sample using a soil texture conversion value.
	EC se - correct electrical conductivity of a soil sample, by measuring the 'saturated extract' of a soilpaste (using distilled water).
Soil chemistry	Soil chemistry refers to the composition, structure, properties, and reactions of a soil.
Soil salinity	Soil salinity refers to the accumulation of salts in the environment. Saline soil is normally assumed to be non-alkaline. Where pH>8.5 the soil is referred to as saline-alkaline. (See also **Dryland salinity**).

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