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Appendix F – Technical aspects of salt mapping

Introduction

This appendix reproduces a paper contained in the submission from the Commonwealth Departments of Agriculture, Fisheries and Forestry, and the Environment and Heritage.[1]

The appendix provides technical descriptions of some salinity mapping techniques, including airborne electromagnetic surveys used by the Bureau of Rural Sciences.

This overview is not exhaustive of the range of mapping techniques currently available and employed by private consulting firms. It is also acknowledged that there are other interpretations of the effectiveness and use of the technologies detailed by the Departments in this paper.

Electromagnetic surveys

In general, ground or water that contains much salt conducts electricity better than when there is little salt. This effect is used to measure and map the conductivity of the ground and groundwater together, the 'bulk conductivity'. Generally, high

1 Commonwealth Departments of Agriculture, Fisheries and Forestry, and the Environment and Heritage, *Exhibit no. 69, Technical aspects of salt mapping*.

bulk conductivity corresponds to high electrical conductivity in fluids in the ground but low bulk conductivity can be generated by ground with low porosity, ground with low conductivity fluids, or a combination of both.

Bulk conductivity is measured in the field with hand-held or vehicle-mounted electromagnetic induction instruments (EM31 and EM34). Surveys are conducted along traverses or a grid. EM31 provides a profile of the bulk conductivity to depths of five to six metres; EM34 has the capacity to explore to a depth of 50 – 60 metres depending on the configuration of the equipment and other factors. The benefit of an airborne electromagnetic (AEM) survey is that it offers rapid, accurate coverage of large areas with locations of salt stores and conduits for possible transport of salt, to depths greater than 100 metres below ground surface.

Both ground-based and airborne EM surveys need to be verified against down-hole EM39 induction conductivity logs, which give an absolute field value to compare against modelled bulk conductivity from the electromagnetic survey. This process is known as calibration.

Boreholes need to be drilled specifically to calibrate the survey over the full range of conductivities obtained in the survey. These can be converted later to groundwater monitoring bores to assess the performance of salinity amelioration treatments in the catchment.

It is important to note that ground-based and airborne EM surveys map bulk conductivity, which is proportional to both electrical conductivity (EC) of pore fluids or groundwater *and* porosity of the formation. The internationally accepted unit of measure for EC is milliSiemens per metre (mS/m). Conversion of bulk conductivity to EC therefore requires a good knowledge of the porosities of the soils and rocks in the saturated zone and volumetric water content (the ratio of the amount of water stored in a material to its total volume) in the unsaturated zone.

In practice, porosity and volumetric water content are generally poorly known, so a well-calibrated EM survey should be done against measurements of the pore fluids in the unsaturated zone, groundwater ECs in the saturated zone and porosities, in addition to the down-hole EM39 logs.

Assessment of salt stores and groundwater conduits from EM surveys requires expert hydrogeological interpretation in order to advise on the best options for management intervention—that is, the maps by themselves are no good to lay users and carry an inherent danger of being misinterpreted. Also, EM surveys do not differentiate primary salinity (naturally occurring in soils and rocks) from secondary salinity (salinity resulting from human activities), whereas mapping of new salinity outbreaks is a measure of secondary salinity.

Airborne electromagnetic (AEM) surveys

AEM induces an electromagnetic pulse from a transmitter towed from a low flying aircraft, generally about 120 metres above the ground. The survey can be flown by either fixed-wing aircraft or helicopter, flying sequences of parallel survey lines, generally at 200 m or more line spacing. The transmitted pulse induces a secondary electromagnetic response in the ground that gives a pseudo three-dimensional image of the ground's bulk conductivity structure.

Airborne electromagnetics systems such as those flown at Billabung Creek and Bland Creek (NSW), Honeysuckle Creek (Vic), and the Lower Balonne Catchment (Qld), transmit and measure electromagnetic signals that vary as a function of time. The signal received and 'mapped' by the system is sensitive to variations in the electrical conductivity of the ground, but the raw data itself in not a direct measure of the ground's conductivity.

Converting the data captured by the survey into an approximation of the bulk conductivity of the ground is done using various software-based processing or imaging methods, such as Layered Earth Inversion (LEI) or Conductivity Depth Imaging (CDI). Retrospective research in the lower Balonne and Honeysuckle Creek surveys showed that very little information was lost had the line spacing been increased by up to three times, raising the possibility of tripling the survey area for the same cost.

Salt mapping using AEM requires some initial understanding of the subsurface characteristics. Airborne electromagnetics is not always the most suitable technology for salt-mapping in the landscape. As a rule, AEM is most applicable for salt mapping where one or more of the following conditions hold:

- Where the terrain is relatively flat. Converting the raw data captured in the survey into an estimate of the Earth's conductivity requires certain assumptions to be made during the processing. AEM modelling processes are based on a 'layer cake' stratigraphy model—they assume that the Earth's material in the study area is made up of flat layers of material, laid down one on top of the other. Where this is not the case, for example, where there is extensive folding or faulting, the 'layer cake' assumption does not hold.

- In areas where the salinity target being mapped is relatively simple (that is, a single conductive unit rather than multiple salt-bearing units). It is difficult to convert the raw data into an approximation of the Earth's conductivity when there are several very conductive (potentially salty) materials at different depths; one layer of conductive material tends to hide another. The mathematical algorithms and modelling processes are continually improving – however, current imaging methods work best with relatively simple conductivity targets, which is the dominant situation over most of Australia's extensive agricultural areas.

- Where the salinity target is easily defined (that is, where the unit being mapped is definable and significantly different from the background materials). Again, this relates mainly to shortcomings with the techniques used to transform the raw electromagnetic data into estimates of the Earth's bulk conductivity. Does this mean that the unit is too obvious and is therefore smoothed or smeared?
- Where there is a high value asset to be protected. Flying airborne electromagnetic surveys costs between $2 and $10 per hectare. These costs are based on flight-line costs of $50-$100 per line kilometre at a line spacing of 100-400 metres. Mobilization is expensive (around $70 000) so economies of scale are important—limiting practical survey areas to greater than 50,000 ha. It is important to note however, that these economies of scale do make large airborne electromagnetic surveys very cost efficient, producing salt mapping at an overall cost of around $2-3 per hectare.

There is potential to double or triple the flight line spacing with insignificant loss of information, so survey costs could be reduced to less than $1 per hectare. In high-value irrigation lands, the AEM survey costs represent significantly less than 1 per cent of the value of applied water annually.

Airborne radiometrics

Radiometric surveys measure the natural radioactivity of soils. It measures gamma emissions from Uranium (U), Potassium (K) and Thorium (Th). Different soil types generate different ratios of U, K and Th, which allow the radiometric signature to map soils by their different mineral compositions. Because not all soil types give a unique gamma-ray signature, it is important that field investigation is always incorporated into any radiometrics survey.

Airborne gamma-ray spectroscopy surveys are commonly used to map soils, and are really only applicable for surface and near-surface investigations—to a maximum depth of 30cm. The distribution and shape of the different soil materials can indicate where they have come from and where they might move. In some situations, near surface conditions are indicative of deeper materials and radiometrics can be used to infer deeper geological characteristics. However, this relationship cannot always be assumed and field verification is always necessary.

Unlike AEM, radiometrics cannot generate a 3D salinity map, except by inference based on expert interpretation. Soils higher in clay content are more likely to store salt in the landscape. Note however that this does not mean a clayey soil is by definition likely to be a salt store.

Airborne magnetics

The primary magnetic field of the Earth induces smaller magnetic fields around magnetically susceptible (receptive) minerals—most commonly iron-rich minerals such as magnetite (George et al 1998).

A magnetics survey will not map salt but it can map sub-surface structures that can influence salt movement. The principle use of airborne magnetics surveys in salinity mapping is in conjunction with AEM, where it may give insights into the geology of the area where salt is being mapped. For example, because of the comparative heaviness of iron-rich minerals, they commonly occur as sedimentary lag deposits in ancient stream channels that are buried under later-deposited sediment. Aeromagnetics can measure these iron-rich deposits, which may define present conduits for groundwater movement and provide information on how the groundwater may influence salt deposition, accumulation and its potential for movement.

Aerial photographs and satellite imagery

The expansion or contraction of salt-affected areas in the landscape can be recorded by plotting visibly affected land on successive air photos (Coram et al. 2001). Air photos are also useful in mapping variations of catchment vegetation over time and photogrammetry with control points can provide elevation data for salinity outbreaks.

Satellite imagery using several bandwidths and wavelengths can be combined with other spatial information to map salinity outbreaks but the satellite record is much shorter than that for air photos. Interpretation of satellite imagery requires extensive experience in reading the images produced by remote sensing.

Soil surveys

Soil samples are taken from salt-affected areas and adjacent land or along surveyed traverses. Soil salinity measurements are interpreted on the basis of 1:5 soil:water EC extracts and moisture contents measured on the samples. Soil EC is generally reported in deciSiemens per metre (dS/m). Repeat soil surveys have the potential to map salinity change but these are point measurements only and cannot provide the spatial variability information of on-the-ground GPS mapping or aerial surveys. Soil surveys also provide little information on the impact of treatments on salinity since most groundwater flow systems are strongly buffered against change and long delays are expected between treatments and the amelioration of soil salinity (Coram et al. 2001).

References

Coram J., Dyson P. & Evans R. 2001, *An Evaluation Framework for Dryland Salinity*, report prepared for the National Land and Water Resources Audit (NLWRA), sponsored by the Bureau of Rural Sciences, National Heritage Trust, NLWRA and National Dryland Salinity Program.

George R. J., Beasley R., Gordon I., Heislers D., Speed R., Brodie R., McConnell C., and Woodgate P. (1998). *Evaluation of Airborne Geophysics for Catchment Management*. The National Airborne Geophysics Project National Report.