Electromagnetic probe for hidden salt

Blindfolded, you'd have no difficulty distinguishing a subway from a lift — your voice would sound different. In much the same way as environments differ acoustically, so they do electromagnetically, and a radio receiver will pick up different signals according to the electromagnetic 'ambience' in which a nearby transmitter is operating.

For many years geophysicists have been making use of this characteristic to prospect for minerals. They transport a transmitter across the terrain, and check whether an accompanying receiver picks up the tell-tale 'reverberation' of the sought-after ore body. Effectively, the technique measures the average electrical conductivity of the ground through which the signal passes.

The depth to which the conductivity measurement applies depends on the frequency of the transmitter, but common instruments work down to 30 m using a 400-Hz signal. Greater depths mean lower frequencies and larger aerial loops, and sheer size soon imposes a practical limit of several hundred metres.

Exploration geologists have been aware that the earth's electrical conductivity depends not only on the mineralogy of the underground rock but also on the water, clay, and salt content of the surface soil. They developed techniques for minimising the influence of these extraneous factors, which in extreme cases can totally obscure an ore body further down.

Several years ago scientists in the CSIRO Division of Water Resources Research recognised that they could exploit this 'disadvantage' and use electromagnetic (EM) techniques to rapidly survey the extent and concentration of subsurface salinity.

Salinisation of land, caused by the appearance of saline groundwater at the soil surface, has become a major problem over large sections of Australia where native vegetation has been cleared for agriculture. Detecting the steady advance of this hidden menace is important, but drilling bore holes to allow direct measurements is a slow and expensive way of doing it.

In 1979, Dr Baden Williams of the Division began assessing how accurately the EM technique could map the salt stored away below the surface. Quite well, it turned out, and 6 years later he has extended EM mapping to the tasks of pinpointing shallow aquifers and finding preferred locations for planting trees.

The same basic technique can be used to provide salinity maps over entire farms or over thousands of square kilometres.

Dr Williams uses a commercial (Geonics) electromagnetic conductivity meter, which can operate at three frequencies (400, 1600, and 6400 Hz), corresponding to effective penetration depths of 30, 15, and 7·5 m.

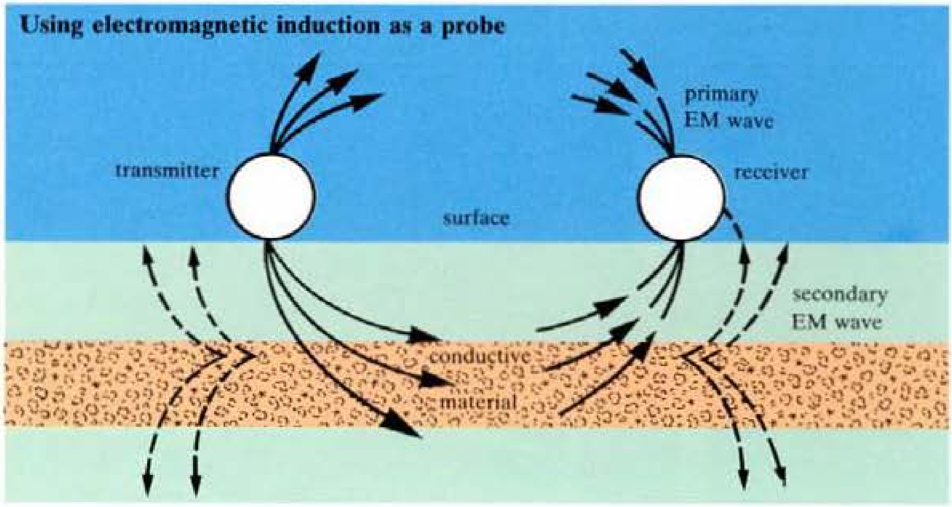
At the highest frequency, the transmitter and receiver coils, each 50 cm in diameter, are spaced 10 m apart. This allows the whole system to be mounted on a vehicle, and mapping can proceed while the operator drives across the countryside at about 4 km per hour.

Several State authorities now possess their own Geonics units, which cost about $25 000 apiece, and use them for mapping soil salinity in areas where they have research under way. The Victorian Rural Water Commission is collaborating with the Australian agents of the Canadian-manufactured Geonics units in experimental trials of an airborne system. Flying at an altitude of about 100 m, and using the plane's fuselage as aerial, a pulsed-transmitter arrangement can sense the conductivity of the ground below (the reading reflects conditions about 30 m below the surface).

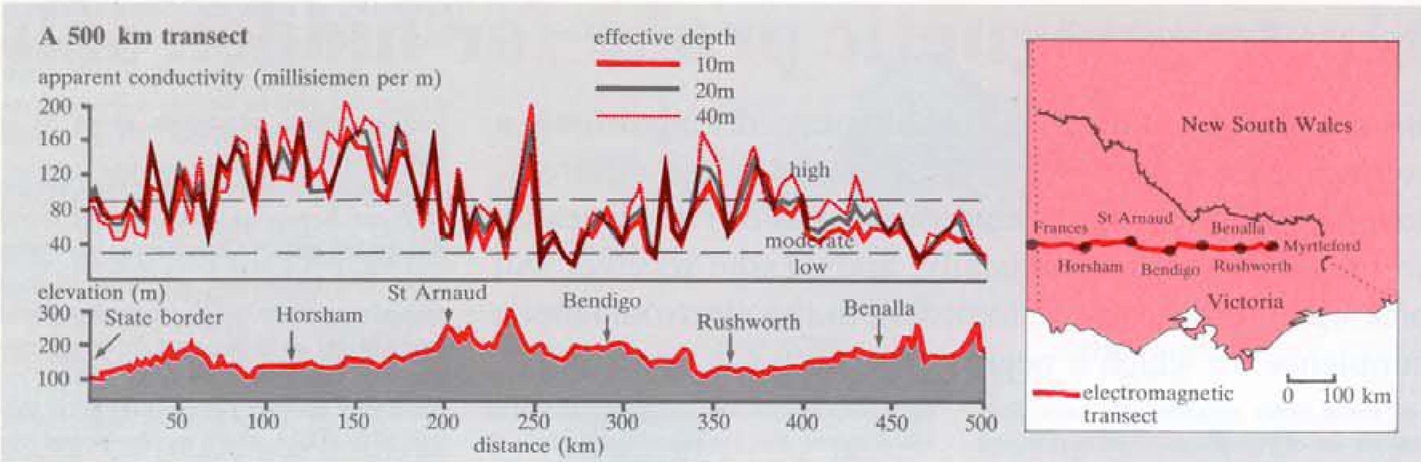
At the Perth laboratories of the Division of Water Resources Research, Mr David Williamson and Dr Chris Barber have been using EM techniques not only to map subsurface salinity but also to track polluted groundwater as it disperses from a waste-disposal site (see the box). They are employing another pulsed-transmitter system, SIROTEM, which was developed into a commercial instrument several years ago by the CSIRO Division of Mineral Physics and Mineralogy. But, as we were discussing, one of the unsurpassed advantages of the Geonics units is the greater portability of its coils.

In an early (1982) paper, Dr Williams and colleague Mr Geoff Baker described how they had made a reconnaissance of some 10 000 sq. km in the Lachlan River Valley of New South Wales. Large tracts of this land have already become salinised (where the saline groundwater has reached the surface and affected the vegetation), and on these areas the EM instrument generally gave the expected high conductivity at shallow depth (that is, using the high-frequency setting).

But, of much more value, additional information from the lower-frequency settings disclosed regions where the salt concentration was relatively low near the surface and at a maximum just beyond the reach of tree roots. Conductivities of up to 140 millisiemens (mS) per m were frequently encountered for depths down to 20 m, compared with 60 for depths to 10 m. This can be compared with values of about 200 for depths to 10 m in an obviously saline soil. (Conductivity is the inverse of resistance, and so 1 millisiemen = 1000 ohms.)



The changing magnetic field of the transmitter loop induces currents in nearby conductive material; these give rise to a secondary electromagnetic field that alters the amplitude and phase of the primary wave in the receiver loop.



This electromagnetic survey showed high levels of subsurface salinity extending nearly 200 km west of St Arnaud, Vic.

A comparison of EM readings with actual salinity measurements obtained from 19 bore holes showed that the highest values corresponded to a concentration of soluble salts of 0·7% — hazardously high. A statistical analysis showed that approximately two-thirds of the variability of the conductivity readings could be explained in terms of salinity alone.

Results like these provide a warning that the locality needs to be treated with care — it has the potential for increased surface salinisation if the salt should be carried upwards by a rising water table.

Mapping the millisiemens

A glimpse of the enormous capabilities inherent in the EM technique can be had

Tracking groundwater pollution electromagnetically

When Dr Jock Buselli and his colleagues at the CSIRO Division of Mineral Physics and Mineralogy set about devising a world-class electromagnetic tool for mineral exploration, they had no idea that this instrument, SIROTEM, would find an application in keeping watch on an expanding plume of polluted groundwater near Perth.

That it is now doing so is a compliment to the information-gathering capacity of SIROTEM's signal-processing circuitry.

With a transmitter loop 50 m square, scientists used SIROTEM to measure the conductivity of the earth adjacent to Canning Vale's waste lagoons. Higher readings (colour) indicate where pollution has contaminated the groundwater.

Whereas the electromagnetic instrument used by Dr Williams detects the secondary currents induced in the ground by a continuous-frequency transmitter, SIROTEM (CSIRO transient electromagnetics) detects the decaying signal produced by suddenly switching off a direct current induced in the ground.

Mathematically, the transient technique is equivalent to obtaining a sounding from a whole series of simultaneous continuous frequencies. That is, SIROTEM operates in the time domain, in contrast to the frequency domain of the other approach.

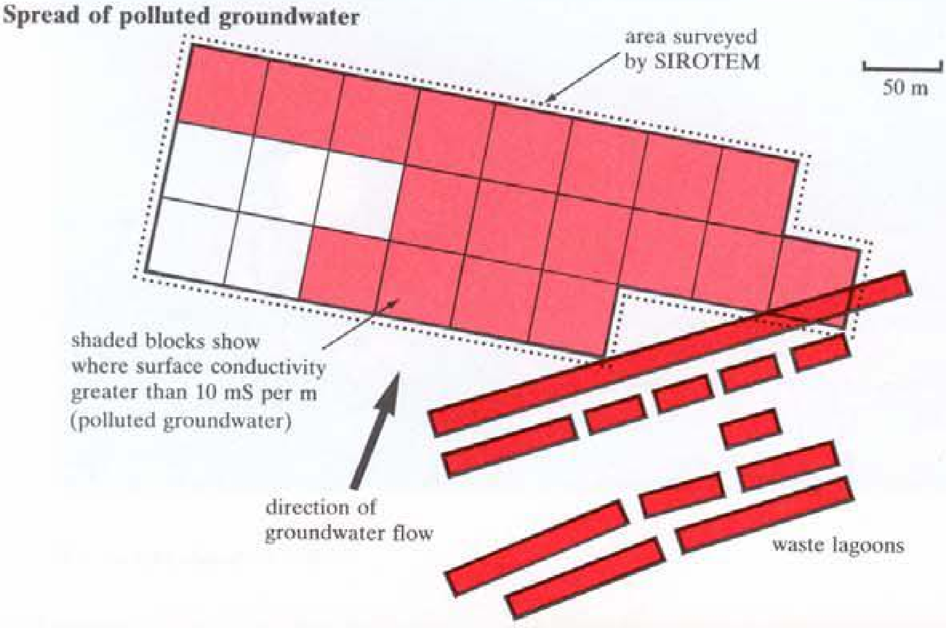
The advantage of SIROTEM is the wealth of detail that can be obtained quickly and easily. The earliest signal coming back to the instrument — with a delay of some 50 microseconds — corresponds to near-surface features (similar to high-frequency operation of its cousin); the latest response — 50 000 μsec delay — comes from features about 100 m down, and to detect them the other way it would need something like a 50-Hz continuous frequency. The wide range of frequencies results in a much better vertical resolution of the ground conductivity.

When Dr Buselli produced his first instrument, its earliest time channel had a delay of 500 μsec, and so information from the first 50 m down was lost. It quickly became apparent to him that, for application to near-surface mapping of salinity, shorter delay times were needed. He therefore modified SIROTEM so that it could register the earlier signals from the shallower layers.

Mr David Williamson of the Perth laboratory of the Division of Water Resources Research saw the value of SIROTEM for the studies he and his colleagues were doing on Western Australia's salinity problem. In 1985, he and Dr Buselli carried out the first tests of this application of 'early time' SIROTEM.

Mr Williamson and Dr Chris Barber have used the instrument to map areas with subsurface salinity in the Collie catchment. As found by Dr Williams, differences in salt levels registered by the instrument indicate the amount of leaching and groundwater recharge.

Spread of polluted groundwater



from a survey conducted by Dr Williams and his colleague, Dr Mike Braunach, which started at Frances in South Australia and ended at Myrtleford in north-eastern Victoria — a distance of 500 km. Every 5 km, they took a conductivity reading using three different coil spacings, corresponding to depths of 7·5, 15, and 30 m.

The complete conductivity profile is shown in the accompanying diagram. It contains some interesting variations. Sometimes the surface conductivity value is higher than that at depth; sometimes the reverse. However, for a distance of 200 km west of St Arnaud, values are consistently high (more than 90 mS per m), indicating a massive salt accumulation.

Also notable are the abrupt changes in conductivity, which are not related to topography. To get a clearer picture of how salt appears in the landscape, and how it's affected by hydrology and surface features,

With transmitter and receiver loops mounted on a vehicle, conductivity readings covering 4 km can be made in an hour.

To detect deep-lying features (more than 50 m down), SIROTEM uses a large square transmitter loop 100 m across. This creates a disadvantage in terms of portability and speed of operation, so for near-surface mapping, the researchers use a smaller loop with sides one-quarter as big.

In some cases, they use the large transmitter loop, together with a small roving receiver coil 0·5 m across, which allows them to make many measurements at points inside and outside the loop. They can achieve a horizontal resolution of 5 m, or less, this way.

Mr Williamson sees SIROTEM as a tool that can tell a land manager the most appropriate EM signal frequency to use before he or she begins surveying for recharge areas with a continuous-frequency unit. The two instruments have complementary roles in searching out salt in the landscape, he believes.

An important feature of SIROTEM is that its data can be interpreted in terms of a two-layer model of ground conductivity — a high-conductivity layer overlying a low-conductivity one. With computer processing, the data emerge as average conductivity values for each layer, and the depth of the interface between them. The diagram (right) shows an example.

The same technique has recently been put to another application — monitoring of groundwater pollution. In this case, the researchers were aware that pollutants increased the conductivity of any groundwater in which it is carried (although not to the same extent as salt does). They therefore put SIROTEM to the task of tracking the spread of pollution from the (now closed) Canning Vale liquid-waste disposal site.

The Canning Vale site consisted of a series of pits into which biodegradable liquid wastes (principally from septic tanks) have been emptied for evaporation and infiltration. The site, complete with monitoring bore holes, provided a good test of whether the EM technique could pick out the small conductivity differences between clean and contaminated groundwater in the underlying aquifer.

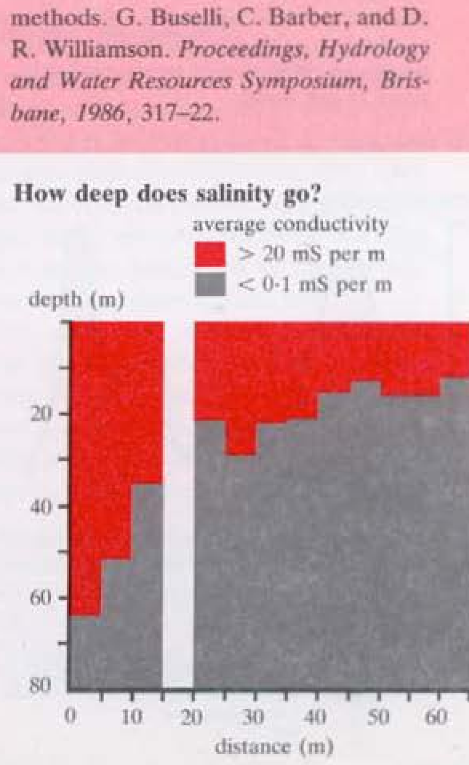
SIROTEM readings were taken every 50 m in three parallel lines downstream of the waste pits. Setting a criterion that groundwater was polluted if its conductivity exceeded 10 mS per m, the researchers judged that pollution had spread some hundreds of metres, as shown in the diagram on page 12.

Satisfyingly, the distribution of the polluted water, as judged this way, largely coincided with the region deemed to be polluted as indicated by existing bore holes and by a method involving the detection of traces of methane given off by the polluted groundwater. The method was devised by Dr Barber and Dr Greg Davis, and uses gas chromatography to analyse samples collected in the field by gas-sampling probes.

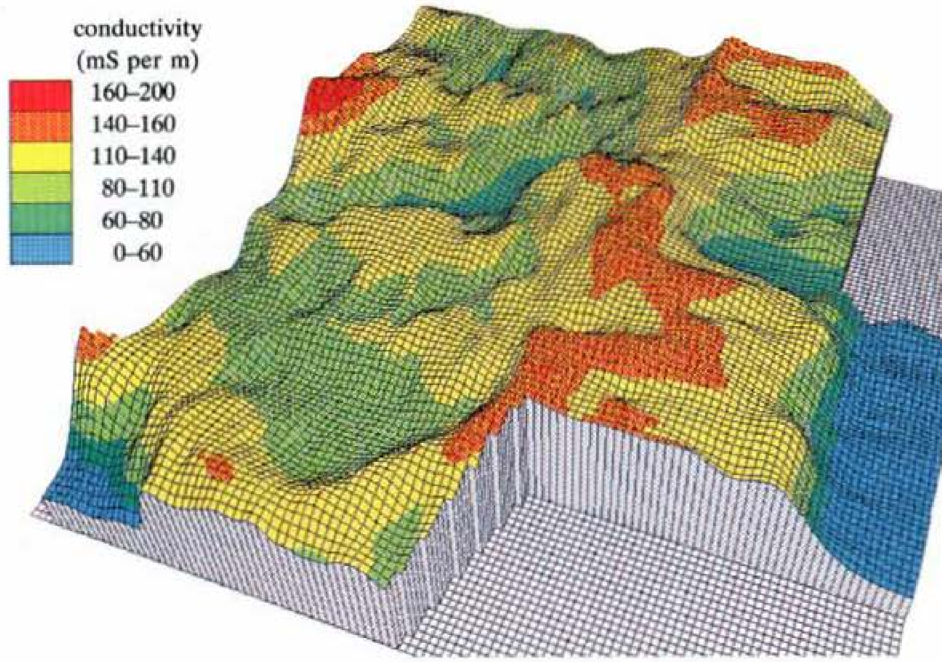
The scientists have also applied the SIROTEM technique to a landfill site at Morley, and they are mapping a planned site at Mindarie before disposal begins so that a more accurate picture of any leakage from it can be drawn up.

The mapping of groundwater contamination and soil salinity by electromagnetic methods. G. Buselli, C. Barber, and D. R. Williamson. *Proceedings, Hydrology and Water Resources Symposium, Brisbane, 1986*, 317–22.

How deep does salinity go?



Computer-processing of SIROTEM data, using a two-layer model, can reveal the depth of the boundary between saline and non-saline regions.



This computer plot of a grazing property near Benalla, Vic., shows both the region's topography and, as colour, its conductivity. The plot covers 120 ha.

a much more detailed investigation would be needed.

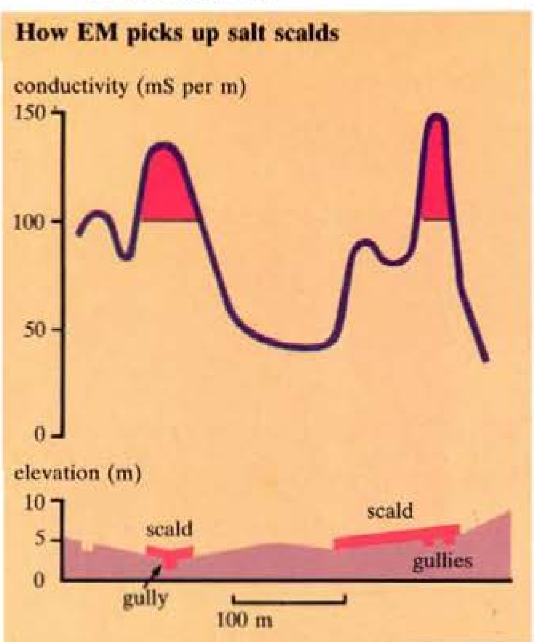
However, while conductivity measurements are a good general guide to what's below the surface, Dr Williams would make the point that they aren't the 'be all and end all' of salinity assessment.

For example, on a few occasions at locations where high near-surface conductivity values were recorded, there was no sign of salt-affected vegetation. Yet a few other readings above salt scalds were on the low side.

The problem arises because the EM technique's conductivity readings are affected by factors other than salt alone. The arrangement of gaps in the soil structure, the ground's mineral type, and the degree of 'connectedness' of soil particles and water films — all these have a bearing on conductivity. Obviously, a good knowledge of hydrology and geology is needed to complement the information provided by the EM instrument.

Nevertheless, it remains true that the instrument can provide a useful warning of the potential for salinisation. Dr Williams impresses upon us, therefore, that approximately 300 km of that 500-km transect indeed has the potential for surface salinisation — if groundwater levels rise and bring salt to the surface.

When the conductivity of a salt-degraded paddock near Goulburn, N.S.W., was measured, high values corresponded to areas of salt scald.



Water divining

Further work over 706 sq. km of the Major Creek catchment in central Victoria has confirmed the high correlation between high conductivity readings and elevated salt content. This investigation involved drilling 23 holes down to depths as great as 15 m. In this exercise, Dr Williams found a correlation coefficient of 0·85, indicating a strong relationship.

Several years of working with the technique have given Dr Williams confidence that the EM approach, properly interpreted, gives a valid picture of salt stored in the landscape. In more recent times, therefore, he has pushed the method to its limit of resolution, producing maps of square kilometres of country with grid spacing as little as 10 m.

Remarkably, even at this level of detail, very rapid changes in conductivity with distance are apparent. In other words, within an area relatively high in salt, local low-conductivity zones can appear. How is that possible?

Dr Williams has found that the amount of salt held in the soil profile is closely related to the amount of clay present, and this depends on local geology. If an area happens to be free from clay deposits, and is sandy instead, then it will be low in salt because most will have been leached away by infiltrating rain-water. Similarly, areas of fractured rock can easily be leached and give low EM readings.

So if an EM instrument indicates a sudden drop in conductivity, this may indicate the presence of a sandy layer below. And, since sand beds often act as shallow aquifers, an experienced operator can use the EM method for 'water divining'!

Dr Williams finds it is the relative changes in conductivity values within a given survey area, rather than their absolute values, that are the important indicators. Of course, the method only works for shallow aquifers within the range of the EM instrument (less than 30 m deep).

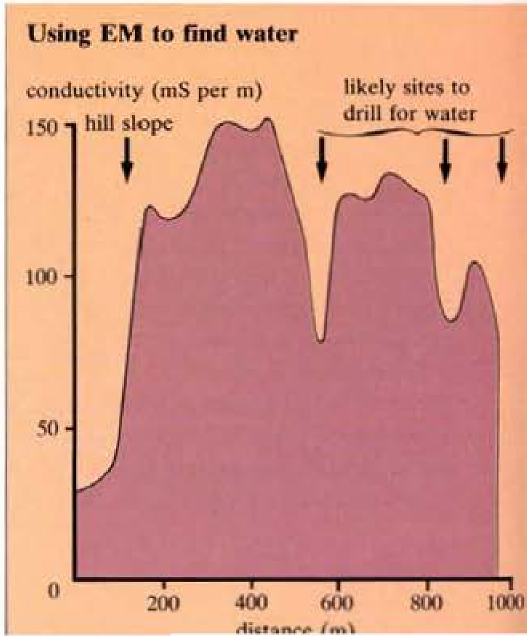
Not all sand beds contain water, of course, and even those that do may be too salty or low-yielding. The only way to find out is by drilling. Like the dowser with his or her divining-rod, though, the EM instrument has the advantage that it tells you exactly where to drill, potentially saving large amounts of time and money.

The EM meter has scored hits at Mongarlowe, N.S.W., and Nagambie, Vic., but an 'aquifer' picked out at Griffith, N.S.W., proved dry.

For irrigators, EM mapping can be used to help in strategies against salinity. The first is to find fresh-water aquifers that can provide cheap irrigation water; alternatively, saline aquifers can be pumped to lower groundwater levels.

Another strategy is to use the EM instrument to locate non-porous (aquifer-free) regions on which salt-evaporation pans can be established. There's no point in pumping saline water onto these pans if sandy soil underneath allows the salt to drain back into the water table.

A sudden drop in conductivity in an otherwise featureless region points to a likely shallow aquifer.



Dr Williams is currently using his Geonics units to check that saline water pumped into the Noora evaporation basin (near Loxton, S.A.) is not percolating into the ground and spreading laterally.

Where to plant trees

Because areas of sand and fractured rock reveal themselves as sites of pronounced leaching, it follows that these same localities must also be groundwater recharge zones. Now since excessive recharge — because of vegetation clearance — is the major cause of salinisation, the ideal place to reverse the process, by planting trees, is in the recharge zone. Electromagnetic surveys can therefore serve as tree-planting guides.

Using this logic, about 1000 salt-tolerant trees have been planted on a severely salt-scalded and eroded property near Yass, N.S.W. An EM survey conducted by Dr Williams and his colleague Mr Peter Richardson determined a number of zones on the property where conductivity was relatively low (less than 100 mS per m), and the New South Wales Soil Conservation Service planted the trees to largely coincide with these zones.

The area is being periodically monitored to check how the trees are affecting salt and groundwater levels.

Andrew Bell

More about the topic

The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soils. B. G. Williams and D. Hoey. *Australian Journal of Soil Research*, 1987, **25**, 21–7.

Electromagnetic induction as an aid for tree-planting strategies in salt-affected land. P. R. Bullock and B. G. Williams. *Proceedings, International Soil Science Society Symposium, Karnal, India, 1987.*

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The use of electromagnetic induction for locating subsurface saline material. B. G. Williams and F.-T. Fidler. *Proceedings of the International Association of Hydrological Sciences, Hamburg, 1983.*

The detection of subsurface salinity within the northern slopes region of Victoria, Australia. B. G. Williams and M. Braunach. *Proceedings of the International Symposium on State-of-the-Art Control of Salinity, Utah, 1983.*