

ELECTROMAGNETIC INDUCTION AS A TECHNIQUE FOR DIAGNOSING AND MAPPING SOIL SALINITY

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Abstract

Conventional methods of measuring salinity involve soil sampling with an auger followed by analysis of a water extract of the sample in the laboratory. This procedure is slow, laborious and expensive. The EM-38 electromagnetic induction soil conductivity sensor of Geonics Ltd (Canada) has been developed to facilitate rapid field measurements of soil salinity. It responds to the electrical conductivity (EC) of the bulk soil, and this is influenced by the salinity level as well as the water content. The depth of influence of the sensor is approximately 1,5 m. Calibration equations presented allow estimation of the EC of the saturation extract for the upper 1,2 m soil depth for various categories of texture and water status. Soil salinity maps for a study area at the La Mercy farm demonstrate the utility of the sensor for salinity mapping.

Introduction

Soil salinity problems occur in the sugar industries of Southern Africa, predominantly in the low rainfall regions of the irrigated lowveld. This has been documented for South Africa by Maud and Mann (1965, SASEX internal report), von der Meden (1966, 1967), Johnston (1977, 1978) and Wood (1991); for Swaziland by Workman *et al.* (1986) and Nixon and Workman (1987) and for Mozambique by Laperre (1973). Some localised problems are also found in the high rainfall coastal regions of Natal/kwaZulu (Johnston, 1980). A primary cause of soil salinisation in these regions is the development of high water tables, which allow capillary rise of saline ground water into the rooting depth of the crop. It is the fine textured soils of low permeability that are the most problematic.

The need often arises to diagnose soil salinity or to evaluate the extent of salinity problems. The conventional method of measuring soil salinity involves sampling to depth with an auger, sample drying and grinding, and then the analysis of a water extract in the laboratory. The procedure is laborious and expensive. For large scale investigations of soil salinity involving many samples, the delay in obtaining results is usually considerable. It is clearly desirable, therefore, to develop techniques that can make rapid, on-site measurements of soil salinity.

Over the past decade or so, two electrical techniques have been developed in the United States and Canada that allow rapid characterisation of soil salinity status. These are the four-electrode and the electromagnetic induction (EM) methods. A recent study, funded by the Water Research Commission, investigated the use of these methods under southern African conditions (Johnston, 1994). The EM technique, using the Model EM-38 of Geonics Ltd (Ontario, Canada), was found to be particularly useful in agriculture. This corroborates the experience of scientists in overseas countries: Kingston (1985) in Australia, McKenzie *et al.* (1990) in Canada, and Rhoades (1990) in the United States.

This report outlines the principles of the EM technique, and explains how measurements made with the EM-38 sensor can be interpreted. Further, calibration relationships obtained for different soil conditions are presented that allow estimation of the conventional index of soil salinity, *viz.* the electrical conductivity of the saturation extract (EC_s). The use of instrument-based measurements for mapping soil salinity is also compared with conventional procedures in a salinity mapping exercise.

Features of the EM-38 Sensor

The instrument is 1,05 m in length, has a mass of 2,5 kg and is powered by a small 9 V battery. It is therefore easily portable and can be operated by one person. Transmitter and receiver coils are situated at each end, spaced 1,0 m apart, and housed within the sensor together with the other electronic components. The readout of electrical conductivity is provided over the range of 0 to 1 000 mS/m. The instrument has a port for connection to a data logger for electronic storage of readings. Measurements are taken in the field with the instrument placed on, or slightly above, the soil surface, with the instrument in a vertical or horizontal position (Figure 1).

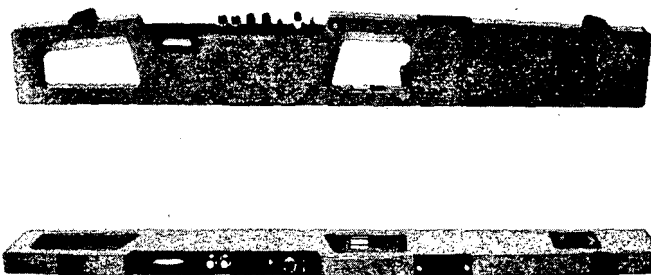


FIGURE 1 The EM-38 sensor in the vertical (upper) and horizontal (lower) positions.

Principle of operation

During operation the transmitter coil is energised with an alternating current at audio frequency (13,2 kHz). The time-varying magnetic field arising from this alternating current induces small eddy current loops in the soil, shown diagrammatically in Figure 2. These currents generate a secondary magnetic field, the strength of which is strongly influenced by the EC of the soil. Both fields are sensed by the receiver coil, and the instrument derives the EC of the bulk soil from the ratio of the secondary to primary magnetic fields. Since rock material and solid soil particles have very low electrical conductivity (McNeill, 1980a), it is primarily changes in the conductive liquid phase (in terms of water content and electrolyte concentration) that give rise to instrument response.

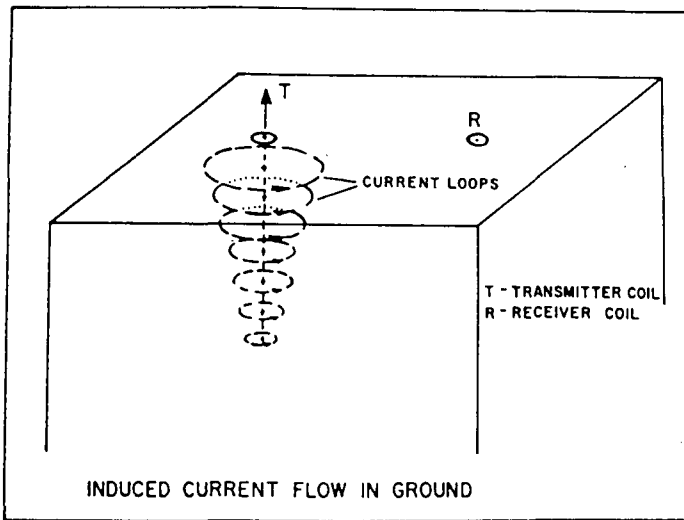


FIGURE 2 Principle of operation of the electromagnetic induction soil salinity sensor (after Rhoades and Corwin, 1981).

An important feature of the instrument is the response distribution with depth. The distribution that applies to the horizontal position of the coils differs quite markedly from that for the vertical position. These distributions have been described mathematically by McNeill (1980b), and are shown graphically in Figure 3. It can be seen that in the horizontal position the instrument is more responsive to the surface soil layers, whereas in the vertical position it is more responsive to the deeper layers. Seventy per cent of the response is ascribed to the upper 0,75 m of soil in the horizontal position, and 68% is ascribed to the upper 1,50 m in the vertical position. This feature allows one to judge whether the soil salinity increases or decreases with depth. A higher reading in the horizontal than in the vertical position implies that the soil is more saline near the surface than deeper, and *vice versa*.

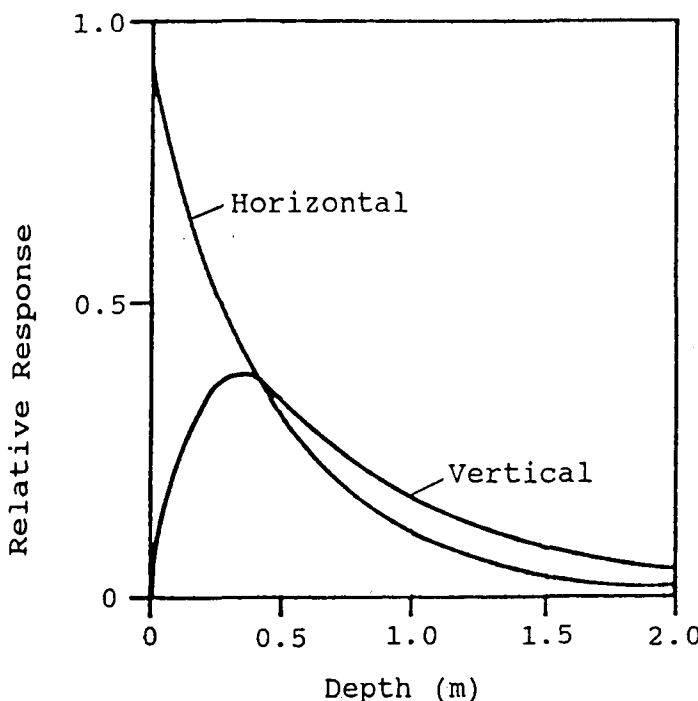


FIGURE 3 Relative response distributions for the vertical and horizontal positions of the EM-38 sensor.

Interpretation of instrument readings

Various approaches have been made to the interpretation of readings. One has been to develop regression equations for conversion of the EM reading to the EC of the bulk soil (EC_b , as measured with a four-electrode probe) for various depth intervals down the profile (Rhoades, 1990). This approach requires further interpretation of EC_b in terms of EC of the saturation extract (EC_e). A second option has been to relate EM readings to a single-valued EC_e , weighted according to instrument response with depth (Wollenhaupt *et al.*, 1986). This approach was taken further by McKenzie *et al.*, (1989), who developed a set of equations for various categories of texture, water status and instrument orientation. A third approach has been to define categories of soil salinity in terms of instrument readings (Kingston, 1985).

A. Development of calibration equations

In this study the approach favoured for interpretation of instrument readings was to relate them to a single-valued EC_e for each site. In order to develop a set of regression equations for different soil conditions, a suitable data set was required.

Procedure

Studies were made at a total of 110 sites in various irrigated areas countrywide. These included Pongola, Mkuze, Douglas, Vaalharts Irrigation Scheme, Sundays River Scheme, Fish River Scheme and the Loskop Dam Scheme. At each site readings were taken with the EM-38 sensor in both orientations, and soil samples were taken at depth intervals of 0,30 m to a depth of at least 1,20 m. Soil temperature was also measured at these intervals. For each sample the clay, silt and sand contents were measured or estimated, and soil texture classified as coarse, medium or fine according to McKenzie *et al.*, (1989).

Water status was categorised by the plant available water capacity (AWC), i.e. <30%, 30 to 85% and >85% according to McKenzie *et al.* (1989). The saturation extract was prepared on each sample and EC_e determined. All EM readings were corrected to 25°C from temperature-correction factors given by Richards (1954), in accordance with the findings of McKenzie *et al.* (1989). This data set was used to establish linear regression equations between temperature-corrected mean EM values (i.e. mean of the horizontal and vertical readings) and mean EC_e for the 0 to 1,2 m depth.

Results and discussion

The regression equations developed for eight different soil categories based on texture and water status are shown in Table 1. Certain of the drier water status categories were

TABLE 1

Linear equations ($y = mx + c$) to convert mean EM readings (x) to mean EC_e (0 to 1,2 m), where units are in mS/m (after Johnston *et al.*, 1994).

Soil texture	Water status (% AWC)	Equation	r^2	n
Coarse	>85	$y = 3,15x - 35$	0,85**	19
Medium	30-85	$y = 4,89x - 60$	0,92**	13
Medium	>85	$y = 3,84x - 122$	0,83**	22
Fine	30-85	$y = 5,28x - 185$	0,92**	14
Fine	>85	$y = 3,78x - 173$	0,84**	23
Fine, other than smectic clays	30-85	$y = 5,20x - 164$	0,90**	11
	>85	$y = 4,25x - 157$	0,91**	11
Smectic clays	>85	$y = 3,22x - 186$	0,93**	11

omitted because of insufficient data. Also, it was found desirable to create a separate category for smectitic clays, owing to their rather unusual characteristics. In this context, their high cation exchange capacity (CEC) and water retention is believed to have resulted in a lower regression slope and intercept than that for the other fine textured soils.

Soils in the higher water status category (>85% AWC) consistently display lower regression slopes than their counterparts in the lower water status category (30 to 85% AWC). This is because drier soils have a lower volume fraction of water, resulting in a relatively low EM value for a particular salinity level in the soil water.

B. Use of the EM-38 Sensor for mapping soil salinity

To evaluate the use of the EM-38 sensor for salinity mapping, an area was selected for a pilot survey. The main objective was to compare instrument-based salinity mapping with that done by conventional sampling and analysis.

Procedure

The study area selected was a 7,2 ha field (Field 206/9) on the La Mercy farm of the South African Sugar Association. This field was known to be affected by salinity, and showed a range of soil types varying from hydromorphic black clays in the valley bottom (Rensburg and Willowbrook forms), through sandy clay loams (Kroonstad and Katspruit forms) to deep sands (Fernwood form) in the upslope areas (Anon, 1991). Soil depth generally exceeded 1,2 m.

In preparation for the survey, the area was pegged on a 25 m grid, and positions were marked on a map with a scale of 1:1 560. Measurements were made with the EM-38 on the soil surface in both the horizontal and vertical positions, and the mean of these figures entered on the map. A follow-up exercise was then carried out, during which additional

readings were taken strategically between grid points where there was a large change in EM reading. At selected sites, soil temperature was measured at a depth of 0,45 m to allow correction of EM readings to 25°C. Soil water status was also rated in relation to AWC (<30%, 30 to 85% or >85%).

Soil samples were then taken with an auger at 0,3 m depth intervals to 1,2 m. In the laboratory, the saturation extract was prepared according to Richards (1954), and measurements made of the electrical conductivity (EC_e) and concentrations of Na, Ca, Mg and K. The mean EC_e for the 0 to 1,2 m depth was calculated for each grid point.

Three maps of soil salinity were produced on the computer, using NCAR Graphics (Clare and Kennison, 1989). The first can be regarded as a reference map, where mean EC_e (measured values) for the 0 to 1,2 m depth is used (Figure 4), and the other two are based on instrument readings. Predicted mean EC_e (0 to 1,2 m), from equations in Table 1, and instrument readings are used, i.e. the mean of readings taken in the vertical and horizontal positions (Figures 5 and 6).

Results and discussion

Soil in the study area was found to vary in salinity status from non-saline (mean EC_e, 0 to 1,2 m <150 mS/m) to highly saline (EC_e >500 mS/m, Figure 4). Two intermediate categories of salinity were used in the mapping exercise, viz. 150 to 300 mS/m (slightly saline) and 300 to 500 mS/m (moderately saline).

Comparison of the reference map (Figure 4) with those based on instrument readings (Figures 5 and 6) illustrates that the latter were generally successful in identifying the pattern of salinity distribution, as well as the level of salinity. A comparison between Figures 4 and 5 suggests that the general equations in Table 1 tended to over-predict EC_e levels to a slight extent under these soil conditions. This

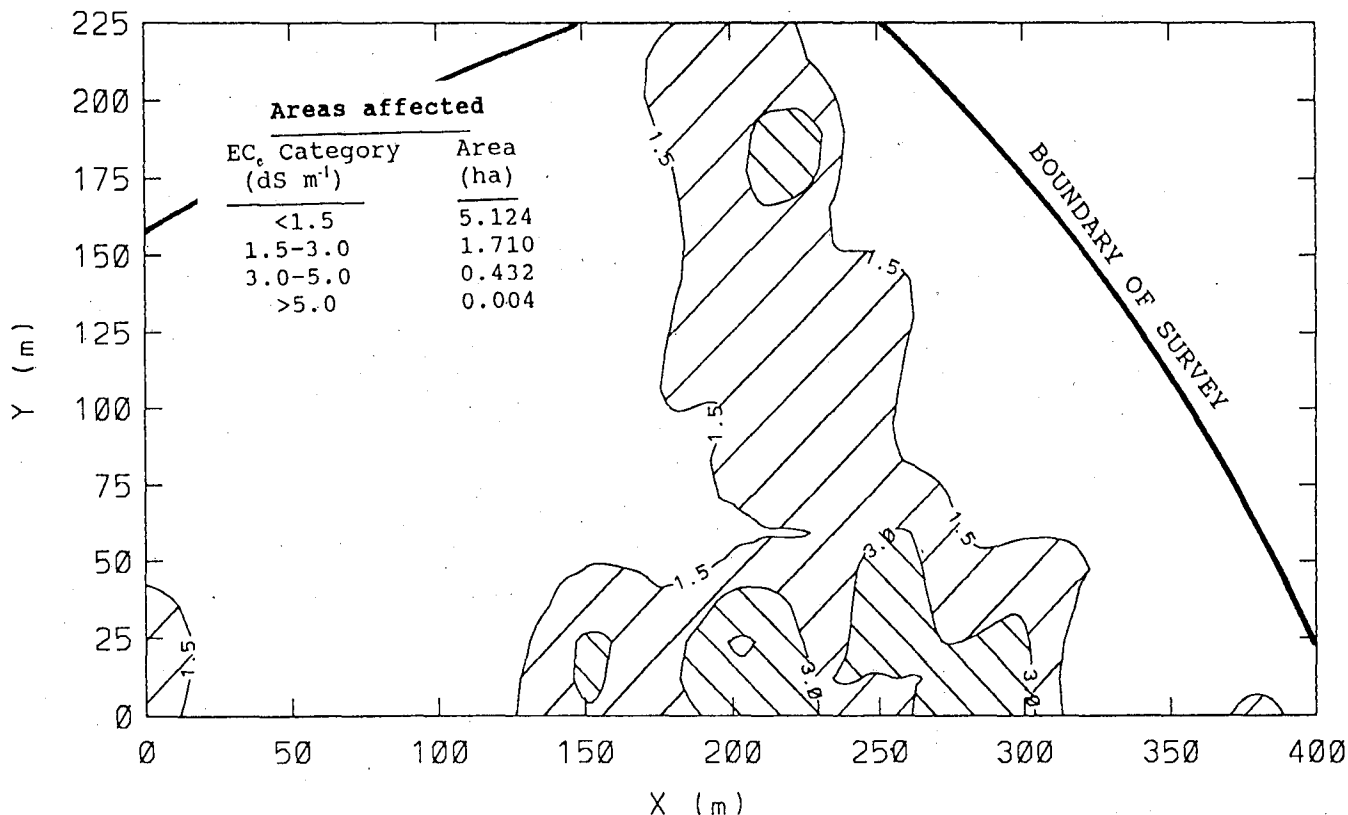


FIGURE 4 Map showing salinity boundaries based on measured mean EC_e (0 to 1,2 m), using units of dS/m (where 1 dS/m = 100 mS/m).

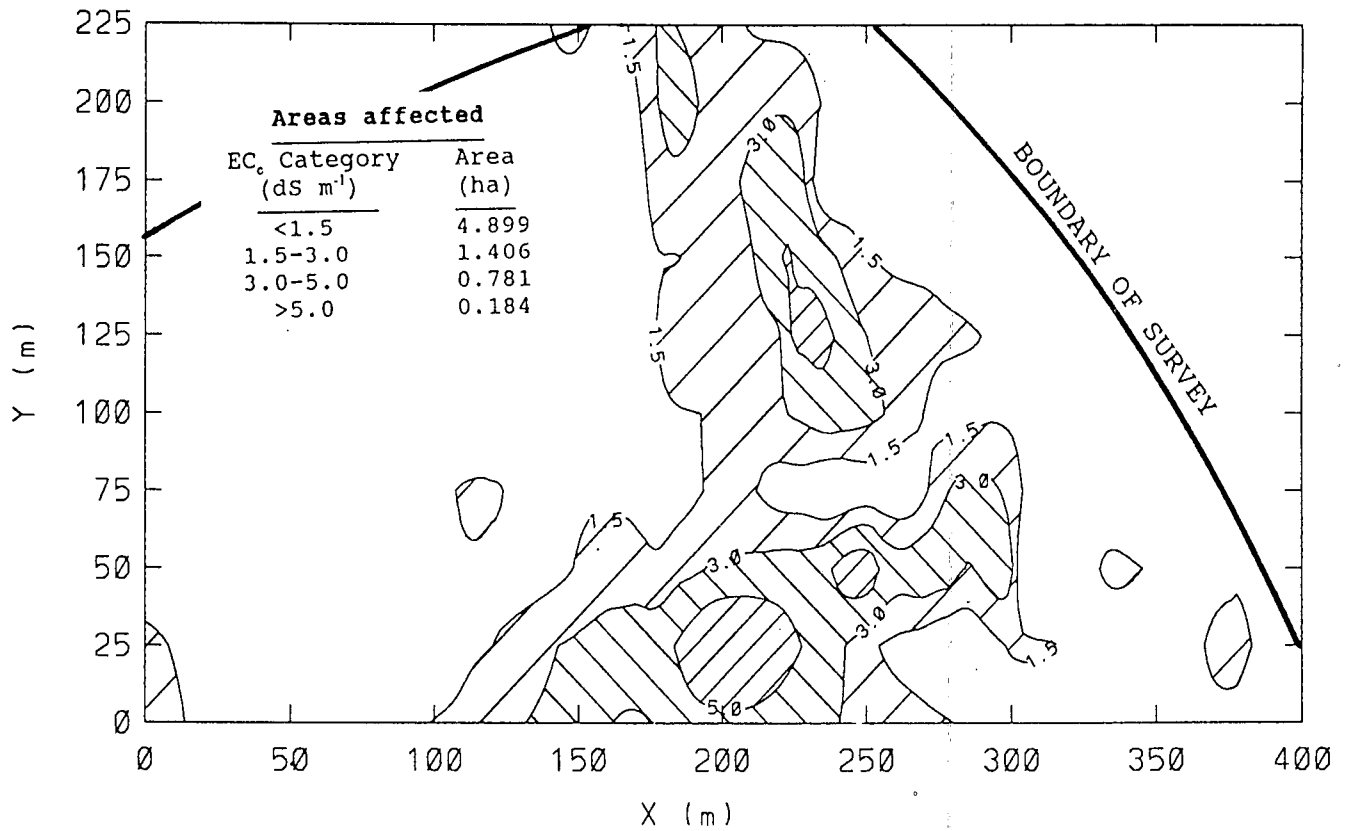


FIGURE 5 Map showing salinity boundaries based on mean EC_e (0 to 1,2 m) predicted from mean EM readings.

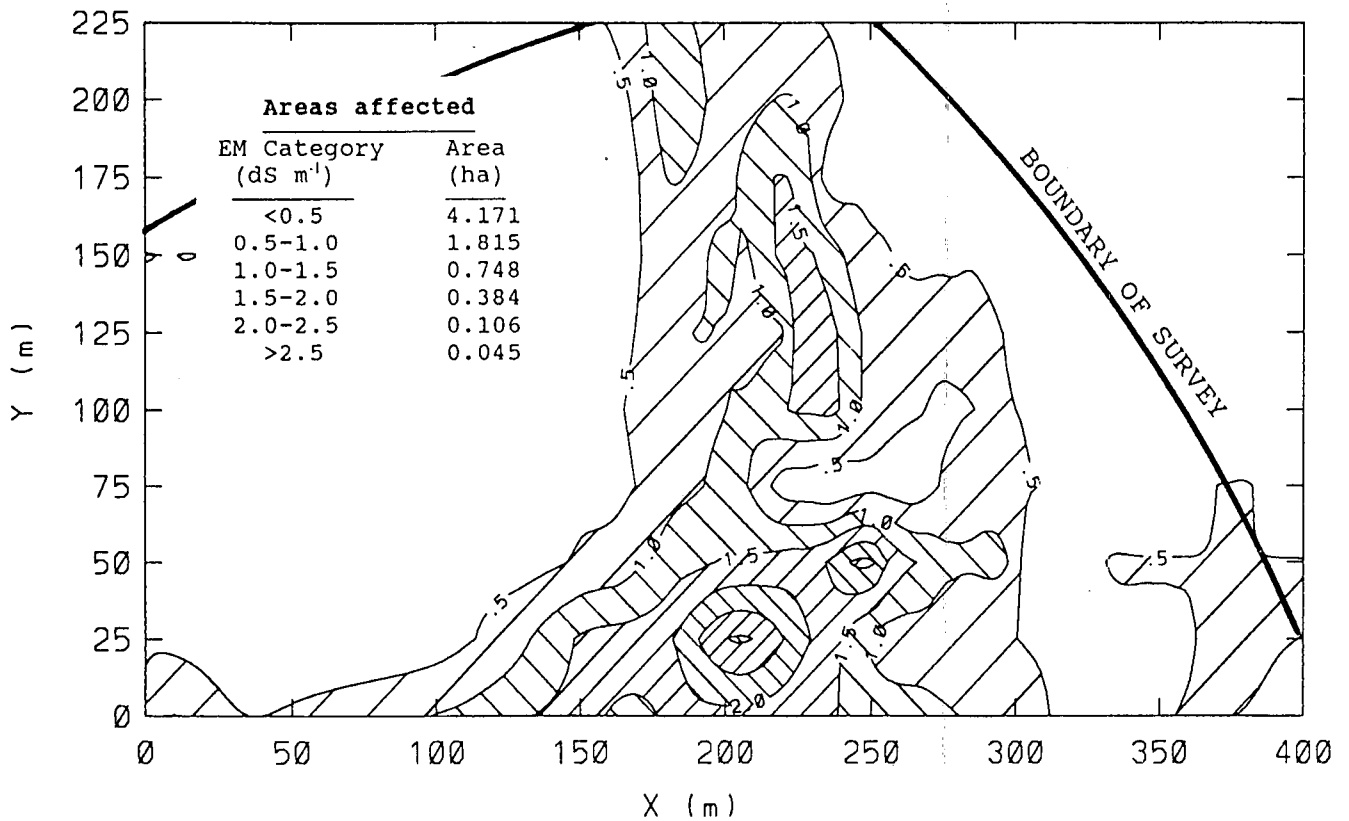


FIGURE 6 Map showing salinity boundaries using the mean of the vertical and horizontal positions of the EM-38 sensor.

confirms results reported elsewhere that empirically-determined calibration equations differ for different geographical areas (Rhoades and Corwin, 1981; Wollenhaupt *et al.*, 1986), and that calibration equations should ideally be determined for specific conditions of soil type, water status and water content distribution.

Figure 6 demonstrates how instrument readings can be used directly to characterise salinity patterns. Although the class intervals selected cover a wider range in salinity than those in Figures 4 and 5, the general pattern of salinity distribution is similar. Appropriate descriptions for the salinity categories are as follows:

- < 50 mS/m: non saline
- 50 to 100 mS/m: slightly saline
- 100 to 150 mS/m: moderately saline
- 150 to 200 mS/m: highly saline
- > 250 mS/m: very highly saline

An evaluation was made of the relative cost of mapping salinity using the procedures described. Cost factors taken into account were salaries for technical staff, soil analysis, data processing, computer time plus printing, and instrument costs. With the conventional procedure the cost was about R1 100/ha, while that for the estimated EC_e based on instrument readings was approximately R75/ha (Johnston, 1994).

Conclusions

The EM-38 salinity sensor has been shown to be a useful tool for mapping soil salinity. The method is rapid and is conducive to large scale mapping. The cost of mapping was found to be about 10% of the conventional procedure.

The generalised calibration equations of Johnston *et al.*, (1994) were found to be fairly reliable, but tended to overestimate soil salinity levels. Ideally, equations should be produced for the specific conditions of soil type and water status pertaining to any particular survey.

Acknowledgements

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