Electro-magnetic ground conductivity mapping

Electro-magnetic (EM) ground conductivity mapping has been in use since the early 1960s and is perhaps one of the most frequently used geophysical methods in environmental and engineering applications today. For further discussion of this method see Reynolds (2011).

Principle of operation

An electro-magnetic field is transmitted in air using a coil of wire separated from a receiver coil by a fixed distance of between 1 m and 40 m. The transmitted energy propagates into the sub-surface where a secondary electro-magnetic field is generated due to the effect of soil moisture, conductive earth materials and buried objects. Both fields are detected at the receiver coil, but the instrument compensates for the primary field, enabling measurement of the secondary. The ratio of the field strengths is controlled by the apparent conductivity of the ground through which the EM radiation has passed. The most frequently used systems are those manufactured by Geonics Ltd, Canada, and comprise the EM38, EM31 and EM34 systems. Their respective maximum effective depths of penetration are 1.5 m, 6 m, and 60 m. The transmitted field is at one or more fixed frequencies, and the method is often referred to as Frequency Domain EM to distinguish it from Time Domain EM.

Modes of deployment

The orientation of the coils influences the depth of penetration achievable. When the plane of the coils lies parallel to the ground surface, the Magnetic Dipole orientation is said to be vertical, hence the term Vertical Magnetic Dipole (VMD). When the coils are at right-angles to the ground surface, this is known as the Horizontal Magnetic Dipole (HMD) orientation. Effective depths of penetration are typically 1.5 and 0.75 times the inter-coil separation in the VMD and HMD orientations respectively. There is no requirement to couple the coils with the earth and it is usual for the operator(s) to carry them a set distance above the ground, though the larger coils used for some instruments may be rested on the ground or dragged on sleds. As small changes in the relative position of the instrument coils can affect the instrument reading, surveying using unmounted coils, such as those used in the EM34 system, will usually take longer than surveying using a fixed-coil system like the EM31due to the requirement that the coils must be correctly positioned by hand.

Modern instruments measure two components of the field for each dipole orientation, termed the *in-phase* and *quadrature* components. The quadrature component indicates the bulk apparent conductivity of the volume of ground sampled, in milli-Siemens per metre (mS/m). Conductivity is the inverse of resistivity; the value measured is an *apparent* conductivity because it represents an average of the true conductivity values of all materials within the sampled volume. By increasing the inter-coil separation, the sample volume rises, hence apparent conductivity values obtained using different EM instruments over the same ground will differ.

Interpretation

The *true* conductivity is a physically diagnostic property and can be used to differentiate between materials. When searching for buried objects and contaminant plumes the interpreter will look for anomalous values in the data. A knowledge of characteristic anomaly shapes is important, as the position of the maximum amplitude anomaly is a function of the width of the causative body and instrument orientation. For example, a narrow conductive body such as a pipe might generate an 'M' shaped anomaly, comprising two high values with a peak-to-peak separation equal to the coil

Figure 1: Acquisition of EM31 data.

separation. The in-phase component is typically expressed in parts per thousand (ppt). Phase changes between the primary and secondary field are used to indicate the presence of metallic objects.

Single profiles of data (*e.g.* Figure 2) do not always make best use of the available information. Significant improvement may be offered by use of contoured 2D images, in vertical section or plan view. Plan view representations are often used when searching for shallow-buried structures or contaminant plumes (Figure 3). Comparison between contoured data from both dipoles or between different systems improves understanding of vertical conductivity changes. Modelling the apparent conductivity values using dedicated software (e.g. IX1D v3 from Interpex Ltd, USA), can produce a layered-ground model, indicating the probable range of true conductivity and thickness of each layer. This requires two data sets at three different penetrations, *e.g.* EM34 at each coil separation (10 m, 20 m and 40 m) and both vertical and horizontal dipole orientation (for depths to 7.5 m, 15 m, 30 m and 60 m). Borehole depth data can be used to constrain the geophysical model so that only the true conductivity values are unknown prior to modelling, improving the accuracy of the final interpretation.

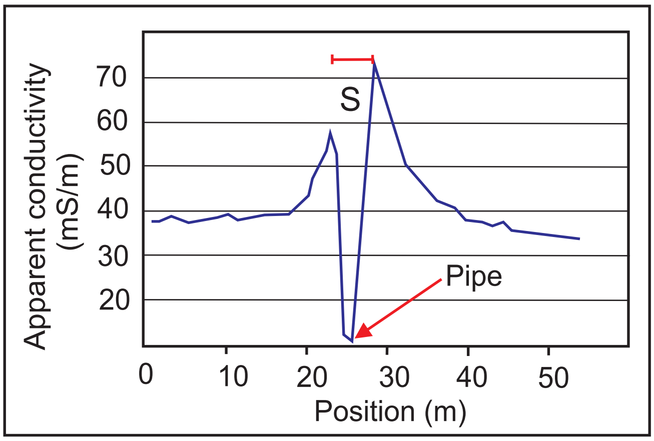

Figure 2: Apparent conductivity profile obtained using an EM31 ground conductivity meter over a buried metal pipe. The peak-peak distance is of the order of the inter-coil separation, *s*.

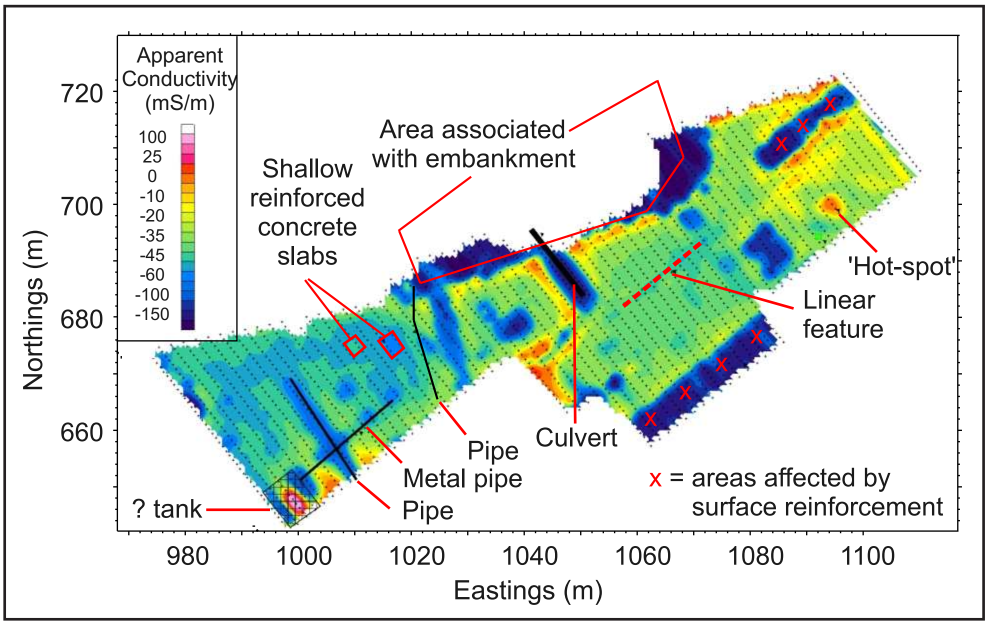

Figure 3: 2D plan of EM31 VMD ground conductivity data acquired over a contaminated site.

Reference

Reynolds, J.M. 2011. *An Introduction to Applied and Environmental Geophysics*. John Wiley & Sons Ltd, Chichester, 2nd ed., 712 pp.

