# Towed transient electromagnetic survey using various loop configurations

**Dr David Allen**
*Groundwater Imaging Pty ltd*
*82 St Georges Trc, Dubbo, NSW 2830, Australia*
*David@GroundwaterImaging.com*

## SUMMARY

Towed transient electromagnetic (TEM) survey, coupled with resistivity modelling software is an effective method of detailing small scale groundwater conceptual models and assisting with near surface geological investigations. Practical investigation depth ranges from 1m to 100m or more given the restrictions of today's electronics and practical trailer dimensions.

Towed TEM survey using loops on trailers behind land vehicles or boats may be conducted using various loop configurations. Due to the loop area and separation requirements of loops from each other and from towing vehicles, design of trailers and/or sleds must be tightly integrated with design of loop configurations. Although separated loops (slingram configuration) are good for avoiding mutual inductance problems and may permit exploration to maximum possible depth, they are difficult to tow, especially around corners. Alternative arrangements with overlapping loops or bucking coils, all on a single platform, permit design of more practical platforms. On such platforms, not only must mutual inductance of coils be minimized but practical means of minimization are limited by achievable dimensional accuracy and stability of towed platform designs. Design is further restricted by the need to avoid use of metallic materials in most places and the need to separate and/or de-couple the metal survey vehicle from the loops.

Case studies showing results of survey conducted with various platforms will be presented.

**Key words:** electromagnetic, resistivity, groundwater, towed, pulled.

## INTRODUCTION

Towed transient electromagnetics (Towed TEM) is a technique useful on cleared land for underground moisture and water quality study, geological mapping, and occasionally for mineral and coal prospecting. It offers a tighter footprint than airborne EM and excellent segregation of cultural effects (fences, buried cables etc.) from the bulk of the data collected. It can also be conducted flexibly without considerable setup and mobilization cost. With data observed en-route, densification and concentration of coverage over anomalies can occur during survey.

Practicality of towed transient electromagnetic systems is strongly dependent on design innovation, particularly with regard to loop configurations. Problems that must be addressed are:

- Sufficient separation of metallic objects from the antennae – a problem that is worse over resistive terrain.
- Minimization of mutual inductance between the transmitting and receiving coils.
- Minimization and simplification of the footprint of the system
- Ability to fix the loops to a trailer system and tow the resultant system through difficult vegetation and around tight bends, and
- Segregation of near surface response of the antennae configuration from deeper response.

Three configuration types are considered, in detail, in this paper and reasons for rejection of others are given.

## LOOP CONFIGURATIONS FOR TOWED TEM

The simplest loop configurations (Co-incident loop and in-loop) that centre the receiver loop with or within the transmitter loop lead to extremely high primary field pickup in the receivers. This results in severe primary field overprint on data and necessitates turning amplification down so far that little useful data can be collected. In-loop configuration is, however, simple to implement in a towed trailer and has been chosen as a solution in many early towed TEM systems (Allen, 2007, Barrett et. al., 2006, Harris et. al., 2006).

There are three configurations of merit for towed TEM as presented in figure 1.

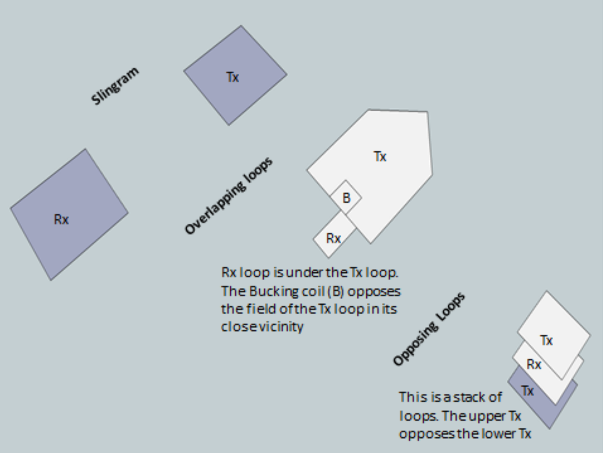



**Figure 1. Loop configurations useful for towed TEM survey presented in 3D perspective. Grey loops are on or near the ground plane while white loops are above it.**

**Separated loops (Slingram)**

Separated loop configuration (Slingram) (see figure 1) overcomes the problem of excessive primary field pickup as the primary field strength drops off steeply with distance from the outside of the transmitter loop. Geonics have recommended this solution for small loop survey since at least the early 1990s (McNeill, 1991). This solution also overcomes problems with superparamagnetic effect and induced polarization of the near surface. The author has operated towed TEM in this mode for many years with success following on from the example of the Aarhus Geophysics Group with their PATEM system (Sørensen, et. al., 2000).

There are certain cons to towed slingram survey. Firstly, a separation of many metres is usually utilized as a practical trade-off between equipment dimensions (and footprint) and primary field pick-up reduction (proportional to loop mutual inductance). With such dimensions, added to loop dimensions and the separation necessary between the metallic towing vehicle and the 1st trailer, the resulting system typically resembles a road train in proportions and has a very poor turning circle not ideally suited to off road survey.

Toft, 2001, compared the response of slingram and in-loop TEM systems to shallow three dimensional resistive and conductive bodies. He presented modelled results that revealed that 1D inversion of slingram data (not horizontally smoothed) over such bodies results in erratic and confusing responses. In practice, slingram data must thus be horizontally smoothed prior to submission to 1D inversion. This limits the footprint of the configuration considerably, and, as a side effect, results in the need for considerable blanking zones over buried cables and other such cultural effects. The footprint can be so wide that it cannot be used to detect small prior streams.

**Overlapping and bucking loops**

Mutual inductance cancelling loops (see figure 1), used to cancel out primary field pick-up while keeping equipment dimensions and footprint small may be of two types that also may be used in combination. The types are bucking coils and overlapping loops (placement of the receiver loop a precise distance over the transmitter loop edge). The receiver loop may be moved to a different plane to the transmitter loop to decrease the mutual inductance sensitivity to dimensional stability. Bucking coils are used in most metal detectors and some airborne systems. The overlapping loops configuration, without a bucking coil, is used in the SkyTEM airborne TEM system (www.SkyTEM.com ). Bucking coils placed very close to the receiver coil result in need for extreme dimensional stability and so are problematic for large towed TEM systems. They may however be placed at some distance from the receiver coil, necessitating cancellation of more of the effect of the main transmitter loop in the ground. Overlapping loops, placed in different planes to increase dimensional stability of the mutual inductance cancellation, do not require any cancellation of the effect of the transmitting loop on ground response. Choice of combinations of bucking and overlapping loops may also take into consideration the different dimensional stability of different parts of the survey platform and consideration of minimization of sensitivity of the system to the metal towing vehicle and the dimensional stability of its separation from the loop system.

**Opposing loops**

Towed TEM has traditionally not been applied to rootzone depth survey due to difficulty in configuring it to image such depths. The opposing loop configuration presented here is set to open up the possibility of using TEM at such depths for more than just metallic target discrimination.

Opposing loops (see figure 1) consist of transmitting loops and a centralized receiver loop in a vertical stack. For added horizontal focus, the central receiver loop may be split up into several loops in the same plane. The top transmitter loop polarity is opposite to the bottom transmitting loop. This results in cancellation of primary field both at the receiver loop plane and at greater depth and distance from the loops. It is thus useful for focused near surface exploration with primary field cancellation that permits amplification of the receiver signal. Opposing loops are investigated here as a means of enhancing near surface ability of towed TEM systems. The transmitting and receiving coils may be swapped with each other. Due to its cubic shape, the opposing loop configuration can be mounted on an extremely rigid structure so that excellent mutual inductance cancellation may be maintained.

Vertical stacks of loops have been used in metal detectors for some years (McNeill, et. al. 2000) for focusing on shallow metallic targets and determination of their depth, however, the configurations used are somewhat different to that presented here largely due to the long decay time constants and small dimensions of metal UXO targets.

An instance of the configuration, with 2 x 2 metre loops at 0.3, 1.3 and 2.3 metres above the ground and assuming a turnoff time of 12.5 µS (long for shallow investigation) was theoretically modelled and some of the results are presented here. The response of various 2 layer ground resistivity models were calculated using EM1DInv (Auken et. al. 2002). Some had 5 ohm.m basement and some had 50 ohm.m basement. The surface layer resistivities and thicknesses were varied and the decay curves observed, both for the lower transmitter loop alone and for the combination of the opposing loops (see figure 2). Separation of curves of different models of interest is not dramatically improved by the opposing loop configuration, but, given the primary field cancellation opportunities it offers, the data can be amplified greatly and noise levels then drops considerably.

It is clear from consideration of comparison of the magnitude of system noise with the separation of the curves of the different models that, with the system studied, resistivity contrasts can be identified in the first half to one metre provided that their response is not overwhelmed by deeper (within the first 10 metres) conductive features. It is also clear that any conductive feature within the first 4 metres will mask out most of the response of more subtle or resistive features. Of course the system could be improved from the example given by diminishing the turn off time and sampling much earlier (250nS may well be feasible) as well as reducing system dimensions but the modelling done does indicate that the modelled system is similarly capable to existing soil conductivity meters (Geonics EM31, DualEM 4) but with the added benefit of vertical resolution – a feature sadly missing from traditional soil EM surveys.

## AN EXAMPLE

A towed slingram and a towed overlapping loop system both were used to survey an alluvial plain, with results presented in Figure 3, for the purpose of optimizing groundwater extraction for irrigation. Observe that the slingram data images fresh resistive basement rock (although the horizontal smoothing in the example is poor) while the slightly smaller moment overlapping loop system struggles to resolve this sub 60m layer. The two datasets are otherwise similar in depth of investigation. Both were collected in equal amounts of time (4 hours) but over twice as much data could be collected with the faster more agile overlapping loop system. Further, there are metal artefact responses left in the slingram data simply because totally removing them would result in very little remaining data at all while the smaller near surface footprint of the overlapping loop system resulted in tight exclusion of metal object anomalies and little loss of data coverage.

## CONCLUSIONS

Except where maximum exploration depth is sought, towed TEM may be most practically conducted without resorting to Slingram (separated) loop configuration only should a rigid primary field cancelling loop configuration be implemented. With such configurations, the entire system can be towed on one rather than two trailers. Additional benefits are:

- that the footprint is simpler resulting in less erratic response to near surface inhomogeneities,
- tight turning circles are possible facilitating survey in difficult terrain and vegetation,
- denser coverage is possible, and
- that near surface resolution is improved and footprint is more compact.

Near surface resolution and footprint may be additionally improved by multiplexing data stacks from an overlapping loop configuration with data from an opposing loop configuration as in Figure 1, or, at the cost of depth of exploration, by using the opposing loop configuration alone.

## REFERENCES


Allen, D.A., 2007, Electrical Conductivity Imaging of Aquifers Connected to Watercourses - A Thesis Focused on the Murray Darling Basin, Australia: *UTS PhD Thesis*, 480 pages (http://hdl.handle.net/2100/428, Abstract 0.1 MB; Full Thesis 12 MB)

Auken, E., Nebel, L., Sørensen, K.I., Breiner, M., Pellerin, L. and Christiansen, N.B., 2002: "EMMA – A Geophysical Training and Education Tool for Electromagnetic Modelling and Analysis" *Journal of Environmental & Engineering Geophysics*, 7, 57-68.

Barrett, B., Heinson, G., Hatch, M., Telfer, A., 2006, River sediment salt-load detection using a water-borne transient electromagnetic system: *J. App. Geoph.* **58**, 29-44

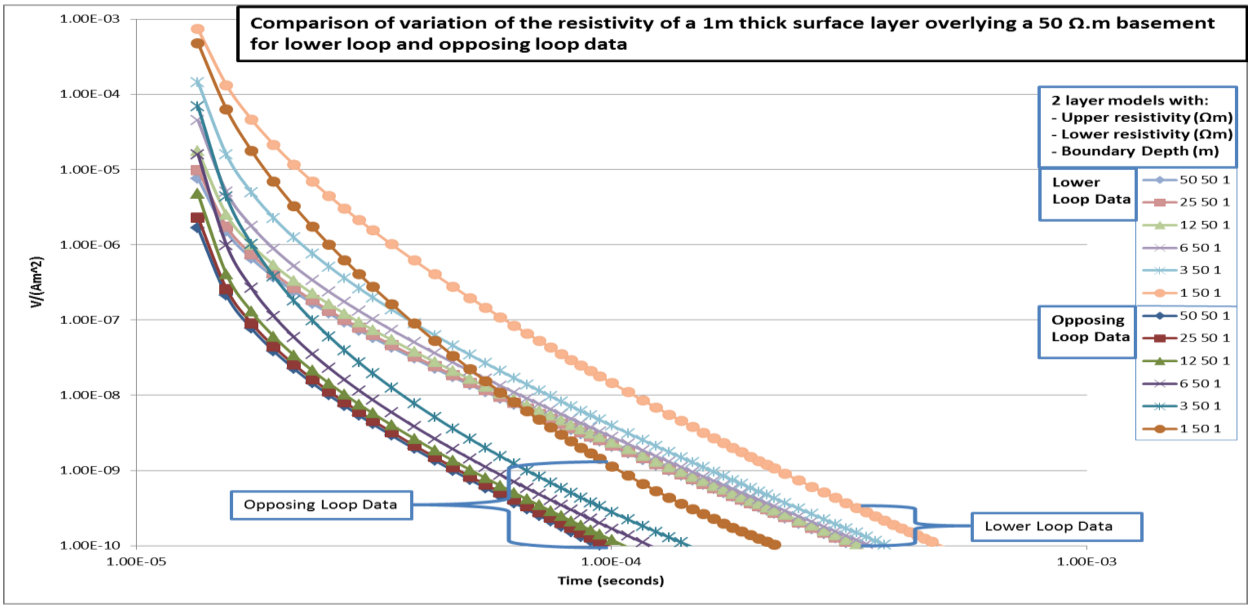
Harris, B.D., Wilkes, P.G., and Kepic, A., 2006, Acquisition of very early time transient electromagnetic data for shallow geotechnical, environmental and hydrogelogical applications: *SAGEEP Proceedings*, EEGS.

McNeill, J.D., circa 1991, Protem 47 Transient Electromagnetic System Manual, www.geonics.com

McNeill, J.D., Bosnar, M., 2000, Geonics TN-32 Application of TDEM techniques to metal detection and discrimination, a case history with the new Geonics EM-63 full time-domain metal detector. http://www.geonics.com/pdfs/technicalnotes/tn32.pdf (checked Feb. 2013)

Sørensen, K.I., Auken, E. and Thomsen, P., 2000, TDEM in Groundwater Mapping – A continuous approach: http://hgg.au.dk/media/soerensen2000cpresentation.pdf , Dept. of Earth Sci., Geoph. Lab. Univ. of Aarhus, Denmark.

Toft, M.W., 2001, Three-dimensional TEM modelling of near-surface resistivity variations: *University of Aarhus, Denmark Thesis*. 112 pages.


**Figures 2. Comparison of variation of resistivity of a 1m thick surface layer for various conditions. The cases of lower loop and opposing loop data are compared over 50 ohm.m basement.**

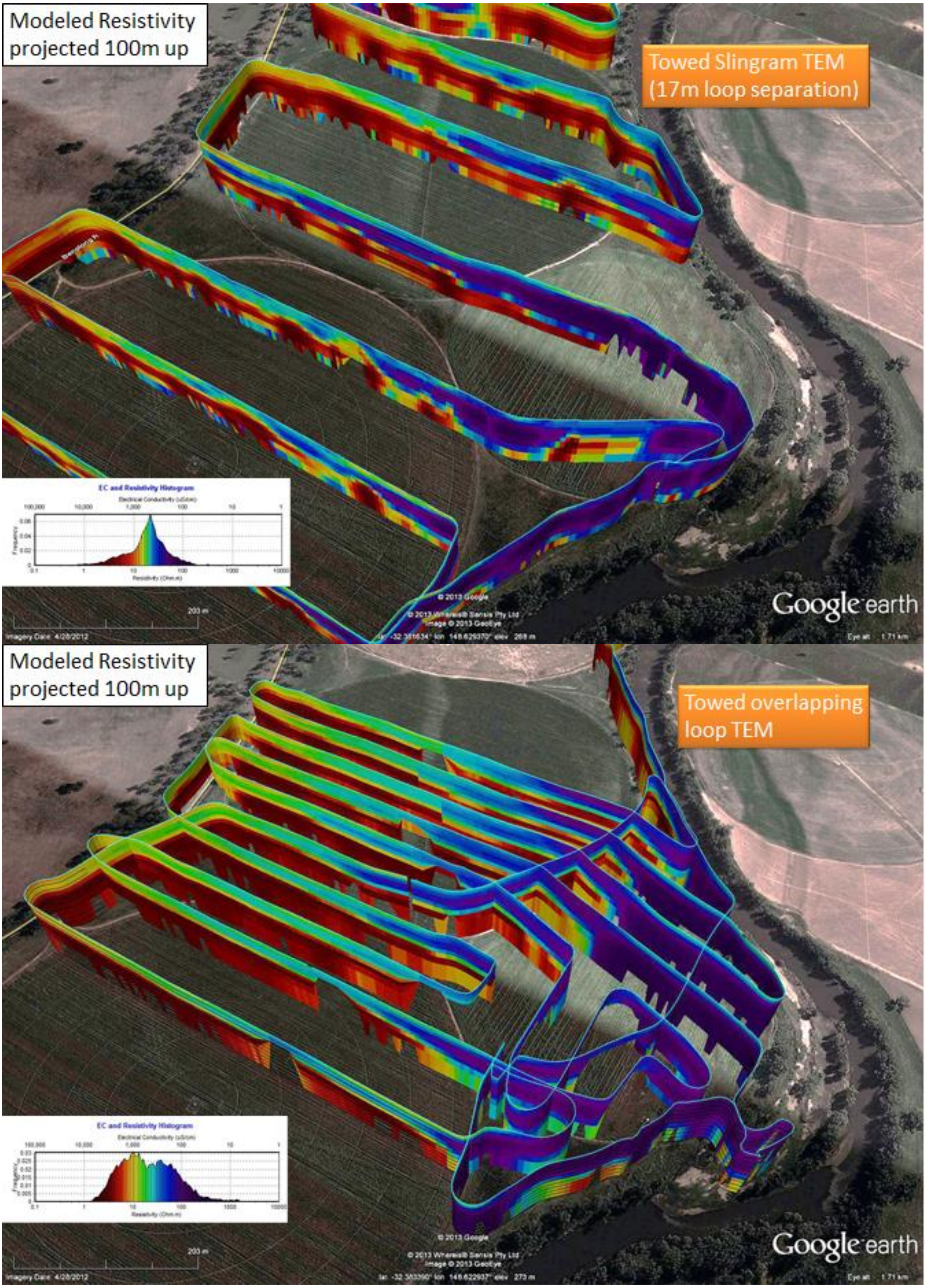



**Figure 6. Comparison of slingram (upper image), and overlapping loop towed TEM (lower image) system data presented in 3D perspective. Differences in the histograms reflect the wider (non – public domain) extent of these datasets not shown.**