

# Techniques for defining variations in riverbed salt loads as an aid to managing river salinisation and the deterioration of nationally significant water resources

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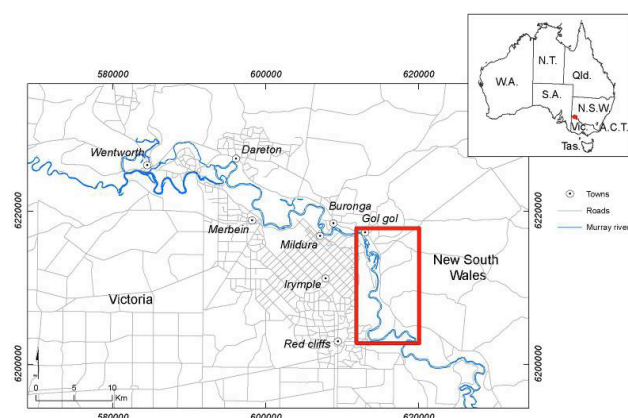
<sup>5</sup>Australian Water Environments,

## Introduction

A number of techniques have been developed to help define stretches of river systems that are subject to the accrual of high salt loads, primarily as a result of groundwater discharge. These include the Run-of-River surveys (ROR), which directly measure river water or stream bed salinity with a submerged probe (Porter, 1997); the “instream” towed NanoTEM (a time domain EM system) (Barrett, 2003; Telfer et al., 2004); the “instream” towed array DC Resistivity system (Allen, 2006; Snyder et al., 2002); and more recently helicopter-borne time and/or frequency domain EM systems (Fitzpatrick et al., 2007; Paine et al., 2006). All of these techniques have been used to directly measure the salt load entering the river or to image the distribution of subsurface conductivities in or beneath the riverbed, from which inferences about the salt load can be made. The ROR approach provides a direct measure of salt loads in the river, but tends to be relatively coarse in resolving where the salt actually enters the river, unless it is used to sample the river sediments directly. The three geophysical techniques examined provide information about the conductivity distribution under the river, which then may be related to salt loads.

Each of the geophysically-based methods sample the instream environment at three to 20 metre intervals, with the “instream” methods providing information from near the river surface to depths of between 10 and 40 metres below the surface. The in stream techniques tend to be limited by their depth of penetration, making it difficult to assess how the river and saturated sediments may interact with more regional aquifer systems. In contrast, the helicopter EM systems provide information at greater depth up to 80+ m, and they can also be used to readily acquire additional conductivity information along adjacent riverbanks and floodplains, thereby helping elucidate processes linking the river and adjacent areas.

The primary intent of this paper is to briefly review the various instream sampling techniques and to assess their suitability for characterizing stream salinisation.



**Figure 1** Map showing location of comparison area (highlighted in red).

## Method and results

First, we summarise the hardware and sampling procedures adopted for each technique. This allows users to compare the underlying fundamentals of each technique. We then examine and compare the results obtained from each technique using a “standardised” display to help provide a more objective assessment of their relative capabilities.

Table 1 presents a synopsis of the data collection parameters and sampling footprints for each of the methods reviewed here along with the “basic products” that each technique provides. All of the techniques reviewed here were run over the same stretch of the River Murray in south eastern Australia, making a direct comparison of their results relatively straightforward. Between 2004 and 2006 each of these techniques were run from approximately River Km 895 to 920, (between roughly Kings Billabong and Red Cliffs, between Victoria and NSW) - (Figure 1).

The geophysical data presented here were processed using a variety of inversion routines, thereby making direct comparisons more difficult. The NanoTEM data were inverted using STEMINV, a “smooth model” 1D layered earth inversion (MacInnes, 2007) as were the RESOLVE Frequency Domain HEM data but using a 25 layer “smooth model” inversion developed by Ross Brodie (Geoscience Australia). The Blue Eel DC resistivity data were inverted using Dave Allen’s HydroGeoimager program (Allen and Merrick, 2007), a five to seven layer “discrete layer” inversion. To assist our comparative interpretation, we sought to display the processed data using a common display package, in this case Encom’s Profile Analyst. For each data set, the same colour stretch, depth and horizontal scale were used. Figure 2 shows the results for part of the comparison area along the river. Examination of Figure 2 suggests that all three techniques compare relatively well over this section. There are obvious differences in the depth penetration and resolution for each of the techniques under different subsurface conditions, and the various inversion schemes used emphasise different qualities associated with each of the techniques. Nevertheless the underlying hydrogeological story is very similar for each technique. For this stretch of the river, gaining and losing reaches of the river have been identified. Conductive zones have been generally related to “gaining river ” conditions, where groundwater discharges salt into the river, while more resistive zones have been related to “losing river” conditions, where fresh river water is lost to the underlying sediments, creating a “flushed zone”.

Future work will involve a comparison of data using other processing and inversion routines to determine what influence, if any, particular processing strategies may have on the interpreted results. Inversions using the same inversion package and display routine should make these data sets more readily comparable.

## **Conclusions**

The three geophysical techniques reviewed produced comparable results, in that they all identified similar hydrogeological conditions along the river. Primary interpretation is based on the zone immediately under the river when attempting to locate sources of saline groundwater influx into the river. All of the geophysical techniques identify similar geoelectrical properties for the zone immediately under the river. The observed patterns of instream conductivity are also strongly correlated with underlying geology and structure, which may have significance in determining the hydrogeology of a particular stretch of the river.

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## **References**

- Allen, D.A., 2006, Electrical conductivity imaging of aquifers connected to watercourses - A thesis focused on the Murray Darling Basin, Australia [PhD dissertation - pre-refereed thesis]: Sydney, Australia, University of Technology.
- Allen, D.A., and Merrick, N., 2007, Robust 1D inversion of large towed geo-electric array datasets used for hydrogeological studies: *Exploration Geophysics*, v. 10, p. 50-59.
- Barrett, B., 2003, Water-borne geophysics for Murray River salt-load detection [Unpublished MSc thesis]: Adelaide, University of Adelaide.

- Fitzpatrick, A., Munday, T., Berens, V., Hatch, M., and Telfer, A., 2007, Mapping salt-loads of the Murray River, Australia, using airborne and in-river electromagnetic methods, SAGEEP 2007, Volume Extended Abstracts: Denver, Colorado, USA, EEGS.
- MacInnes, S., 2007, STEMINV: Smooth model TEM Inversion: Tucson, AZ, Zonge Engineering.
- Paine, J., Collins, E.W., Nance, H.S., and Niemann, K.L., 2006, Streambed induction logs: an airborne approach to identifying salinity sources and quantifying salinity loads, 19th Annual SAGEEP Symposium on the Application of Geophysics to Engineering and Environmental Problems: Seattle Washington, USA, EEGS, p. 96-104.
- Porter, B., 1997, Run of river data collection and calculations results and recommendations: Murraylands Region, South Australia Department of Environment, Heritage and Aboriginal Affairs, Natural Resources Division, p. 14.
- Snyder, D.D., MacInnes, S., Raymond, M.J., and Zonge, K.L., 2002, Continuous resistivity profiling in shallow marine and fresh water environments, SAGEEP 2002: Las Vegas, Nevada, USA, EEGS.
- Telfer, A.L., Berens, V., Hatch, M., and Palfreyman, C., 2004, Instream NanoTEM: providing increased resolution to stream salinisation and floodplain processes along the River Murray, South-East Australia, 1st National Salinity Engineering Conference: Perth, Western Australia.

**Table 1 Synopsis of “In-stream” survey techniques reviewed in this paper**

Technique name	Basis	Sampling density / Production rate	Nominal Footprint (lateral)	Approx. geophysical footprint (lateral)	Sampling density / Production rate	Depth range (approx.)	Basic Product
FDHEM: HEM RESOLVE	Inductive – frequency domain	Helicopter speed: 100 km/hr, 10 soundings per second.	Bird flown at 60 to 80 m elevation. Sounding spacing approx. 3m.	40m at surface. Less than 125m at 20m depth.	Helicopter speed: 100 km/hr, 10 soundings per second. Sounding spacing approx. 3m.	Near surface to 30 to 60m	Depth section. Depth slices and ribbon plots can be prepared.
Instream NanoTEM	Inductive – time domain	Typical boat speed: 6 km/hr, soundings collected every 4 seconds.	7.5m x 7.5m frame towed behind boat. Sounding spacing approx. 7m.	10m at surface. Less than 80m at 20m depth.	Typical boat speed: 6 km/hr, soundings collected every 4 seconds. Sounding spacing approx. 7m.	Near surface to 20m	Depth section. Depth slices and ribbon plots can be prepared.
Instream Resistivity: Blue Eel	Galvanic	Typical boat speed: 8 km/hr, soundings collected every 4 seconds. Sounding spacing approx. 10m.	150m long ‘blue eel’ towed behind boat. Sounding spacing approx. 10m.	20m at surface. Approximately 135m at 20m depth.	Typical boat speed: 8 km/hr, soundings collected every 4 seconds. Sounding spacing approx. 10m.	Near surface to 15m to 40m	Depth section. Depth slices and ribbon plots can be prepared.
Run-of-River	Direct measurement of salinity in river	Typical boat speed: 40 km/hr. One EC measurement is made every km. Readings are repeated on 5 consecutive days.	Water conductivity measured from moving boat. One EC measurement is made every km.	Kilometre scale.	Typical boat speed: 40 km/hr. One EC measurement is made every km. Readings are repeated on 5 consecutive days.	Readings are taken at surface so no depth information. Salt loads need to be migrated back to source location.	Maps of salt loads along river

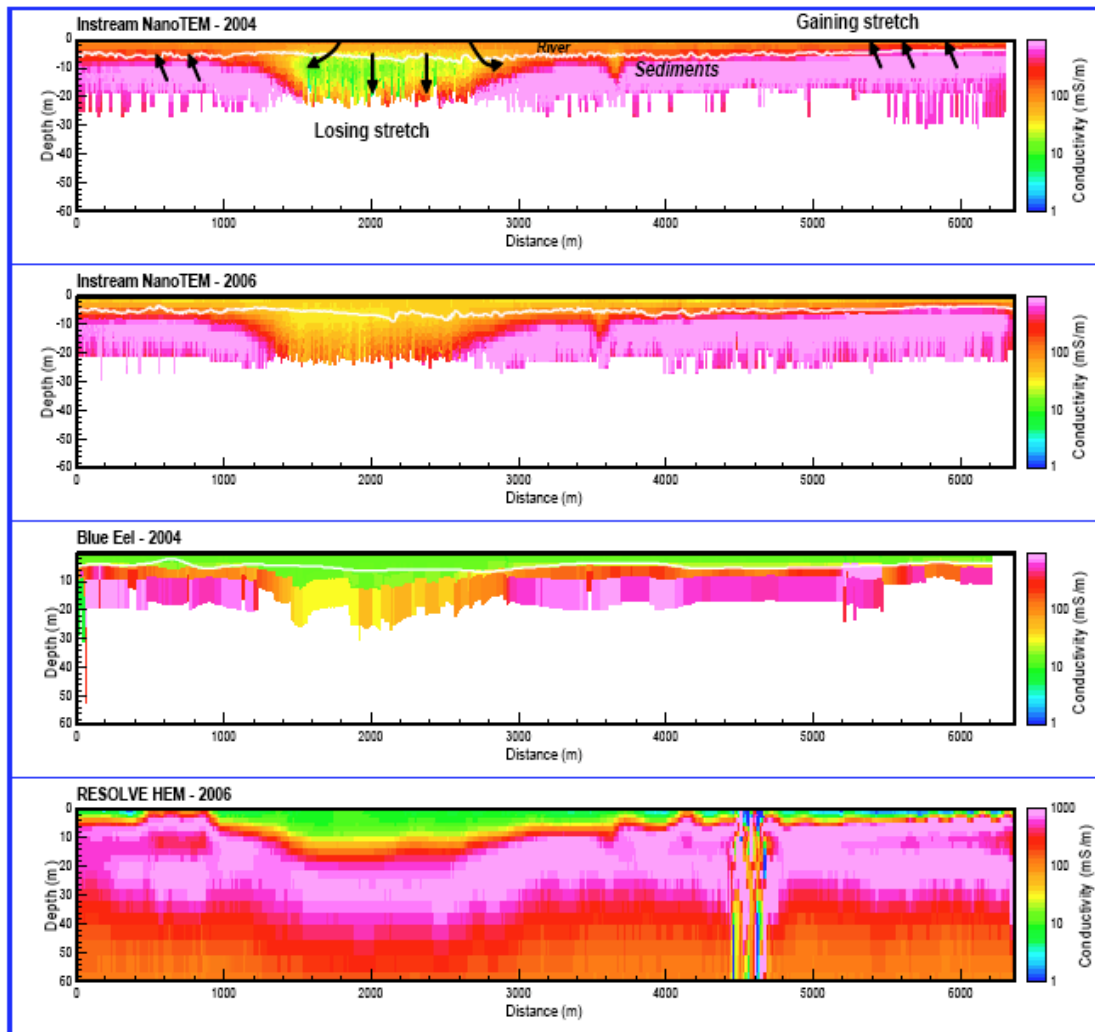


Figure 2 Stacked conductivity-depth sections of inverted in stream NanoTEM data (for two different years), in stream Blue Eel, and RESOLVE FDHEM data for a similar stretch of the Murray River south of Mildrura in Victoria. For all plots the vertical axis is depth below the river surface in metres. The horizontal axis is distance along the river in metres. Water depth (as measured at the time of each survey) is indicated with a white line in the top three plots. Water depth was not measured during the RESOLVE survey. The upstream end of the river is on the right. A simplified interpretation, explaining the causes for the observed conductivity structure seen in all sections, has been annotated on the topmost NanoTEM section. The noise observed in the RESOLVE section at around 4600m is attributed to the effects of high tension power lines.