An Assessment of "In-Stream" Survey Techniques along the Murray River, Australia

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SUMMARY

A number of tools have been developed to help understand the processes of salinisation at work along the Murray River in Southern Australia. Four techniques that have been used to help investigators either directly measure the salt load entering the river, or to image the distribution of conductivities under the river are examined here. They include Run-of-River surveys (ROR), in-stream towed NanoTEM, in-stream towed Resistivity, and Helicopter EM (specifically using the RESOLVE FDHEM system). Each technique has strengths and weaknesses related to its mode of operation and the approach adopted in field data collection. Run-of-River samples the water salinity directly and then attempts to estimate river salt load and source location. It provides a direct measure of the salt entering the river but a) only provides salt load information and b) generally only provides information on a kilometre scale. The other three techniques are all geophysical techniques that do not directly inform the investigator about salt loads in the river, but provide information about conductivity distributions in the sediments under the river, which then may be related to salt loads. Each of the geophysical techniques sample the instream environment at three to 20 metre intervals, and provide information from near the river surface to depths of between 10 and 40 metres below the surface. Data may be displayed as depth sections, or as contoured depth slices prepared to examine different levels beneath the river bottom.

Key words: “in river” salinity surveys, River Murray, NanoTEM, resistivity, airborne EM

INTRODUCTION

In the late 1970’s, investigators and regulators involved with management of the Murray River in southern Australia realised that much of the groundwater underlying the Murray Basin was a) very saline and b) contributed large amounts of saline water to the river. It became apparent that river water quality would be affected both for towns along the river using it as a drinking water source as well as for the large number of irrigators. Delineating zones within the river where large saline inflows occurred became a high priority. Shortly thereafter the first of many Run-of-River surveys was undertaken and, as a direct result, in 1990 the first of the Waikerie Salt Interception Schemes (SIS) was designed and built. From that time through the early 2000’s at least six SIS’s were built along the river to remove saline groundwater from the sediments immediately adjacent to the river before it entered the river. All were located and designed based on information from the integration of data collected from Run-of-River surveys and more traditional hydrogeological investigations.

Recently it has become obvious that higher resolution techniques are needed to help find smaller saline groundwater sources, as well as to evaluate how well the existing Salt Interception Schemes are working. In 2003 Australian Water Environments and Zonge Engineering in association with the University of Adelaide (Barrett, 2003) and Sydney University of Technology (Allen, 2006a) tested the applicability of the NanoTEM and resistivity systems as in-stream tools that could be used to map river bed salinity along the Murray. These tests were successful, and resulted in the continued development of both systems and the use of the NanoTEM system to collect over 2000 kilometres of instream data on the Murray and a number of its anabranches between 2003 and 2006 (Telfer et al., 2005; Telfer et al., 2006; Telfer et al., 2004).

While the use of these in-stream techniques has become widely accepted, there was a recognition that their suitability and relative effectiveness had not been subject to detailed, objective assessment and that there was only very limited validation data to provide the basis for such a review. To address these issues, a review and validation program was commissioned by the Mallee CMA and the MDBC. Some of the results emerging from this study are presented here.

The primary intent of this paper is, for the first time, to provide a comparison of the various instream sampling techniques and to test their suitability for characterising stream salinisation.

METHOD AND RESULTS

In this paper we discuss the specifics of the hardware and sampling procedures adopted with each technique, and then examine the results obtained from each using a “standardised” display to help provide a more objective assessment of the relative capabilities

Table 1 summarises the data collection parameters and hardware and sampling footprints for each of the methods reviewed here along with the “basic products” that each technique provides. It is worth noting that three of the techniques discussed here (the instream NanoTEM, the instream resistivity and the HEM) are similar in that they are geophysical techniques that attempt to produce accurate geoelectrical sections of the subsurface. This geoelectrical information is then assumed to correlate with presence (or absence) of saline groundwater, depending on whether the zone immediately under the river is sufficiently conductive. This assumption seems reasonable, at least where studied so far (see Telfer *et al.* (2004), Tan *et al.* (2006), Berens and Hatch (In press)). Others have also noted strong correlations between the location of zones that are more conductive along the river and zones that are gaining saline groundwater.

Run-of-River, on the other hand, is a technique that directly measures river salinity and flow over a number of days. This information is used to calculate how much salt is added to the river per kilometre (Porter, 1997). Obviously ROR does not attempt to inform users of depth to features (or even the location of geological features), but attempts to directly locate areas of elevated salt levels along the river. As ROR is intrinsically different to the other techniques reviewed here it is not considered further, although it is the subject of analysis in a new report (Hatch et al., In press)

In order to compare the results of each of the survey methods it is necessary to look at data collected over the same stretch of river. For this study there are overlapping data sets for each technique from approximately River Km 895 to 920, (between roughly Kings Billabong and Red Cliffs, between Victoria and NSW) - see Figure 1 for an overview of the survey area and Figure 2 for a map showing the depth section locations. All of the geophysical data collected over this stretch of the river were processed using the operator’s / interpreter’s preferred software. For the In-stream NanoTEM, this was Zonge Engineering’s suite of programs and the STEMINV inversion package (MacInnes, 2007). For the Instream resistivity this was HydrogeoImager (Allen, 2006b). For the Resolve HEM this was Fugro’s in-house processing (Garrie, 2006), and EMFlow (Macnae et al., 1998). Future work on these data sets will involve the analysis of results from other processing and inversion routines to determine what influence, if any, particular processing strategies would have on the interpreted results.

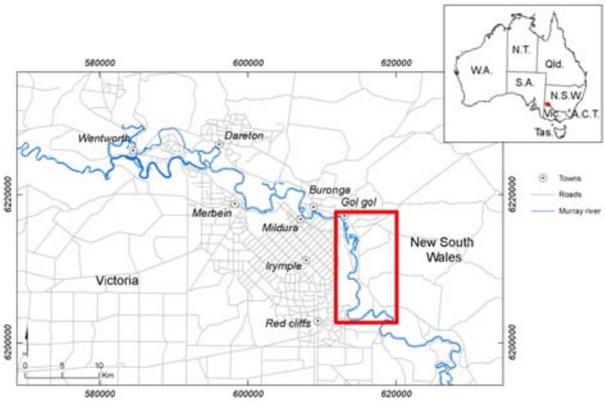

Figure 1: Overview map of survey area.

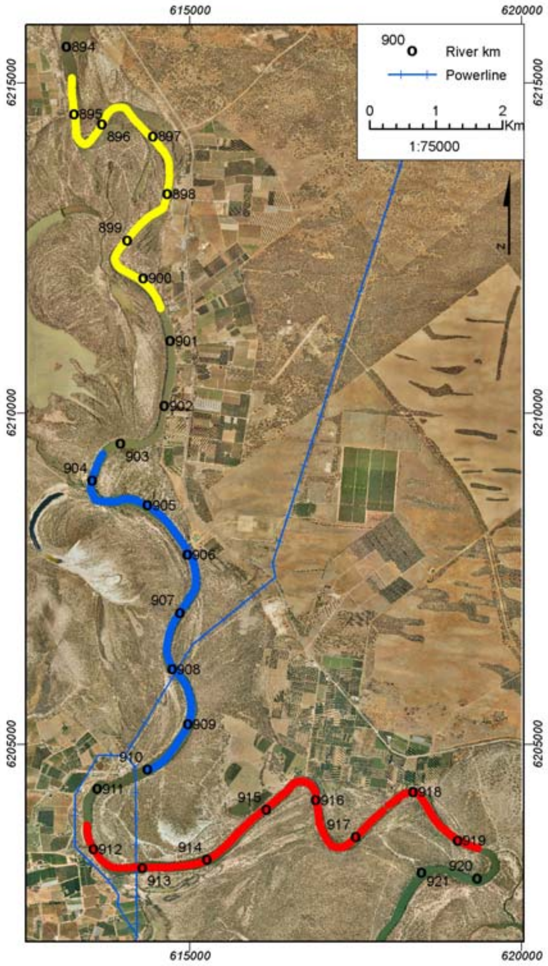

Figure 2: Map showing locations of depth sections along river. Yellow area: North section. Blue area: Mid section. Red area: South section. River kilometres are shown also.

Strip plots of all of the geophysical data were prepared using a single “standard” contouring package. In each case, the same colour stretches, depth scales, horizontal scales etc. were used. Encom’s Profile Analyst was chosen to display the results. We chose to present the inverted data with a common colour scale, without any additional smoothing or filtering. Whilst this promotes the direct comparison of the results, it is acknowledged that sensitivity of particular technologies may not be presented “optimally”.

Figure 3 shows the results for the “Mid” stretch of the comparison area along the river. Note that this area was run twice using the in-stream NanoTEM, first in 2004 and then again in 2006. Displaying both data sets allows comparison of the repeatability of the NanoTEM, as well as comparison against the other techniques. Examination of 3 suggests that all three techniques (as well as the two generations of NanoTEM data) compare relatively well over this section. Overall, the sediments underlying the river appear to be conductive, except from approximately station 1100 to 3000, where the sediments appear resistive. All of the techniques do similarly well at resolving this zone, but of the three, the RESOLVE HEM data detects a highly conductive zone under the resistive zone that the other techniques only hint at. The Instream NanoTEM and Instream Resistivity both seem to "see" to a depth of approximately 20 metres in this area. It appears that the depth of penetration for the Resolve HEM is between 20 and 30 metres over this stretch of the river. EMFlow calculates a "skin depth line" for this type of data that indicates a depth below which the interpreter should have less confidence in the inverted results. This line is highlighted in black on the Resolve HEM strip in Figure 3. Beneath this line is a layer of very high resistivity (the entire zone has been assigned a value of exactly 1 mS/m) that is most likely an artefact of the inversion. The feature in the Resolve HEM from station 4200 to 4350 appears to be related to the high voltage power line in that area.

Shallow resolution is also interesting to examine in Figure 3 as there are differences worth discussing. First, the Instream Resistivity appears to have done the best job of resolving the value of the water conductivity, and has done a fair job of resolving the depth of the water. The water conductivity in this area was about 11 mS/m at the time of the survey, and the Instream Resistivity estimated a value of approximately 14 mS/m. Second, where the RESOLVE HEM system has been able to resolve the shallowest layer, which it has only done over approximately 50% of the complete run, EMFlow has done a reasonable job in determining river conductivity. While water depth data are not collected during HEM surveys a rough examination of the near surface data suggests that the HEM system does not "see" much of the water, particularly in the conductive stretches of the river. Third, the Instream NanoTEM is not as effective as the other techniques in resolving the conductivity of the river in this area (water conductivities from the NanoTEM ranged from approximately 40 to 110 mS/m for the two surveys). However, it does detect the bottom of the river from which inferences about the depth of the water can be made.

As has been noted, the area immediately under the river bottom is important in determining the likelihood of saline groundwater entering the river system. When instream geophysical data are collected along with water depth, conductivity information from immediately beneath the river bottom can be extracted from the inverted data sets. This shallow sediment data can then be contoured and displayed as an interval conductivity image of the area. This has been done to all of the data sets reviewed in this study. It is important to note that as water depth information is not part of an airborne EM survey data set (including the Resolve HEM); the EMFlow results for the 8 to 10 metres depth interval were used instead. This is a reasonable approximation to the depth of the river in this area. Figure 4 shows an example of a comparison between the 2004 Instream NanoTEM data set and the Resolve HEM. While the two data sets are obviously different, they both highlight similar features along the river suggesting that an interpretation based on either data set would yield similar conclusions.

CONCLUSIONS

The three geophysical techniques reviewed produced comparable results, in that they all defined "gaining" and "losing" stretches of the river. While information about the zone immediately under the river is of primary interest when attempting to locate sources of saline groundwater influx into the river, this is not the only information that can be garnered from the observed conductivity response. 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.

Currently we are examining alternative inversion strategies for processing data acquired from these in stream and airborne techniques. While smooth-model layered inversions appear to produce readily interpretable results, i.e. the water depth is better determined, and the area immediately under the bottom of the river can be easily examined, we are also considering the merit of "few-layer" or blocky LEI's.

ACKNOWLEDGMENTS

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Technique name	Basis	Footprint	Sampling density / Production rate	Depth range (approximate)	Basic Product
HEM FDHEM: RESOLVE	Inductive – frequency domain	Bird flown at 60 to 80 m elevation	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	7.5m x 7.5m frame towed behind boat	Typical boat speed: 6 km/hr, soundings collected every four seconds. Sounding spacing approx. 7m.	Near surface to 20m	Depth section. Depth slices and ribbon plots can be prepared.
Run-of-River	Direct measurement of salinity in river	Water conductivity measured from moving boat	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
Instream Resistivity	Galvanic	150m long “blue eel” towed behind boat	Typical boat speed: 8 km/hr, soundings collected every four seconds. Sounding spacing approx. 10m.	Near surface to 15m to 40m	Depth section. Depth slices and ribbon plots can be prepared.

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

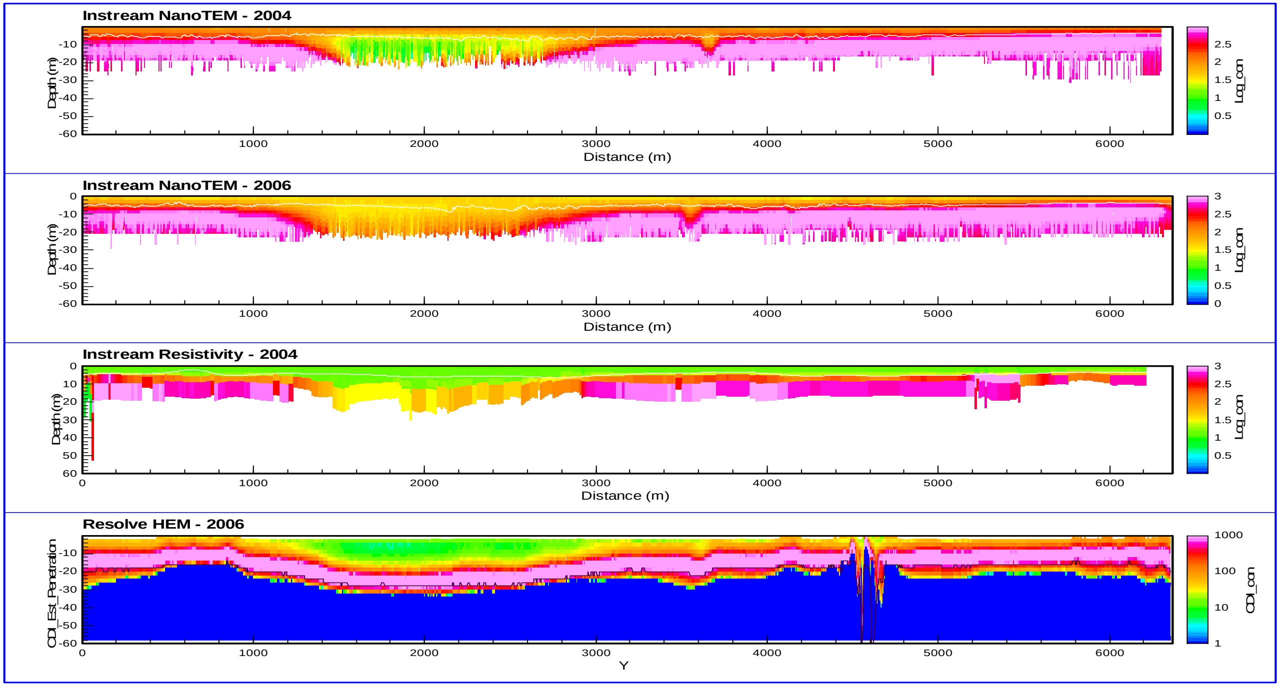

Figure 3: Stacked depth sections of the Mid section of the river. For all plots the vertical axis is depth below river surface in metres. The horizontal axis is distance along the river in metres. Water depth (as measured at the time of each survey) is indicated with a white line. Water depth was not measured during the RESOLVE survey. The upstream end of the run is on the right. The black line running through the RESOLVE data is based on the skin depth and shows the approximate depth of investigation for the HEM system.

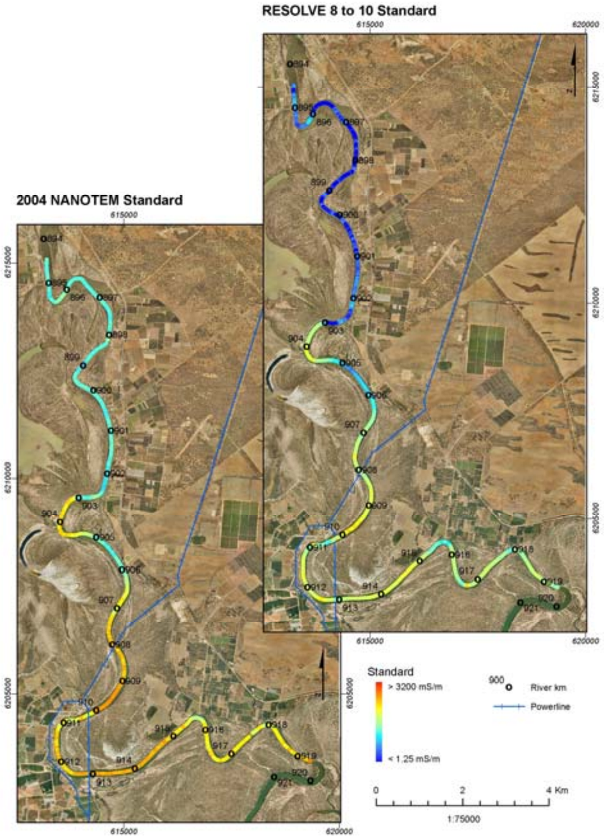

Figure 4: On the left is the contoured 2004 Instream NanoTEM data extracted from the layer immediately below the base of the river. On the right is the contoured 2006 RESOLVE HEM data. The RESOLVE data were extracted from the EMFlow results from 8 to 10 metres deep. Both images use the same standardised colour scale.