TEMPORAL MONITORING OF FLOODPLAIN HYDROGEOLOGY USING ELECTRICAL AND ELECTROMAGNETIC GEOPHYSICAL METHODS

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INTRODUCTION

The effects of saline ground water entering the Murray River are likely to continue worsening over time (Murray Darling Basin Ministerial Council 2001), even with our best efforts to improve the handling of groundwater near the river. At this time it is important to locate areas of significant salt accession in the river and the nearby floodplain (and then mitigate the salinity) as salinity is predicted to worsen over the next 25 years with implications for both irrigation and drinking water (Murray Darling Basin Ministerial Council 2001). To this end, a great deal of effort has gone into designing and building hydrogeological models based on the available data.

Input data for these models consist of drill hole information, pump tests, water levels, etc. Analysis of drill hole samples tells us a great deal about the materials in that hole, but do not tell us much about the area away from the hole. We can image further from the hole by geophysical logging of the hole, but most techniques do not yield enough information far from the hole and often the results are ambiguous. Furthermore, it is difficult to analyse for anisotropic properties, which may affect any number of parameters that we wish to know about. Taking core samples from a hole and then testing them in a laboratory may tell us something about the properties that we wish to measure, but the sampling procedure may actually damage or destroy those very properties. Moreover it may not be applicable to extrapolate those measured micro-scale properties to the larger picture. Piezometers and pump tests provide good information about local *in situ* hydrology, but there are rarely enough holes to yield a true picture of local and regional anisotropy.

Geophysics has always had the potential to fill in at least some of the gaps, but often it is better at identifying areas that require further investigation, or at qualitatively informing us about an area without providing quantitative hydrogeological numbers to put into a model. This paper will outline how to better use geophysical techniques to improve imaging of the top 1-20 m of various parts of the Murray River ecosystem to help understand the processes that are involved with salt flux and water motion in those systems. By measuring geophysical parameters repeatedly over changing systems, it is hoped that we will be able to use the change in these parameters as an input into existing, sparsely populated, hydrogeological models. This paper will then review geophysical techniques that are used to assist with hydrogeological work, especially along the Murray River, and then focus on where research will be developed over the course of the next few years.

HYDROGEOLOGY OF THE MURRAY

The overall hydrogeology and hydrostratigraphy of the Murray River Basin is well documented, so will not be described in great detail here. See Figure 1 for a schematic representation of the stratigraphy of the Basin. Much of the focus of our study will be on the floodplain and temporal floodplain processes in the Bookpurnong area (specifically Clark's Floodplain) and the Chowilla Creek area. Both areas will be extensively studied by a number of other researchers over the course of the next few years. All of this research will be focusing on integrating not only geophysical data but data from ecological studies, as well as "conventional" hydrological and geological studies to assess changes in floodplain health. In both areas the floodplain units of major interest will be the near-surface Coonambidgal and Monoman Formations. For nearby highland processes the Blanchetown Clay, and the various units making up the underlying Loxton Formation, will be primary interest.

For more in-depth overviews of the stratigraphy and hydrogeology of the Murray Basin see, for example, Brown & Stephenson (1991), Lukasik & James (1998), Telfer *et al.* (2003) and Munday *et al.* (2004).

EXISTING TECHNOLOGIES

A number of groups have been involved in modelling hydrological components of the Murray River system in South Australia. Two of the pertinent models have been by Yan *et al.* (2005) and Doble *et al.* (in press). The work of Yan *et al.* (2005) has concentrated on regional scale processes from south of the Loxton

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Irrigation area to north of the Bookpurnong Irrigation area. This, in turn, is also a subset of a larger model that looked at the system from Lock 3 to the SA/Victorian border (Yan *et al.* 2004). The work of Doble *et al.* (in press) has concentrated on the individual floodplain level, specifically Clark's floodplain near Bookpurnong. These ongoing modelling projects have yielded information about floodplain and river-system processes. Nevertheless they are limited by the fact that input parameter coverage is incomplete.

A number of techniques and technologies are being used to help delineate near-surface processes involved with salt emplacement on the Murray and over its floodplains. We concentrate in this paper on Run-of-River surveys, Airborne Electro-Magnetics (AEM), in-stream Time-domain EM (TEM), ground EM and resistivity, and Ground Penetrating Radar (GPR).

Run-of-River surveys (Porter 2002) have provided a great deal of information about salt flux into the river. Starting in 1985, the South Australian Department of Water, Land and Biodiversity Conservation (SA DWLBC) ran the first of approximately forty Run-of-River Salinity Surveys (Porter *pers. comm.*). Salt loads are calculated by taking GPS-located salinity measures at the surface of the river on successive days from a speedboat. The migrating salinity patterns are then extrapolated back to their original locations (Porter 2002). This approach helps locate large-scale salinity sources that require salt mitigation infrastructure. However, as most of the larger sources of salinity have been found, it is now necessary to locate smaller problem areas.

AEM surveys are often used to map both near-surface geology and regional salt stores on a large scale. Recently, groups in Denmark have been involved in the development of innovative AEM systems applied to hydrogeological problems. Denmark is very dependant on fresh water aquifers for its water supply and has pioneered the use of electrical methods to precisely map the location and quality of these aquifers. Sorenson & Auken (2004) and Smith (2004) present interesting innovations in AEM systems and excellent case studies of their use in Denmark. In Australia, ongoing research has usually been concerned with large-scale salinity distribution so the focus has been slightly different, e.g., Lawrie *et al.* (2003) and Christensen (2003). Barnett & Munday (2004) discuss the process of optimising survey design and choosing a particular survey "brand" so as to "guarantee" that the survey results match the specific survey goals.

In general, AEM surveys are very fast, covering many hectares per day (depending on line spacing and aircraft speed). For example the Helicopter EM (HEM) data run in July 2005 at Chowilla collected approximately 1,000 line-kilometres of data at mostly 200 m line spacing in four to five days (compare to ground based techniques at one to five line-kilometres per day). Where resolution is less critical, an aeroplane-based system can collect up to 1,000 line kilometres in a day. The limitations to AEM include that the data resolution is dependent on platform speed (i.e., helicopter or aeroplane) and data point spacing (often at least 40 m between readings along line and at least 100 m between lines). Resolution is also limited in that the vehicle is constantly moving so there is no time to stack in a given location to improve data quality (as can be done with most ground based surveys). Huge amounts of data are collected over a large, geologically variable survey area, sometimes making it difficult to process the data to a consistently interpretable form. Great strides are being made in this area, for example, Munday *et al.* (2004) describe the calibration and ground truthing on the 2003 Loxton airborne surveys.

Ground based EM and Direct Current (DC) resistivity surveys are also commonly used to help locate groundwater. In Australia a number of authors have described using ground-based EM to help define problems with groundwater, especially salinity, e.g., Acworth *et al.* (2005), Skinner & Heinson (2004) and Dahlin *et al.* (2002). Overall, results from ground geophysics have better resolution than airborne surveys, but are much slower and therefore more expensive for large-scale surveys. Ground surveys are often run when the size of the survey area is not large enough to warrant the mobilisation expense of an airborne survey, or when there is a need for greater precision, or for a technique that is not EM based.

Instream-TEM (Barrett *et al.* 2005, Telfer *et al.* 2004) is a variation of ground based EM surveying, where a small transmitting loop and a receiving loop are towed behind a boat and readings are taken at close spacing as the boat travels along the river. Readings are then processed and the results combined into a continuous section starting at the surface of the river down to a depth of at least 20 m. Berens & Hatch (in press) report that there is good correlation between the conductivity results from the instream-TEM technique and the results from laboratory measurements of sediments collected at approximately 25 sites in the Waikerie area along the survey run. Barrett (2003) and Allen (2005) describe using a long multi-electrode streamer behind a boat to take resistivity data in a similar manner (this is analogous to running a dipole-dipole survey on land, except that data are collected while the electrode array is moving). Allen has compared the results of both types of towed survey and report that they are similar. Results of these new types of surveys are adding a great deal of information about the hydrogeology of the area directly under the river, both on a very fine scale as well as regionally.

GPR has been used extensively to help delineate the near-surface for hydrogeological purposes but has had limited success in Australia. This is due to the rapid attenuation of radar signal in Australia's generally conductive soils, greatly limiting the depth of penetration (Annan 2005). Time-Domain Reflectometry (TDR) (Topp *et al.* 1980) is one of the standard methods used to directly estimate the near surface water content. Its use is limited in that the a probe needs to be in direct contact with the soil sample and therefore samples only a very small soil volume (Huisman *et al.* 2003). Turesson (2005) presents a method for measuring soil moisture over a larger scale in Sweden. For his study, the soil is a simple gravel-sand mixture (with fairly pure water in the matrix) and is therefore both fairly homogeneous and resistive—a "perfect" work area for GPR. He compares the ability of an electrical resistivity survey and the GPR to measure water content and porosity in the test area. In that setting both techniques were successful. Huisman (2003) presents a review of various GPR techniques applied specifically to the measurement of soil water content in the vadose zone. In this situation selection of the right antenna frequency and technique (multi-offset or select use of the received ground wave) might be successful in getting this type of information at high resolution in Australian ground conditions.

WHERE TO NOW?

One of the central research questions in hydrogeology at the moment is in the area of assessing temporal response of a near-surface aquifer system to external intermittent water movement (i.e., drought and flooding cycles, or changes in water levels above locks, etc.). An obvious corollary that goes with this is what do solutes (specifically salt) do in this near-surface zone as water levels change? We can dig holes and measure things near or in the hole, but this is point-source data and may be problematical to extrapolate. We can observe changes in vegetation health but this is slow and somewhat subjective (and may be strongly influenced by other factors). There is an obvious need for data that can be acquired at a suitable density, economically and repeatably. Geophysics has the potential to fill this niche but it is not as simple as may be hoped. Most geophysical data collected for hydrogeological studies up to now have been collected as a snapshot of the system at an instant in time. Attempts are then made to try to match that data with certain parameters in the hydrogeological system. We feel that this may not be the correct approach and we will be taking data over study areas a number of times and then work with the changes in geophysical parameters, tying those into changes in the hydrogeological system.

Clark's Floodplain within the Bookpurnong SIS (Telfer & Philp 2005) and various parts of the floodplain in Chowilla Creek (Munday 2005) have been set up as areas for continued research in characterising floodplain processes with the aims to understand these processes and to help manage salinity issues over both areas. Current practice is based on performing the experiment (i.e., a controlled flood as an example), measure the response in the piezometers, etc., and then measuring what the response in vegetation is (ultimately what percentage lives or dies). We propose to use a number of ground-based shallow EM and DC resistivity techniques to help characterise these areas before and after controlled flooding and other experiments. Some interest has been expressed (Telfer *pers. comm.*) that work be done to characterise the very shallow vadose zone using high-resolution techniques, as this zone is poorly understood and needs to be characterised efficiently. Huisman's (2003) article suggests a number of possible solutions involving GPR. Overall, surveys will be run before changes are made in the system and then repeated once the system has been modified. Ultimately, we will be concentrating on the change in measured parameters over time and evaluate how these changes can be substituted into hydrogeological equations and modelling routines to help fill out the sparse information that is often used to make important decisions about how to deal with the health of the river and the floodplain.

Another area that deserves more work is to improve the instream-TEM system. This system is based on a ground acquisition system and could benefit from investigation into some unexpected results that appear to be particular to running EM on water. Furthermore, the data processing stream is also based on ground systems, and could be improved both in the filtering algorithms used to lessen the effect of noisy data as well as in the inversion process improving the ability to constrain the data to known conditions.

The continuous collection of data used for the instream-TEM could also be applied to high resolution, shallow land-based surveys. If this could be developed it would greatly improve our ability to image from the ground surface to a depth of 5-10 m. This type of data collection technology needs to be experimented with further on land. Experiments on this using smaller transmitting and receiving loops mounted on sleds or carts on land show promise, but interpretation of this type of data is not straightforward. Carlson & Zonge (2003) reports on a system of this type developed for use in the detection of unexploded ordinance and other metallic culture that so far is not suitable for the high resolution mapping that is necessary for hydrogeological studies.

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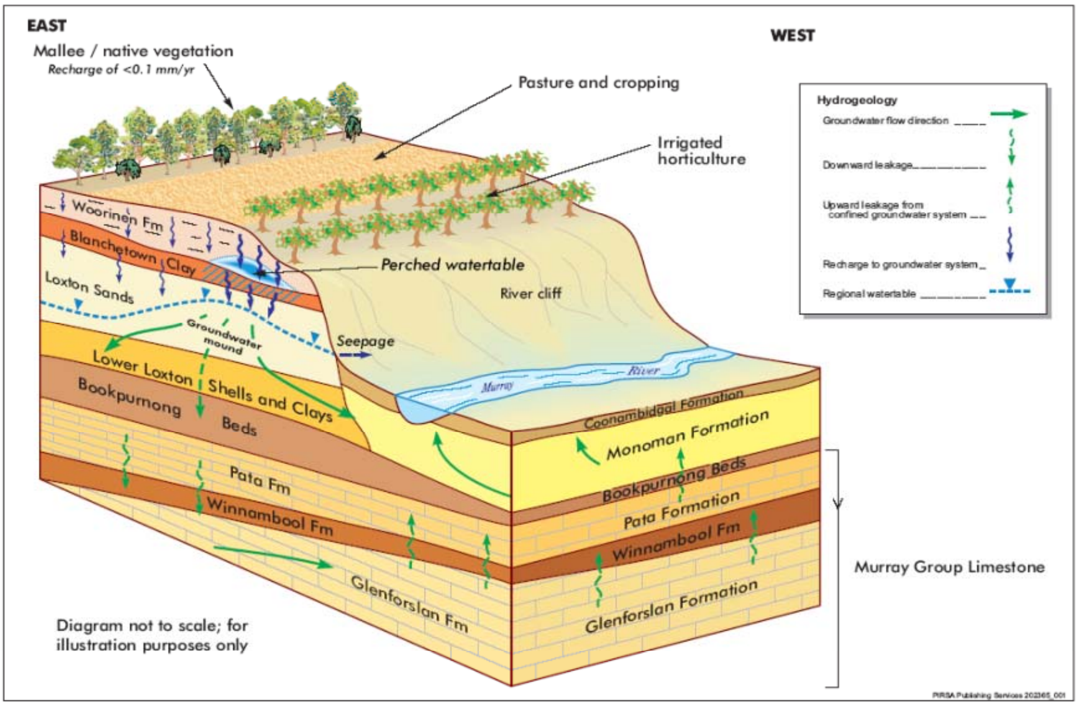

Figure 1: Schematic outline of the hydrostratigraphy of the Murray Basin. From SA DWLBC.