Final Report: Locating groundwater resources for the Aboriginal Communities in the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands, in the far north-west of South Australia

Dr. Michael Hatch
University of Adelaide
28 February, 2013

Participants:
Professor Graham Heinson, University of Adelaide
Dr. Michael Hatch, University of Adelaide
Adrian Costar, Department of Energy, Water and Natural Resources, South Australia (was Department for Water, Land and Biodiversity Conservation)
Simon Wurst, South Australian Water Corporation
Grant Mclean, South Australian Water Corporation
Professor Craig Simmons, Centre for Groundwater Studies, Flinders University of South Australia
Dr. Dennis Cooke, University of Adelaide

Students (all University of Adelaide)
Kent Inverarity (all phases)
David Pedler-Jones (Phase 1)
James Wilson (Phase 1)
Anastasia Costopoulos (Phase 2)
Robert Lampe (Phase 2)
Alison Langsford (Phase 2)
Katherine Stoate (Phase 2)
Aims and Objectives
The aim of this research program was to test whether geophysical surveys, specifically the magnetotelluric (MT) technique, could be used to help locate groundwater resources for Aboriginal communities in the Anangu Pitjantjatjara Yankunytjatjara (APY) lands of far northern South Australia. In these semi-arid to arid parts of Southern Australia, there are generally few supplies of permanent surface water. Rainfall is generally low (<250 mm), with only occasional high rainfall events. These communities rely on boreholes in deep-aquifers within fractured rock for their potable water supplies. Maintaining and developing existing groundwater supplies and identifying new resources is essential to maintaining these remote communities.

The objective of the program was to use MT to collect data across a small survey area using a relatively dense array of sites to image the three-dimensional electrical conductivity structure from close to the surface to a depth of 1 km or greater. It was hoped that the variability in electrical conductivity both laterally, and with depth, would yield a method for identifying groundwater resources to better target boreholes, and hence increase water-bore drilling success.

Overview
Unfortunately, after an initial campaign to collect MT data near an Aboriginal community, and with the plan of honing our hydrogeophysical skills on another related, but different project (see Phase 2, below), to then return to another Aboriginal community to complete this project, we were thwarted in our efforts to get work permits that would allow us to collect data near this second community. We were forced to complete the project by continuing to improve our near-surface MT skill set by collecting more Phase 2 type data. Our progress is described below. While it is disappointing that we were unable to test our improved abilities on a real-world problem, we are confident that the insights that we have gained from this work will be readily transferable when we get an opportunity in the future to continue this work. Additionally, the vast array of experience that our students have gained from these projects will stand them in good stead for the rest of their careers.

Phase 1: Initial survey at Nepabunna, South Australia
This phase of the project consisted of an extensive MT survey in the area around the Aboriginal settlement of Nepabunna in northern South Australia in June 2010. The purpose of this survey was to see whether MT could be used to help define zones in the subsurface associated with water in fractured rock aquifers, focusing on the use of phase tensors (Caldwell et al., 2004) to image electrical anisotropy. In these environments anisotropy may be related to fracture alignment in the earth that would indicate the location of fractures that are then likely to hold water. The upshot of this work was that the MT method, specifically the use of phase tensors, was a promising avenue for research in fractured rock and/or fault defined water bearing systems. Unfortunately at Nepabunna the MT data were
corrupted by powerline noise, despite its extremely remote location. As the powerlines are there to provide electricity to the existing wells, the worst of the noise occurred in the areas of highest interest (nevertheless nearly all of the data were corrupted to some extent by 50 Hz powerline noise).

The results of this part of the project have been reported in The Leading Edge (Inverarity et al., 2011)(http://library.seg.org/doi/full/10.1190/1.3575286), and was presented at the Geological Society of America conference in 2011 (https://gsa.confex.com/gsa/2011AM/finalprogram/abstract_191797.htm). Additionally, the two students who worked on this project prepared honours theses on their work in the area.

**Phase 2: Geophysical surveys on the Great Artesian Basin – in conjunction with GAB Project**

Between the completion of the Nepabunna work and the intended final phase of this project, our research group at the University of Adelaide has been working on similar projects in the southern Great Artesian Basin (GAB) to characterise artesian “mound springs” both in the near-surface, as well as at depth. These mound springs have been used as water sources for thousands of years by Aboriginal groups (Harris, 2002) and then by early settlers (Harris, 2002) as they are the only sources of permanent surface water over much of the southern GAB (to the south of APY lands). There is a great deal of interest in understanding the development of these springs as they have great cultural significance to Aboriginal groups living in the GAB, but the artesian aquifers they tap are also potential water sources for new mines (and have been over-exploited during last century by the livestock industry). Additionally, they are of great interest to ecologists, as these springs are important oases for many native creatures (Ponder, 1986). This work was completed together with other institutions as part of a federally (Australian) funded project titled “Allocating Water and Maintaining Springs in the Great Artesian Basin”.

For our GAB work, we took various groups of our fourth year students (“honours” students – the fourth year is devoted to a research project and short thesis at most Australian universities) to a number of GAB springs in the southwestern corner of the GAB to determine the geophysical response at a number of scales and depths of investigation over some of these springs. For the largest project, at Wabma Kadarbu Conservation Park, we ran surveys that covered a number of the small springs at that site with shallow terrain conductivity, shallow TEM, resistivity/induced polarization, self potential (SP), and MT.

One of the major focuses of this work was to improve our ability to work with the higher frequencies in the MT band i.e. looking at the near-surface information which is most likely to provide information about the hydrogeological structure of a site. Interestingly, the resistivity data (both raw and inverted) provided little information about the structures that feed these surface springs as there is little electrical contrast between the thick near-surface aquitard unit and the very narrow pathways that the water follow to get to the surface. As with the Nepabunna work, the phase tensor provided us with the most information about
shallow structure and orientation, which allowed us correlate this response with the interpreted deep source for the spring. This work is ongoing (part of a PhD thesis being prepared by Kent Inverarity).

Preliminary results for this project have been reported on to the working group in charge of the GAB project, and will be presented in a number of papers in the future, as Kent completes his PhD work. Preliminary results were also presented as a poster (attached) at the 21st EMI Workshop, held in Darwin, Australia in 2012. Additionally, the four students who worked on this project prepared honours theses on their work in the area.

Phase 3:

On completion of phase 1 (the Nepabunna MT project) and the GAB work we intended to continue to the final phase of this project by performing similar surveys in another more remote Aboriginal settlement in the APY lands of far northwestern South Australia. The process for getting permits to work in the APY lands is complicated and time consuming. After many delays, it appeared that we were going to be able to collect another set of data in September 2012; unfortunately due to factors beyond our control the permits were again delayed. As the southern hemisphere summer was rapidly approaching we decided that it was nearly impossible to complete the intended program in a reasonable time frame. As a result we switched our focus back to the GAB.

While not the original goal of this survey, it was decided to finish this project by returning to the GAB to develop our near-surface hydrogeophysical skills by continuing our work on the important GAB mound springs. For this work we added a number of MT sites and did more SP and near-surface TEM over one of our other field sites. This extra work was directed by and benefitted from our Wabma Kadarbu experience. We then continued working on another set of springs (the Freeling Springs, north of William Creek) using the same suite of techniques (SP, shallow TEM and MT) that provided us with the most information about these spring systems.

Preliminary results for this project will be presented at the 2013 ASEG Conference, to be held in Melbourne in August (short abstract attached). When completed, final results will be presented in a number of papers in the future, again, as Kent completes his PhD work.

Results

Lessons Learned

- For MT to provide useful information for “shallow” hydrogeological characterisation the ability to collect high frequency information is crucial. Additionally, having receiver equipment that allows closely spaced data sets (higher spatial frequency) may be important for some projects (e.g. 50-m receiver dipoles, immediately adjacent to one another).
• Depending on the specifics of the project, shallow TEM and SP should be kept in mind as surveys that have the potential to add information about the hidden hydrogeology of an area. SP is particularly undervalued but useful.
• In shallow settings, where targets may be small, and related to the fabric of the bedrock, MT phase tensors may provide much more useful information about the hydrogeology than “standard” (but high effort) depth sections of inverted resistivity.

**If money were no object what would we add to this project?**

We were surprised to find that in Phase 1 of this project that the cultural noise from what appeared to be small powerlines used to power local pumps overwhelmed the high frequency MT data that we attempted to collect. Improved 50 Hz (and harmonics) filtering capability would be a useful improvement to our instruments when this work continues.

At Nepabunna, scalar CSAMT data were collected approximately one year before our group collected the MT data sets described here. The CSAMT was not particularly useful in this complicated setting, and most importantly, was not able to provide tensor phase information. It is worth considering running a full tensor CSAMT survey in the Nepabunna area a) to collect higher frequency / shallower information than the MT is able to, and b) to help overcome the powerline noise. It would be possible to calculate phase tensors from this type of data.

**Sustainability of the project upon completion**

In the future, after this project officially ends, we hope for the opportunity to continue this work by applying these methods over a wider range of similar targets across arid parts of southern Australia and other deserts, as we feel that it has great potential to improve the understanding of the various mechanisms in both the near surface and deeper environments that govern the location of water and how it flows in these challenging environments. We are actively looking for students and further funding to continue this work.

**Student involvement:** (all are or were students at the University of Adelaide)

Phase 1: Kent Inverarity (PhD), David Pedler-Jones (Honours), James Wilson (Honours)
Phase 2: Kent Inverarity, Anastasia Costopoulos (Honours), Robert Lampe (Honours), Alison Langsford (Honours), Katherine Stoate (Honours), James Wilson (Honours), Sebastian Schnaidt (PhD)
Phase 3: Kent Inverarity (PhD)
References
Harris, C., 2002, Culture and geography: South Australia’s mound springs as trade and communication routes: Historic Environment, 16, no. 2, 8-11.
Appendix 2: Publications and presentations


3) Abstract for 2012 EMI Workshop is attached below.

4) Poster for 2012 EMI poster is attached below.

5) Short abstract for 2013 ASEG conference is attached below. Extended abstract is being prepared at this time.
Characterization of artesian springs in the Great Artesian Basin of central-eastern Australia using magnetotelluric, time-domain electromagnetic, and self-potential measurements

Kent Inverarity\textsuperscript{1}, Michael Hatch\textsuperscript{1} and Graham Heinson\textsuperscript{1}

\textsuperscript{1}Geology and Geophysics, University of Adelaide. Contact: kent.inverarity@adelaide.edu.au

**SUMMARY**

The shallow underground structure of artesian springs in the Great Artesian Basin in northeast South Australia is poorly understood. We undertook a geophysical field program over two spring complexes, using induced polarization, time-domain electromagnetic (TEM), natural source audiomagnetotelluric (AMT), and self-potential techniques. The aim was to characterize the springs’ electrical structure and groundwater flow paths, along with identifying the best geophysical techniques for such an investigation.

Correlation of positive features in the self-potential data with surface spring vents showed that this technique is most suited to identifying flow paths, while the inductive methods revealed resistive structures associated with springs set against a highly conductive 100 m-thick regional aquitard. The shallow electrical resistivity structure of the springs was best resolved by modelling of TEM data, with resistivity variations correlating closely to self-potential features with high wavenumbers.

Resistivity modelling by smooth inversion for AMT data required only broad and slightly resistive zones underneath springs, but analysis of AMT phase tensors from a number of sites suggested the presence of narrow conductive zones which are likely related to broader positive self-potential features with lower wavenumbers. These conductive zones may be related to fluid flow from the confined aquifer to the near surface aquitard, and differ in their relation to spring vents between the two spring complexes studied.

All techniques provided useful information, but the combination of early-time TEM, tensor AMT, and self-potential was found to be the most effective method for looking at groundwater flow in the shallow subsurface (< 200 m) in such a conductive area.

**Keywords:** groundwater, audiomagnetotellurics, self-potential, time-domain electromagnetics
1. Introduction

Artesian mound springs occur in semi-arid parts of South Australia, on the margin of the Great Artesian Basin (Figures 1 and 2). They act as oases for wildlife and flora and are important cultural heritage sites for Aboriginal people. Understanding the way in which groundwater flows underneath these springs is important in managing and maintaining spring flows.

Figure 1: Map of study sites in the southwestern Great Artesian Basin.

We undertook a geophysical field program over two spring complexes to investigate the location and nature of underground flow paths, using spectral induced polarization (SIP), time-domain electromagnetic (TEM), natural source audiometerotelluric (AMT), and self-potential (SP) techniques.

2. Resistivity structure

Results from the SIP, TEM, and MT surveys show a horizontally layered electrical structure, with a conductive layer of 1 - 2 Ωm between 10 and 30 m depth, with resistivity then increasing to 60 - 110 Ωm at 200 m depth.

3. Self-potential (SP)

Depth sections were generated from SP data by mapping correlation coefficients for simulated potentials due to individual sources (Figs 3, 4; Hammann et al., 1997). Positive correlations (blue) indicate likely locations of positive SP sources (upward flow of water) and negative (brown) indicate downward flow.

Figure 3: Red arrows show possible faults related to downward flow.

Figure 4: Three SP image reconstructions.

4. Magnetotellurics

MT data shows an anisotropic response beneath Beresford Spring between 70 and 300 m deep (Figure 5). This is not seen at Wabma Kadarbu, and may be indicative of a relatively narrow zone feeding upward at the surface.

Figure 5: MT data from Beresford Spring.

References


Thanks are due to Dean Ah Chee, Volmer Berens, Goran Boren, Anastasia Costopoulos, Robert Lampe, Alston Langford, Andy Love, Jonathan Ross, Sebastian Schmidl, Norm Simms, Katherine Stolte, and James Wilson. Map data from Geoscience Australia.
SUMMARY

Artesian mound springs occur along the south-western edge of the Great Artesian Basin, in northern South Australia, but their underground structure and relationship to faulting is not well understood. We have performed geophysical surveys over three different systems (Beresford/Warburton Spring, springs at Wabma Kadarbu Conservation Park, and Freeling Springs) using a range of techniques: early-time TEM, self-potential, and magnetotellurics.

The self-potential data contains a local response due to specific spring vents, and also a broader stronger response due to laterally extensive upwelling in the lower part of the Bulldog Shale, at depths of approximately 100 m. Modelling of TEM and magnetotelluric data show that the confining Bulldog Shale, which is generally very conductive, contains resistive areas underneath springs and spring complexes which are believed to be related to spring-related carbonate deposition. Magnetotelluric modelling in particular indicates an anisotropic conductivity response at depths between 200 and 1000 m, suggesting that parallel faults several hundreds of metres wide may be responsible for flow up to the springs, rather than a single large fault, and that due to a lack of resistivity contrast in the aquifer and confining layers, the faults can be sensed only in the basement.

Key words: artesian springs, Great Artesian Basin, magnetotellurics, self-potential, anisotropy