ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15–18 February 2015 Perth, Western Australia

An investigation of the hidden precious water resources of Dampier Peninsula using airborne electromagnetic method

John Joseph
Geophysical Consultancy Services
26 Challenger Avenue, Morley, WA 6062
john_joseph@iprimus.com.au

Josephine Searle
Department of Water-WA
P.O. Box K822, Perth 6842
Josephine.Searle@water.wa.gov.au

SUMMARY

An airborne electromagnetic (AEM) survey was carried out over the Dampier Peninsula, North of Broome, WA during September-October, 2012. The key objectives of this geophysical survey funded by the Department of Water was (i) to obtain a better understanding of the nature of the contact between the base of the Broome Sandstone and the underlying siltstone; (ii) to identify areas of water retentive clay layers in the near surface, (iii) to create a map of the water table; (iv) to study the detailed geometry of the near shore saline intrusion; and thus (v) assist the conceptualisation of the hydrogeology and determine the quantity and quality of available groundwater resources for the benefit of local communities, government and industry. The survey was conducted using SkyTEM, a helicopter-borne time domain AEM system.

The processed AEM data for each of the survey lines were examined and inverted using the industry standard inversion techniques. The results were then compared with available bore-hole geophysical logging as well as the regional geophysical, geological and hydrogeological data. Apart from successfully mapping the depth to water table for the whole project area, this survey has clearly delineated the thickness of Broome Sandstone, shallow impermeable layers within the Broome Sandstone and areas of possible saline sea water intrusions. The survey has also successfully identified a WNW-ESE trending lineament (a basement high) and couple of NW-SE trending structural features (such as fault structures) from the central part of the survey region. The regional geophysical data images obtained from Department of Mines & Petroleum supports this finding.

Key words: Airborne EM, Data inversion, Broome Sandstone, Water table, Seawater intrusion, Structural features.

INTRODUCTION

The Dampier Peninsula is comprised of a series of troughs, terraces and shelves, bound by NW trending faults. The central area is a part of the Fitzroy Trough, with sediments up to 15 km thick (GSWA 2007). To the north, the Fitzroy Trough is bound by the Beagle Bay Fault and the Lennard Shelf, to the south is the Fenton Fault and the Jurgurra Terrace (Yeats et al., 1983). The Lennard Shelf is an area of shallow basement (~2000m) with gently dipping strata, whereas the Jurgurra Terrace is of intermediate depth (~3000m) on the Dampier Peninsula. Within the Fitzroy Trough there are many E-W trending en-echelon folds in the older rocks with the major folding being the Baskerville anticline.

The sedimentary sequences of interest to this study are the Wallal Sandstone (Forman and Wales, 1981) overlaid by Alexander Formation, Jarlemai Siltstone, Broome Sandstone and Quaternary sediments. Together the Wallal Sandstone and Alexander Formation comprise the Wallal Sandstone aquifer, a regional scale aquifer of fresh – saline water, which is artesian in the project area (Searle, 2012). The Jarlemai Siltstone overlies the Wallal and Alexander formations, and is an aquiclude of up to 275m thick (Towner and Gibson 1983; Yeats et al 1984). The Broome Sandstone aquifer is the major freshwater aquifer on the Dampier Peninsula. It is made up of fine to very coarse sands, variably consolidated, inter-bedded with minor siltstone and claystone. The Broome Sandstone contains heavy minerals (Towner and Gibson, 1983) and is noted for its Lower Cretaceous plant fossils dinosaur footprints (Playford et al, 1975). The Broome area has the greatest number and variety of dinosaur footprints of any area in the world (Kenneally et al., 1996).

The northern remote town of Broome in the south western part of Dampier Peninsula is increasingly becoming attractive to both tourism and resources industry. This leap in activity is reflected in the need for more water resources. With an average rain fall of 600 mm/year and no major lakes or rivers, the town of Broome and neighbouring local communities depend fully on the groundwater from the unconfined Broome Sandstone aquifer. Although data across the Dampier Peninsula is sparse, large quantities of fresh groundwater have long been thought to be available. However, factors likely to locally determine the limits to groundwater use vary across the Peninsula and until now have been largely unquantified.

Department of Water manages the water resources of WA, ensuring there are no unacceptable impacts to the environment, other water users, or the resource itself. The increased interest in industrial and agricultural development across the peninsula has triggered the department to undertake a regional scale groundwater investigation, in order to address the increasing requirement for verified information on the peninsula's groundwater resources, and improve our understanding of the issues and risks of potential groundwater development. The investigation is a four year, Royalties for Regions funded, multi-disciplinary project, including an airborne electromagnetic survey (AEM) survey, analysis of red edge spectral imagery, investigative drilling, groundwater sampling and analysis, and vegetation mapping.

Electromagnetic (EM) method of geophysical investigation is proved to be effective in delineating the subsurface structures in terms of electrical properties. This method is capable of distinguishing saturated and unsaturated rocks, clay layers, presence of saline water etc. But the remoteness and size of the area, cultural and political sensitivities, and lack of access roads make it difficult to carry out ground based studies. This situation prompted the usage of airborne surveys, capable of covering any ground situations without any interruption, but quicker with continuity and precision. With the recent advancement of technologies it has become possible to conduct high resolution airborne electromagnetic (AEM) surveys flying at very low (~30m) altitude. Such an AEM survey was conducted over Dampier Peninsula in Sept-Oct 2012.

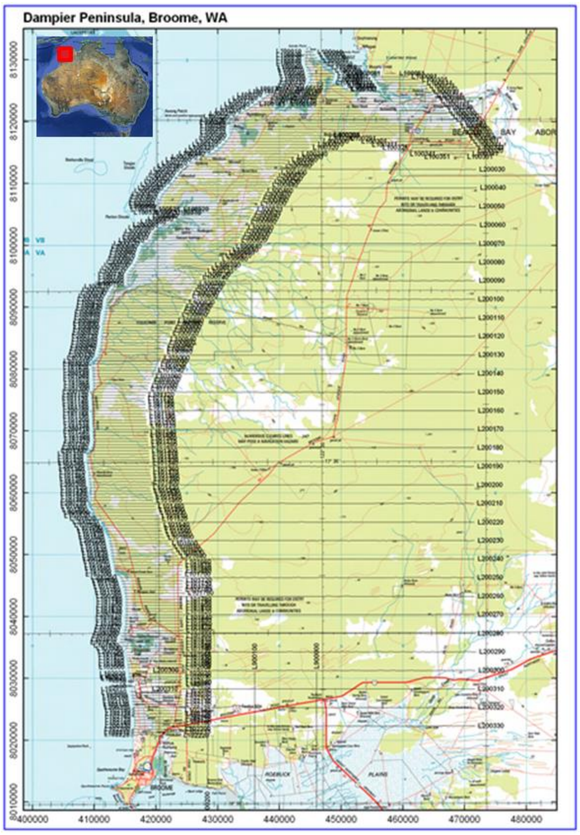

Figure 1. Topographic map of the survey area along with the survey lines. Inset: Red spot on the map shows the survey location with respect to Australian continent.

METHOD AND RESULTS

The area of interest spreads approximately 4200 square kilometres north of Broome on the Dampier Peninsula. The AEM survey was flown at 3000m survey line spacing covering the entire area, while the coastal regions were flown with 500m line spacing. Figure 1 shows the survey area long with survey lines. This survey was conducted using SkyTEM, a helicopter-borne time domain AEM system. The SkyTEM operates in dual moment mode, combining the ability to collect shallow high-resolution data with a large depth of investigation capability in a single survey pass. Figure 2 shows the SkyTEM system in survey mode.

Figure 2. SkyTEM airborne EM system in operational mode.

The processing of the raw data was conducted using the proprietary software packages, and the processed AEM data for each survey line were examined for data quality. For better understanding of the data in terms of depth-resistivity or depth-conductivity distribution, data inversions were carried out using the industry standard HyTEM-LPC (Christensen and Tølbøll, 2009) and Aarhus Workbench (Auken et al., 2008) inversion techniques. HyTEM LPC (Lateral Parameter Constraints) inversion forces the layer resistivities to vary gradually along a given profile, but it will permit abrupt lateral changes in resistivity where demanded by the data. An automated data pre-processing is performed to remove non-monotonic decays prior to inversion.

The data were also processed and inverted using a laterally constrained inversion (LCI) in Aarhus Workbench, a unique software package initially developed at Aarhas University, Denmark. In this LCI algorithm, a group of time-domain EM (TEM) soundings are inverted simultaneously using 1-D models. Each sounding yields a separate layered model, but the models are constrained laterally on a number of model parameters such as resistivity, layer thickness and/or depth to layer boundaries (i.e. these parameters are permitted to vary only gradually along a profile). This code was run in multi-layer (30 layers), smooth model mode, where the layer thicknesses are fixed and the data are inverted only for resistivity. Smoothness constraints are applied on the variation of resistivity with depth, in addition to the lateral constraints between adjacent models. Multi-layer smooth-model inversion is slower to compute, but is usually able to provide a very close fit to the observed data.

Figure 3 shows the 2-D conductivity section along survey line L100410 created from the results obtained from HyTEM-LPC and Aarhus Workbench LCI inversions. It may be noted that the western end of this survey line is the coast line. Clear indication of the saline sea water and its intrusions are indicated by very high conductivity (hot colours). The cold colours clearly demarcate the less conductive Broome Sandstone (saturated and unsaturated) followed by moderately conductive siltstone/clay.

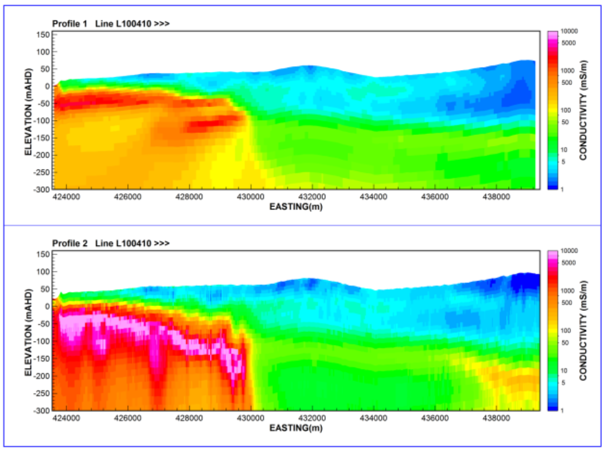

Figure 3. 2-D conductivity sections along survey line L1000410. The top and bottom images are from the results obtained from Workbench and HyTEM-LPC inversions.

Depth slices of the conductivity distribution of the whole survey area were also created from the inversion results. Figure 4 shows the depth slice corresponding to 40-50m below the ground level. Possible shallow structural trends are indicated by dashed lines. Saline sea water intrusion could be demarcated by very high conductivity (>1000 mS/m).

We also made an attempt to compare the geophysical logging data available from limited number of bore holes in this survey region. It may be remembered that the bore hole measurements provide the in-situ values whereas the airborne measurements provide an averaged response of a wider area which depends on the survey altitude, size of the transmitter loop, the transmitter moment etc. Most of these bore holes have metallic casings up to few tens of metres. Hence the valid bore-hole geophysical measurements are from the bottom of the casing. Figure 5 show a comparison of bore hole conductivity measurements with 1-d sounding results from the AEM data corresponding to the bore hole location DPB06A. A thick less-conductive layer (< 10 mS/m), followed by a moderately conductive layer (> 50 mS/m) is clearly seen on both profiles. The bore hole has a metallic casing up to about 42m depth.

Analysing the inversion results and correlating with available geological and hydrological information we have successful created a regional contour map of the water table, isopach map of the Broome Sandstone, as well as the areas of significant sea water intrusion. A detailed discussion on these findings will also be presented.

CONCLUSIONS

The Airborne EM survey conducted using SkyTEM systems has satisfactorily achieved the original survey objectives. The survey has successfully mapped the depth to water table for the whole project area. Depth to the water table varies within the survey area, which is very shallow closer to the coast, while in the central part of the survey region it seems to be as deep as 160-180 m. Depth to the water table obtained from the AEM survey data are comparable with available drill-hole data.

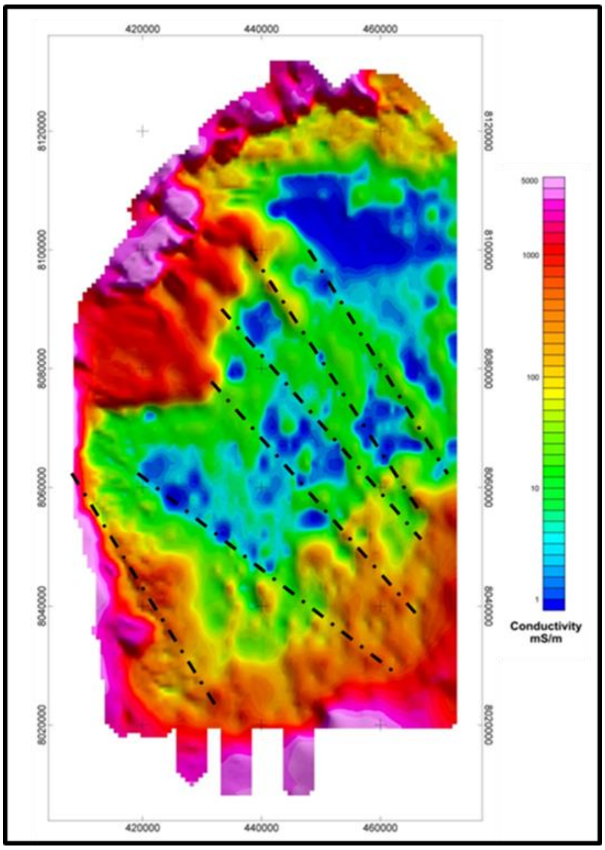

Figure 4. Depth slice of the conductivity distribution of the whole survey area corresponding to 40-50m bgl.

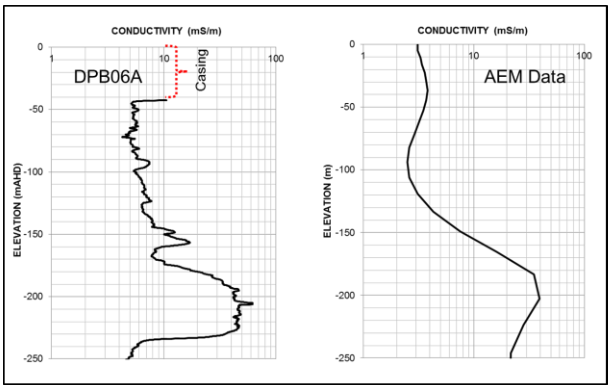

Figure 5 A comparison of bore hole resistivity measurements with 1-d sounding results from the AEM data corresponding to the bore hole location DPB06A.

The survey has delineated the thickness of the Broome Sandstone which is the main water source of Dampier Peninsula. Towards the northern end of the survey region, the Broome Sandstone seem to be very thick (>400m), which coincides with a gravity low on the regional gravity anomaly map. Although a conductivity contrast exists between unsaturated and saturated sandstone, there is a variable conductivity contrast between them due to the presence of thin inter-bedded impermeable layers, which in some areas resulted in having perched water tables. Shallow and thin impermeable layers within the Broome Sandstone formation were identified in various parts of the project area. A closer analysis of all available data is needed to differentiate these formations.

A WNW-ESE trending lineament (a basement high) was identified in the central part of the survey region, which is interpreted as the major structural feature called Baskerville Anticline. The NW-SE trending structural features (such as fault structures) were identified from the central part of the survey region (see Fig 4). The regional magnetic data images obtained from Department of Mines & Petroleum supports such findings. The detailed geometry of the near-shore saline seawater intrusion has been successfully defined in three dimensions. The intrusions mainly occur in the unconfined aquifer (Broome Sandstone) above the impermeable Jarlemai Siltstone. Saline water intrusions in the NW part of survey region shows a consistent trend, while the south block shows a sudden change in the intrusion pattern due to structural changes in the west which is also demarcated on Fig 4.

ACKNOWLEDGMENTS

Authors wish to thank Department of Water, Government of Western Australia for giving permission to present these results. SkyTEM Aps, Denmark and GroundProbe-Geophysics are thanked for carrying out the survey and processing the data.

REFERENCES

Auken, E., Christiansen,A.V., Jacobsen, L. H., and Sørensen, K. I. 2008. A resolution study of buried valleys using laterally constrained inversion of TEM data, Journal of App. Geophysics 65, 10–20

Bentley, J., 1984. Petroleum potential of the central Broome Platform. In PURCELL, P. G., (Ed)., The Canning Basin, W.A.: Proceedings of the Geological Society of Australia and Petroleum Exploration Society of Australia Symposium, Perth, 1984. p. 157-168.

Christensen N. B. and Tølbøll R.J. 2009, A lateral model parameter correlation procedure for 1D inverse modelling: Geophysical Prospecting, 57, 919-929.

Forman, D.J. & Wales, D.W. (Compilers), 1981 - Geological evolution of the Canning Basin, Western Australia. Bureau of Mineral Resources Australia Bulletin, 210.

Gibson, DL 1983a, Broome, Western Australia 1: 250 000 Geological series–explanatory notes, Geological Survey of Western Australia, Perth.

GSWA, 2007, Prospectivity of state acreage release area L07-1, Fitzroy Trough and Lennard Shelf, Canning Basin, Western Australia Geological Survey,.Report

Kenneally, K.F., Edinger, D.C., & Willing, T. 1996, 'Broome and beyond: plants and people of the Dampier Peninsula, Kimberley, Western Australia, Department of Conservation and Land Management, Perth.

Peiris, E. P. W., 2004, Mineral occurrences and exploration activities in the Canning area: Western Australia Geological Survey, Record 2004/3, 37p.

Playford, P.E., Cope, R.N., Cockbain, A.E., Low, G.H., & Lowry, D.C., 1975 – Phanerozoic, In Geology of Western Australia, Geol. Survey Western Australia Memoir 2, 223-433.

Searle, J.A., 2012, Groundwater resource review, Dampier Peninsula, Hydrogeological record series, Report No.HG57

Towner, R.R. & Gibson, D.L., 1983 - Geology of the onshore Canning Basin, Western Australia. Bureau of Mineral Resources Australia Bulletin, 215.

Veevers, J.J. and Wells, A.T. 1961, The geology of the Canning Basin, Western Australia, Bureau of Mineral Resources of Australia Bulletin, 60,323p.

Yeates, AN, Gibson, DL, Towner, R, & Crowe, RWA 1984, 'Regional geology of theonshore Canning Basin, W.A', in The Canning Basin, WA, (ed. Purcell, PG), Geological Society of Australia/Petroleum Exploration Society of Australia Symposium, Perth 1984, Proceedings, pp. 23–55.