The East Kimberley Ord Bonaparte Plains Project: de-risking investment in agriculture and water infrastructure through airborne and ground geophysical investigations

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SUMMARY

The Ord Bonaparte Plains area is a priority area for irrigated agriculture development as part of the Ord Stage 3 development in the East Kimberley region of Western Australia. Irrigated agriculture in this area will depend on access to groundwater resources in underlying bedrock aquifers. A program of airborne electromagnetics (AEM), drilling, ground and borehole geophysics and hydrogeological investigations is being undertaken to confirm the presence of suitable groundwater resources, map the connectivity between surface and groundwater systems, and identify potential risks to agriculture and water infrastructure including salt stores, groundwater salinity and seawater intrusion.

Preliminary analysis shows that the AEM survey has successfully mapped key elements of the groundwater system, including aquifer and aquitard extent, groundwater quality (salinity) distribution, hydraulic properties, compartmentalisation and inter-connectivity, the seawater intrusion (SWI) interface in coastal zones, and key tectonic elements of regional hydrogeological significance. The survey has mapped significant faulting within the Cockatoo Sandstone and Point Springs Sandstone aquifers, while conductivity distributions suggest that faults within and bounding major stratigraphic units display both fault barrier and conduit behaviour. The survey has also found that fresh groundwater in the aquifer system continues offshore as discontinuous lenses.

Initial inversions have been used to target drilling, hydrochemical investigations, and a program of ground geophysics (including Surface Nuclear Magnetic Resonance (SNMR)). Further analysis and groundwater modelling is required to determine appropriate development and management of any groundwater resource and the potential risks to agricultural development.

Key words: Airborne electromagnetics, SNMR, irrigation.

INTRODUCTION

Development across northern Australia is hindered by the lack of relevant geoscience and geospatial datasets and knowledge at appropriate scales. This information is required to help identify areas suitable for minerals, energy and agricultural development, thereby reducing the risks to private sector investors, while ensuring development proceeds responsibly. These datasets and knowledge are also required to aid infrastructure planning by Governments and the private sector. A critical factor in the development of energy, minerals and agriculture sectors will be the availability of adequate water resources and supporting infrastructure. There are limited areas where rainfall is sufficient to solely underpin agricultural development, however even in these areas, there will often be a need for additional water sources and storage due to the unreliability of seasonal rainfall and timing of agricultural production. Previous investigations have also shown there are limited opportunities for surface dams across northern Australia (CSIRO, 2009), while the infrastructure and energy costs of long-distant water delivery in pipelines or surface channels is often prohibitive. The development of unconventional oil and gas resources similarly requires water for fracking and processing, while the minerals sector requires water for mine operations and ore processing.

The Ord Irrigation Expansion Project (OIEP) was initiated in 2009 to support the development of several large areas (> 30,000 ha) of ‘black soil’ irrigated farmland near Kununurra. These areas include those which drain to the Keep River (Weaber, Knox and Keep Plains) and those in the Ord River catchment including Mantinea and Ord West Bank. The OIEP also includes additional areas of red sand and sandy loam of the Cockatoo Sands land system located adjacent to Kununurra, and an area of over 30,000 ha in a more remote area centred about 50 km north of the Ord River off Ningbing Road, west of the WA-NT border (Figure 1). The latter area has been identified as a priority area for irrigated agriculture (horticulture) development as part of the Ord Stage 3 development, and is the focus of this investigation.

Risk assessment and planning projects supporting the OIEP commenced with the acquisition of the GA-CSIRO led AEM Project (Lawrie et al., 2010) and has been continued as part of the Federal and WA State Governments joint $515m investment which concluded in 2014 with a Chinese investor taking the development lease. Investigations since 2010 have been led by the WA State government (Department of Agriculture and Food, DAFWA) as a means to support irrigation development and management of land and downstream risks defined via the WA Environmental Protection Agency (EPA) and federally under Conditions defined within the Environmental Protection and Biodiversity Conservation (EPBC) Act. The data and knowledge gained in these investigations was subsequently incorporated in groundwater modelling undertaken by DAFWA. These studies de-risked business investment decision by identifying areas suitable for development as well as areas at risk from rapid rises in groundwater levels and salinity. This information contributed to modifications to the proposed development areas, the infrastructure design (and costs), and cropping strategies.

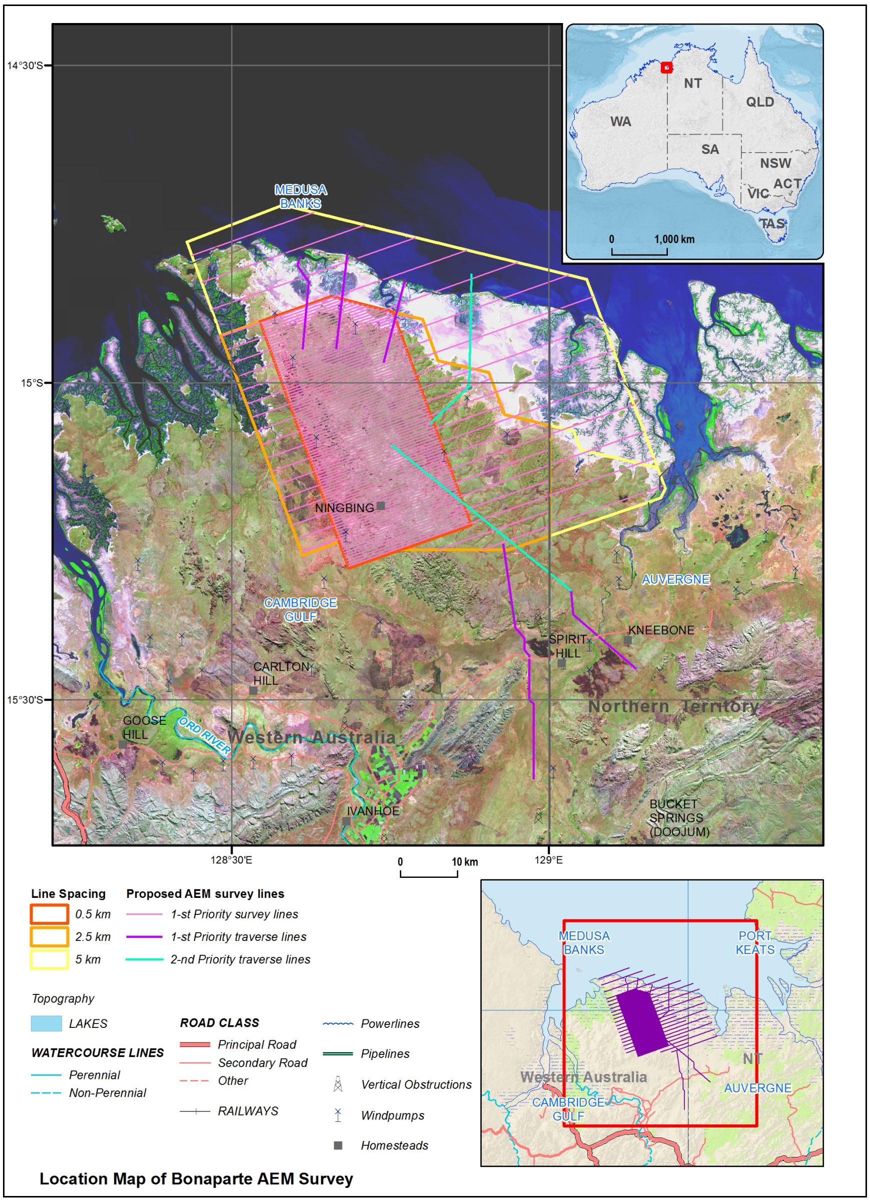

Figure 1. Location map of the Ord Bonaparte Project area showing AEM survey lines.

The Ord Bonaparte Plains area is also of interest for energy exploration. Oil and gas drilling occurred in the study area in the 1960s (e.g. Bonaparte 1 and 2 wells; Alliance Oil Development). Utah Development undertook coal exploration along the coastal margin (Williams 1982). Advent Energy currently holds the ground and has been active to the south of the Weaber Range (Waggon Creek and Vienta gas prospects).

METHODS

The Northern Australian Land and Water Task Force (2009) recommended that "Australian governments should support a comprehensive geophysical survey program to quantify groundwater resources and salinity risks in priority groundwater provinces of northern Australia, particularly where new consumptive uses, such as for intensive agriculture, are most prospective". In congruity with these recommendations, the WA Government's Water for Food Program (2014-2018) has commissioned a number of AEM surveys as part of inter-disciplinary investigations to identify and de-risk irrigation development opportunities in priority areas across Western Australia (WA, 2015).

This study includes the acquisition of an AEM survey (Figure 1), and production of a suite of interpretation products through integration of AEM, drilling, geophysics (including surface and borehole NMR), hydrogeological, hydrochemical and remote sensing data and products. A 3D geological model that shows the distribution of the hydrostratigraphy and groundwater salinity in near-coastal aquifers will also be produced by integrating AEM, drilling and remote sensing datasets.

The primary objectives of this study are:

- Reconnaissance mapping of the underlying groundwater system (Cockatoo and Point Springs Sandstones) to determine their extent, water quality (salinity) distribution, hydraulic properties, compartmentalisation and inter-connectivity;
- Mapping of the seawater intrusion (SWI) interface in coastal zones;
- Mapping of tectonic elements of regional hydrogeological significance;
- Salt store and salinity hazard mapping to identify potential risks to agricultural development and environmental assets.

The survey focal area is approximately 30,000 ha and is consistent with the footprint of the Cockatoo Sands soil mapping (Smolinski et al., 2010). The survey also includes a wider area (covered by a lower resolution – line spacing) that includes the Ningbing Range to the west, Weaber Range to the south, the coastal margin, and wetlands, and crosses the WA-NT border near Keep River estuary to the east. Surveying outside the proposed area is seen as essential to understand the broader groundwater system and connectivity to the Keep River estuary, and to assess potential hazards to environmental assets.

The primary focus of investigations is poorly consolidated sandstones initially thought to be 150 m thick and overlying thick shales. Marine clays and buried intertidal surfaces are expected near the coast. A priori data comes from limited oil and coal industry exploration bores, and recent drilling at one site comprising one shallow (80m) and one deep (180m) bore. Industry seismic reflection data also provide a regional perspective on hydrostratigraphy and tectonics. The area contains hydrocarbon accumulations at depth, and is prospective for unconventional shale gas.

An AEM system was selected after a rigorous technology suitability assessment exercise was carried out under Geoscience Australia's Deed arrangements. The detection of near surface soil properties was seen as the key aim of the survey and detectability and resolvability modelling indicated that the SkyTEM312 system had the highest probability of fulfilling these objectives. The AEM survey was flown in October/November 2015 with a total of 2,780 line kilometres of data acquired. The survey consisted of parallel lines flown with a spacing of 500 metres over the Cockatoo Plains, with 2500 metre spacing over Tanmurra and the Cleanskin Plain, and individual traverses to the north and south-east of the survey area (Figure 1).

The SkyTEM312 system includes a 337.0 m^2 loop that transmits a low moment (two loop turns) and a high moment (12 loop turns). The low moment has a peak current of -5.9 A, with a linear rise of 0.8 ms, a linear ramp off of 1.010 ms, a base frequency of 275 Hz and a peak moment of ~3,980 Am^2. The high moment has a peak current of 117 A, using a pseudo-rectangular waveform with an on time of 5.0 ms and linear ramp off of 15.0 ms, a base frequency of 25Hz and a peak moment of ~473,000 Am^2. The Z- and X-component data were measured at the receiver coil using 18 gates for the low moment and 21 gates for the high moment. High altitude lines were flown throughout the survey to estimate levels of additive noise. The repeatability of the system was tested by collecting data along repeat lines throughout the survey.

PRELIMINARY RESULTS

Contractor-provided AEM inversions (SkyTEM LEIs) have been used for preliminary interpretation and the planning of drilling and other ground investigations (including borehole Nuclear Magnetic Resonance (NMR) and Surface Nuclear Magnetic Resonance (SNMR)). It is planned to carry out borehole-constrained inversions after completion of the drilling phase of the project. Some of the preliminary findings are outlined below.

The AEM data successfully mapped the extent of the major stratigraphic units in the onshore Bonaparte Basin within the study area (Figure 2). This includes (from west to east), the Late Devonian Cockatoo Group Sandstone; the Late Devonian Ningbing Group limestones, and the Carboniferous Point Spring Sandstone, with regional aquitards including the Carboniferous Milligans Formation and Tanmurra Formation (Mory & Beere, 1985; Beere & Mory, 1986; GSWA, 2011; Ahmad & Munson, 2013). Notably, the Point Spring Sandstone underlies the target Cockatoo Sands land system. The AEM data reveal significant faulting and folding within the aquifers, with stratigraphic units fault-bounded in the west. The AEM data reveal a gently NW-dipping stratigraphic sequence in the north east, with steeply-dipping stratigraphy coincident with basin inversion along the ranges (Mory & Beere, 1988), where major stratigraphic units display both fault barrier and conduit behaviour.

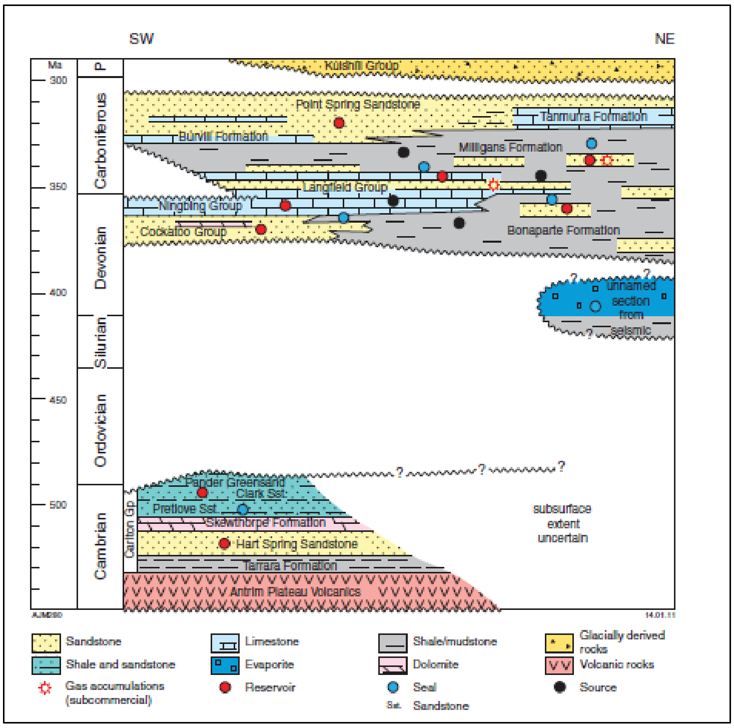

Figure 2. Stratigraphy of the onshore Bonaparte Basin (GSWA, 2011)

The Point Springs Sandstone and Ningbing Limestone are electrically resistive onshore, consistent with observations that the Point Springs Sandstone aquifer contains significant volumes of fresh groundwater in porous sediments. The survey has also found that fresh groundwater within this aquifer continues offshore as discontinuous fresh water lenses in an otherwise saline formation (Figure 4). The AEM data appear to confirm that the Point Spring Sandstone aquifer is at least 150 – 200m thick.

Within the Point Springs Sandstone, the AEM data map a significant semi-continuous shale layer (~30m thick) that separates an upper from a lower sandstone sequence (Figure 5). This is also consistent with pre-existing drilling. The lower sandstone aquifer is slightly more electrically conductive than the upper unit, suggesting that the former may contain more clay and/or more brackish groundwater Vertical offsets up to 40m displace this marker horizon, and may locally compartmentalise the groundwater system (Figure 5). Conductivity distributions in depth slices also suggest that some faults may act as barriers to lateral flow (Figure 6). However, elsewhere, the AEM data show that faults are conduits for vertical groundwater flow (e.g. fault-related mound springs associated with a splay of Ivanhoe Fault). A thick (~200m) and weakly conductive Tanmurra Formation is interpreted to underlie the sandstone.

Initial interpretation of the AEM data also suggests that there is limited connectivity between the Ningbing Group limestones and the Point Spring Sandstone in the east. These formations are separated by a more conductive zone, thought to be either Tanmurra Formation or Milligans Formation (Figures 3, 5). The AEM data successfully map the salt water intrusion (SWI) interface proximal to the estuarine flats at Tanmurra and Cleanskin plain. In the east, the SWI interface is apparently coincident with mud flat distribution and a major NW-trending fault (Cockatoo Fault?), parallel to the basin edge.

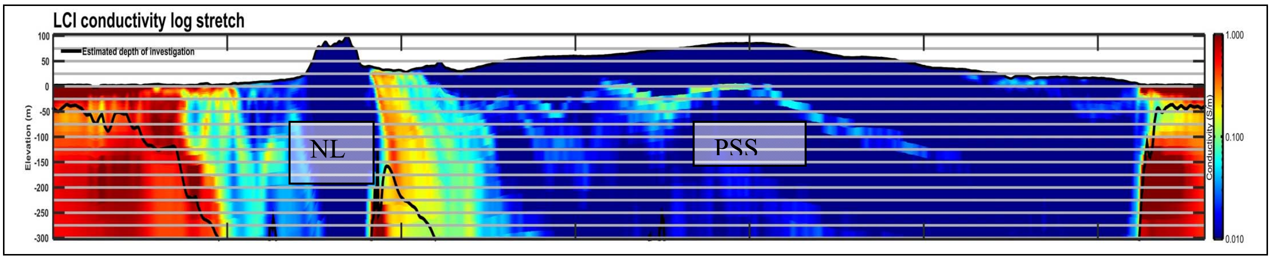

Figure 3. Conductivity section oriented ENE-WSW showing the Ningbing Limestone and Point Springs Sandstone. The shallow seawater intrusion wedge is shown on the far right.

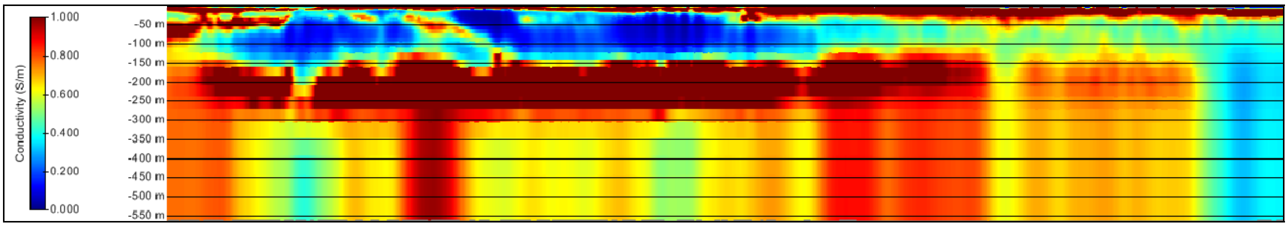

Figure 4. Most northerly AEM conductivity section (ENE-WSW) showing continuity offshore of fresh groundwater in the Point Springs Sandstone aquifer (dark blue). Fresh groundwater lenses are also preserved offshore in many of the AEM conductivity sections.

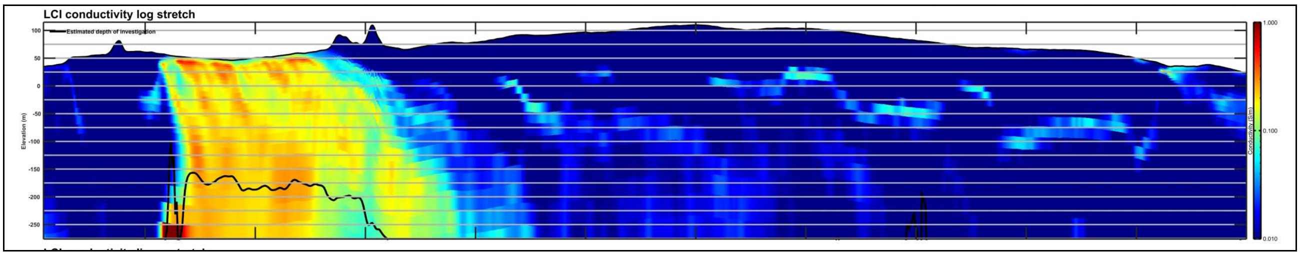

Figure 5. AEM conductivity section showing faulted shale layers within the Point Springs Sandstone aquifer.

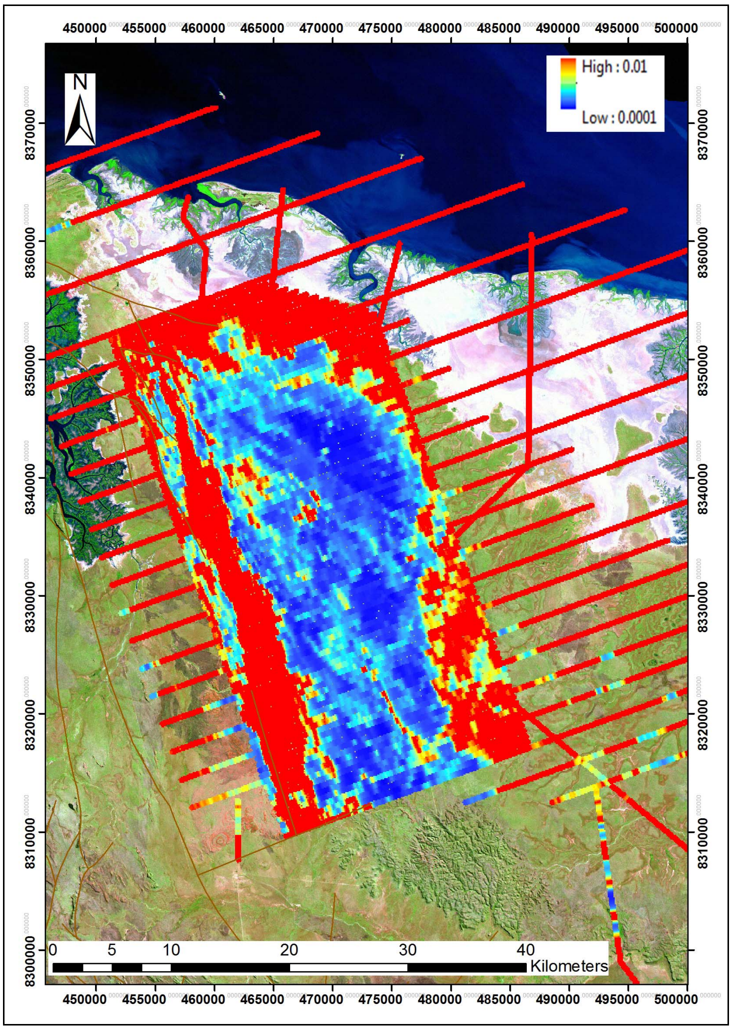

Figure 6. Conductivity depth slice (~30m) showing a window into the Point Springs Sandstone aquifer. The image has been colour-stretched to emphasise the more resistive areas (<0.01 S/m). The data show that the aquifer is resistive, but with subtle linear internal variations suggestive of faults. The eastern boundary shows the shallow seawater intrusion interface, while the western margin is interpreted to be bounded by a steeply-dipping fault-controlled shale unit.

CONCLUSIONS

Preliminary analysis of AEM inversions indicated that the AEM survey has successfully mapped the primary groundwater targets, including the extent of fresh groundwater within the major aquifers, the major tectonic elements including inter- and intra-formational faulting, and the seawater intrusion interface. The AEM data are being used to target drilling and plan a program of ground and borehole geophysics and hydrochemistry to determine groundwater quality, aquifer transmissivities, recharge dynamics and surface-groundwater connectivity. Drilling and ground geophysics will be used to constrain further inversions of the AEM data.

The AEM data will help de-risk investment in agriculture and water infrastructure through providing an important baseline dataset for 3D mapping of the groundwater system and surface-groundwater connectivity. The data provide a key input for assessment of groundwater resources and potential risks to environmental assets including salinity hazard and the risk of seawater intrusion.

ACKNOWLEDGMENTS

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