AQUIFER DELINEATION USING THE TEMPEST AEM SYSTEM

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SUMMARY

The Western Australia Department of Water and Environmental Regulation (DWER) utilized the Tempest system in a survey over the North Gnangara Mound, Perth Basin in 2013, to image hydrogeology relevant to groundwater resources important to Perth's public water supply. In 2017, DWER extended the survey to target the Leederville-Parmelia aquifer, by flying an adjacent area covering the Dandaragan Plateau approximately from Gingin to Eneabba to the north, using an updated Tempest system.

In total over 10 000 line kilometres have been flown covering a combined area of over 6000 km^2. Borehole resistivity, lithological logs and groundwater chemistry from over 300 bores was used to help interpret and constrain the inversion of the acquired AEM data. Recharge zones, regional throughflow directions, faults that act as flow barriers, groundwater discharge zones, and the extent of regionally important aquitards have been able to be inferred and mapped. Estimates of the minimum thicknesses of fresh groundwater (< 500mg/L and < 1000 mg/L TDS) have been made for the Superficial and Leederville-Parmelia aquifers. The surveys have helped clarify hypotheses about faults that act as flow barriers and regional flow directions that are important for groundwater allocation planning.

In this paper we present the results of both surveys, and key hydrogeological outcomes. We also compare the data from the two AEM surveys highlighting system developments, how these have led to improved data quality, and improved interpreted geological and hydrogeological outcomes.

Key words: groundwater, aquifer, Tempest, time domain electromagnetics, salinity

INTRODUCTION

The northern Perth Basin supplies water for residential consumption, agriculture and mining operations in the area. The Perth Basin is a north to north-northwest trending, onshore and offshore sedimentary basin extending about 1,300 km along the south-western coast of Australia. Sediment thickness extends to about 12 km onshore. There are four primary aquifers in the basin: the Superficial, Leederville, Leederville-Parmelia and Yarragadee aquifers. Using a network of more than 700 monitoring bores, it has been found that in some places the depth to watertable has risen due to extensive clearing of native vegetation, while elsewhere it has declined due to extraction and a drying climate.

The area has been extensively studied with hydrogeological investigations in order to provide a secure supply of water. The Tempest fixed-wing electromagnetic system has contributed to the understanding of the hydrogeological conditions of the area with a survey flown over the North Gnangara Mound in 2013 and a recent extension of that survey over the Dandaragan Plateau to target the Leederville-Parmelia aquifer.

The Tempest system has been used extensively for hydrogeological mapping and groundwater exploration. The fixed-wing Tempest platform is able to economically survey extensive areas, important for regional surveying. Tempest has been extremely successful in hydrogeological applications due to its calibration providing data ideal for inversion modelling. A study by Sorensen et al (2015) compared calibration of ground and airborne EM data, finding that conductivity models from ground EM and Tempest provided consistent results. The authors concluded that Tempest could be used to standardise ground-based or other airborne-based survey data.

The calibrated nature of Tempest ensures that data is repeatable. This is very important for large regional scales which may be surveyed over multiple years and where consistency and repeatability of the system data is necessary for correct interpretation of data. Fitzpatrick (2013) used 36 Tempest surveys collected over a decade to build a basin-wide conductivity model for uranium exploration. Fitzpatrick showed that Tempest conductivity depth slices from different surveys (and flown with different aircraft) could be merged together without any levelling, speaking to the calibration of the system. This is important for merging the northern Perth Basin survey here (flown with a Cessna 208) with the North Gnangara Mound survey flown in 2013 (using the Shorts Skyvan).

METHOD AND RESULTS

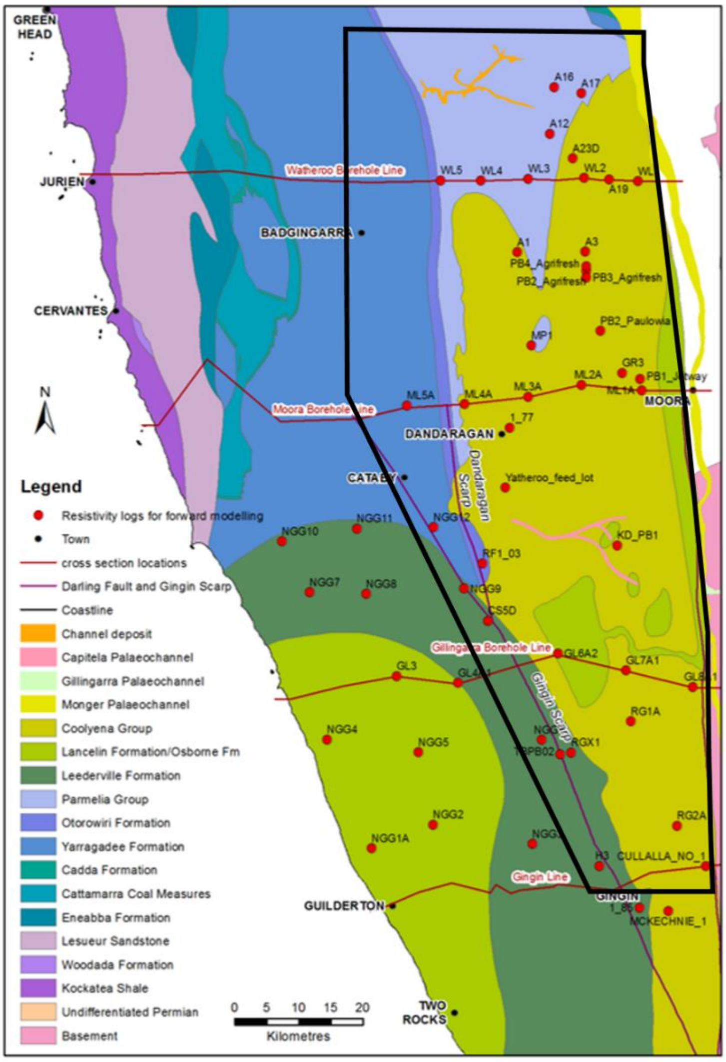

Figure 1: Sub-cropping geology of the northern Perth Basin. Boreholes in are denoted by red circles while the black outlines shows the current AEM survey area.

Tempest electromagnetic and magnetic data were collected in June of 2017, covering 6,350 line-km. The survey area is shown in Figure 1 along with the sub-cropping geology. Tempest was operated at a 25 Hz base frequency (the system is able to operate from 12.5 to 225 Hz). Tempest transmits a 50% duty cycle square wave which is deconvolved to a 100% step response, providing 20 ms of measurement time with a 13 microsecond sample interval. The system receiver measures all 3 components of the electromagnetic field. Data is stacked to provide a measurement station approximately every 12 m. The receiver is nominally 115 m behind and 45 m below the transmitter; this is monitored with a GPS on the receiver to ensure accuracy when inverting Tempest data. Inclinometers provide transmitter and receiver attitude. Data are currently being modelled with the 1D inversion algorithm GALEI (Brodie, 2016).

An example of borehole resistivity data with lithology from drilling compared with AEM 1D inversion from the 2013 North Gnangara survey is shown in Figure 2. Note that the 2013 survey utilised a 75 Hz base frequency so will not have the same investigation depth as a 25 Hz dataset. The inversion model from the Tempest data shows excellent agreement with the borehole resistivity log in the near-surface, speaking to the calibrated nature of Tempest. Tempest correctly shows increased conductivity at the conductive Upper Parmelia and Kardinya Shale units. At depths greater than 100 m, the Tempest-derived model shows correlation with the borehole resistivity trend but as the unit is beneath the conductive shale (resistor under conductor) it is more difficult to image precisely.

Figure 3 shows profile data from the Tempest system along with Layered Earth Inversion (LEI) and a Conductivity Depth Image (CDI) created from EMFlow (Macnae and Lamontagne, 1991). The borehole lithology (colours show lithology change, not conductivity) is superimposed over the LEI and CDI models. The LEI section of the Tempest data maps the thickness of the surficial sediments well and correctly maps depth extent of the relatively conductive silty sandstone and shale units. The section then slowly transitions to show the resistive sandstones at depth.

Figure 4 shows an example CDI section from the current survey. In an effort to map the water quality in the region, a previously determined power relationship between formation resistivity and groundwater salinity from borehole data for sediments in the Perth Basin has been applied to determine conductivity zones representing groundwater with different amounts of total dissolved solids (TDS). The colour palette reflects this conversion of total dissolved solids to conductivity for the region; starting from resistive, the colours indicate groundwater with salinity of less than 500, 1000, 1500, 2000, 3000 and more than 5000 mg/L TDS. The thick red layer at the left side of the section is thought to relate to evaporation concentration of salt near the coast while the thin red layers inland are likely clay layers.

CONCLUSIONS

Inversion of the newly acquired data acquired at 25 Hz in the northern Perth Basin by GALEI algorithim is ongoing. Preliminary results have shown excellent correlation with outcropping clayey formations such as the Otorowiri Formation that is consistent with existing 3-D geological modelling. This has allowed the geological model to be refined. While the power relationship between formation resistivity and groundwater salinity from borehole measurements is strictly representative of groundwater salinity from sandy beds a broad approximation of the general 3-D salinity distribution to moderate depths in the aquifer consistent with borehole data has been delineated. When the derived salinity zones are viewed in conjunction with the modelled location of clayey formations a clear picture of the distribution of groundwater salinity can be inferred at a regional scale. Important results to date include to detection of fresh groundwater under clayey formations which is consistent with field observations. The confidence depth of the data is however, a very important consideration when inferring deep fresh groundwater as resistive artefacts under shallow conductive zones can occur.

Overall the surveys have provided an excellent regional scale delineation of major aquifers, aquitards and the 3-D distribution of salinity in the northern Perth Basin. Ongoing constrained inversion of the acquired data will continue to improve the the 3-D conceptualisation of groundwater flow in the northern Perth Basin.

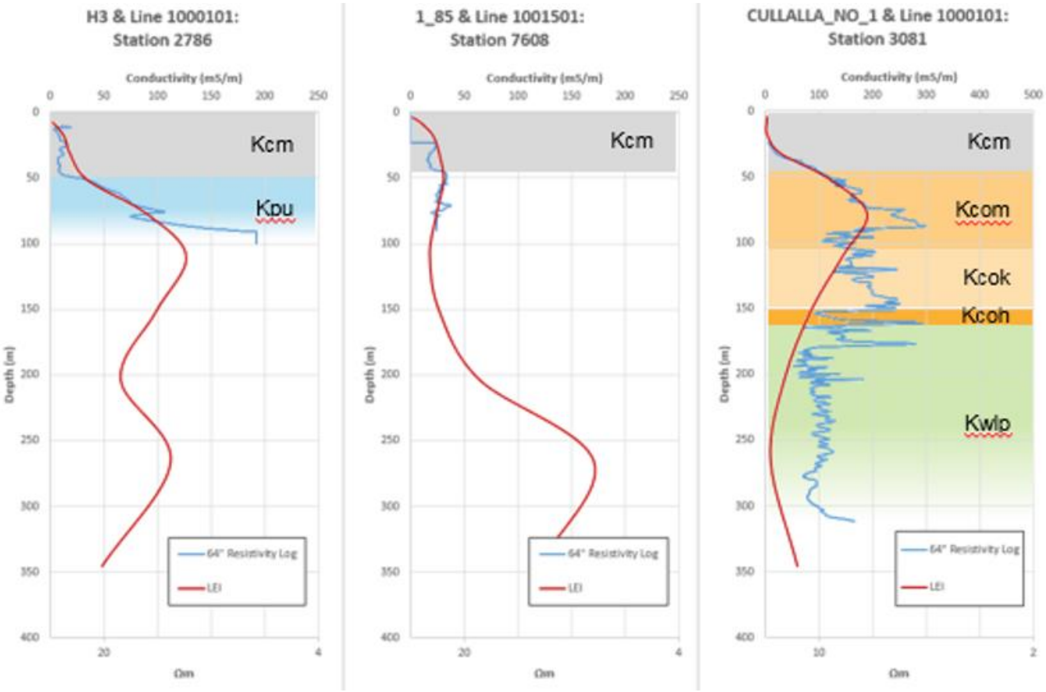

Figure 2: Wireline borehole conductivity (blue line) with drilled lithology information (coloured box). AEM LEI data is superimposed in red. Kpu – Upper Parmelia (sandstone with basal siltstone which acts as aquitard); Kcm – Molecap Greensand surficial sediment; Kcok Mirrabooka Member silty, poorly-sorted sandstone; Kcok Kardinya Shale; Kcoh-Henley Sandstone; Kwlp – Pinjar Member of the Leederville Formation. The right-most image is the Cullalla_NO_1 borehole shown in Figure 3.

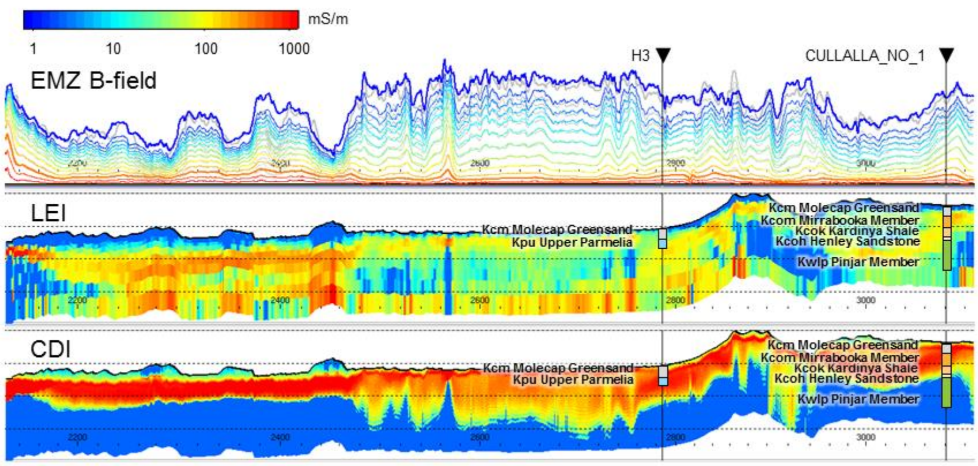

Figure 3: Tempest 75 Hz data (top) along with layered earth inversion model (middle) and EMFlow conductivity depth image (bottom). The borehole lithology log has been superimposed with colour denoting a different lithology, not conductivity.

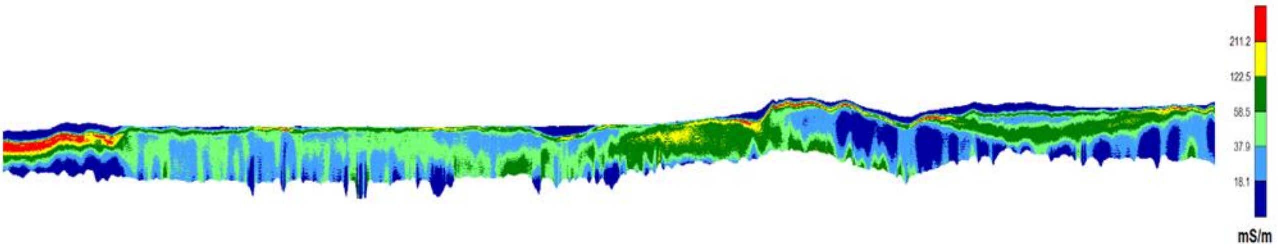

Figure 4: Conductivity depth section (EMFlow) with the colour intervals corresponding with amount of total dissolved solids in a sandy formation (providing an indication of water quality), ranging from brackish (red) to fresh (blue).

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