The use of SkyTEM geophysics in a salt water intrusion setting

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ABSTRACT

In the Pilbara region of Western Australia, a major water management scheme on the fringe of a large hypersaline lake system (the Fortescue Marsh) has been operating since 2008. The scheme supports the Cloudbreak iron ore mining operations, and has the Indigenous name of Papa Warringka. A key input for water management decisions on the fringes of the Fortescue Marsh is hydrogeological drilling data; however, due to the heterogeneity of the aquifer and the salt-interface, it has been a challenge to model aquifer processes using borehole data alone. To address this challenge, recently-acquired SkyTEM geophysics has been successfully employed to map saline-interface processes.

The SkyTEM survey involved flying over 1500 kilometres of line data, covering an area of 80 kilometres by 10 kilometres. SkyTEM is a helicopter-mounted, time domain electromagnetic (TDEM) system that maps subsurface conductivity and is particularly suited to hydrogeological assessments and saline-interface mapping.

This paper presents, for the first time, the recently-acquired SkyTEM data. The data are presented within the context of: the density-coupled FEFLOW modeling work to date; current mining operations; and the overarching management challenges and opportunities that the scheme presents. Within a major saline-interface scheme, the application of next-generation geophysical tools is presented as an important tool for integrating hydrogeological datasets.

INTRODUCTION

The Fortescue Marsh forms an extensive intermittent wetland in Western Australia’s arid to semi-arid Pilbara region. The marsh includes hydrologically distinct eastern and western regions, which are separated by a catchment divide between the Upper and Lower Fortescue Catchments at the Goodiadarrie Hills. The eastern portion is approximately 100 km long and 3 - 10 km wide. The Goodiadarrie Hills catchment divide represent the terminus of the upper Fortescue catchment, and produces internally-draining conditions in the Fortescue Marsh’s eastern region.

When the marsh floods after major rainfall events, a freshwater lake in the marsh’s eastern portion extends for up to 1,000 km\textsuperscript{2} and supports rare fauna and flora, including large populations of waterbirds. The marsh is nationally significant (it is listed in the Directory of Important Wetlands in Australia) and has a long history of Aboriginal occupation (with numerous ethno-archaeological sites). Due to the low average rainfall (260 mm/year), high
evaporation (in excess of 3000 mm/year) and internal drainage, the marsh is usually dry for most of the year, with extensive salt deposition and hypersaline aquifers.

The Chichester Range lies immediately north of the Fortescue Marsh and is host to numerous iron ore mines and mining projects, including Fortescue Metals Group Ltd.’s (Fortescue’s) Cloudbreak mining operations. The Cloudbreak deposit extends over about 40 kilometres strike length, lies from between 3 to 5 kilometres from the marsh boundary, and has about 90 percent of its resource below water table (up to about 50 metres below water table). The ore host unit (mineralised Marra Mamba Formation) is a variable but transmissive aquifer, with ore typically existing within a lens of fresh-to-brackish groundwater that are underlain by (and sometimes linked to) the Fortescue Marsh’s hypersaline (over 80,000 mg/L) aquifers.

Large-scale pit dewatering (tens of giga litres per year) is required to facilitate mining operations, and a Managed Aquifer Recharge (MAR) scheme is employed to preserve the finite fresh-to-brackish groundwater resource for environmental management and future ore processing needs. Furthermore, dewatering abstraction has the potential to induce salt water intrusion, so abstraction and injection is calibrated to transient water-quality conditions.

The operation of the water management scheme is informed by hydrogeological data, and to date, this requirement has been met by an extensive drilling program, including over 200 production and injection bores and 150 multi-level monitoring bores. Furthermore, a groundwater model, using density-coupled finite element FEFLOW modeling code, is utilised to assess and predict dewatering and injection responses. But given the aquifer heterogeneity and the extent of the aquifer systems, an additional methodology was required to help characterise the salt-interface setting and to guide abstraction and injection management. The SkyTEM survey was undertaken to meet this aim.

**METHOD**

The SkyTEM survey involved flying over 1500 line kilometres of data, covering an area of about 80 kilometres by 10 kilometres. SkyTEM is a helicopter-mounted, time domain electromagnetic (TDEM) system, where a dual TDEM moment, 24 metre wide (311 m²) electromagnetic loop was towed at a nominal 30 metre terrain height along regularly-spaced grid lines. Its depths of investigation (ranging from <10 metres to ~250 metres) make it particularly suited to hydrogeological assessments and saline-interface mapping. The SkyTEM survey was conducted by Geoforce Pty Ltd over an eight-day field program. Data coverage extended from the marsh boundary to the northern limit of saturated ore, and also included the Christmas Creek deposit to the east of Cloudbreak.

Data-inversion was carried out using the Laterally-Constrained Inversion (LCI) method developed at the University of Aarhus. The LCI inversion technique is a relatively new inversion methodology whereby field data are filtered then modeled against a subsurface layer structure that is constrained laterally on a number of chosen model parameters (including layer conductivity and layer thickness).

Geophysical data are integrated with hydrogeological datasets using several data visualisation and presentation methodologies. Data are variously: compared with hydrogeological drilling data in cross section; assessed in plan-view via plane-intersection outputs from 3D gridded datasets; and viewed using 3D visualisation software as isosurfaces of defined conductivity.
RESULTS AND DISCUSSION

A subset of the SkyTEM survey results are presented in Figure 1 (cross section) and Figure 2 (plan view).

SkyTEM data have:

- Helped map the position of the salt interface, in three dimensions, over the Cloudbreak (and Christmas Creek) deposits’ strike length.
- Highlighted the heterogeneity of the salt interface, with saline zones often aligned with structural lineaments and other preferential flow systems.
- Highlighted surface drainage and brackish groundwater processes via inverse conductivity (resistivity) data.
- Identified saline zones that are disconnected from principle flow mechanisms (‘fossil’ groundwater).
- Demonstrated that the extremely high electrical conductivity of saline aquifer zones at Cloudbreak is such that saline strata may mask the responses from deeper hydrogeological units.
- Presented opportunities to assess transient saline-interface changes (such as potential saline upconing due to aquifer depressurisation).
CONCLUSIONS

Water management solutions at the Cloudbreak mine are informed by ongoing hydrogeological assessments. One important new methodology is the SkyTEM system, which has successfully mapped the Cloudbreak saline interface region. The SkyTEM data will continue to be utilised to enhance hydrogeological interpretations and water management decision making at Cloudbreak.

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