Frontier groundwater investigations in the west Kimberley (Fitzroy) Region: preliminary assessment of groundwater resource potential and the salinity hazard to proposed irrigation developments

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SUMMARY

A regional reconnaissance AEM survey in the west Kimberley region (lower Fitzroy River valley and May-Meda Catchments) has successfully mapped the extent of regional Canning Basin aquifers (e.g. Pool Sandstone, Grant Group and Erskine Sandstone) confirming these as significant potential groundwater resources. The survey has successfully mapped a multi-layered hydrostratigraphy to depths of ~400m (in resistive areas), also revealing significant tectonics manifested as large scale basin-scale tilting of stratigraphy and more localised folding and faulting.

The survey also mapped other key objectives including: the seawater intrusion (SWI) interface for the lower Fitzroy River valley and the May and Meda River Catchments; river flush zones along the Fitzroy, May and Meda Rivers; groundwater salinity variations and potential salt stores in the shallow alluvium of these rivers and proposed irrigation areas. River-parallel surveys also identified reaches of the May and Meda Rivers with direct contact between the rivers and underlying regional aquifers of the Pool Sandstone and Grant Group. These reaches are areas of potential recharge, and/or groundwater discharge, with the AEM used to target hydrochemical investigations, drilling and aquifer testing. The AEM data reveal more complex relationships between perennial in-stream pools along the Fitzroy River, underlying aquifers, tectonics, and river alluvium.

AEM survey design incorporated time series analysis of surface water availability through time (Water Observations from Space (WOfS)) derived using the Australian Geoscience Data Cube (AGDC). This has facilitated investigations of surface-groundwater interaction through ensuring the AEM transects coincide with permanent water holes and river reaches considered to be potentially sustained by groundwater discharge. The AEM data provide a framework for hydrogeological process understanding, while the knowledge generated in this project will inform water resource allocation planning, help assess risks to culturally and environmentally sensitive riverine ecosystems, and de-risk investment in agriculture and water infrastructure more broadly.

Key words: Airborne Electromagnetics (AEM); SkyTEM; Groundwater; Fitzroy, May and Meda Rivers.

INTRODUCTION

Previously, the Northern Australia Sustainable Yields (NASY) project found there was insufficient historical groundwater monitoring data and groundwater data to make quantitative estimates of groundwater development potential in the Fitzroy River Catchment (CSIRO 2009). However, a more recent review of the groundwater systems found that the regional Canning Basin aquifers offer the potential for large scale groundwater development in the lower Fitzroy River valley (Harrington and Harrington, 2015). The combined Poole Sandstone and Grant Group aquifers, Erskine Sandstone and Devonian limestones, are seen as prospective resources, with existing borehole data indicating that the groundwater in these aquifers is of low-moderate salinity, with bore yields potentially suitable for sustaining large-scale developments (Harrington and Harrington, 2015). This contrasts with more complex shallow alluvial aquifers associated with the Fitzroy River which appear to be vulnerable to seasonal climate fluctuations and more connected to groundwater-dependent assets of ecological and cultural significance (Lindsay and Commander, 2005; CSIRO, 2009; Fitzpatrick et al., 2011; Harrington et al., 2013).

In 2010, a small (274 line kilometres) AEM reconnaissance survey was conducted in the lower Fitzroy River valley to provide initial insights into the extent of Fitzroy River alluvium, salt stores, river flush zones, and improve knowledge of the deeper geological structure (Fitzpatrick et al., 2011). The results helped conceptualise hydrogeological models for the Fitzroy River (Harrington et al. 2011). Integration of AEM and hydrochemical investigations found that the persistence of in-stream pools along the Fitzroy River is controlled almost entirely by groundwater discharge, with the spatial and temporal variability and mechanisms of discharge of both saline and fresh groundwater to the river found to be quite complex (Harrington et al., 2013). One conclusion from these studies is that there is insufficient knowledge of the potential ecological response to altered hydrological regimes including surface water levels and flows, as well as groundwater levels and fluxes (Harrington & Harrington, 2015).

Following the initial success of the earlier AEM survey, the Western Australian Government's Water for Food Program commissioned Geoscience Australia in the second half of 2015 to acquire a larger AEM survey to map the extent of regional groundwater resources in 6 sub-regions of the lower Fitzroy River, May and Meda River Catchments (Figure 1). In total, ~5000 line kilometres were flown in an area ranging from Derby in the north-west, along the May and Meda rivers in the north, to around Fitzroy crossing in the south-east and along the Fitzroy river in the south of the survey area (Figure 1). This paper reports on the initial interpretation of AEM survey results.

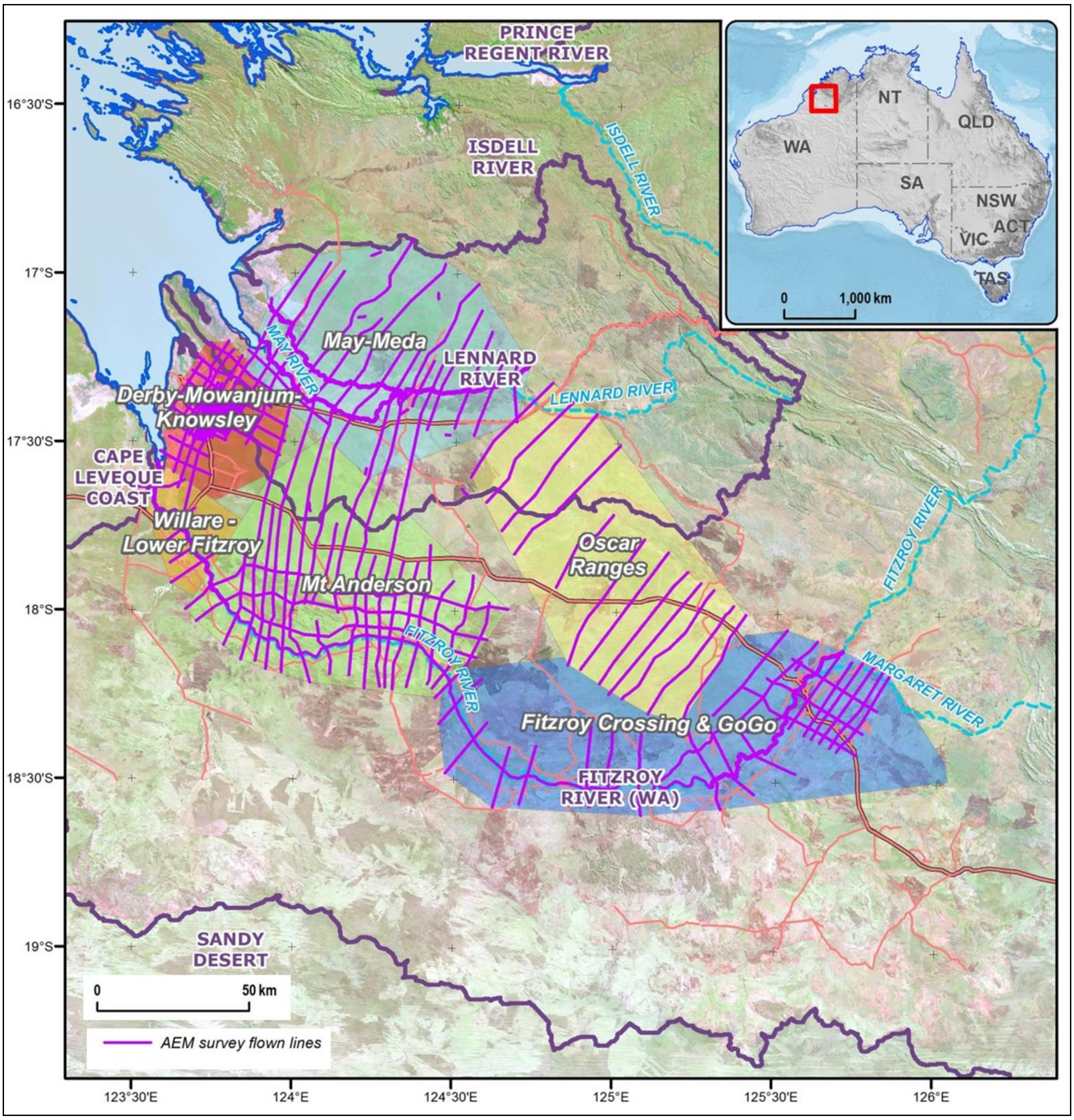

Figure 1. Map showing the AEM transects acquired using the SkyTEM312 AEM system during September-October 2015. The map also shows the 6 project sub-areas. Denser survey line spacing was acquired in areas of proposed irrigation development at Derby-Mowanjum-Knowsley and Fitzroy Crossing /GoGo.

METHODS AND RESULTS

The primary objectives of the AEM survey included mapping the extent of regional Canning Basin aquifers to aid assessment of groundwater resources and sustainable yield estimates for agricultural development; provide AEM data in transects to underpin studies of surface-groundwater interactions (groundwater discharge and recharge potential) associated with the major rivers, and permanent river pools in particular; detect and assess potential groundwater salinity hazards within proposed irrigation areas; and map the SWI interface. Very specific mapping objectives were developed for each sub-area, and the survey designed with these detailed local objectives in mind. AEM survey design incorporated time series analysis of surface water availability through time (Water Observations from Space (WOfS)) derived using the Australian Geoscience Data Cube (AGDC). This ensured that AEM transects coincide with permanent water holes and river reaches considered to be potentially sustained by groundwater discharge, while also taking into consideration areas of historical flood inundation.

The AEM data were acquired using the SkyTEM312 system after a rigorous technology assessment exercise. To meet a range of objectives over a relatively large area, an irregular survey design was employed that was made up of high density areas (e.g. 400 m line spacing), low density areas (up to 4 km line spacing), regional transects and lines flown along rivers (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. The gate times for the high moment were changed during the survey. 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 interpretation of the AEM data has utilised a priori drilling and published geological and hydrogeological maps, datasets and reports. Initial interpretation of AEM survey results are provided below for each sub-area. The AEM data are being used to plan a drilling program and aquifer testing in mid-2016.

Derby/Mowanjum/Knowsley sub-project area

Preliminary interpretation of the AEM data for the Derby/Mowanjum/Knowlsley sub-project area suggests that the survey has successfully mapped key elements of the hydrogeological system including the SWI interface (Figure 2), the shallow Quaternary alluvium, and a multi-layered hydrostratigraphy of the shallow Canning Basin sediments (Figure 3). In the coastal zone, the AEM data has mapped a SWI wedge as it ingresses into the Erskine Sandstone (beneath the Munkyarra Shale), with both downward leakage of saline surface water, and up-coning of saline groundwater from the SWI interface into the Wallal Sandstone implied from conductivity variability observed with increasing distance offshore (Figure 2).

The AEM data has also successfully mapped areas of low electrical conductivity interpreted as potential fresh groundwater resources within the Wallal Sandstone, Erskine Formation and Liveringa Group (Figures 2, 3). The AEM data appear to map the base of the Wallal Fm and the on-lap of the Monkyarra Shale onto basement highs (Figure 2), with the depth of investigation >300m in areas where there are more resistive sandstones in the sequence (Figure 3). The interlayering of the Walall Sandstone, Munkyarra Shale, Erskine Sandstone, Blina Shale, Liveringa Group and Noonkanbah Formation permits large-scale basement folding and faulting to be identified (Figure 3). Low electrical conductivities in the underlying Erskine Sandstone would appear to confirm the presence of relatively low salinity groundwater within an extensive aquifer (Figure 2, 3). Thin semi-continuous and discontinuous conductive layers within this formation are interpreted as clay/shale layers and/or local salinity variations. The base of this unit in places lies below the depth of investigation (>350m). The DOI in the far south of the sub-project area where there is a very resistive sequence from the surface (i.e. no intervening Munkayarra Shale, and no SWI interface).

The data also reveal localised salt stores in the shallow alluvium in the existing and proposed irrigation areas; and salt stores in the unsaturated zone. This new knowledge provides a basis for the understanding of surface-groundwater interactions and provides a foundation to inform land suitability and salinity hazard assessments for irrigation development and inform groundwater processes, and recharge estimates.

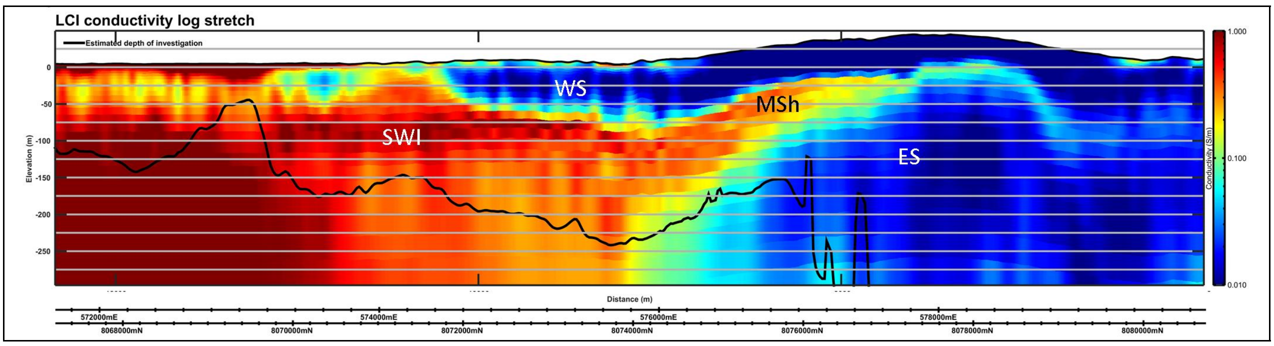

Figure 2. Conductivity depth section showing the SWI wedge, and inter-layered Wallal Sandstone, Munkyarra Shale and Erskine Sandstone.

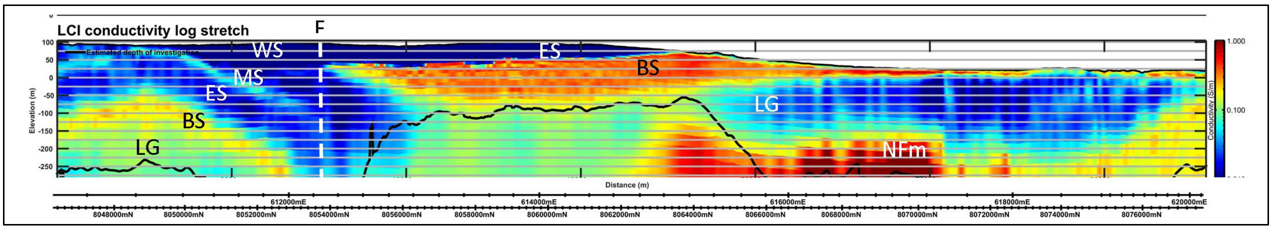

Figure 3. Conductivity depth section showing inter-layered Wallal Sandstone, Munkyarra Shale, Erskine Sandstone, Blina Shale, Liveringa Group, and Noonkanbah Formation. A significant Neogene fault is also mapped.

May & Meda Rivers sub-project area

In this sub-area, the AEM data have successfully mapped key elements of the hydrogeological system including the extent and nature of the alluvium, lithostratigraphy (e.g. sand and clay distribution); hydrostratigraphy including water quality (groundwater salinity) variability in the top 20m of the sedimentary system within the existing and proposed irrigation areas; river flush zones associated with the May and Meda rivers; the extent and nature of the alluvium; salt stores in the unsaturated zone; and zones of potential river-aquifer connectivity beneath the May and Meda Rivers (Figure 4). These data provide a basis for understanding surface-groundwater interactions, and will inform land suitability assessments for irrigation development, and recharge estimates and processes. The data also map the location and extent of the SWI interface in the May and Meda River Catchments. This interface extends further inland than the Fitzroy, probably reflecting the size and age of surface drainage, and catchment water balance.

The AEM survey has also permitted mapping of Canning Basin hydrostratigraphy to depths up to ~300m, including the Erskine Sandstone, Blina Shale, Nookanbah Formation, Liveringa Group, Poole Sandstone and Grant Group (Figure 4, 5). The AEM data shows that the basin stratigraphy is complexly folded and faulted with significant Neogene structures observed (Figure 4, 5). These structures may compartmentalise the basin hydrostratigraphy, and locally appear to control the location of lamproite pipes. The AEM data successfully maps variations in electrical conductivity within the major aquifers that are interpreted as clay/shale layers and/or variability in groundwater salinity. Overall, the AEM data appear to confirm the presence of significant potential groundwater resources within the major aquifers.

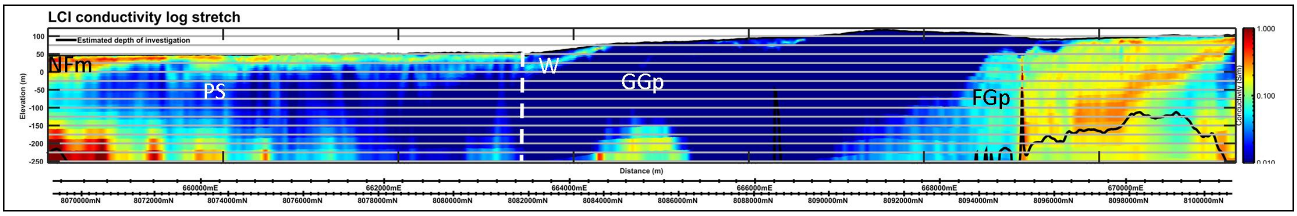

Figure 4. Conductivity depth section parallel to the May River showing the Poole Sandstone and Grant Group sandstones sub-cropping in the river bed. This reach of the river is an area of both potential recharge and groundwater discharge. The unit underlying the Grant Group is the Fairfield Group. Faulting is also evident in this section.

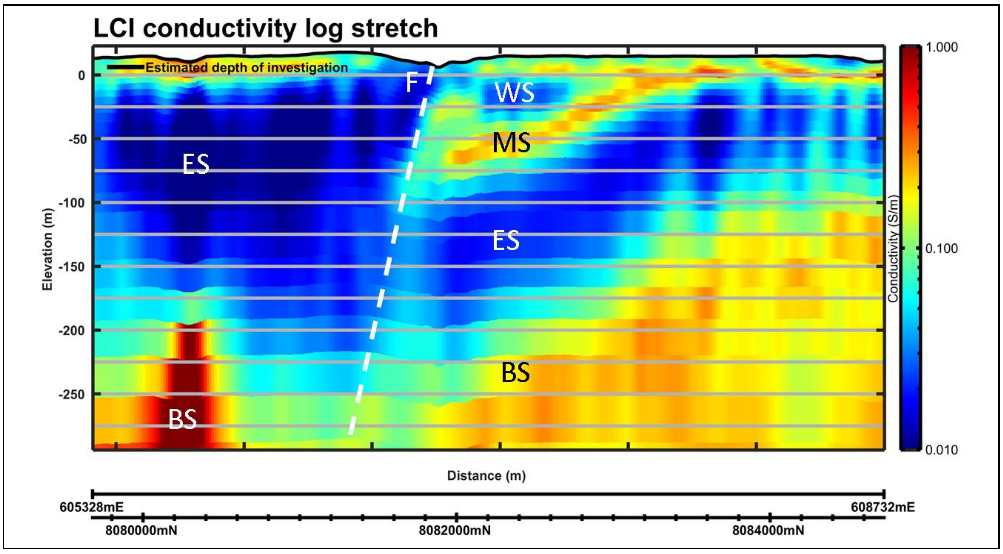

Figure 5. Conductivity depth section showing the Erskine Sandstone and Blina Shale in the hanging wall of a reverse (and/or strike-slip) fault (left hand side), with inter-layered Wallal Sandstone, Munkyarra Shale, Erskine Sandstone and Blina Shale on the down-thrown block (right hand side).

Fitzroy Crossing & GoGo sub-project area

In this sub-area the AEM successfully maps the a relatively thick alluvium associated with the Fitzroy River (~40m) with local scale variations thought to reflect variations in groundwater salinity within the top 30m of the sedimentary system within the proposed irrigation area. The AEM data also maps river flush zones associated with the Fitzroy River and associated channels, and has identified zones of potential river-aquifer connectivity beneath the Fitzroy River and associated channels, as well as significant salt stores in the unsaturated zone within the alluvium. Integration of temporal Landsat (Water Observations from Space (WOfS) that maps perennial surface water pools, with the AEM data, helps explain surface pool persistence by mapping surface-groundwater connectivity. These data provide an important hydrogeological framework to understand surface-groundwater interactions, and connectivity of groundwater systems with perennial river pools in particular. The data on salt stores and saline groundwater distribution will assist land suitability assessments for local irrigation development at GoGo station.

The AEM data also successfully mapped key elements of the regional basin hydrostratigraphy (Figure 6). This includes the distribution of key Canning Basin aquifers and their surface and near-surface distribution (e.g. Poole Sandstone & Grant Group; the Nookanbah Formation and Fairfield Group; and Liveringa Group). The AEM data have revealed that the area is complexly deformed, with basin aquifers folded and faulted (and potentially compartmentalised). Follow-up investigations are required to ascertain if these faults localise surface-groundwater interactions and/or inter-aquifer leakage and connection between the shallow alluvium and deeper aquifer systems. Neogene faults are also observed to localise lamproite pipes (Figure 6). The AEM survey confirms that the main aquifers are predominantly electrically resistive, potentially indicating the presence of fresh groundwater.

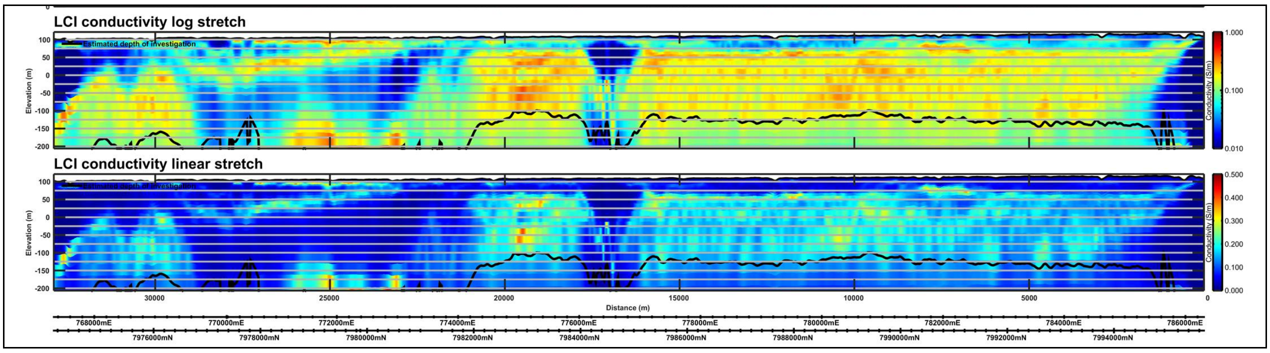

Figure 6. Conductivity depth section near Fitzroy Crossing. The image shows the Grant Group and Pool Sandstone aquifers on the left of the image. In the centre of the image, there is an intrusive feature (lamproite/diatreme) that has punched through regional shales and siltstones of the Fairfield Group.

Willare/Lower Fitzroy sub-project area

The AEM survey has successfully mapped a thin alluvial sequence (<30m) along this reach of the Fitzroy River. The data also reveal small flush zones associated with the main river and smaller associated channels. The data also reveal a relatively simple SWI interface at the Fitzroy River mouth. Perhaps the most significant feature evident in the AEM data is a major fault of regional significance that locally controls the location of the Fitzroy River (Figure 7). This fault has a significant vertical displacement (>500m?), and juxtaposes the Liveringa Group with an aquifer thought to be the Broome Sandstone. The sharp contact along the fault between saline Noonkanbah Formation and Broome Sandstone suggests this fault may locally be a barrier to lateral groundwater flow (Figure 7). Elsewhere in this sub-area, the AEM data map the Erskine Sandstone, while overall there would appear to be a potentially larger volume of fresh groundwater in aquifers than previously thought.

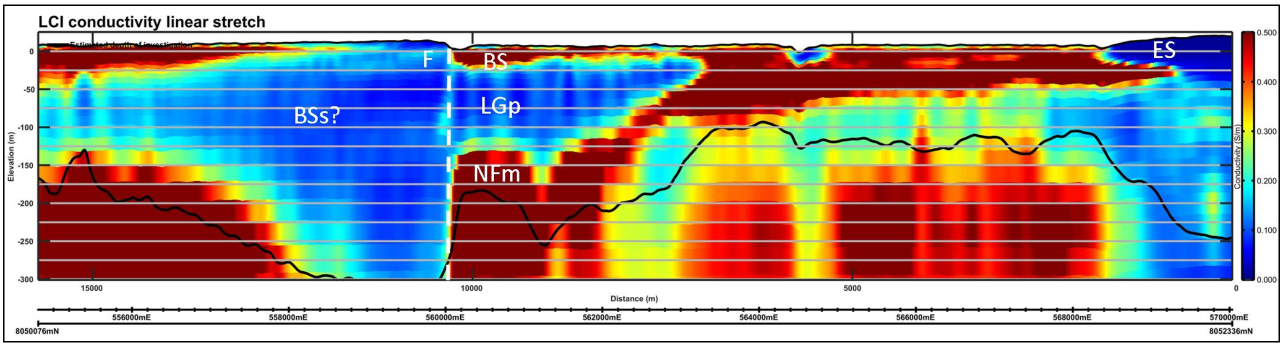

Figure 7. Conductivity depth section at a high angle to the Fitzroy River, near the river mouth. The image shows a significant Neogene fault that separates inter-layered Blina Shale, Liveringa Group and Noonkanbah Formation on the right hand side of the fault, from what is presumed to be Broome Sandstone on the left of the fault. The sharp contact along the fault between saline Noonkanbah Formation and Broome Sandstone suggests this fault may locally be a barrier to lateral groundwater flow.

Oscar Ranges sub-project area

The AEM data in this area reveals the geometry, extent and thickness of the Poole Sandstone and the Grant Group aquifers, and also maps the underlying Devonian sediments and overlying Noonkambah Formation (Figure 8). The AEM data also reveal shale layers within the Grant Group and Poole Sandstone that act as marker horizons to reveal intra-formational faulting and folding that might compartmentalise the groundwater system and influence inter-aquifer leakage (Figure 8). The data identify areas of potential recharge. The data also permit the geometry, extent and thickness of the Liveringa Group and Nookanbah Formation to be mapped.

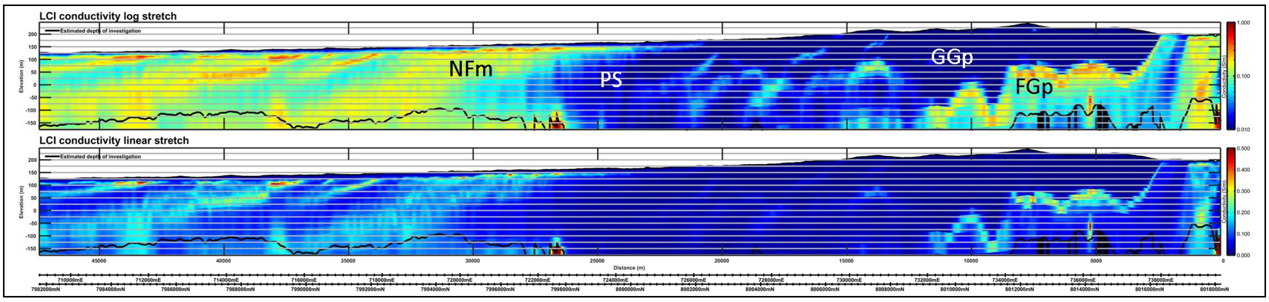

Figure 8. Conductivity depth section across the Oscar Ranges, showing the Poole Sandstone and Grant Group sandstones between the underlying Fairfield Group and overlying Noonkanbah Formation. Significant folding and faulting of the hydrostratigraphy is evident in this section.

Mt Anderson sub-project area

In this area, the AEM data have revealed a complexly deformed inter-layered hydrostratigraphy (Figure 9). The Grant Group and Poole Sandstone aquifers occur within the core of a major anticline, with a significant regional fault observed to offset the hydrostratigraphy (Figure 9). This fault appears to act as a barrier, at least locally, to lateral groundwater flow. There appears to be little connectivity between the river, alluvium and underlying Poole Formation and Grant Group aquifers. The AEM data reveals that the alluvial sequence in the Fitzroy River is relatively thin.

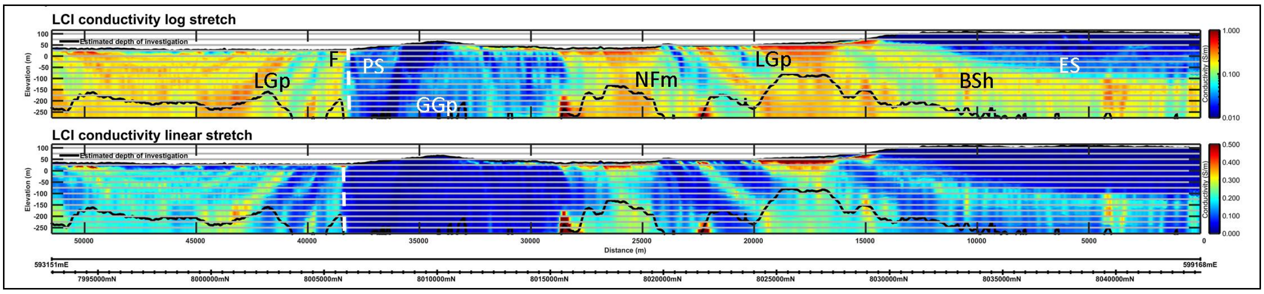

Figure 9. Conductivity depth section in the Mt Anderson area. This section reveals a complexly folded and faulted inter-layered hydrostratigraphy with the Poole Sandstone and Grant Group sandstones at the core of a regional anticline.

CONCLUSIONS

Preliminary interpretation of the Fitzroy-May-Meda AEM survey has successfully mapped the extent of regional Canning Basin aquifers (Figure 10), confirming these as significant potential groundwater resources. The survey also mapped other key objectives including: the seawater intrusion (SWI) interface for the Fitzroy River Basin and the May and Meda River Catchments; river flush zones along the Fitzroy, May and Meda Rivers; and potential salt stores in the shallow alluvium of these rivers and proposed irrigation areas. River-parallel surveys also identified reaches of the May and Meda Rivers where there appears to be direct contact between the rivers and underlying regional aquifers of the Pool Sandstone and Grant Group. These reaches are areas of potential aquifer recharge, and/or groundwater discharge, with the AEM mapping being used to target hydrochemical investigations. The AEM data reveal more complex relationships between perennial in-stream pools along the Fitzroy River, underlying aquifers, tectonics, and river alluvium. The AEM has been used to identify a number of groundwater targets, to be drilled in mid-2016.

Use of the Australian Geoscience Data Cube (AGDC) has facilitated survey design and the acquisition of AEM transects to coincide with permanent water holes and river reaches considered to be potentially sustained by groundwater discharge will aid surface-groundwater investigations. The AEM data provide a framework for hydrogeological process understanding, inform water resource allocation planning, help assess risks to culturally and environmentally sensitive riverine ecosystems, and de-risk investment in agriculture and water infrastructure more broadly.

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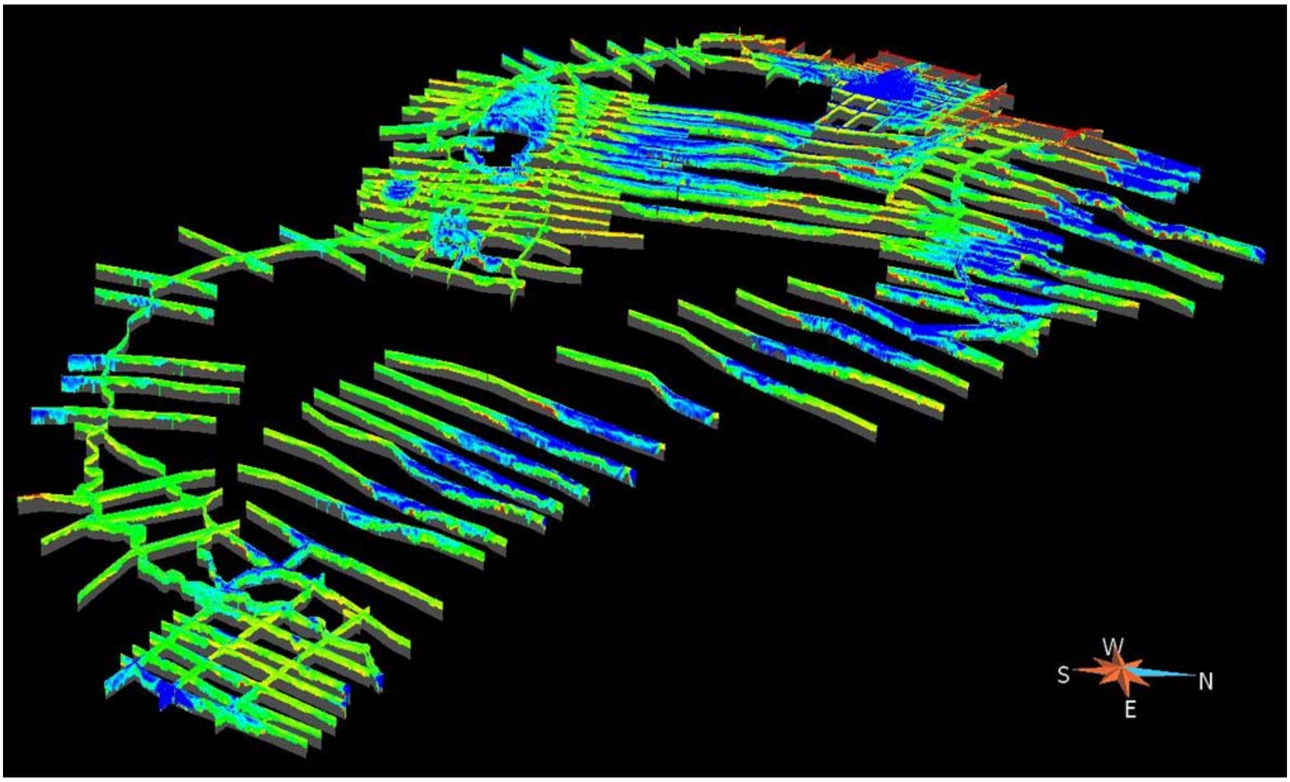

Figure 10. Google Earth image showing the 3D distribution of electrical conductivity across the Fitzroy-May-Meda AEM survey area. The oblique image is taken from the ESE. The significant groundwater resources are indicated in blue, with the SWI mapped in red in the coastal zone.

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