THE POTENTIAL OF GEOPHYSICS TO MAP SALT WATER INTRUSION IN THE BURDEKIN DELTA

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INTRODUCTION

The economic significance and environmental sensitivity of the Burdekin Delta have made it the subject of ongoing research by many agencies. A recent CRC LEME investigation (Lawrie *et al.* 2004) carried out geophysical logging of 73 key bore holes and a literature review of the Cainozoic stratigraphy within the Delta. This paper reports on the geophysical component of that study with particular reference to the use of electrical geophysical methods to map the distribution of saline water intrusion. Geophysical logging was carried out on 73 selected key boreholes within the Lower Burdekin Delta study area focusing on nested piezometers, including those within the known area of salt water intrusion. Conductivity (electromagnetic induction) and natural gamma radiometric logging techniques were used. In addition, a standing water level reading was collected at the time of measurement. Additional single boreholes were selected for logging to provide a good spatial and depth coverage across the Delta.

PREVIOUS WORK

Previous geophysical investigations across the Burdekin Delta have been limited, with the most detailed work to date carried out by Wiebenga *et al.* (1975). In this study, ground resistivity surveys were conducted in order to delineate the zone of saltwater intrusion. This method effectively mapped the distribution of saline water with depth, although spatial coverage was limited to the number of ground traverses. Recently a high resolution Digital Elevation Model (DEM) was derived from an airborne laser scanning survey undertaken for the Burdekin Shire Council over the Delta. The DEM has a 10 metre lateral resolution and sub-metre vertical resolution.

Regional aeromagnetic coverage across the area consists of 400 m to 1500 m line-spaced data. The Delta itself appears as a magnetic low. Magnetic highs surrounding this low indicate both shallow and outcropping bedrock (magnetic basement). East-west structural trends are visible in the lower half of the image and are enhanced by the increased resolution in data in this sector.

Airborne radiometric coverage is confined to the lower half of the Burdekin Delta as 400 m line-spaced data. The Delta sediments display a near-white radiometric signature in ternary images, reflecting an even mixing of radioelements. In contrast, the shallow/outcropping bedrock displays predominantly red and greenish components, reflecting high potassium and thorium sources.

METHODS

Methods employed in this study included down-hole gamma (Chopra *et al.* 2002) and conductivity (Hallenberg 1984, Lane 2002). AUSLOG geophysical tools were used for logging. Tool models and serial numbers are listed below in Table 1.

Laboratory calibration of the gamma tool and conductivity tools were conducted at AUSLOG's office in Brisbane, prior to the tools being shipped to the study area. The gamma tool was calibrated to API standard values using two gamma radiation sources. The conductivity tool was placed in a Faraday cage to reduce external electrical interference and calibrated using a zero free-air measurement and 1000 mS/m calibration disc. Both logging tools were expected to stay calibrated for periods between 1 to 3 months, amply covering the survey period.

Table 1: Geophysical logging tools used in the Burdekin study.

Tool	Model Number	Serial Number
Natural gamma	A031	A538
Conductivity	A038	A973

No in-field calibration checks were performed for the gamma tool for OH&S reasons. Field verification of the calibration was performed by collecting time-based measurements in the field using calibration discs (100 mS/m and 300 mS/m). This did not alter the calibration constants of the digital logging system, but was completed to verify that the tool was properly calibrated. In addition, free-air measurements were collected prior to and following the logging of each borehole. Unfortunately, due to the presence of electric powerline interference, deviations of up to 100 mS/m were observed in these measurements. To ensure that the geophysical tools were operating correctly and did not show significant instrumental drift, a single borehole (RN 119110257) was chosen for repeat readings collected over the duration of the field acquisition. The conductivity log showed good repeatability, with a maximum difference of up to 10 mS/m between repeated logs (Figure 1).

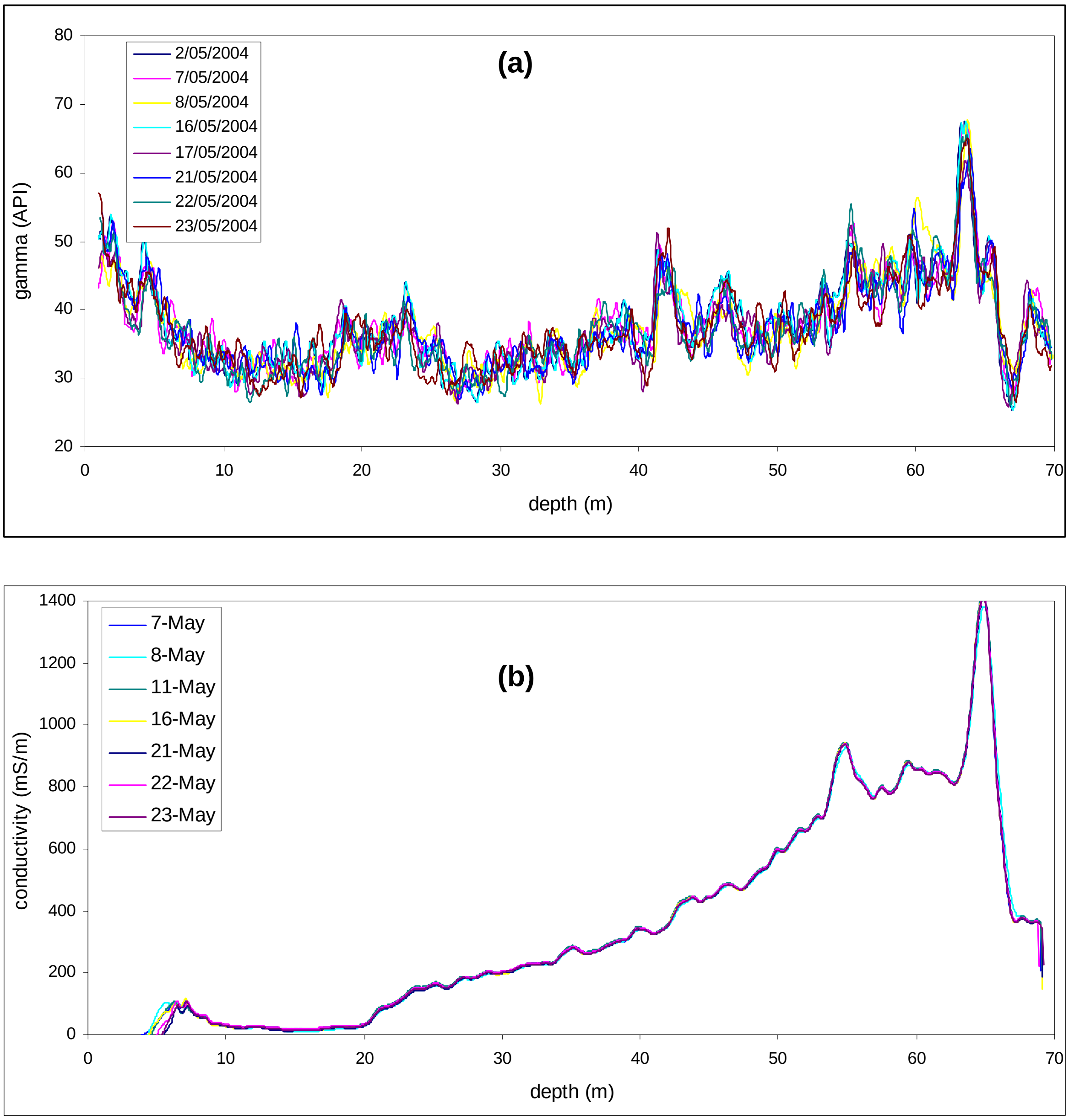

Figure 1: (a) Gamma logging for repeat measurements at "base station" borehole 119110257. **(b)** Conductivity logging for repeat measurements at "base station" borehole 119110257.

Down-hole logging was completed at 12-15 m/min and up-hole logging at 6 m/min. Both logs were simultaneously plotted to ensure repeatability, and the up-hole logs were kept as the final measurement for each borehole. Up-hole logging is the preferred method, as the tool is less likely to get caught on the way up. The holes logged in this study are shown in Figure 2.

RESULTS - STRATIGRAPHY

Geophysical logs were plotted against lithological logs provided by NRM&E. Two holes were also logged by CRC LEME to validate the NR&E geological desciptions. In general, gamma measurements mapped strong contrasts between sand and clay units in the upper part of the sequence. In deeper holes, the correlation is poor, possibly due to weathering effects. Conductivity logs appear to be strongly influenced by groundwater salinity and secondarily by clay content. In areas of relatively fresh groundwater, anomalous readings are associated with clay bands. However in areas of significant saline water, higher conductivity is found in sand (aquifer) bands and relatively less in clay bands.

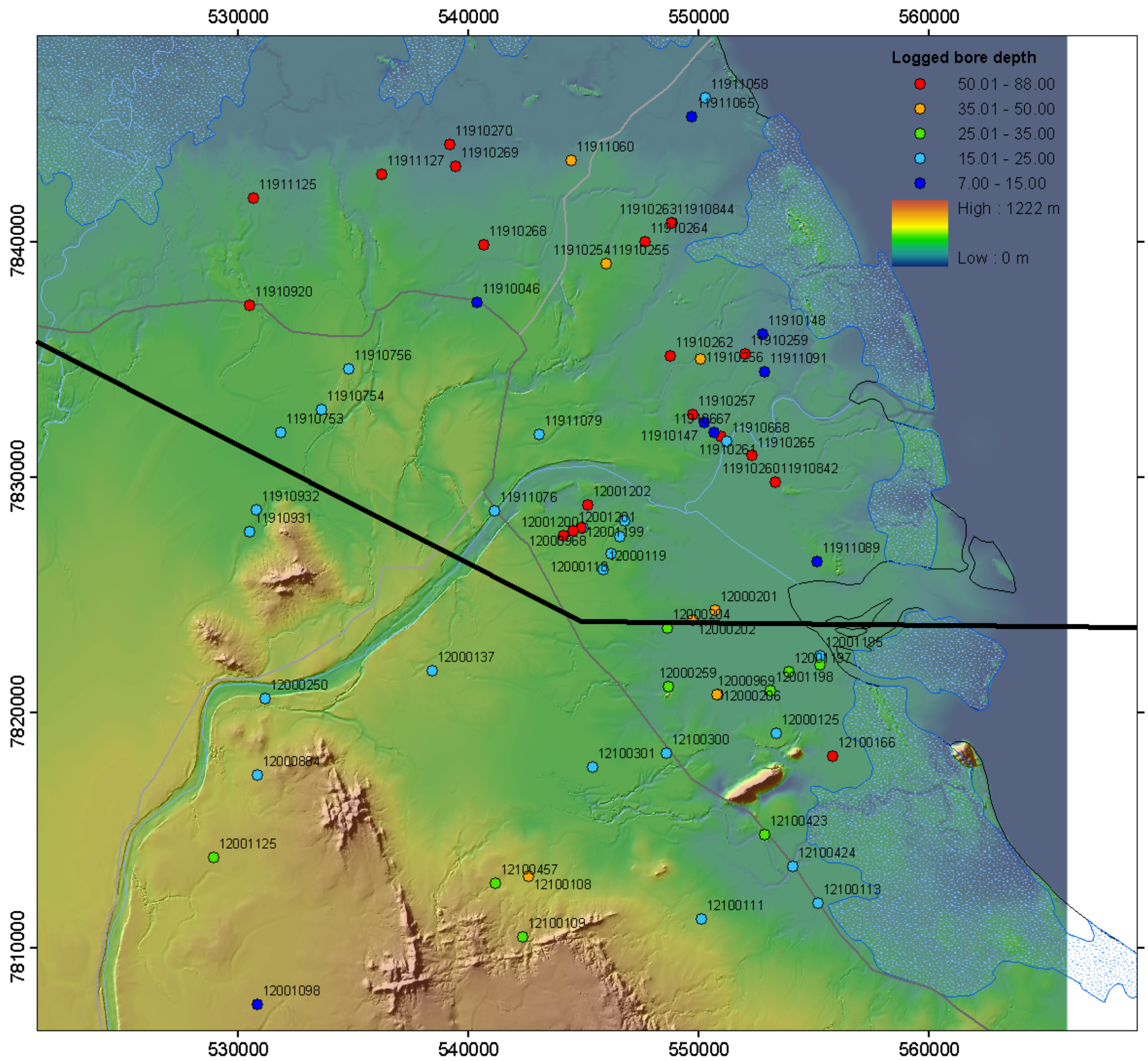

Figure 2: DEM over the Burdekin Delta, 10 m pixel resolution, submetre vertical resolution (from NR&E). Location of geophysically logged boreholes colour-coded by depth.

Trial geophysical logging has shown excellent correlation between the logged materials and the geophysical signatures. In particular, the base of Holocene, the palaeosol clays at the top of the Pleistocene and the sediment-bedrock interface show a particularly good correlation and can be recognised in every hole where present. The relationship between the gamma logs and older sediments is more problematic with variable degrees of correlation. In general, the deeper part of the deltaic succession shows poorer correlation than the shallower part. In particular, the correlation appears to break down where there is a conductive bulge in the conductivity logs, interpreted as reflecting the presence of saline water. In the main conductive bulges, clay units appear as more resistive units.

The poor correlation in the lower parts of the holes is assumed to be due to the variable diagenesis and weathering of feldspars and micas, with a possible overprint of infiltrated or flocculated clays. The cause for this diagenesis may reflect the presence of saline groundwater, or is simply related to weathering associated with buried land surfaces. These factors can only be clarified by detailed analysis of the mineralogy and petrography of the samples, including examination of thin-sections from cores, and more detailed geophysical logging using active tools. The GILMORE study of the relationship between primary and secondary mineralogy, sedimentology, diagenesis and gamma logs (Tan *et al.* 2002) is a prime example of the type of investigation needed to clarify the relationship between diagenitic history and mineralogy. The more resistive nature of clay units within the conductive bulge was interpreted to be the result of less saline connate waters locked within the higher porosity but lower permeability clays.

Figure 3 shows an integrated log of one bore hole was that re-logged by CRC LEME. It shows the close relationship between grainsize and the gamma curve and the presence of a conductivity bulge at depth interpreted to indicate the presence of saline water.

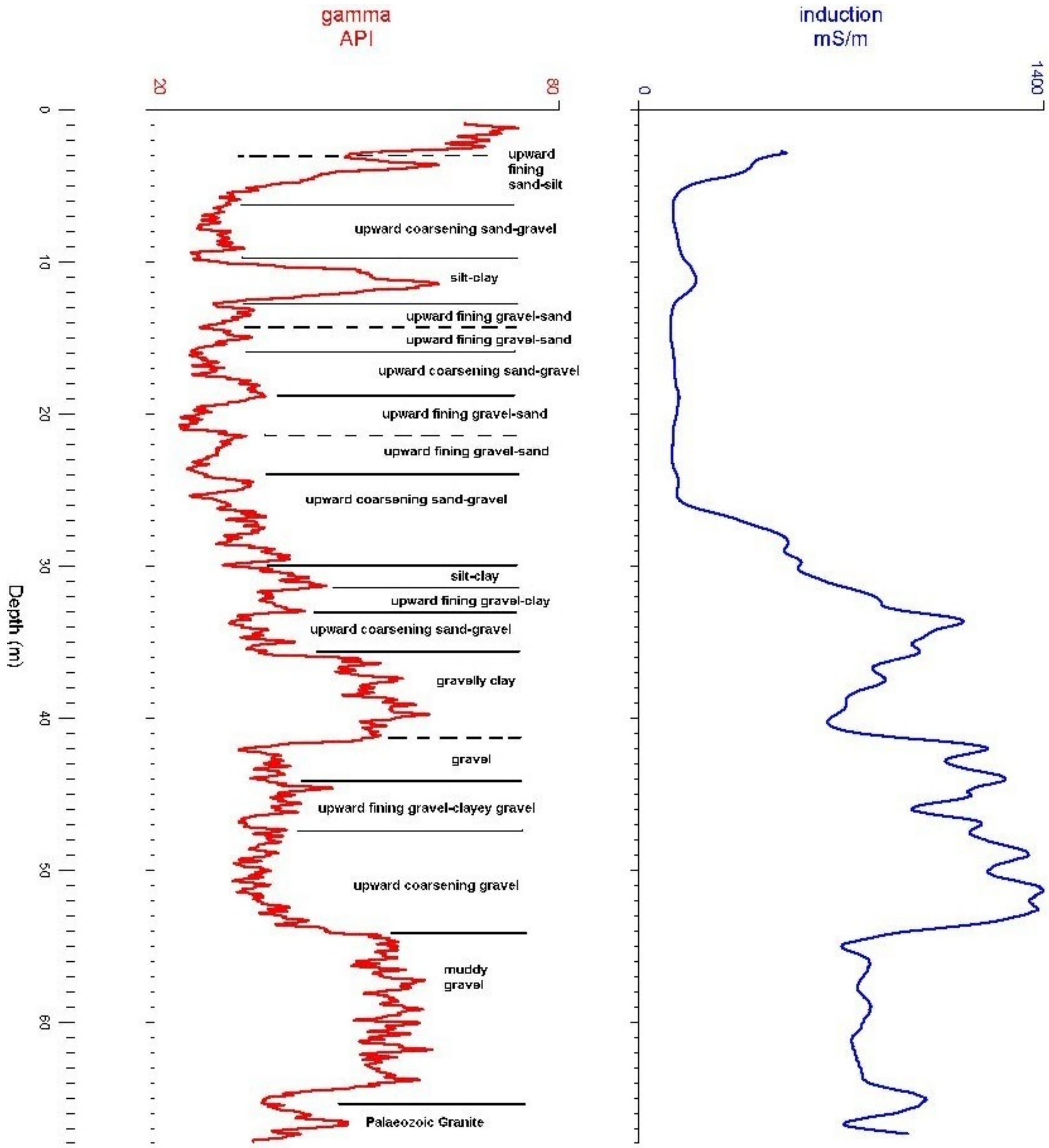

Figure 3: Integrated geophysical and geological log of RN 11911125. Conductivity bulge at depths > 30 m is interpreted to be due to the presence of saline groundwater.

RESULTS - GROUNDWATER CONDUCTIVITY

Electrical conductivity pore fluid measurements were completed by NR&E during March 2004 for all monitoring bores within the Delta. The average borehole conductivity was calculated over the slotted interval of the piezometer for all borehole measurements in order to directly compare with groundwater EC measurements. A cross-plot between pore-fluid ECs and the geophysical conductivity logging is shown in Figure 4 (**a**- linear space, **b**- logarithmic space) for all logged boreholes. A good correlation is observed between electrical conductivity and pore fluid EC measurements (R^2 ca. 0.69). Scatter in the data, evident in both plots, is likely a function of varying clay content.

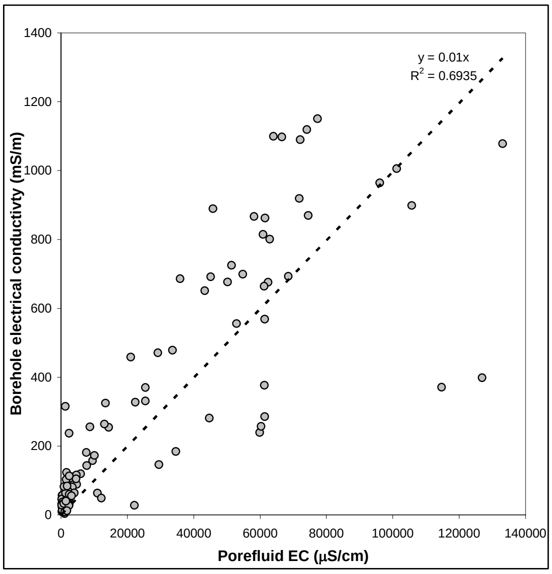

Figure 4a: Average conductivity log versus pore fluid EC for all boreholes.

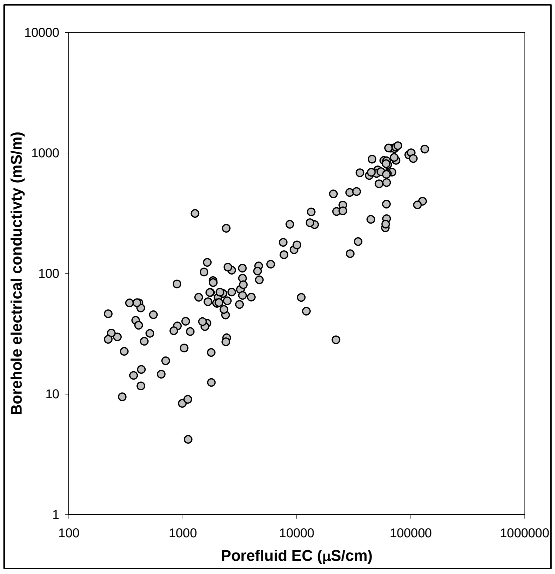

Figure 4b: Average conductivity log versus pore fluid EC for all boreholes (logarithmic).

CONCLUSIONS

This study determined the conductivity structure of Cainozoic sediments within the Lower Burdekin Delta area. This was achieved largely though geophysical logging of key boreholes from selected nested piezometers, as available historic data was very sparse. Techniques used include induction (conductivity) and gamma radiometric logging. The study showed that areas of salt water intrusion and many aspects of the sedimentary architecture could be determined from such logs. The data also provides a basis for determining the scale of any future air or ground geophysical program using electrical methods.

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