The application of airborne geophysical data as a means of better understanding the efficacy of disposal basins along the Murray River: An example from Stockyard Plains, South Australia

Andrew Fitzpatrick
CSIRO
PO Box 1130, Bentley WA
Andrew.Fitzpatrick@csiro.au

Tim Munday
CSIRO
PO Box 1130, Bentley WA
Tim.Munday@csiro.au

SUMMARY

The pumping and disposal of saline groundwater from the margins of the River Murray in South Australia is an integral part of the State Government's salinity management strategy. It is specifically aimed at reducing ground water levels and salt accession to the River Murray. Large volumes of saline water are typically disposed at the land surface in what are referred to as "saline-disposal basins". Although these disposal basins are now common, surprisingly little is known about their long-term efficacy or environmental effects. This study focuses on the analysis and interpretation of RESOLVE frequency domain helicopter electromagnetic data acquired over the Stockyard Plains saline-water disposal basins located southwest of Waikerie, South Australia, with a view to determining the extent of saline plume migration and informing our current understanding of the hydrodynamics of saline groundwater disposal in the area. The airborne EM data was calibrated using conductivity borehole data and statistical methods prior to modelling. Two sets of conductivity models were generated using smooth layered inversion and constrained layered earth inversion. The constrained inversion model provided information on the depth, thickness and presence or absence of aquitards, specifically the Blanchetown Clay, and map variations in groundwater conductivity in the region around the existing natural disposal basins. The smoothed inversion model defined the extent and condition of the groundwater mound beneath the existing disposal basin. In addition these data can be used to investigate the potential for extending disposal options in the vicinity of the existing basin by identifying areas where aquitards (the Blanchetown Clay) are present or absent.

Key words: airborne electromagnetics, disposal basin, constrained inversion, clay mapping.

INTRODUCTION

The pumping and disposal of saline groundwater from the margins of the River Murray in South Australia is an integral part of the Sate Government's salinity management strategy. It is specifically aimed at reducing ground water levels and salt accession to the River Murray. Large volumes of saline water are typically disposed at the land surface in what are referred to as "saline-disposal basins". Although these disposal basins are now common, surprisingly little is known about their long-term efficacy or environmental effects. Issues of concern include salt leakage into underlying aquifers and ultimately into the river. Density gradients which often exist between disposal basins and regional groundwater systems can significantly alter the hydrodynamics beneath basins and further increase the salinity of deeper aquifers. Processes of convection may cause brines to mix over distances several orders of magnitude greater than by diffusion alone, with consequences for solute transfer to deeper aquifers. The effective management of extant basins and their potential for expansion requires a better understanding of these processes, supported by site specific field observations.

The Stockyard Plains Airborne Electromagnetics (AEM) Project was initiated by the South Australian Governments Department of Water, Land and Biodiversity Conservation, and focuses on the acquisition, analysis and interpretation of airborne (AEM) geophysical data acquired over the Stockyard Plains natural saline-water disposal basins located southwest of Waikerie, South Australia. The projects' intent has been to determine the extent of saline plume migration around the extant basin at Stockyard, and to inform our current understanding of the hydrodynamics of saline groundwater disposal in the area. It also aims to determine the potential for extending disposal options in the vicinity of the existing basin by identifying areas where aquitards (the Blanchetown Clay) are present or absent.

Airborne geophysics, particularly airborne EM, has significant, though unrealised potential to inform our understanding of disposal basin hydrodynamics, as has been suggested at limited local scale by ground geophysics (Barrett et al., 2002; Hatch et al., 2002). This project will, for the first time, provide valuable insight into the scale and magnitude of processes operating around a disposal basin as well as contributing practical information to inform the development of appropriate disposal basin strategies along the Murray River.

METHOD AND RESULTS

The Stockyards Helicopter EM survey was conducted over an area that covers the existing Stockyard Plains Disposal Basin, located to the ~15km south west of Waikerie, in the South Australian Riverland, and incorporates areas to the south and west (Figure 1). The Stockyard survey was undertaken with the RESOLVE Frequency Domain helicopter EM (FDHEM) system (Figure 2). The landscape of the survey area is similar to that shown in Figure 3

The RESOLVE FDHEM system has been successfully deployed to help understand landscape characteristics along the Murray River of South Australia, with a demonstrated ability to define very near surface conductivity structure (<5m), and in particular the thickness of the Blanchetown Clay unit in these environments (e.g. Brodie et al., 2004b). The survey was flown with a 200 m line spacing, with parallel flight lines orientated in a North-South direction. Tie lines were flown every 2 kms orientated in a East-West direction. During surveying, the bird is flown ~30 m above the land surface. Using six different frequency-coil-pair combinations, the electromagnetic response is measured as a function of frequency. Data are acquired about every 3 - 5m along flight lines. For the Stockyard Plains survey, the RESOLVE bird was also fitted with a boom, mounted perpendicular to the bird housing, with differential GPS mounted at both ends (Figure 2). These systems, when coupled with the GPS in the Bird itself, supply attitude information (roll, pitch) of the Bird and are intended to assist in the more accurate recovery of conductivity data in the near surface.

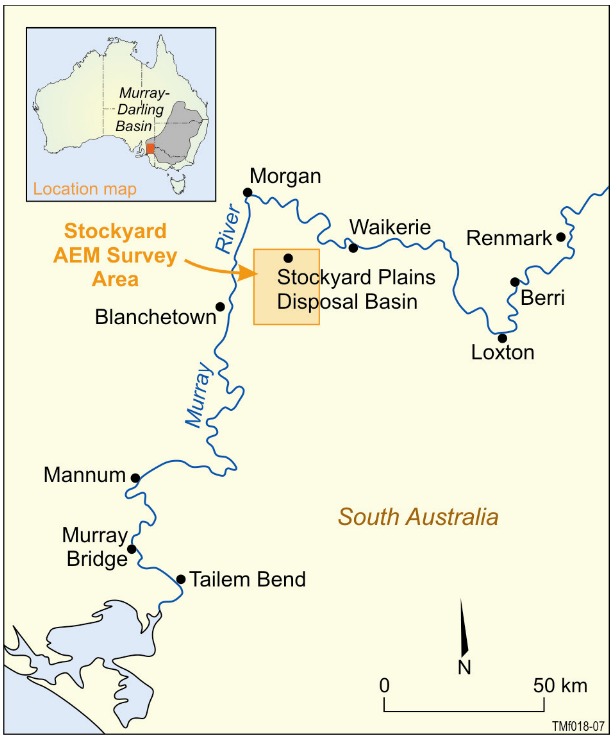

Figure 1. Location of the Stockyards Plains airborne geophysical survey, Sourth Australia.

The very high frequencies help detect very near surface conductors as might be represented by the clay-rich near-surface materials found in the sediments over the Stockyard Plains survey area. Decreasing the frequency increases the depth of exploration, and data from the lower frequencies will provide information on the groundwater quality. Groundwater is ~30m below the ground surface in this region.

Calibration

The good calibration of airborne electromagnetic data, using a combination of ground EM and borehole conductivity measurements is critical to obtaining accurate conductivity-depth models (Brodie et al., 2004a). This is particularly so for helicopter frequency domain EM data where calibration and other errors can have a significant effect on the results of inversion. Inductive conductivity data from twenty boreholes located within the survey area were used to calibrate the airborne data. The calibration procedure followed the methodology described by Brodie, et al., (2004). Forward models of the borehole data were compared to the observed FDHEM responses for each frequency in order to calculate the scaling coefficients (Figure 4). The subsequent scaled data were used as input into the inversion modelling. The scaling factors are described in Table 1.

Frequency	**400 Hz**	**1800 Hz**	**3300 Hz**	**8200 Hz**	**40 kHz**	**140 kHz**
Scaling factor	1.01	1.06	1.01	1.27	1.19	1.14

Table 1. Scaling factors obtained from comparing borehole data to airborne data used to calibrate the six frequencies from the RESOLVE survey.

Conductivity Models

Two sets of conductivity models were derived for the Stockyards data. These include a smoothed layer conductivity model using 25 layers, whose thickness increased exponentially with depth, and a blocky constrained 4 layer model (based on the method described by Brodie, et al., 2004b) which was constrained to the water surface of the unconfined regional aquifer, in order to estimate the thickness and depth to the Blanchetown clay layer (Table 2). The smooth layered inversion was produced in order to image the leakage of the recharge basin and for comparison with the 4 layer model to assess any bias in the constrained inversion.

Layer	Geology
1	Recent sands
2	Blanchetown Clay
3	Loxton Parilla sands above water table
4	Saline groundwater constrained to water surface

Table 2. Summary of 4 Layer model used for 4 layered constrained inversion.

Results

An example of the two inversion conductivity models show that the RESOLVE system successfully maps a conductive Blanchetown clay unit overlying the conductive saline groundwater (Figure 5). Although the smooth inversion does successfully image the clay layer, the 4 layer model allows a map of clay thickness to be derived as a specific product from the data which has value in the determination if areas suitable for extending disposal options (Figure 6d). Figure 6a shows a Landsat TM true colour composite image of the survey area, with the saline disposal basin located in the north-east of the image. The digital elevation model (Figure 6b) derived from the RESOLVE survey clearly indicates the prevalent east-west orientated modern dune system.

The conductance image derived from the first three layers of the blocky model was produced to illustrate the high conductivity associated with the disposal basin and its margins. The RESOLVE has limited depth penetration over the disposal basin of several metres, due to its highly saline nature, however laterally leakage can be easily identified, illustrated in Figure 6c as a highly conductive plume extending south of the existing basin. Examination of conductivity depth sections show a connection between a conductive brine plume emanating from the basin and extending downwards to the groundwater system at depth. The HEM data suggest that the basin may preferentially leak in a southerly direction, which is somewhat at odds with the modelled behaviour of the basin (see Collinham 2005). At this stage there is no evidence in the HEM data to suggest that regional groundwater gradients (which trend westerly) are influencing the brine pulse. Northwest-south-east orientated structures are also observed in the conductance image, which correlate with basement faults identified in the magnetic data. The conductivity data suggest these faults may propagate up to the surface through the overlying sedimentary sequence. The conductance image shows a good correlation to the clay thickness map (6d), since it does not include the contribution of layer 4 (saline groundwater). The clay thickness image (Figure 6d) shows that the majority of the survey area has intermediate thickness of clay sediments, flanked by areas of little or no clay on the east and western margins. The thickest accumulations of clays are coincident with large dune systems that occur to the east of areas that have been eroded out. (Figure 6b). Future disposal basins would ideally be located in areas of low elevation where intermediate thickness of Blanchetown clay is present. These areas would be preferable to slow infiltration and recharge from the surface to the underlying regional groundwater system.

CONCLUSIONS

The RESOLVE frequency domain HEM system has been used to map the distribution of clays in and around the Stockyards Disposal Basin of South Australia. The data have determined the extent of the saline plume migration laterally around the boundary of the basin and provide a better understanding of the hydrodynamics of saline groundwater disposal in the area. The inferred Blanchetown Clay thickness map provides a basis for determining which areas might be preferentially considered for an extension of disposal options in the vicinity of the existing basin.

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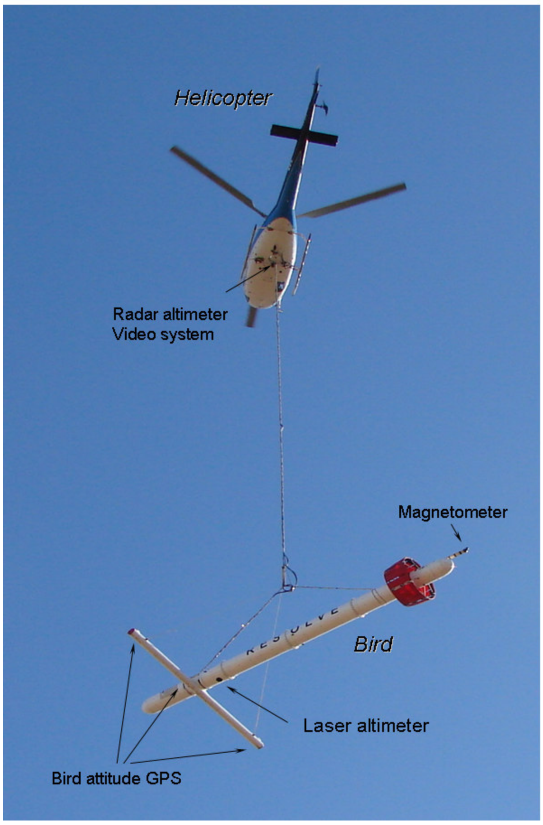

Figure 2: The RESOLVE FDHEM system

Figure 3. View north across the Stockyard Plains Disposal Basin from adjacent dunes.

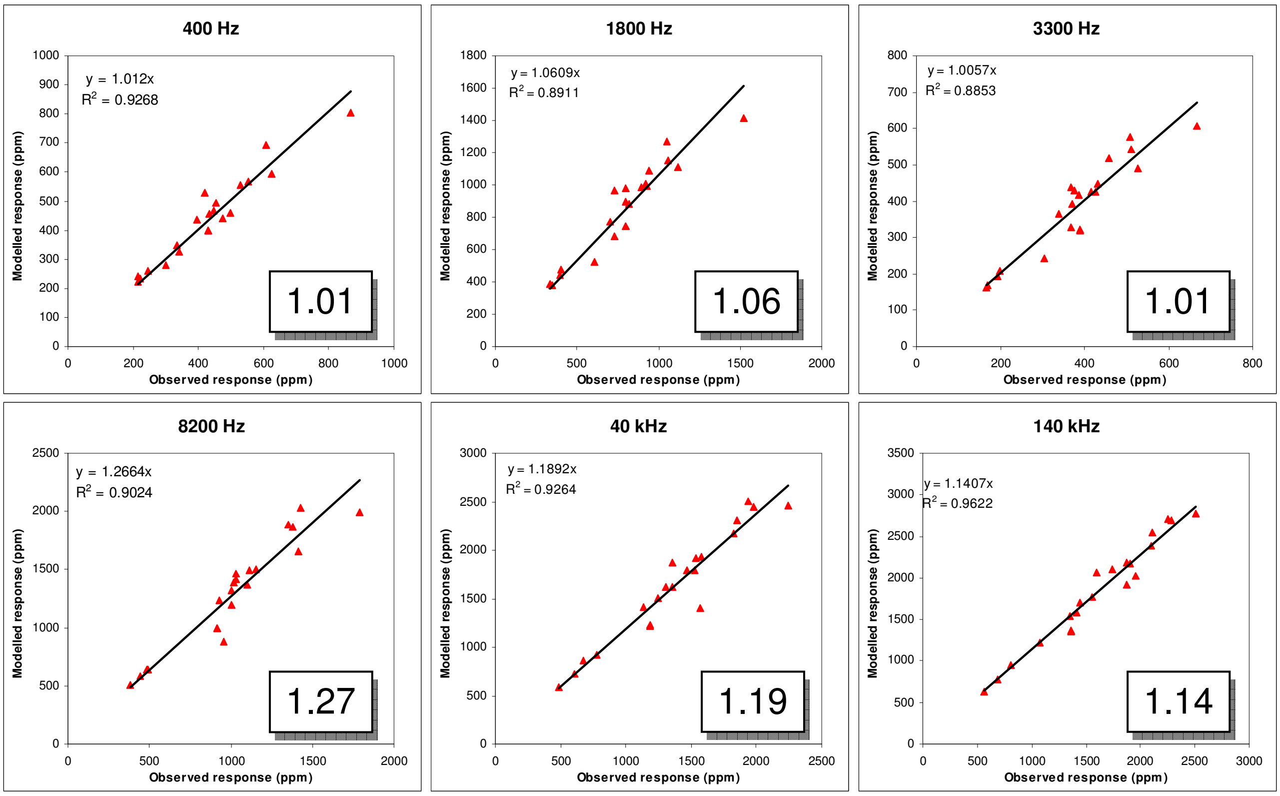

Figure 4. Calibration data for the six frequencies of the RESOLVE system calculated by comparing forward models of borehole conductivity data and observed RESOLVE data. Numbers indicate the scaling number required for each frequency.

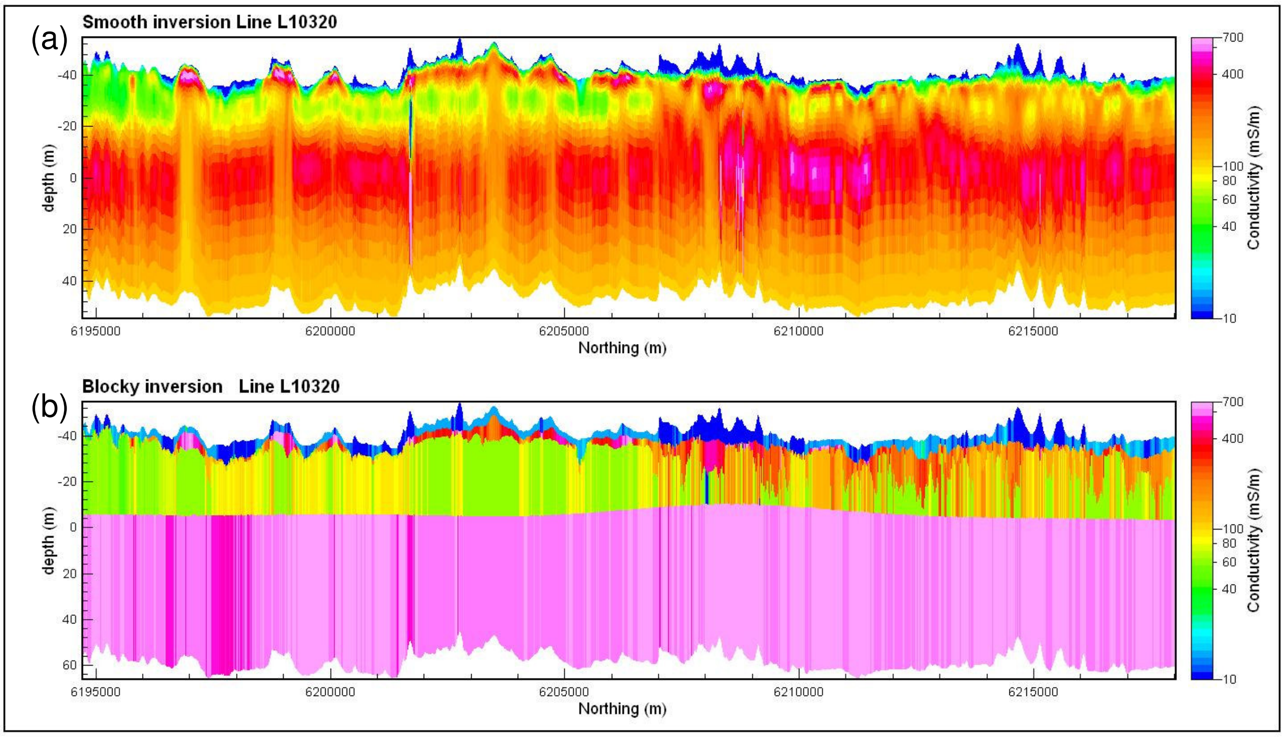

Figure 5. (a) Smoothed layered (25 layers) inversion of the RESOLVE data. (b) 4 layer "blocky" inversion of the RESOLVE data. The near surface conductive features reflect the presence of Blanchetown clay. The lower conductive anomaly represents the regional saline groundwater.

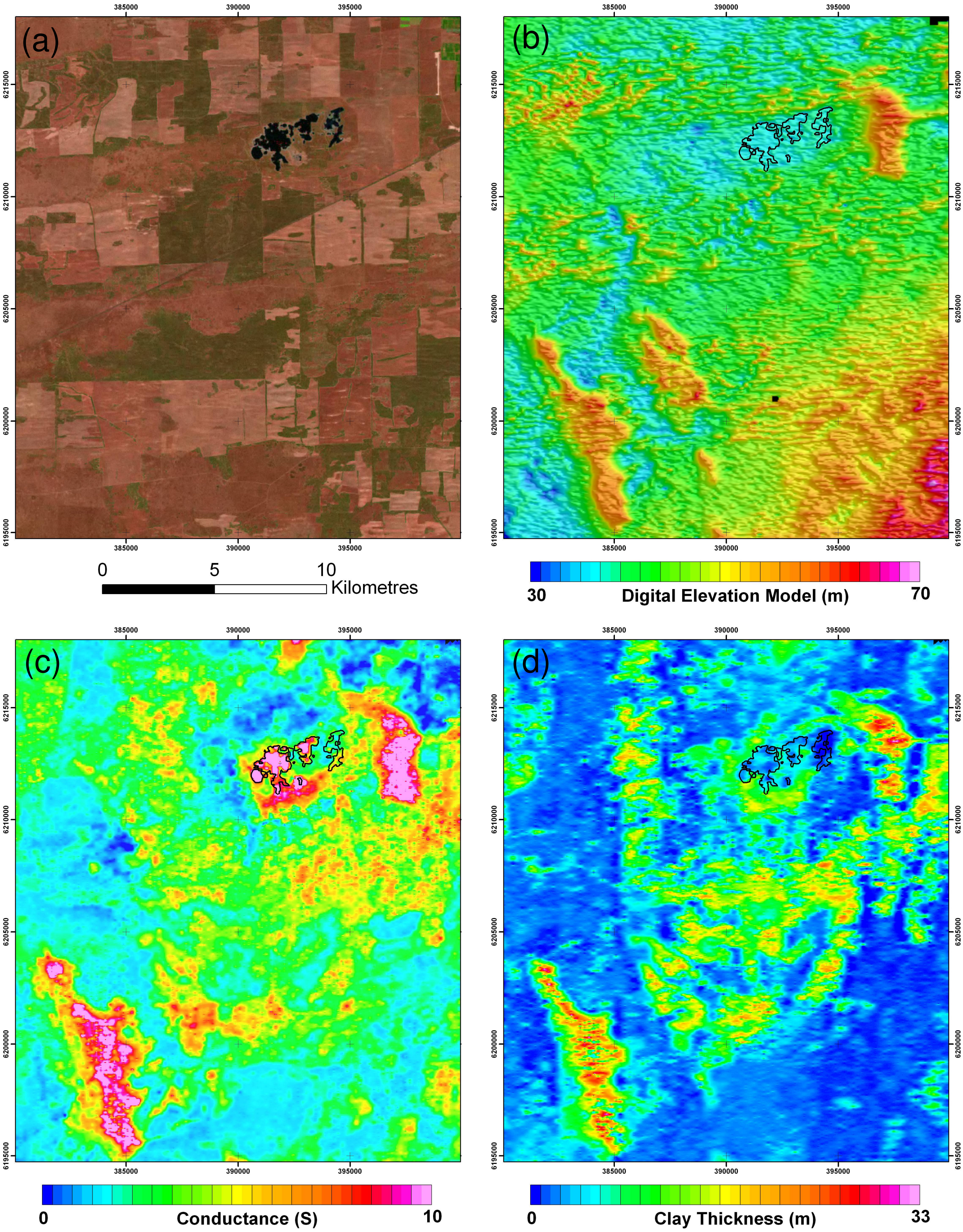

Figure 6. (a) Landsat image of the Stockyard Plains survey area, the lake feature represents the current saline disposal basin. (b) Digital elevation model derived from the RESOLVE system. (c) Conductance image of the first three layers of the 4-layer blocky inversion model. (d) Clay thickness map product derived from the 4 layer inversion. Black outline indicates the boundary of the current Stockyard Plains saline water disposal basin.