Frequency and/or Time Domain HEM Systems for Defining Floodplain Processes Linked to the Salinisation along the Murray River?

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SUMMARY

Geophysical, particularly electrical, methods have the potential to provide detailed spatio-temporal information on the distribution of salinity in soils and groundwater that characterise the floodplains of the Murray River in southeastern Australia, thereby assisting our understanding of floodplain processes. This knowledge can help manage the ecology of these settings, particularly in a time of severe drought when floodplain salinisation, vegetation dieback or health decline is a growing problem.

In this paper we examine the relative merits of high resolution helicopter EM technologies for elucidating floodplain processes. Specifically we consider the relative performance of the RESOLVE frequency domain helicopter EM (FDHEM) and the SkyTEM time domain helicopter EM (TDHEM) systems for defining variations in near surface conductivity and sediment salt load across the Bookpurnong Floodplain in the Riverland of South Australia. Results from coincident surveys are reviewed as are strategies for the inversion of these data. Data are examined against available borehole information including sediment chloride content and groundwater conductivity.

Key words: Helicopter EM, SkyTEM, RESOLVE, inversion, salinity, Murray River.

INTRODUCTION

Across the floodplains of Murray River in South Australia, as much as 40% of floodplain vegetation is now dead, dying or in a severe state of decline (White et al. 2006). This is primarily linked to increases in floodplain salinisation associated with enhanced groundwater discharge (related to increased recharge from irrigation on adjacent highland areas), a rise in evapotranspiration coupled with a marked decrease in flooding frequency. The result has been the accumulation and concentration of salt within floodplain soils and an increase in salt loads to the river.

Geophysical, particularly electromagnetic data have considerable potential for providing detailed spatio-temporal information on the distribution of salinity in soils and groundwater, thereby indicating spatial patterns and processes realting to groundwater evapotranspiration and baseflow across salinising floodplains. With that in mind, we have acquired high resolution helicopter EM across the well characterised Bookpurnong floodplain in the Lower Murray region of South Australia, with a view to determining their relevance and value as a source of information on salinising processes and the nature of surface-water - groundwater interactions that characterise these landscape systems. In this paper we examine data from two helicopter EM systems, specifically RESOLVE and SkyTEM, which are capable of providing near surface conductivity data and by inference information on the distribution and amount of salt stored in these landscapes. We also examine their potential to define sub-surface variability in highland areas adjacent to the river; areas where land use has a significant bearing on what happens in neighbouring floodplains.

Study area and hydrogeology

The Bookpurnong floodplain is located in the Lower Murray region of South Australia (Figure 1). The study area has a hydrogeology characteristic of the eastern part of the lower Murray River. Floodplain sediments consist of a clay (the Coonambidgal Clay) ranging from 3 to 7 m thick, overlying a sand (the Monoman Formation) which is approximately 7-10m thick in this area. These sediments occupy the Murray Trench which cuts into a sequence of Pliocene sands (the Loxton-Parilla Sands) up to 35m thick. The Loxton-Parilla Sands outcrop in the adjacent cliffs, and are covered by a layer of Woorinen Sands over Blanchetown Clay, each approximately 2 m thick. Regional groundwater salinity in the Loxton Sands and Monoman Formation ranges between 30-40 000 mg/L, with the high salinities commonly found on the floodplain resulting from evaporative concentration. Groundwater levels are 2-6 m below the floodplain and 20-30m below the ground surface in adjacent highland areas. Irrigation recharge salinity is typically 1 000-3 000 mg/L.

METHOD AND RESULTS

AEM system selection

Given that the primary objective of the Bookpurnong study was to understand spatial processes associated with floodplain salinisation, we were particularly keen to map near surface (<10m) variations in conductivity associated with the floodplain sediments. High resolution, high frequency, low power EM systems are most suited for this purpose. An additional constraint for surveys across the Murray River floodplains is associated with their varying width and that the Murray has incised into the surrounding landscape forming a trench. Therefore helicopter EM systems were deemed the most suitable for surveys in this environment. In July 2005, the Bookpurnong area was flown with the Fugro RESOLVE frequency domain helicopter EM system. In August/September 2006, we flew the same site with the

SkyTEM time domain EM system. The repeat survey across Bookpurnong provided an opportunity to investigate the relative merits of these systems for surveying the Murray River corridor.

The RESOLVE FDHEM System

RESOLVE is a six fixed-frequency EM system mounted in a 9m long "bird" towed beneath a helicopter at a nominal survey altitude of 30m above the ground (Figure 2), although for the Bookpurnong survey, the nominal altitude was ~45m because of the presence of tall trees along the river. The bird contains 5 rigidly mounted horizontal coplanar coils, and in the Bookpurnong survey measured an EM response at 390Hz, 1798Hz, 8177Hz, 39470Hz and 132700Hz. It also has one coaxial coil pair which measured a response at 3242Hz.

The SkyTEM TDHEM System

The SkyTEM time domain EM system is carried as a sling load towed beneath the helicopter (Figure 2). Survey altitude of the transmitter in the Bookpurnong survey was ~60m, mainly because of tall trees. The transmitter, mounted on a lightweight wooden lattice frame, is a four-turn, 16 x 16 m^2 eight sided loop divided into segments for transmitting a low moment in one turn and a high moment in all four turns. SkyTEM is capable of operating in a dual transmitter mode (Sorensen and Auken, 2004). In the Low Moment mode, a low current, high base frequency and fast switch off provides early time data for shallow imaging. In contrast when in High Moment mode, a higher current and a lower base frequency provide late time data for deeper imaging. The two modes can be run sequentially during a survey, as was the Bookpurnong survey. In low moment mode the transmitter base frequency is 222.22 Hz and in High Moment mode base frequency is 25 Hz. Peak current in the low moment is about 40 A with a typical turn-off time of about 4 µs; while the high moment transmits approximately 90 A and has a typical turn-off time of about 29 µs. The receiver loop is rigidly mounted at the rear and slightly above the transmitter loop in a near-null position relative to the primary field, thereby minimizing distortions from the transmitter (see Figure 2).

Data acquisition

Twenty six lines and (7 lie lines) of RESOLVE data orientated NW-SE were acquired over the floodplain with a line spacing of 100m (Figure 1). A single calibration line orientated NE-SW over the adjacent highland area was also acquired. Twenty nine lines of SkyTEM data were surveyed on the floodplain in a similar orientation to the RESOLVE data, with 100m spacing between lines. One line was collected perpendicular to the primary flight line orientation, and two calibration lines coincident with the RESOLVE calibration line (see Figure 1).

Data processing and interpretation

Conductivity depth images (CDI's) of the RESOLVE data over Bookpurnong Floodplain were generated using EMFlow (Macnae et al., 1998). An interval conductivity slice was then calculated for the 0-4m depth interval from the surface and these data were gridded and imaged (Figure 3). The SkyTEM data were inverted using piecewise 1-D laterally constrained inversion (LCI) (Auken et al., 2005) and conductivity depth interval extracted. A 0-4m depth interval is shown in Figure 3.

The interval conductivity slices (Figure 3), show a highly conductive floodplain which reflects the marked concentration of salt in the near surface sediments (see Figure 4). The most conductive responses are observed near surface, particularly on the NE floodplain (Clarkes Floodplain) adjacent to Bookpurnong highlands. Both EM systems identify a flushed (resistive) zone which parallels the main channel of the Murray River (Figures 3 and 4) where relatively high river levels have promoted losing stream conditions and lateral or bank recharge. This zone is characterized by low levels of chloride (salt) in the floodplain sediments, and in places it can extend up to 0.5km from the river bank. There is a close spatial relationship between areas of the floodplain with high conductivity (ie areas of high chloride content) and reaches of the river with high sediment conductivity. These correspond to 'gaining' reaches where baseflow from the regional groundwater system discharges salt into the river. Where the river cuts close to the Bookpurnong highlands the local groundwater mound promotes discharge from the regional groundwater system.

Local differences are apparent between the interval conductivity images for the two systems. Given their geometry we might expect the two systems to have similar footprints, but with the spatial sampling and stacking filters applied, combined with the higher frequencies and the lower power of RESOLVE its footprint is likely to be somewhat smaller than that of SkyTEM. Some differences may reflect changing conditions across the floodplain in the year between the surveys. For example, there is a suggestion that the effects of the Bookpurnong SIS scheme are apparent at location A (Figure 3) where a previously gaining stretch of the river has become a losing section – in response to over pumping.

Both HEM data sets were also inverted using a using the smooth model Occams style inversion (Constable et al. 1987, Sattel 2005). The SkyTEM Low and High Moment data were jointly inverted, and are presented with results from a joint Laterally Constrained Inversion (LCI) inversion of the same data for the calibration lines along Nitschkes Road which crosses the Bookpurnong highland adjacent to the floodplain (Figure 5). Ground NanoTEM data, inverted to a model resistivity vs. depth using STEMINV (MacInnes and Raymond, 2001) are presented with the interpreted geology (summarised in the top section, along with the position of the water table), which has been defined from scout holes drilled along the road. These data provide an indication of how the RESOLVE and SkyTEM systems perform in regards the definition of significant elements of the local hydrogeology.

A near surface, relatively conductive clay unit known as the Blanchetown Clay is resolved in the NanoTEM data. Similarly, the LCI inversion and the smooth model layered earth inversions for both HEM systems also define a near surface conductor. The smooth model Occams inversion of RESOLVE suggests a more complex set of conductors near surface, which is not supported by available borehole data. The smooth model inversion of SkyTEM data and the 19 layer LCI map a single near surface conductor, although the position and continuity varies. Further work on the starting models used in the inversion is likely to resolve these apparent differences. The two HEM systems define the highly conductive saline groundwater system, although the water level appears to be better defined in the LCI and smooth model inversions of SkyTEM rather than those for RESOLVE (Figure 5). Overall, we believe that a blocky, or "few-layer" inversion might be more appropriate for more accurately defining the conductivity, thickness and extent of the Blanchetown Clay and variations in ground water conductivity.

CONCLUSIONS

Both HEM systems effectively define salt stores and variations in salinity across the floodplains and in river sediments at Bookpurnong. Results suggest they could be used as a means of monitoring spatial changes in floodplain salinity, which would provide an invaluable insight into surface-water - groundwater interactions and processes of salinisation operating along the Murray River in Australia. Both systems define the extent of the flushed zone along the river, and identify gaining stretches. Whilst the smaller footprint of RESOLVE would imply that finer scale variations over the floodplain might be defined relative to SkyTEM, realistically the operational costs would in all probability limit acquisition to coarser scale (ie wide line spacing ~ >150m) except in certain situations. Information on groundwater conductivity at depth will be limited over the more conductive floodplains for RESOLVE, because of its limited skin depth. The High Moment data from SkyTEM should address this limitation.

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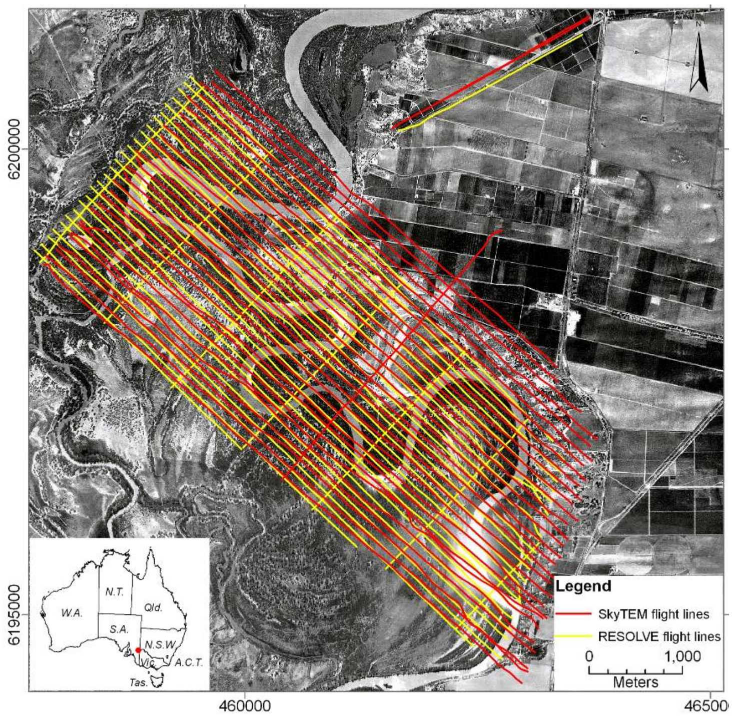

Figure 1. Location of the Bookpurnong Floodplain study site in South Australia. Lines for two EM systems, the RESOLVE (yellow) and SkyTEM (red) systems are shown. The survey area covers most of the Bookpurning floodplain and parts of the adjacent highlands where irrigated agriculture has been developed. Near-coincident calibration lines (2 for SkyTEM and 1 for RESOLVE) were acquired along Nitschke Road, orientated NE-SW north-east of the survey area.

Figure 2. The RESOLVE FDHEM (top) and SkyTEM TDHEM (bottom).

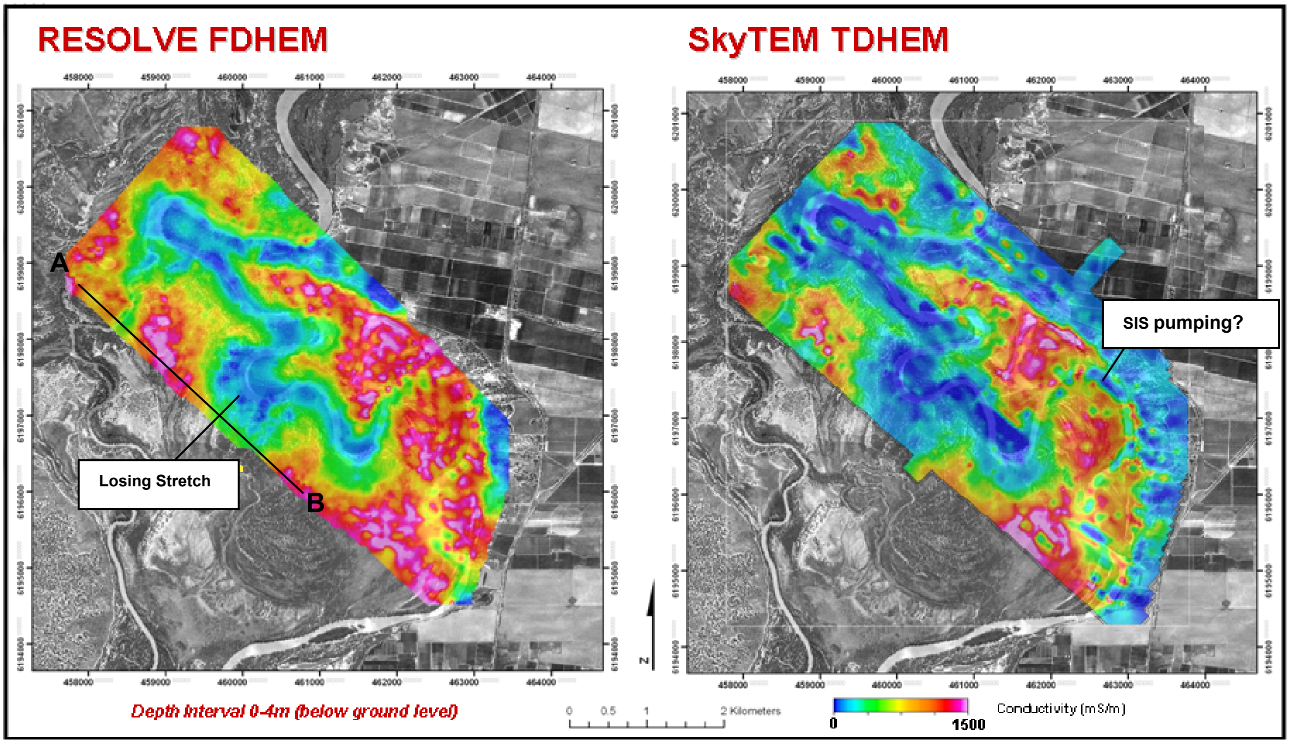

Figure 3. Interval conductivity for a 0-4m depth slice from the surface for RESOLVE (determined from EMFlow) and SkyTEM (determined from an LCI inversion) for the Bookpurnong floodplain. A conductivity Depth Section for flightline segment A-B is shown in Figure 4 below.

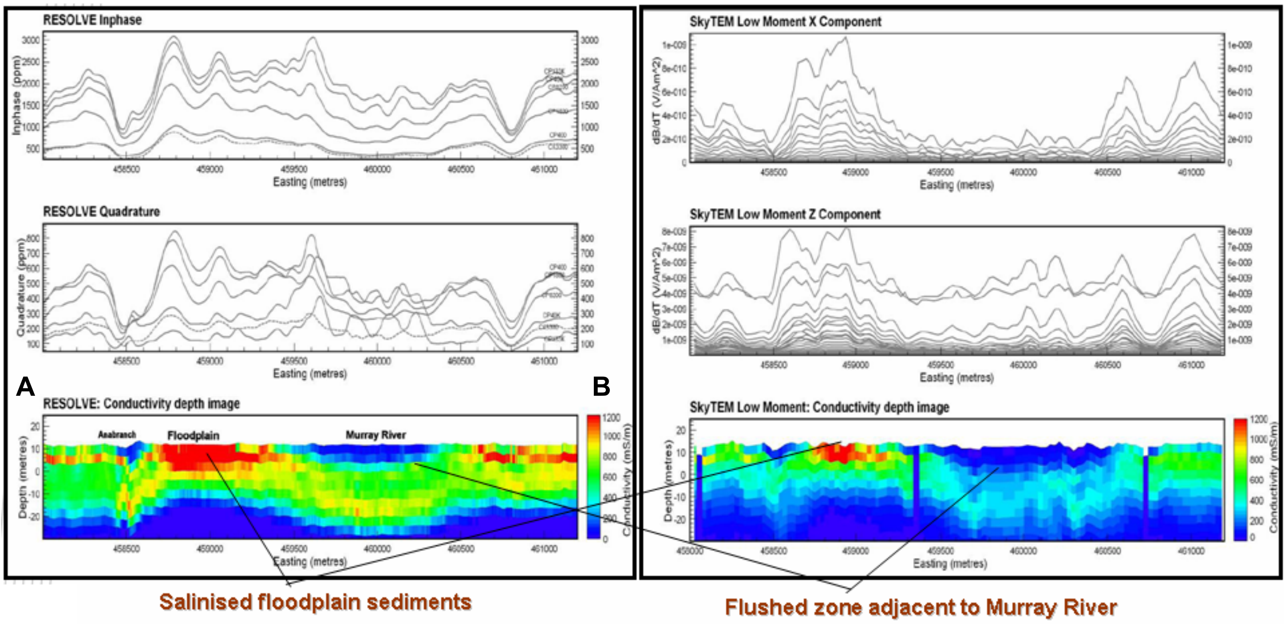

Figure 4. Comparison of RESOLVE and SkyTEM Low Moment CDI sections (derived from EMFlow) for a flight line section in the southern part of the survey area (see Figure 3 for location).

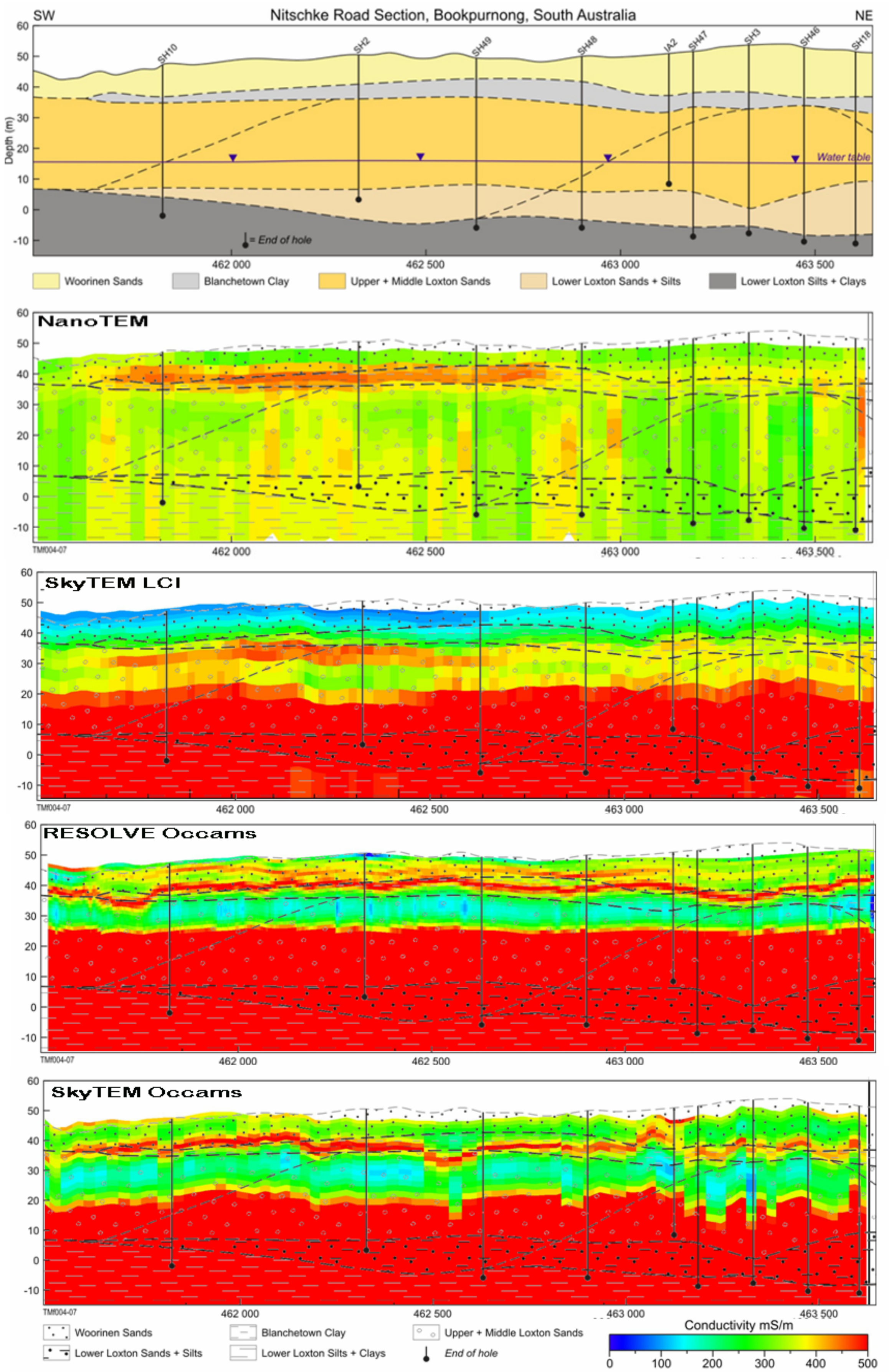

Figure 5. Conductivity Depth Sections derived from the inversion of ground EM (NanoTEM data), RESOLVE and SkyTEM data for the calibration lines along Nitschke Road in the Bookpurnong Highlands