Study of groundwater flow in sediments and regolith defined by airborne geophysical surveys.

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SUMMARY

An airborne electromagnetic survey over the wetlands north of Esperance was interpreted to assist in defining the groundwater conditions within the surrounding floodplain and its influence on Lake Warden. The study shows the Esperance Floodplain is underlain by sediments of Eocene age deposited in shallow marine conditions onto an undulating granitic, gneiss basement. In the western part of the study area, surface water flow is directed towards Lake Warden from areas of shallow basement above the escarpment. Subsurface drainage is interpreted to flow towards Pink Lake. A continuous basement ridge forms the north side of Lake Warden.

The Eocene sediments are thicker towards the south of the lakes and the undulating basement surface has a regional dip towards the east. Deep drainage is indicated from the main lakes into Esperance Bay in the region west of Bandy Creek. Deep drainage from Lake Warden probably also occurs in the northeast of the lake along the direction of the gneissic banding. Small islands of granitic basement poke through the sediments in the region around Windabout Lakes and a more continuous north-south barrier appears to partially separate the east part of the floodplain from the west in the area west of Station Lake. In the eastern parts of the catchment under an area of parabolic dunes, the EM data indicates a deep palaeochannel joining the Neridup area with the sea. This may be part of the Cowan Palaeochannel. Drilling into the edge of this structure showed it is under artesian pressure and some upward seepage may be expected. Deep parabolic sand dunes cover most of the palaeochannel on the floodplain but seepage may occur along the edge of the dune field. High salt storage is indicated under the major lakes and in the eastern parts of the catchment.

Key words: 1 to 5 key words in 9 pt Times New Roman, separated by commas; these will assist in the cross-indexing of the article.

INTRODUCTION

Lake Warden is located on the northern outskirts Esperance on the south coast of Western Australia, approximately 600 km southeast of Perth. It is one of nine wetlands of international importance in Western Australia listed under the Ramsar Convention. Lake Warden is under threat from increased salinity and is a Recovery Catchment under the Western Australian State Salinity Action Plan (*www.salinity.org.au*).

In March 2004, the Department of Conservation and Land Management (CALM), commissioned an airborne electromagnetic (EM) survey over part of the Lake Warden catchment. Figure 6 shows that the survey covered Lake Warden and wetlands across the floodplain north of the Town of Esperance. The survey was carried out using the HoisTEM (Meyers and Hashemi, 2004), helicopter time-domain EM system.

The purpose of the survey was to assist in defining;

- Regolith thickness across the coastal floodplain and surrounding escarpment;
- Continuity of shallow granite across the floodplain escarpment; and
- Extent of palaeochannel formations.

Other geospatial data such as topographic data; aerial photos, regional magnetic data, cadastre and drainage have been incorporated into a GIS project and jointly interpreted with the geophysical data to extract information on present landforms and geological history in order to gain knowledge of the hydrogeological processes operating today in the catchment.

The aim of the interpretation of the EM inversion products along with hydrogeological data provided by CALM is to attempt to answer the following questions.

- What is the volume within the survey boundary of the following units if present- Quaternary sequences (dune sands and lunettes), Tertiary (Pallinup Siltstone and Werillup Formation and weathered saprolite) units above the granite basement and sediments in palaeochannels across both the
 - Floodplain; and
 - Escarpment?
- Is the upper catchment groundwater system linked to the floodplain via direct groundwater flow?
- If so, where is the floodplain directly linked to the upper catchments?
- Where are salts concentrated and how are they distributed within the sedimentary units across both the:
 - o Floodplain; and
 - Escarpment?
- Is there groundwater connectivity between the coastal floodplain and the marine sedimentary sequences to the south?

METHOD AND RESULTS

The EM survey flown in March 2004 (Figure 6) forms the basis of the study. The EM data is badly affected by electromagnetic noise from the town infrastructure, particularly from radio stations in north of the area and major power lines. The data was processed a number of times using EMAX software (Fullagar, 1989) and EMFlow (Macnae et al., 1998).

The regolith in this area is considered be represented by the weathered basement; Eocene sediments of the Werillup Formation and Pallinup Siltstone and/or Quaternary surficial sediments. Werillup if present is always overlain by Pallinup but both units may be absent.

The relative level of the basement calculated from the layered earth inversion (LEI) of the HoisTEM (Figure 2) shows an uneven basement surface, such as expected from an eroded laterite profile. Under the floodplain, the depth of conductive material in the regolith is deepest in the area east of Bandy Creek. The axes of magnetic highs and lows are superimposed to show how the shape of the basement surface is strongly controlled by the basement geology. The depth to basement in resistive areas is over-estimated in the inversion routines due to the effects of noise in the data and most of this area has been masked off and areas of basement outcrop/subcrop and shallow basement have been interpreted using early time CDI images and geology maps.

Figure 2 shows a depth to basement image created from borehole data. These data were used to better constrain the model and identify spurious inversion depths from the LEI. Figure 7 shows a composite image created from EM inversions, geology outcrop map and drillhole data with lakes superimposed above. This image shows that the lakes sit above a shelf of basement with deeper sediments to the south and deep drainage paths towards Esperance Bay.



Figure 1. RL of basement produced with EMAX inversion. Areas of uncertainty are masked in black and interpreted shallow basement further overlaid in pink. Lowest RL is blue through to highest in red. Dashed lines are the metamorphic fabric from regional magnetic data.



Figure 2 Depth to basement created from borehole data.



Figure 3. Log of drillhole into eastern part of catchment. Only the top part of the hole could be logged.

Figure 3 shows downhole EM and gamma logs of a drillhole into the eastern part of the study area. These data were used to constrain EM inversions. The hole shows higher conductivity and gamma radiometric counts in the upper Werillup Formation. The lower parts of the hole could not be logged due to collapse of free flowing Werillup Formation sands.

Figure 4 shows the thickness of the Werillup Formation which is the main saline aquifer in the area and Figure 5 shows the thickness of the Pallinup Formation. This was created using the constrained inversions as well as geology and borehole data. Similar maps were created for the other formations in the area.



Figure 4. Thickness of Werillup formation from constrained inversions.



Figure 5. Thickness of Pallinup Formation from constrained inversions.

CONCLUSIONS

The Esperance Floodplain is underlain by this sequence of Eocene sediments that were deposited in the southern end of the Cowan palaeovalley during a series of marine transgressions and regressions. These were laid down on a partially stripped, uneven granitic gneiss basement. Sediments derived from weathering of the inland laterite surface were first deposited in backswamp, low-oxygen environments in shallow depressions in the basement surface. Later deposition occurred in a shallow marine seaway as siltstones and where starved of sediments as a marine spongolite.

A HoisTEM airborne EM survey flown over the floodplain shows variations in conductivity from very resistive in areas of granitic outcrop to a deep highly conductive zone in the southeast.

Various methods and iterations EM data processing were tried and over 2800 different files were generated from the HoisTEM survey. However, noise in data from infrastructure and particularly from radio transmitters often gave spurious results. In addition, the laser altimeter employed to give altitude of the HoisTEM loop did not give accurate measurement over the lakes. Shallow and surface drainage in the western parts of the survey area are mostly directed into Lake Warden via small seasonal creeks. Regional magnetic data shows that the Biranup Complex crystalline basement rocks in this part of the study area are metamorphosed into bands and the EM data shows that bedrock depths are greatest in the more mafic units. The major lakes sit on a shelf within one main band of the Biranup Complex. Over the zones of deeper bedrock, Eocene sediments were deposited with Werillup Formation dominated by clays and only minor sands overlain by a thicker less permeable layer of Pallinup Siltstone.

A barrier of shallow basement rock prevents deeper drainage to Lake Warden from the north. A band of thicker Eocene sediments, which deposited in an old drainage line, extends from the catchment above the escarpment to the north to an area of high salt storage north of Pink Lake. Limited drill results indicate that this area is a thick accumulation of grey clay. In this study, it is interpreted to be fine sediments of the Werillup Formation deposited in calm water conditions such as a lagoon behind a sand bar. Sands are suspected, associated with the unit, and deeper drainage is interpreted to follow this path. Further drilling is needed to confirm this.

Pink Lake is fed by seepage from the surrounding parabolic dunes and probably by the deeper drainage system from a catchment that extends above the escarpment to the north.

There is no surface water outlet from Pink Lake and Lake Warden. No major exit for deeper water from Pink Lake was identified in this study although the zone of thicker sediments appears to continue under the centre of Pink Lake and towards the southeast under Esperance. A link to Lake Warden from the northeast section of Pink Lake is also inferred in original survey data and supported with extra flight lines. The regolith and sediments under Lake Warden deepen towards the southeast and deeper drainage from Lake Warden and possibly Pink Lake is most likely in this direction.

The north/central part of the study area is dominated by the exit point of Coramup Creek from the escarpment. Coramup Creek extends some 30km inland from the escarpment into areas with saline lakes and may contribute higher salinity water to the floodplain. Where it crosses the escarpment onto the floodplain the creek lies towards the east side of an incised valley cut into Pallinup sediments. Basement depth indicates the creek may have existed prior to the Eocene as the deep basement feature lies west of the present creek. This is interpreted as the palaeodrainage of Coramup Creek, which cut a valley through the basement and may have been a tributary of the Cowan Palaeochannel. Subsequent Eocene sedimentation filled the valley with sands and silts of the Plantagenet Group. The Werillup Formation forms the basal unit of these sediments and is often highly permeable sand. Therefore, the deep regolith section through the escarpment may act as a conduit for water through an area dominated by basement highs. This deeper drainage from Coramup Creek appears to flow towards the area under Windabout Lakes.

Depth-to-basement inversions indicate deepest basement depths are in narrow zones. These deeper zones appear to be directed towards an area under Lake Wheatfield. Small 'islands' of basement highs are indicated in the data and further smaller structures may be present which are not resolved by the EM data. Salt storage increases downslope from the escarpment towards the area under Windabout Lakes and the conductivity data suggests that most of the deep drainage from Coramup Creek catchment appears to flow to this point. Further east, the salt storage indicates south draining groundwater towards areas under Mullett and Station Lakes.

East and west of Coramup Creek there are many small creeks, which rise where there is local near-surface run-off in shallow soils and/or seepage from the Pallinup sediments. The groundwater in the Pallinup is lower in salinity than the Werillup (Johnson and Baddock, 1998) and this seepage into creeks is likely to be low in salinity.

The eastern lakes section of the study area is dominated by a deep palaeochannel that crosses the eastern scarp and exits to the sea. The groundwater in the channel is under artesian pressure. High salinity along its margin is considered to indicate either seepage from the channel or hydraulic pressure forming a barrier to drainage of surface water into the channel. The depth to basement under the eastern escarpment is much deeper than the escarpment along the northwest side of the floodplain. It appears to be an erosional feature cut into Plantagenet Group sediments by recent marine incursions.

Two creeks, Neridup and Bandy exit the escarpment onto the floodplain in the eastern catchment associated with alluvial fan sediments with high salt storage.

Quantitative interpretation of the thickness of each of the Eocene and Quaternary sedimentary layers was carried out using the EM and drillhole data. A basement of variable topography is indicated with steep sided "islands" rising through the overlying sediments. Initial interpretation suggested that Werillup Formation was very limited in extent and only small amounts of Werillup Formation have been found in existing drillholes. The EM data indicates it may be more extensive in small pockets throughout the floodplain. From analysis of extra bore information from Water Corporation a thin sequence (<10m thick) of Werillup sediments cover was inferred over much of the floodplain. The southern end of the Cowan Palaeochannel under the eastern end of the floodplain has the most extensive area of Werillup Formation and may be hydraulically connected with Werillup Sediments intersected by drillholes in previous studies in the Neridup Catchment.

A 10-20m layer of Pallinup Siltstone underlies most of the floodplain. The thickness of 100m of Pallinup Siltstone under the eastern escarpment indicates how much as been eroded by marine transgressions since the Eocene. Quaternary formations are thickest along the coast southwest of Pink Lake and in an area of parabolic dunes overlying the palaeochannel in the east. Over most of the area, the thickness of Quaternary formations is interpreted as less than 5m.

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Figure 6. Location of main survey marked in red and extension to north marked in green over wetlands north of Esperance.



Figure 7. Basement topography with lakes, coastline and interpreted subsurface drainage paths superimposed.