# REGOLITH CONSTRAINTS ON MODELING SALT MOVEMENTS IN UPLAND LANDSCAPES IN THE MURRAY-DARLING BASIN

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**SUMMARY**

Research conducted over the last decade by CRC LEME has demonstrated that beneath our shallow soils, Australia's regolith landscapes are complex over much of the continent. As this regolith layer is the main store for salts, and the groundwaters that mobilise these salts, resolving this regolith architecture is a high priority for salinity and groundwater studies. Recently, projects in the Murray-Darling Basin, and eastern and southern Australia more generally, have demonstrated that surface maps of soils and topography *may not be* a good guide for predicting sub-surface salt and groundwater movements *particularly at sub-catchment scales*. This is on account of landscape disequilibrium, where a long history of erosion and deposition can result in development of out-of-phase landscapes. This is particularly true in areas with a protracted landscape history and/or in areas where tectonic and volcanic activity has influenced landscape development. Landscape disequilibrium appears to be a common situation in eastern and southern Australia, where valley-fill sediments are preserved in erosional landscapes, and vice-versa. One consequence of this is a poor reliability in the use of present day landforms and models based on the use of Digital Elevation Models (DEMs) and terrain indices to predict sub-surface regolith landscapes, salt stores and groundwater movements.

Further complexity in predicting regolith salt stores is introduced by differential weathering of bedrock mineral systems. Key components of the latter are not commonly mapped, and this project has developed a methodology for incorporation of value-added mineral system data for groundwater and salinity studies in erosional landscapes. Similarly, it has been demonstrated that value-adding to existing Groundwater Flow Systems (GFS) frameworks is required in order for these frameworks to support targeted salinity management interventions *at sub-catchment or farm scales*. Importantly, studies involving CRC LEME have demonstrated a new approach for mapping salt stores and groundwater flow systems down to sub-catchment scales, for both present-day depositional and erosional landscapes. This new integrated geoscience approach is already leading to adoption of novel, cost-effective, *targeted* salinity management intervention strategies. The approach maximises the use of existing geoscientific data (borehole and geophysics) from the minerals industry, combined with limited acquisition of new geoscientific data (stream conductivity, regolith, geophysics and hydrogeology).

**INTRODUCTION**

Existing salinity modeling activities include the CSIRO Biophysical Capacity to Change Model (Dowling *et al*. 2003), the New South Wales Department of Infrastructure, Planning and Natural Resources (DIPNR) CATSALT model (Tuteja *et al*. 2003a, b), the Victorian Department of Primary Industries CAT model (Beverly *et al*. 2003) and the Queensland Department of Natural Resources and Mines (QDNRM) salinity hazard/risk mapping (Moss *et al*. 2002). These are examples of salinity models that utilise different approaches and reflect data availability, skills within those organisations and organisational priorities (Littleboy 2004).

Some modeling approaches, for example, Biophysical Capacity to Change, were developed to support salinity management planning at catchment and regional scales and generally operate at too coarse a scale and time step to be appropriate for recent demands to support property to sub-catchment scale decision-making responsibilities embedded in State Salinity policies and the National Action Plan for Salinity and water Quality (NAPSWQ). Other modeling approaches, e.g., the DIPNR CATSALT model, consider salt and water movement down to a property scale, but are currently limited for widespread application because of the extensive data and modeling resources requirements (Littleboy *pers. com.* 2004).

The lack of a consistent salt balance modeling approach across eastern Australia has led to anomalies in model output along State borders and results that cannot be readily compared across States. CRC LEME has been commissioned by the Murray-Darling Basin commission (MDBC) to assist with calibrating existing salinity modeling frameworks in the Murray-Darling Basin (M-DB), particularly in respect to providing sub-surface regolith and bedrock constraints in erosional landscapes. The aim of the 2C model is to quantify surface and groundwater contributions of salt to catchment-scale salt export, and to predict the impacts of land use change on salt movement at a catchment scale. In detail, CRC LEME's role in assisting with predicting salt movements particularly in erosional landscapes in the M-DB is essentially to:

- Improve the usefulness of the existing groundwater flow systems approach by incorporating subsurface characterisation with hydrogeological interpretation and mapping of shallow salt store distribution;
- Provide improved surface and subsurface data to assist in the spatial delineation of hydrogeomorphic units (HGUs), at appropriate scales to management decision making;
- Describe the locations and mobilisation pathways of critical salt stores within the surface and shallow subsurface of each hydrogeomorphic unit; and,
- Link to existing salinity and salt export modeling, and to matrix farming trial studies for salinity and recharge management.
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The preliminary results reported on here are more fully documented elsewhere (Lawrie *et al*., 2004).

**PHYSIOGRAPHIC REGION, REGOLITH AND BEDROCK GEOLOGICAL MAPPING**

Preliminary mapping of the physiographic regions of the southern and eastern M-DB has revealed significant changes in landscape complexity both across and along the Eastern Highlands. The boundaries of these regional variations have not previously been mapped, and yet they appear to place important constraints on landscape complexity, regolith thickness and potential salt stores. These variations appear in part to be related to major tectonic and thermal subsidence and uplift events associated with episodic crustal events that occurred from 90 Ma to present. Even older regolith histories are preserved within some regions. Variations occur at several scales, ranging from hundreds to tens of kilometres. These variations are not recorded on any existing maps, yet this information has the potential to significantly value-add to GFS and other groundwater and salinity models in Australia.

First order magnitude variations in landscape complexity and regolith thickness are related directly to crustal movements, thermal subsidence to form the main M-DB, and changes related to base level fluctuations. These have produced the broad physiographic regions recognisable in present day landforms. However, second order variations within these physiographic regions are particularly important, as these have produced variations that are not easily predicted from present day landforms. In NSW, major, systematic, order of magnitude variations in saprolith thickness have been recognised for sub-catchments in similar landscape settings, and for similar geological units. In similar landscape present-day landscape positions, and for similar underlying bedrock geology, significant regional variations in saprolith thickness are recorded. For example, saprolith thickness is in the range 70-150 m in volcanic units in the Bland Catchment, 20-50 m in the Waugoola sub-catchment near Cowra, and 5-10 m in the Bodangara sub-catchment near Wellington. None of these variations are recorded or reflected in existing geology or GFS maps.

Within sub-catchments in this study, a third order variability in saprolith thickness has been mapped, and a methodology developed to predict this where borehole information is unavailable. Significant variability in saprolith thicknesses is still observed within units, and is largely dependant on the degree of complexity and intensity of post-formation overprinting events (hydrothermal alteration, deformation and metamorphism). Many of these elements are not recorded on existing regional geological maps. A comparison of a published regional 1:100,000 geological map and a bedrock geology map where structural geological elements and lithological sub-divisions are recorded is shown in Figure 1.

Despite this variability, systematic variations in saprolith thickness have been found by grouping geological units into erosional or depositional landscapes, and then by rock type and rock age. Errors are further reduced by adding mineral system data to existing bedrock geology maps. Systematic variations have been found. For example, in the Bland Catchment, similar rock units of similar age in depositional landscapes have saprolith thicknesses double that of their counterparts in adjacent erosional landscapes. This relationship holds true for several different rock types and these associations, once determined within a sub-catchment, can then be used to estimate saprolith thickness within a defined region.

The causes of this landscape complexity are many and varied, and impact not only on saprolith thickness, but also on sedimentary infill. Erosional landscapes with a long history of weathering, erosion and neotectonics gradually accumulate complexities that are not in phase with the modern environment. In the past there has been a common assumption that the modern land surface reflects, at least to some extent, the nature of the underlying regolith. Landforms have often been used as a surrogate for regolith type. There are at least two circumstances that lead to a contrast between land surface morphology and the subsurface 3D distribution of regolith materials:

1. Where an erosional landscape has formed and has then been buried by subsequent terrestrial deposition, the surface morphology and associated geomorphic processes will differ markedly from those associated with the now-buried landscape. We have found this to be the case in the GILMORE project area in NSW and in the Lower Balonne area in southern Queensland. In both cases the modern landscape has very low relief, with only a few low hills of bedrock rising above an alluvial cover. Yet at depth the buried bedrock has a highly variable weathering profile and the base of the transported sediments can have orders of magnitude more relief than the modern surface. Moreover, the shape of the buried landscape controlled the location of sedimentation, resulting in a complex transported cover of alluvial regolith. Finally, the transported cover weathers after it is deposited, adding to the complexity. The result of all this is that the modern surface on the depositional part of the system in no way reflects the character of the regolith more than a few metres below the surface. The extent to which the surface reflects the subsurface distribution of regolith depends on the landscape involved. For example, AEM in the Lower Balonne project area suggests that, on the younger alluvial surfaces, the surface expression continues to about 15m deep.
2. Erosional landscapes with a long history of weathering and erosion gradually accumulate complexities that are not in phase with the modern environment. They thus have, for example, palaeo-landforms and associated materials that are likely to be in disequilibrium with present day processes. This is certainly the case on the Bathurst 1:250,000 sheet area, of which the Cowra study area is a part. In this area there are at least 2 distinctive geomorphic environments in the erosional areas. First, there are steeper and more eroded areas where the soils and regolith cover is thin and more or less at equilibrium with modern geomorphic processes. Elsewhere, in lower relief areas with more gentle slopes, there are deep weathering profiles and palaeo-landsurfaces that are a result of long periods of stability and weathering during the Tertiary. In these latter areas surface form is not a good indication of regolith depth and character. For example, it has been shown that in low relief areas the weathering front often varies in depth a great deal while the modern surface remains uniform. This circumstance is often a result of different bedrock types with different lithologies, and different resistance to weathering.

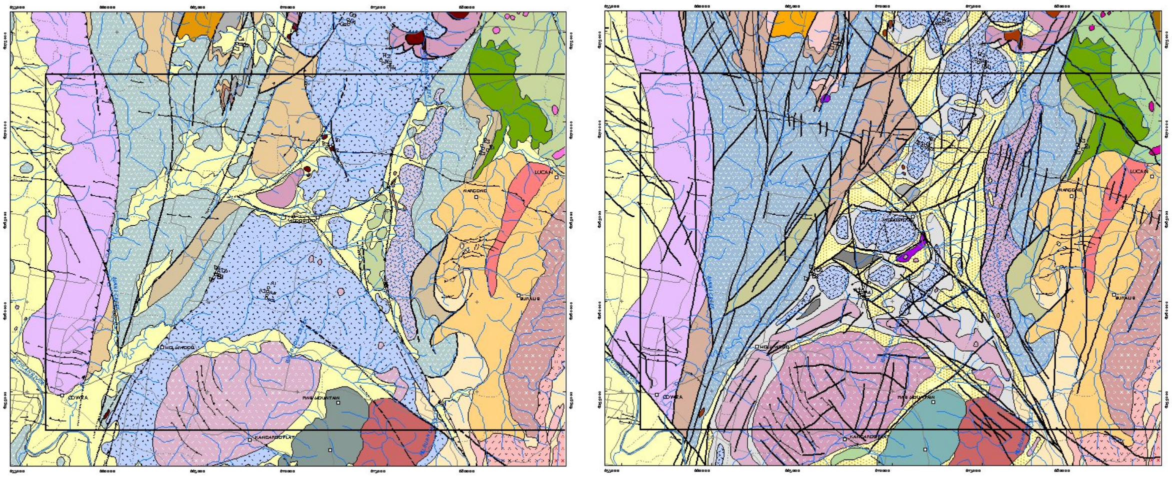


**Figure 1:** Comparison of a published bedrock geological map and the same map with structural and lithological information added for the Waugoola sub-catchment. The box delineating the field area is approximately 40 km in the long axis.

The implication of CRC LEME's experience working in a large number of landscapes is that surface morphology is a poor surrogate for subsurface regolith, and this stresses the importance of an understanding of the geology of study areas, field work, drilling, and various geophysical tools. An example of this landscape disequilibrium is shown in Figure 2a, b.

This study has found that in the erosional landscapes in study areas in southern Queensland, NSW, and SA, present-day erosional landscapes contain palaeo-landforms and associated materials that are in disequilibrium with present day processes. For example, palaeo-valley fill materials occur in a range of landscape positions that do not coincide with present valley floors. Hence models of regolith thickness and salt store potential that rely primarily on present day morphology and DEMs, do not give reliable estimates of these parameters in many landscapes. None of the mapped variability in regolith thickness and complexity is predicted from terrain index approaches (such as MrVBF or FLAG).

The nature of sedimentary fill material plays a significant role in defining the response time of groundwater flow within any GFS. At present, no information on the hydraulic conductivities of regolith materials, whether saprolith or sedimentary fill, is incorporated in GFS frameworks. This project has demonstrated a methodology for incorporating such information, either from existing borehole information, or with less certainty in a predictive sense given an understanding of landscape evolution and the links between bedrock composition, weathering and erosion processes. Up to eight orders of magnitude variation in hydraulic conductivities is recorded in regolith materials within one sub-catchment, so the ability to map and/or predict these properties in the sub-surface should significantly aid predictive models of groundwater and salt mobility. This approach shows that even in areas of thick regolith and 'high potential salt store', high hydraulic conductivities

In summary, a holistic approach to the understanding of regolith landscapes and bedrock geology has the potential to greatly improve our understanding of salinity and groundwater process models and the pathways and responses of salt mobility in Australian landscapes. This is true even in the erosional landscapes of the M-DB, which are some of our youngest and perhaps least complex regolith landscapes in Australia. The success of the approach will depend on the scale of application, and data availability. However, it is predicted that even in relatively data poor areas a limited amount of bedrock and regolith input has the potential to significantly improve our models of salt mobility.

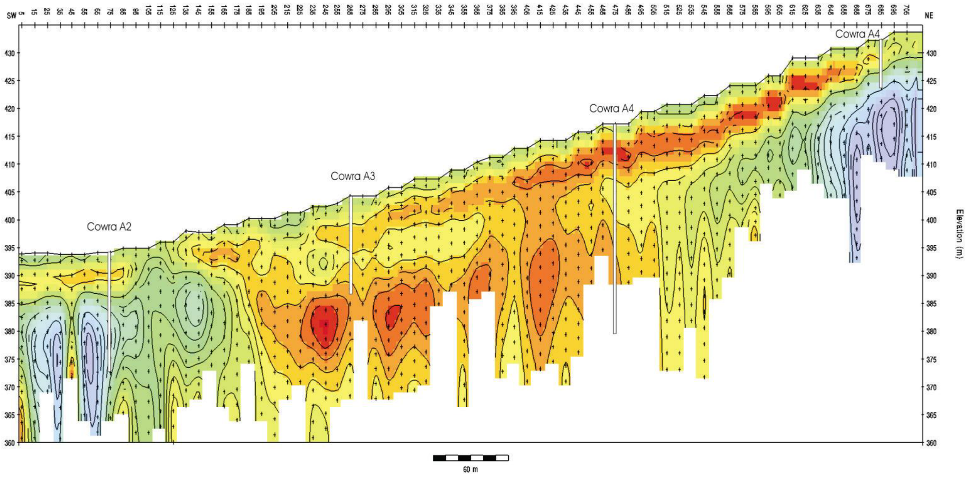
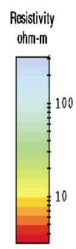



**Figure 2a:** Cowra transect A. This line was chosen to transect across a colluvial slope and valley floor. Holes were positioned over the upper, mid and lower parts of the colluvial slope and areas adjacent to the alluvial channel. A NanoTEM geophysical image showing variations in regolith and bedrock conductivity was collected over the same transect. High conductivities (red in 3a) correspond to transported clay and highly weathered bedrock.



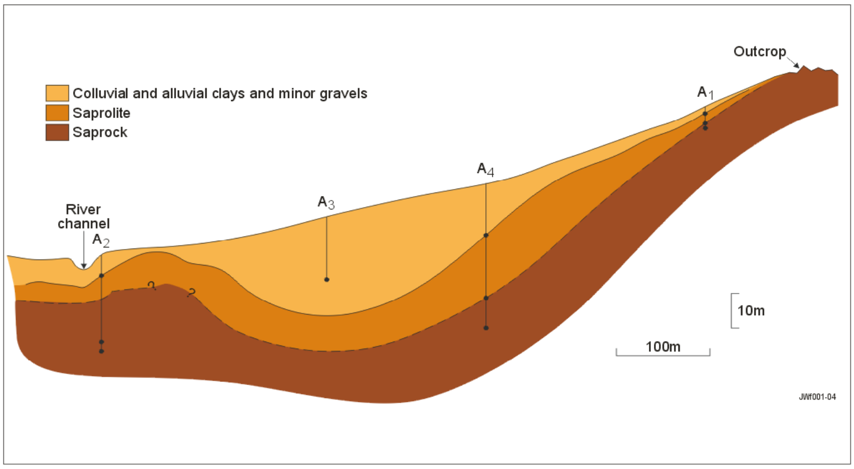



**Figure 2b:** Regolith interpretation of the transect based on analysis of ground geophysics and drilling information.

## CONCLUSIONS

This project has described the enormous complexity of the subsurface landscape in several project areas in and adjacent to the M-DB. The project findings have major implications for our understanding of how salt is stored and transported in landscapes, and differ significantly from the previous understanding provided through interpreting surficial datasets alone.

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