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The role of geophysics in understanding salinisation in Southwestern Queensland

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Key Words: salinity, electromagnetics, radiometrics, land management, southwestern Queensland

ABSTRACT

This study, combining geophysical and environmental approaches, was undertaken to investigate the causes of secondary salinity in the Goondoola basin, in southwestern Queensland.

Airborne radiometric, electromagnetic and ground electromagnetic datasets were acquired, along with data on soils and subsurface materials and groundwater. Relationships established between radiometric, elevation data, and measured material properties allowed us to generate predictive maps of surface materials and recharge potential. Greatest recharge to the groundwater is predicted to occur on the weathered bedrock rises surrounding the basin. Electromagnetic data (airborne, ground, and downhole), used in conjunction with soil and drillhole measurements, were used to quantify regolith salt store and to define the subsurface architecture. Conductivity measurements reflect soil salt distribution. However, deeper in the regolith, where the salt content is relatively constant, the AEM signal is influenced by changes in porosity or material type. This allowed the lateral distribution of bedrock weathering zones to be mapped.

Salinisation in this area occurs because of local- and intermediate-scale processes, controlled strongly by regolith architecture. The present surface outbreak is the result of evaporative concentration above shallow saline groundwater, discharging at break of slope. The integration of surficial and subsurface datasets allowed the identification of similar landscape settings that are most at risk of developing salinity with groundwater rise.

This information is now being used by local land managers to refine management choices that prevent excess recharge and further salt mobilisation.

INTRODUCTION

In recent years, salinity studies in Australia have integrated the interpretation of airborne geophysical data with more traditional environmental approaches. This allows regolith architecture and salt distribution to be resolved in three dimensions, greatly improving our understanding of water movement and salt mobilisation. In the National Airborne Geophysics Program evaluation, George and Woodgate (2002) noted this potential value of geophysical data to describe the nature of the materials in which salinity occurs and, importantly, therefore provide a focus for management. The variety of salinisation settings throughout Australia requires a tailoring of geophysical and other environmental datasets to understand groundwater and regolith processes in specific landscapes.

Through the Australian Government's National Action Plan on Salinity and Water Quality (Commonwealth of Australia, 2004), high-resolution airborne electromagnetic (AEM), radiometric, and magnetic data were acquired for the lower Balonne area in southwestern Queensland, in order to elucidate salinity processes in a complex alluvial landscape (Chamberlain and Wilkinson, 2004). The lower Balonne is also an area of high agricultural productivity, with a wide range of land uses.

The Goondoola basin, a known secondary salinity site in the east of the area flown (Figure 1), was chosen for a detailed study. The aims of this study were to define the current extent and severity of salinisation at the farm scale and to understand the causal processes, thus better informing land management options. A secondary aim was to evaluate the effectiveness of geophysical techniques in understanding these drivers. Details of the study area have been presented in Wilkinson (2003).

Study area

The Goondoola basin is an area of subdued topography, adjacent to the Moonie River, 50 km southeast of St George. This region is characterised by a semi-arid climate, with a mean annual rainfall of 520 mm, which falls in a summer-dominant pattern (Bureau of Meteorology, 2004). The basin is a small, closed depression filled with Cainozoic clays, developed on the Cretaceous Griman Creek Formation of the Surat Basin (Exon, 1976). The surrounding rises consist of ferruginised and partly indurated bedrock, with a relatively shallow cover of permeable soil (Kandosols and Dermosols). The Goondoola basin is fed by ephemeral and interrupted drainage from rises to the northeast. Close proximity to a major river system suggests that it may also receive sediment during flood events.

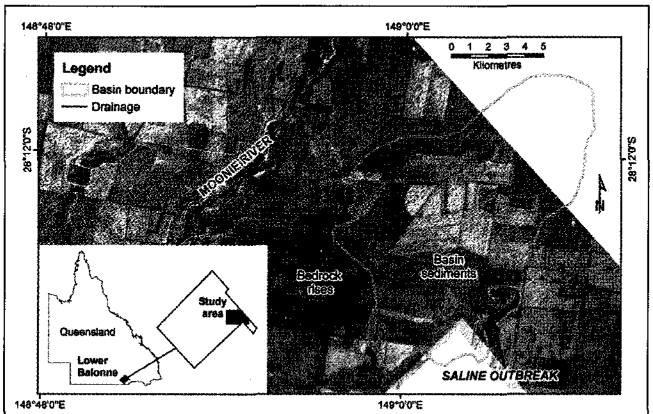

Fig. 1. Location and main features of the Goondoola basin study area in southwestern Queensland (background – Landsat RGB321 draped on shaded topography).

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Land salinisation and management

Galea (2003) described the farming history of the Goondoola basin. The study area was dominated by open woodland until the 1900s, when it was cleared and used as grazing land for sheep and cattle. Although there is local anecdotal evidence of a relatively shallow, salty water table since settlement, no effects were observed at the surface. Management practices changed in the 1980s and the basin was used predominantly for the farming of winter cash crops. Soon after the change in land use, waterlogging began to appear on the lower-lying land and surface expressions of salt appeared at the break of slope. To counteract the rising saline groundwater, landholders are now converting all lower-lying areas in the basin to deep-rooted pasture, while on the surrounding rises, a rotation of grazing and cash cropping is envisaged.

The current surface expression of salinity is limited to the base of a ridge on the southeast side of the basin (a 500 m × 300 m strip) (Figure 1), though shallow saline groundwater (50 000 μS/cm) occurs throughout the area. A better understanding of the processes causing this outbreak will allow improved local management. Ultimately, it is important to minimise enlargement of the saline area and salt mobilisation into surface water resources.

METHODOLOGY

Geophysical data acquisition

Radiometric and magnetic data covering the Goondoola basin area were acquired by Tesla Geophysics in April–May 2001, at a line spacing of 100 m and survey height of 60 m (Tesla Geophysics, 2001). The AEM survey was flown by Fugro Airborne Surveys in August 2001 using the fixed-wing TEMPEST system, at a line spacing of 250 m and survey height of 120 m (Owers et al., 2003). Elevation data were recorded in both surveys.

Frequency-domain ground apparent conductivity surveys were undertaken to validate the contractor-supplied AEM products. Over 400 line kilometres of EM31 (vertical dipole) data were collected along paddock boundaries. The maximum line spacing was 1 km and data points were recorded every metre. Sixteen line kilometres of EM34-3 data were collected along four profiles. Readings were taken at 50 m intervals using coil separations of 10 m, 20 m, and 40 m. Six boreholes (detailed below) were logged with a combined EM39 and natural gamma tool. The holes were logged at a speed of 5 m/min and recorded every 50 mm. Low-induction number corrections were made to these conductivity datasets. The EM31, EM34-3, and EM39 instruments allowed the comparison of conductivities at various depths.

The ground geophysical data served two purposes. They validated and led to an improved inversion of the AEM data. They also gave a better representation of material variation, both spatially and with depth, than is possible with AEM, due to the smaller sampling volume. This allows the detailed mapping of current salinity outbreaks, as well as discrimination between saline and fresh groundwater, and sand and clay in the bore profiles (when gamma is used in conjunction with conductivity).

Discrepancies between ground and downhole EM conductivities and AEM products supplied by the contractor led to reprocessing of the AEM data, as described by Lane et al. (2004). Considering the different volumes being measured, these final constrained inversion products correlate closely with both near-surface EM31 and downhole conductivities. The final AEM products included conductivity slices at 5 m depth intervals (to 200 m). In the Goondoola basin, these slices were converted into four conductivity-depth (cross) sections to investigate conductivity variations between drillholes. An east-west section is discussed in this paper (Figure 2).

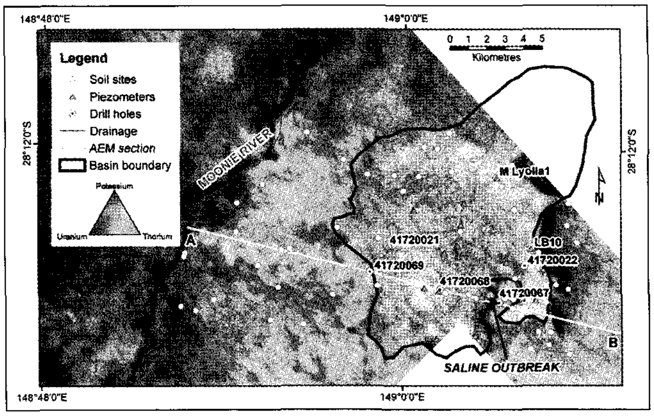


Fig. 2. Location of AEM conductivity-depth section, drillholes, piezometers, and soil sampling sites in the Goondoola basin study area (background – radiometrics ternary image draped on shaded topography).

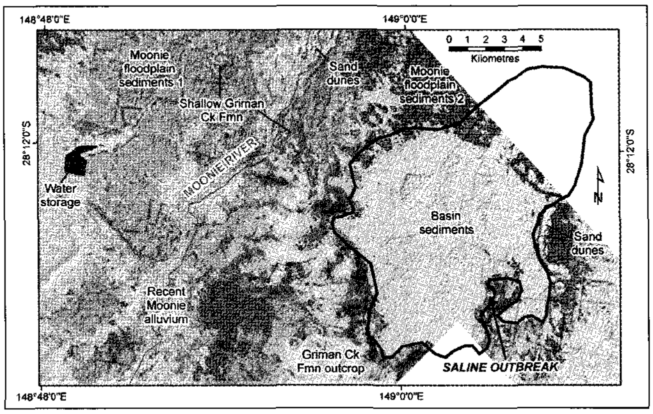


Fig. 3. Surface materials map of the study area (unsupervised classification of radiometric and elevation data draped on shaded topography).

Soil sampling

Fifty-four soil cores were collected (to depths of up to 4 m) to provide morphological and chemical information on surficial materials (Figure 2). Soil horizons were described, and bulk samples from each 0.5 m interval were analysed for soil pH, air dry moisture content, electrical conductivity, particle size, chloride, and cations (using methods from Rayment and Higginson, 1992).

Groundwater sampling

Twenty piezometers were installed in the Goondoola basin in 1999 at depths between 5 m and 18 m (Figure 2). Each bore was logged geologically each 0.5 m. Water depths are recorded biannually, and groundwater conductivity measured periodically.

Geology and regolith

Five air and mud rotary holes, and one cored hole, were drilled to a maximum depth of 60 m (Figure 2). All were geologically logged, and the cored hole sampled every 0.5 m and/or each

[1] The Multi-Resolution Valley Bottom Flatness Index is a composite scale index constructed from measures of flatness and local lowness (Gallant and Dowling, 2003).

facies change for moisture content, pore fluid chemistry, and bulk density (Jones, 2003). The rotary-drilled holes were developed as monitoring bores, from which water depths were measured and samples taken for chemical analysis.

RESULTS AND DISCUSSION

Surficial materials and processes

Distribution of surface materials

The radiometric data are related to material properties in the top ~0.5 m of the regolith and allow the discrimination of different surface materials (see Figure 2). When used in conjunction with elevation data, the distribution of materials can be related to landform.

Elevated radiometric thorium and uranium concentrations in the bedrock rises are coincident with high iron oxide content, consistent with observations in ferruginised regolith in Western Australia (Wilford et al., 1997). Outcrop on the crests of the rises displayed slightly higher thorium and uranium concentrations than the lower slopes. Radiometric signatures on the Moonie floodplain reflect two phases of deposition, with a potassium/uranium mixed unit likely to be sourced partly from surrounding bedrock. Moderate potassium concentrations north and east of the basin suggest that alluvial cover extends further than previously mapped in soil and land system surveys (e.g., Manning et al., in prep; Galloway et al., 1974). Several source-bordering sand dunes associated with the basin and the Moonie River channel are highlighted as very low responses in all three radioelements. The basin sediments contain high concentration of all three radioelements.

A map of surface regolith materials provides a framework for understanding current landscape processes. An unsupervised classification of the radiometric and elevation data (into seven classes), along with field investigation, was used to produce a surface materials map (Figure 3). As the saline outbreak in the southeast of the basin did not display a unique radiometric signature, the extent of surface saline occurrences could not be mapped using these data.

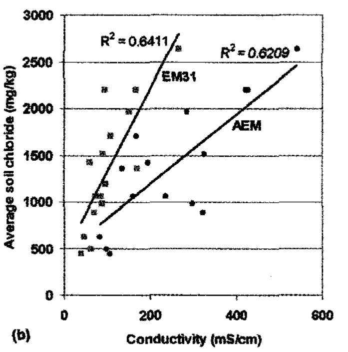
Surface salt load

The EM31 data were shown to have a greater capacity for discriminating areas of elevated surface conductivity than the AEM data. The highest conductivity values in the EM31 data coincide with the known extent of land salinisation. The 0–5 m AEM slice, however, which maps the entire area of basin sediments as highly conductive, does not isolate the saline outbreak. This is due to averaging of the AEM data over a larger sample space than the EM31.

Sixteen of the soil sites were cored to depths >3.5 m. Relationships between the electromagnetic data and soil attributes (averaged over depth of sampling) from these sites were investigated using regression analysis (Figure 4a). The strongest relationships exist between conductivity (EM31 and AEM) and soil salt indicators (chloride, EC 1:5, and moisture), while there

	EM31 (r^2)	AEM 0-5 m slice (r^2)
Chloride	0.64	0.62
Air-dry moisture content	0.51	0.70
EC	0.54	0.32
Clay %	0.24	0.4
Clay activity ratio	0.12	0.07

(a)



(b)

Fig. 4. Results of regression analysis of conductivity data and soil attributes; (a) strongest relationships exist between conductivity and soil salt indicators, (b) difference in spread of data against chloride reflects the larger sample size of the AEM compared to the EM31.

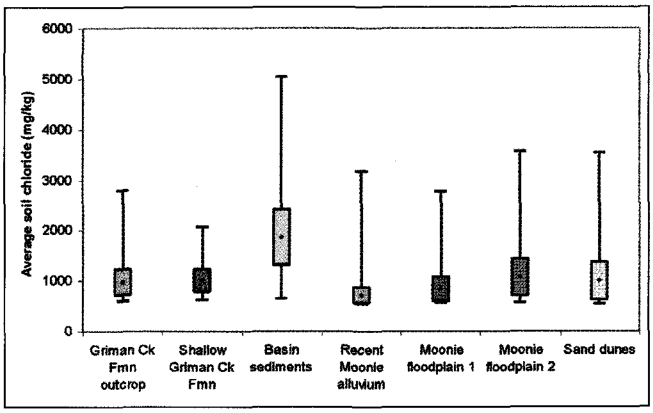


Fig. 6. Distribution of soil chloride within surface materials regions (box plot charts one standard deviation either side of the mean, along with minimum and maximum values).

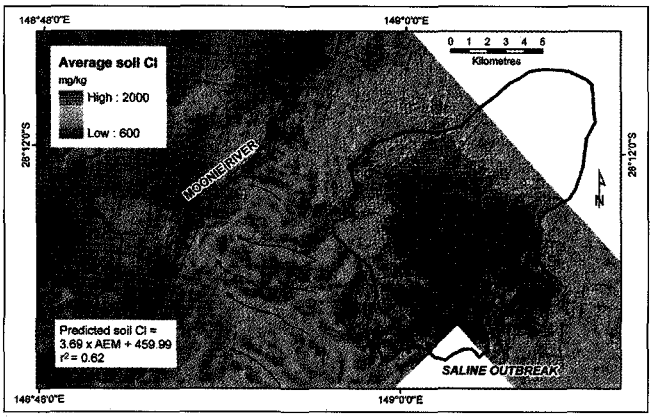


Fig. 5. Predicted average soil chloride concentrations for the top 5 m, showing highest values within the Goondoola basin, and the linear features surrounding the basin. The latter maybe are related to sediment-filled palaeochannels that continue to depth.

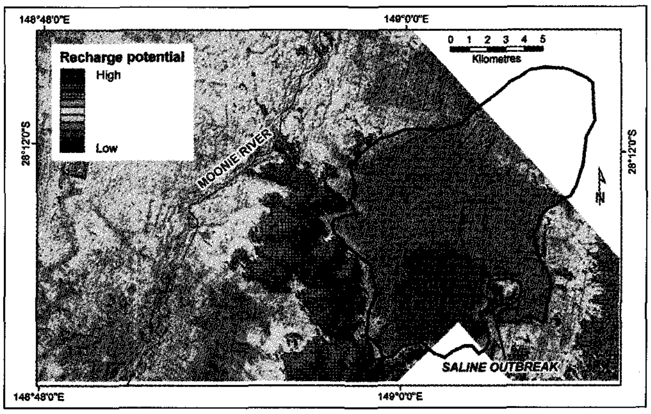


Fig. 7. Recharge potential map, showing high-recharge rises surrounding low-recharge basin sediments (recharge potential dataset draped on shaded topography).

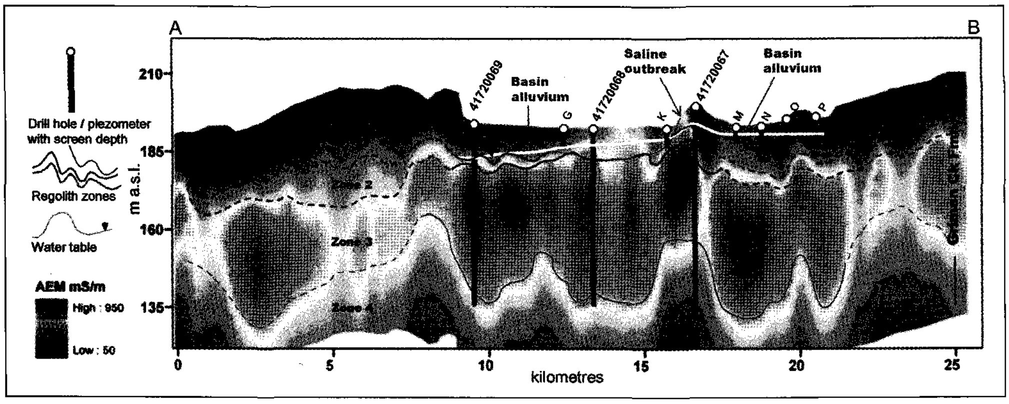


Fig. 8. AEM conductivity-depth section (location shown in Figure 2) with interpreted subsurface regolith architecture extrapolated from boreholes; note the absence of the indurated zones 1 and 2 beneath the basin sediments, with elevated conductivity values above.

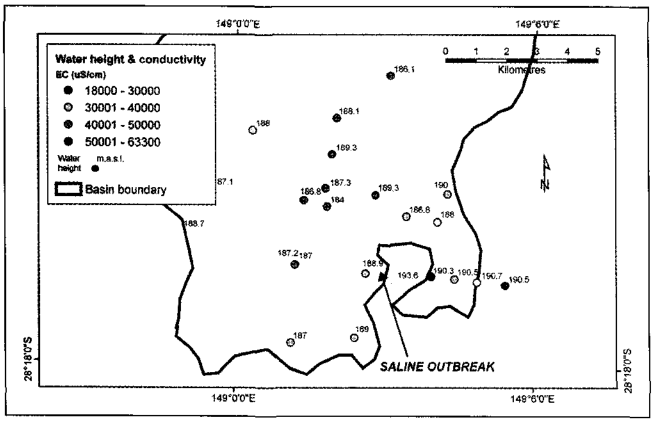


Fig. 9. Standing water level and groundwater EC measurements in summer 2003 for monitoring bores in the Goondoola basin study area.

was little correlation between conductivity and clay, suggesting that the conductivity data primarily reflect soil salt content. Figure 4b illustrates the different spreads of data between the AEM and EM31 when plotted against soil chloride. This again reflects the different sample size of the two methods.

A map of average soil chloride, generated using the relationship between the AEM data and chloride (r^2 = 0.62), shows high predicted chloride values within the basin (Figure 5). Linear features, characterised by elevated conductivity values, are apparent on the rises surrounding the basin. These features are also present in the deeper AEM conductivity slices (down to 30 m) and are not always coincident with current drainage features. As they show some relationship to linear patterns evident in maps of the first vertical derivative of magnetic data, the features are likely to be the result of a variable weathering overprint (goethite was noted in cores in the area). Since these features run between the saline Goondoola basin and the adjacent Moonie River system, further investigation is needed to see whether they have any effect on groundwater movement, such as providing preferential flow paths for saline water. There are no piezometers appropriately located to determine the hydraulic gradient between the basin and Moonie River, but the regional trend suggests an east-west gradient (Pearce et al., 2004). In the communication activities associated with this work, recommendations have been made to investigate these features.

The distribution of soil chloride does not relate directly to surface material type and texture alone, as large variability occurs in each surface material class (Figure 6). This indicates that the soil salt store does not principally reflect the natural soil salt distribution (balance between recharge and soil permeability); rather it is predominantly influenced by subsurface processes such as a shallow water table and lateral groundwater movement. Thus, the soil salt stores could not have been predicted based only on the surface distribution of materials.

Recharge properties

Highest recharge to the groundwater tends to occur on elevated landforms consisting of permeable materials (SalCon, 1997). The elevated landforms in this study area consist of permeable Kandosols, whilst the basin is dominated by slowly permeable Dermosols. An understanding of surface materials was sufficient to estimate recharge potential in the study area, because the water table is shallow.

A map of recharge potential across the study area was generated using a combination of elevation and radiometric potassium (Figure 7), as potassium correlates with particle size distribution in the 0–0.5 m interval (r^2 up to 0.75 for silt and clay content and -0.76 for fine sand content).

Regolith zone		Description
Basin sediments		Grey/brown clay and silt; low porosity; high moisture content; high salt load
Griman Creek Formation bedrock	Zone 1	Soft grey clay with iron oxide mottles, partially indurated near bottom; least porous zone with low moisture content; impediment to vertical water movement; low salt load
	Zone 2	Soft to hard, white siltstone and sandstone; most porous zone with high moisture content; moderate salt load; can be indurated
	Zone 3	Light grey siltstone, mudstone and sandstone with some mottling; moderate porosity; high moisture content; high salt load
	Zone 4	Fresh bedrock; hard, dark grey/brown sandstone with minor coal lenses; some mottling and iron oxide staining; low porosity and low moisture content; low salt load

* Conclusions on porosity and salt load from core analysis (Mullen et al., 2004).

Table 1. Regolith zones intersected in cored hole LB10.

Claridge and Grundy's (2004) spatial modelling of deep drainage also shows higher drainage on the elevated, low-potassium areas. It is predicted that highest levels of recharge to groundwater occur on the rises surrounding the basin (where weathered bedrock is exposed or close to the surface) and on the sand dunes. The sediments within the basin have the lowest recharge potential.

Subsurface materials and processes

Regolith properties

Drill logs indicate that the Goondoola basin sediments are up to 10 m thick. There is significant variation in properties of the underlying bedrock, and four distinct weathering zones have been recognised (Table 1) (Kellett and Mullen, 2003). Not all four zones are present in all locations.

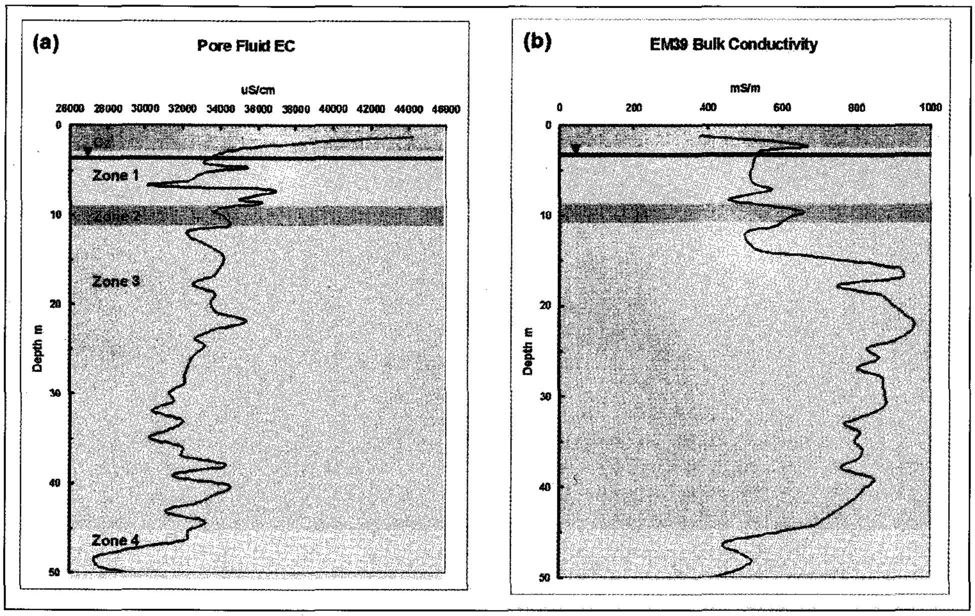


Fig. 10. (a) Profile pore fluid EC measured in cored hole LB10; (b) downhole EM39 measured in cored hole LB10.

The specific petrophysical properties of these regolith zones can be distinguished using a combination of downhole EM39 and natural gamma measurements. The variation in AEM response between each regolith zone allowed their lateral variation to be extrapolated from drillholes using AEM conductivity-depth sections (Figure 8). The most notable finding is that bedrock zones 1 and 2 appear to be absent in some areas beneath the basin sediments. These indurated zones are likely to hinder vertical water movement, so their absence may provide a "window" that permits saline water to move upward into the basin sediments (from an overpressured aquifer). Higher near-surface conductivities and measured soil salinity indicators in these areas support this hypothesis.

The AEM data do not appear to show any response to the water table, apparently due to a lack of sufficient conductivity contrast at the top of the water table.

The presence of fractures, especially in outcrop, and anomalous young isotopic ages of two groundwater samples taken in the larger lower Balonne study area (Herczeg, 2004) indicate that the Formation is a dual-porosity medium. The implications of this on salinisation processes is unknown, although it seems likely that there are areas where bypass flow through open fractures may accelerate recharge to the water table.

Groundwater

The similarity of water heights and major ion chemical composition of waters from piezometers screened in the basin sediments and Griman Creek Formation indicates that a continuous aquifer exists within the Formation, extending into the basin sediments. The groundwater is not free flowing; holes tend to be dry when drilled, but fill with water overnight.

Standing water levels indicate that overall flow direction is east to west, although a localised mound occurs under the ridge above the saline outbreak (hole 41720067). This is consistent with higher recharge in these permeable landscape units.

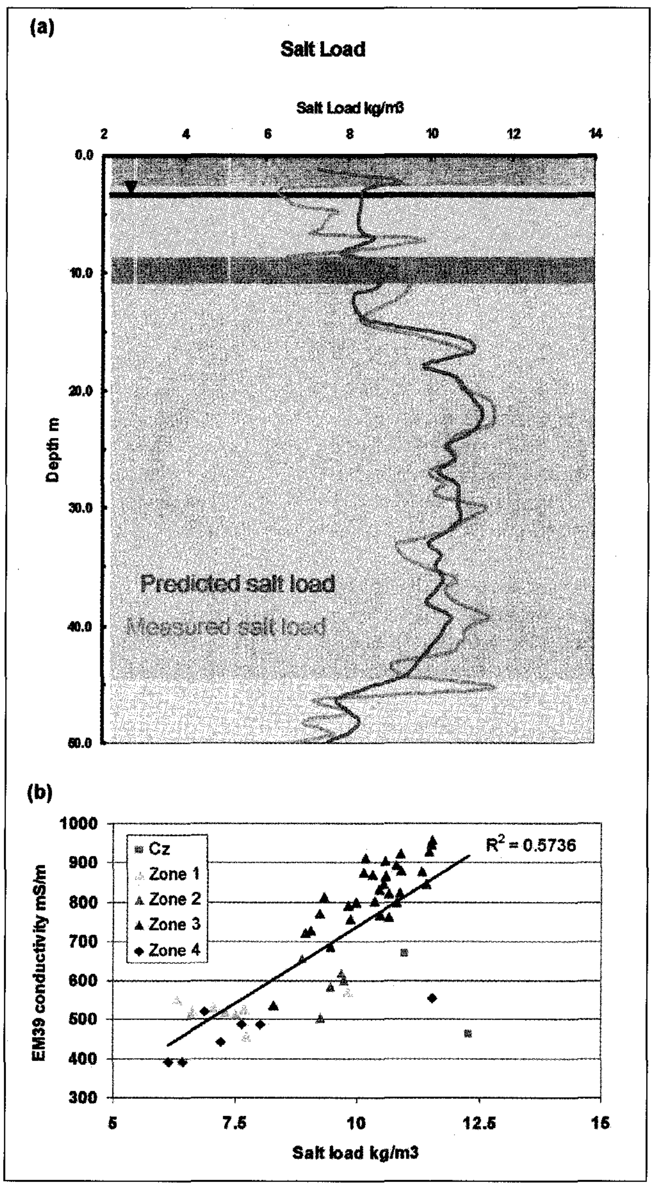


Fig. 11. (a) Profile of measured salt load (from equation 1) and salt load predicted using EM39; (b) the relationship between the salt load measured in cored samples and EM39 conductivity.

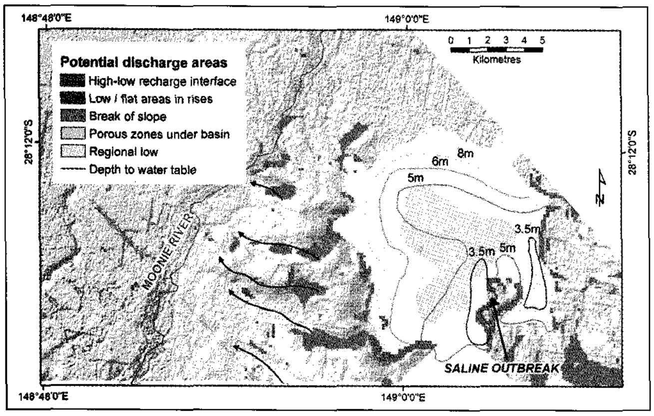


Fig. 12. Location of potential discharge areas and depth to water table in the study area.

The groundwater lies within 10 m of the surface and in some areas as close as 2 m (Figure 9). Major ion compositions are dominated by sodium, chloride, and magnesium. Water salinity ranges from 30 000 µS/cm in the east to 60 000 µS/cm in the centre of the basin. Water table height has decreased recently with drought (an average fall of 2 m in the last three years), although water salinity has remained constant. Anecdotal evidence from landholders indicates that water levels in piezometers are quick to respond to rainfall events, consistent with a local groundwater flow system.

Salt stores

A peak in the pore fluid EC (and all measured ions) occurs in the upper part of the basin sediments, evidence of evaporative concentration operating near surface. Below this, the EC is relatively constant, indicating that vertical flow processes dominate. However, bulk conductivity as measured by the EM39 does not reflect a similar pattern, suggesting that other factors are influencing the EM39 signal (Figure 10).

If regolith salt load is defined as a combination of pore-fluid total dissolved solids (TDS) and volumetric moisture (porosity and moisture content), the relationship with EM39 bulk conductivity improves:

$$\text{Salt load (kg/m}^3\text{)} = \text{TDS (mg/l)} * 0.001 * \text{volumetric moisture}$$

This measured salt load is consistently high throughout zone 3, making it the most significant salt store (Figure 11a). Other factors, such as clay type and content, may be involved in these relationships but appropriate data were not available to sufficient depth.

The ability to predict salt load from EM39 conductivity was also explored (Figure 11a and b). The strength of this prediction was found to vary between zones, indicating that complex relationships exist in each zone between conductivity and other physical properties not accounted for in the salt load equation. The most accurate predictions occurred in zone 3 (Figure 11a), the most conductive zone. This indicates that at higher conductivities the influence on conductivity is primarily from salt load, while other factors (such as clay mineralogy and cation exchange capacity) may have a greater influence at low conductivities.

Discharge potential

At present, discharging saline water occurs only in a small region at a break of slope. Current water levels, and the subdued topography of the area, are such that relatively small increases in groundwater levels will significantly increase in the area of discharge and salinisation. Evaporative concentration of salts in soils can occur when groundwater is ~<2 m. A conceptual model was developed to predict areas most likely to discharge in the future with increased groundwater recharge (Figure 12). These include the influence of both local- and intermediate-scale systems. It is proposed that the risk of discharge is highest in the following areas:

(1) *Local interface between high and low recharge areas*: recharge encounters sediments of significantly lower hydraulic conductivity, causing water to accumulate (predicted using a slope derivative of the recharge potential dataset). This predicts discharge to occur in a ring around the margin of the basin, including around the ridge where the saline outbreak is present.
(2) *Local low/flat areas within bedrock rises*: water accumulation in local low points (taken as values >2.75 in the Multi-Resolution Valley Bottom Flatness Index[1]; only for the bedrock rises). These are likely to be transient local systems. Several broad areas are predicted in the lower areas within the rises, both east and west of the basin.
(3) *Local break of slope*: the current saline outbreak occurs in this setting (predicted using high slope combined with low relative elevation values). This predicts discharge in some isolated areas around the margin of the basin.
(4) *Area beneath basin where indurated zones are absent*: intermediate scale; absence of subsurface induration permits preferential vertical water movement (delineated from drill logs, and AEM cross-sections and slices). Discharge through this area would occur due to a regional increase in water table. This prediction covers a large area in the centre of the basin.
(5) *Regional low of basin*: intermediate/regional scale; discharge may occur in depression if regional water table rises. This was predicted using the full extent of basin sedimentation.
(6) *Linear conductive features in AEM data:* possible preferential paths for water flow into the river. Further investigation is required.

Of the modelled potential discharge sites, those processes acting at a local scale in conjunction with a shallow water table will be most sensitive to changes in local land management practices.

Land management considerations

It is likely that a shallow saline water table would exist under natural conditions. Increased recharge because of land-use change has caused a rise in the water table resulting in waterlogging and land salinisation in the most susceptible areas of the landscape. From a salinity perspective, land management options must focus on limiting recharge to the water table.

Areas where greatest potential exists for recharge to reach the water table are highlighted in Figure 4. Land use in these areas should favour options with low deep-drainage rates, such as retaining or increasing deep-rooted perennial vegetation. In addition, it may also be beneficial to plant a row of deep-rooted vegetation or trees between recharge and discharge sites, in order to intercept water.

The current saline outbreak can be managed by covering the affected area with hay. This will impede evaporative concentration of salts near surface, and allow the downward flushing with rainfall. In time, it may be possible to establish salt-tolerant species. The potential discharge sites highlighted in Figure 12 may also be stabilised by the planting of salt- and water-tolerant species before surface salinisation occurs.

The landholders have formed an action group and are currently adopting cropping techniques that address issues of water-use efficiency. Pasture trials of salt-tolerant species such as lucerne, which provides good stock fodder as well as building soil nitrogen levels, are also currently underway in the study area.

CONCLUSIONS

Shallow saline groundwater is present over the entire study area (depth 2–10 m below ground surface). The current surface-salinity outbreak in the Goondoola basin results from the evaporative concentration of saline water, discharging at a recharge gradient and break of slope. It is important that recharge to the water table be limited, as any rise in water table height would result in an increase in area of salinisation.

The integration of airborne and ground geophysical data with soil and borehole data allowed the interaction of surficial and subsurface salinity drivers to be understood and the identification of landscape settings similar to the current outbreak.

Within the basin sediments, both ground and airborne electromagnetic surveys provide a snapshot of salt distribution. The current extent of the surface saline outbreak can be mapped using the EM31 dataset. Highest near-surface salt concentrations occur within the basin and in linear features in the adjacent rises. High salt stores also exist throughout the subsurface, but the ease with which they are mobilised is controlled by the weathering overprint.

Radiometric and elevation data were used to map the nature and distribution of surface materials. These did not reflect the subsurface properties and salt stores. Salt profiles (EC and major ions) in the basin sediments indicate that evaporation/transpiration of the shallow groundwater is the main process controlling surface salt distribution. These data were also used to predict recharge potential to the groundwater, which is necessary for effective land management.

The AEM data, used in conjunction with drillhole data, were invaluable for determining subsurface architecture. In contrast to the basin sediments, within the weathered Griman Creek Formation the salt content is relatively constant, so that the AEM can be used to map the lateral distribution of the weathering zones, because the AEM signal influenced by changes in porosity or material type.

The mapping of potential salt stores, recharge, and discharge sites has led to a number of land-management recommendations. Future land-management decisions can be refined by the continued monitoring, with increased intensity, of water table heights to provide information on the hydrological response times in different regions. Repeat ground EM surveys may also be beneficial to map mobilisation of salt caused by seasonal factors and land-use changes.

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クィーンズランド州南西部における土壌塩害の研究

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要 旨： 本研究では物理探査法と環境科学的手法を組み合わせてクィーンズランド州南西部の、Goondoola 盆地の二次塩化の原因を調査した。
地表および地下の物質と地下水についての情報に加えて、一連のエアボーン電磁・放射線探査および地表での電磁探査データを取得した。放射線探査と標高のデータとサンプルで測定された物性の間から導かれた関係から、地表の物質分布と塩分涵養の可能性の予測地図が作成された。地下水中への塩分の主な涵養源は堆積盆周辺の風化した基盤岩中にあることが推定された。
地下構造と表層風化層中の塩分貯留域の定量的把握には、土壌と孔井の測定とともに、エアボーン・地表・孔井の電磁探査データが使用された。
一般に、電気伝導度は土壌中の塩分分布をよく反映する。一方、塩分含有量が比較的一定な風化層深部においては、エアボーン電磁探査の信号は孔隙率の変化と岩質の違いに影響されるという特徴を持つ。そのため、エアボーン電磁探査データを用いて、風化域の水平分布図を描くことが可能となる。
この地域の塩害化は表層風化層の構造に強い影響を受け、局所的あるいは中規模区域のプロセスで生ずることが確認された。地表データと地下データのこうした結合によって、地下水面の上昇に伴う塩害が広がりそうな地形を認知できるようになった。この結果は、今後特に過度な塩分の涵養と移動塩を防ぐための管理計画の整備に利用される。

호주 Queensland 남서부 지역의 염분작용 조사

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요 약: 이 연구에서는 지구물리 및 환경공학적 방법을 동원하여 호주 Queensland 남서부 Goondoola Basin 에서의 2 차 염분작용의 원인을 조사하였다.
지표 및 지하 물질과 지하수에 대한 정보와 함께 항공 방사능 및 전자탐사 그리고 지표 전자탐사 자료가 얻어졌다. 방사능과 고도자료 및 측정된 물성간에 얻어진 상관관계로부터 지표 물질 및 지하수 유입 포텐샬의 예측도를 만들 수 있었는데, 가장 큰 지하수 유입은 분지를 둘러싼 풍화 기반암에서 일어나는 것으로 예측되었다. 전자탐사자료(항공, 지표 및 시추공)는 토양 및 시추자료와 함께 천부 소금층의 크기와 지하 구조를 규명하는데 사용되었다. 전기전도도 측정자료는 토양 염분의 분포를 반영하고 있다. 그러나 표토 깊은 곳에서는 염분함량이 상대적으로 일정하여, 항공전자탐사 신호는 공극률 또는 물성의 변화에 따라 영향을 받았으며, 이러한 결과로부터 기반암 풍화대의 수평적인 분포를 탐지할 수 있었다.
이 지역의 염분 작용은 표층 구조에 의해 강하게 좌우되는 국부적 및 중간 크기 과정의 결과로 발생하며, 현재의 지표 현상은 사면의 균열에서 유출되는 천부 염분 지하수 상부에서의 증발 농축의 결과이다. 표층과 지하 자료의 종합으로부터 지하수위 상승에 따른 염분도 증가로 야기되는 유사한 산사태 구조의 규명이 가능하였다.
이 정보는 현재 지방 토지 관리자가 과도한 지하수 유입과 더 이상의 염분 이동을 막는 관리방법의 개선에 이용되고 있다.

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