South Australian Salinity Mapping and Management Support Project: Final Report

A synthesis of research carried out under the South Australia Salinity Mapping and Management Support Project [SA SMMSP]

Glen Walker[1,2], Richard Cresswell[2,3], Tim Munday[3,4] and Craig Liddicoat[1]

1 – Rural Solutions SA,

2 – CSIRO Land and Water,

3 – CRC for Landscape Environments and Mineral Exploration,

4 – CSIRO Exploration and Mining]

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Land and Biodiversity Services Division
Department of Water, Land and Biodiversity Conservation
Soil and Water Environs Centre, Waite Rd, Urrbrae
GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8303 9500
	International	+61 8 8303 9500
Fax	National	(08) 8303 9555
	International	+61 8 8303 9555

Website www.dwlbc.sa.gov.au

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EXECUTIVE SUMMARY

While much is known of the processes leading to salinity throughout South Australia, implementation and prioritisation of salinity management often requires detailed spatial knowledge of where measures are best targeted. With the promise of obtaining cost effective spatial information to assist with salinity management, airborne geophysics were put to the test in the $3.8M South Australian Salinity Mapping and Management Support Project (SA SMMSP), jointly funded by the Australian and South Australian Governments through the National Action Plan for Salinity and Water Quality (NAP).

The SA SMMSP represents a significant departure from previous studies seeking to apply airborne geophysics in salinity management, in that it was the first occasion in Australia where geophysical data were deliberately acquired a*s part of* a broader natural resource management strategy. A carefully targeted approach was taken, giving due consideration to the problems being addressed. Particular importance was attached to ensuring that geophysical data could provide a product of value and perhaps more importantly, how that product could be incorporated into the implementation of appropriate management strategies. This approach reflected the thinking promoted earlier by George and Green (2000) on the relevance of airborne geophysics to land management.

Five key areas across the state were chosen to trial the technology. These were: the Riverland (border to Lock 3), Angas-Bremer Plains, Tintinara, Jamestown and the Bremer Hills. These were chosen on the basis of priority for salinity management as well as representing a range of different landscapes, assets at risk, potential management options and maturity of regional planning. The extent of existing knowledge was also a factor and substantial existing information was essential for both proving the technology and enhancing interpretation of the acquired data. Different management issues required tailored approaches for the geophysical techniques to be taken at each site.

In the Riverland, mapping the shallow subsurface Blanchetown Clay was deemed a priority to assist with future irrigation planning and efficiency improvements to reduce recharge and the impact of high salt loads being driven into the River Murray. Airborne electromagnetics (AEM) has successfully mapped this impeding layer of clay, at a much greater resolution than was previously possible. This improved information on the Blanchetown Clay has been utilised in regional planning and decision support tools, which combine a range of other regional spatial data, to help assess the impacts of development on salinity in the River. Additional unexpected benefits have come through the delineation of buried ancient stranded beach dune systems (‘strandlines’) that offer hydraulically conductive features for use in pumping groundwater to reduce saltloads going into the Murray. The design of the Bookpurnong salt interception scheme (SIS) has already benefited from this discovery.

At Tintinara, two sites were investigated. In the east (mallee highlands), mapping subsurface clay will enable irrigation planners to slow the rate of salinisation of the local underlying fresh groundwater resource. In the west (coastal plains) the focus is on identifying native vegetation at risk from salinity. At the Tintinara East site, significant insight has been obtained into the thickness and extent of the sub-surface clay. Spatial estimates of recharge, salt flux and groundwater salinity have identified zones at particular risk, under dryland and irrigated agriculture. Further scenario modelling will enable planners to investigate tradeoffs between rates of salinisation and potential beneficial uses of the groundwater resource. In the West site, zones of shallow saline groundwater were successfully detected and areas of native vegetation at risk have been identified. A further discovery, following an enquiry from a driller, has been the identification of zones of shallow granite basement in the west of the coastal plains study area which should be avoided when drilling for locally scarce, fresh groundwater resources.

Across the Angas-Bremer Plains, the initial goal of identifying buried ancient drainage lines (paleochannels), as a possible means for better control and protection of the locally important irrigation aquifers, was abandoned after these features did not appear to be significant based on the airborne data. The study changed focus to investigate dominant recharge mechanisms and build further on knowledge of the aquifers. Analysis of groundwater and surface water geochemistry; AEM; the digital elevation model (DEM), produced by the SA SMMSP surveys; and a thorough investigation of new and existing borelogs and previous work in the area has yielded an enhanced understanding of aquifer geometry (salinity and geological boundaries) and its recharge mechanics.

Around Jamestown, salinity and waterlogging have impacted on high value cropping land, generally following periods of higher-than-average rainfall. While the region has successfully implemented a variety of salinity management options and localised expressions of salinity have abated in recent years, it was thought that mapping of subsurface features associated with the movement of groundwater would help better understand salinity processes and assess recharge control options. Paleochannels, buried beneath the valleys of the Jamestown region, were successfully mapped using a combination of magnetics and AEM data, while radiometrics data offered improved insight into soils, landscape processes, and potential land management units. The underground network of paleochannels thus provide zones of enhanced groundwater transport and appear to alleviate potential for salinity where drainage is good and exacerbate salinity problems where they converge into ‘bottlenecks’.

In the Bremer Hills, the aim was to identify and map the causes of saline input to streams, with a focus on zones of deeply weathered rock. Modelling based on radiometrics data and topography was used to successfully map zones of deep weathering which potentially provide storage for large quantities of cyclic (rainfall deposited) salt. Rainfall and drainage conditions were also found to be important factors in determining whether these deeply weathered profiles were actually storing and releasing salt to the waterways.

The SA SMMSP has successfully demonstrated a range of applications of airborne geophysical techniques for assisting with salinity management. Successful outcomes were achieved through the engagement of an experienced, multidisciplinary team (spanning several organisations) and regular liaison with regional communities. The lessons learnt from this project have yielded guidelines for the planning, design, and implementation of future surveys. These technologies are recommended for application elsewhere in the state, in line with regional NRM investment priorities and the applicability of targets for investigation through geophysical methods. In some cases, the SA SMMSP has highlighted where analysis of previously existing lower-resolution geophysics data could yield significant benefits for salinity management, at reduced cost.

Where high value assets are at risk, and appropriate preparatory work has established the validity of the target and approach being adopted, airborne geophysics offer a suite of investigative tools that are worthy of consideration in the field of salinity management.

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INTRODUCTION

This report synthesises results for the South Australian Salinity Mapping and Management Support Project (SA SMMSP). With investment provided by the Australian and South Australian Governments under the National Action Plan for Salinity and Water Quality (NAP), the project had the following aims:

- to test airborne geophysical techniques (in particular electromagnetics [EM], radiometrics, and magnetics) to determine their value in application to salinity management,
- to further refine and adapt the technology to suit this application, and
- to provide specific information to assist with salinity management in five key areas of South Australia.

The SA SMMSP adopted a pioneering approach compared to traditional research programs involving the acquisition of geophysical data. Instead of accepting data collected in an arbitrary manner, which may add to knowledge but be of little use for management, considerable thought went into how the data generated could contribute to the implementation of salinity management options applicable at each site.

By providing interpreted, appropriately targeted, spatial geophysical data and associated decision support tools, the program seeks to reduce the impacts of salinity on land, surface water quality, groundwater quality and biodiversity.

Advancing considerably on existing knowledge, the outputs of the SA SMMSP offer:

- Detailed knowledge of the distribution and causes of dryland and irrigation-induced salinity.
- Potential land and water management solutions, using a multidisciplinary approach.
- Salinity and materials mapping, and on-ground calibration information, which will enable regional bodies to develop and refine their respective Integrated Natural Resource Management (INRM) Plans.
- More effective targeting of planning controls, development incentives, trading schemes and protection zones in INRM plans and subsequent investment via the NAP or other funds.
- Identification of both current and future impacts of salinity on natural ecosystems, and biodiversity assets at risk.

This project was conducted at five study areas in SA. The study areas were chosen on the basis of priority for salinity management as well as representing a range of different landscapes, assets at risk, potential management options and maturity of regional planning. All the sites are shown in Figure. 1. Four study areas were in the western Murray Basin (Riverland [Lock3 to Border], Tintinara, Angas-Bremer Plain, and the Bremer Hills) and one was in the mid-North (Jamestown).

Table 1 shows the issues and targets for each study area. This lists the assets at risk, management issues, geophysical targets and characteristics of the geophysical devices flown.

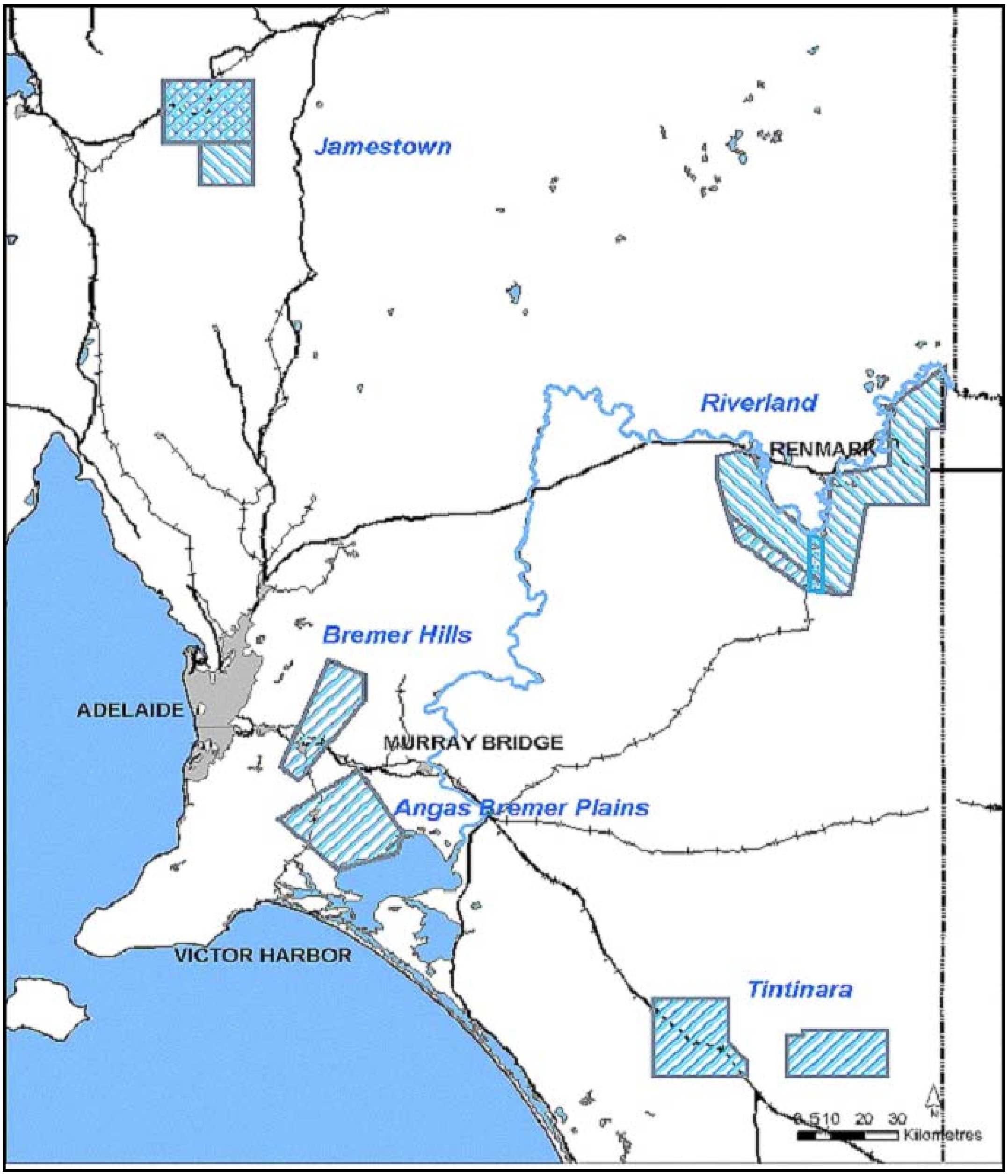

Figure 1. Location of the 5 study areas

Table 1. Issues and targets for the study areas. (Bracketted targets were additional to the original project schedule; *target changed from original)

	Main asset at risk	Management options targetted	Geophysics target	Geophysical Device
Riverland	River Murray water Floodplain biodiversity	Irrigation zoning Siting of revegetation and recharge reduction Salt Interception Schemes)	Sub-surface Clay (Aquifer properties)	Helicopter-borne RESOLVE fixed frequency electromagnetic induction 150-300 m line spacing
Tintinara	Groundwater resource Remnant native vegetation	Land use planning Irrigation management Groundwater management	Sub-surface clay Salinity of shallow groundwater (Presence of shallow basement rock)	Helicopter-borne RESOLVE fixed frequency electromagnetic induction 300 m line spacing
Angas-Bremer Plains	Groundwater resource Remnant native vegetation	Water allocation planning Irrigation management Groundwater management	*Shallow paleochannels Spatial patterns of groundwater salinity at various depths Soil properties	Plane-borne TEMPEST time domain electromagnetic induction 200 m + 400 m line spacing Radiometrics – magnetics 100 m line spacing
Jamestown	Agricultural land	Recharge reduction	Soil properties Salinity of groundwater at various depths (Shallow paleochannels)	Plane-borne TEMPEST time domain electromagnetic induction 400 m line spacing Radiometrics – magnetics 100 m line spacing
Bremer Hills	Stream water quality	Siting of recharge reduction	Depth of weathering Soil properties	Radiometrics – magnetics 100 m line spacing

PART A. PROJECT OBJECTIVES AND EXPECTED OUTCOMES

The SA SMMSP was funded as a Priority Project under the NAP. The Project Schedule sets out a series of objectives and expected outcomes for the project.

1 Project Objectives

The priority action seeks to reduce salinity impacts on land, surface-water quality, groundwater quality and biodiversity in key areas of the state by providing interpreted spatial geophysical data and associated decision support tools for salinity management. The work will specifically acquire the geophysical data, calibrate the data though field and laboratory work, interpret the data in a way meaningful for salinity management, and develop support tools to make best use of the data.

Each of the five study areas was assigned a specific major management objective. Tintinara was split in to 2 sites with differing salinity concerns. In addition, a number of other site-specific scientific and environmental objectives were determined, as outlined in Part C. The overall aims were to:

- Map the Blanchetown clay layer within a 12 km zone of the River Murray from Lock 3 to the Border and adapt tools to use this information for predicting the impact of land management decisions on salt loads to the River Murray.
- Map the shallow clay within the Tintinara region and adapt tools to use this information to predict the impact of land management decisions on quality of the underlying groundwater resource.
- Map zones of groundwater salinity on the Coastal Plain near Tintinara and use this information to study salinity impacts on native vegetation.
- Provide information on salt stores and zones of high permeability in the Angus-Bremer Plain that may enable targeted groundwater control to protect high-value horticulture.
- Provide information on depth, structure and salinity variations within alluvial groundwater systems of the Jamestown area and salinity interpretations of radiometric data over the wider upland area, and develop tools that use this information to predict impacts of land management on land salinity.
- Interpret radiometric and magnetic data in association with other datasets to better understand the relationship between stream salinity in the upland portion of the Bremer catchment and regolith, groundwater, soils and land use."

2 Expected Outcomes

Outcomes from the overall program were to include:

- Salinity mapping and on-ground calibration information that will enable regional bodies to develop and refine their respective INRM plans.
- More effective targeting of planning controls, development incentives, trading schemes and protection zones in INRM plans and subsequent investment under the NAP, or other funds.
- Botanical surveys to identify both current and future impacts of salinity on natural ecosystems and identify biodiversity assets at risk from salinity.

It was expected that the results from this Project would feed directly into the managerial plans of the respective NRM groups and result in implementation of management options by landholders, State agencies or community / interest groups. This Project does not develop the activities that might be expected to flow from this work, but considerable effort has been undertaken in communicating the results from this Project to parties that are in a position to carry out those managerial decisions.

The site-specific outcomes are summarised in Part C and overall project outcomes are presented in Part D. The latter includes a discussion of the following components:

- Project design and implementation;
- Project management;
- Project benefits, and
- Project implications for future surveys – refining the technology.

Reports generated from the SA SMMSP are listed in Appendix A. This includes detailed technical reports covering individual components of the work and summary reports which synthesise the work undertaken in each study area.

PART B. AIRBORNE GEOPHYSICAL TECHNIQUES

One of the major aims of the SA-SMMSP was to assess the usefulness of airborne geophysics in addressing salinity and water quality issues, such as resource evaluation and problem mitigation. Four distinct geophysical techniques were employed across the five study areas (see below and Information Box on next page), with each technology used for a different but complementary purpose. Variations and combinations of the techniques enable a tailored approach to the different conditions and management issues encountered.

3 Techniques and Targets

Airborne electromagnetics (AEM) are used to define the 3-dimensional conductivity structure of a region to describe the salt-water-materials relationships in terms of their defining electrical conductivity signal. This can potentially spatially define high (and low) salinity groundwaters and zones of high (and low) salt load. It may also indicate sub-surface variability in materials, specifically the clay: silt: sand contribution[1].

AEM requires careful calibration to determine the relative contribution of conductive materials, but is the only geophysical technology that has the potential to map salt load directly in the sub-surface with good vertical resolution.

Radiometrics can give a spatially precise picture of surface soil and rock variability across a landscape. Flood plain, or alluvial, sediments can be contrasted with the coarser slope, or colluvial, deposits and the bedrock on ridges.

Magnetics detects the presence of iron-rich minerals which are commonly associated with older sub-surface drainage lines – palaeochannels – that may act as conduits for groundwater flow. Geological structures (eg. faults, dykes, etc) are also often emphasised using this technology.

Altimetry / Elevation information is required to process the geophysics data but also can be of great value in helping to understand and / or model landscape processes.

[1] Sub-surface material differentiation was examined in the companion Riverland and Tintinara East surveys, while groundwater quality was the focus for Tintinara West. For the Jamestown and Angas-Bremer surveys, the distribution of groundwater conduits and aquifer extents defined the role of AEM.

Airborne Geophysical Techniques

AIRBORNE ELECTROMAGNETICS (AEM)

A pulse of EM radiation is emitted from the aircraft and interacts with conductive material in the ground. A modified, secondary signal 'bounces' back to a towed receiver that collects parcels of data in either time or frequency domains. These signals can then be modelled, or 'inverted', to define the 3-dimensional conductivity structure of the survey area. From the electrical conductivity signals and appropriate ground-truthing, the relative composition of salts, water and materials in the profile can be defined. Potentially, this can spatially define high (and low) salinity groundwaters and zones of high (and low) salt load. It may also indicate sub-surface variability in materials, specifically the clay: silt: sand contribution.

Vertical reliability and resolution is strongly dependent on the modelling routines used to convert the raw data into depth images and this is highly constrained by the interpretation of drill-hole data and pre-conceived ideas about the landscape and nature of the sub-surface (e.g. Hunter, 2001; Christensen, 2002). Interpreted data must, therefore, be treated with extreme care.

RADIOMETRICS (GAMMA)

Radiometrics detect the natural gamma radiation signal given off by near-surface (< 30cm) materials and can give a spatially precise picture of soil and rock variability across a landscape. The relative amounts of radioactive elements, namely potassium (K), uranium (U) and thorium (Th), are indicative of source minerals and hence soil and rock-types. This can help contrast regions of differing clay, silt and sand compositions. The ratio of different gamma intensities can give clues to a landscape's development. For example, potassium depletion may indicate an older and hence thicker weathering profile which may be correlated with elevated salt loads (Wilford, et al., 2001). It should be noted, however, that, with existing technology, radiometrics cannot measure salt directly.

MAGNETICS

Airborne magnetics detects the subtle variability in the earth's magnetic field caused by the presence and absence of ferromagnetic minerals such as magnetite (Fe_3O_4), maghemite (□-Fe_2O_3), pyrrhotite (FeS) and ilmenite ($FeTiO_3$). These minerals are commonly associated with stream-bed deposits and have been used (e.g. around Jamestown (Wilford, 2004) and to the east across Honeysuckle Creek, Victoria (Cresswell, et al., 2004)) to pick-out sub-surface drainage lines – palaeochannels – that may act as conduits for groundwater flow. Further, these minerals are common in many igneous rocks, both as primary and secondary minerals, and can often be used to depict geological structures in the sub-surface from discontinuities seen in the airborne images.

ALTIMETRY

As a necessary by-product of flying the other 3 geophysical techniques, a precise digital elevation model (DEM) is generated from the radar and laser altimetry used to precisely locate the aircraft above the ground. The resolution is a function of the spacing of the flight lines and the signal repeat time, but generally this results in a spot measurement taken every 10m along the flight path, with flight paths 100m apart for the combined radiometrics and magnetics survey and between 100 and 400m for the AEM survey. The resultant data is interpolated to give an exact surface on which to "hang" the other data sets and provide a surface reference for other studies. The DEM also often gives new insights into the evolution of landforms and landscape relationships (Gibson, 2004).

4 Limitations

There are three significant limitations to the application of airborne geophysical techniques:

1. All surveys represent a snap-shot in time of the geophysical properties of the landscape. As such, they are only an approximate indication of the average ambient conditions across a region and the observations must be carefully evaluated with respect to their position in time and relative to ambient climatic conditions.
2. Careful, systematic and accurate ground-truthing, or calibration, is a vital pre-requisite for realistic interpretations of the airborne geophysical data. This generally costs at least as much as the surveys.
3. Each technology has its own strengths and weaknesses, and AEM, in particular, comes in a number of guises, each with peculiarities that allow it to be tailored to address the most prevalent issue for a given area. Forward modelling, or scenario-testing, is a useful exercise that should be carried out on dummy data sets representative of conditions expected to be met over the real survey area.

Bearing these caveats in mind, airborne geophysics provides a suite of powerful tools that can give un-paralleled insights into landscape form and function, providing a quasi-continuous image of ground conditions and hitherto unprecedented spatial analysis of fundamental environmental features. Used without due diligence, however, the data can also give misleading, or even quite erroneous, results.

5 General Approach

All available existing datasets (e.g. groundwater records, mineral exploration surveys, hydrology investigations, previous geophysics, historical anecdotes) were accessed and analysed with regard to the investigations to be conducted at each study area. This provided the framework onto which the airborne geophysics could be placed and an essential context for interpreting the results.

Following flying of the airborne geophysics, field validation was undertaken:

1. Drillholes were sunk at strategic locations throughout each of the study areas;
2. Sub-surface geophysical properties (conductivity, radiometrics and magnetic susceptibility) were logged, and the materials encountered described;
3. Water levels and groundwater salinities were measured in existing and new bores,
4. Groundwater and soil samples were taken for analyses, and
5. Field conditions and landscape features were assessed.

Following the field investigations, the airborne geophysical data was re-interpreted and re-modelled, in an iterative process. This was particularly the case for the AEM data. As more on-site / ground-based information becomes available, so a closer match to reality can be achieved through modelling of the remotely sensed data. Interpretation must be viewed as a continually evolving process in order to benefit from the increased availability, quality and variety of datasets at our disposal.

Engagement of the local community was achieved through public meetings and interaction with management committees. This provided feedback on the efficacy of the approaches and the relevance to local issues. Appendix C provides a list of communication activities and examples of media clippings, used to engage with local communities and NRM planning bodies.

Figure 2. A fixed wing aircraft featuring the TEMPEST AEM system as used for the Jamestown and Angas-Bremer surveys (Image provided by Fugro Airborne Surveys).

Figure 3. The helicopter-borne RESOLVE AEM system used for the Riverland and Tintinara surveys. This system is better suited to resolving shallow targets (such as the Blanchetown Clay), than the fixed wing system.

PART C. RESULTS FROM EACH REGION

The following summaries are drawn from the final reports for each study area, which are in turn a synthesis of a number of technical reports prepared for each area. The full list of technical and site summary reports are listed in Appendix A.

6 Riverland

Overall Aim:

Map the Blanchetown clay layer within a 12 km zone of the River Murray from Lock 3 to the Border and adapt tools to use this information for predicting the impact of land management decisions on salt loads to the River Murray.

Objectives:

Determination of the depth, thickness and continuity of the Blanchetown Clay at sufficient resolution to enable:

- targeting of recharge-reduction options in dryland areas
- focus for improved irrigation efficiency and drainage works in irrigation areas;
- zoning of irrigation development.

Outputs:

- A map of the Blanchetown Clay within a 12 km zone from Lock 3 to the Border, as inferred from an EM conductance map and field calibration (Cook *et al.*, 2004);
- Improved regional planning tools including:
    - o Improved recharge maps for underlying groundwater systems up to 100 years into the future, using the Blanchetown Clay map and recent developments in soil hydrology (Cook *et al.*, 2004).
    - o A floodplain impacts model that simulates the impact of the floodplain on salt loads to the River Murray and impact of irrigation development on the floodplain (Overton *et al.*, 2003).
    - o Improvements to SIMPACT (irrigation planning model) and Border-to-Lock 3 MODFLOW model (used for land use changes and salt assessments) to incorporate improved recharge maps and floodplain attenuation model. (Cook *et al.*, 2004; Barnett and Yan, 2004)
- Information assisting salt interception schemes (unexpected output) (Munday *et al.*, 2004a)
- Report on overall investigations (Munday et al., 2004b)

The following summary of the Riverland work is drawn from Munday et al. (2004b), which itself is a synthesis of SA SMMSP work conducted in this study area.

6.1 BACKGROUND

In the Riverland region of South Australia natural inflows of highly saline groundwater to the River Murray have been exacerbated by irrigation development. Dryland agricultural land use and further irrigation development will continue to increase these inflows into the future. Salinity mitigation measures to maintain water quality in the river include groundwater pumping schemes, irrigation zoning, improvements in irrigation water use efficiency and recharge control through revegetation with perennial plants.

For both irrigation and dryland farming land use, there are long time delays between development and the impacts on salt loads in the River to be fully realised. Similarly, for salinity mitigation options, there is a long time delay between the change in land use and salinity benefits in the river. These time delays critically affect the viability of salinity mitigation land use options. It is important to be able to estimate these time delays for any land use change on a given area in order to develop zones for irrigation development or prioritise areas for revegetation or improvements to water use efficiency.

These time delays are dependent on a number of factors, the primary one being distance from the river, but also depth to groundwater, hydrogeological parameters, groundwater salinity and soil hydraulic parameters. Some of these factors, e.g. depth to water table, are easy to estimate by interpolating information between existing bores. However, some of these factors can be too spatially variable to interpolate even in a regional sedimentary basin such as that in the Riverland. Previous work has illustrated that one of the key determinants of time delays is the Blanchetown Clay, an extensive deposit of relatively shallow clays and silts. The primary objective of the SA SMMSP was to map the thickness of the Blanchetown Clay and then use the data in models that support land use planning in the area.

The RESOLVE helicopter-borne EM (HEM) system was chosen to map the Blanchetown Clay (and similar materials) as this was identified as the system best suited to detecting this target. The survey covered a 10–15 km wide corridor following the southern bank of the River Murray, between the border and Kingston-on-Murray (Lock 3). This study area on the southern side of the river was chosen because of the new developments occurring there and the absence of current groundwater pumping schemes.

6.2 OUTPUTS / IMPROVEMENTS IN REGIONAL KNOWLEDGE

The geophysical data was converted into depth sections via a process called ‘inversion’, which was constrained by all available hydrogeological data. Predictions of the distribution and thickness of the clay layer (resulting from the inversion), compared well with available ground data and were further validated with additional drilling. The resulting map of the Blanchetown Clay (Figure 4) is more detailed than previous compilations based on bore hole logs.

Estimates of drainage since land clearance, beneath dryland agriculture, have been made from analyses of water content and chloride concentration from 14 soil cores obtained within the study area. The estimated mean drainage rates range between 0.1 and 14.8 mm/yr, with an average of 2.7 mm/yr (Cook *et al.*, 2004).

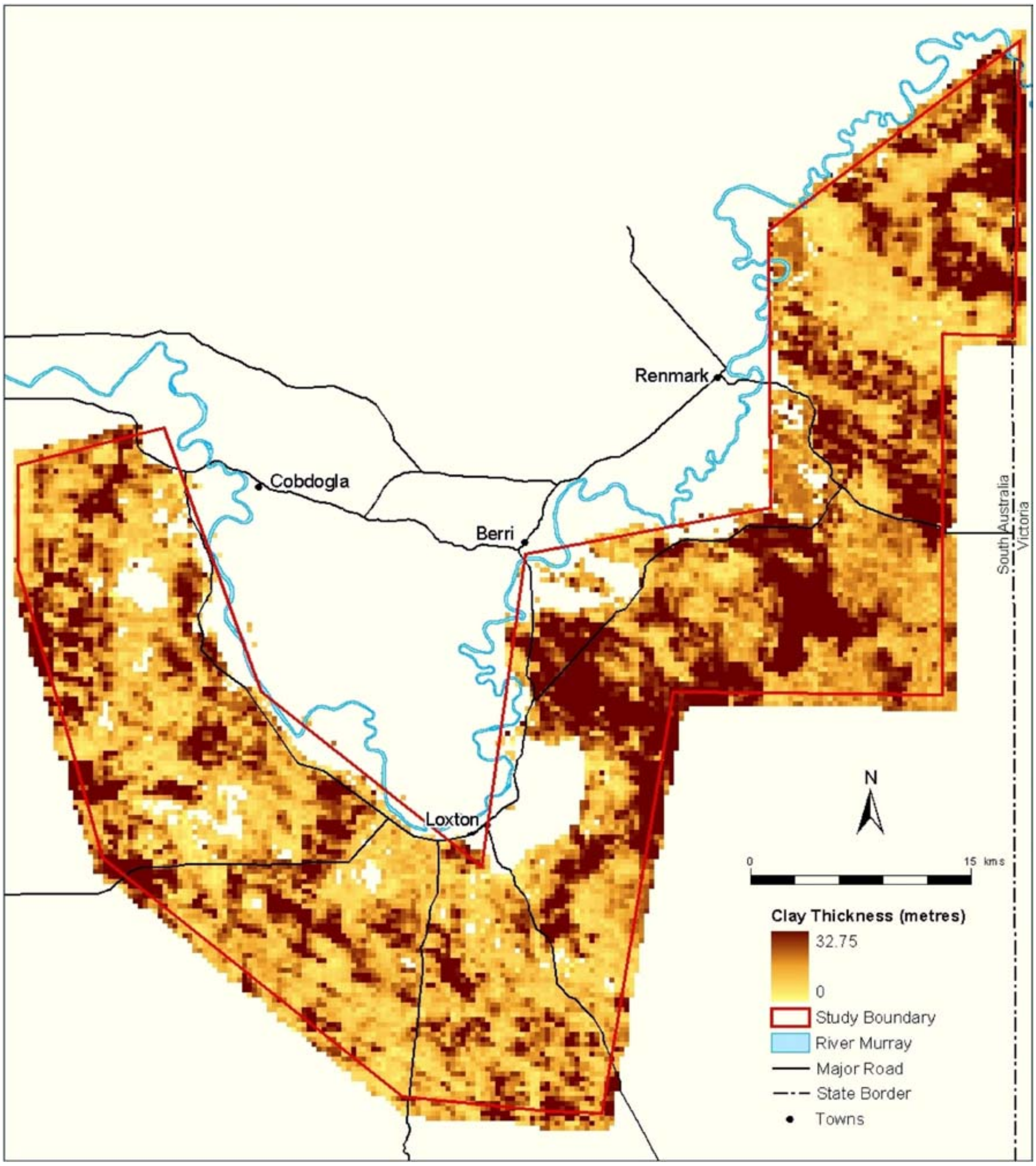

Figure 4. Map of thickness of the Blanchetown Clay (Cook *et al.*, 2004)

Empirical equations that relate drainage beneath dryland agriculture to soil texture and rainfall have been developed, based on the point estimates of drainage obtained in this and in previous studies, These equations have been developed to extrapolate from available data to predict drainage across the northeast Mallee (and across the entire South Australian Mallee region) using Soil Landscape mapping data. The derived drainage map (Figure 5) has been combined with the map of Blanchetown Clay thickness to produce maps of groundwater recharge in the years 2004, 2050, and 2100 (Munday et al., 2004b). Figure 6 shows one example of these groundwater recharge maps, for the year 2050. The recharge maps shown in Munday et al. (2004b) replace the earlier recharge maps of Cook *et al* (2004), and reflect revised, lower estimates of deep drainage based on clay content in the top 2m (as discussed in the Addendum to Cook *et al* (2004) and Wang *et al* (in prep)).

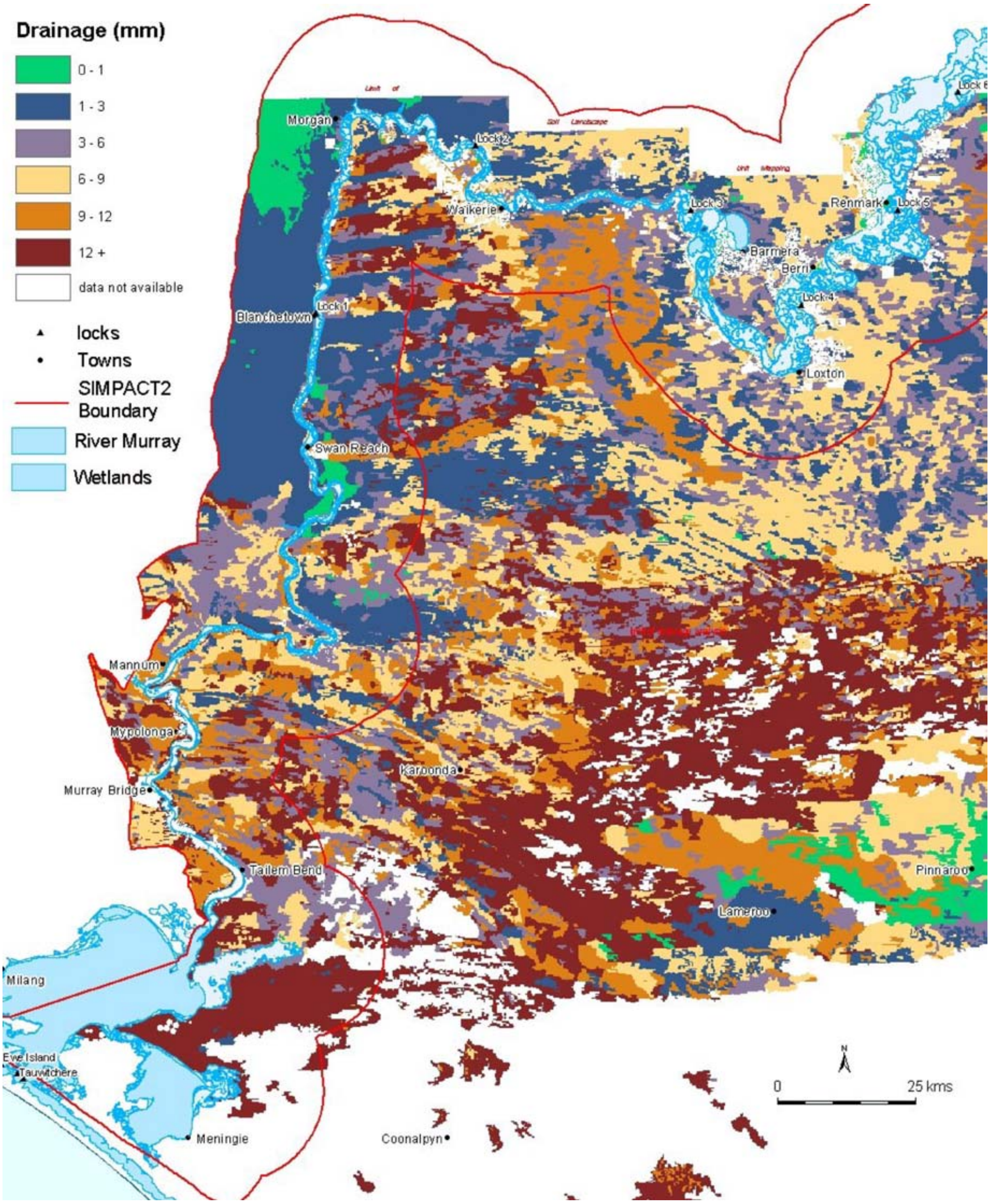

Figure 5. Revised drainage map for the South Australian Mallee region. Drainage passing the root zone of crop/pasture rotation system based on mean annual rainfall and soil clay content in the top 2 metres (Cook *et al.*, 2004).

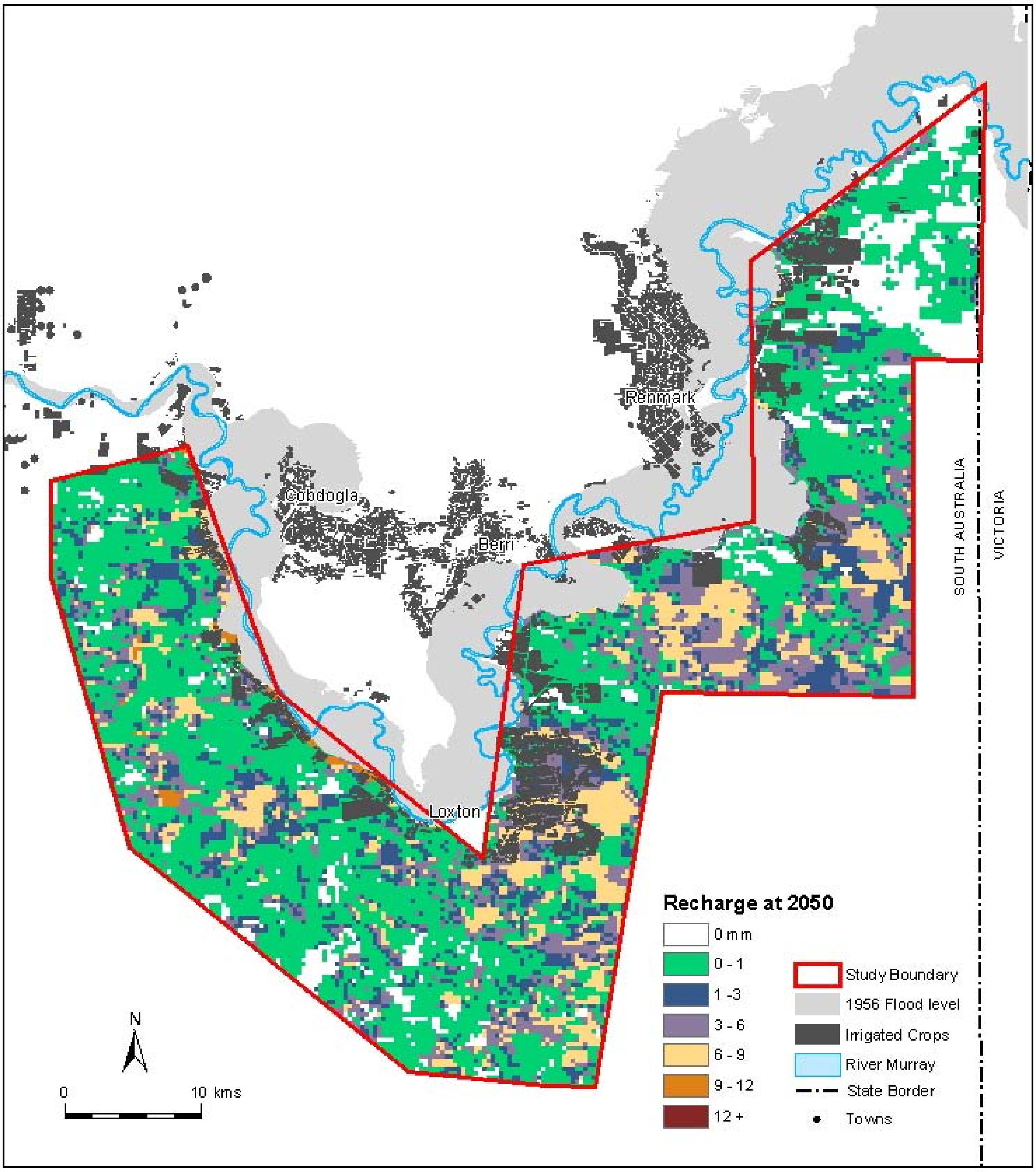

Figure 6. Map of predicted mean dryland recharge rates for the study area in 2050 (130 years after the clearing of mallee vegetation) (Munday *et al.*, 2004b).

The revised estimates of aquifer recharge and lag times have been incorporated into the SIMPACT/GIS and MODFLOW groundwater models for the Riverland region. Previous modelling exercises to predict the impacts of vegetation clearance on the river were carried out with the best recharge information available at the time, but were ultimately hampered by the use of broad landscape units and recharge rates derived from measurements carried out in wetter areas of the Murray Basin. Improvements to these models have now been made with information derived from the SA SMMSP work.

The SIMPACT/GIS model provides a framework for simulating the impacts of land use changes on salt loads to the river. Revised estimates of root zone drainage (based on new estimates of clay content in the top 2m) and the derived information on the Blanchetown Clay have been incorporated into the SIMPACT model and algorithms for better using this data have been included. The resultant model (SIMPACT II) has been used to generate high and low salinity impact zones and target areas for revegetation.

The complementary development of a revised MODFLOW groundwater model for the Riverland area, which has a smaller grid size and better calibration than the models used previously in the study area, has also been completed (Barnett and Yan, 2004). This model has been used to predict the impacts of increased recharge following clearing on salt inflows to the river and floodplain. It has also been used to examine the efficiency of various management strategies undertaken to minimise salinity impacts to the river, including the targeteted revegetation scenario derived from SIMPACT.

The SIMPACT and MODFLOW models provide estimates of saltloads discharging to the River Murray valley, however the impacts of the floodplain in attenuating groundwater flows and saltloads have previously been poorly understood. SA SMMSP funds were used to supplement the development of a Floodplain ImPacts (FIP) Model (Overton *et al.*, 2003). This existing project was supported by a partnership between the Department for Environment and Heritage, the Natural Heritage Trust, the RiverMurray Catchment Water Management Board, DWLBC and CSIRO Land and Water.

The Floodplain Impacts Model is capable of providing spatial predictions of salt loads, vegetation health, seepage and attenuation of groundwater flows through evaporative discharge throughout the floodplain. The FIP model provides a means of determining floodplain attenuation at any location along the lower River Murray for any rate of groundwater inflow to the river valley. The model can be used to predict areas of floodplain at risk from future development and the impacts of management scenarios. The average floodplain attenuation predicted by the FIP model is around 30% of inflows (consistent with assumptions made in the regional MODFLOW model - Barnett *et al.*, 2001), however there is considerable spatial variability (see Figure 7).

A synthesis of findings, concerning dryland areas impacting on river salinity, from the related River Murray Dryland Corridor Project (RMDCP) and the SA SMMSP Riverland Study will be presented in Wang et al (in prep). This report collates NAP funded work in the region aimed at identifying dryland areas to target for revegetation in order to achieve reduced salinity impacts in the River Murray. The RMDCP study area comprised a 15 km buffer from the 1956 floodplain, extending from the border to Lake Alexandrina. This area included the SA SMMSP Riverland study area.

Three main points emerge from this report:

1. Priority areas for targeted revegetation have been identified.
2. Salinity benefits achieved in the river (within a 100 year time frame) from targeted revegetation in these priority dryland areas are small (< 4EC (μS/cm) reduction at Morgan) and are not likely to meet expectations for a proposed salinity credits trading scheme.

   Conversely, this indicates that the predominant cause of human-induced salinity impacts on the river is due to irrigation activities, with some areas having greater impact than others.

3. The methodology used for estimating salinity impacts and benefits from changing land use (eg. dryland agriculture to native vegetation) can be adapted to other types of land use change (eg. irrigation to more efficient irrigation, or a change to native vegetation or some form of low recharge agriculture). Hence, the model used in this work can be further applied to examine potential salinity benefits from a change in land management for high salinity impact areas that are currently under irrigation.

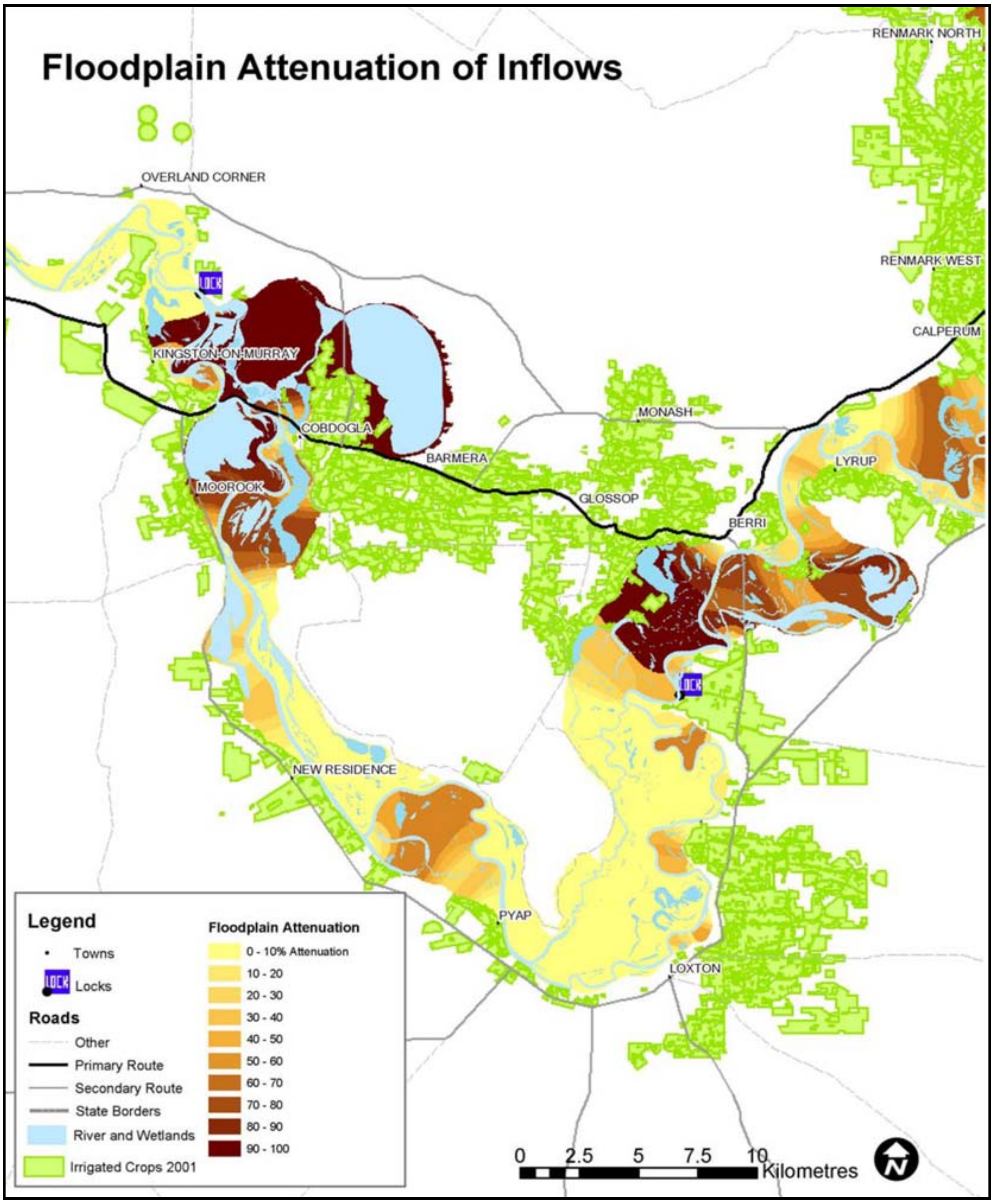

Figure 7. FIP Model predictions of floodplain attenuation, as a percentage of inflows, for the area between Lock 3 and 4 under current inflow conditions. The degree of attenuation can be seen as a function of locking, floodplain width and of magnitude of groundwater inflow (Overton *et al.*, 2003)

Unexpected Findings

An image of the base of the Blanchetown Clay reveals the ancient topography of the landscape, prior to the development of a large lake that once flooded the Riverland region (Lake Bungunnia). This palaeo-landscape is dominated by the barrier-beach strandlines associated with the Loxton Sands (see Figure 8). These parallel dune-like structures are analogous to today's Younghusband Peninsula along the Coorong, with many such structures having been deposited as the ancient coastline retreated to the southwest.

While knowledge of the depositional environment for the Loxton-Parilla Sands has been long established, the HEM data revealed details relating to these sediments that were not well understood. Results from the constrained inversion of HEM data have helped to better define the geometry of this sedimentary system. Together with a hydrogeological interpretation this information has contributed to a more informed approach to the design, development and potential performance of the Loxton Sands Salt Interception Scheme (SIS) borefields at Bookpurnong and Loxton (Munday *et al.*, 2004a). This new knowledge and understanding has the potential to inform other SIS that are being considered in the central Murray Basin, particularly when dealing with the Loxton sands aquifer.

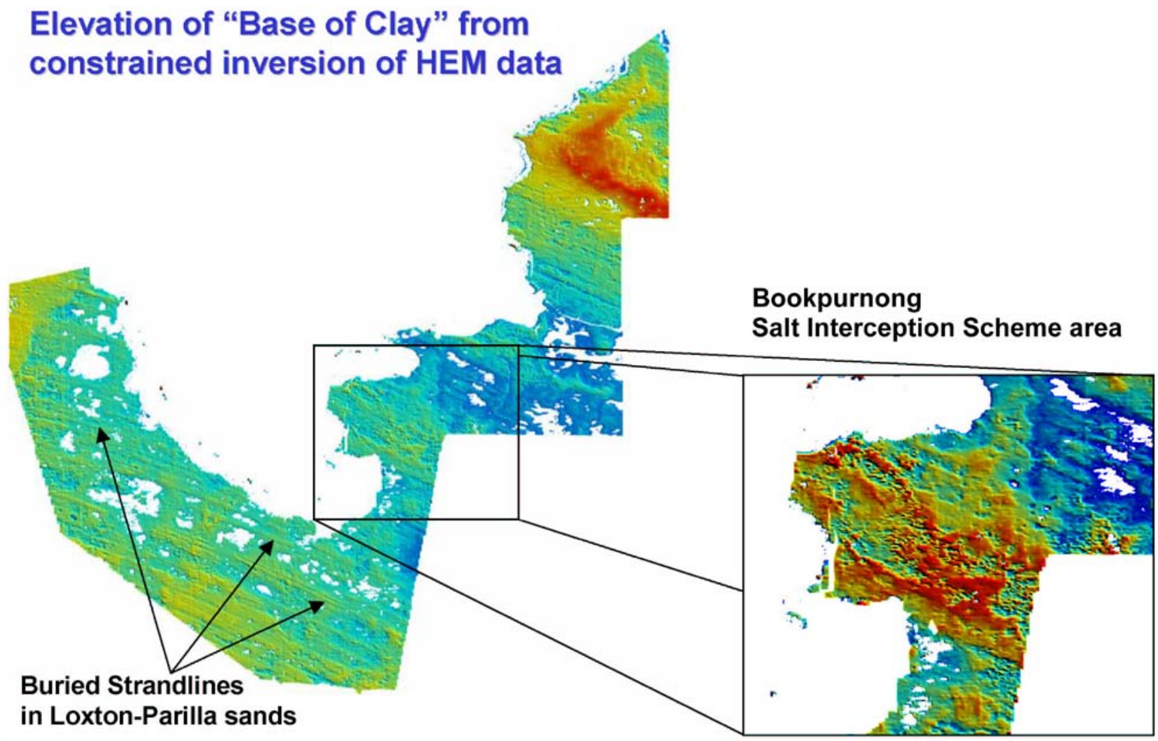

Figure 8. Buried strandlines (linear features running NW to SE) provide a high hydraulic conductivity target for groundwater pumping in Salt Interception Schemes (SIS). (The location of the survey area is shown in Figure 1.)

6.3 FURTHER WORK

It may be possible to use currently existing geophysical data to assist in the generation of higher resolution soil maps. In the Loxton district, a recent comparison between an EM 38 ground survey conducted for soil property mapping purposes, and the apparent conductivity for the highest frequency of the RESOLVE HEM system indicated a high degree of correspondence. The detail contained in the high frequency (near surface) HEM data may not reduce the requirement for a high density of soil pits, routinely sampled when mapping soils in high value horticultural areas, however such data will significantly improve the understanding of soil variation between pits (Rod Davies, pers. comm.). Airborne radiometrics also provide information on soils, however high resolution radiometrics were not acquired in the Riverland under the SA SMMSP.

A preliminary investigation of the helicopter EM data from the River Murray floodplain suggests that the technology could be effective in providing valuable spatial detail on the salinisation of floodplain soils. While further work is required to better determine this potential, airborne geophysics such as that already acquired in the Riverland region, could help link run of river salinity determinations and river floodplain processes, thereby helping inform policy for floodplain protection and salinity mitigation.

Further work which should be investigated is listed below.

Recommendations for Further Work

1. The current geophysical data should be further scrutinised to support the design of salt interception schemes at Murtho, Pike River, etc.
2. Further work should be conducted to better understand the distribution of floodplain soils, recharge during floods and salt discharge to the river. Results here looked promising and past run-of-river surveys using TEM have also proven to be useful.
3. Results show that EM data could assist with siting further disposal basins.
4. Further investigations are warranted in the application of the current data for improving soil maps in the Riverland.
5. The maps of root zone drainage in areas unsuited for cropping e.g. SW of Waikerie should be reviewed.
6. Drainage processes in the vicinity of identified strandlines should be further investigated to determine whether such areas may be poorly suited for siting of new irrigation developments or whether water use efficiency measures should be targeted at these areas. Higher rates of drainage will be associated with sandier surface soils and/or reduced thickness or absence of the Blanchetown Clay. When such conditions are combined with good hydraulic connection to the river (via strandlines in the Loxton Sands), this will hasten groundwater discharge to the river.

7 Tintinara

The Tintinara study area was divided into two separate sites (east and west), each with different salinity issues.

Overall Aims:

1) East / Mallee Highland - Map the shallow clay and adapt tools to use this information to predict the impact of land management decisions on quality of the underlying groundwater resource.
2) West / Coastal Plain - Map zones of groundwater salinity and use this information to study salinity impacts on native vegetation.

Objectives:

Improved irrigation and groundwater management planning tools:

- In the Mallee Highlands: mapping the distribution, thickness and hydrogeological characteristics of the discontinuous underlying shallow clay layer to facilitate management practices that minimize flushing of near-surface salt down into the groundwater;
- Mapping the extent of dryland salinity in the coastal plain.

Outputs:

- East -

- A map of the clay across the main area of concern, as inferred from the EM conductance map and on-ground calibration (Leaney *et al.*, 2004).
- Improved estimates of salt loads to the groundwater using the additional information from geophysics and drilling (Leaney *et al.*, 2004).
- Improved groundwater model of the area, incorporating the high resolution data obtained from the geophysics together with improved recharge data. The groundwater model is currently being used for water allocation planning (Osei-Bonsu *et al.*, 2004).

- West -

- On the Coastal Plain, report on associations between vegetation health and salinity (Camp, 2003).
- An additional output, arising during the course of the project, was to map the extent of shallow basement rock to the west of the Coastal Plains study site.
- Report on overall site investigations (Walker and Liddicoat, 2004)

The following summary of the Tintinara work is drawn from Walker and Liddicoat (2004), which itself is a synthesis of SA SMMSP work conducted in this study area.

7.1 BACKGROUND

In the Tintinara East study site the quality of the locally important groundwater resource is at risk from salt stored in the deep soil profiles being leached into the aquifer. This leaching has occurred following clearing for dryland agriculture and increases in horticultural development over the last decade have accelerated the process. Sub-surface clay has contradictory effects on groundwater salinisation: more clay means more salt, but it also slows down the leaching processes. Information on the distribution of the recharge-inpeding clay layer will assist with management decisions to delay salinisation and hence maximise the beneficial use and lifetime of the groundwater resource.

In the western study site, on the Coastal Plains, water tables are shallow and remnant native vegetation is at risk of stress from waterlogging and salinity.

A combination of airborne geophysical techniques, rigorous field testing and modelling has shed light on these risks.

The RESOLVE helicopter-borne EM system, as used in the Riverland study area, was employed for both Tintinara sites. This system was suited for investigating the relatively shallow clay target in the eastern site and the shallow saline groundwater in the western site.

7.2 OUTPUTS / IMPROVEMENTS IN REGIONAL KNOWLEDGE

7.2.1 Tintinara East / Mallee Highland

The geophysics provided a reliable map of the thickness of sub-surface clay across the eastern study area (see Figure 9). There was a good match with recent, carefully logged drillholes. However, there was some discrepancy for large clay thicknesses with a few older records, extracted from the drillhole database. Previous experience from the Riverland, the good match with recent logs and the spatial pattern that corresponded to a geomorphic understanding of the landscape suggests that the maps are nonetheless reliable.

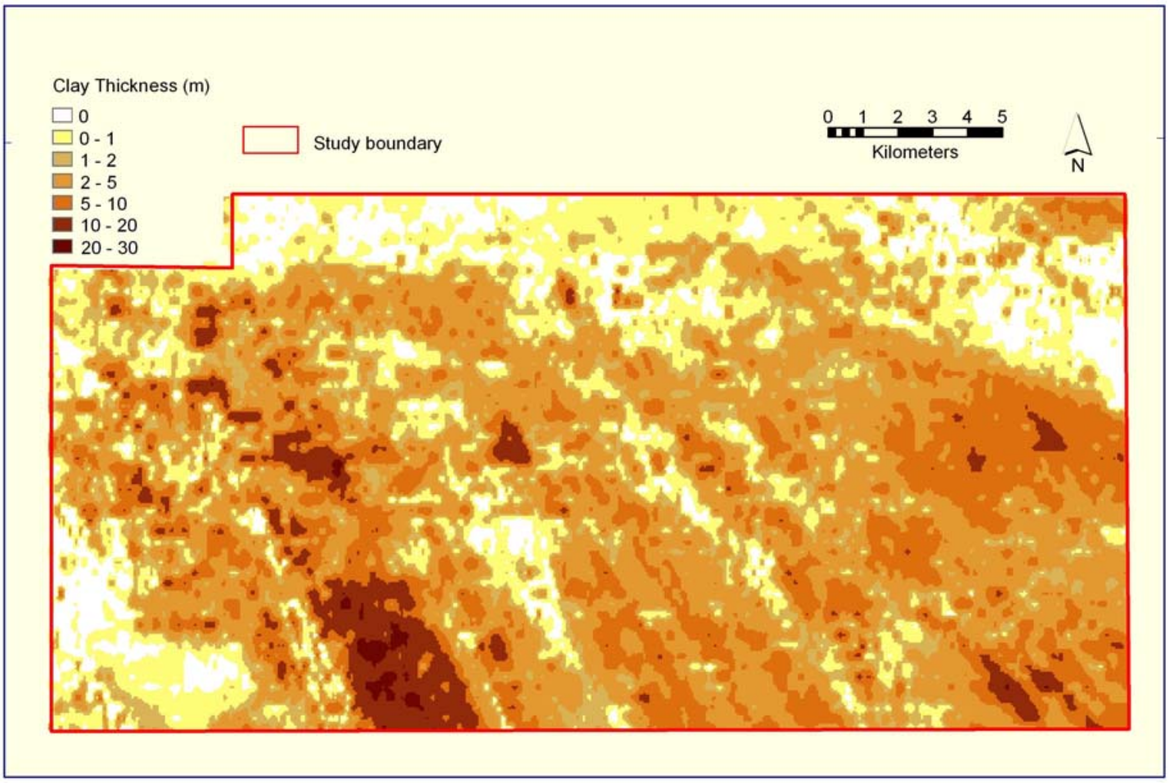

Figure 9. Map of the clay thickness for the Tintinara East study area (Leaney *et al*., 2004)

This information was used as an input to a salt leaching model (eg. see Figure 10). This provided predictions of the impact of clearing of native vegetation in the area for agriculture on salt movement to the watertable. The results showed that the amount of salt being leached into the aquifer increased as the effect of clearing reached the water table, and then decreased as the total salt store leached out. The time for this to happen was shorter for the shallow water table areas to the west, where there is evidence of this occurring already. To the east, where the watertable is much deeper, the process may take 200 years. Superimposed on this east-west trend is a series of north-south trending linear features associated with the sub-surface clay, where delays are associated with greater thickness of clay.

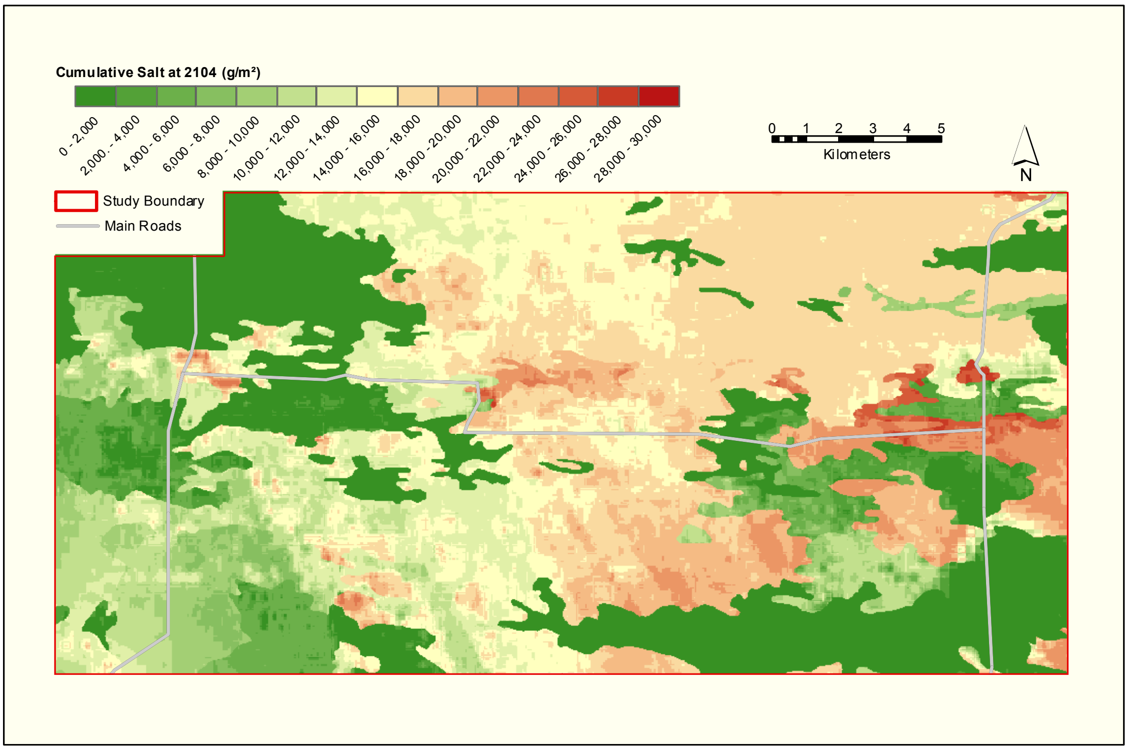

Figure 10. Example output from the salt leaching model: Map of predicted cumulative salt input for the study area in the year 2104 (144 years after clearing), under dryland conditions (Leaney *et al.*, 2004).

The salt leaching model was also applied to simulate the impacts of irrigation development. The deep drainage flux under irrigated crops is likely to be dependent on the crop, irrigation management and soils. To produce a risk map, it was assumed that the deep drainage was a flat 150 mm/yr. As a rule of thumb, this would cause the salinisation process to occur about 5 times faster than under dryland agriculture.

A subsequent scenario with a spatially variable rate for irrigation drainage (where irrigation drainage was chosen to be 5 times that of clearing induced drainage) was used as an input to groundwater models (see below) employed to determine aquifer salinity trends. A spatially variable rate was chosen for this subsequent work to give greater account of the influence of variation in soil texture on drainage rates and provide continuity between leaching under dryland farming and the introduction of irrigated agriculture.

The salt leaching model outputs, for both dryland and irrigation, were used as inputs to a MODFLOW groundwater model and the associated "MT3D" (groundwater salinity modelling package) to predict impacts on groundwater levels, groundwater direction and groundwater salinity (see Figure 11). A good calibration was achieved.

The models predicted that even without irrigation, sufficient increases in groundwater salinity would occur in 50-100 years time to threaten the viability of the groundwater resource for irrigation for some types of crops, or suitability for irrigation at all. Groundwater salinity increases will result in unsuitability for new vegetable irrigation (in areas not previously irrigated), in about 50 years time. Significant areas will not have groundwater suitable for domestic consumption in about 80 years, while lucerne irrigation in new areas and stock supplies will be able to be maintained indefinitely (Osei-Bonsu *et al.*, 2004).

These models should enable the impacts of a range of scenarios on groundwater salinity to be assessed. The models can be used to consider the trade-offs between development and sustainability of the groundwater resource and between planning to optimise sustainability and equity issues.

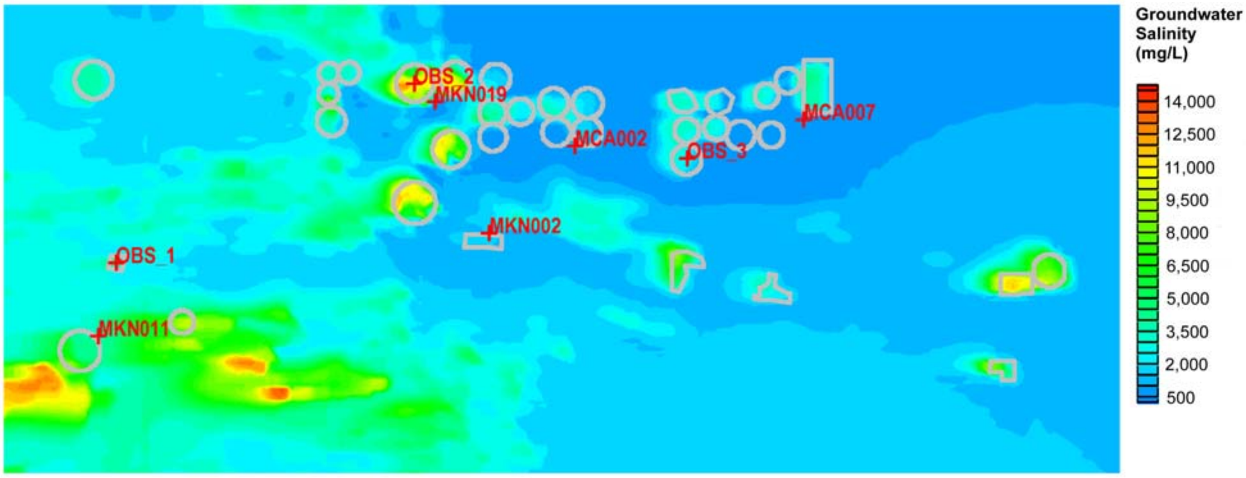

Figure 11. Example of improved groundwater model output. This map shows the predicted groundwater salinity in the Murray Group limestone aquifer in 2054, in response to salt flux under irrigation (irrigation drainage assumed to be 5 times that of clearing-induced drainage) (Osei-Bonsu, pers. comm.).

Improvements in water use efficiency will improve the longevity of the resource. This would entail an understanding of deep drainage for combinations of irrigation management, crop type and soils. Interpretation of previously surveyed radiometrics data for the area may improve the mapping of surface soils which may further improve estimates of drainage rates.

7.2.2 Tintinara West / Coastal Plain

The airborne geophysics was used to map groundwater salinity in the western site (Coastal Plain). Here the contrasts in groundwater salinity were so large as to over-ride any conductivity differences associated with spatial variability in materials (eg. different soil textures). Even specific features such as irrigation recycling appeared to be detected. The groundwater salinity map was used to investigate the influence of salinity on the health of remnant native vegetation. Unfortunately, there was no clear correspondence between plant health measures and groundwater salinity, even though there were indicators of increases in plant stress over the study period.

From around 3000 ha of existing remnant vegetation in the Tintinara West site, an estimated 605 ha was currently affected by salinity (see Figure 12). Predictions are that increasing salinity will impact a further 2 ha of remnant vegetation in 50 years and another 51 ha in 100 years. While the spread of salinity is not predicted to be large, rising salinity levels will intensify the stress on already salt affected vegetation. Areas affected and at risk are low, compared to the total site area (60650 ha), because of the large areas of remnant communities already cleared for agricultural development, and because significant areas already have quite shallow watertables. A longer period of monitoring is required to really detect trends against the background. Because sites were selected before the geophysics became available, some are not ideal locations. Those, that are, should be continued to be monitored.

Towards the west of the Coastal Plains site, where the unconfined groundwater system becomes too saline for use, the confined aquifer is used. However, the basement granite rises in places causing this aquifer to be absent. The high basement elevations were mapped (see Figure 13) to assist landholders and drillers to avoid these granite basement highs when drilling for water.

All of the set objectives were achieved, with an additional output also being provided. The flying at this site benefited from pre-flight testing in the Riverland. A much greater spatial definition of conducting layers has been achieved that would not otherwise be feasible using drilling alone or through any other remote sensing techniques. The unusual processes associated with groundwater salinisation in the eastern site means that while the whole methodology is unlikely to have wide application, individual components will. Areas with underlying regional sedimentary aquifers will tend to benefit from geophysics applied to assets such as a water resource.

7.3 FURTHER WORK

Tintinara East / Mallee Highland

Data suggests that efficient irrigation on appropriate soils may lead to deep drainage rates comparable to that of dryland conditions. Thus, adaptation to more efficient irrigation can lead to a better overall outcome. Modelling results can provide the basis of a more sensible public discussion of the issues, including the tradeoffs between beneficial uses and longevity of the groundwater resource.

To better inform management strategies, Osei-Bonsu *et al.* (2004) recommend that modelling of salinity responses to varying irrigation drainage rates be undertaken, to simulate the variation in irrigation efficiencies under different crop types

Existing radiometrics and near-surface AEM data could assist in refining soil maps for the area, which would further improve model estimates of drainage and aquifer salinisation.

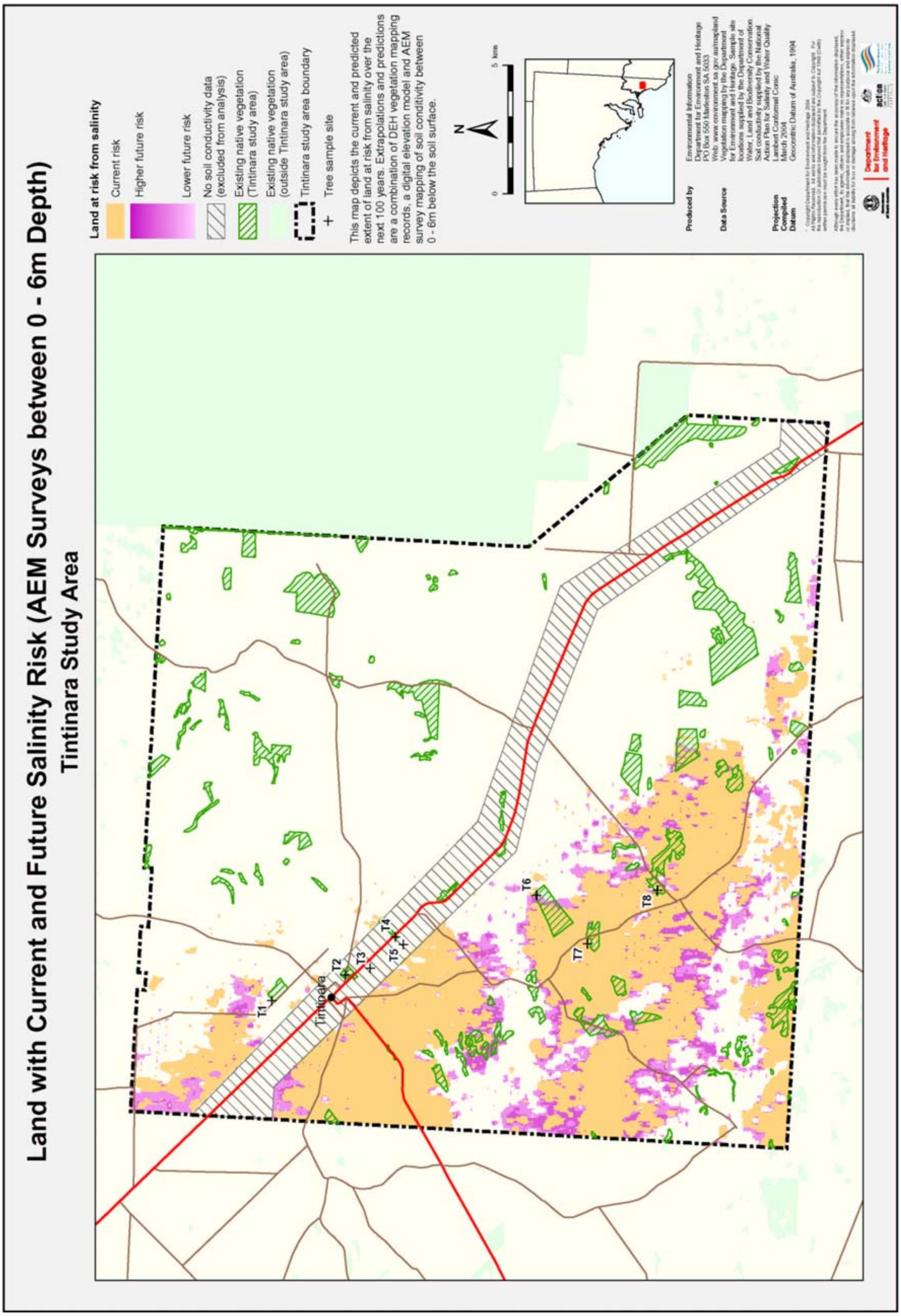

Figure 12. Areas of native vegetation overlain on land currently affected and at future risk of salinity – Tintinara West (Camp, 2003)

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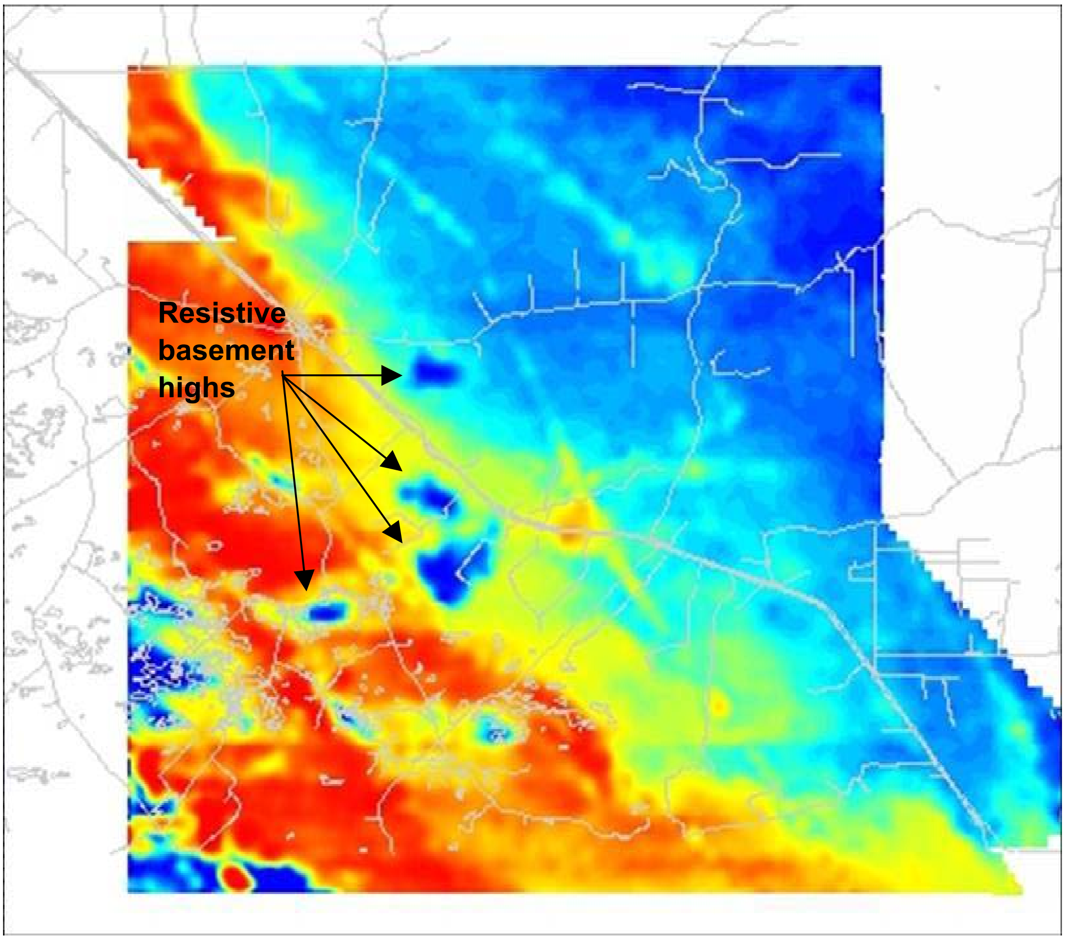

Figure 13. Distribution of granite basement highs (Tintinara West study area). These are areas to avoid when drilling for good quality water as the confined aquifer is usually absent.

8 Jamestown

Overall Aim:

To provide information for salinity management plans to protect high value cropping land, based on an improved knowledge of groundwater, soil and salinity distributions.

Objectives:

Provide information on depth, structure and salinity variations within alluvial groundwater systems of the Jamestown area and salinity interpretations of radiometric data over the wider upland area, and develop tools that use this information to predict impacts of land management on land salinity.

Outputs:

- Maps and associated products including enhanced soil and regolith maps demonstrating salt stores, solute transport pathways, salt sinks, synthesis of all available data to indicate hazards and management options (Cresswell and Herczeg, 2004; Wilford, 2004a).
- Hydrogeological model for the valley-floor groundwater systems (Henschke *et al.*, 2004).
- Report on the application of ground-based techniques for non-water table related salinity (Fitzpatrick *et al.*, 2003).
- Report on overall site investigations (Cresswell and Liddicoat, 2004).

The following summary is drawn from Cresswell and Liddicoat (2004), which is itself a synthesis of the SA SMMSP work undertaken in the Jamestown study area.

8.1 BACKGROUND

In the Jamestown region of the Northern and Yorke Agricultural District, the aim of the geophysical survey was to map groundwater systems rather than salinity, with a view to providing improved information to assist in the protection of high value cropping land.

Three expressions of salinity are recorded in the region:

1. **Water-table driven salinity**, south of Jamestown and east of Caltowie, has developed where groundwater flow systems are restricted above confluences (bottlenecks) of surface and sub-surface water flow. Hence the system cannot drain as fast as it fills. This occurs particularly following a run of wetter than average years. Rising water-tables entrain the salts in the landscape, bringing them to the surface.
2. **Break-of-slope salinity** occurs locally where coarser-grained hill-slope sediments meet the finer-grained valley sediments along valley margins. Rainfall recharging on

the hills flows through the coarser sediments, but cannot flow as rapidly through the valley floor sediments, so seeps out at the junction. Evaporation concentrates the salts in the near-surface at these sites.

3. **Dry saline land** (ie. transient salinity, 'magnesia patches', sub-soil salinity) is not associated with groundwater or shallow watertables. Magnesia patches are expressed where hillslope vegetation is removed, topsoils erode and naturally saline sub-soils are exposed. Transient salinity, as the name suggests, can produce intermittent low yields or patchy growth in crops and pastures. It is caused by the seasonal movement of salts up and down the unsaturated soil profile, generally where salts have been trapped above an impermeable sodic clay sub-soil. Unlike the other forms of salinity, dry saline land increases in area during dry years, and reduces during wet years, as the salts are flushed deeper into the soil profile.

The differing geological setting for the three main valleys in the study area gives rise to different expressions of salinity. Each expression needs to be viewed in the appropriate context with regard to groundwater flow systems, landscape geomorphology and soil/ regolith[2] profile.

The TEMPEST fixed wing airborne EM system and Radiometrics / Magnetics systems were used in the Jamestown survey.

8.2 OUTPUTS / IMPROVEMENTS IN REGIONAL KNOWLEDGE

A combination of airborne geophysical techniques and rigorous field and chemical analyses has shed light on the recharge mechanics and groundwater movement through the three north-south valleys of the study area and helped define the extents of the groundwater systems and the origins of salt in the region.

Combining the images generated from the airborne technologies it has been possible to accurately map the groundwater systems of the region in 3 dimensions (see Figure 14). Surface water and groundwater flows are not always coincident, but it is now possible to determine where surface waters and groundwater will travel throughout the study area.

The recent geological history controls the present-day expression of salinity across the region. Incised valleys have slowly filled with sediments eroded from the hills and washed down during flood events. As these sediments have filled the valleys, so constrictions in the bedrock structures have enhanced the build-up of salts in soil and regolith profiles.

Watertable driven salinity is expressed at the surface where convergent groundwaters are impeded by bottlenecks in the subsurface geology. This is compounded for the Caltowie Valley (to the west), as it has a shallow groundwater system, while good sub-surface drainage in the Belalie valley (to the east) suggests salinity will not be a major problem. During wetter than average years the central, Bundaleer, Valley will experience salinity south of Jamestown.

Accumulation of sediments to the north of the Belalie Valley has resulted in overflow of the surface waters (ie. Belalie Creek) into the Jamestown/Bundaleer Valley to the west. This compounds the problem of excess water seen during wet years in the Jamestown/ Bundaleer Valley, but further reduces the issue for the Belalie valley. While the surface

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[2] Regolith comprises the soils and weathered material that overly fresh (unweathered) bedrock.

water drains west into the Jamestown/ Bundaleer Valley, groundwater from this area drains south beneath the Belalie Valley (see Figure 14).

Close attention to rainfall trends and monitoring of groundwater levels is vital to give good prior warning of impending salinity. The use of surface water drains to protect important assets, such as the township of Jamestown, is appropriate. Maintaining vegetation cover on hillslopes will also moderate any water-table rise that will lead to salinity.

Salt in the region is predominantly derived from rainfall (*i.e.* it is cyclic) and has accumulated in the soil and groundwater over the millenia. Some water-rock interaction takes place as the groundwaters move through the soils, but most salt in the groundwaters is derived from evaporative concentration of rain-waters.

As part of the Jamestown study, work was also undertaken with ground-based techniques to determine their value in detecting non-watertable related salinity (Fitzpatrick et al., 2003). The EM-38 (handheld conductivity meter) performed well in detecting shallow subsoil and surface expressed dry saline land at sub-paddock scales. The larger, and slightly deeper probing, EM-31 was not as good at mapping shallow accumulations of salt but provided insight into soil and landscape processes associated with deeper salt storage and movement.

Following the SA SMMSP work, further research has commenced, investigating links between the ground-based survey results, airborne radiometric data and topographic modelling, in order to better understand the soil and landscape processes leading to expressions of shallow non-groundwater associated salinity (Mark Thomas, pers. comm.).

Ultimately different expressions of salinity can only be distinguished by on-ground investigation. Remote techniques (including airborne and ground geophysics), however, can define the landscape environments that are prone to particular expressions and indicate where to concentrate further investigation. Once particular associations of remotely-sensed data can be ascribed to a particular expression of salinity, that combination may be used to identify other areas with a similar problem.

Combining the digital elevation model with the precise radiometrics images, for example, provides a detailed regional soil mapping tool and may be used to define the extents of land management units (see Figure 15).

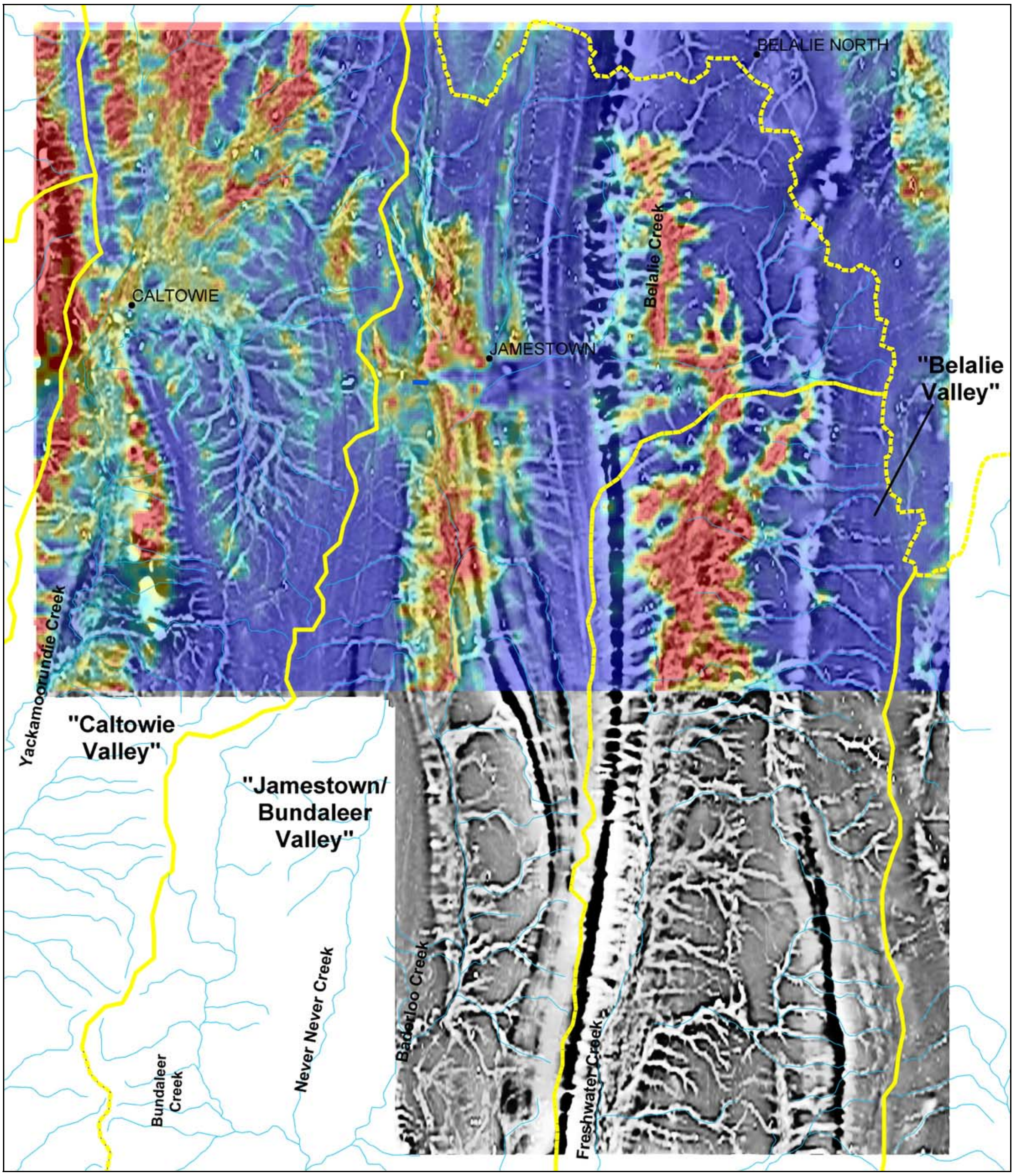

Figure 14. **This map combines (i) magnetics data (black & white) - showing a complex network of buried prior stream channels (paleochannels) which would act as conduits for groundwater flow, as well as other geological features; and (ii) EM data (in colour, red-yellow being more conductive) – from 15-20m deep indicating the presence of saline groundwater in the paleo-drainage features. To the west, higher conductivities are associated with clayey sediments..**

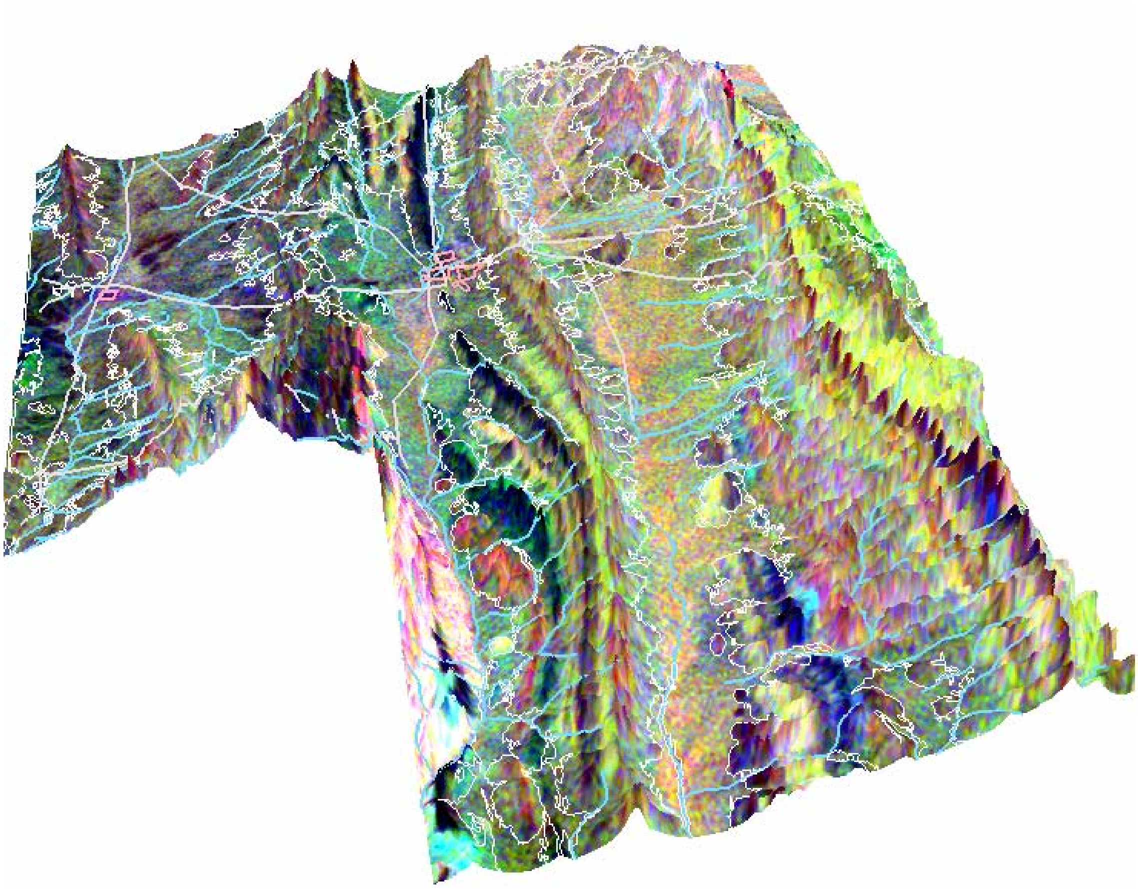

Figure 15. 'Ternary' (3 band) radiometrics imagery draped over the digital elevation model shows the complexity of soils and geology found in the study area. Outcrops of rock occur along the ridges, grading down to colluvial deposits and alluvial sediments on the valley floors. The white lines delineate zones of erosion (slopes above 1.5°) and deposition (slopes below 1.5°) (*from* Wilford, 2004a).

This work has provided information that is relevant to the management of salinity in the region:

1. Current theories regarding valley floor salinity in the region have been confirmed, however the geophysics work has yielded significant new insights and provided detailed spatial information on the distribution of groundwater systems in the study area.

2. Climate variability is the dominant driver for salinity. Monitoring of bore networks and response to rainfall events will give time constraints on water table rise and fall.

3. Sub-soil constraints (eg. boron toxicity, sodicity) are known to occur in the region but are difficult to identify at the padock scale. Techniques are sought which can help identify their presence or absence, without the expense and effort currently required (eg. deep soil sampling and analysis). However airborne geophysics did not prove useful in this regard.

4. Magnetics and airborne electromagnetics (AEM) can delimit zones of higher moisture content. These may be areas that are more productive during drier periods, but may become water-logged and saline during wetter times. Some of these areas may require planting with salt-tolerant species to help maintain ground cover during periods of high water tables.

5. Geophysics can provide information on areas where drains might be appropriate (eg. where bottlenecks are identified).

6. Prolonged wet periods (>3-5 years) will result in elevated water-tables regardless of intervention strategies. Living with a few years of salinity-affected land should be accepted. Salinity will abate once a drier cycle ensues. The land should be managed to ameliorate the symptoms. Salt tolerant plant species and controlled grazing are options.

7. Dry saline land is minimally expressed in the region, mainly due to the adoption of best management practices: contour-banking to maintain moisture in hillslope profiles, restricted stocking in prone areas and maintenance of cover (*e.g.* crop stubble) to minimise evaporation.

9 *Angas-Bremer Plains*

Overall Aims / objectives:

- To provide information that allowed prevention of, or better management of shallow, saline groundwaters and soil salinity, and protection of sensitive aquatic habitats.

Outputs (revised from original project schedule):

- Three-dimensional maps of the soils and regolith, with emphasis on aquifer boundaries and constraints to recharge (Gibson, 2004).
- Maps and associated products demonstrating salt stores, solute transport pathways, salt sinks, groundwater interaction and aquifer connectivity (Cresswell and Herczeg, 2004b).
- Assessment of groundwater models, with documentation (Cresswell and Gibson, 2004).
- Evaluation of associations between vegetation health and salinity (Camp,2003).
- Report on overall site investigations, including a synthesis of all available data to indicate hazards and management options (Cresswell and Gibson, 2004).

The following summary of the Angas Bremer Plains work is drawn from Cresswell and Gibson (2004), which is itself a synthesis of SA SMMSP work conducted in this study area.

9.1 BACKGROUND

In the Angas Bremer Plains region of the Murray Basin, the focus of the geophysical survey was to map groundwater systems and properties of the region's irrigation aquifer, *rather than* pure salinity issues.

It should be noted that the original contracted outputs were changed subsequent to flying the magnetics. Initially a large focus for this study area was to provide information on zones of high permeability (paleochannels) that may enable targeted groundwater control to protect high-value horticulture. However palæochannels were not found to be a prominent feature of the region.

The emphasis shifted to answer resource management issues associated with recharge mechanisms and sustainability of the locally important irrigation aquifer.

For sustainable management into the future, local irrigators need to know:

- At what rate can they support future expansion of irrigation?
- How robust is the system?
- How do they control the water balance and the salt balance?

- Where are the best sites to re-vegetate for recharge control and for other environmental benefits?

A combination of airborne geophysical techniques (TEMPEST fixed wing AEM, radiometrics and magnetics) and rigorous field and chemical analyses has shed light on the recharge mechanisms and groundwater movement across the Plains and helped define the extents of the groundwater systems and the origins of salt in the region. The new information gained through the SA SMMSP will help to address the questions posed by local groundwater resource managers.

9.2 OUTPUTS / IMPROVEMENTS IN REGIONAL KNOWLEDGE

This project has specifically helped by defining a number of attributes of the groundwater system.

- Combining the images created from the airborne technologies with drill-hole data, a precise boundary to the deep, confined aquifer can be drawn (see Figure 16). In addition, structural features in the sub-surface that control groundwater movement can be delineated. A good distinction can be made between the upper, unconfined aquifer and the lower, confined aquifer, with well- defined leakage zones along the river-beds.

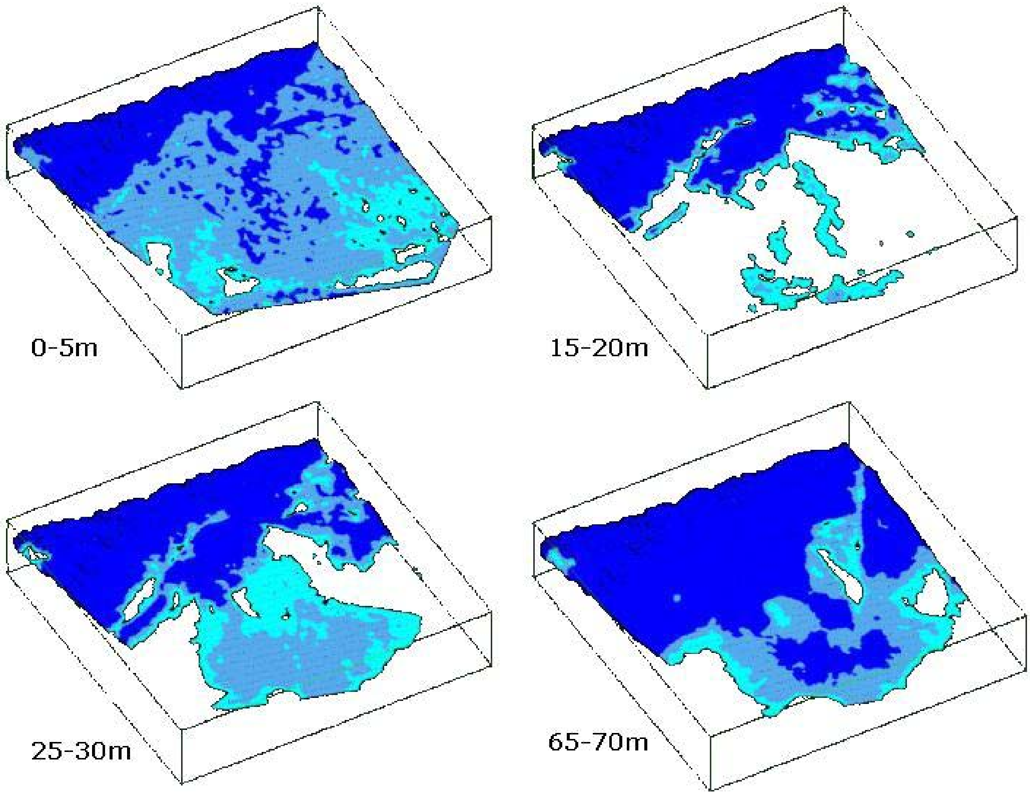

Figure 16. This figure depicts the 3-dimensional distribution of the unconfined aquifer (lighter blue areas in 0-5m slice), the clay-rich aquitard (white zone in 15-20m slice), and the confined aquifer (lighter blue areas in the 25-30m and 65-70m slices). Dark blue areas to the north of the study area indicate resistive (non-conductive basement). Higher conductivity zones (>200mS/m, associated with higher salinity groundwater) represent boundaries to the confined aquifer and are removed from these images.

- Major structural constraints can be imaged. Thus, the prominent faults that bound the eastern margin are seen to extend to considerable depth, and the northern boundary is seen to be a change in sediment characteristics (associated with different depositional environments), rather than a faulted boundary. To the north-west, however, a fault does mark the structural margin of the plains. These faults define groundwater movement in the region.
- Conductivities measured by airborne electromagnetics are similar to the measured salinities of groundwater in the deep aquifer. There is poorer correspondence for the shallow aquifer, as the measured AEM is strongly dependent on the near-surface water content and refined modelling is required to extract the near-surface detail.
- Recharge zones are clearly defined by the AEM. Lower conductivity regions along the courses of the rivers (and conductivity contrasts adjacent to faults) indicate where recent, fresher, flood waters have entered the system (see Figure 17).

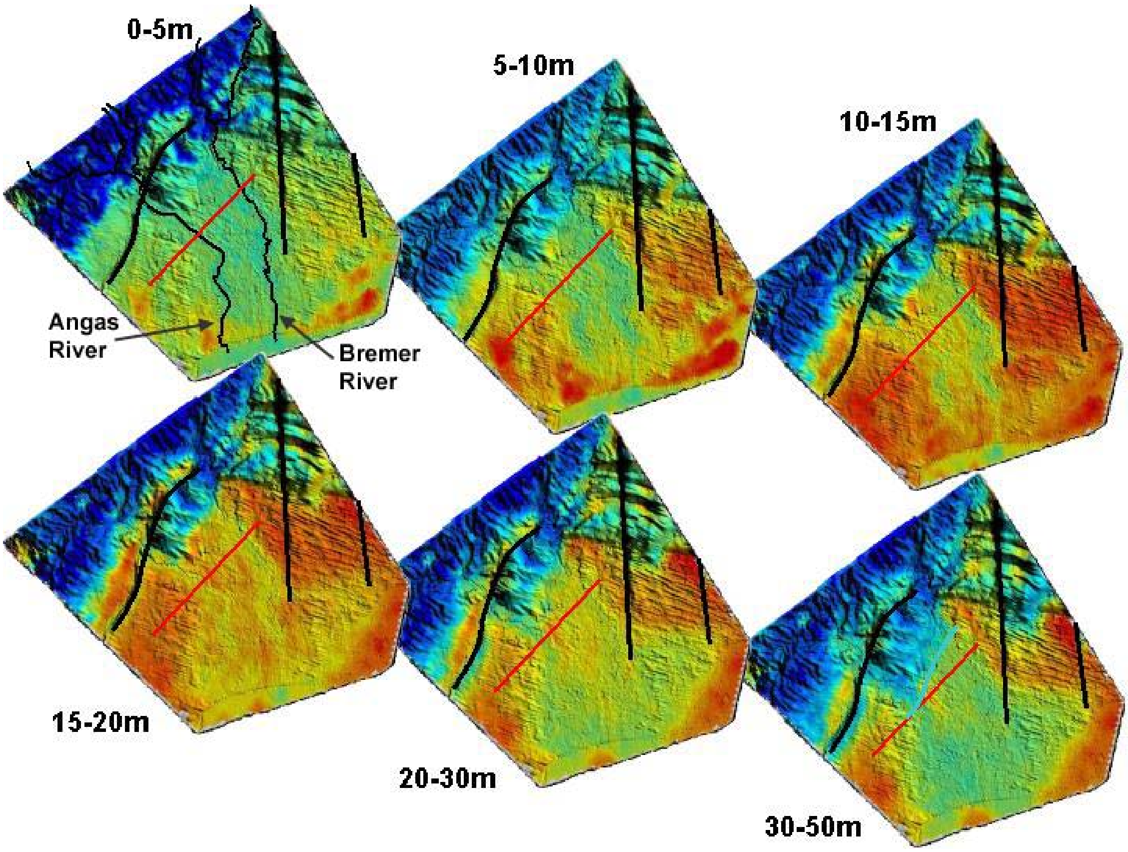

Figure 17. Depth slices from the AEM highlight the aquifer boundaries and the change from the shallow, unconfined aquifer to the deeper confined aquifer. Recharge zones appear as fresher (blue-green) areas along the courses of the major rivers and adjacent to fault zones (black lines). The previously postulated major recharge zone (fault) is indicated by the red line.

- Recharge is seen to be dominantly vertical across the plains, though there is some lateral input from the northern hills. The dominant recharge mechanism is direct recharge concentrated along the courses of the major rivers, particularly during high flow or flooding events. This was evidenced by almost complete recovery of depressed water levels following the large flood of 1992 (Cresswell and Herczeg, 2004).

- While there is a strong chemical similarlty between the upper and lower aquifers, indicating similarity in recharge processes, much older Carbon-14 groundwater ages in the deeper aquifer suggest that inter-aquifer mixing takes place over thousands of years, except in localised areas close to the rivers (Cresswell and Herczeg, 2004). There is rapid (seasonal) recharge to the upper, unconfined aquifer. Away from the rivers, recharge to the lower aquifer appears to integrate over much longer time periods (thousands of years), but shows a rapid pressure response to major flood events.
- Salt in the region is predominantly derived from rainfall (*i.e.* it is cyclic). Some water-rock interaction takes place in the deep carbonate-rich aquifer, but most salt in the groundwaters is derived from evaporative concentration of rain- and river-waters.

With the amount of information now available for the Angas-Bremer Plains region, there is the potential to develop truly sustainable conjunctive water management decisions from the paddock through to catchment scale. This would involve the use of all water resources, whether surface or groundwater, naturally or artificially recharged, in a sound, responsible, sustainable manner. This could be driven, not by hypothetical ideals and models, but through pro-active response to real data: using data as a sound basis for policy.

The airborne geophysics has also provided impetus for further work relating to resource management. Specifically, we can combine the digital elevation model with the precise radiometrics to provide a detailed regional soil-mapping tool that exactly defines the extents of land management units (see Figure 18).

The goal of the project to delineate significant groundwater drainage features (palaeo-channels) was not realised. This suggests that the existing rivers have followed similar courses for the last 2 million years, or may merely reflect a lack in contrast, in the AEM and magnetic signals, between the channels and other sediments.

Minimal vegetation stress was observed within the Angas-Bremer Plains, largely reflecting the dominant uptake of fresh, surface waters. Water-tables were generally deep at the study sites, thus did not impact on vegetation health. An objective measure of stress is advised (such as chlorophyll fluorescence yield) to monitor vegetation health, rather than the use of subjective observations.

The Angas Bremer Plains work provides information that has direct bearing on management directives. In particular we note:

1. The prominent role of river / flood recharge, both in providing surface water to replenish floodplain soils and provision of recharge waters for both the unconfined and confined aquifers, means clever management of flood waters is crucial for the long-term health of the region. High streamflows are the primary source of recharge across the plains so any change to flooding conditions will affect the water system in the floodplain. Salinity is intimately entwined with this and salt may be slowly accumulating in the near surface with implications for future disposal to maintain healthy soils.
2. Water levels need to be controlled both in the unconfined and confined aquifers by judicial use of groundwaters augmented by aquifer storage and recovery (ASR)

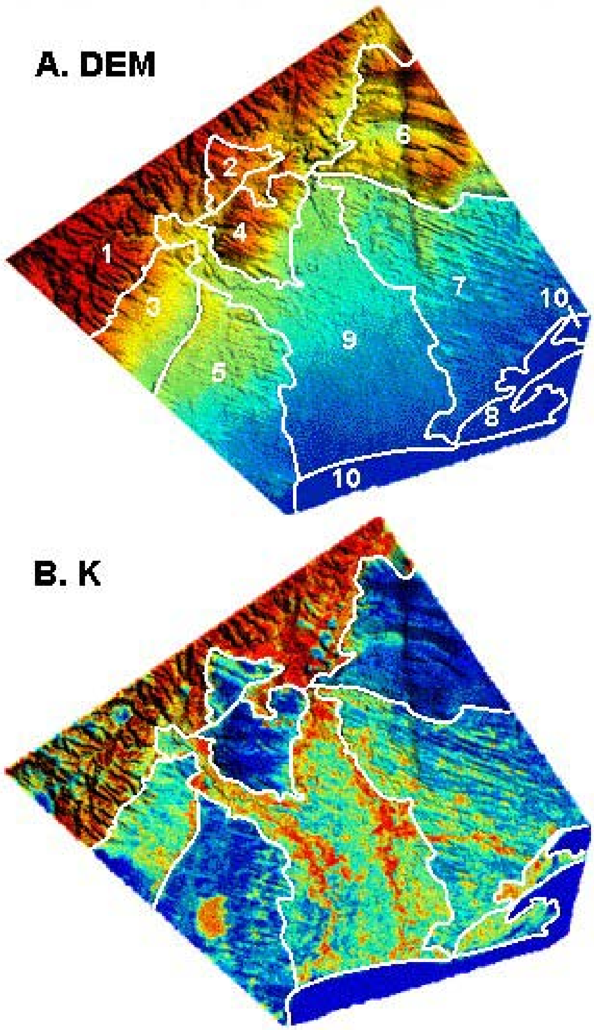

Figure 18. Division of the region into 10 land Management Units based on geophysical response, landscape, regolith and geology. Note that each unit may consist of a number of sub-units (*from* Gibson, 2004). A) shows the units over elevation data (blue=low, red=high). B) shows the Potassium (K) channel of radiometrics (blue=low, red=high).

and continuing use of Murray water, via Lake Alexandrina. Water levels have almost returned to pre-irrigation levels, but a complete return to pre-irrigation levels may mean loss of productive land along the lakeshore as waterlogging and salinisation is expected along this zone. It needs to be noted that the new groundwater regime is 0.75m higher than the natural one due to the effects of the barrages on artificially raising the height of the lake's surface.

3. Salt levels across the region are gradually increasing due to the application of irrigation waters. This increase in root-zone salinity can be controlled by increased leaching in some areas, but must be managed such that deep drainage to the aquifer is minimised. The rate of increase can readily be measured by using devices such as FullStops, which are currently installed across the region. The rate of accumulation can be evaluated and, if necessary, this salt might be released to the upper aquifer in a controlled manner, such that there is minimal leakage to the confined aquifer. Drainage of the upper aquifer to the lake would dilute the salt sufficiently for disposal. This should be seen as a very long-term approach.

4. An improved groundwater model should be generated to enable modelling of these scenarios. There is now sufficient data to facilitate this activity.

10 Bremer Hills

Overall Aim:

Interpret radiometric and magnetic data in association with other datasets to better understand the relationship between stream salinity in the upland portion of the Bremer catchment and regolith, groundwater, soils and land use.

Objective:

To determine the relationships between geology, geomorphology, groundwater and stream salinity.

Outputs:

- Map and associated products including soil and regolith maps demonstrating soil stores, solute transport pathways, salt sinks, synthesis of all available data to indicate hazards and management options (Wilford, 2004b; Walker *et al.*, 2004);
- Report on stream salinity in the Bremer River and comparison with soils, regolith and groundwater (Wilford, 2004b; Smitt *et al*., 2003; Cox *et al*., 2002);
- Report on overall site investigations (Walker *et al.*, 2004).

The following summary is drawn from Walker et al. (2004), which is itself a synthesis of the SA SMMSP work undertaken in the Bremer Hills study area.

10.1 BACKGROUND

The primary goal of the Bremer Hills site was to provide information to support decisions on managing stream salinity. Previous understanding led to prioritisation of certain geologies, which were thought to be associated with high salt stores. However, deeply weathered zones associated with ancient land surfaces have been shown to be important salt stores elsewhere in Australia. A hypothesis underlying this study was that higher salt exports are derived from catchments with high fractions of deeply weathered materials.

10.2 OUTPUTS / IMPROVEMENTS IN REGIONAL KNOWLEDGE

Geochemistry studies show that the major component of salt found in groundwater and streams is derived from wind-blown oceanic sources ('cyclic' salt) rather than directly from rock weathering. For isolated bores, the component of weathering could be as high as 25%, but this did not appear to move into streams. This cyclic salt is very low in concentration in rainfall, but concentrates with evaporation at the surface, before being transported or accumulating in soils, weathered materials, ground or surface waters. Thus, any 'hotspots' of stream salinity are not caused by rocks breaking down to release high concentrations of salt, but are to do with mobilisation processes.

Radiometrics were used to detect areas of deep weathering (see Figure 19). Weathering (the process whereby rock chemically breaks down over millennia to clays and other minerals) leads to a change in the proportions of the radionuclides. Thus, they can be detected as being different from the background rock. This mapping was validated with drilling.

The primary factor governing salt stores was rainfall. In the higher rainfall areas, higher rates of water movement lead to decreased salt concentrations compared to low rainfall zones. Nonetheless, the salt export (tonnes/year), which is a product of water exports and salt concentration will generally be as high or even higher in these areas. For a given rainfall zone, salt stores are higher for deeply weathered zones.

It is generally thought that the larger volume of water in the deeply weathered regolith and low permeability means that it takes longer to leach the salt out than areas of shallow regolith. Groundwater modelling also suggests that the impact of recharge reduction takes longer in these areas. Trend analyses suggest that salinity is not becoming worse, but responds to rainfall variations. The high salt export to input ratios (3-6) associated with deeply weathered zones suggest that there is an opportunity to reduce the export of stored salt from these catchments.

10.3 FURTHER WORK

It is recommended that some investigations be undertaken in these mapped areas to determine more accurately the real risks of salinity and look for best management solutions.

The methodology used here has broader application to fractured rock areas, where salinisation of water resources is an issue e.g. some of the eastern Murray-Darling Basin catchments. For many such areas, some radiometric data is generally available, albeit at a coarser resolution. The combination of such data with digital elevation models could be used to broadly define deep regolith. It is recommended that existing data be used across broader areas of the eastern Mt Lofty Ranges.

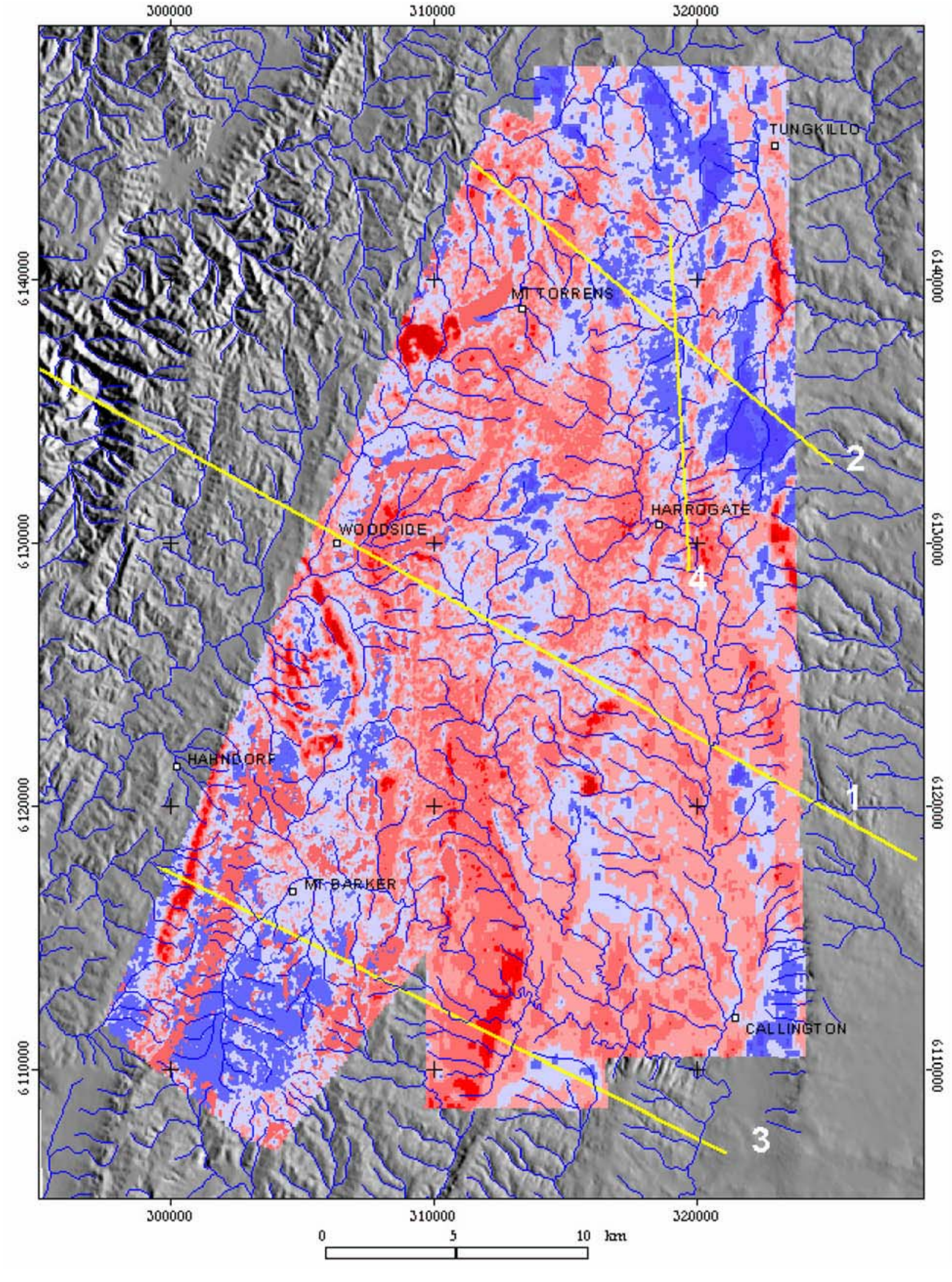

Figure 19. Map of deeply weathered zones based on low potassium signal and topographic modelling (Wilford, 2004b). Blue areas have a higher probability of comprising deeply weathered material (potential salt stores) while red areas correspond to predicted areas of shallower regolith or fresh bedrock. More detailed ground-truthing is recommended before this map should be used for localised management decisions. The map combines the SA SMMSP study area and previous data from a PIMA Mining survey.

PART D. OVERALL PROJECT OUTCOMES

As well as the site-specific outcomes, outlined in the preceding section, a number of general comments can be made reflecting the project as a whole, the approach adopted by the collaborators and reflections on future surveys and applications. These can be summarised into 4 broad themes:

- Project design and implementation;
- Project management;
- Project benefits, and
- Project implications for future surveys – refining the technology.

11 Project Design and Implementation

One of the outcomes of the National Air-borne Geophysics Program was the acceptance that airborne geophysics was no longer a research tool and should be used to support salinity management. This was the context in which the SA project was conducted. There are a number of consequences of adopting this approach:

a) ***Varying Approach*** - The issues and landscapes are likely to be highly variable and hence the targeted way in which geophysics should be applied will also be highly variable. As can be seen in Table 1 (in the Introduction), a range of different geophysical techniques and devices are required.

b) ***Additional work to link geophysics data to dynamics of salinity*** - The traditional outputs of geophysical surveys are maps of either processed data or geological layers. Salinity, however, is a process that necessarily involves mobilisation processes and, hence, salinity management requires a dynamic component to be added to the rather static geological architecture. This usually involves either recharge estimation and/or geochemistry to detect potential interaction of aquifers or mobility within aquifers. This data may then be used in soil or groundwater models. Thus, to develop the links between geophysical data and salinity management requires a number of additional activities, as illustrated in Table 2 for the SA-SMMSP.

c) ***Communication*** - The communication requirements of the Project were much greater than initially planned, and had to be expanded to allow broader communication of results. For every site, there was a strong interest in the results. This resulted in applications of the results in ways not previously envisaged.

d) ***Adapting the technology to new situations*** - The notion that geophysics for salinity management was no longer a research tool was generally proven to be the case. There was a need for some improvements in the application of specialised geophysical data processing techniques. Examples included the need to re-process inversions of the geophysical data (eg. EM data in the Riverland); pre-flight, forward modelling and constrained inversions. This highlights the fact that these new, target-specific applications of geophysics cannot at this stage be tackled with "off-the-shelf" products and that specialised geophysicists were

Table 2. Additional investigations needed to link geophysics data with information required for salinity management, in the SA SMMSP (✓= yes, ✗ = no).

Site	Geochemistry	Recharge Estimation	Modelling	Vegetation Surveys	Soils
Riverland	✗	✓	✓	✓	✓
Tintinara	✗	✓	✓	✓	✗
A-B Plains	✓	✓	✓	✓	✓ *
Bremer Hills	✓	✗	✓	✗	✓
Jamestown	✓	✗	✓	✗	✓ **

(* Maschmedt, pers. comm.; ** SA-SMMSP Associate Project: GRDC – Targetting salinity at the farm scale (Kingham et al., 2004).)

required within the project team. Also, the need to use a wide range of geophysical devices (and airborne platforms) meant that management of flying contracts required a range of appropriate skills and knowledge in this field.

e) ***Use of 'proven' technologies*** – While some degree of innovation was required, only developed technologies were considered for the SA SMMSP. Technologies requiring extensive research into their applicability were considered outside the scope of the project.

f) ***Multidisciplinary teamwork*** – Essential to the success of the project was the combined skill base of the assembled multidisciplinary team. Specialist skills in geophysics and associated field and modelling work were provided from team members spanning several organisations.

12 Project Management

Because of the large number of institutions involved in the project, the project management was complex, but worked surprisingly well, despite limited resources. A high level of trust amongst project team members and dedication to project objectives allowed the project to run smoothly. For various reasons, the project-planning phase was overly long and led to delays in contracting flights and problems with timetabling of staff-time.

A key component contributing to the success of the Project was the establishment of the Project Steering Committee and their consequent enthusiastic, constructive and diligent input to the project. Fortunately, the membership of the Steering Committee was relatively stable over the life-time of the Project and included members from Commonwealth and State governments and the relevant Integrated Natural Resource Management (INRM)

Groups. The Steering Committee was responsible for signing off on milestones, changes to budgets and input to the communications activities.

Membership of the SA-SMMSP Project Steering Committee consisted of:

- Bryan Harris, DWLBC (Chairperson)
- Peter Butler, DWLBC
- Mary-Anne Young, Northern and Yorke Agricultural Districts INRM Group
- Jan Whittle, SA Murray-Darling Basin INRM Group
- Jenny Walker, Joint NAP Implementation Team
- Colin Grant / Peter Baker, Bureau of Rural Sciences

In addition, State and Commonwealth representatives from the Technical Working Committee were invited to Project Steering Committee meetings to provide briefings on activites and results.

Other states:

Queensland is the only other state in which a similar project has been funded via the NAPSWQ program. One of the difficulties in getting activities initiated has been to obtain broader support from governments and regional groups. This represents an obstacle for all new technologies that require a large upfront investment. In the case of airborne geophysics, the South Australian experience may help provide confidence in the technology, assisting its uptake in other states and regions.

13 Project Benefits

Benefits may be considered in terms of scientific advances, managerial confidence and resource manager satisfaction. These may be described, respectively, in terms of whether the Project team achieved the outcomes posed; whether value for money was given and whether the findings were adopted by the local resource management community.

13.1 ACHIEVEMENT OF OBJECTIVES

All objectives of the project were met. This reflects the effort that was spent in carefully defining the project objectives and the outputs and activities needed to achieve them during the planning phase. The only disappointment regarding pre-conceived expectations for the Project was the lack of paleo-channels in the Angas-Bremer Plain. However this expected output was redefined (to investigate recharge mechanisms and aquifer connectivity) and the geophysical survey still met the objectives through providing useful results for groundwater management in the area.

This emphasises the need for some pre-flight testing, which may have avoided the need to change focus during the project. The ability to stage future projects to enable field-testing before contracting any flying is therefore strongly recommended. However, this will generally lengthen the period of time for the program and cause uncertainty for budgets until after this stage has been completed.

The project also provided some additional, albeit unexpected, outcomes:

- Delineation of strandlines with the potential to inform the design of salt interception schemes - Riverland
- Detection of salt stores and recharge zones on the floodplain – Riverland
- Correlation with soil mapping – all sites
- Mapping of elevation highs for basement rock – Tintinara West
- Sustainable aquifer extents – Angas-Bremer

These unexpected outcomes reinforce the view that it is not possible to predict all outcomes beforehand and there needs to be some flexibility in the budgets to deal with this. In the case of the Riverland study area, it was feasible within the overall project budget to integrate the geophysical data into the development of salt interception schemes.

13.2 COST-BENEFIT-ANALYSIS

There was a view at the outset that some of the geophysical techniques have been 'oversold' with regard to their applicability and this had led to a negative view from the technical community, but also within catchment groups. The project team deliberately tried to convey objectivity when discussing the project externally and this generally helped transform the general opinion about the technology and allowed groups to judge it on its merits. In this regard, there is little doubt that the technology has added significant value to previous knowledge. We have made no attempt, however, to demonstrate whether or not the SA SMMSP was good value for money, and we have not carried out a cost-benefit-analysis. Considerable benefits were obtained, however, and these are outlined in the following section.

13.3 BENEFITS FROM THE PROJECT

The benefits from the project fall into the following categories:

a) ***Changed decisions*** – It is clear that some decisions have changed as a result of the work:

- Development of salt interception schemes - Riverland
- Priority areas for on-ground actions to manage salinity in the Bremer Hills

b) ***Building confidence in current understanding*** – It is also clear that the geophysics provided greater confidence in the understanding of the landscape and salinity processes, and hence can support decisions or provide confidence in current management actions / plans:

- Irrigation zoning in Riverland
- Revegetation areas in the Riverland
- Water allocation in the Angas-Bremer Plains

- Recharge reduction and surface water management in Jamestown.

c) ***Changes to conceptual understanding*** – There have also been some changes to conceptual understanding in the Riverland, Angas-Bremer Plain, Jamestown and Bremer Hills that will lead to further changes in salinity management plans and actions. Thus, the data will be used to support future decisions with respect to: salt interception schemes at Pike River and Murtho in the Riverland; land use planning in Tintinara; water allocation planning in Angas-Bremer Plains; recharge reduction strategies around Jamestown and targeted catchments in the Bremer Hills.

d) ***Building upon current datasets*** – The project has added to the list of datasets available to natural resource managers. Further to this, there are opportunities to add value to the SA SMMSP datasets (eg. to improve soil mapping, mapping of floodplain salt stores and integration of datasets for salinity management).

e) ***Building confidence in the technology*** – There has been development of some confidence in the use of geophysics for a range of applications and landscapes, development of GIS-based spatial models to make better use of the spatial datasets and some technical geophysical development.

f) ***Appreciation of scale effects*** – Comparisons between airborne ground and sub-surface geophysics and comparisons to existing geological and soil surveys have highlighted the need to understand the scale at which a datset is acquired and the scale at which it is processed. Further, the scale of any management issue must be ascertained and coupled with the appropriate scale of investigation, and hence to the correct investigation technique. Limitations in the airborne geophysics due to the large footprint of the detection devices were highlighted, but also showed the way forward in the design of future surveys (see below).

g) ***Postgraduate training*** – Three associate projects are supporting training of postgraduate students and further post-graduate projects are planned.

h) ***Non-NRM applications*** – There has been some interest in the data from mining and mineral sand companies, but the outcome of their analyses are unknown.

14 Project Implications for Future Surveys – Refining the Technology

14.1 POSSIBLE COST SAVINGS

One of the key limitations in broader application of the techniques is the cost. Cost factors include:

a) ***Type of geophysical technique*** – The two main detection devices utilised here are considerably different, with radiometric/magnetics being about an order of magnitude cheaper than electromagnetic induction techniques. For large survey areas (over a million ha) radiometrics/ magnetics cost around $1-2/ha, while AEM costs around $10/ha. The adopted technique will be largely target specific, therefore there will generally not be opportunities to substitute one technique for another. Notwithstanding this comment, sometimes a surrogate target may be available which allows a cheaper technique to be used. For example in the Bremer Hills, AEM techniques could have been used to detect deeply weathered (clayey) materials, however this would have been very expensive to ground-truth in such a variable landscape. These deeply weathered zones were able to be mapped using radiometrics because of the specific surface chemical signature resulting from the weathering process.

b) ***Flight line spacing*** – Apart from the actual technique used, the main determinant of cost is the spacing between flight lines. As a rough guide, to detect a target of a certain width requires a line spacing of half that width, or less. For example, to find a 300 m hole in the Blanchetown Clay requires flight paths to be 150 m or less. In some cases, and with the aid of hindsight, some line spacings could have been widened. Wider flight lines across the 5 field sites may have reduced flight costs by about 30%. To have the confidence to widen flight spacing, however, would require significant field work prior to contracting the flying. Flight line spacings used in the SA-SMMSP are shown in Table 3.

Table 3. Flight line spacings used in the SA-SMMSP

Site	EM line spacing (m)	Radiometrics / Magnetics line spacing (m)
Riverland	100-300	Not used
Tintinara	300	Not used
Angas-Bremer Plains	200 – 400	100
Bremer Hills	Not used	100
Jamestown	400	100

c) ***Associated field and modelling activities*** – The geophysical flying and contracting amounted to approximately $1.6M of the $3.8 M used for the whole project. Associated field work, data processing and analysis and modelling studies accounted for most of the remaining funds. The project was also supported through some additional in-kind resources through each of the partner organisations involved, but these were not quantified. There are trade-offs in changing the balance between flying and associated projects. Greater effort into the associated projects would enable more analysis of the data, development of decision support tools based on these and communication of the results. Greater effort into the flying provides a larger dataset that will continue to be used for decades.

Taking into account the split in activities and opportunities in widening line spacing, the maximum decrease in costs would be about 15%. However, if all in-kind contributions were quantified, this saving is unlikely to be realised. Thus, the only real way of minimising costs is to cut down the number of objectives.

14.2 TARGETTED SURVEYS VERSUS LARGE AREAL SURVEYS:

This project used a principle of defining targets to determine flight plans. Governments and the mining industry have used large areal surveys to support mineral exploration and there have been arguments that similar flight patterns with wide line spacing should be used to support Natural Resource Management. This approach is discussed below:

a) ***Geophysical technique*** – The cheaper cost of radiometrics/magnetics and its widespread applicability to improving soil mapping makes this a more viable option for large scale surveys than electromagnetic (EM) induction techniques.

b) ***Salinity hazard*** – The use of large areal EM surveys for mapping salt hazard is problematic. With field validation, such flight patterns may be able to provide information on salt stores. However, for many salinity problems, the issue is larger fluxes of water and mobilisation of salt with this. The damage done to an asset is often not sensitive to the salinity of the water above some threshold value. For example, in many areas where rainfall is less than 800 mm/yr, there is sufficient salt in shallow groundwater to cause damage to crops or to infrastructure. On the other hand, impacts on water resources and some biodiversity is sensitive to such salinity. Groundwater movement is slow (10's of metres per year) so that salt within a few hundred metres of an asset needs to be considered. Where the asset is a river used as a water resource, targeted electromagnetic induction techniques, combined with gauging data, run-of-river salinity surveys, in-stream electromagnetic induction techniques can provide useful information on salinity hazards. Within the SA SMMSP, electromagnetic induction measurements have indicated applicability to floodplain salt stores on the River Murray and have been used to measure the extent of a beneficial groundwater resource in Tintinara and Angas-Bremer Plain.

c) ***Salt* mapping** – Despite the project's name, geophysics wer not used to map salt. Remote technologies such as satellite imagery, aerial photography and radar have been used to monitor the extent of saline or waterlogged land. Such estimates are useful for risk assessment or audit processes. For the agricultural areas of South Australia, the extent of saline land is well understood through systematic soil surveys. However, the mapping of sub-surface features that control the movement of water and salt is required for salinity management and planning. The SA SMMSP focussed on these aspects.

PROJECT RECOMMENDATIONS

Applicability of airborne geophysics for salinity investigation, planning and management:

Recommendation 1.

Airborne geophysical technologies should be encouraged for further use in supporting salinity management.

Recommendation 2.

The results of the SA SMMSP should be widely communicated to engender confidence in the uptake of the technology. This could be enhanced by scoping further work that is based on regional INRM plans in SA and elsewhere. The credibility of the techniques and of the objectivity of the advice of government agencies needs to be emphasised and demonstrated at all levels.

For future airborne geophysical surveys:

Recommendation 3.

Planning, design and budgeting of future surveys for salinity management should adopt the following principles:

a) Clear objectives relating to regional salinity management.

b) Consultation with stakeholders at an early stage.

c) A focussed, targeted approach.

d) Consideration of the use of different geophysical techniques based on the nature of the landscape and the specific target.

e) Consideration and rigorous examination of existing site information, as this will aid in the interpretation, and help to make best use, of the acquired geophysical data.

f) Incorporation of complementary studies, where appropriate, to enhance understanding of salinity processes (eg. Recharge estimates, hydrochemistry, modelling and soil studies). Such multidisciplinary skills are not likely to exist in any single organisation.

g) Inclusion of ancillary and complementary work into the budgets during project development. Sufficient resources must be allocated to support all related activites. A holistic approach needs to be adopted.

h) Careful staging of the outputs to enable strategic field testing to be carried out before, during and after the airborne geophysical surveys. This will help ensure that true and appropriate targets are being addressed.

Recommendation 4.

Should funding become available for future airborne geophysics work (in NAP regions or elsewhere) it is recommended that the following steps be undertaken to determine priorities:

- A scoping team of appropriate stakeholders, technical experts and Regional and State representatives be formed to review Regional and State INRM / salinity plans to identify problem areas and priorities.
- With input from technical specialists, discussions be held to determine how available airborne geophysical techniques could be appropriately applied to add value to salinity management in identified problem areas.
- Scoping / costing work should be undertaken for potential projects judged by the team to be the most feasible.
- Priorities for future work should be developed.

Regional implementation and further work arising from the SA SMMSP:

Recommendation 5.

Clear extensions of the current geophysical work include:

a) Work that can be quickly implemented:

SA Murray-Darling Basin	• Analysis of existing radiometrics data in the Tintinara region for improving mapping of surface soil clay content. This would improve estimates of recharge and aquifer salinisation rates.
Mount Lofty Ranges & Greater Adelaide	• Analysis of existing radiometrics data across the eastern Mt Lofty Ranges for the distribution of potential deeply weathered zones.

b) Work that requires longer term planning:

SA Murray-Darling Basin	• Interpretation of the existing Riverland data in relation to Salt Interception Schemes, particularly at Murtho and Pike River. • Investigation into the applicability of AEM techniques to understanding the distribution of floodplain salt storages and dynamic processes. • Improved soil mapping using AEM data • Identifying possible salt disposal sites • Reviewing recharge maps in areas of no cropping • Reviewing soil drainage processes in vicinity of strandlines as the basis for identifying areas poorly suited for new irrigation developments or where recharge control measures should be targetted

Recommendation 6.

Clear extensions of non-geophysical work include:

SA Murray-Darling Basin	• Improvements to groundwater modelling in the Angas-Bremer Plain. • Further scenario simulations in the Tintinara region.
Mount Lofty Ranges & Greater Adelaide	• Investigations into salinity risk processes and management options for deeply weathered zones in the Bremer Hills.

ACKNOWLEDGEMENTS

This report was produced for the Department of Water, Land and Biodiversity Conservation as part of the South Australian Salinity Mapping and Management Support Project funded by the National Action Plan for Salinity and Water Quality. The National Action Plan for Salinity and Water quality is a joint initiative between the Australian, State and Territory Governments.

This report summarises a $3.8M project that tested the application of airborne geophysics, in five priority areas of South Australia, to improve salinity management.

Successful results came from the combined skill base of the assembled multidisciplinary team. Team members came from the following organizations: CSIRO Land and Water, CSIRO Exploration and Mining, Bureau of Rural Sciences, the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME), Geoscience Australia, (SA) Department of Water, Land and Biodiversity Conservation (DWLBC), Rural Solutions SA, and consultants.

Valuable local input and insight from the various study areas has resulted in a more meaningful study and special thanks should go to the many landholders who allowed access to properties and gave freely of their time and knowledge. Also thanks go to the various community and regional groups who contributed to the project: the Bremer Barker Catchment Group; the Angas-Bremer Water Management Committee, the Tintinara-Coonalpyn Water Allocation Planning Committee, the Bundaleer / Belalie East branch of the Agricultural Bureau of SA, the Northern and Yorke Agricultural Districts INRM Committee Inc. and the INRM Group for the SA Murray-Darling Basin Inc.

ABBREVIATIONS

AEM – Airborne electromagnetics

BRS – Bureau of Rural Sciences

CRCLEME – Cooperative Research Centre for Landscape Environments and Mineral Exploration

DEM – Digital Elevation Model

DWLBC – Department of Water, Land and Biodiversity Conservation

EM – Electromagnetics

GA – Geoscience Australia

HEM – Helicopter-borne electromagnetics

INRM – Integrated Natural Resource Management

NAP(SWQ) – National Action Plan for Salinity and Water Quality

RMDCP – River Murray Dryland Corridor Project

SA SMMSP – South Australian Salinity Mapping and Management Support Project

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Overton, I., Jolly, I., Holland, K. and Walker, G. 2003. The Floodplain Impacts Model (FIP): A tool for assisting the assessment of impacts of groundwater inflows to the floodplains of the Lower River Murray, Progress report for the River

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Soil and Land Information, 2004. Land Resource Information – Murraylands [CD ROM], Soil and Land Information Group, Department of Water, Land and Biodiversity Conservation.

Smitt, C., Cox, J. and Davies, P. 2003. Salt Transport in the Bremer Hills, SA: Interpretation of Spatial Datasets for Salt Distribution (Fourth report for NAP SA SMMSP) ,CSIRO Land and Water Technical Report 49/03.

Walker, G., Cox, J., Wilford, J. Smitt, C. and Liddicoat, C. 2004. Application of airborne geophysical techniques to the investigation of salt stores and stream salinity in the Bremer Hills, South Australia (SA SMMSP Site Summary Report), Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2004/ 38.

Walker, G. and Liddicoat, C. 2004. Application of airborne geophysical techniques to groundwater salinisation issues in the Tintinara region, South Australia (SA SMMSP Site Summary Report). Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2004/ 36.

Wang, E., Schultz, T., Miles, M.W., Cook, P.G., Maschmedt, D., Munday, T., Leaney, F., Walker, G.R. and Barnett, S.R. (in prep) Targeting dryland areas in the mallee for controlling groundwater recharge and saline discharge to the Murray River. CSIRO Land and Water, Technical Report

Wilford, J.R. 2004a 3D regolith architecture of the Jamestown area – implications for salinity. Report to SA-SMMSP / CRC LEME Open File Report 178. Cooperative Research Centre for Landscape Environments and Mineral Exploration.

Wilford, J.R. 2004b. Regolith-landforms and salt stores in the Angas-Bremer Hills. CRC LEME Open File Report 177. Cooperative Research Centre for Landscape Environments and Mineral Exploration. ix + 100pp.

Wilford, J., Dent, D.L., Braaten, R. and Dowling, T. 2001. Running down the salt in Australia 2: Smart interpretation of airborne radiometrics and digital elevation models. The Land, **5**, 79-101

Personal Communications

Rod Davies, DWLBC, Berri, 2004

Kwadwo Osei-Bonsu, DWLBC, 2004

Mark Thomas, CRCLEME / University of Adelaide, 2004

David Maschmedt, DWLBC, 2004

APPENDIX A. LIST OF SA SMMSP REPORTS

The following list describes all the technical and summary reports produced from the SA-SMMSP. These reports will be available for downloading from the DWLBC website at URL: http://www.dwlbc.sa.gov.au/

ALL SITES

[Flying (Data Acquisition) Report]

Brodie, R.C. and Cresswell, R.G. 2004. Acquisition, quality assessment and control, and delivery of airborne geophysical data – South Australian Salinity Mapping and Management Support Project, BRS Technical Report, August 2004. v + 9 + 4 Appendices.

[Appendix 1 to Flying Report]

South Australian Salinity Mapping and Management Support Project [SASMMSP] Schedule: Geophysical data acquisition and delivery (v12) (Commonwealth)

[Appendix 2 a,b,c to Flying Report – 3 x Fugro Airborne Surveys reports]

Cowie, D., Garrie, D. and Tovey, A. 2003. Riverland and Tintinara, SA – RESOLVE Geophysical Survey Acquisition and Processing Report (Report to the Bureau of Rural Sciences), Fugro Airborne Surveys (Job #1543).

Murphy, S. and Stenning, L. 2003. Jamestown and Angas-Bremer South Australia – Airborne Magnetic, Gamma-ray and Elevation Survey Acquisition and Processing Report , Fugro Airborne Surveys (Job #1545).

Owers, M. and Stenning, L. 2003. Jamestown and Angas-Bremer Plains TEMPEST Geophysical Survey Acquisition and Processing Report, Fugro Airborne Surveys (Job #1544).

[Appendix 3 to Flying Report]

Fitzpatrick, A. 2004. Calculation of conductivity depth images (CDI) S.A. AEM data using EMFLOW 5.30 (AMIRA-P407B): RESOLVE: Riverland & Tintinara (East & West); TEMPEST: Jamestown & Angas Bremer Plains, CRC LEME Open File Report 176, Cooperative Research Centre for Landscape Environments and Mineral Exploration, July 2004.

[Overall project summary report]

Walker, G., Cresswell, R.G., Munday, T. and Liddicoat, C. 2004. South Australian Salinity Mapping and Management Support Project – Final Report. (Overall Project Summary Report). South Australia. Department of Water, Land and Biodiversity Conservation, Report, DWLBC 2004/ 39.

ANGAS BREMER PLAINS

Camp, A. 2004. Salinity and Native Vegetation Health – Tintinara and Angas-Bremer Plains 2003, Department of Water, Land and Biodiversity Conservation.

Cresswell, R.G. and Gibson, D.L. 2004. Application of Airborne Geophysical Techniques to Groundwater Resource Issues in the Angas-Bremer Plains, South Australia (SA SMMSP Site Summary Report), Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2004/ 35.

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Henschke, C.J. 2003. Angas-Bremer Plains: Drilling to verify recharge mechanisms causing dryland salinity. Rural Solutions SA, report to SA SMMSP, October 2003.

Gibson, D.L. 2004. An enhanced framework for natural resource studies in the Angas-Bremer Plains area, South Australia. Technical Report to SA-SMMSP/ CRC LEME Open File Report 172. Cooperative Research Centre for Landscape Environments and Mineral Exploration.

Also see Murphy and Stenning (2003), Appendix 2b to Flying Report (listed in ‘All Sites’).

Also see Owers and Stenning (2003), Appendix 2c to Flying Report (listed in ‘All Sites’).

Also see Fitzpatrick (2004), Appendix 3 to Flying Report (listed in ‘All Sites’).

BREMER HILLS

Cox, J., McEwan, K., Davies, P., Smitt, C., Herczeg, A. and Walker, G. 2002. Salt transport in the Bremer Hills, SA – Report for NAP South Australian Salt Mapping and Management, CSIRO Land and Water Technical Report 50/02, November 2002.

Smitt, C., Cox, J. and Davies, P. 2003. Salt Transport in the Bremer Hills, SA: Interpretation of Spatial Datasets for Salt Distribution (Fourth report for NAP SA SMMSP) ,CSIRO Land and Water Technical Report 49/03.

Smitt, C., Cox, J., McEwan, K., Davies, P., Herczeg, A. and Walker, G. 2003. Salt Transport in the Bremer Hills, SA – FLOWTUBE Modelling (Second report for NAP SA SMMSP), CSIRO Land and Water Technical Report 06/ 03.

Wilford, J.R. 2004. Regolith-landforms and salt stores in the Angas-Bremer Hills. CRC LEME Open File Report 177. Cooperative Research Centre for Landscape Environments and Mineral Exploration. ix + 100pp.

Walker, G., Cox, J., Wilford, J., Smitt, C. and Liddicoat, C. 2004. Application of airborne geophysics to the investigation of salt stores and stream salinity in the Bremer Hills, South Australia (SA SMMSP Site Summary Report), Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2004/ 38.

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Cresswell, R.G. and Herczeg, A.L. 2004b. Groundwater flow systems and salinity in the valleys around Jamestown, South Australia: Geochemical and isotopic constraints. CSIRO Land and Water Technical Report No. 30/04 / BRS Technical Report, June 2004.

Cresswell, R.G. and Liddicoat, C.A. 2004. Application of Airborne Geophysical Techniques to Salinity Issues around Jamestown, South Australia (SA SMMSP Site Summary Report) Department of Water, Land and Biodiversity Conservation, DWLBC Report 2004/ 37.

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Wilford, J.R. 2004. 3D regolith architecture of the Jamestown area – implications for salinity. Report to SA-SMMSP./ CRC LEME Open File Report 178. Cooperative Research Centre for Landscape Environments and Mineral Exploration.

Also see Murphy and Stenning (2003), Appendix 2b to Flying Report (listed in ‘All Sites’).

Also see Owers and Stenning (2003), Appendix 2c to Flying Report (listed in ‘All Sites’).

Also see Fitzpatrick (2004), Appendix 3 to Flying Report (listed in ‘All Sites’).

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Barnett, S. and Yan, W. 2004. Groundwater Modelling of Salinity Impacts on the River Murray due to Vegetation Clearance in the Riverland area of SA, Department of Water, Land and Biodiversity Conservation, Report, DWLBC 2004/ 42.

Brodie, R., Green, A. and Munday, T. 2004a. Calibration of RESOLVE airborne electromagnetic data – Riverland and East Tintinara, South Australia, CRC LEME Open File Report 173, Cooperative Research Centre for Landscape Environments and Mineral Exploration, December 2003 / Republished September 2004

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Cook, P.G., Leaney, F.W. and Miles, M. 2004. Groundwater Recharge in the North-East Mallee Region, South Australia, CSIRO Land and Water Technical Report No 25/04.

Green, A. and Munday, T. 2004. Forward modelling airborne electromagnetic data for the Riverland, South Australia, CRC LEME Open File Report 171, Cooperative Research Centre for Landscape Environments and Mineral Exploration, November 2002 / Republished September 2004.

Munday, T.J., Hill, A.J., Wilson, T., Hopkins, B., Telfer, A.L., White, G.J. and Green, A.A. 2004a. Combining geology and geophysics to develop a hydrogeologic framework for salt interception in the Loxton Sands aquifer, Central Murray Basin, Australia. CRC LEME Open File Report 180. Cooperative Research Centre for Landscape Environments and Mineral Exploration. September 2004.

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Tan, K.P., Munday, T. and Leaney, F. 2004. The validation of RESOLVE helicopter EM data: Mineralogical and petrophysical results from field investigations in the Riverland area, South Australia. CRC LEME Open File Report 179. Cooperative Research Centre for Landscape Environments and Mineral Exploration, September 2004.

Also see Cowey et al (2003), Appendix 2a to Flying Report (listed in 'All Sites').

Also see Fitzpatrick (2004), Appendix 3 to Flying Report (listed in 'All Sites').

TINTINARA (EAST & WEST)

Leaney, F., Barnett, S., Davies, P., Maschmedt, D., Munday, T. and Tan, K. 2004. Groundwater salinisation in the Tintinara Highland area of SA: revised estimates using spatial variation for clay content in the unsaturated zone, CSIRO Land and Water Technical Report No. 24/04, July 2004.

Osei-Bonsu, K., Barnett, S., Leaney, F. and Davies, P. 2004. Modelling Groundwater Salinisation in the Tintinara Highlands area of SA, Department of Water, Land and Biodiversity Conservation, DWLBC Report 2004/ 44, December 2004.

Tan, K.P, Munday T.J. and Leaney, F. 2004. The validation of RESOLVE helicopter EM data: Mineralogical and petrophysical results from field investigations for the Tintinara East survey area, in the south east of South Australia. CRC LEME Open File Report 174. Cooperative Research Centre for Landscape Environments and Mineral Exploration, September 2004.

Walker, G. and Liddicoat, C. 2004. Application of airborne geophysical techniques to groundwater salinisation issues in the Tintinara region, South Australia (SA SMMSP Site Summary Report). Department of Water, Land and Biodiversity Conservation. Report, DWLBC 2004/ 36.

Also see Brodie et al. (2004a), listed under Riverland.

Also see Camp (2003), listed under Angas Bremer Plains.

Also see Cowey et al (2003), Appendix 2a to Flying Report (listed in ‘All Sites’)

Also see Fitzpatrick (2004), Appendix 3 to Flying Report (listed in ‘All Sites’)

APPENDIX B. LIST OF KEY PRODUCTS

Note: Geophysical data (including DEMs) in GIS format currently reside with the SA SMMSP data custodian within PIRSA, Minerals and Energy Division (Senior Geophysicist, Domenic Calandro).

Table - SA SMMSP Outputs

Outputs (* additional to NAP Schedule)	**Completed (✓), Reference & Comments /**
Riverland	
• A map of the Blanchetown Clay within a 12 km zone from Lock 3 to the Border, as inferred from an EM conductance map and field calibration;	✓ Cook et al (2004)
Improved regional planning tools including:	
• Improved recharge maps for underlying groundwater systems up to 100 years into the future, using the Blanchetown Clay map and recent developments in soil hydrology	✓ Munday et al (2004b) revised from Cook et al (2004)
• A floodplain attenuation model that simulates the impact of the floodplain on salt loads to the River Murray and impact of irrigation development on the floodplain	✓ Overton et al (2003)
• Improvements to SIMPACT (irrigation planning model) and Border-to-Lock 3 MODFLOW model (used for land use changes and salt assessments) to incorporate improved recharge maps and floodplain attenuation model.	✓ Improvements to existing models have incorporated more detailed data for the Riverland study area. ✓ Cook et al (2004) ✓ Barnett & Yan (2004) also see: Wang et al (in prep)
• Report on overall site investigations	✓ Munday et al (2004b)
• * Information on strand lines to assist design of Salt Interception Schemes	✓ Munday et al (2004a)
Also:	
• Improved conceptual model for landscape / regolith formation	✓Munday et al. (2004a)
• Digital Elevation Model (DEM)	(PIRSA data custodian)

Tintinara • A map of the clay across the main area of concern, as inferred from the EM conductance map and on-ground calibration. • Improved estimates of salt loads to the groundwater using the additional information from geophysics and drilling (report). • Improved groundwater model of the area, incorporating the high resolution data obtained from the geophysics together with improved recharge data. (The groundwater model is currently being used for water allocation planning.) • On the Coastal Plain, report on associations between vegetation health and salinity. • Report on overall site investigations • * Mapped granite basement highs in Coastal Plains Also: **East / Mallee Highland** • Recharge estimates under: o Dryland conditions o Irrigated conditions • DEM **West / Coastal Plain** • Map of groundwater salinity zones • Benchmark vegetation survey data • DEM	✓ Leaney et al (2004) ✓ Leaney et al (2004) ✓ Osei-Bonsu et al (2004) ✓ Camp (2003) ✓ Walker (2004) ✓ Walker (2004) ✓ Leaney et al. (2004) ✓ Leaney et al. (2004) (PIRSA data custodian) ✓ Camp (2003) ✓ Camp (2003) (PIRSA data custodian)
Angas-Bremer Plains • Three-dimensional maps of the soils and regolith, with emphasis on aquifer boundaries and constraints to recharge. • Maps and associated products, demonstrating salt stores, solute transport pathways, salt sinks, groundwater interaction and aquifer connectivity. • Assessment of groundwater models, with documentation. • Evaluation of associations between vegetation health and salinity. • Report on overall site investigations, including a synthesis of all available data to indicate hazards and management options.	✓ Gibson (2004) – paleochannels not detected. ✓ Cresswell & Herczeg (2004a); Henschke (2003). ✓ Cresswell and Gibson (2004) ✓ Camp (2003) ✓ Cresswell and Gibson (2004)

Also: • Recharge estimates • Radiometrics maps to refine soil / land management units • DEM	✓ Cresswell and Gibson (2004) ✓ Gibson (2004) (PIRSA data custodian)
Jamestown • Maps and associated products including enhanced soil and regolith maps demonstrating salt stores, solute transport pathways, salt sinks, synthesis of all available data to indicate hazards and management options. • Hydrogeological model for the valley-floor groundwater systems. • Report on the application of ground-based techniques for non-water table related salinity. • Report on overall site investigations. Also: • Magnetics map indicating subsurface drainage (ie. paleochannels) and prominent geological features. • Radiometrics map for refining soil maps and land management units. • DEM.	✓ Wilford (2004a); Cresswell and Herczeg (2004b) ✓ Henschke et al (2004) ✓ Fitzpatrick et al (2003) ✓ Cresswell & Liddicoat (2004) ✓Cresswell & Liddicoat (2004) / (PIRSA data custodian). ✓Cresswell & Liddicoat (2004) / (PIRSA data custodian). (PIRSA data custodian)
Bremer Hills • Map and associated products including soil and regolith maps demonstrating soil stores, solute transport pathways, salt sinks, synthesis of all available data to indicate hazards and management options. • Report on stream salinity in the Bremer River and comparison with soils, regolith and groundwater. • Report on overall site investigations. Also: • A radiometric map of the higher rainfall areas of the Bremer Catchment; • A map of deeply weathered zones as inferred from the radiometric imagery; • 6 landscape models associated with deeply weathered zones, explaining salinity processes; • DEM	✓ Wilford (2004b); Walker et al (2004) ✓ Wilford (2004b); Cox et al (2002); Smitt et al (2003a) ✓ Walker et al (2004) Wilford (2004b) Wilford (2004b) Wilford (2004b) (PIRSA data custodian)

APPENDIX C. COMMUNICATION ACTIVITIES

The following tables list communication activities undertaken for the SA SMMSP:

This is followed by some examples of media clippings.

ALL SITES

Activity	Audience	Date(s)
Media release by Commonwealth Minister for Forestry & Conservation (The Hon Wilson Tuckey MP) – to highlight commencement of national campaign of aerial geophysics surveys for salinity.	Public	8 Feb 01
Site and overall project information sheets	Public	Jul 02
Project Updates emailed and posted on web [URL-http://www.saltcontrolsa.com/salt_mapping.htm#progress_report]. Update documents provide reasonable discussion of methods and findings, contain data images, and briefly discuss associated projects. And highlights posted on SALTLIST, and in NDSP Salinity Updates, and 'Focus on Salt' newsletter.	INRM Groups, LAP Officers, Interested public, Subscribers to: - SALTLIST, - NDSP Salinity Update - Focus on Salt newsletter	Nov 02 - June 04
Article in PIRSA 'Open Gate', quarterly supplement to Stock Journal.	Farmers, agricultural / NRM workers	Mar 03
Article in 'IAH News', newsletter of the Australian Chapter of the International Association of Hydrogeologists	IAH – Aust. Chapter	Mar 03
Presentation summarising project findings (Glen Walker) to Hydrological Society Seminar (Engineering House, Bagot St, Nth Adelaide) Poster prepared for display at Seminar.	Hydrologial Society, International Association of Hydrologists (SA), Australian Geomechanics Society (SA), State agencies, researchers.	14 July o3
Technical Workshop held at Waite campus, to discuss and review project findings.	Technical / scientific / NRM peers	22-23 Oct 03
Forum at Waite Plant Research Centre Auditorium – summarising site & project results.	State agencies, CSIRO, researchers, scientists, NRM workers.	19 May 04
NDSP / State Dryland Salinity Committee Salinity Seminar (held at Waite campus)– presentation summarising site & project results.	Salinity / NRM workers, scientists, farmers, State agencies, interested public.	21 Jun 04
Article in CSIRO's 'Land and Water Link'	CSIRO, Land and Water researchers	Dec 04
Site and overall project fact sheets to be produced	Public	TBA

RIVERLAND

Activity	Audience	Date(s)
Meeting / presentation (Steve Barnett, Glen Walker) with SA Murray-Darling Basin INRM Group.	SA MDB INRM Group	Aug 02
Visit to John Berger (SA MDB INRM Group) to show Riverland raw data/ images	SA MDB INRM Group member	8 Jan 03

Article submitted to 'Murray Pioneer' newspaper.	Riverland community	14 Jan 03
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	4 Feb 03
Poster prepared for Riverland Field Days	Public, State agencies, NRM workers	10-11 Sep 03
ABC Radio media interview (Alice Plate – Riverland) with Glen Walker.	Public	Dec 03
Presentation at 9th Murray-Darling Basin Groundwater Workshop (Bendigo)	Scientific / Technical peers, and public	17-19 Feb 04
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	6 Apr 04
Riverland Workshop – detailed afternoon discussion & evening overview of results.	Public, irrigators, LAP members, State agencies	14 Jul 04

ANGAS-BREMER PLAINS

Activity	Audience	Date(s)
Presentation/ meeting (Steve Barnett, Glen Walker) with SA MDB INRM Group	SA MDB INRM Group	Aug 02
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	4 Feb 03
Article provided to 'Southern Argus' newspaper	Angas-Bremer Plains community, southern Mt Lofty Ranges.	22 May 03
Presentation/ meeting (Richard Cresswell, Steve Barnett) with AB Plains community / ABWMC	Angas-Bremer Water Management Committee, local irrigators.	11 Nov 03
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	6 Apr 04
Presentation / meeting (Richard Cresswell) with ABWMC	Angas-Bremer Water Management Committee, local irrigators.	30 Aug 04

TINTINARA

Activity	Audience	Date(s)
Presentation/ meeting (Steve Barnett, Glen Walker) with SA MDB INRM Group	SA MDB INRM Group	Aug 02
Presentation (Steve Barnett) to Tintinara-Coonalpyn Water Allocation Planning Committee	TCWAPC, members of South East Catchment Board & Coorong Districts LAP	13 Nov 02
ABC media enquiry (Stewart Stansfield, Mt Gambier) to Richard Cresswell	Public	10 Jan 03
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	4 Feb 03
Presentation (Craig Liddicoat) to CRC for Plant-based management of dryland salinity, on bus trip of Coorong Districts & Upper SE.	CRC for Plant-based management of dryland salinity - SA	25 Jun 03
Presentation (Steve Barnett & Fred Leaney) to local community / TCWAPC, 'Kynoch woolshed'.	Tintinara-Coonalpyn Water Allocation Planning Committee, and landholders in the Tin. East flyzone.	29 Mar 04
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	6 Apr 04

JAMESTOWN

Meeting (Richard Cresswell and Craig Liddicoat) with local landholders, PIRSA staff (Mary-Anne Young	Local landholders, PIRSA staff.	Nov 02
Article in Northern Argus (local newspaper)	Mid North / Jamestown area – local community	20 Nov 02
Article in PIRSA newsletter 'Stock, Crop & Country'	Landholders in Jamestown district	Jan 03
Presentation (Craig Liddicoat) to NYAD INRM Group, and open to public (at Jamestown)	NYAD INRM Group, involved landholders members of public.	29 Jan 03
Focus group meeting for GRDC Associate Project (Richard Cresswell, BRS staff and local landholders)	Local landholders, PIRSA staff, BRS staff	3 Feb 03
Article in Northern Argus (local newsletter) Re: drilling	Mid North / Jamestown area – local community	23 April 03
Presentation (Craig Liddicoat) upon request, to 'Southern Flinders Native Producers Association'	Members of S'thn Flinders Native Producers Assoc.	10 Jun 03
Media release on GRDC project in Jamestown (Richard Cresswell)	Public	Jul 03
Poster prepared for Paskeville Field Days	Public, State agencies, NRM workers	30 Sep - 2Oct 03
Presentation (Richard Cresswell) to NAYAD INRM Group, at Crystal Brook.	NAYAD INRM Group	11 Mar 04
Field Day and Public Forum (Richard Cresswell, Rob Kingham (BRS) and Baskaran Sundaram (BRS))	Local landholders, PIRSA staff, GRDC representatives	27 Jul 04

BREMER HILLS

Presentation (Glen Walker) to MLR INRM Group.	MLR INRM Group	Nov 02
Article submitted to 'The Courier' newspaper (Not published)	Mt Barker and central hills community (Not Published)	Mar 03
Presentation (Glen Walker) to SA MDB INRM Group	SA MDB INRM Group	6 Apr 04
Presentation (John Wilford) to Waite scientists / researchers	CSIRO, Adelaide Uni., State agencies, NRM workers.	22 Apr 04
Presentation (John Wilford, Jim Cox) to local community / BBCG.	Bremer Barker Catchment Group	22 Apr 04
Presentation (John Wilford, Chris Smitt) to MLR INRM Group	MLR INRM Group	23 Apr 04

Farm Review

Mapping to help lick salt problem

Dr Richard Cresswell speaks to local farmers Reinhold Wehrmann, Glan Moore and Tim Lehmann.

Salt mapping was the focus at a gathering of Jamestown farmers, organised by the Bundaleer Agricultural Bureau.

They heard about the progress of the Salt Mapping and Management Support Project of the National Action Plan for Salinity and Water Quality, which recently involved aerial surveys covering 100,000ha centred on the town.

Jamestown is one of only five sites in SA to trial the airborne technologies which, if successful, could be applied to other agricultural areas across the state.

The project targets regions with recognised salinity problems and aims to help scientists and landowners understand the hydrology of these problem areas much more accurately.

The $3.8 million SA project is jointly funded by the State and Commonwealth Governments, and managed by the Department of Water, Land and Biodiversity Conservation.

Results of the project will be presented to the Northern and Yorke Agricultural Districts Integrated Natural Resource Management (NAYAD INRM) Group to assist with salinity management.

NAYAD INRM Group chair Merv Lewis said the group was looking forward to the results of the project and hoped it would improve their understanding of salinity in the area and how to manage it.

Dr Richard Cresswell, a research scientist from the Bureau of Rural Sciences in Canberra and manager of the Commonwealth part of the project, gave local farmers a run down of the technologies used to gather information about salt in the landscape.

Three different techniques are being trialed:

- **Electromagnetics** are able to identify three dimensional zones of high electrical conductivity and can map potential zones of high salt storage or conducting material such as clay.
- **Magnetics** can provide an insight into the underground 'plumbing' or groundwater flow systems.

They do not directly detect salinity but measure local variations in the earth's magnetic field which are often associated with different rock types, faults, fractures and ancient buried drainage systems.

- **Radiometrics** measure variations in the natural radioactivity of the upper 30 centimetres of the land's surface and can provide information about different soil types or drainage patterns that may be linked to salinity.

The salinity picture developed from the three survey methods will help to target areas for action where benefits for salinity management can be maximised, while containing the loss of productive agricultural land.

Salinity management measures might include increased water use by plants, for example, by using perennial pasture, improving crop production or planting trees.

Lucerne, a perennial pasture with numerous varieties, is likely to play a major role due to its commercial viability and ability to reduce recharge to groundwater.

Further, where local groundwater salinity is low, lucerne is capable of substantially lowering shallow watertables.

Other measures include drainage works and groundwater pumping.

Ground-truthing and drilling for the NAP Salt Mapping Project will take place over the next few months, with interpreted maps of salt and groundwater flow systems expected by December 2003.

Local farmer Leith Cooper summed up the sentiment of the meeting.

"Anything that improves our understanding of the salt problem has got to be a good thing," he said.

Dr Cresswell is also interested to hear from farmers who live directly under the fly zone to gather information for an associated Grains Research and Development Corporation project.

He is interested to know whether the information gathered from the surveys can provide a management tool for farmers to use at the paddock scale.

This requires ground-truthing of the aerial images at a scale beyond the scope of the NAP Salt Mapping Project, with the potential to apply the information contained in the images to a range of land management issues.

Further information on the NAP Salt Mapping Project is available from the State project manager Dr Glen Walker on 8303 8743 (walker.glen@saugov.sa.gov.au).

Dr Cresswell can be contacted on 02 6272 5675 (richard.cresswell@brs.gov.au) for further information on the GRDC project.

Inspecting maps of the Jamestown NAP Salt Mapping project area are (from left) Mary-Anne Young, Dr Richard Cresswell, Neil Lange, John Wurst, Judy Lange, Tim Hall and Dom Clark.

Figure C-1. Article from 'Northern Argus' (20 Nov 02), following a meeting with some Jamestown farmers.

Aeroplanes and drilling rigs – looking into a salty problem

A low flying aeroplane and a drilling rig may sound like an odd partnership. But around the Angas - Bremer Plains both have been involved in work for the SA Salt Mapping and Management Support Project.

Drilling activities, undertaken over the last week, are part of the ground-truthing phase, required to verify geophysics data gathered from the air, in August 2002.

The Project trials geophysics techniques, at five sites across SA, to determine their value in increasing our understanding of salinity processes, and is funded by the State and Commonwealth Governments through the National Action Plan for Salinity and Water Quality.

Results of the project will be presented to the SA Murray Darling Basin Integrated Natural Resource Management (SA MDB INRM) Group to assist with salinity management.

Interestingly, three of the five project sites are within the extensive area covered by this regional INRM Group, with other MDB sites at the Riverland and Tintinara.

SA MDB INRM Chair Leon Broster said the group was looking forward to the results of the project. "Where our groundwater resources for irrigation are facing the salinity threat, the more we know, the better we'll be able to manage it".

In the Angas-Bremer Plains the technology is being used to look at the groundwater flow systems, including zones of higher salinity, the mechanisms of recharge and the connection between the shallow alluvial and deeper limestone aquifers.

The three geophysical techniques being trialed on the Plains are: Electromagnetics – which can detect three dimensional zones of high conductivity, such as salt or clay.

Radiometrics – which detects differences in the chemical composition of the land's surface, and can provide information about different soil types, drainage patterns and sediments that may be linked to salinity, and Magnetics – which detects tiny magnetic fields associated with different rock types, faults, fractures and iron coated pebbles in ancient buried drainage systems (paleochannels).

While not directly detecting salinity they can provide an insight into the underground 'plumbing' or groundwater flow systems.

Ground-truthing activities such as drilling are very important in identifying what the airborne techniques have detected. Samples are taken from the soil and weathered rock profile to be analysed for salt levels, particle size, and sediment/rock type.

There has been good correlation between the conductive zones detected by the electromagnetics and the extensive groundwater monitoring data collected by the Angas-Bremer Water Management Committee.

This existing groundwater data helps to verify the airborne data, while conversely the opportunity arises to improve the resolution of current groundwater salinity maps.

The most interesting part of the study will be trying to better understand how water enters the alluvial and limestone aquifers, and how these systems are connected.

The airborne geophysics data provides valuable information on the structure of the aquifers and enables researchers to pinpoint areas to study this.

Analysis of groundwater chemistry in these selected areas will hopefully provide information to groundwater managers on the dominant processes of natural recharge, whether this occurs at the fault zone, during times of flood or from drainage from the alluvial to the limestone aquifer.

Final results, including improved geology and groundwater models of the area are expected by December 2003.

Further information on the NAP Salt Mapping Project is available from the State project manager Dr Glen Walker email (walker.glen@saugov.sa.gov.au).

Analysing the sediment profile are (from left) John Spring and Grant Jones, both from the Bureau of Rural Sciences, Canberra, and project leader Dave Gibson from Geosciences Australia. In the background are Tony Page, Paul Juett and Byron Devenish from Underdale Drillers.

ARGUS AGRICULTURE

18th Ayrshire calf and junior handlers day held at Meadows

This event was held on May 18, 2003 at

Figure C-2. Article from the 'Southern Argus' (22 May 03) newspaper, following drilling activities on the Angas-Bremer Plains.

action Salinity & Water AUSTRALIA

Government of South Australia

Airborne Geophysics supporting salinity management in the Riverland

The 'SA Salinity Mapping and Management Support Project' Riverland investigation has produced some major results, with great potential to improve the management of irrigation impacts on River salinity, and of benefit for the design of salt interception schemes.

Two information sessions will discuss the findings, and further potential, of the Riverland geophysics data, and also how the region can best use this information to assist with salinity management.

The Riverland Airborne Geophysics project area

Where: **Riverview Lounge, Berri Resort Hotel,**

When: **Wednesday 14th July,**

- **1 – 5pm Workshop** (for an in depth look at the information), or
- **6.45 – 8.20pm Overview**

All are welcome to attend.

For further details, or if you would like a program for the sessions, please contact Craig Liddicoat, Ph: (08) 8303 9342, Fax: (08) 8303 9320, or Email: liddicoat.craig@saugov.sa.gov.au

Figure C-3. Advertisement in the 'Murray Pioneer' newspaper (6 & 9 Jul 04) promoting community meeting to discuss Riverland survey results.

APPENDIX D. PROJECT TEAM MEMBERS

Project Steering Committee

Bryan Harris, DWLBC (Chairperson)

Peter Butler, DWLBC

Mary-Anne Young, Northern and Yorke Agricultural Districts INRM Group

Jenny Walker, Australian Government NRM Team

Colin Grant / Peter Baker, Bureau of Rural Sciences

Jan Whittle, SA Murray-Darling Basin INRM Group

Executive Officer

Glenn Gale (DWLBC)

Technical Working Group

Glen Walker (Rural Solutions SA / CSIRO) SA Manager

Richard Cresswell (Bureau of Rural Sciences/CSIRO) Commonwealth Manager

Tim Munday (CSIRO / CRC LEME)

Steve Barnett (DWLBC)

David Tonkin (DWLBC)

Ken Lawrie (CRC-LEME/GA)

Peter Cook (CSIRO)

Communications

Craig Liddicoat (Rural Solutions SA)

Project Leaders

Fred Leaney (CSIRO)

Peter Cook (CSIRO)

Andrew Herczeg (CSIRO/CRC-LEME)

Jim Cox (CSIRO/CRC-LEME)

Rob Fitzpatrick (CSIRO)

Ian Jolly (CSIRO)

Tim Munday (CRC LEME/CSIRO)

Chris Henschke (Rural Solutions SA)

Steve Barnett (DWLBC)

Amanda Camp (DEH/DWLBC)

Matt Miles (DEH)

Richard Cresswell (BRS/CSIRO)

Dave Gibson (CRC-LEME/GA)

John Wilford (CRC-LEME/GA)

KokPiang Tan (CRC-LEME/GA)