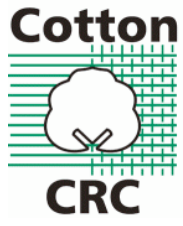




***Understanding the salinity threat
in irrigated cotton growing areas
of Australia
- Phase III –
Implementation and
Management***

CRC – 11C

**Australian Cotton Cooperative Research Centre
Centre for Salinity Assessment & Management
The University of Sydney**



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Final Report

Part 1 - Summary Details

Please use your TAB key to complete part 1 & 2.

		CRDC Project Number: CRC-11C
January Report:	<input type="checkbox"/>	Due 29-Jan-01
August Report:	<input type="checkbox"/>	Due 03-Aug-01
Final Report:	<input checked="" type="checkbox"/>	Due within 3 months of project completion

Project Title: *Understand the salinity threat in irrigated cotton growing areas of Australia - Phase III - Implementation and Management*

Project Commencement Date: 01/07/1999 **Project Completion Date:** 30/06/2002

Research Program: Soils

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Part 3 - Final Report

Australian Cotton Cooperative Research Centre: CRC-11C

Understand the salinity threat in the irrigated cotton growing areas of Australia

– Phase III – Implementation and Management

1. List the project objectives and the extent to which these have been achieved.

One third of global food and fibre is produced by irrigation agriculture and it is predicted that this will rise by 50 % in 2040 (Rhoades *et al.* 1992¹). Management of the irrigated land is therefore an important factor in ensuring sustainable production. However, in the Murray-Darling Basin of Australia, inefficient irrigation practices have resulted in the creation of perched water tables, waterlogging, rising water tables and salt mobilisation. In NSW alone 40% of irrigated areas is prone to shallow water tables and this is increasing (Murray-Darling Basin Commission, 1999²). The common cause of degradation is deep drainage (*DD*) or groundwater recharge, which is the process whereby water passes through the root-zone into the water table. With the increasing pressures on water resources and expectations from the community regarding natural resource management it is necessary that methodology be developed for identification of where salinisation has occurred, what are the processes, which have created these problems and determine where improvements can be made in natural resource management.



Figure 1. Water logging and soil salinisation adjacent to a) supply channel and b) water storage in the Bourke Irrigation District, Darling River valley.

As shown in Figure 1, point source soil salinisation and water logging are evident in many irrigated cotton-growing districts in south-eastern Australia (e.g. Bourke, Trangie and Warren). Although many farmers are successfully managing these outbreaks, the cause of soil salinisation is not clearly understood. Part of the problem is the lack of natural resource information, such as root- (0-2 m) and vadose- zone (2-7...15 m) information, which are required for soil attribute mapping

¹ Rhoades, J.D., Kandiah, A. & Mashali, A.M. 1992. The use of saline waters for crop production. FAO irrigation and Drainage Paper 48, pp 133.

² Murray-Darling Basin Ministerial Council. 1999. The Salinity Audit of the Murray-Darling Basin. Murray-Darling Basin Commission. Canberra..

and modelling (e.g. chloride data for estimation of groundwater recharge rate). In order to develop suitable methodology, the major aim of Phase II (Methods and Techniques) was developing techniques to understand the salinity threat at the

- a) field,
- b) district and
- c) regional levels.

The use of consistent methodology would allow comparisons at different scales and between different areas and landscapes. The objectives were achieved with the development of a) a Mobile Electromagnetic Sensing System (MESS), b) broadscale EM34/38 surveys, and c) reconnaissance soil-survey data collection (in collaboration with Dr Inakwu Odeh - Australian Cotton CRC), respectively. At each level of study case studies were undertaken to demonstrate and test the methods in the lower Gwydir and Namoi valleys.

In order to provide similar information for comparison, the major aims of Phase III (Implementation and Management) were to:

- a) initially consult with community groups (e.g. Macquarie 2100) to ensure research projects developed were consistent with natural research management issues in each of the major cotton growing areas of central and northern NSW and southeast Queensland;
- b) generate matching research funds through the Natural Heritage Trust and Salt Action Programs to extend the field, district and regional methods, developed as part of Phase II, to other irrigated cotton growing districts (e.g. lower Macintyre, Macquarie and Darling River valleys);
- c) collection of EM data, and soil information in the root- (0-2 m) and vadose-zones (2-12 m) to measure, model, map, manage and monitor soil salinisation processes at various scales.

These objectives were met by:

- a) and b) initiating project proposals and obtaining supplementary funding from Salt Action and the Natural Heritage Trust (NHT) in association with:
 - i) Macintyre River Valley Water Users Association,
 - ii) Gwydir Valley Irrigators Association,
 - iii) Upper Namoi Cotton Growers Association,
 - iv) Macquarie 2100,
 - v) Bourke Irrigators Association;
- c) collection of electromagnetic (EM) and soil information at the
 - i) Field scale (Mobile Electromagnetic Sensing System)
 - lower Namoi valley ("*Cumberdeen*"),
 - lower Namoi valley ("*Warianna*"),
 - ii) District scale
 - lower Macintyre River valley (southeast of Toobeah),
 - lower Gwydir River valley (northeast of Moree),
 - upper Namoi valley (southeast of Gunnedah),
 - lower Macquarie valley (southeast of Warren and Trangie),
 - lower Darling valley (west of Bourke).

2. How has your research addressed the Corporations three outputs: Sustainability, profitability and international competitiveness, and/or people and community?

Profitability and competitiveness

With the investment of the Cotton Research and Development Corporation the Australian Cotton Cooperative Research Centre was able to match the Corporations contribution with funds obtained from the Natural Heritage Trust. This was achieved in consultation with various industry and community groups in the five major cotton-growing areas of northern New South Wales and southeast Queensland. The source of funding, project code, title, amount of funds, year(s) of funding and collaborating community group are provided below.

Funding body	Title	Amount	Years	Group
1. National Heritage Trust (NW0709.97)	<i>Using and developing decision support guidelines in cotton areas of NSW</i>	\$ 84,000	1998-2001	Coordinating committee of Namoi valley water users association
2. Salt Action (NW1058.98)	<i>Determine salinity threat in irrigated cotton in upper and lower Namoi valley</i>	\$ 65,143	1998-1999	Coordinating committee of Namoi valley water users association
3. National Heritage Trust (Qld-992952)	<i>Understanding salinity threat in irrigated areas of Macintyre River valley</i>	\$ 93,476	1999-2000	Macintyre Valley River Basin Water Users Association Incorporated
4. Salt Action (CW0396.99)	<i>Understand and manage causes of salinity in irrigated systems in the lower Macquarie valley</i>	\$ 89,464	1999-2000	Macquarie 2100
5. Salt Action (WN0688.99)	<i>Determine causes/controls of salinity in irrigated farming systems in the Bourke irrigation district</i>	\$ 89,464	1999-2000	Bourke Cotton Growers Association
6. National Heritage Trust (CW0708.00)	<i>Assess relationships of irrigated farming to rising saline groundwater south-east of Warren</i>	\$ 114,650	2000-2001	Macquarie 2100
7. National Heritage Trust (NW0523.00) (GW3036.01)	<i>Salinity risk assessment in irrigated farming systems across the lower Gwydir valley</i>	\$223,647	2000-2003	Gwydir Valley Irrigators Association
8. National Heritage Trust (NA3035.01)	<i>Understand the salinity threat in the irrigated cotton growing area in the upper Namoi valley"</i>	\$ 117,975	2002-2003	Upper Namoi Cotton Growers Association

Note 1: Projects 1-6 were obtained as matching funds against Phase III monies.

Note 2: Projects 7-8 will be completed as part of Phase IV.

The funds obtained enabled specific natural resource management issues to be addressed in each of these study areas. For example in the lower Gwydir and Macquarie valleys deep drainage risk maps were produced at the request of the Gwydir Valley Irrigators Association and Macquarie 2100 (see conference paper entitled: Triantafylis et al (2002)-Irrig. Assoc. Sydney). These maps have led to a greater understanding of where improvements in water use efficiency can be made particularly with respect to relocation of water storage reservoirs and supply channels.

Sustainability of natural resources

Sustaining natural resources requires detailed information, particularly in areas where soil water logging and water salinisation are evident. This project initiated the collection of data in cotton growing fields and districts in each of the five major cotton-growing valleys of southeastern Australia. For example, an irrigated cotton field (i.e. Field 54) at “*Cumberdeen*” (lower Namoi valley) was studied due to the seasonal soil salinisation evident near a large water storage. During the interpretative phase of the project it was recognised that the storage was leaking, resulting in mobilisation of salts into an adjacent field (i.e. Field 54). This occurs during the winter and spring. Subsequent irrigation during the summer leaches the salts beyond the root zone. Natural resource management could be improved either through waterproofing, relocation or not using the reservoir during the winter. This is similarly the conclusion drawn with respect to a major supply channel at “*Auscott-Midkin*” (lower Gwydir valley).

The situation at “*Cumberdeen*” is site specific to the Pilliga Scrub and therefore most other irrigated cotton farms in the lower Namoi valley around Wee Waa are not prone to similar problems. This is because they have been developed on the clay alluvial plains. This includes areas such as “*The Gardens*,” Doreen Lane and the large corporate farms of “*Togo*” and “*Auscott*”. In the lower Gwydir and Macquarie valleys maps have been generated which show the areas at greatest risk of excessive deep drainage with respect to the location of irrigated fields, supply channels and large earthen water storage’s. The high-risk areas are consistent with areas of known problems. The results are being used to assist irrigators make decisions relating to improving water use efficiency by relocation of water storage and conveyance structures to more suitable locations. In many instances, the reservoirs have been de-commissioned or used only to store storm water.



Figure 2. Management of water tables requires a) retirement of inefficient water storage structures and b) only using conveyance structures during irrigation season (e.g. Macquarie and Gwydir valleys).

In the Bourke Irrigation district information is being collected which will assist in understanding the location and cause of soil salinisation and possible management strategies to minimise off site impact.

People and communities

The Corporation's investment (along with matching funds from NHT) enabled the project to expand significantly from 2½ research positions (1 Senior Research Fellow and 1½ Technical Officers) to 5 research positions over the three-year duration of the project. This enabled significant training and extension of the project's long-term benefits to growers, farm managers and the irrigation community in general. Technical positions were filled by the following personnel (current affiliations shown in brackets);

Dr Thomas Bishop (University of Florida, Dept. Soil & Water Science)
Dr Raj Singh Malik (University of Sydney, Australian Cotton CRC)
Mr Mathew McRae (NSW Agriculture – Orange)
Mr Danny Moore (AgriLINK – Narrabri)
Mr Michael Short (University of Sydney, Australian Cotton CRC)
Dr Ranjith Subasinhge (University of NSW, Recycled Organics Unit).

Attracting postgraduate students enhanced the corporation's investment. Mr Andrew Huckel and Mr Faruque Ahmed, who both worked as technical officers, were awarded Masters of Science in Agriculture (i.e. research) degrees in 2001. It is anticipated that Ms Esta Kokkoris will complete in 2003.

Mr Andrew Huckel (NSW Farmers Association – Sydney)
Mr Faruque Ahmed (University of Sydney, PhD – SUNfix)
Ms Esta Kokkoris (Department of Primary Industries, Tasmania).

Four under-graduate students also undertook projects as part of their final year. This included:

Mr James Cupitt (University of Sydney, Aust. Centre for Prec. Ag.)
Mrs Amanda Jarman (University of NSW, Recycled Organics Unit)
Ms Lisa Nelson
Mr Owen Gwilliam

In addition, the funds allowed the group to consult with and develop various research projects in the major cotton growing areas of southeastern Australia. Six different community groups actively participated in the development, submission of NHT applications as well as administering funds and various aspects of project management. This included consultation with various executives and key stakeholders:

Macintyre River Valley Water Users Association
Bruce McCollum (border Rivers Food and Fibre),
Cam Turner ("*Oonavale*"),
David Turner ("*Macintyre Downs*")

Gwydir Valley Irrigators Association
Wal Murray (Executive Officer)
John Seery ("*Kooroogamma*")
Will Kirkby ("*Glen Prairie*")
Richard (Dick) Browne ("*Auscott-Midkin*").

Coordinating committee of lower Namoi valley water users association
Jerry Killen (Executive Officer)
Bernie George ("*Togo Station*")
Philip Norrie ("*Mollee*")

Upper Namoi Irrigators Association
Mark Hickman (NSW Agriculture)
Chris McNamara (President)
Judy Middlebrook (Secretary)
Macquarie 2100
Rob Kelly/Adam Collings (Salinity Prevention Officers)
Bill Williamson (President)
Nick Wilson (Executive Officer)
Mal Carpenter (“Agriland”)
Bourke Cotton Growers Association
Ian Cole (Executive Officer)
Stephen Buster (“Darling Farms”)
Peter Cottle (Clyde Agriculture)



Figure 3. Representatives of a) Gwydir Valley Irrigators Association, b) Bourke Cotton Growers Association, c) Macquarie 2100 and d) Coordinating Committee of lower Namoi valley water users association.

Finally, on several occasions the research carried out assisted various individual cotton farmers with understanding the problems associated with water logging and isolated instances of soil salinisation and management of soil sodification. This included:

- Mr Peter Glennie, “Norwood”, lower Gwydir valley
- Mr Phil Lawrence, “Cumberdeen”, lower Namoi valley
- Mr Phil Firth, “Warrianna”, lower Namoi valley
- Mr Mal Carpenter, “Agriland Byron”, lower Macquarie valley

3. Detail the methodology and justify the methodology used.

The traditional methods used for the acquisition of soil information involve intensive field survey and laboratory analysis that are time-consuming and costly. As a consequence only a limited amounts of data are collected. The low resolution of the spatial data used to provide indicators of the distribution of soil properties and soil condition may lead to errors in interpretation and possibly soil management. Specific to soil salinity assessment and determination of irrigation/drainage efficiency, more detailed quantitative information is required.

The development of new technologies has revolutionised the way in which the soil information can be obtained more efficiently. One of these technologies is electromagnetic (EM) induction instrumentation (e.g. EM38, EM31 and EM34), which measure the apparent bulk soil electrical conductivity (EC_a). The instruments work by emitting an alternating current through a transmitter coil, which induces a primary magnetic field to pass perpendicular to the coil orientation and into the soil. As this current passes through soil, eddy currents are generated. The strength of these is a function of:

- a) amount of negative charge on the clay particle;
- b) clay content;
- c) concentrations of salts in the soil solution; and,
- d) soil moisture content.

The more conductive the soil, the greater the secondary magnetic field produced. The ratio of the two magnetic fields (i.e. primary and secondary) determines EC_a . As such, EM instruments have been used extensively to determine the spatial distribution of soil attributes including clay content, moisture, soil salinity, nutrient status, depth to a clay layer, identification of high sodium adsorption ratio and exchangeable sodium percentage and determination of organic carbon fraction. All of these studies were based on the initial calibration, which determines the soil attributes that most contribute to the response of the instrument.

To improve the efficiency of field measurement of EC_a EM instruments have been mounted onto small platforms (e.g. quad bikes, tractors) and along with Global Positioning Systems (GPS) the data collected can be used to produce rapid and repeatable information at the field level. As part of this project the system developed by the Australian Cotton Cooperative Research Centre was used to describe the spatial distribution of soil clay content, salinisation and identify management zones in a field affected by prolonged use of high sodium adsorption ratio water.



Figure 4. Electromagnetic field methods for a) field level (i.e. Mobile EM Sensing System-MESS) and b) district level (i.e. EM34) investigations.

EM instruments can also be used at the district level to upscale results achieved at the field scale and also to identify where more detailed information may be appropriate at the field level. As part of this project 7 separate district scale surveys were undertaken in 6 cotton growing valleys using both the EM38 and EM34 instruments. These were undertaken on 500-m grid spacing.



Figure 5. Soil data collection involved a) sampling to depths of 0-2...15 m), b) soil drying and grinding, c) soil storage and d) laboratory analysis (i.e. EC_e -dS/m, particle size fractions, exchangeable cations, pH, chloride content, etc.).

With the EC_a data generated, soil-sampling sites can be strategically selected to determine the reasons for the spatial variation in EC_a , and hence soil properties, across a given field. These measurements can be used for targeting the location of soil samples sites to calibrate the EM instrument. Once a suitable relationship is established between one or a number of soil attributes a map can be produced. As such measures of EC_a , add value to the limited soil information collected using traditional methods.

The major reason for the selection of this methodology was

- availability of the EM instruments (University of Sydney),
- previous use and success in determining spatial distribution of soil properties relevant to salinity assessment and management, and
- increasing use by consultants.

With respect to point c) it is anticipated that the calibration equations derived in each study area, for example average clay content and soil salinity etc in the root and vadose zone, will be made available. This will allow consultants to produce maps of these soil properties, rather than raw EC_a measurements, and hence provide information about the spatial distribution on the field or farm level.

4. Detail results including the statistical analysis of results.

In the following section a summary of interpreted results are presented from the EM and soil data collected as part of Phase III. This includes, three field- and two district-level investigations carried out in the lower Namoi, Gwydir and Macquarie valleys and in the Bourke Irrigation District. Details of exploratory data analysis at the district scale are provided in Section 5. The appendix section contains selected publications, which provides a more comprehensive description of the research carried and development carried out.

Field level deep drainage risk mapping in the lower Gwydir valley

Soil salinity assessment and management in the lower Namoi valley

Multiple-field mapping of salinisation in the lower Namoi valley

District level deep drainage risk mapping in the Gwydir and Macquarie valleys

Mapping saline subsurface material in the Bourke Irrigation District



Field level deep drainage risk mapping in the lower Gwydir valley

Improving irrigation efficiency is of primary importance in arid and semi-arid regions of the world as a consequence of increasing incidences of soil and water salinisation. In the cotton-growing regions of Australia salinisation and waterlogging are generally a result of inefficient irrigation practices, which lead to excessive deep drainage (*DD*). There is therefore the need to apply a relatively inexpensive approach to assessing where inefficiencies occur and make prediction of suitability of existing and new water storage sites. However, physical methods of measuring *DD*, such as flux meters and lysimeters are time consuming and site specific. In this research we apply a rapid method for determining the spatial distribution of *DD* risk in an irrigated-cotton field at “Auscott-Midkin” in the lower Gwydir valley. The field selected was Field 11, which has a known history of water logging associated with the head ditch and the red soil types (Figure 6a)

First, EC_a data (using EM38 and EM31) were used to determine a soil-sampling scheme for collecting soil information such as clay content and exchangeable cations to a depth of 1.2 m. The soil data and water quality information were inputted into the Salt and Leaching Fraction (SaLF) model to estimate *DD* rate (mm/year) at each site. In developing the relationship between EC_a and estimated *DD* at all the sites sampled (i.e. 81), three exponential models (2-, 3- and 4-parameter) were compared and evaluated using the Aikakie Information Criteria (AIC). The 3-parameter exponential model was found to be best and used for further analysis. Using the geostatistical approach of multiple indicator kriging (MIK), maps of conditional probability of *DD* exceeding a critical cut-off value (i.e. 50, 75, 100 mm) were produced for various rates of irrigation ($I = 300, 600$ and 1,500 mm/year).

The areas of highest risk (i.e. conditional probability > 0.8 : red areas) were consistent with where water-use efficiency was problematic near the head ditch and thus leads to the creation of perched water tables (Figure 6b). The advantage of this approach is that it is quick and it is applicable to situations where efficient use of water is needed. The results can be used for irrigation planning particularly in the location of large irrigation infrastructure such as water reservoirs.

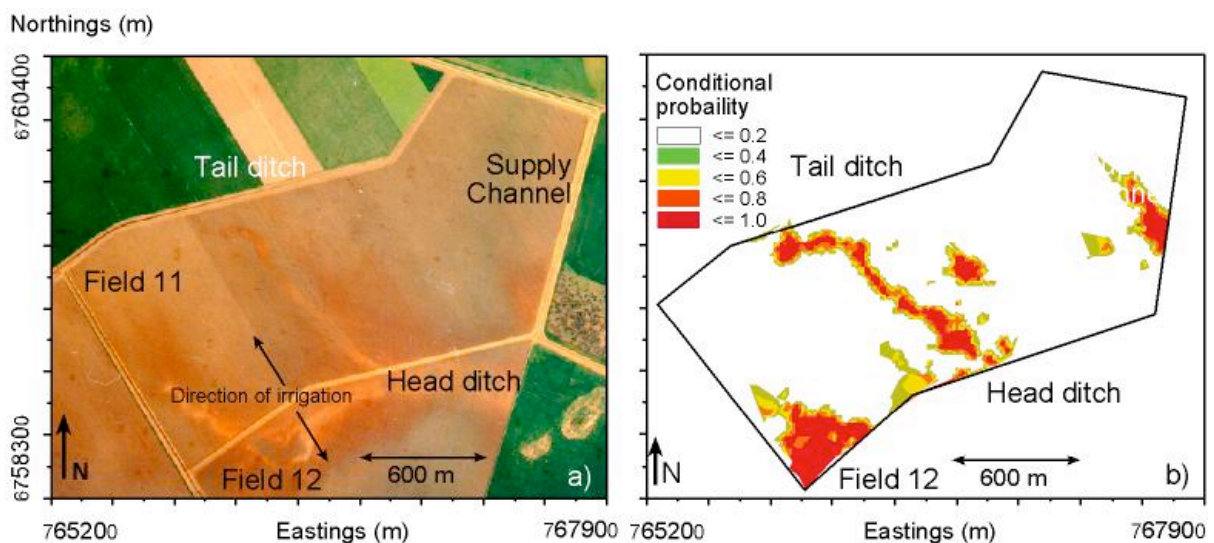


Figure 6. a) Aerial photo of “Auscott Midkin” Field 11 and b) spatial distribution of deep drainage risk (i.e. DD exceeding 100 mm/year) if Irrigation = 1,500 mm/year and Rainfall = 584 mm/year.

Soil salinity assessment and management in the lower Namoi valley

In a field study undertaken at “Cumberdeen” (i.e. Field 54) the MESS (Figure 4a) was used to assist in ascertaining the cause and control of soil salinisation. Initially, the correlation between, and the spatial distribution of EC_a , obtained using an EM31 and EM38, provided a basis for determining the sampling strategy for the inventory of selected soil properties (Figure 7a). To gain knowledge of the soil properties, which contribute to the response of the EM38 and EM31, simple linear regression models were fitted. The models compared EC_a average values to a depth of 2.0 m of gravimetric field moisture and clay content (%), salt concentration (EC_e -dS/m) and effective cation exchange capacity (ECEC-cmol(+) kg^{-1} of soil and clay solids). The results suggest that ECEC and EC_e were most strongly correlated with EC_a . Further analysis of the samples (i.e. high Ca/Mg ratio and low ESP – see Figures 7c and d) indicated that the likely area of leakage from the reservoir, and hence the cause of soil salinisation (see points 18 and 20 – Figure 7c), is due to seepage from the reservoir during the winter and spring. This is because a large hydraulic head in the water storage forces water and salt seepage near the northeast corner of the reservoir at point 19. Here the soil is structurally more stable (i.e. ESP < 6 and Ca:Mg > 1). As a result water seeps from this portion of the reservoir and the soil becomes salinised: evidenced by stunted appearance of cotton seedlings.

In terms of management, several options relating to improving water use efficiency merit consideration. The first is the relocation of the reservoir to another part of the farm more suited for containment. An alternative approach is excavation of a trench beneath the northeast corner of the reservoir bank, which could either be lined with an impermeable geomembrane (e.g. bentonite) or filled with some reactive clay soil to reduce leakage. Increasing the size of the reservoir to the north is not recommended. This is because clay minerals such as smectite that are suited for this purpose are not prevalent in this area.

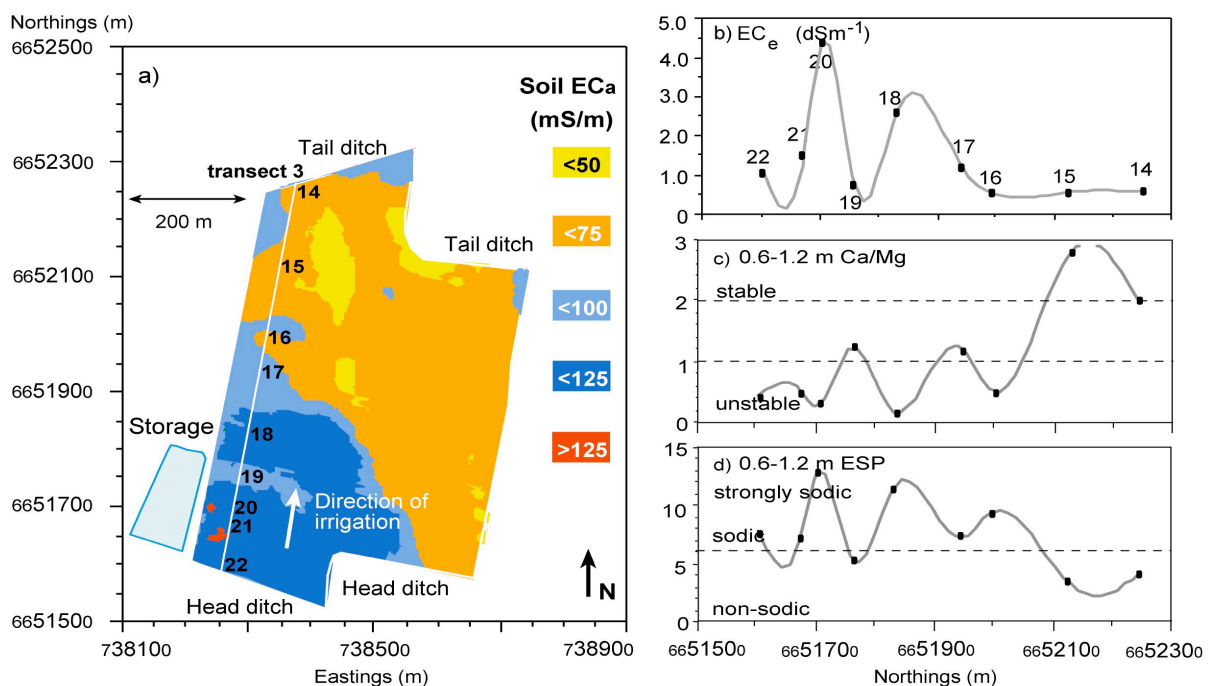


Figure 7. Spatial distribution of a) soil EC_a (mS/m) obtained with an EM31 in “Cumberdeen” Field 54, b) average 2.0 m EC_e (dS/m), c) 0.6-1.2 m Ca:Mg and d) 0.6-1.2 m ESP along transect 3.

Multiple-field mapping of salinisation in the lower Namoi valley

In the lower Namoi valley high levels of subsoil salts were associated with some of the oldest irrigated fields developed for cotton production. These were located in the northernmost parts (i.e. Fields 18-20) of “Auscott-Narrabri”. It was not clear whether irrigation was creating this saline bulge or whether it was a natural phenomenon. Figure 8 shows the spatial distribution of EC_e in fields 18-20 as determined using regression kriging. It is obvious that EC_e at a depth of 0.90-1.20 m (Figure 6a) is lower as compared to salinity at 1.80-2.10 m (Figure 8b). At a depth of 0-0.30 m soil EC_e was below 3.5 dS/m (Figure not shown). It is also apparent EC_e is higher in the northern parts of Fields 19 and 20 as compared with the southern areas. This is similarly the case in Field 18.

The reason for the salt accumulation in these areas is attributable to Galathera Creek. Galathera Creek and its tributary, Tarlee Creek, have their headwaters in the nearby pedimented slopes of Pilliga Sandstone and Tertiary weathered sandstone, respectively. Initially, they flow in a westerly direction before heading south toward the Namoi. As Galathera approaches the clay plains it veers away from the Namoi turning northward (see Triantafyllis *et al* 2000).

Owing to the lower gradients in this area, approximately 0.6 m per km, the water flowing in these creeks on the plains lose energy. This is evidenced by the meandering nature of Galathera Creek on the plains proper. Just beyond the study area and to the west, the channel itself becomes ill defined as the water is dispensed, fanning out over a small area. As a result, dissolved salts have also been dispensed and subsequently accumulated in these areas and in particular at depths between 0.9-2.0 m along old drainage lines and previously lower lying areas. This is the case in the northeast-facing arc of higher EC_e shown in Fields 19 and 20 (Figure 8a) and the higher areas of EC_e in the north and western part of Field 18 (Figure 8b), respectively.

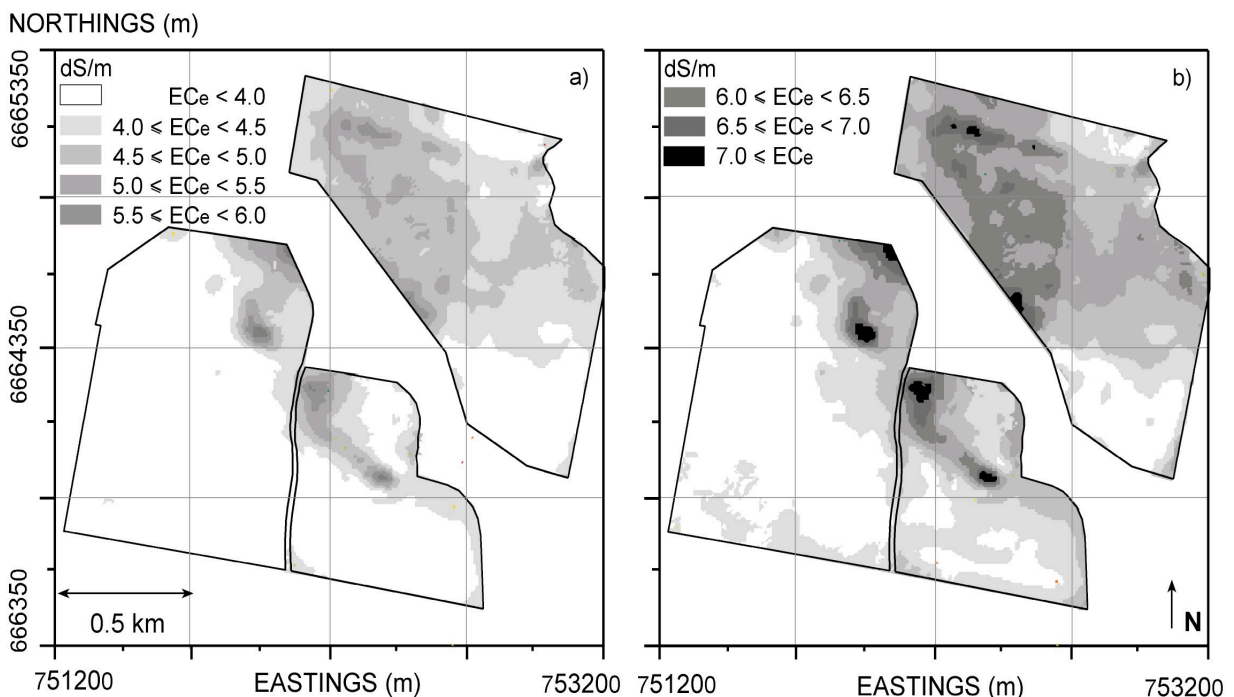


Figure 8. Maps of the spatial distribution of soil salinity (EC_e – dS/m) in fields 18-20 depths of a) 0.90-1.20 m and b) 1.80-2.00 m.

District level deep drainage risk mapping in the Gwydir and Macquarie valleys

In the lower Gwydir and Macquarie valleys, in the north and central western NSW, Australia, extensive irrigated cotton production is an important contributor to the nations export earning. However, there are problems of excessive deep drainage (*DD*) in these regions. In order to address these problems soil and water quality information are necessary but there is little quantitative information to a) plan for and b) implement improved water use efficiency practices. In this research, we report on methods that efficiently generate data on natural resources at the district level. First we used an EM38 survey to characterise broad soil profile types in the Ashley (lower Gwydir) and Trangie soil (lower Macquarie) districts. From the apparent electrical conductivity (EC_a – dS/m) data collected using the EM38, soil profile sites were selected and sampled with laboratory analysis carried out to determine exchangeable cations and clay content. The soil data was inputted into a salt and leaching fraction (SaLF) model along with water quality and quantity parameters such electrical conductivity of irrigation water (EC_{iw} - dS/m) and rainfall (R - mm/annum). Various water application rates were also considered to simulate irrigated cotton and rice production ($I = 600 - 1,200$ mm/annum) as well as shallow water reservoirs ($I = 1,800$ mm/annum). An exponential function was used to describe the relationships between EC_a values obtained with the EM38 and *DD*. These relationships were used to estimate *DD* at each of the EM38 survey sites whereupon cut-off (z_c) values were used for indicator transforms of the data.

The risk map for the location of storages for the Ashley district is shown in Figure 9a where a z_c value of 100 was used. Here, two areas stand out as being most suitable: “Auscott Midkin” and “Milo”. This is similarly the case on the landholdings of “Caroale” and “Listowel”. However, it is also evident that some of the districts storage infrastructure is located in areas where water loss may be high and hence efficiency in water storage and delivery could be improved. This is particularly the case in the area north and south of the Gingham Road. Here the risk was consistently high (i.e. $CP \geq 0.9$). It is worth noting that of the storages located here, two experience some problems with leakage. This includes the dual-cell storage located in the center of the study area (Easting 771000, Northing 6753000). The southern cell is located predominantly in the moderate risk zone (i.e. $0.5 \leq CP < 0.7$), whilst the northern cell lies exclusively in the moderate to high-risk area (i.e. $0.7 \leq CP < 0.9$). The northern cell creates waterlogged soil conditions around the perimeter, suggesting the simulation is consistent with the farmer’s experiences. The same is the case with respect to the storage located at an Easting of 766000 and Northing of 6751000. This storage is only used as a reservoir for holding water that falls on-farm during heavy rainfall events.

Figure 9b shows the map of CP that *DD* will exceed 200 mm/annum if a reservoir or supply channel carries 1.8 m of freestanding water in the Trangie district. It is evident that most of the area, according to this simulation, is unsuitable for the location of such structures. This is not the case in the northernmost farm of “Boomerang” where two of the most recently built storages are located. The results achieved at “Agriland Byron” are consistent with the management experience with respect to the storage located in the central part of the farm (Easting 613000, Northing 6560000), where shallow water tables and soil salinisation which prevail during wet seasons. This reservoir is no longer used to store water for long-term purposes. This has mitigated the problem of the shallow water tables and soil salinisation in most seasons, although in wet years some areas are still affected.

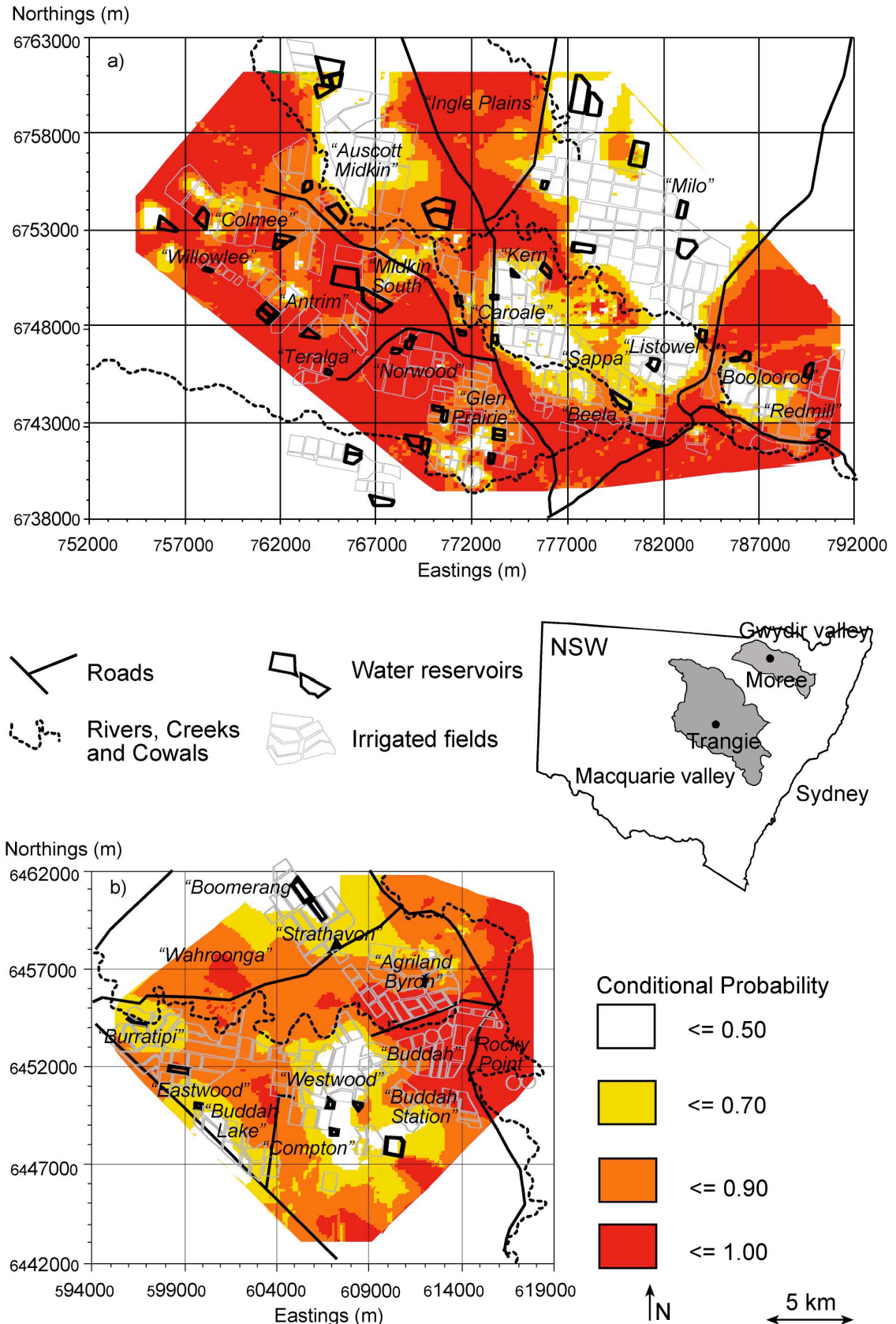


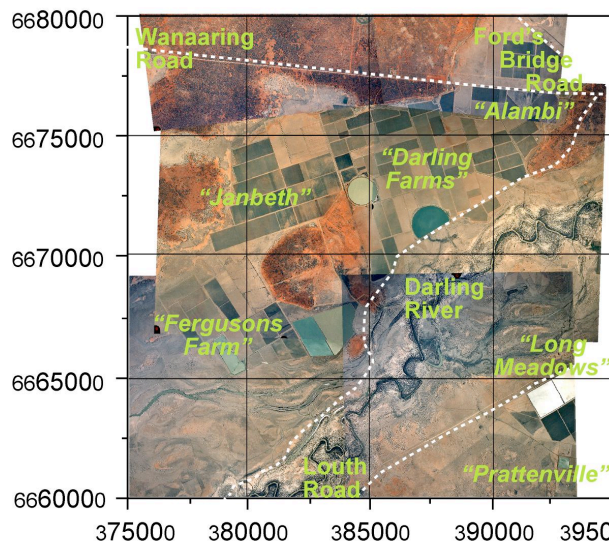
Figure 9. Map of conditional probability (CP) that soil at a particular site will exceed an estimated deep drainage (DD) value of 50 mm/annum if 1,800 mm of irrigation water (I) was applied and a) 584 mm of rainfall (R) was assumed in the Ashley area (Gwydir valley) and b) 412 mm of rainfall (R) was assumed in the Trangie area (Macquarie valley).

Mapping saline subsurface material in the Bourke Irrigation District

Soil salinisation is one of the major factors affecting agricultural production, especially in arid and semi-arid irrigated regions. The expression of salinisation is a result of complex interactions between geology, hydrology, topography, climate and agronomy. In the irrigated cotton growing areas of central and northern New South Wales (NSW) Australia, perched water tables have caused isolated instances of water logging and soil salinisation. This is the case in the Bourke Irrigation District (BID) located in the far northwest corner of NSW.

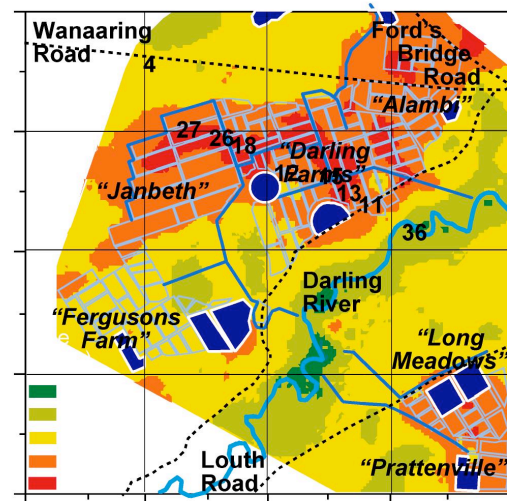
In order to assist in understanding the cause and best management soil and vadose zone information is required. This information is currently not available although it is known that a saline aquifer exists. What is also known is that the soil types predominantly used for irrigated cotton production are the deep yellow-grey (Ug5.22) and grey cracking clays (Ug5.24 and 5.25), which have developed on the alluvial plains of the Darling River. The redder areas shown in Figure 10 are associated with the sandier and elevated parts of the landscape. These areas are dunal in nature and have not been developed for irrigated or dryland agricultural production. The soil profiles are characterized by sporadically bleached A2 horizons (Dr1.33). In some cases, supply channels have been constructed across these areas (see Figure 10).

Northings (m)



375000 380000 385000 390000 395000

Eastings (m)



375000 380000 385000 390000 395000

Figure 10. Airphoto of Bourke Irrigation District (BID). Note: Red ridges.

Figure 11. Spatial distribution of average EC_e (dS/m) between 6-12 m.

The impact of irrigation, storage reservoirs and supply channels on groundwater height is not known. Neither is its impact on the nearby Darling River water quality. The use of electromagnetic (EM) induction instruments, such as an EM34, has assisted in understanding the spatial distribution of soil and water salinisation, however. This is because the instrument can be used in three different coil separation distances and therefore provides information at several depths. In the first instance an EM34 survey was carried out on a 500 m grid spacing across the BID. Measurements were made in the horizontal mode of operation and at 10,

20 and 40 m coil spacings. At these coils spacings theoretical depth of measurement are 0-7, 0-15 and 0-30 m, respectively. In all 1,200 sites were visited. From these 50 sites were selected to enable the instrument to be calibrated to a depth of 12 m. Figure 11 shows the location of 9 calibration sites located along a east-west transect (i.e. sites 4, 27, 26, 18, 12, 15, 13, 11 and 36). A simple linear regression relationship was established between average EC_e (dS/m), between the depths of 6-12 m, for 36 of the soil sampling locations and EC_a as measured by the 40 m coil spacing. The regression equation had a correlation coefficient of 0.68 and was of the form average $EC_e = 0.106 \times EC_a - 7.573$.

Using this equation average subsurface EC_e was estimated at each of the 1,200 measurement sites and interpolated to produce Figure 11. It is evident that the larger values of average EC_e , at a depth of 6-12 m, coincide with the areas developed for irrigated cotton production in the BID. This is particularly the case between Fords Bridge Road and Wannaring Road and beneath the irrigated fields at “Alambi,” “Darling Farms,” “Janbeth” and “Ferguson’s Farm”. It is also evident that the large storage structures on many of these landholdings overlie the more saline subsurface areas. This is particularly evident to the east of the dual-cell storage located on “Ferguson’s Farm”. Conversely, lower subsurface salinity values were consistent with the red ridge country directly to the north of “Alambi,” “Darling Farms” and “Ferguson’s Farm” as well as the area south of “Darling Farms” and “Janbeth”. This was similarly the case with areas adjacent to the Darling River.

To better understand the subsurface saline material, Figure 12 and 13 show the spatial distribution of clay content and salinity, respectively, along the east west transect shown in Figure 10. It is evident that on the red ridge, the surface (i.e. 0-1 m) clay content is less than 20 % (Easting 380000). However, the remainder of the transect shows that the clay content is generally greater than 50 % to a depth of 5 m. This is where the irrigated infrastructure has been developed. This includes the large circular storage located at an Easting of 386000. It is evident beneath this storage that a water table is within 6 m of the surface and is associated with sandier sediments. As shown in Figure 13, the saline subsurface material is quite saline (i.e. $EC_e > 12$ dS/m). The storage is also known to leak however the extent of the area or the impact on local groundwater hydrology is known. This is similarly the case with the semi-circular storage located to the east. What is required is the installation of a piezometer network and development of a groundwater model to better understand the relationship between irrigation and groundwater flux.

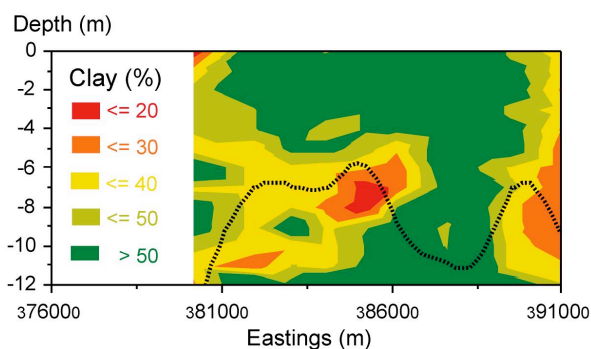


Figure 12. Spatial distribution of clay (%) along detailed soil transect. Note: dotted line indicates water table.

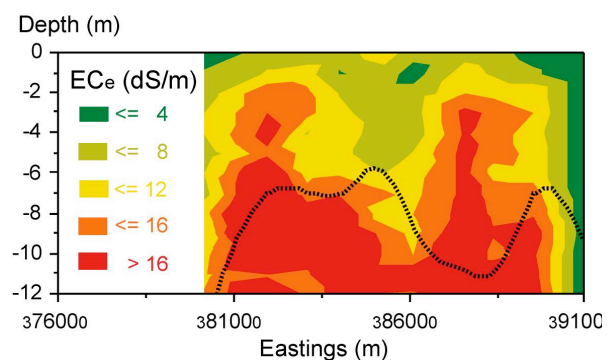


Figure 13. Spatial distribution of subsurface salinity (EC_e - dS/m) along detailed soil transect.

5 Discuss the results, and include an analysis of research outcomes compared with objectives.

In the following section a brief description of each of the Salt Action and Natural Heritage Trust projects undertaken as part of Phase IV (i.e. CRC project 11C) are presented. This includes exploratory data analysis of the EM34/38 and soil data collected in the following irrigated cotton-growing areas and valleys:

lower Macintyre valley (Toobeah),
 lower Gwydir valley (Ashley),
 lower Namoi valley (Wee Waa)
 upper Namoi valley (Breeza)
 lower Macquarie valley (Trangie and Warren), and
 Darling River valley (Bourke Irrigation District).

Various research officers undertook the work described herein. The following pages acknowledge their contribution and the methods used.

Abbreviation	Method of determination
CEC (cmol(+)/kg)	The cation exchange capacity is the summation of exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+). The method used to determine CEC was that of Tucker, BM 1974. Reference: Laboratory procedure for cation exchange measurements in soils. CSIRO Division of Soils, Technical Paper No 23. (CSIRO, Australia).
EC_e (dS/m)	The electrical conductivity of a saturated soil paste extract is determined by weighing 125-250 g of soil, which is made into a saturated paste according to the procedure outlined by the U.S. Salinity Laboratory Staff (1954). The paste is left to stand for a period of up to 12 hours prior to extraction by suction. The electrical conductivity of the soil solution extract is then measured. Reference: Diagnosis and improvement of saline and alkali soils, Agriculture Handbook 60, United States Department of Agriculture (US Government Printing Office).
$\text{EC}_{1:5}$ (dS/m)	The electrical conductivity of a 1 part soil to 5 part water mixture is determined by weighing 5 g of soil into a pop-top tube, which is diluted with 25 ml of deionized water. The tube is spun for half an hour and left to stand for half an hour. The electrical conductivity of the solution is then measured directly. The pH of the solution can also be measured ($\text{pH}_{1:5}$).
Particle size analysis	Determination of clay, silt and sand fraction was conducted using the hydrometer method.

Personnel



Mr Michael Short

Carried out EM34 and soil surveys at Toobeah, Moree, Gunnedah, Warren and Bourke and all EM38 surveys.

Mr Mathew McRae

Carried out EM34 and soil surveys at Toobeah, Moree, Gunnedah, Trangie and Bourke.



Dr Ranjith Subasinghe

Carried out EM34/38 surveys at Toobeah and Warren.

Carried out particle size analysis for Bourke, Toobeah, Moree, Gunnedah, Trangie, Warren and Bourke.



Mr Faruque Ahmed

Carried out cation exchange capacity for all soil samples collected in Toobeah, Moree, Wee Waa, Gunnedah, Trangie, Warren and Bourke.



Mr Andrew Huckel

Carried out EM34 surveys in Toobeah, Moree, Wee Waa, Gunnedah, Trangie and Warren.



Dr Raj Singh Malik

Carried out soil EC_e , EC_p , chloride determination and saturation percentage for Toobeah, Moree, Wee Waa, Gunnedah, Trangie, Warren and Bourke.

Understand salinity threat in irrigated cotton areas of Macintyre River valley

Project Funding	Natural Heritage Trust (Queensland)
Project Code	992952
Community Group	Macintyre River Valley Water Users Association
Funding period	1999-2000
Location	Lower Macintyre River valley, southeast of Toobeah
Farms visited	"Euroka," "Oonavale," "Brindle Downs," "Gubbagunyah," "South Callandoon," "Booberoi," "Riverview," "Macintyre Downs," "Stuartville," "Carbucky," "Trinkey," and "Mundine."
EM measurements	1,206 EM38 (EC_a @ 0-2 m); and EM34 (EC_a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	42
Depth of sampling:	0-1.5 m @ 0.30 m and 2-12 m @ 1m intervals
Analysis:	EC_e (dS/m), Cl_e , Cl_m , SP, pH_e , $pH_{1:5}$, $EC_{1:5}$, exchangeable cations (Ca^{++} , Mg^{++} , Na^+ , K^+), particle size fractions (clay, silt and sand).

Exploratory data analysis

The spatial distribution of soil EC_a as collected by the EM38 in the horizontal mode of operation is shown in Figure 14. It is evident that most of the irrigated cotton fields are located on the more conductive parts of the landscape (i.e. $EC_a > 100$ mS/m) although on "Carbucky" and "Euroka" many fields are in areas where EC_a was less than 100 mS/m. This is also the case with many of the large storage structures (e.g. "Mundine" and "South Callandoon").

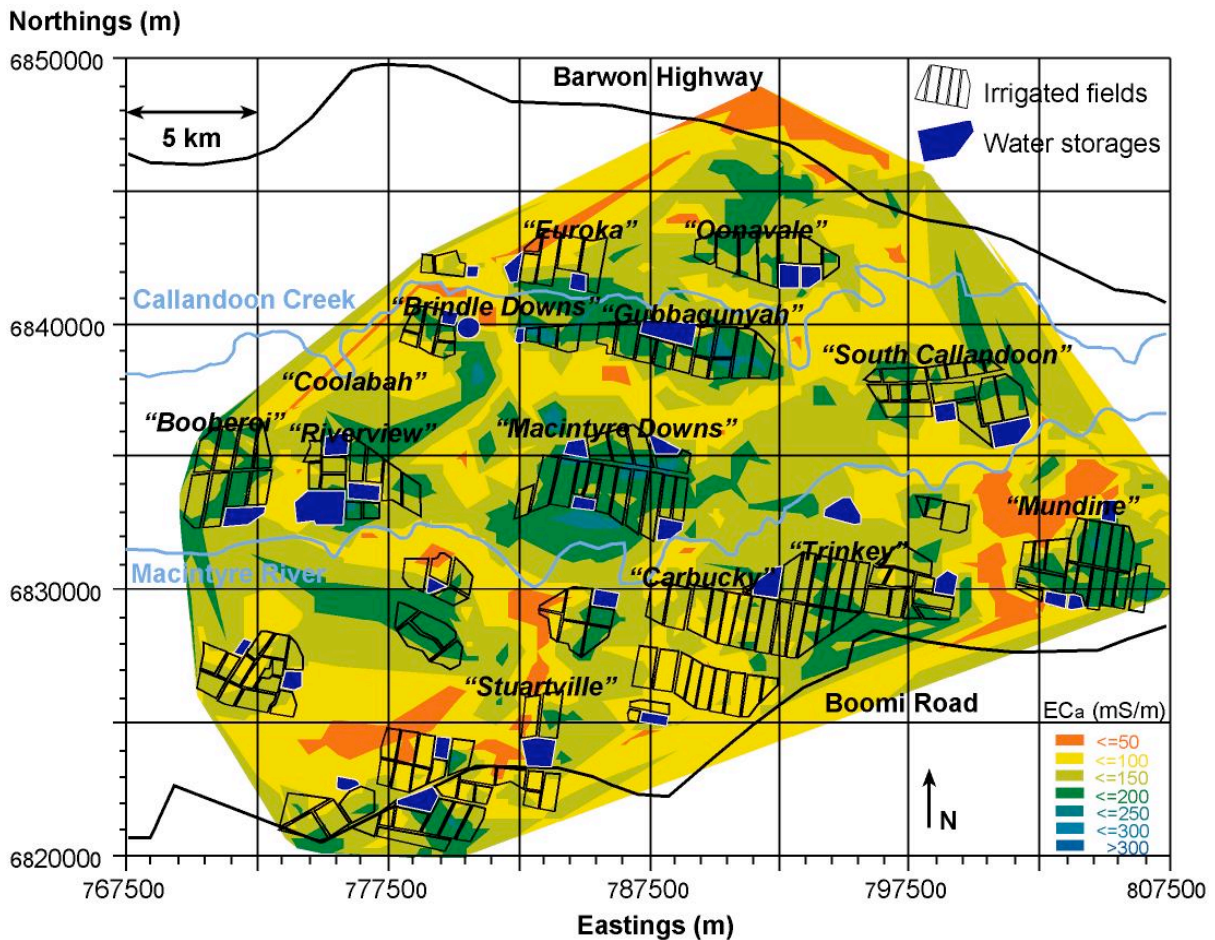


Figure 14. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

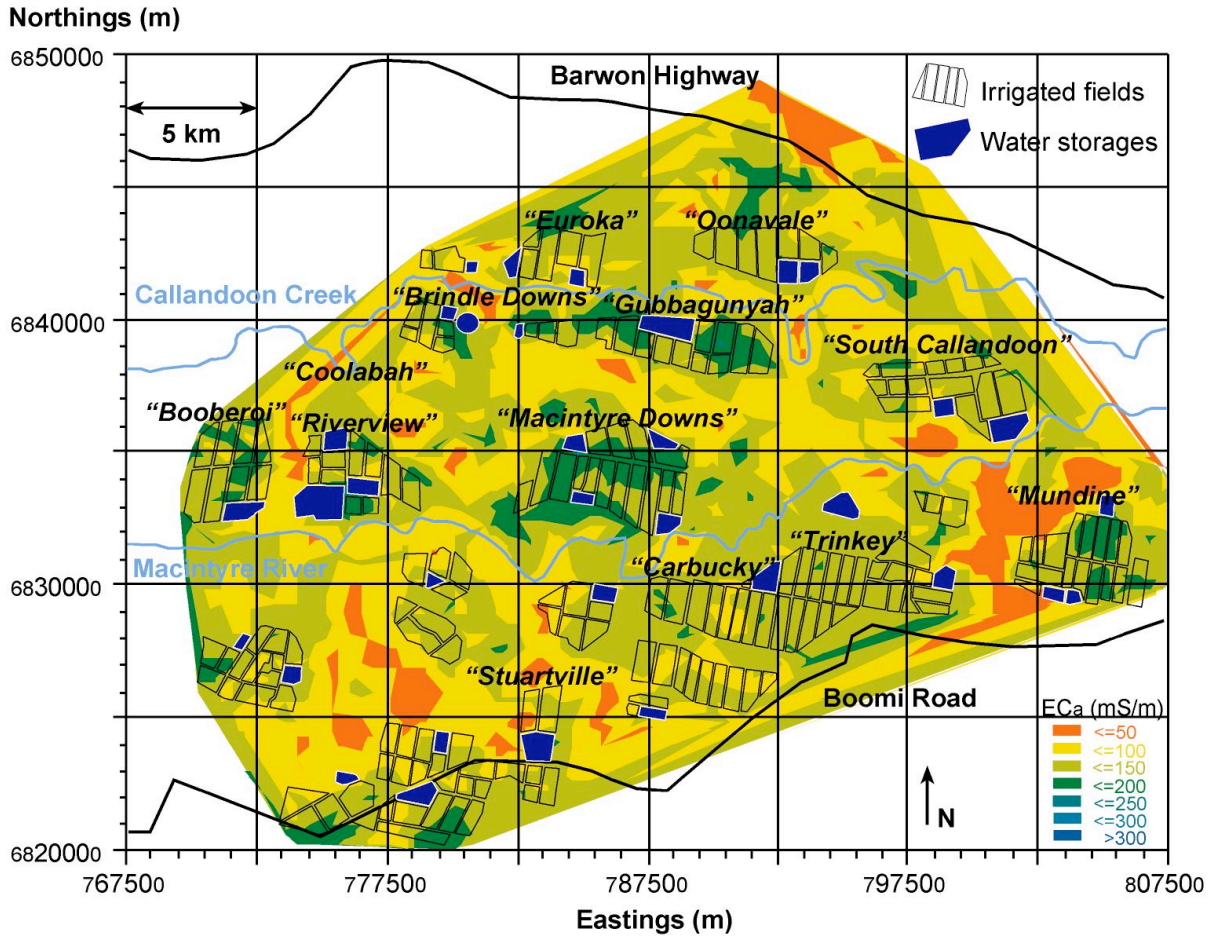


Figure 15. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

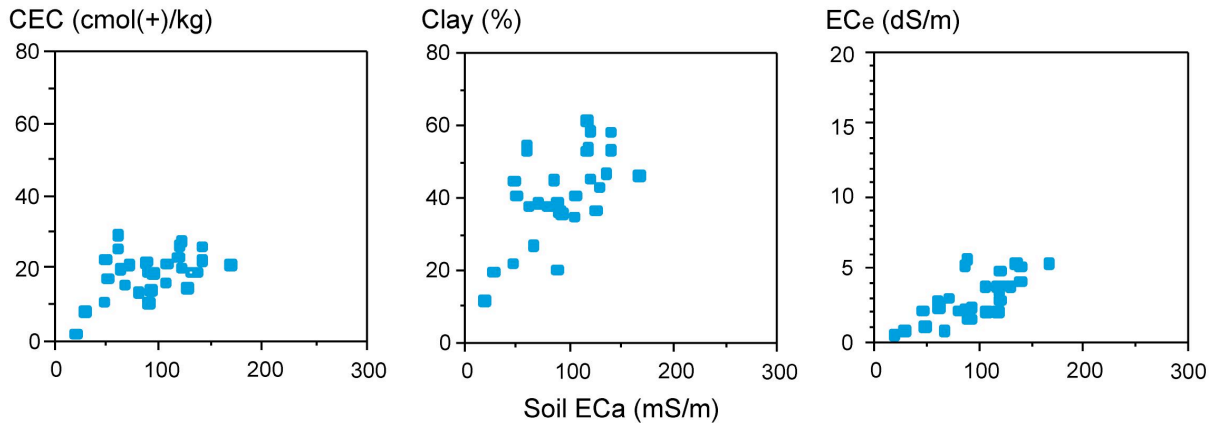


Figure 16. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

The spatial distribution of soil EC_a as collected by the EM34 in the horizontal mode of operation and at a 10 m coil spacing is shown in Figure 15. Similar patterns of high and low EC_a are evident although it is apparent that a larger proportion of the area is less conductive than 100 mS/m.

Figure 16 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 42 calibration sites. It is evident that these variables are well correlated with EC_a , in particular salinity and clay content. Soil salinity is very low in the sandier profiles and low in the clayier sediments.

Salinity risk assessment in irrigated farming systems across the Gwydir valley

Project Funding	Natural Heritage Trust (NSW-Gwydir Catchment)
Project Code	NW0523.00 and GW3036.01
Community Group	Gwydir Valley Irrigators Association
Funding period	2000-2001 and 2001-2002
Location	Lower Gwydir valley, north of Moree (centred around township of Ashley)
Farms visited	<i>"Auscott Midkin," "Midkin South," "Milo," "Colmlee," "Willowlee," "Antrim," "Teralga," "Norwood," "Glen Prairie," "Caroale," "Kern," "Sappa," "Beela," "Santis," "Listowel," "Booloroo," "Redmill" and "Ingle Plains."</i>
EM measurements	1,516 EM38 (EC _a @ 0-2 m); and EM34 (EC _a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	53
Depth of sampling:	0-1.5 m @ 0.30 m and 2-12 m @ 1m intervals
Analysis:	EC _e (dS/m), Cl _e , Cl _m , SP, pH _e , pH _{1:5} , EC _{1:5} , exchangeable cations (Ca ⁺⁺ , Mg ⁺⁺ , Na ⁺ , K ⁺), particle size fractions (clay, silt and sand).

Exploratory data analysis

Figure 17 shows the spatial distribution of EC_a as measured with the EM38 (horizontal mode). The higher values of EC_a (i.e. > 150 mS/m) are consistent with the plains of self-mulching clays. In general, most of the fields developed for irrigation are located in these areas. This includes *"Auscott Midkin," "Milo," "Caroale," "Sappa," "Listowel,"* and *"Booloroo."* However, several storages and some of the irrigated fields are located in areas where EC_a is less than 100 mS/m but greater than 50 mS/m. This is the case in the south-eastern areas and in particular south of the Gingham Road. These areas are associated with the current stream channels of Marshalls Ponds Creek and the Gwydir River as well as a prior stream channel south of the current day Caroale Creek. As such, the sediments are sandier in nature and more likely to be susceptible to deep drainage as compared with the more conductive (EC_a > 100 mS/m) clay alluvial plains.

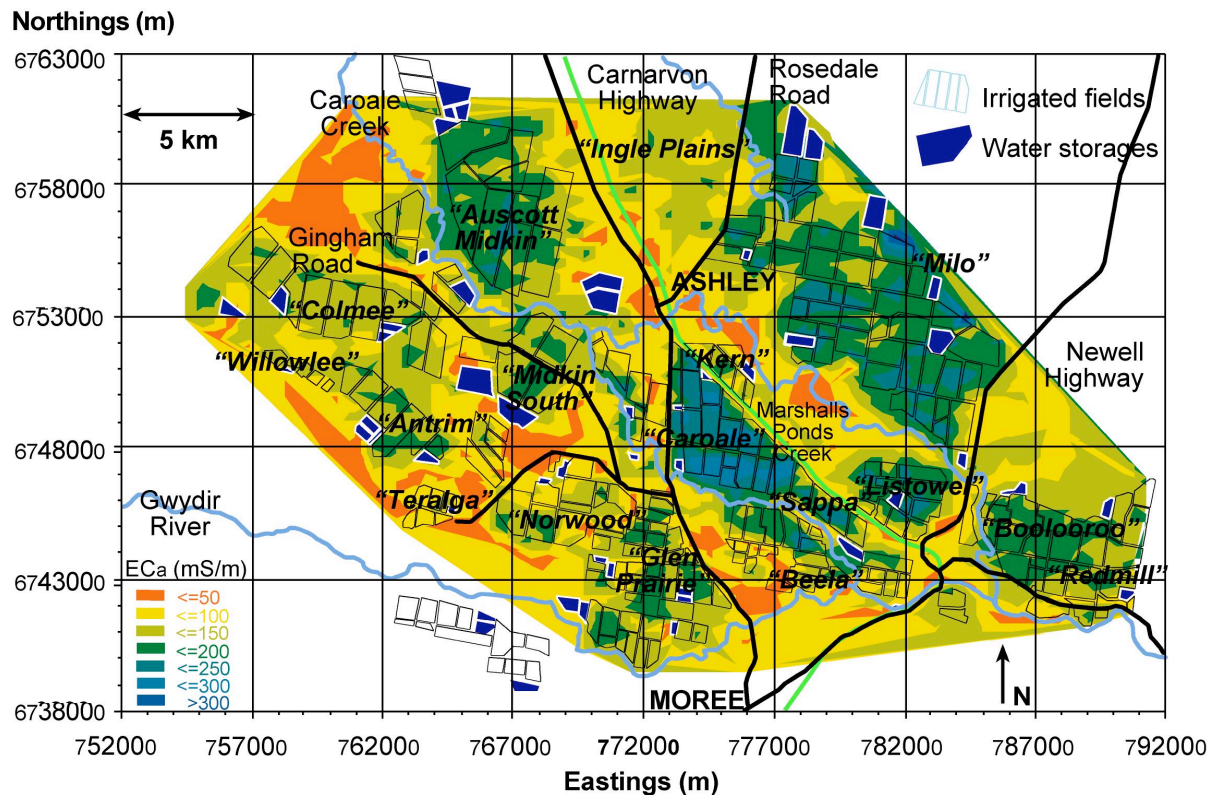


Figure 17. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

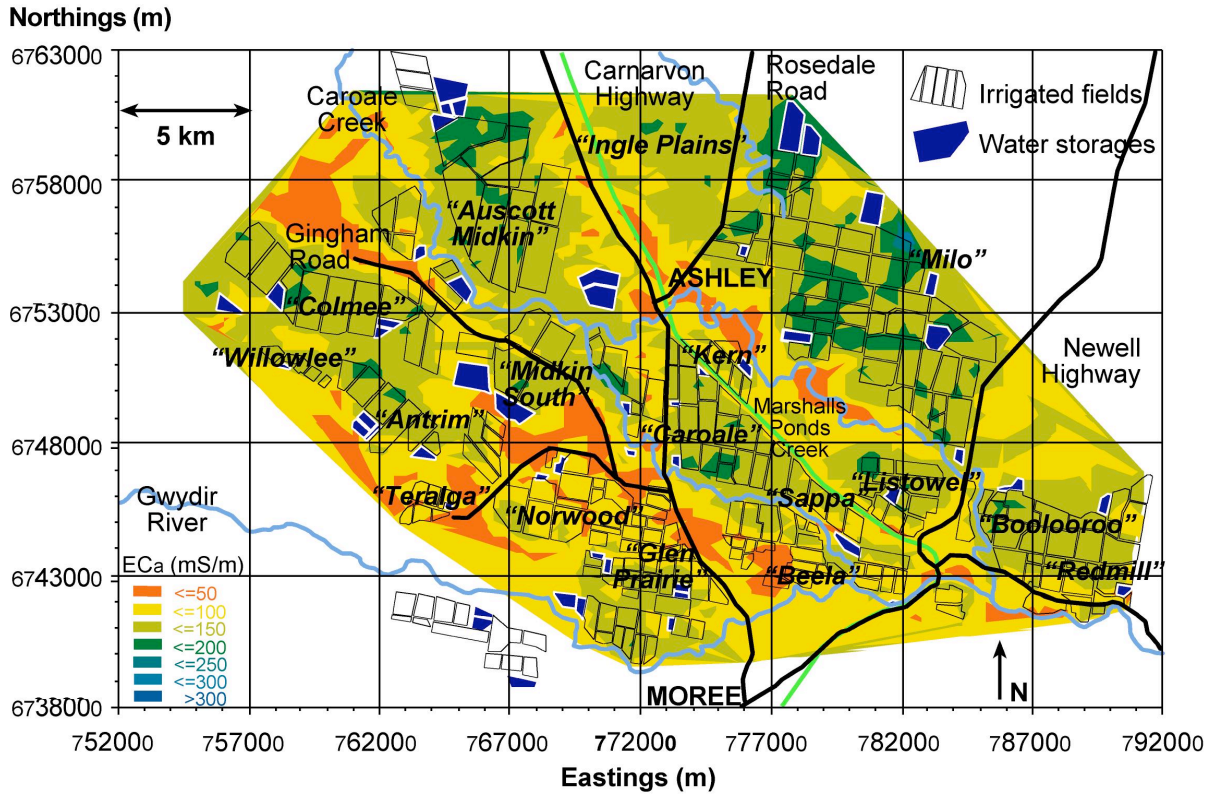


Figure 18. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

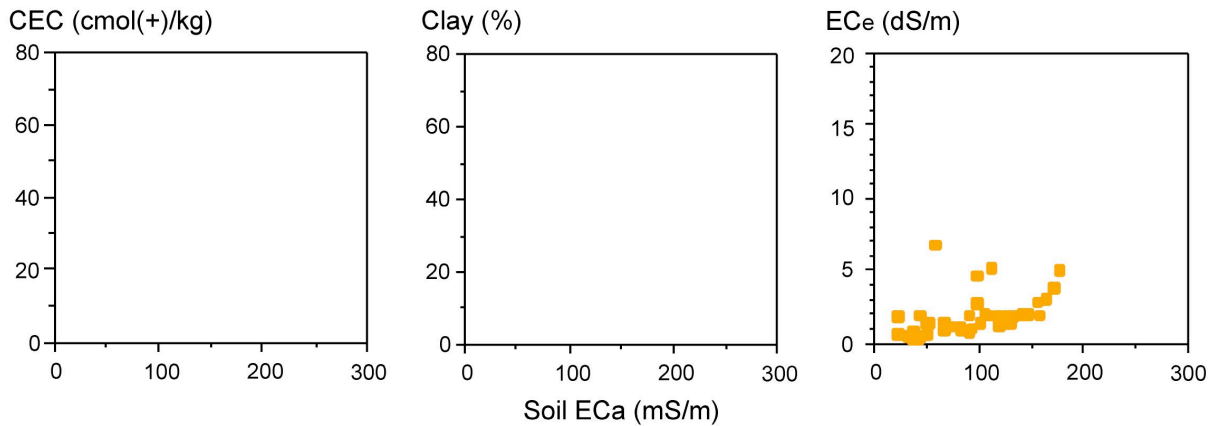


Figure 19. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

The spatial distribution of soil EC_a as collected by the EM34 in the horizontal mode of operation and at a 10 m coil spacing is shown in Figure 18. Similar patterns of high and low EC_a are evident. It is apparent that a large proportion of the area has EC_a less than 50 mS/m. This is the case along Marshall's Ponds Creek and south of the Gingham Road.

Figure 19 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m EC_e (dS/m) at the 53 calibration sites. It is evident that EC_e is low in each of these profiles and are correlated with EC_a . The analysis of the samples for CEC (cmol(+)/kg) and clay (%) is currently in progress and due for completion by March 2003.

Determine salinity threat in irrigated cotton in upper and lower Namoi valley

Project Funding	Salt Action and Natural Heritage Trust (NSW-Namoi Catchment)
Project Code	NW0709.97 and NW1058.98
Community Group	Coordinating committee of lower Namoi valley water users association
Funding period	1998-1999 and 1998-2001
Location	Lower Namoi valley (centred on Wee Waa)
Farms visited	"Auscott Narrabri", "Togo Station", "Apple Trees", "Unfaan", "Cumberdeen", "Tulladunna", "Carrigan", "Hazeldean", "Goroka", "Doreen", "Havana", "Willawood", "The Gardens", "Cudgewaa", "Milloo", "Grey Lands", "Widgee", "Kyema", "Waverley", "Lammermoore", "Myola", "Kerribee", and "Boolcarool."
EM measurements	1,896 EM34 (EC _a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	36
Depth of sampling:	0-1.5 m @ 0.30 m and 2-18 m @ 1m intervals
Analysis:	EC _e (dS/m), Cl _e , Cl _m , SP, pH _e , pH _{1:5} , EC _{1:5} , exchangeable cations (Ca ⁺⁺ , Mg ⁺⁺ , Na ⁺ , K ⁺), particle size fractions (clay, silt and sand).

Exploratory data analysis

The maps of EC_a as measured by the EM34 at 10 and 40 m coil spacings are shown in Figures 20 and 21, respectively. In general, they reflect the physiographical perceptions of the area. This was the case for the data presented at 10 m coil spacing (Figure 20). The low values of EC_a (i.e. < 100 mS/m) coincide with the location of prior-stream channels and the low dissected floodplains of the Namoi River. This was most evident in a north-westerly direction and in parallel with Spring Plain road and to a lesser extent in a westerly direction from Wee Waa to Merah North. In some of these areas, EC_a was very low (i.e. < 50 mS/m). This was similarly the case in the area southeast of Wee Waa and associated with the Pilliga Scrub Complex near "Cumberdeen". Here EC_a at 10 m inter-coil spacing was less than 30 mS/m. The clay plain was also well defined. This was evident south of Merah North (i.e. "The Gardens"), the area roughly bounded by the Kamilaroi Highway and Spring Plains Road and north-east of the Spring Plains Road and associated with the landholdings of "Auscott", "Togo Station" and "Boolcarool". In these areas, EC_a at each coil spacing was greater than 100 mS/m. In some areas (e.g. "Boolcarool"), EC_a was greater than 150 and 200 mS/m

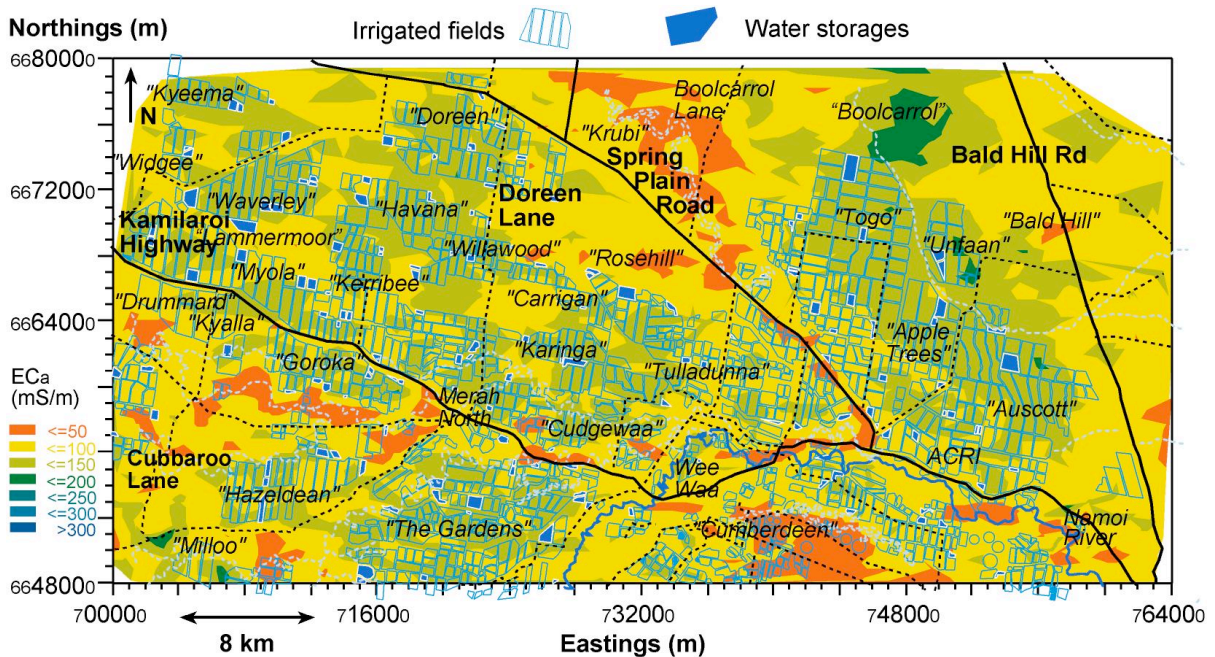


Figure 20. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

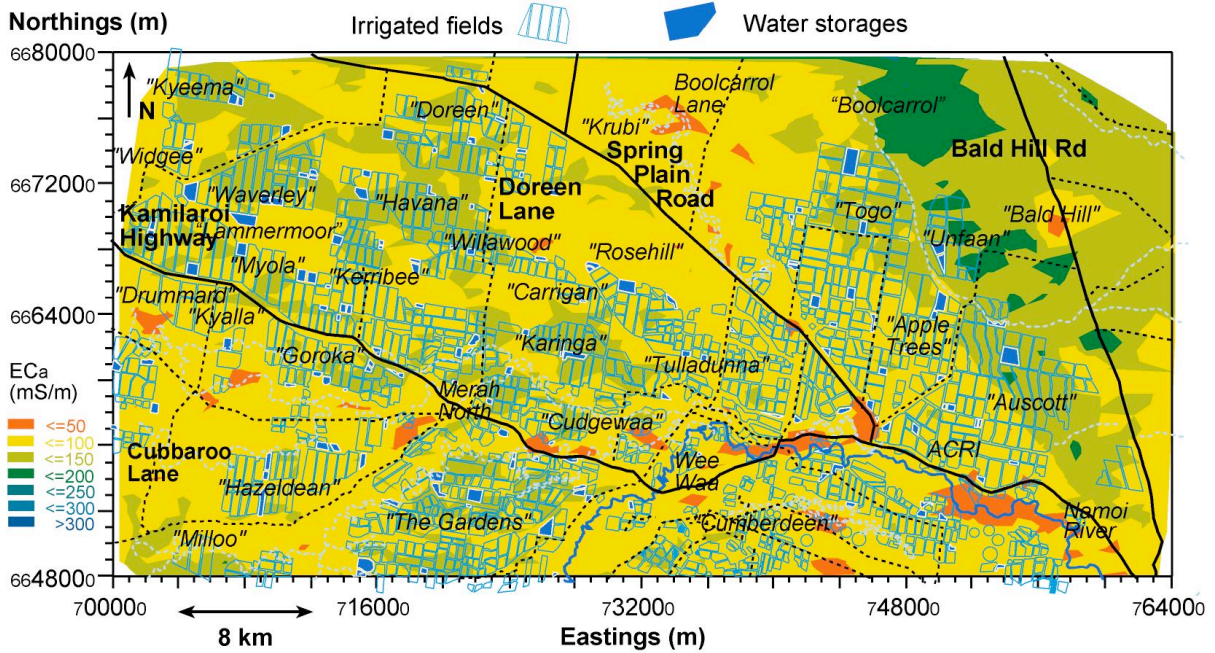


Figure 21. Spatial distribution of EC_a (mS/m) recorded with EM34 at 40 m spacing (horizontal mode).

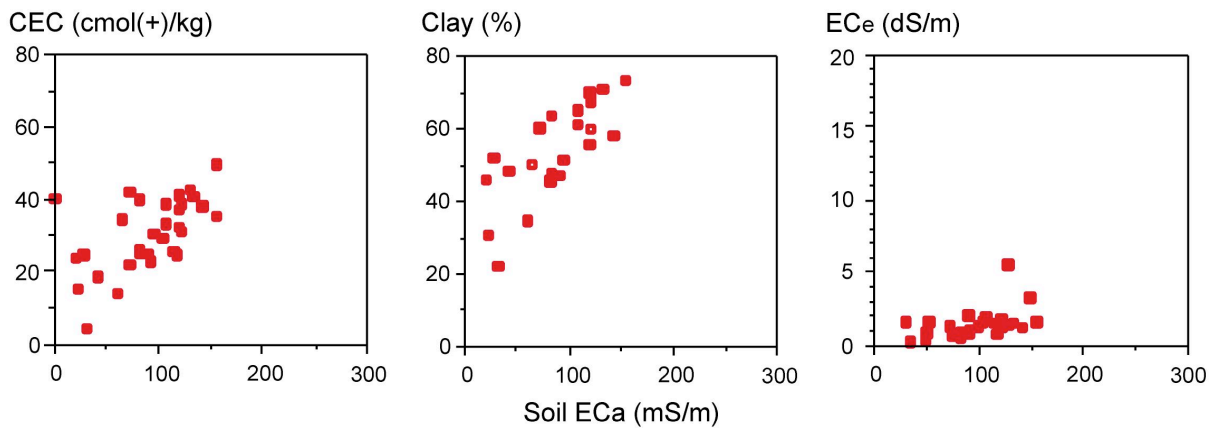


Figure 22. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

One major difference was evident between the pattern of EC_a generated at 40 and 10 m coil spacing. The values of EC_a generated within approximately 8 km west of and in parallel with Bald Hill Road were generally higher (i.e. > 150 mS/m) than on the clay plains, near “The Gardens” and “Doreen” (i.e. < 150 mS/m). The higher EC_a values recorded were consistent with the presence of slightly saline and saline aquifers located at depths of about 20-30 m. It is evident therefore that the EM34 at a coil spacing of 40 m (i.e. 0-30 m) was sensing the deep saline aquifers, beyond the depth of measurement of the 10 m spacing (i.e. 0-7 m).

Figure 22 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 36 calibration sites. It is evident that these variables are well correlated with EC_a . In comparison with the Toobeah and Ashley study areas it is evident that stored soluble salts are lowest in this valley and clay content and CEC are generally higher.

Understand salinity threat in irrigated cotton area in the upper Namoi valley

Project Funding	Natural Heritage Trust (NSW-Namoi catchment)
Project Code	NW1058.98 and NA3035.01
Community Group	Coord. Comm. Namoi Water Users & Upper Namoi Cotton Growers Assoc.
Funding period	1998-2001 and 2002-2003
Location	Upper Namoi valley (southeast of Gunnedah)
Farms visited	"Warilda", "Gabo," "Battery Hill," "Longacres," "Gowangardie," "Drayton," and "Merrigle."
EM measurements	871 EM38 (EC _a @ 0-2 m); and EM34 (EC _a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	35
Depth of sampling:	0-1.5 m @ 0.30 m and 2-12 m @ 1m intervals
Analysis:	EC _e (dS/m), Cl _e , Cl _m , SP, pH _e , pH _{1:5} , EC _{1:5} , exchangeable cations (Ca ⁺⁺ , Mg ⁺⁺ , Na ⁺ , K ⁺), particle size fractions (clay, silt and sand).

Exploratory data analysis

Figure 23 shows the contour plot of EC_a as recorded by the EM38 in the horizontal mode of operation across the Curlew district southeast of Gunnedah. Apart from the area adjacent to the Pullaming Stock Route in the south most irrigated fields have been developed upon the more conductive parts of the landscape. This includes "Warilda", "Gabo," "Battery Hill," and "Longacres" where EC_a was generally greater than 150 mS/m. The areas of low to intermediate EC_a (i.e. 50-150 mS/m) were generally associated with the Mooki River. The lowest EC_a (< 50 mS/m) measurements were found to the east of Curlew and Long Point Road.

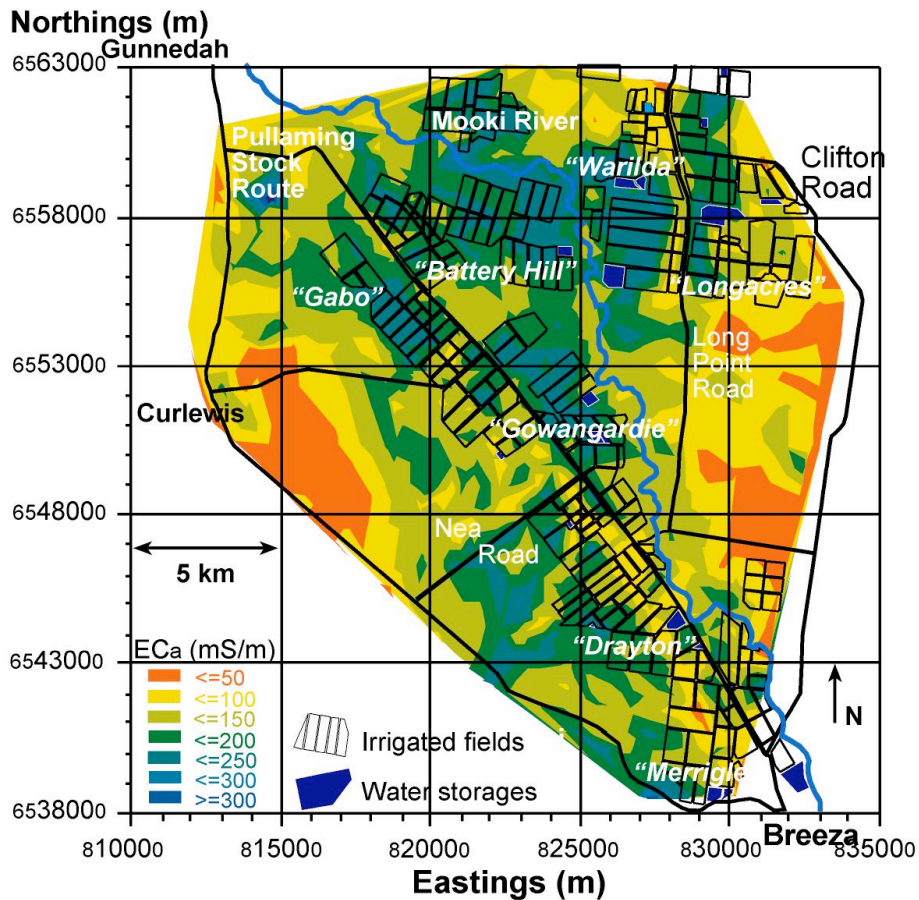


Figure 23. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

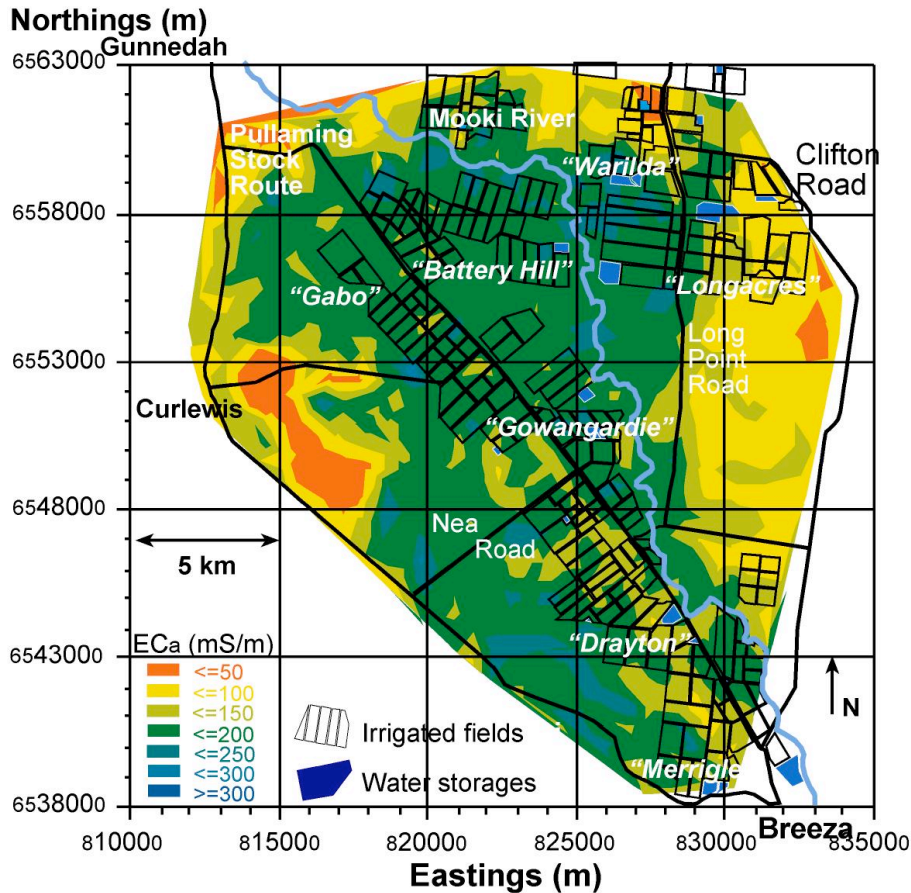


Figure 24. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

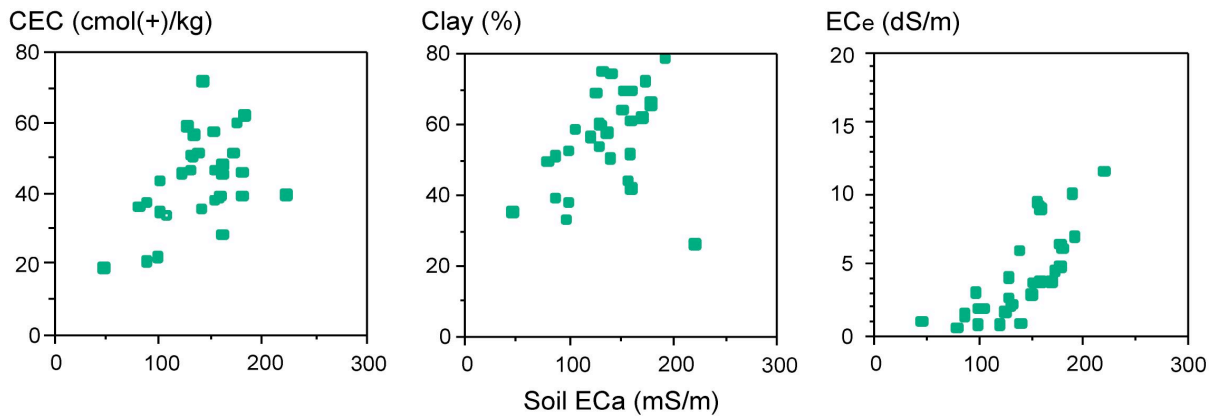


Figure 25. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

At an inter coil spacing of 10 m the spatial distribution of soil EC_a as recorded by the EM34 shows similar patterns although here as compared to the lower Macintyre, Gwydir and Namoi valleys EC_a was universally much higher at depth (i.e. > 150 mS/m). As shown in Figure 24, EC_a was however low (i.e. < 100 mS/m) in the northern part of the area associated with the Namoi River.

Figure 25 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 35 calibration sites taken within the area. It is evident that EC_e is well correlated with EC_a . In comparison with the Toobeah, Ashley and Wee Waa study areas it is evident that stored soluble salts are greater in this area, with clay content and CEC generally similar to that in Wee Waa.

Understand and manage cause of salinity in the lower Macquarie valley

Project Funding	Natural Heritage Trust (NSW-Macquarie Catchment)
Project Code	CW0396.99
Community Group	Macquarie 2100
Funding period	1999-2000
Location	Lower Macquarie valley (southeast of Trangie)
Farms visited	"Agriland Byron," "Boomerang," "Strathavon," "Burratippi," "Buddahglen," "Rocky Point," "Eastwood," "Westwood," "Buddah Lake," "Compton," "Wahroonga," "Lady Bower," and "Old Buddah Lake."
EM measurements	755 EM38 (EC_a @ 0-2 m); and EM34 (EC_a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	48
Depth of sampling:	0-1.5 m @ 0.30 m and 2-15 m @ 1m intervals
Analysis:	EC_e (dS/m), Cl_e , Cl_m , SP, pH_e , $pH_{1:5}$, $EC_{1:5}$, exchangeable cations (Ca^{++} , Mg^{++} , Na^+ , K^+), particle size fractions (clay, silt and sand).

Exploratory data analysis

Figure 26 shows the pattern of EC_a for the Trangie study region as measured with the EM38 in the horizontal mode of operation. The coarse sediments of the Trangie Cowl, which runs east to west through the midline of the study area, is characterised by low values of EC_a (i.e. < 50 mS/m). This is also the case for the meander plain of the Old Alluvium Pedoderm located in the southern part of the study area. Low EC_a values were also associated with the Contemporary Macquarie Pedoderm, adjacent to the modern-day Macquarie River. High values of EC_a (i.e. > 100 mS/m) were obtained in the areas associated with the back plain of the Old Alluvium Pedoderm that is clay in nature. Higher values of EC_a were also evident on "Boomerang" and "Agriland Burratippi". Unlike the Toobeah, Ashley and Gunnedah study areas, it is evident that most of the irrigated cotton fields and storages in the Trangie district are located in areas where EC_a is less than 100 mS/m.

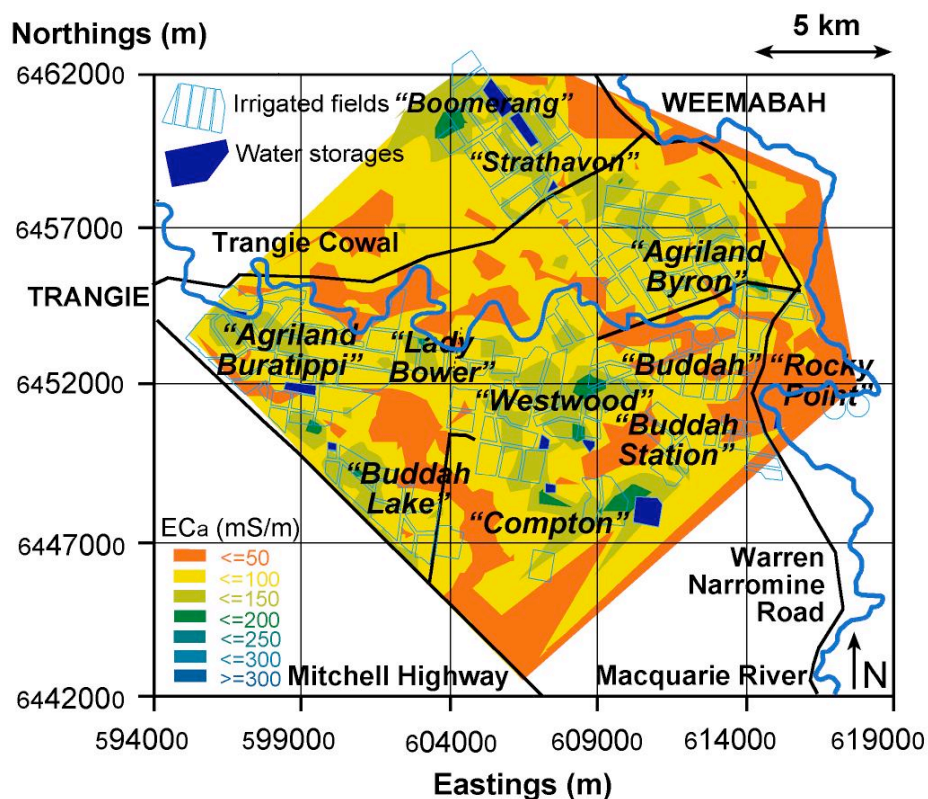


Figure 26. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

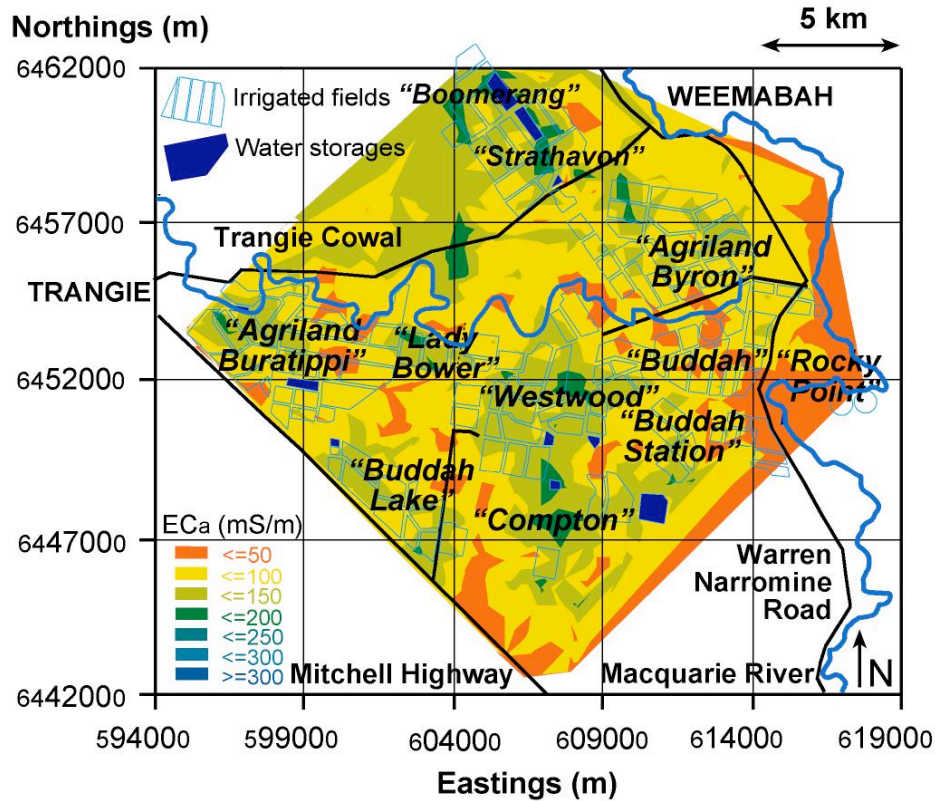


Figure 27. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

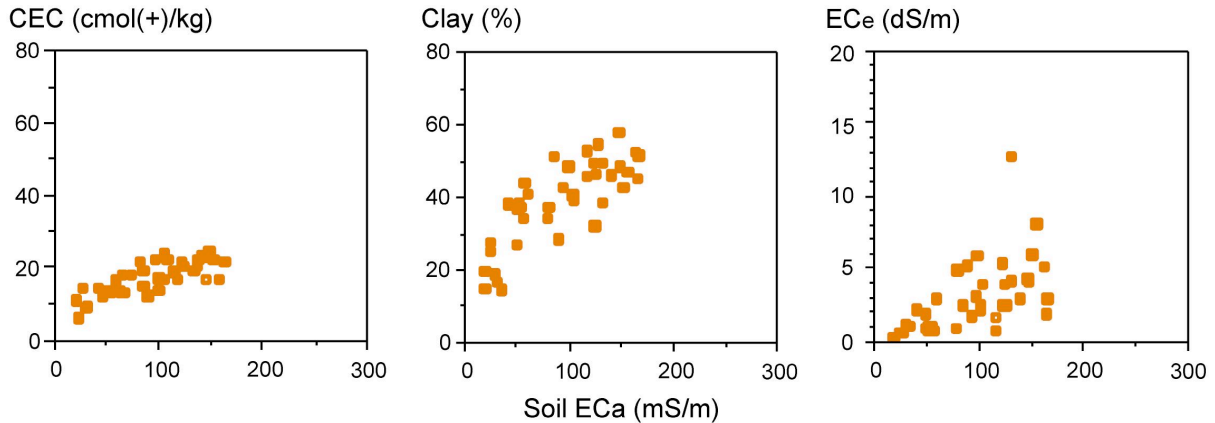


Figure 28. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

Figure 27 shows the spatial distribution of EC_a obtained by the EM34 at the 10 m coil spacing. The coarser sediments of the Trangie Cowal and the Old Alluvium meander plain are again characterised by low values (i.e. < 100 mS/m). The lowest values (i.e. < 50 mS/m) were again associated with the Contemporary Macquarie Pedoderm adjacent to the Macquarie River. High values of EC_a (i.e. 100-150 mS/m) were recorded in various locals including “Burratippi,” “Buddah Lake,” “Wahroonga,” “Boomerang,” “Strathavon,” “Westwood,” and “Compton”.

Figure 28 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 48 calibration sites. It is evident that EC_e is not well correlated with EC_a . This is probably a function of the mobilisation of salts in the area. Reasonable correlations exist between CEC and clay content, however.

Assess relationship of irrigated farming to rising groundwater near Warren

Project Funding	Natural Heritage Trust (NSW-Macquarie Catchment)
Project Code	CW0708.99
Community Group	Macquarie 2100
Funding period	2000-2001
Location	Lower Macquarie valley (southeast of Warren)
Farms visited	<i>“Ewenmar,” “Whiteacres,” “Kulkine,” “Wambianna,” “Wambadry,” “Killowen,” “Bowen Park” “Mullah,” and “Ellengerah.”</i>
EM measurements	565 EM38 (EC _a @ 0-2 m); and EM34 (EC _a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	35
Depth of sampling:	0-1.5 m @ 0.30 m and 2-12 m @ 1m intervals
Analysis:	EC _e (dS/m), Cl _e , Cl _m , SP, pH _e , pH _{1.5} , EC _{1.5} , exchangeable cations (Ca ⁺⁺ , Mg ⁺⁺ , Na ⁺ , K ⁺), particle size fractions (clay, silt and sand).

Exploratory data analysis

Figure 29 shows the pattern of EC_a for the Warren study area as measured with the EM38 (horizontal mode). The coarse sediments associated with Ewenmar Creek in the north and the Macquarie River which runs diagonally across the study area were characterised by low values of EC_a (i.e. < 50 mS/m). This is similarly the case with the area south of *“Ellengerah.”* The highest values of EC_a were obtained on *“Ellengerah,”* where soil salinisation is evident adjacent to the large triangular storage. As with the Trangie survey data, most of the irrigated cotton fields and storages in the district are located in areas where EC_a was less than 100 mS/m.

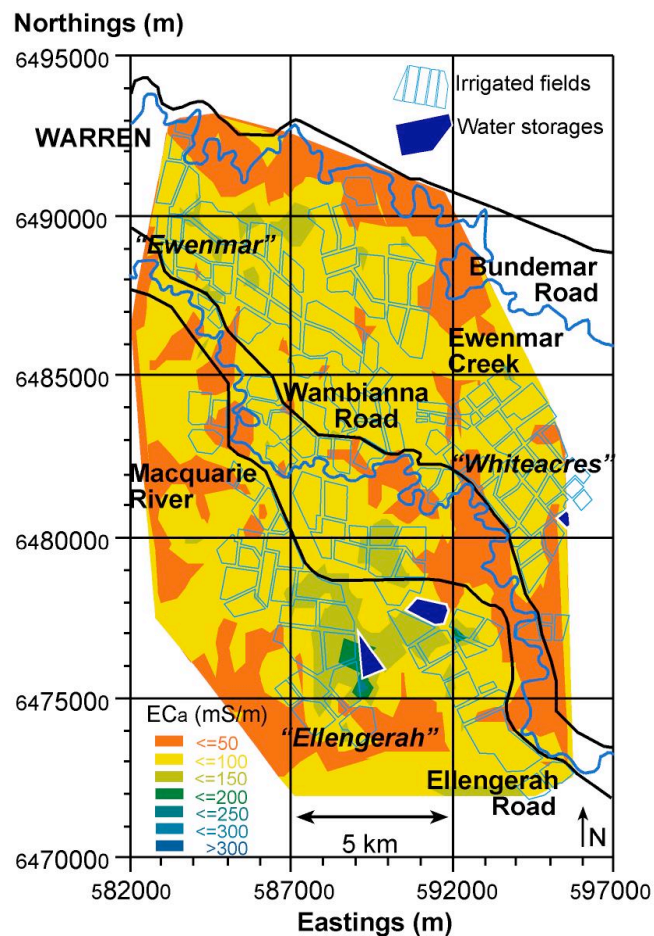


Figure 29. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

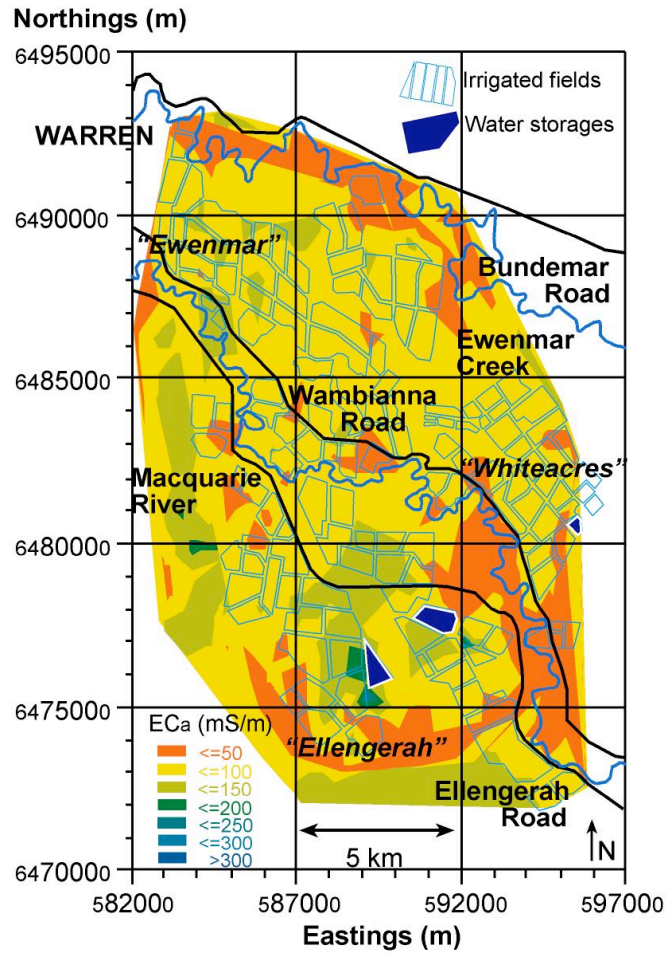


Figure 30. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

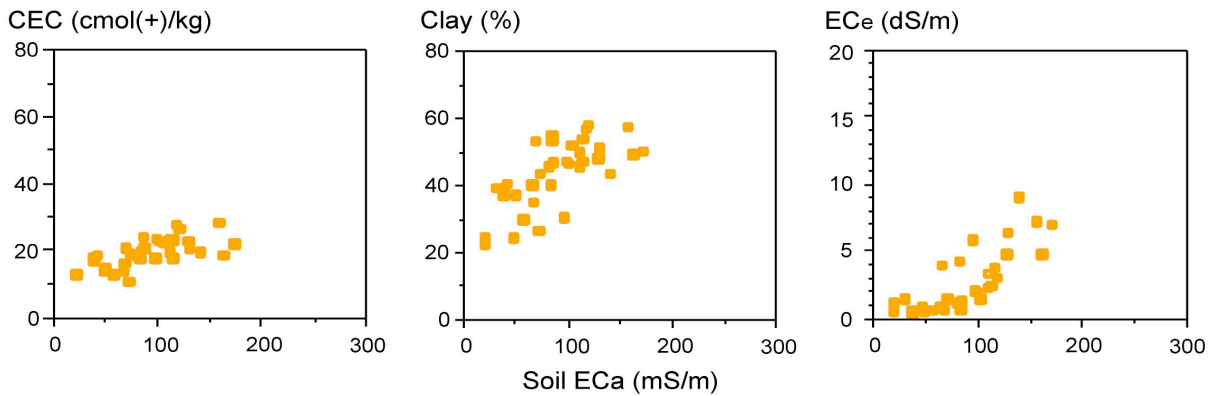


Figure 31. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

Figure 30 shows the spatial distribution of EC_a obtained by the EM34 at 10 m coil spacing. The pattern was similar, particularly where EC_a was low. It is evident that a plume of higher subsoil EC_a is evident at "Ellengerah" and associated with the large triangular storage.

Figure 31 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 35 calibration sites. The correlations are similar as compared with the nearby Trangie area, except EC_e was better correlated with EC_a .

Determine causes/controls of salinisation in the Bourke Irrigation District (BID)

Project Funding	Natural Heritage Trust (NSW-Far west catchment)
Project Code	WN0688.99
Community Group	Bourke Cotton Growers Association
Funding period	1999-2000
Location	Darling River valley (centred on Bourke)
Farms visited	"Gidgee," "Alambi," "Cabuu," "Darling Farms," "Janbeth," "Ferguson's Farm", "Longmeadows," "Prattenville," and "Latoka."
EM measurements	1,144 EM38 (EC_a @ 0-2 m); and EM34 (EC_a @ 0-7, 0-15 and 0-30 m)
Soil sample locations:	50
Depth of sampling:	0-1.5 m @ 0.30 m and 2-12 m @ 1m intervals
Analysis:	EC_e (dS/m), Cl_e , Cl_m , SP, pH_e , $pH_{1:5}$, $EC_{1:5}$, exchangeable cations (Ca^{++} , Mg^{++} , Na^+ , K^+), particle size fractions (clay, silt and sand).

Exploratory data analysis

Figure 32 shows the pattern of EC_a for the Bourke Irrigation District as measured with the EM38 (horizontal mode). Of all the study areas, the highest values were recorded here with the EM38. This is the case with respect to each of the storages located north of the Darling River, in particular the circular and semi-circular storages on "Darling Farms." The intermediate to high values of EC_a (i.e. 200-300 mS/m) characterise the yellow-grey soil types on which most of the irrigated cotton fields have been located upon. The lowest EC_a values located between "Gidgee" and "Darling Farms" are associated with dunal red soil types.

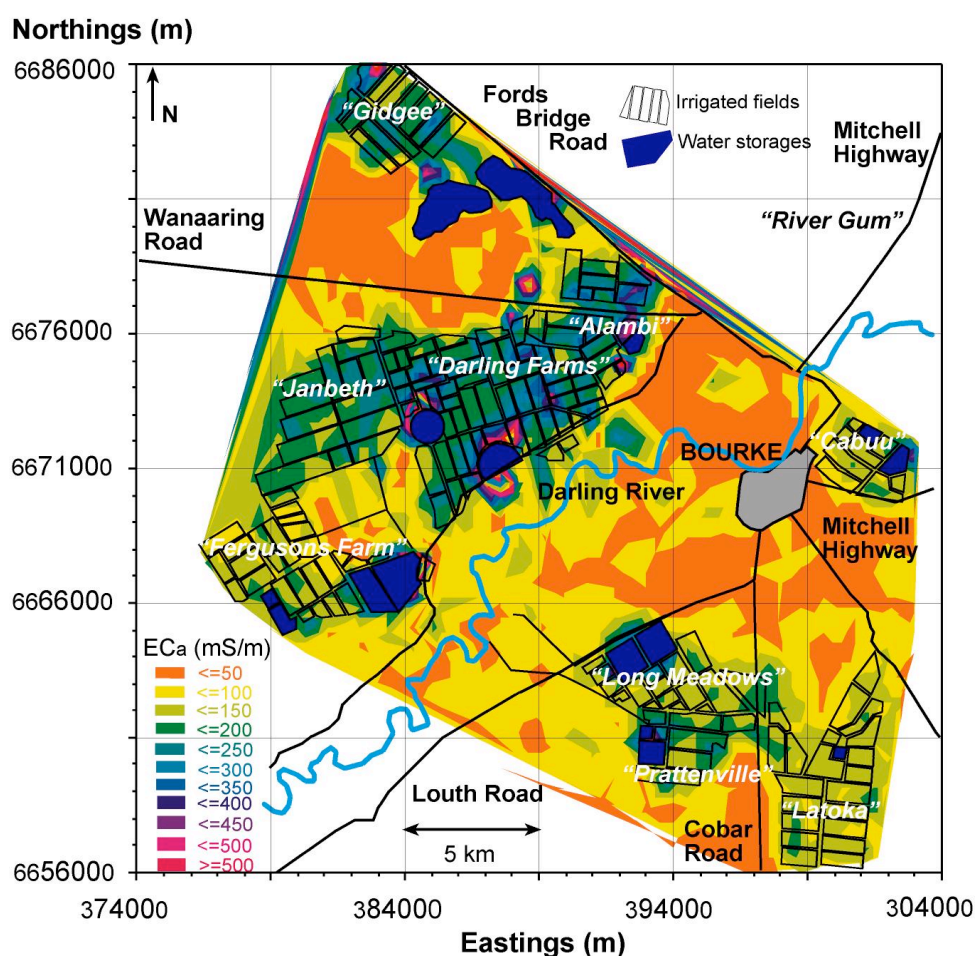


Figure 32. Spatial distribution of EC_a (mS/m) recorded with EM38 in horizontal mode.

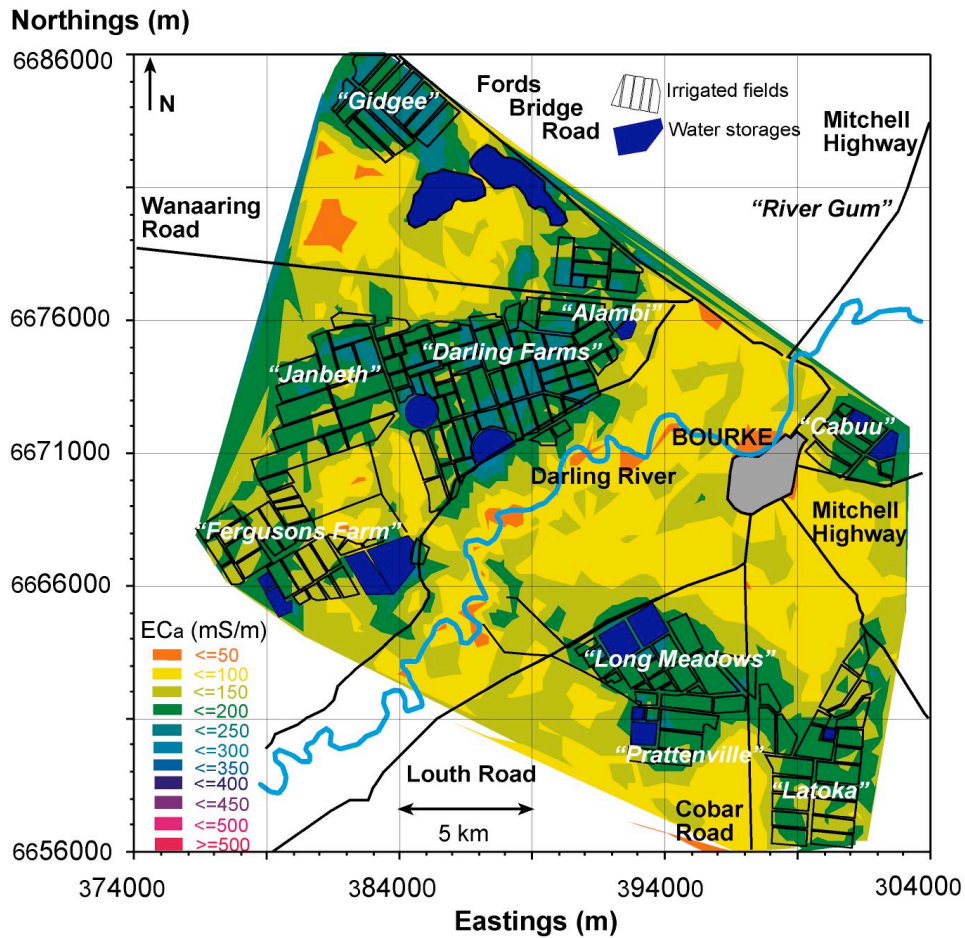


Figure 33. Spatial distribution of EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode).

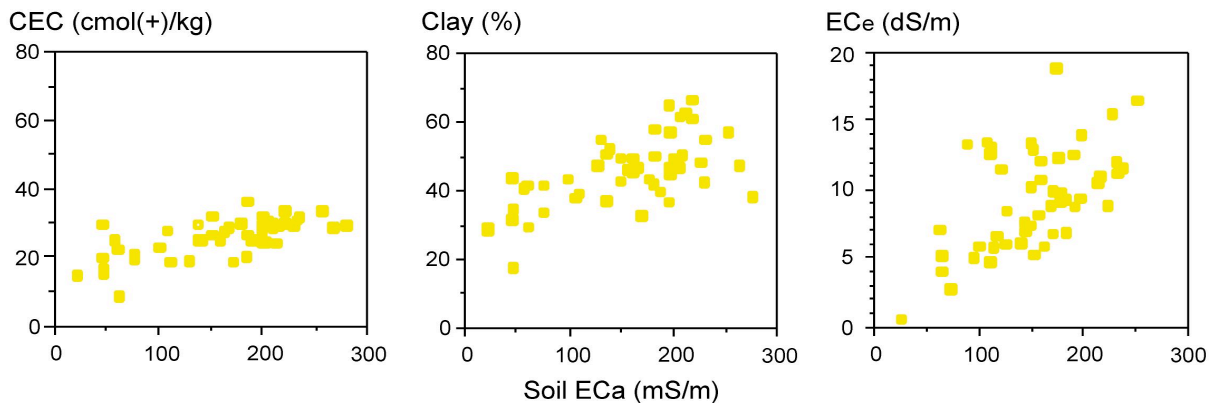


Figure 34. EC_a (mS/m) recorded with EM34 at 10 m spacing (horizontal mode) versus average 7.0 m CEC (cmol(+)/kg), clay content and EC_e (dS/m).

Figure 33 shows the spatial distribution of EC_a obtained by the EM34 at 10 m coil spacing. It is evident EC_a is generally much higher across larger areas of the district. This is consistent with the presence of a saline groundwater aquifer, which is present beneath the clayier surface sediments.

Figure 34 shows the relationship between soil EC_a (EM34 in the horizontal mode of operation and at a 10 m coil spacing) and average 7.0 m CEC (cmol(+)/kg), clay (%) and EC_e (dS/m) at the 50 calibration sites. Compared with all the other areas the Bourke Irrigation District contains the largest amounts of stored soluble salts.

6 Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry and future research needs.

Impact of results

The root- and vadose-zone soil and EM data collected, as part of this project will be used to produce various research products on the field and district levels:

- a) estimates of groundwater recharge rate
- b) maps of average clay content
- c) clay stratigraphy
- d) location of subsurface saline material
- e) deep drainage risk areas
- f) spatial distribution of soil salinisation
- g) sodic soil management units

These results will provide a better understanding of the landscape to irrigators in each of the areas studied and identify future research priorities to assist in determining best management strategies.

Conclusions

Collection of natural resource information is time consuming and labour intensive. In today's funding environment it is also difficult to obtain sufficient monies, to enable the collection of such information, from a single source. Therefore, a large amount of work needs to be done to develop a) targeted research proposals, b) collaborative ties with various community groups and government agencies, and c) administer and account for funds received for different areas.

The work carried out as part of Phase III, demonstrated that such an approach can be successful and yield natural resource information about the spatial distribution of soil- (0-2 m) and sub-soil (0-12 m) properties, as well as information about the location of water tables. The data shown in Section 5 suggests that of all the districts studied Bourke contained the largest amounts of soluble salts within the top 7 m. Gunnedah, Trangie and Warren and then Toobeah, Ashley and Wee Waa followed this. Various other comparisons can be made with respect to clay content and mineralogy, etc. The correlation between these soil properties and EM measurements (some of which are shown in Section 5) will allow various research results, described in section a), (see also results in Section 4) to be produced.

Future Research Needs

It is envisaged that with continued support (CRDC and Australian Cotton CRC):

- a) interpret data collected (as suggested in Section 6a),
- b) incorporate results into a Geographic Information System (GIS),
- c) present demonstrated case studies on the Web,
- d) identify new methods and techniques (i.e. gamma radiometrics)
- e) conduct similar EM studies at Hillston and Collarenebri (NSW) and Dirranbandi and St George (Queensland).

7 Detail a plan for the activities or other steps that may be taken;

Soil salinisation results from the accumulation of soluble salts in the root-zone. In the Australian environment, large quantities of stored salts have accumulated naturally. This process, termed primary salinisation, is attributable to the geological age and generally arid to semi-arid moisture regimes that prevail. In the areas studied as part of Phase III, it is evident that large amounts of salts are stored in many of the profiles sampled within the Bourke Irrigation District (Figure 34) and the area southeast of Gunnedah (Figure 25) on the Breeza Plains.

In the Bourke Irrigation District, irrigation inefficiencies have resulted in the mobilisation of stored salts into the root zone. This is similarly the case in the lower Macquarie valley. In both cases shallow water tables have developed in isolated areas and generally in association with water reservoirs and supply channels. In comparison and although similar irrigation inefficiencies occur in the lower Macintyre, Gwydir and Namoi study areas, there are no multiple-field scale examples of soil salinisation despite the fact that water logging and in some cases shallow water tables are evident in some locals.

The results shown in Sections 4 and 5 point clearly therefore to the following recommendations:

- (a) to further develop or to exploit the project technology.
 - 1) On the field-scale deploy MESS to determine specific cause and management of soil salinisation in Bourke, Trangie and Warren;
 - 2) On the district-scale:
 - a) use existing piezometer network, soil data and MODFLOW, model to show how saline shallow groundwater interacts with the Darling River near Bourke and how irrigation may contribute to the problem
 - b) estimate groundwater recharge rate in various irrigated cotton growing areas (e.g. lower Macintyre, Gwydir and Namoi valleys) using a simple chloride mass balance model
 - c) map average clay content (0-7 m) in the lower Macquarie valley
 - d) Extend the methods to Hillston, Collarenebri, Dirranbandi and St George where no detailed vadose zone (0-15 m) information exists.
 - 3) Assess usefulness of Radiometric data for natural resource management (Namoi) for regional soil surface attribute mapping.

- (b) for the future presentation and dissemination of the project outcomes.
 - 1) Extend and interpret the results and data from Phase III and IV for improved natural resource management through:
 - a) development of a Geographic Information System (GIS) of data collected;
 - b) development of a Web page (Centre for Salinity Assessment and Management) to allow extension officers and growers access to demonstrated case studies and the ability to query the data stored in the GIS;
 - c) publications in international and Australian soil and water related journals;
 - d) publications in industry journals and periodicals (i.e. Australian Cotton Grower and ACGRA Cotton Conference Proceedings).

8 List the publications arising from the research project.

International Journals

Published

- 1 Odeh IOA, Todd AJ, **Triantafilis J** & M^cBratney AB 1999. Status and trends of soil salinity at different scales: the case of the irrigated cotton growing region of eastern Australia. *Nutrient Cycling in Agroecosystems* 5, 99-108.
- 2 **Triantafilis J** Laslett GM & M^cBratney AB 2000. Calibrating an electromagnetic induction instrument to measure salinity in soil under irrigated cotton. *Soil Science Society of America Journal* 64, 1008-1017.
- 3 **Triantafilis J** Huckel IA & Odeh IOA 2001. Comparison of statistical prediction methods for estimating field-scale clay content using different combinations of ancillary variables. *Soil Science* 166, 415-427.
- 4 **Triantafilis J** Odeh IOA & M^cBratney AB 2001. Five geostatistical methods to predict soil salinity from electromagnetic induction data across irrigated cotton. *Soil Science Society of America Journal* 65, 869-978.
- 5 **Triantafilis J** Ward WT Odeh IOA & M^cBratney AB 2001. Creation and interpolation of continuous soil layer classes in the lower Namoi valley. *Soil Science Society of America Journal* 65, 403-413.
- 6 **Triantafilis J** Ward WT & M^cBratney AB 2001. Land suitability assessment in the lower Namoi valley of Australia, using a continuous model. *Australian Journal of Soil Research* 39, 273-290.
- 7 **Triantafilis J** Ahmed MF & Odeh IOA 2002. Application of a mobile electromagnetic sensing system (MESS) to assess cause and management of soil salinisation in an irrigated cotton-growing field. *Soil Use and Management* 18, 330-339.
- 8 **Triantafilis J** Huckel AI & Odeh IOA 2002. Field-scale assessment of deep drainage risk. *Irrigation Science*, (in press).

Submitted

- 9 Odeh IOA Todd AJ & **Triantafilis J** 2003. Spatial prediction of particle size fractions as compositional data. *Soil Science* (in press).
- 10 **Triantafilis J** Odeh IOA Minasny B & M^cBratney AB 2003. Elucidation of physiographic and hydrogeological units using fuzzy k-means classification of EM34 data in the lower Namoi valley. *Environmental Modelling Software* (submitted).
- 11 **Triantafilis J** Odeh IOA Short M & Kokkoris E 2003. Estimating and mapping deep drainage risk at the district level in the lower Gwydir and Macquarie valleys, Australia. *Australian Journal of Experimental Agriculture*, (submitted).
- 12 **Triantafilis J** Odeh IOA Ahmed MF & Warr B 2003. Modeling and mapping the impact of saline water use in the lower Namoi valley. *Agricultural Systems* (submitted).

Conference Proceedings

- 1) **J. Triantafilis**, M.F. Ahmed and A.I. Huckel (2000). Use of a Mobile EM Sensing System for improved natural resource management at the fieldscale. Proceedings of the 10th Australian Cotton Growers Research Association Conference, Brisbane Queensland, August 16-18. pp 379-386.
- 2) **J. Triantafilis**, I.O.A. Odeh, M. Short and M.F. Ahmed (2002). Mapping deep drainage risk in the lower Gwydir and Macquarie valleys. (Ed. B.G. Sutton) Irrigation Australia Conference Proceedings: Conservation or Conflict? Darling Harbour-Sydney NSW, May 21-23. pp 322-329.
- 3) I.O.A. Odeh, **J. Triantafilis**, and A.B. McBratney (2002). The Australian Cotton Soil Database: a simple database assistant for managing soil information. Proceedings of the 11th Australian Cotton Growers Research Association Conference, Brisbane Queensland, August 13-15. pp 491-494.
- 4) **J. Triantafilis**, M.F. Ahmed, I.O.A. Odeh and B. Warr (2002). Soil salinisation risk assessment using saline water in the lower Namoi valley. Proceedings of the 11th Australian Cotton Growers Research Association Conference, Brisbane Queensland, August 13-15. pp 495-508.
- 5) **J. Triantafilis**, I.O.A. Odeh, A.I. Huckel, M. Short and B. Warr M.F. Ahmed (2002). Mapping deep drainage risk at the district levels in the lower Gwydir valley. Proceedings of the 11th Australian Cotton Growers Research Association Conference, Brisbane Queensland, August 13-15. pp 555-570.
- 6) **J. Triantafilis**, S. Buchanan, M. Short and R. Malik (2002). Measuring and mapping subsurface salinisation in the Darling River Valley. In Proceedings of 17th World Congress of Soil Science, Bangkok Thailand August 15-21.

Magazine Articles

- 1) **J. Triantafilis** and A.I. Huckel (1999). On-the-go data collection for soil salinity assessment. The Australian Cotton Grower, Toowoomba Queensland, Sept-Oct. pp. 9-10.
- 2) **J. Triantafilis** and A.I. Huckel (1999). Estimating deep drainage at the field level. The Australian Cotton Grower, Toowoomba Queensland, Nov-Dec. pp. 26-29.
- 3) **J. Triantafilis** (2000). Mapping using an EM34 in the lower Namoi valley. The Australian Cotton Grower, Toowoomba Queensland, Jan-Feb. pp. 58-60.
- 4) **J. Triantafilis** and E. Kokkoris (2000). Identifying hydrological management zones in the lower Macquarie valley. The Australian Cotton Grower, Toowoomba Queensland, Mar-Apr. pp. 74-78.
- 5) **J. Triantafilis**, M.F. Ahmed and I.O.A. Odeh (2000). Estimating the impact of increasingly saline water use in the lower Namoi valley. The Australian Cotton Grower, Toowoomba Queensland, May-Jun. pp. 58-60.
- 6) A.I. Huckel, M. McRae, and **J. Triantafilis** (2000). Mapping soil texture in a leaking storage. The Australian Cotton Grower, Toowoomba Queensland, Sept-Oct. pp. 55-60.

Part 4 – Final Report Plain English Summary

Salinisation as a consequence of irrigation can occur as a result of the application of poor quality (i.e. saline) water or mobilisation of salts from rising water tables (i.e. caused by excessive groundwater recharge). In order to determine the threat of salinisation a project entitled “*Understanding the salinity threat in irrigated cotton growing areas of Australia*” was established in 1991. Phase I (Preliminary Studies) involved testing existing field techniques (i.e. electromagnetic induction – EM) to assess cause and management of subsoil salinity at the field level, in the lower Namoi valley. Phase II (Methods and Techniques) was aimed at extending these techniques by i) automating EM instruments such as the EM38 and EM31 onto a Mobile Electromagnetic Sensing System (MESS), ii) developing district scale EM investigations (i.e. EM38 and EM34) and iii) carrying out regional scale modelling, in the lower Namoi and Gwydir valleys.

Phase III (Implementation and Management-CRC11C) was aimed at implementing the field (i.e. MESS), district (i.e. EM38 and EM34 surveys) and regional (i.e. reconnaissance soil surveys) methodology developed in Phase II, in each of the major cotton-growing areas of central (e.g. Macquarie valley) and northern (e.g. Gwydir valley) NSW and southeast (e.g. Macintyre valley) Queensland. This was achieved by:

- a) initial consultation with various community groups (e.g. Bourke Irrigators Association) to ensure research projects developed were consistent with natural resource management issues in each cotton-growing area;
- b) generate matching research funds through the Natural Heritage Trust and Salt Action Programs;
- c) collection of EM34/38 data and soil information in the root- (0-2 m) and vadose- zones (2-12 m) to measure, model, map, manage and monitor soil salinisation processes.

The main outcomes of the research carried out are the collection of over 7,500 EM34 and EM38 measurements and 350 soil profiles (0-12 m sampled at 1 m intervals) in the seven cotton-growing districts across five valleys. As shown in this report the data collected has been used at the district level to map a) deep drainage risk areas, and b) spatial distribution of subsurface saline material, whilst on the field level the cause and management of a) soil salinisation and b) water logging.

In order to consolidate the data collected in Phase III, for improved natural resource management, a follow up project is required (i.e. Phase IV-Interpretation and Extension). The main aim of Phase IV is to interpret the information collected and develop new methods (i.e. groundwater modelling from piezometric data) for understanding how point source soil salinisation occurs in irrigated cotton-growing areas. From the information collected and modelled it is expected that best management options can be devised for improved natural resource management. This is particularly the case in the Bourke, Warren and Trangie districts, where irrigation salinisation is problematic. In addition, detailed EM surveys are required to understand at the field level what the appropriate management options are required for improved natural resource management.