

Final Report



C.R.D.C.
Projects US22 and US30

Understanding the salinity threat in the irrigated cotton-growing areas of Australia

– Phase II –

Methods and Techniques

Principal Researcher:

Dr John Triantafilis

Project Staff

Mr Andrew Huckel

Mr Faruque Ahmed



Cooperative Research Centre for Sustainable Cotton Production
The University of Sydney

**Understanding the salinity threat
in the irrigated cotton-growing areas of Australia**
— Phase II —
Methods and Techniques

Table of Content

1 SUMMARY	3
2 BACKGROUND	5
3 OBJECTIVES AND ACHIEVEMENTS	6
3.1 OBJECTIVES:.....	6
3.2 ACHIEVEMENTS:.....	6
4 MATERIALS AND METHODS	7
4.1 DEVELOP METHODS AND TECHNIQUES TO ASSESS SOIL SALINITY AND IDENTIFY IRRIGATION INEFFICIENCIES AT THE FIELD LEVEL	7
<i>Introduction</i>	7
<i>Application: Identifying irrigation inefficiencies in an irrigated cotton field (lower Gwydir valley)</i>	8
<i>Conclusion</i>	11
<i>Industry significance</i>	11
4.2 DEVELOP INEXPENSIVE METHODS AND TECHNIQUES TO ESTIMATE GROUNDWATER RECHARGE AT THE SUB-CATCHMENT SCALE.....	12
<i>Introduction</i>	12
<i>Application: Estimating groundwater recharge rate (lower Namoi valley)</i>	13
<i>Conclusion</i>	20
<i>Industry significance</i>	20
4.3 DETERMINE THE EFFECT OF INCREASINGLY SALINE WATER APPLIED TO SOIL AT THE REGIONAL LEVEL.....	21
<i>Introduction</i>	21
<i>Application: Identify impact of saline water use for irrigated cotton production (lower Namoi valley)</i>	22
<i>Conclusions</i>	26
<i>Industry significance</i>	26
5 FUTURE RESEARCH	27
5.1 RECOMMENDATIONS	27
5.2 NEW PROJECT	27
6 PUBLICATIONS	28
7 ACKNOWLEDGMENTS	29
7.1 OTHER SOURCES OF FUNDING	29
7.2 COMMUNITY GROUPS	29
7.3 LANDHOLDERS	29
7.4 RESEARCH ORGANISATIONS	29
REFERENCES	30

1 Summary

In the irrigated cotton growing areas of Australia incipient traces of soil salinity are on the rise. Unfortunately, little information is available at the farm, sub-catchment or regional scale in cotton areas to determine the threat of further soil salinisation. Without suitable methods to generate this information management strategies required to prevent its spread or understand the threat can not be ascertained. The main aim of project US22 and 30C was the development of methods and techniques to generate information which could be used to better understand the salinity threat in the irrigated cotton growing areas at the field, sub-catchment and regional scales.

On the field-scale a Mobile Electromagnetic (EM) Sensing System (MESS) was developed in collaboration with the National Centre for Engineering in Agriculture (University of Southern Queensland). Supplementary funding for the MESS was obtained via a grant from Salt Action in association with the Coordinating Committee of the lower Namoi valley water users and the Cooperative Research Centre for Sustainable Cotton Production. The MESS was used successfully to demonstrate its applicability in identifying areas of irrigation inefficiencies in an irrigated cotton field in the lower Gwydir valley. Other applications of the MESS include soil salinity assessment, location of suitable storage sites and in precision agriculture.

At a sub-catchment level a relatively inexpensive broadscale EM34 survey was demonstrated in the lower Namoi valley. Along with strategic soil sampling and the use of a simple salt-balance model estimates of groundwater recharge were made across a large portion of the valley west of Narrabri. The work also reflected the physiography and hydrogeology of the area studied. The results suggest that most of the irrigated cotton farms are located on the heavier textured clay plains and do not appear to be contributing much to groundwater recharge. Those farms associated with the prior stream formations, the low dissected floodplains and the Pilliga Sandstone are likely to be less water use efficient and contribute more to groundwater recharge. These areas may require more detailed investigation.

A regional scale assessment was made using reconnaissance soil survey information (CRC-1.2.1) and a quantitative decision support model (CRC-1.5.4) to determine the possible impact on irrigated cotton production systems of the application of increasingly saline water. This was carried out across the lower Namoi, Gwydir and Macintyre valleys. The results of the lower Namoi valley are shown. In general, the results suggested that at the present time irrigated cotton production is sustainable using water quality currently available. However, and with respect to the modeling carried out, the clay alluvial plains are susceptible to saline waters particularly if the subsoil is sodic. The reason is that deep drainage is reduced and salts are more likely to accumulate in the rootzone. Conversely, non-sodic clay subsoils and the lighter textured soils will become more permeable and hence less water use efficient with the use of

increasingly saline waters. The consequences of this are likely to be increased groundwater recharge rates and possibly rising saline water tables.

The results of this project suggest that the methods developed are suitable for the assessment of the current status and future threats of soil salinisation in the irrigated cotton growing areas.

In summary, the industry needs to be conscious of the changing nature of the water quality that is available to them and the impact upland areas of their catchment may have on their long term sustainability. Similarly, the industry needs to consider the potential impact it can have on local hydrological groundwater levels and down stream users. This is particularly the case with respect to creation of local shallow groundwater tables from inefficient irrigation methods and layouts.

It is recommended that:

- 1) methods developed during this project be adopted and implemented in areas where irrigation salinity is currently being experienced and where little information is available to assist in determining the cause and suitable management options required to minimise its further impact. This is particularly the case in several of the irrigated cotton growing areas, including the upper Namoi and lower Macquarie valley, Bourke irrigation area and lower Gwydir valley and Macintyre river basin;
- 2) Community groups become involved in facilitating the generation of this information and assist in this process by seeking funds from State (Salt Action) and Federal funding bodies (Land and Water Research and Development Corporation, National Program for Irrigation Research and Development, Natural Heritage Trust, etc.,).

2 Background

Irrigation salinity occurs either as a result of inefficient irrigation practices or the addition of saline irrigation water. In either case soluble salts accumulate in the rootzone. In the irrigated cotton growing areas of Australia incipient traces of soil salinity are becoming increasingly apparent. In the lower Namoi, Macquarie and Bourke irrigation areas, isolated incidences of soil salinity have occurred as a result of rising water tables. In the Darling Downs application of saline groundwater has resulted in accumulation of soluble salts.

Many cotton growers and community groups are becoming aware of the extent of the problems in their respective areas and are concerned about the long term problems of salinity on a valley basis. The concern of the growers regarding the issue of salinity would appear to be due the lack of any reliable natural resource information to determine areas of concern.

In order to provide this information and improve the understanding of the process of soil salinisation a project entitled “Understanding the salinity threat in the irrigated cotton growing areas of northern New South Wales” was proposed by The University of Sydney. The project was renamed “Understanding the salinity threat in the irrigated cotton growing areas of northern New South Wales – Phase II – Methods and Techniques.” This project was one of the core projects described in the “Cooperative Research Centre for Sustainable Cotton Production: Strategic Plan for Soil Salinity Research and Management Strategies for the irrigated cotton growing areas of Australia.”

3 Objectives and achievements

The overall objective of this project was to address the lack of reliable natural resource information in the cotton growing areas by the development of methods and techniques which could be used to understand the salinity threat.

3.1 Objectives:

- 1) develop methods and techniques to assess soil salinity and identify irrigation inefficiencies at the field scale
- 2) develop inexpensive methods and techniques to estimate groundwater recharge rate on a sub-catchment scale
- 3) use a salt and leaching fraction model to determine effect of increasing saline water on soil condition at a regional level
- 4) highlight strategies for the future.

3.2 Achievements:

- 1) a mobile electromagnetic sensing system (MESS) was developed for the purpose of assessing soil salinity and identifying irrigation inefficiencies at the field scale in the lower Gwydir valley
- 2) an electromagnetic induction instrument along with a simple salt-mass balance model were used in tandem to estimate spatial distribution of groundwater recharge rate across the lower Namoi valley
- 3) used SaLF developed by QDNR to estimate the effect of increasingly saline water applied to soil of the lower Namoi, Gwydir and Namoi valleys
- 4) recommendations for further research and development

4 Materials and methods

4.1 Develop methods and techniques to assess soil salinity and identify irrigation inefficiencies at the field level

Introduction

Traditional methods of generating soil information on the field scale involve soil sampling regimes and laboratory analysis. Due to the time consuming nature only limited information can be collected. Nevertheless, maps are generated and inferences about the spatial distribution of soil properties, and soil condition *etc.*, are made from this information. Unfortunately, the use of these maps can lead to errors in interpretation and management. In investigations such as salinity assessment and determination of irrigation/drainage efficiency detailed information is required, to manage soil salinity or related problems.

The development of new technologies and instrumentation has revolutionised the way in which this information can be generated. Electromagnetic (EM) induction instruments, which measure apparent electrical conductivity (EC_a) of soil, have been used to estimate various soil variables and properties. These include: salinity (Lesch, *et al.*, 1995); clay content (Williams and Hoey, 1987); depth to clay (Doolittle *et al.*, 1994), nutrient status (Suddeth *et al.*, 1995); and, moisture content (Kachanoski, *et al.*, 1988). The reason for the wide application is due to the fact that EM instruments respond to various soil attributes including clay content, soil mineralogy, moisture content and salinity.

To improve efficiency of EC_a data collection, Rhoades (1992) and others (e.g. Cannon *et al.*, 1994) have incorporated Global Positioning Systems and EM instruments onto Mobile EM Sensing Systems (i.e. MESS). As a result larger amounts of data can be collected on the field scale which can be used to map the spatial distribution of soil salinity and other related variables.

In association with the Coordinating Committee of the Namoi valley water users association, the University of Sydney developed a MESS to allow rapid, repeatable and reliable collection of EC_a data. The final version is illustrated in Figures 1a and b. The system includes: a 486 computer for data logging, display and instrument set-up; a Trimble™ Ag132 Global Positioning System (GPS) which provides a wide-area differential correction for real-time sub-meter accuracy; a Trimble™ FieldGuide GPS for positioning and guidance; and a Geonics™ EM38 for root-zone and Geonics™ EM31 for subsoil EC_a measurement. All of these components have been mounted on a 4WD hydrostatic and articulated tractor, powered by a 20 HP Kohler Petrol Engine.

The various EM instruments (i.e. EM38 and EM31) and GPS units are hooked up to a 486 computer which integrates and logs this information into a single file that stores GPS Easting and Northing, and EC_a measurements as read by the EM instruments. The 486 computer also acts as the controller allowing the operator to designate whether vertical or horizontal data is collected and the height EM38

measurements are made. Mr Danny Dusza of the NCEA developed the data logger system. Mr David Jones of the NCEA designed and constructed the various components, which support the EM38 and EM31.



Figure 1a. Trimble Ag132, GPS400, RMD and 486 data logger/control box.



Figure 1b. MESS deployed in a field south-east of Moree, Gwydir valley.

Application: Identifying irrigation inefficiencies in an irrigated cotton field (lower Gwydir valley)

Auscott Midkin is a large cotton-growing farm located in the lower Gwydir valley in northern NSW. The field selected for study (Field 11), covers 244 ha and has a long history of problems associated with shallow water tables and water logging. This is particularly the case in the middle parts of the field where sandy soil types are apparent (Figure 2a). In order to map the spatial variability of soil types, and hence determine where irrigation inefficiencies occur, a MESS survey was conducted. In total, 55 transects were traversed every 48 m with 27,000 measurements of soil EC_a recorded.

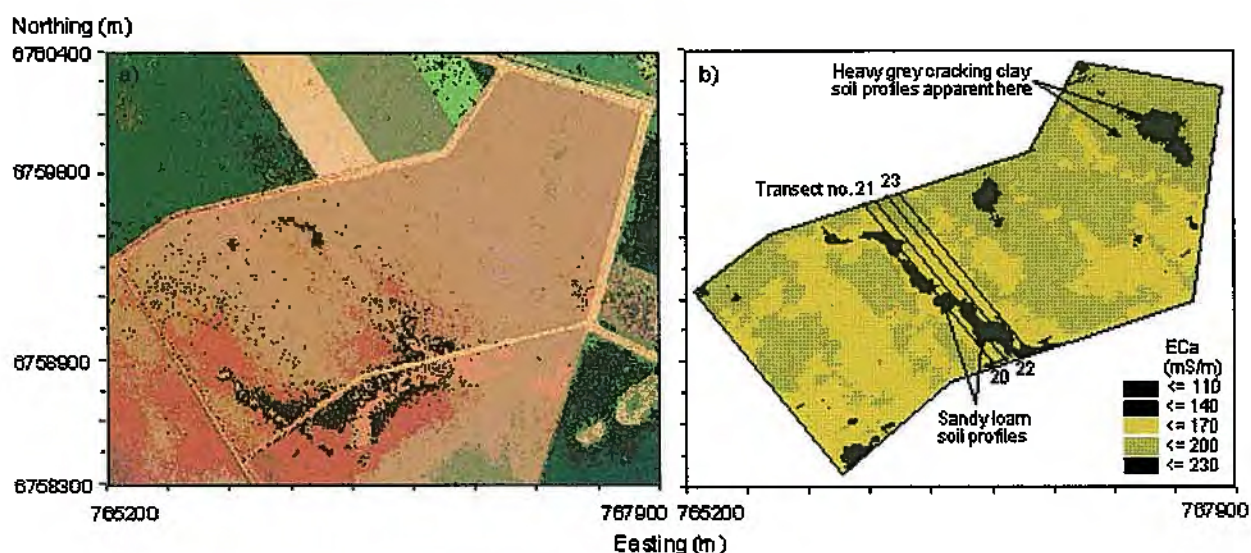


Figure 2. Auscott Midkin Field 11 a) aerial-photo and b) MESS survey.

Figure 2b indicates low, intermediate and high soil EC_a as generated by the EM31. The lighter shaded areas ($EC_a < 140$ mS/m) indicate parts of the field where a prior stream traveled and where sandier

soil types are apparent. In the north-eastern part of the field, larger values of EC_a (>170 mS/m) were generally obtained. These values reflect an area where heavy clay profiles are apparent. Similar EC_a patterns were obtained with the EM38. This suggests the instruments are primarily responding to clay content and hence strongly reflect the geology and geomorphology.

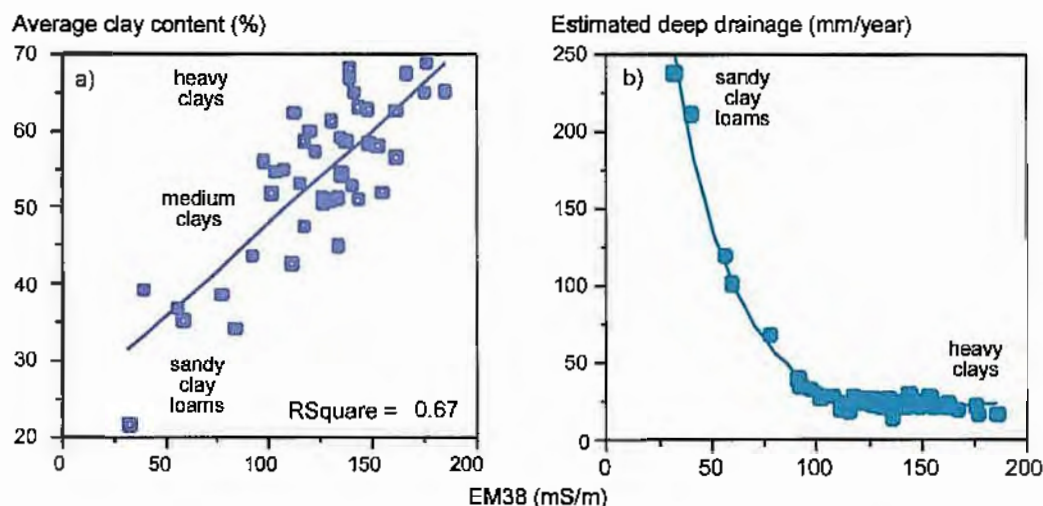


Figure 3. Relationship between soil EC_a (i.e. EM38) and a) average clay content (%) to 1.20 m, b) estimated deep drainage (mm/year)

To confirm this, 46 sites ranging from low, medium and high EC_a measurements were visited with an intact soil core to a depth of 1.5 m collected and bulked into 0.30 m increments. EM measurements were taken directly above each site. Laboratory analysis of soil included, CEC and particle size determination at 0-0.3; 0.3-0.6; 0.6-0.9; and, 0.9-1.2 m depths. Figure 3, shows the relationship obtained between soil EC_a as measured with the EM38 and average clay content (%). The good correlation suggests the EM38 was mostly responding to differences in clay content.

A Salt and Leaching Fraction Model (SaLF), developed by the Queensland Department of Natural Resources, was used to estimate deep drainage (DD in mm/year) at each of the 46 calibration sites. As shown in figure 3b, an exponential relationship can be fitted between EC_a and DD (mm/year). This relationship can be used to predict DD at each of the 27,000 EM measurement sites. Figure 4 shows estimated deep drainage at steady state using 600 mm of irrigation water and assuming an annual average rainfall of 584 mm for four transects located in the middle of field 11 (i.e. transects 20-24).

Along transect 20 deep drainage was estimated to be between 50-225 mm/year in the middle part of the transect. This suggests that approximately 4-17 % of the applied water, leaches through the profile before it can be used for transpiration. As the location of the prior stream nears the head ditch, similar trends in excessive deep drainage and leaching fraction are apparent. Significantly, the estimates of deep drainage shown here are made assuming that each point in the field receives equal amounts of applied water (i.e. irrigation 600 mm). In reality the head ditch receives and transports more than the average, however. Further, the supply channel is used to transport large quantities of water to this field as well as the rest of the farm.

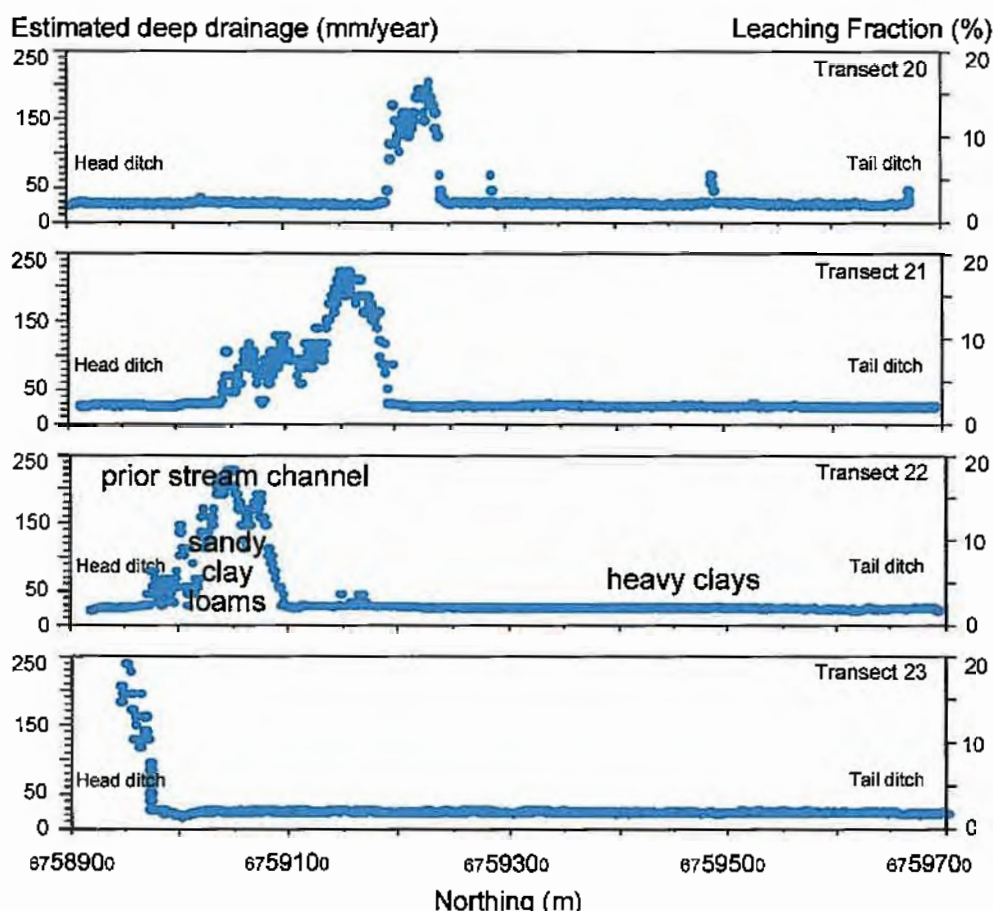


Figure 4. Estimated deep drainage (mm/year) and leaching fraction (%) along transects 20-24.

The significance of this can be better appreciated by running the 46 profiles through the SaLF model, and assuming that at each site 1,500 mm of irrigation water is applied as well as 584 mm of rainfall. This simulates a 2.0 m head of water. A scenario likely to be the situation inside the supply channel and reflecting the amount of water applied near the head ditch of field 11. The result is shown in figure 5, for transect 22. It assumes that the supply channel or head ditch was located along the length of the transect.

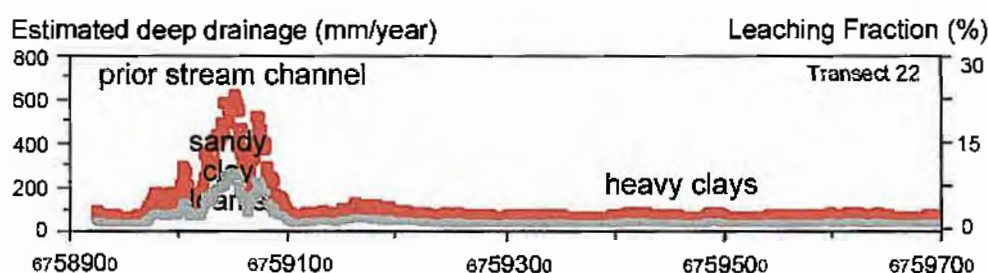


Figure 5. Estimated deep drainage (mm/year) and leaching fraction (%) along transect 22.

It is apparent that in the area of the prior stream channel, almost 30 % of the water applied would be lost due to deep drainage alone. This amounts to about 600 mm of applied water. This suggests that the use of similar sandy clay loam soil types to construct water storage or transport channels will lead to

significant losses and water use inefficiencies in an irrigation system. By the same token it is apparent that the heavier clay soil is more suitable for the construction of such structures since according to the model less deep drainage is likely to occur, particularly when the subsoil is also sodic (i.e. high in ESP).

These results seem consistent with the farmer's perceptions and experience in irrigating this part of the field. Typically it takes approximately 2-3 times longer than the rest of the field. This is particularly the case after a fallow period. Owing to the location of permeable soil near the head ditch and due to the presence of a subsoil clay layer, the excessive *DD* leads to the creation of the shallow water table or at least exacerbates the condition, causing excessive water logging. Fortunately, the perched water table is not interacting with a saline subsoil clay layer and no soil salinity is apparent.

Conclusion

It can be concluded that the MESS developed by the University of Sydney and as part of the Australian Cotton Cooperative Research Centre, provides rapid and reliable measurements for mapping the spatial distribution of soil EC_e on the field scale. These measurements can be related to soil properties such as clay content and coupled to simple salt-balance models can provide an indication of where water use inefficiencies are likely to be occurring. In particular with respect to excessive deep drainage. The applications of the MESS are wide and varied.

- These include:
- a) soil salinity assessment,
 - b) precision agriculture,
 - c) identifying suitable areas for the location of storage dams and supply channels,
 - d) identifying areas in existing structures where leakage is most likely,
 - e) identifying areas of sodic soil condition

Industry significance

The significance to the industry is that a method has been developed for fieldscale deployment of the MESS in areas where soil salinity is being experienced. The information generated will allow cause of problem to be ascertained. Likely management strategies required to minimise the impact can then be suggested.

4.2 Develop inexpensive methods and techniques to estimate groundwater recharge at the sub-catchment scale

Introduction

Groundwater is water that has drained through the soil and accumulated at depth within the deeper subsoil or in bedrock. Groundwater recharge is the process whereby the surplus of infiltration over evapotranspiration drains from the root-zone and continues to flow downward through the so-called vadose-zone toward the ground-water table (Gee and Hillel, 1988). The vadose zone is the volume of deeper subsoil that is not as biologically active as the root-zone, where deep drainage or recharge occurs. The vadose zone is as heterogeneous in nature as the topsoil it lies beneath and because of its inaccessibility is more difficult to map and hence understand the processes occurring in this part of the subsoil. In areas where irrigation is carried out extensively and over a prolonged period of time, such as the irrigated cotton growing areas of northern New South Wales, information is necessary in order to estimate the quantity and fate of groundwater recharge through the vadose zone.

Recently much work has been carried out in the use of airborne geophysics in generating information for the delineation of large stores of soluble salts or the identification of recharge/discharge areas, etc. Despite its advantages in efficiency of data generation over reasonably large areas the cost of such technology is high (up to \$ 12/ha.), however. An alternative to this approach is the use of ground based Electromagnetic (EM) techniques using instruments like the Geonics Ltd EM34-3.



Figure 6a. A Geonics EM34-3 instrument.



Figure 6b. Magellan NavPro5000 GPS.



Figure 6c. Soil sampling for deep samples.

This instrument, along with some soil sampling, has been used successfully to measure and map the extent and causes of dryland salinity (Dixon, 1989), locate sub-surface saline material (Williams and Baker, 1982; Williams and Fiddler, 1983), for groundwater exploration (Potts, 1990), describing the spatial distribution of soil salinity and clay content (Williams and Hoey, 1987) and inferring recharge and discharge areas (Williams and Arunin, 1990). More recently, and coupled to groundwater recharge models it has been used successfully in estimating recharge (Cook *et al.*, 1989a) and describing the spatial distribution of recharge (Cook *et al.*, 1989b).

In the lower Namoi valley an EM34-3 (figure 6a) was used to generate soil electrical conductivity (i.e. EC_a) measurements which could be related to the physiography (geology and geomorphology) and hydrogeology of the lower Namoi valley. Soil samples (figure 6b) were also taken at selected locals in order to calibrate the instrument to estimate groundwater recharge rate.

Application: Estimating groundwater recharge rate (lower Namoi valley)

The study area selected is centred around the small township of Wee Waa. The survey area covered 2,048 square kilometres and was approximately bounded by Bald Hill Road in the east and Cubbaroo Lane in the west. It extends as far north as Boolcarrol Farm and included the cotton growing areas of Myall Vale, Doreen Lane and "The Gardens" as illustrated in Figure 7. The area was chosen since it is one of the oldest irrigated cotton growing areas and because a large number of farms are concentrated in a relatively small area.

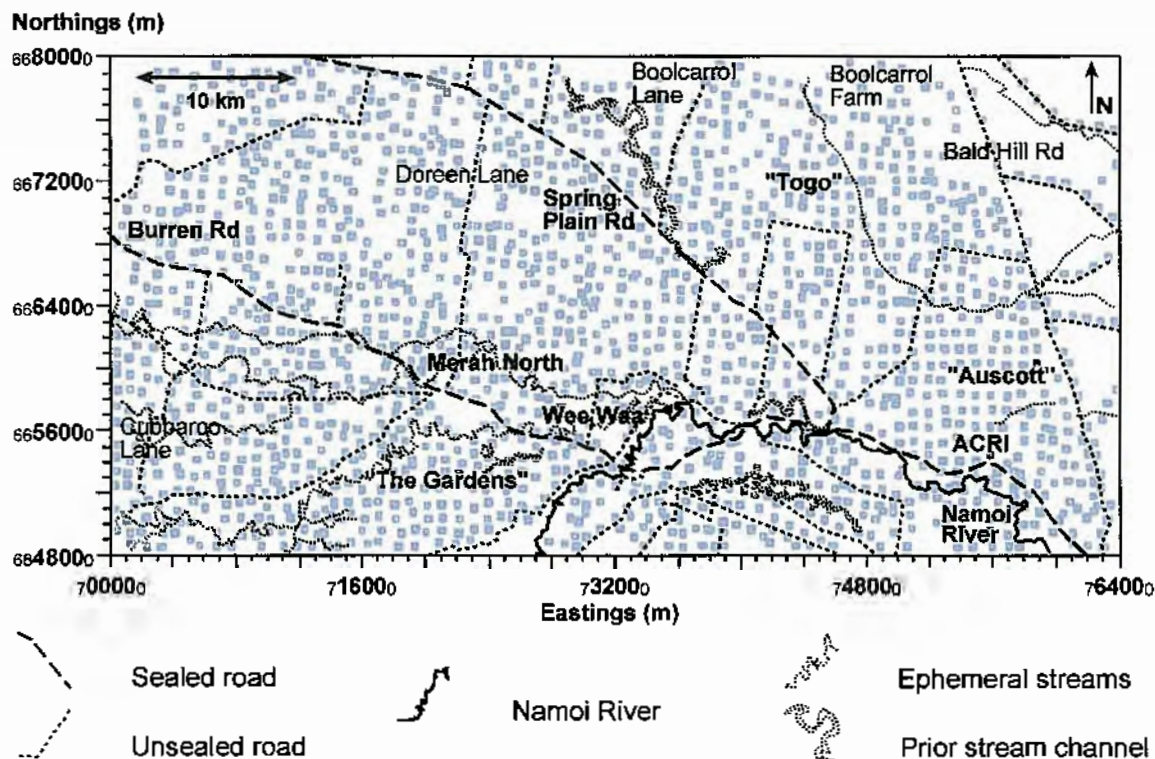


Figure 7. EM34-3 survey area of the lower Namoi valley.

Stannard and Kelly (1977) carried out a reconnaissance soil survey of this part of the lower Namoi valley and identified eight physiographic units including the clay plains, prior stream formations and the low dissected floodplains. These three units form the principal irrigation districts of the area although some irrigation is also carried out in and around the Pilliga Scrub complex. Figure 8 shows the location of these physiographic units. The clay plains dominate the area and are generally uniform in topography except where dissected by present streams. The uppermost sediments are of a fine textured nature upon which clay soil of a self-mulching character have developed.

The prior stream formations mostly occur in continuous belts of slightly elevated and undulating land, the uppermost materials of this formation are of a coarser texture than the clay plains. The relic stream channels and levees are distinguishable, with the former underlain by coarse channel sediments. In some areas, the stream channels are located in lower lying areas with respect to the plain, acting as preferential paths for floodwaters under current conditions. In these situations, the upper sediments are of a fine texture and are identifiable from the normal effluents by their wide meander belts and broad and shallow channels.

The coarse dissected low floodplains lie adjacent to the Namoi River and occupy depressed positions with respect to clay plains and are dissected by small channels. The greatest contribution of this generally coarse textured low flood plain material is the result of dissection of Pilliga Scrub by course of a prior stream formation.

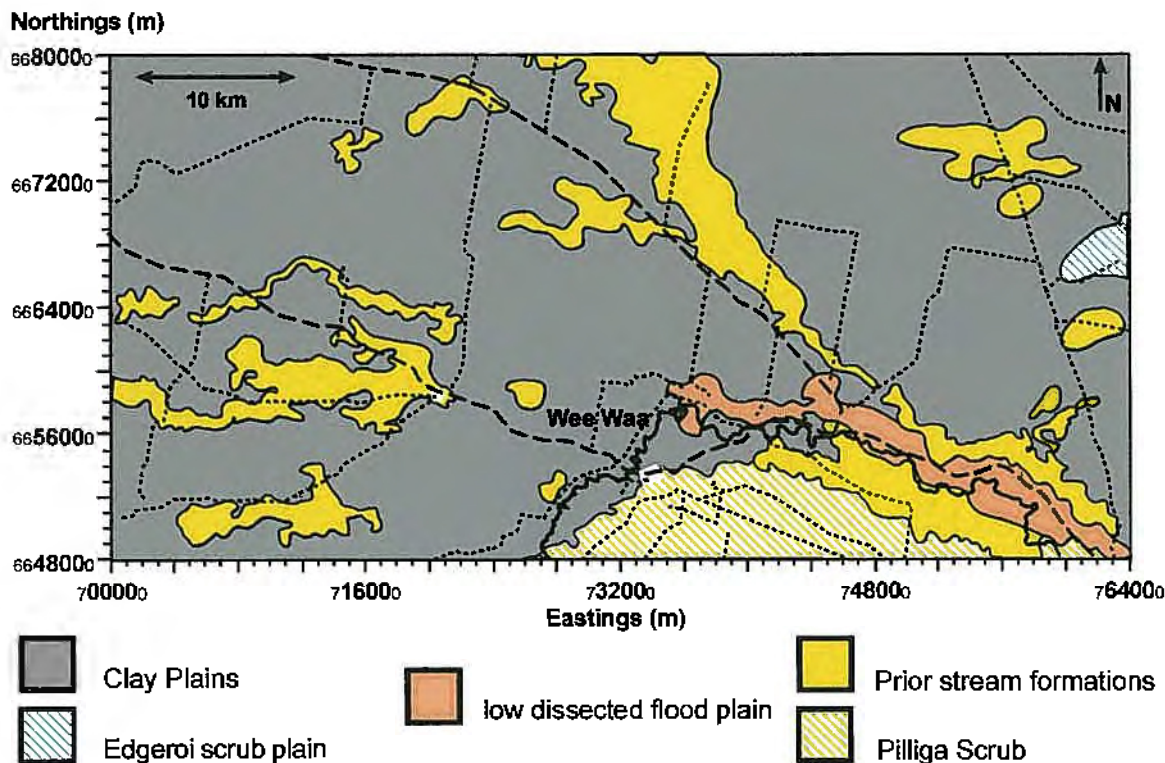


Figure 8. Physiography of the lower Namoi valley (after Stannard and Kelly, 1977).

In order to map this area and confirm these patterns, an EM34-3 survey was conducted and involved taking measurements with the instrument on an approximate 1 km grid. A total of 1,869 sites were visited as shown in figure 7, with measurements made at three fixed coil configurations. The intercoil spacing was varied so that the effective depth of penetration by fixing the coils at 10, 20 or 40 m was 7, 15 and 30 m, respectively in the horizontal mode of operation.

Figure 9 shows EC_a measurements achieved using the EM34-3 in the horizontal mode of operation and at intercoil spacing of 10 and 40 m. With respect to the data generated at an intercoil spacing of 10 m, the results shown in figure 9a strongly reflect the physiography of the area as shown in figure 8.

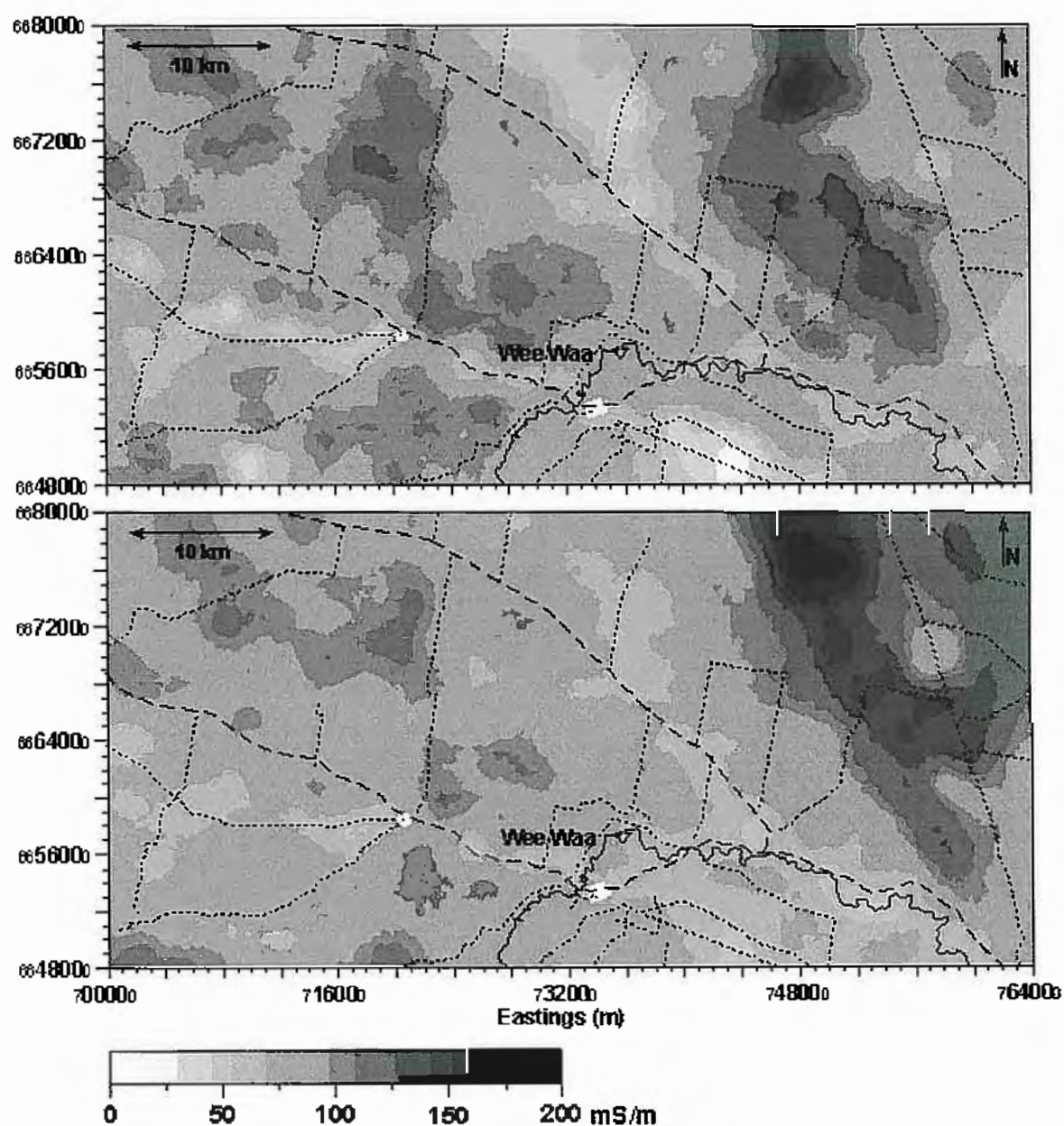


Figure 9. Map of low, intermediate and high soil EC_a (mS/m) as obtained using EM34-3 in horizontal mode of operation and an intercoil spacing of 40 m.

This is particularly the case where the survey reflected the location and passage of prior stream channels of the Namoi River in a north west direction parallel with Spring Plains road and in a westerly direction where Pian Creek now runs. These are defined by lighter shaded areas where soil EC_a was generally low (<70 mS/m). This is more clearly illustrated when considering data along east-west transects as illustrated in figure 10, which shows two transects generated about 20 km apart. The upper panel shows the EC_a measurements at 10 and 40 m intercoil spacings along Northing-6675000, while the lower panel shows similar data generated along the more southern transect of Northing-6656000.

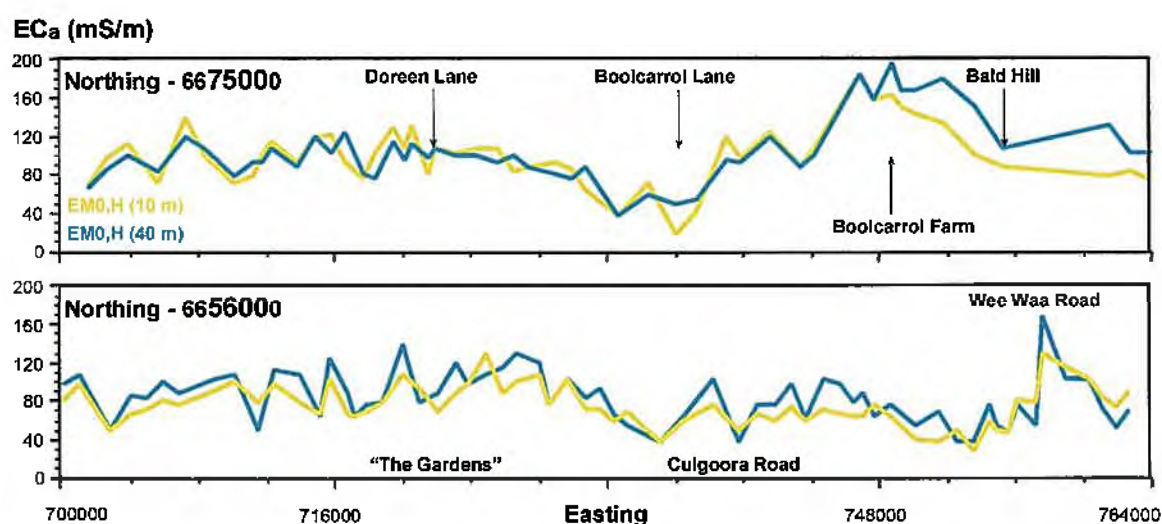


Figure 10. East-west transects of $EM_{0,H}$ at 10 and 40 m intercoil spacing.

It is apparent from these two transects that survey points located adjacent to or within prior stream channels, (i.e. near Boolcarrol Lane in the upper panel and Culgoora Road in the lower panel), soil EC_a is generally much lower than on the clay plains in areas such as Doreen Lane and "The Gardens". The reason for this is that the soil is generally coarser in texture (i.e. sandier) than the clay rich plains and as a consequence the soil is much less conductive. This is better appreciated by considering a cross-sectional view of the general shallow stratigraphy near prior stream channels as identified by Stannard and Kelly (1977) and illustrated in figure 11.

The thickness of the clay alluvium near prior stream channels is also quite variable. This is reflected in the transects shown in figure 10. Despite this, there is still a trend of increasing soil EC_a away from the prior stream channels. This suggests that the thickness of the clay alluvium increases. The depth of this clay can be as much as 10 m, particularly in the areas to the north of Myall Vale (Triantafilis, 1996). However underlying this material the soil is generally sandier consisting of clayey sand and sandy medium clay layers that are not as conductive as the clayier material above (see figure 11). This is not entirely the case in the prior stream channels and in an area of the clay plain located to the north of Myall Vale and the Australian Cotton Research Institute (ACRI).

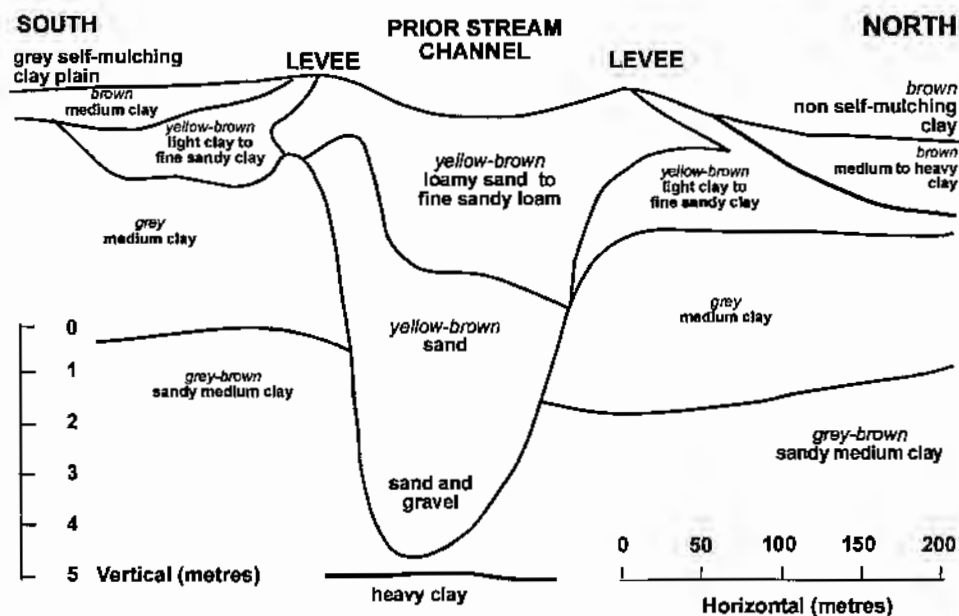


Figure 11. Cross section of a prior stream channel, lower Namoi valley (after Stannard and Kelly, 1977).

In the prior stream channels it is apparent that soil EC_a as measured using the EM34 at a 40 m intercoil spacing is slightly larger by comparison to soil EC_a as measured at 10 m spacing. The reason for this would appear to be that the instrument at 40 m spacing is responding to some conductive material, either presence of a deep subsoil clay layer or groundwater. This is best appreciated by considering the data presented in figure 12 which shows soil EC_a as measured at intercoil spacings of 10 and 40 m, from south of the ACRI near the Namoi River and its floodplain to Boolcarrol Farm. The lower panel shows the ratio of soil EC_a as measured using the EM34-3 at a 40 m and 10 m intercoil spacing.

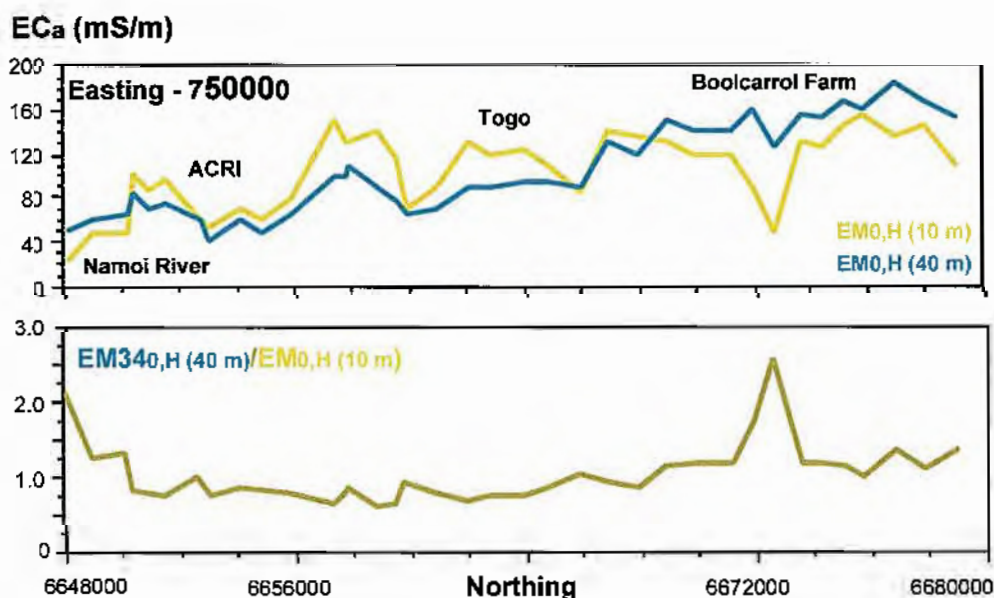


Figure 12. North-south transect of $EM_{0,H}$ at 10 and 40 m intercoil spacing.

What is apparent in the upper panel is the steadily increasing trend in EC_e from the south to north. This is consistent with increasing clay content and thickness of clay further from the river. Significantly the ratio of soil EC_e between 40 and 10 m is large (figure 12) near the Namoi River as compared to the rest of the transect. This suggests the instrument, when used at the 40 m spacing, is probably influenced by presence of good quality groundwater. The reason for the higher ratio on Boolcarrol Farm is most likely attributable to the presence of a number of saline aquifers located at depths around 25 m. Figure 13 shows the location of several saline aquifers (e.g. $1500 < \text{salts} < 3000 \text{ mg/L}$) in the east and northeastern part of the study area. Figure 9b, shows the spatial distribution of soil EC_e as measured by the EM34 at 40 m spacing clearly reflects the location of the saline aquifers shown in figure 13.

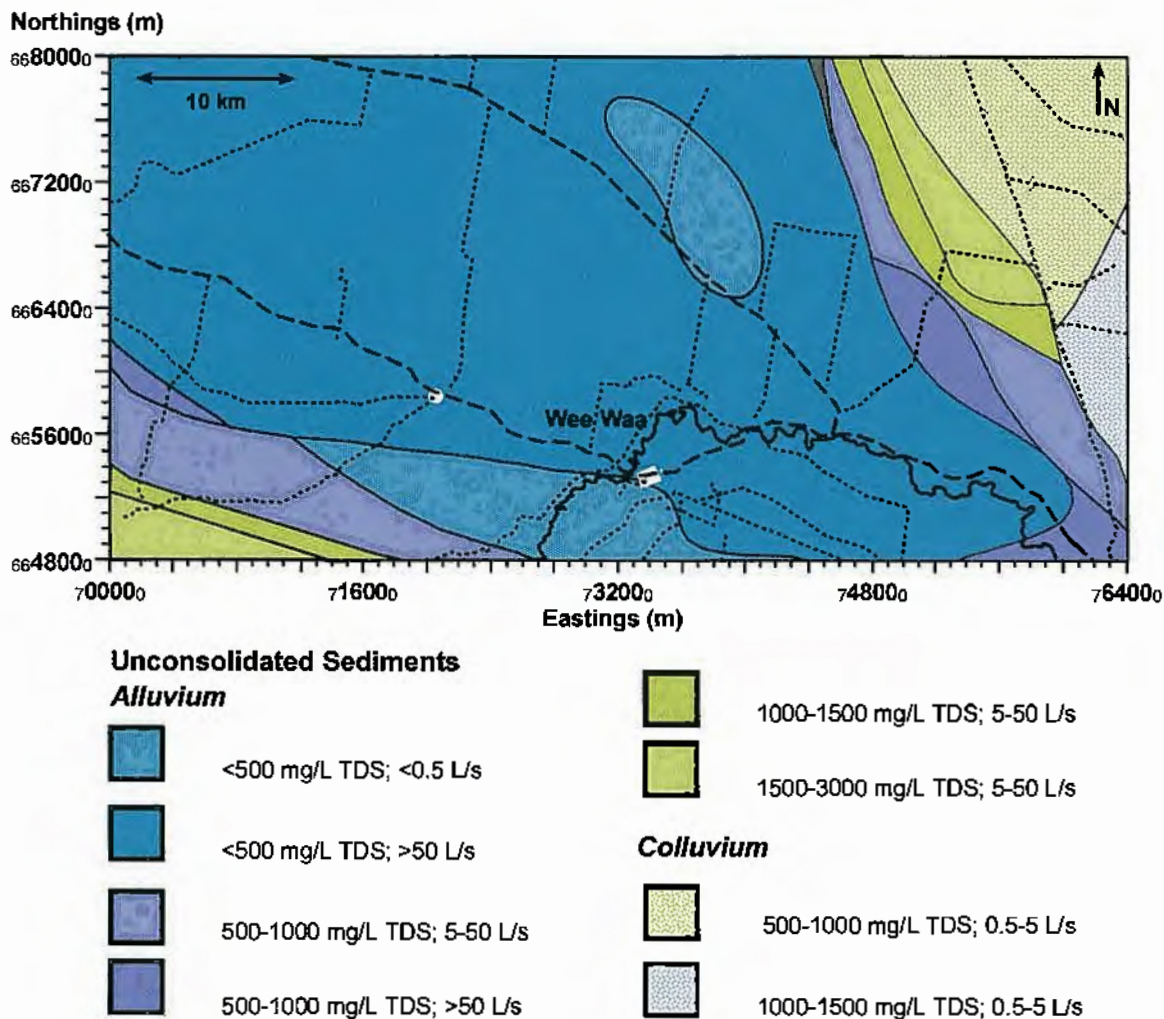


Figure 13. Hydrogeology of the lower Namoi valley area (after Department of Water Resources, 1988).

In order to provide an estimate of groundwater recharge, a number of deep cores were taken across the area. In all, 23 calibration profiles were drilled to depths of at least 7 m. Soil properties such as clay content (%) and soil salinity (EC_e) were determined in the laboratory at intervals of 0.5 m. Average

values were determined and compared against soil EC_a as measured above each calibration site. Soil EC_a as measured at the 10 m intercoil spacing provided the best relationships. These are shown in figure 14.

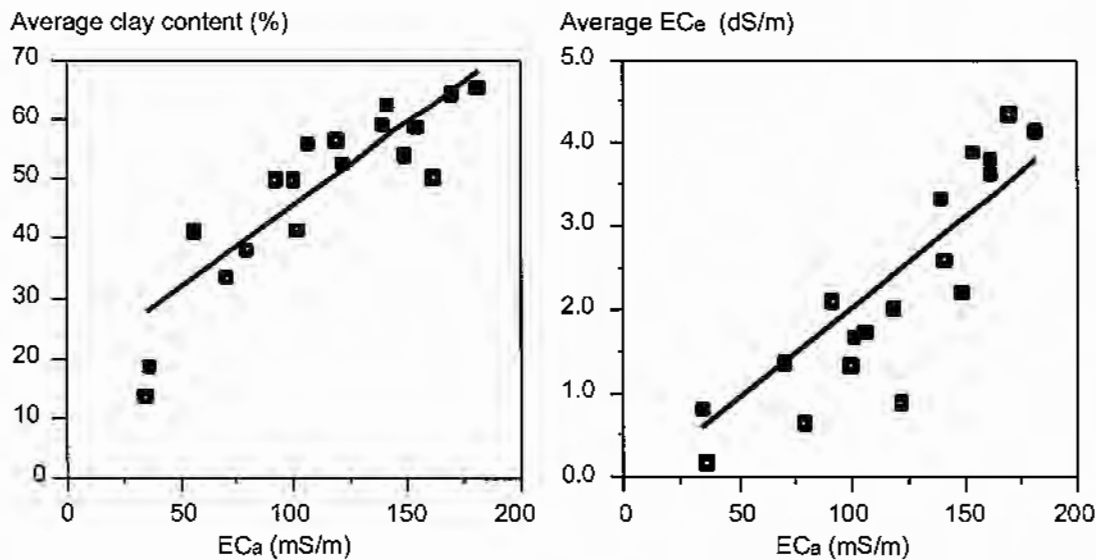


Figure 14. Soil EC_a (10 m separation) versus average clay content (%) and EC_e (dS/m).

Using a simple salt balance model an estimate of groundwater recharge rate (mm/year) was made at each of the calibration sites. We assumed that 600 mm of irrigation water is applied (equivalent to 6 megalitres/ha/annum, which is industry average irrigation volume) and water quality was 0.40 dS/m. The result is shown in figure 15 by the plot of estimated recharge rate (mm/year) and soil EC_a .

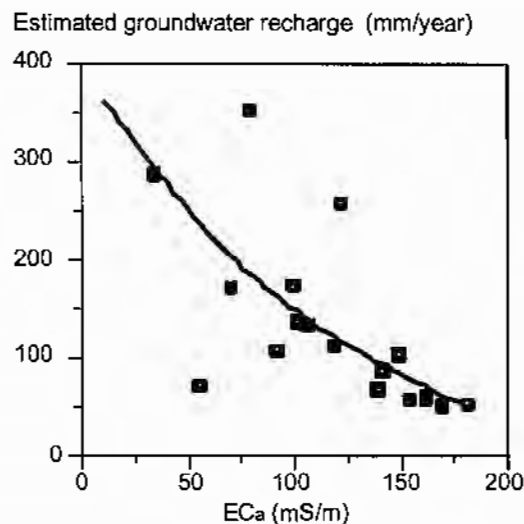


Figure 15. Soil EC_a (10 m separation) versus estimated groundwater recharge (mm/year).

The map shown in figure 16 shows estimated recharge rate as derived from figures 15 and 9a. It clearly shows that the areas associated with the prior stream channels, dissected low floodplains and Pilliga Sandstone areas are most susceptible to excessive groundwater recharge.

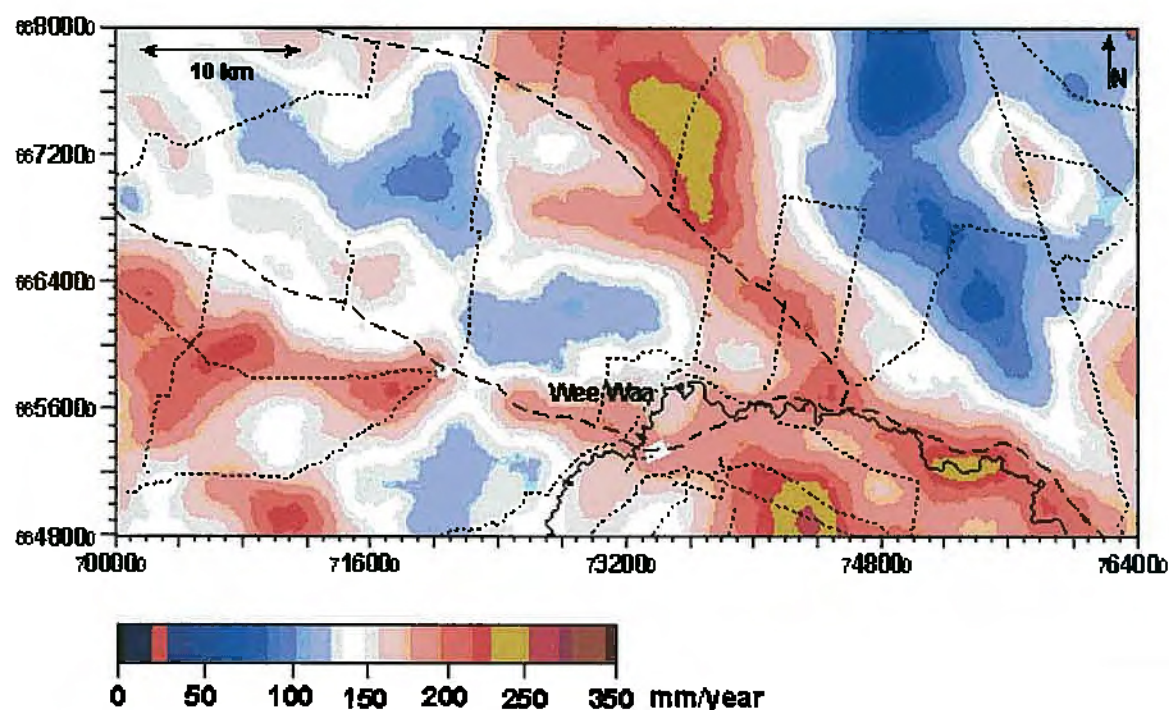


Figure 16. Spatial distribution of estimate groundwater recharge rate (mm/year) in the lower Namoi valley.

Conclusion

The work carried out suggests the EM34-3 instrument is capable of describing the spatial distribution of soil EC_a which can be related to the general physiography and geomorphology, and the geohydrology of the lower Namoi valley study area. The use of a simple salt-mass balance model provided estimates of groundwater recharge rate that assisted in identifying areas where excessive deep drainage is likely to be occurring. This suggested areas in the lower Namoi valley where more detailed work could be conducted in order to determine the consequences of prolonged irrigated cotton production with respect to groundwater tables.

Industry significance

The methodology developed here is relatively inexpensive and is applicable to other irrigated cotton growing areas. This is particularly the case in areas where soil salinity and shallow water tables are apparent and where little reliable information (e.g. physiography, soil, geohydrology) is available. This includes areas in northwest and central New South Wales and south-east Queensland such as

- a) lower Macquarie valley (south-west of Trangie)
- b) upper Namoi valley (south-west of Gunnedah)
- c) lower Macintyre valley (west of Goondiwindi)
- d) Darling River (Bourke irrigation area)

4.3 Determine the effect of increasingly saline water applied to soil at the regional level

Introduction

Irrigation with either moderate to highly saline and/or sodic water can create problems within the root-zone. Application of saline water for example can lead to increased salinity within the seedbed if there is insufficient leaching of the salts through the soil profile. Where there is excessive deep drainage, shallow saline water tables may be created and result in the concentration of salts within the root-zone through capillary rise. In order to determine the possible effect and long term sustainability of irrigated agricultural production in a particular area two things are necessary. The first is information about the spatial distribution of soil and water resources suitable and currently being used for irrigation. This can be collected by reconnaissance soil surveys or from already existing soil and water quality information. Secondly, soil\water balance models can be used effectively to estimate soil salinity build-up and deep drainage beyond the root-zone using this information.

A number of models have previously been developed and are of potential use. Of these the steady-state leaching requirement model of the United States Salinity Laboratory (1954) requires a small number of easily measured soil properties for the calculation of leaching flux beyond the root-zone. Unfortunately, the model assumes that the soil has reached steady state whereby salts applied in the irrigation water equals salts leached in drainage water. If the salinity level in the soil is not in equilibrium the model is invalid. SODICS (Rose *et al.*, 1979), which is a transient mass balance model, is more applicable when this is the case and is suitable in providing predictions of deep drainage, particularly in slowly permeable soils that are prevalent in the irrigated cotton growing areas of northern NSW. This model however, requires soil information at two different times, that is prior to the commencement of irrigation and the present day or at the start and end of a calendar year. This information is then used for the purpose of comparison and calculation of the deep drainage using the chloride profile as an indicator.

Owing to the large area used for irrigated cotton production in the lower Macintyre and Gwydir valleys for example, a simpler model that requires only rudimentary soil survey data would be more appropriate. The so-called Salt and Leaching Fraction Model (i.e. SaLF) was therefore developed by Shaw and Thorburn (1985) and Shaw (1988). It is based on the assumption that soil leaching or deep drainage is related to hydraulic conductivity, which in turn is influenced by the amount of clay (%), clay mineralogy (Cation Exchange Capacity/Clay %) and exchangeable sodium percentage (ESP). Once these soil properties and water quality and quantity parameters have been determined and entered into the empirically based model, estimates of leaching fraction (*LF*) deep drainage (*DD* in mm/year) and average root zone EC_e at steady-state are predicted. A small number of water quality parameters, such as EC_w , depth of irrigation water applied and annual rainfall.

In the lower Namoi valley results are shown of how the model, SaLF, was used on soil survey information generated from a reconnaissance broad-scale soil survey. This soil survey was undertaken as

part of CRC project 1.2.1 (University of Sydney – Dr Odeh). Data from the Edgeroi database was also used. The results show the current status of soil salinity and potential threat due to the application of poor water quality in the lower Namoi valley.

Application: Identify impact of saline water use for irrigated cotton production (lower Namoi valley)

Soil samples were collected and analysed for a small number of rudimentary soil properties in the lower Namoi valley. The location of these sites is illustrated in figure 1. In total 125 soil profiles were recovered on a stratified random sampling grid (approximate grid of 5 km). At each site six soil samples were collected including 0-0.1, 0.1-0.2, 0.3-0.4, 0.7-0.8, 1.2-1.3 and 1.9-2.0 m. Soil properties analysed included pH, EC_{1:5}, chloride, topsoil organic matter, bicarbonate phosphorus and particle size analysis (i.e. determination of clay, silt and sand fractions). CEC was also determined. The Edgeroi data set (McGarry *et al.*, 1989) consists of similar information, however it was collected on a approximate 2.8 km equilateral triangular grid as shown in figure 17.

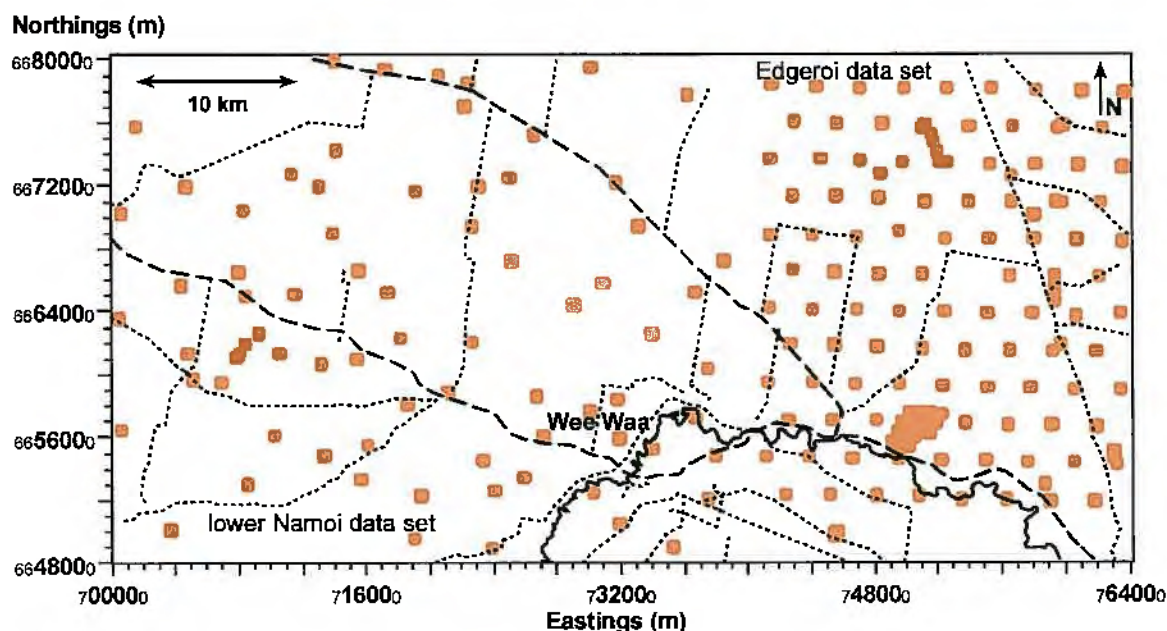


Figure 17. Map of soil sampling sites located in the lower Macintyre and Gwydir valleys.

A reconnaissance water sampling survey was also conducted to assess the current water quality available for irrigation. This involved collecting water samples from the Namoi River. The water quality was found to be good with respect to salinity with an average EC_w value of 0.44 dS/m. This is considered non-saline (i.e. <0.7 dS/m) and well within acceptable limits for irrigation.

With the soil and water quality information generated, the Salf model was used to determine the current status of soil salinity within the root-zone and sustainability with respect to an average water salinity of 0.44 dS/m. At each site, the SaLF program was run by entering the attributes of clay content and cation exchange capacity at four depths (i.e. 0-0.1, 0.2-0.3, 0.6-0.7 and 1.1-1.2 m) and exchangeable sodium percentage at a depth of 1.2 m. We also assumed that at each site the average annual rainfall was

584 mm and that 600 mm of irrigation water is applied annually. In order to determine the effects of applying progressively more saline water with respect to increased soil salinity we also carried out simulations of adding water with EC_w values of 1.4 (slightly saline), 4.0 (moderately saline) and 9.0 dS/m (moderate-high salinity).

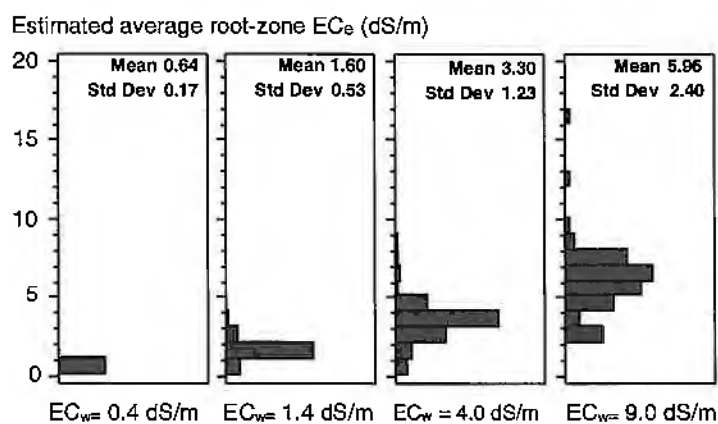


Figure 18. Histograms of estimated average root-zone salinity (dS/m) at steady state using SaLF and various EC_w water quality values.

The simulation results generated by SaLF are illustrated in figure 18. It shows the frequency distribution of estimated average root-zone EC_e (dS/m) for all the sampled sites. The simulation using the current water quality (i.e. EC_w 0.44 dS/m) suggests that at present this water quality is sustainable for irrigated cotton production since average soil salinity (EC_e) in the rootzone across the valley would be 0.64 dS/m. This value is well below an EC_e of 4.0 dS/m which is the critical value required for susceptible crops to be affected (e.g. legumes) and well below the value to affect wheat (i.e. 6.0 dS/m) and cotton (i.e. 7.7 dS/m). This is similarly the case if the slightly more saline water of EC_w 1.4 were to be used, since average EC_e in the rootzone would approximately be 1.6 dS/m. If EC_w of 4.0 dS/m was applied, some crop management may be necessary. This is because the level of salinity within the rootzone on average (i.e. 3.3 dS/m) is approaching a level where sensitive crops may show reductions in yields of perhaps 5 %.

If water of electrical conductivity of 9.0 dS/m were applied, susceptible crops could possibly still be grown with reasonable success if suitable crop, soil (e.g. seedbed design) and/or irrigation management (i.e. method of application) were developed. In most cases and using soil types of a heavy clay nature, irrigated cotton production should theoretically be uninhibited by an average EC_e of 5.96 dS/m, although and with respect to rotation crops such as wheat, these levels may cause some reduction in yield.

The soil types or areas at risk if this water quality was the only one available (i.e. EC_w 9 dS/m) for irrigation can be shown using a geostatistical interpolation method known as indicator kriging. For example, if average soil salinity exceeds 4.0 dS/m at steady state, we can anticipate that there will be a high probability (i.e. 1) that some loss in production will occur if sensitive crops (e.g. legumes) are planted. If it does not exceed this threshold value we would expect there to be a low probability (i.e. 0). The data was therefore transformed into 0 and 1 values, which can be interpolated. The maps shown represent the conditional probability of an area exceeding the critical value of average soil salinity as illustrated in figure 19. For example, figure 19b shows the conditional probability of soil salinity exceeding 6.0 dS/m, when EC_w applied exceeds 9.0 dS/m, which is the critical value for wheat. Figure 20 shows the conditional probability when salinity exceeds critical value for cotton.

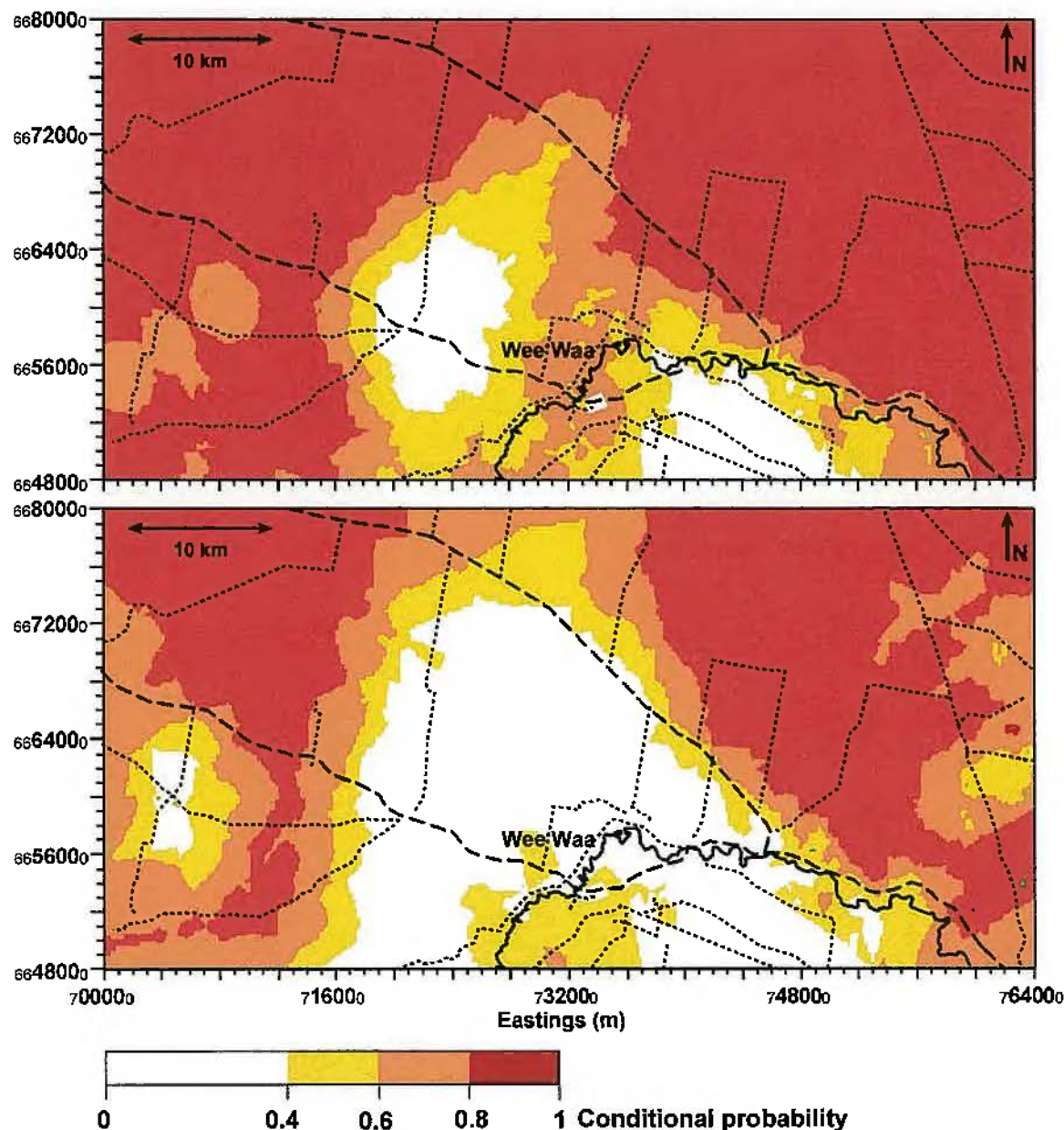


Figure 19. Conditional probability maps of average root-zone salinity exceeding; a) 4 dS/m, and b) $EC_e > 6$ dS/m, when water quality of $EC_w = 9$ dS/m is applied.

Figure 19a suggests that more than two-thirds of the area would contain levels of salinity that exceed values suitable for some legume crops (i.e. $EC_e > 4$ dS/m) if water quality of $EC_w = 9.0$ dS/m was used. This includes the cotton growing areas; north of the Australian Cotton Research Institute and Spring Plain Road, Doreen Lane; and around the middle route. Around Wee Waa there is a lower probability (between 0.4-0.8). Similarly, figure 19b suggests that about half the area would have average soil salinity exceeding lower limit for wheat production. By comparison, figure 20 shows that perhaps only one-third of the area would contain levels of salinity that would exceed the lower limit for cotton. Significantly however, the areas to the north of the Australian Cotton Research institute would be most likely to be affected, including the corporate farms of Auscott and Togo.

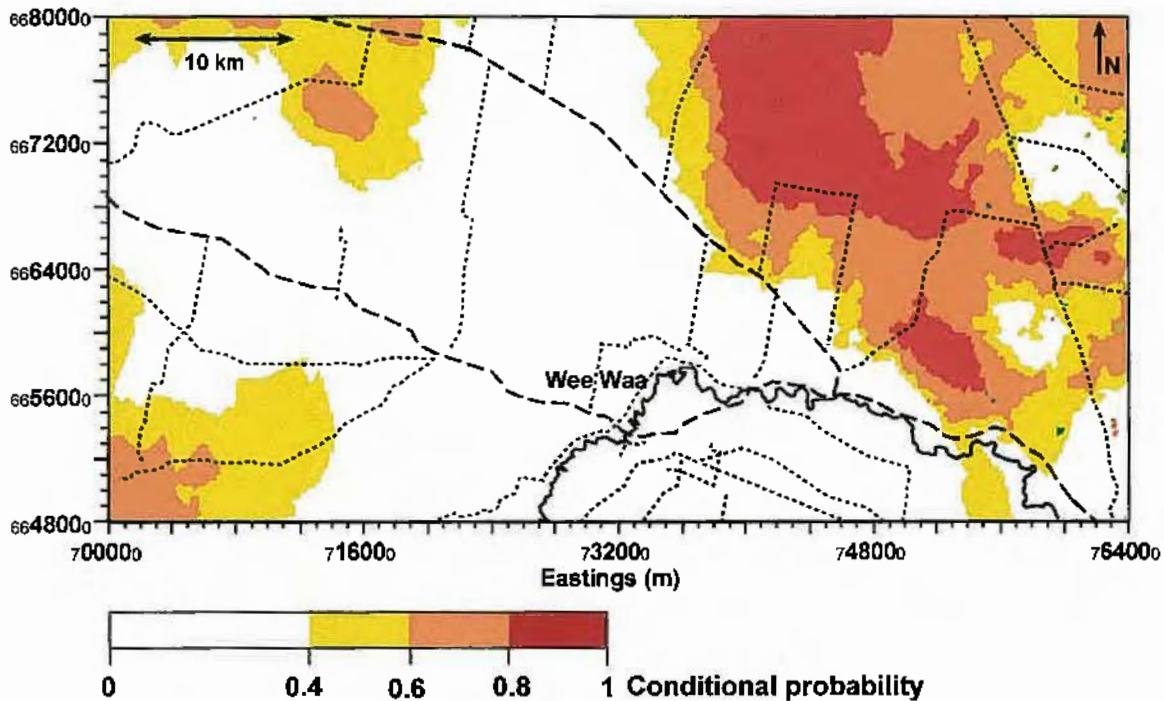


Figure 20. Conditional probability map of average root-zone salinity exceeding; a) 7.7 dS/m when water quality of $EC_w = 9$ dS/m is applied.

What can be concluded from the maps and simulations carried out is that cotton, because of its tolerance to moderately saline soil conditions, can still probably be grown in most of the lower Namoi valley study area regardless of the use of this saline water. However, some management will be required in most areas to enable legume crops and to a lesser extent wheat to be grown in rotation.

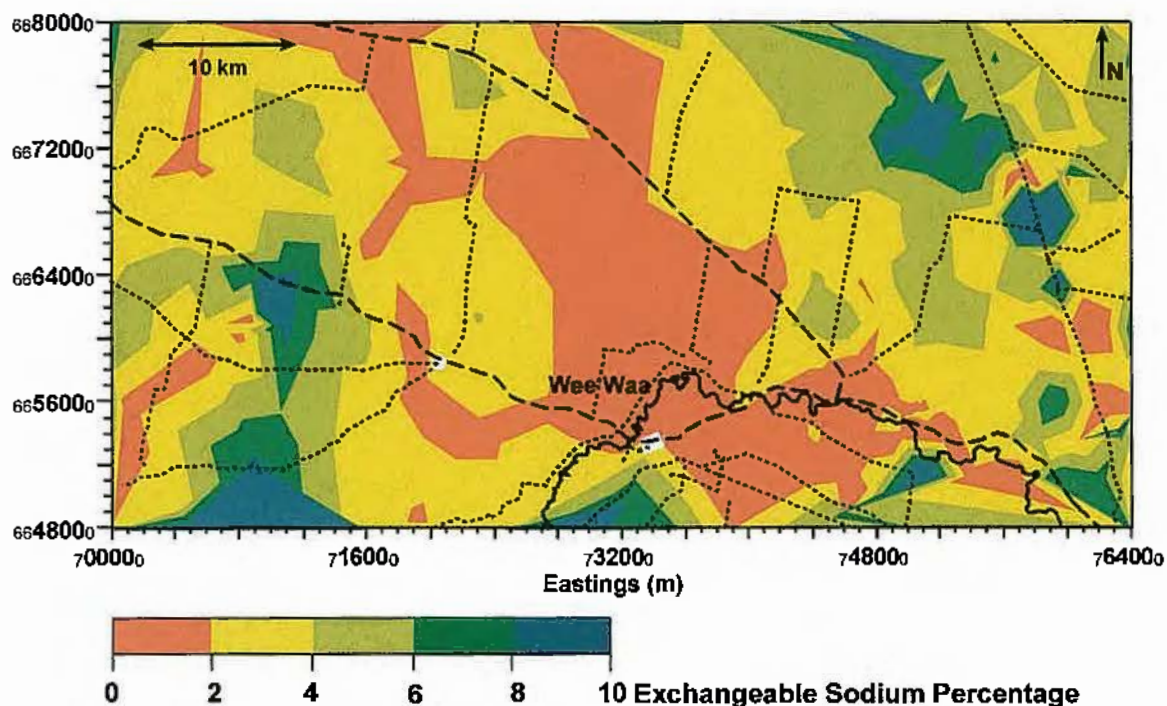


Figure 21. Spatial distribution of ESP at 0.9-1.2 m.

What is also worth noting about these maps is that they reflect to a large extent the soilphysiography map of Stannard and Kelly (1977) shown in figure 8. That is the clay plains coincide with the areas most likely to accumulate salts through the application of saline water. This is particularly the case for figure 19a. However, as the salinity of the water increases some areas appear more likely than others to accumulate salts as shown in figure 20. This can be explained by considering exchangeable sodium percentage (ESP). The spatial distribution of soil ESP at a depth of 1.2-1.3 m is shown in figure 21. This maps shows that in those areas of figure 20, where the probability of salinity exceeds critical limit for cotton, subsoil ESP is generally less than 4 %. This suggests that these areas are likely to have better structured subsoil, and therefore are likely to be more permeable. This will allow salts to be leached beyond the rootzone. In the areas where the probability is higher (i.e. > 0.6), subsoil ESP is much larger by comparison (i.e. > 6 %). The implication from this is that the subsoil is likely to be less stable and perhaps less permeable. Salts applied in irrigation water are less likely to be leached beyond the rootzone and are therefore likely accumulate in profiles with sodic subsoils.

Conclusions

It must be remembered that the work described here is based on simulations generated from a computer model and soil samples collected on an approximate 2.5-5 km grid in the lower Namoi valley and include profiles not currently irrigated. Nevertheless, the results suggest that use of the current water quality ($EC_w = 0.44$ dS/m) for irrigated cotton production should not result in increased levels of soil salinity in the root-zone. Considering the worst case scenario ($EC_w = 9.0$ dS/m), the levels of soil salinity that is likely to result may still be sustainable using a combination of suitable crops (i.e. choice of tolerant species), soil (i.e. change bed design) and/or irrigation management (i.e. method of application) practices. What may be of more concern, however, is the likely increase in deep drainage that may result using the highly saline water and the potential for this to lead to the creation of shallow salinewater-tables in some areas.

Industry significance

The results shown here (lower Namoi valley) have been carried out previously for the lower Macintyre and Gwydir valleys. They showed similar patterns. The modeling suggests that at steady state and with increasing salinity of water, irrigated cotton production is most likely sustainable, with some management) at levels of water salinity some 20 times the current levels. The likely-hood of these levels of water salinity occurring in the short-term (20 years) are unclear. However, it is known that salinity levels are on the rise because of increasing outbreaks of dryland salinity in the upper parts of these three catchments.

5 Future research

This project has provided readily applicable methods and techniques to assist in assessing and understanding the salinity threat in irrigated cotton growing areas of Australia.

5.1 Recommendations

1. The methods developed should be adopted and implemented in areas where irrigation salinity is currently being experienced and where little information is available to assist in determining the future threat, cause and suitable management options to minimise its impact. This is particularly the case in several of the irrigated cotton growing areas, including the upper Namoi valley, lower Macquarie valley, Bourke irrigation area and lower Gwydir and Macintyre valley.
2. It is recommended that community groups become involved in facilitating the generation of this information and assist in this process by seeking funds from State (Salt Action) and Federal funding bodied (Land and Water Research and Development Corporation, National Program for Irrigation Research and Development, Natural Heritage Trust, etc.,).
3. Ensure that any future research carried out in this area is integrated with related CRDC and Australian Cotton CRC projects in irrigation efficiency, soil reconnaissance surveys, farming systems and precision agriculture.

5.2 New project

1. The Cotton Research and Development Corporation in association with the Australian Cotton CRC are funding a new project to provide the core funding to carry out recommendation 1. This project will be based from the University of Sydney and the Australian Cotton Research Institute, Narrabri. It is entitled "Understanding the salinity threat in the irrigated cotton-growing areas of Australia - Phase III – Implementation and Management."
2. Four community groups have been approached and are participating in the establishment of research projects, which will identify the salinity threat in their particular area. These include: Coordinating Committee of Namoi valley water users association (Salt Action-*Determine salinity threat in irrigated cotton in upper and lower Namoi valley*); Macintyre valley river basin water users association (NHT-*Understanding salinity threat in irrigated cotton areas of Macintyre River valley*); Macquarie Valley Landcare Group (Salt Action-*Understand and manage causes of salinity in irrigated farming systems*); and, the Bourke Cotton Growers Association (Salt Action-*Determine causes & controls of salinity in irrigated farming systems*).
3. Collaborative ties are being established with various research groups including University of Southern Queensland (Dr Stephen Raine) and New England (Ms Janelle Montgomery).

6 Publications

- Triantafyllis, J (1996). Strategic Plan for salinity research and management strategies for the irrigated cotton growing areas of Australia. Cooperative Research Centre for Sustainable Cotton Production, Narrabri NSW.
- Triantafyllis, J and McBratney, A.B. (1998). Development of a mobile EM sensing system for soil salinity assessment in irrigated cotton fields. Proceedings of the 9th Australian Cotton Growers Research Association Conference, Broadbeach Queensland, August 12-14, (pg 61-64).
- Triantafyllis, J, Huckel, A.I. and McBratney, A.B. (1998). Estimating deep drainage on the field scale using a mobile EM sensing system and sodium-SaLF. Proceedings of the 9th Australian Cotton Growers Research Association Conference, Broadbeach Queensland, August 12-14, (pg 65-70).
- Triantafyllis, J, Cupitt, I. and McBratney, A.B. (1998). Progress with recharge studies in the lower Namoi valley. Proceedings of the 9th Australian Cotton Growers Research Association Conference, Broadbeach Queensland, August 12-14, (pg 71-78).
- Triantafyllis, J, Ahmed, M.F. and McBratney, A.B. (1998). Assessing sustainability and salinity threat from application of poor quality water in the lower Macintyre and Gwydir valleys. Proceedings of the 9th Australian Cotton Growers Research Association Conference, Broadbeach Queensland, August 12-14, (pg 79-86).
- Triantafyllis, J, and Huckel, A.I. (1999). On-the-go data collection for soil salinity assessment. The Australian Cotton Grower, Toowoomba Queensland, Sept-Oct, (pg 9-10).
- Triantafyllis, J, and Huckel, A.I. (1999). Estimating deep drainage at the field level. The Australian Cotton Grower, Toowoomba Queensland, Nov-Dec, (pg 26-29).

7 Acknowledgments

7.1 Other sources of funding

Salt Action

NW1054.94: Development of Mobile EM Sensing System (\$90,000)

NW1124.96: Lower Gwydir irrigation salinity risk assessment (\$23,228)

Natural Heritage Trust

NW0709.97: Using and developing decision support guidelines to model, map and manage the potential salinity threat in the irrigated cotton growing areas of northern New South Wales (\$90,000)

7.2 Community groups

Coordinating committee of Namoi valley water users association

Mr Jerry Killen, Mr Phil Norrie and Mr Bernie George for their assistance in administering funds for NW1054.96 and NW0709.97

Gwydir Irrigators Association

Mr John Seery, Mr Will Kirkby and Mr Wal Murray for their assistance in administering funds for NW1124.96

7.3 Landholders

Auscott Midkin

Mr Richard Brown, Mr Harvey Gaynor and Mr Terry Haynes for allowing us unrestricted access for fieldscale evaluation of Mobile EM Sensing System on field 11

Lower Namoi valley

All landholders of the lower Namoi valley that allowed us unrestricted access to each of their farms to carry out EM34 survey

7.4 Research Organisations

Queensland Department of Natural Resources

Mr Ian Grodon for providing us with advice and latest versions of SaLF.

CRC for Sustainable Cotton Production

Dr Inakwu Odeh, University of Sydney, collaboration on the simulation study of salinity threat using saline water.

Dr Janelle Montgomery (University of New England)

References

- Cannon, M.E., McKenzie, R.C. & Lachapelle, G.P. (1994). Soil salinity mapping with electromagnetic induction and satellite-based navigation methods. *Can. J. Soil Sci.* 74: 335-343.
- Cook, P.G., Hughes, M.W., Walker, G.R. & Allison, G.B. (1989). The calibration of frequency-domain electromagnetic induction meters and their possible use in recharge studies. *Journal of Hydrology* 107, 251-265.
- Cook, P.G. & Walker, G.R. (1992). Depth profiles of electrical conductivity from linear combinations of electromagnetic induction measurements. *Soil Science Society of America Journal* 56, 1015-1022.
- Department of Water Resources (1988). Narrabri Hydrogeological Map. Department of Water Resources, NSW.
- Department of Water Resources (1988). Narrabri Hydrogeological Map. Department of Water Resources, NSW.
- Dixon, P. (1989). Dryland salinity in a subcatchment at Glenthompson, Victoria. *Australian Geographer* 20, 144-152.
- Doolittle, J.A., Dudduth, K.A., Kitchen, N.R. & Indorante, S.J. (1994). Estimating depths to clay pans using electromagnetic induction methods. *J. Soil and Water Cons.* 49:572-575.
- Gee, G.W. and Hillel, D. (1988). Groundwater recharge in arid regions: review of methods. *Hydrological processes* 2, 256-266.
- Holmgren, G.G.S., Juve, R.L. & Geschwender, R.C. (1977). A mechanically controlled variable rate leaching device. *Soil Science Society of America Journal* 41, 1207-1208.
- Kachanoski, R.G., Gregorich, E.G. & Van Wessenbeeck, I.J. (1988). Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. *Can. J. Soil Sci.* 68: 715-722.
- Lesch, S.M., Strauss, D.J. & Rhoades, J.D. (1995). Spatial prediction of soil salinity using EM induction techniques 1. Statistical prediction models: A comparison of multiple linear regression and cokriging. *Water Resour. Res.* 31: 373-386.
- McGarry, D., Ward, W.T. & McBratney, A.B. 1989. Soil Studies in the Lower Namoi Valley - Methods and Data 1: The Edgeroi Data Set. (CSIRO, Australia, Division of Soils).
- Potts, I.W. (1990). Use of the EM-34 instrument in groundwater exploration in the Shepparton region. *Australian Journal of Soil Research* 28, 433-442.
- Rhoades, J. D. (1992). Instrumental field methods of salinity appraisal. In 'Advances in Measurement of Soil Physical Properties: Bringing theory into Practice', pp 231-248. (SSSA Special Publication No. 30).
- Rose, C.W., Dayanada, P.W.A., Nielson, D.R. & Biggar, J.W. (1979). Long term solute dynamics and hydrology in irrigated slowly permeable soils. *Irrigation Science* 1, 77.
- Shaw, R.J. & Thorburn, P.J. (1985). Prediction of leaching fraction from soil properties, irrigation water and rainfall. *Irrigation Science* 6, 73-83.
- Shaw, R.J. (1988). Predicting deep drainage in the soil from soil properties and rainfall. *Soil Use and Management* 4, 120-123.
- Stannard M.E. & Kelly, I.D. (1977). 'The irrigation potential of the lower Namoi valley.' (Water Resources Commission, NSW).
- Sudduth, K.A., Kitchen, N.R., Hughes, D.F. & Drummond, S.T. (1995). Electromagnetic induction sensing as an indicator of productivity on claypan soils. Proceedings of the Second International Conference on Site Specific Management for Agricultural Systems. (Eds. Probert, P.G., Rust, R.I.H. & Larson, W.E.). pp 671-681.
- Triantafyllis, J. (1996). Quantitative assessment of soil salinity in the lower Namoi valley. PhD Thesis. The University of Sydney.
- Tucker, B.M. (1974). Laboratory procedure for cation exchange measurements in soils. CSIRO Division of Soils, Technical Paper No 23. (CSIRO, Australia).
- United States Salinity Laboratory Staff (1954). 'Diagnosis and improvement of saline and alkali soils.' US Department of Agriculture handbook No. 60, (US Government Printer: Washington).
- Williams, B.G. & Arunin, S. (1990). Inferring recharge/discharge areas from multifrequency electromagnetic induction measurements. CSIRO Division of Water Resources, Technical Memorandum 90/11 November.
- Williams, B.G. & Baker, G.C. (1982). An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. *Australian Journal of Soil Research* 20, 107-118.
- Williams, B.G. & Fiddler, F-T. (1983). The use of electromagnetic induction for locating subsurface saline material. In 'Relation of groundwater quantity and quality' (Proceedings of the Hamburg Symposium, August 1983). IAHS Publishing No 146, 189-196.
- Williams, B.G. & Hoey, D. (1987). The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soil. *Australian Journal of Soil Research* 25, 21-28.