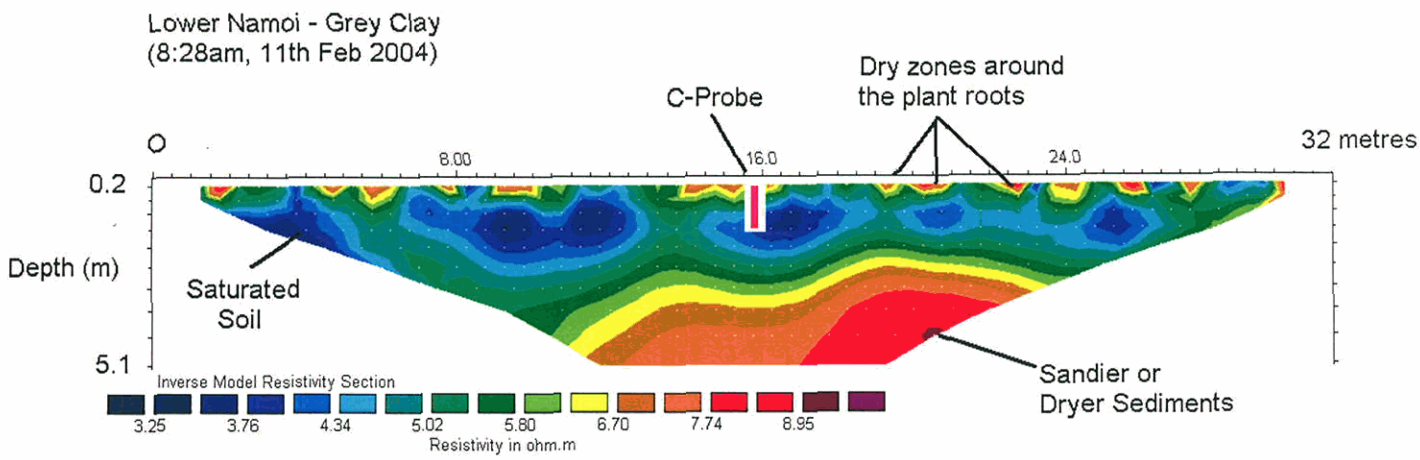
UTS5C

Electrical Imaging of Furrow Irrigation

(Final Report - October 2005)

Dr Bryce Kelly (UTS) and Assoc. Prof. I. Acworth (UNSW)

CRDC grant number UTS5



Australian Government
Cotton Research and Development Corporation

Annual, Progress and Final Reports

REPORTS

Part 1 - Summary Details

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

CRDC Project Number: **UTS5**

Annual Report: ☐ Due 30-September

Progress Report: ☐ Due 31-January

Final Report: ☒ Due 30-September (or within 3 months of completion of project)

Project Title: Electrical Imaging of Furrow Irrigation

Project Commencement Date: 1 July 2005 **Project Completion Date:** 4th Aug. 2005

Research Program: 4 Farming Systems

Part 2 – Contact Details

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Signature of Research Provider Representative: Bryce Kelly

Flow Chart for Reporting Procedure to CRDC

Start of Project
(normally 1st July)

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1. Continuing Project Progress Report

- *Due end of January.*
- If project is only 6 mths old, then Part 3.1.1. Otherwise, Part 3.1.2.
- This report advises funding bodies about progress of project for the previous 6 months.
- *Budgetary information submitted* with this report, ONLY IF:-
  - An increase or decrease in budget for the next year is required.
- Email copy of report and post 50 hard copies.

↓

2. Annual Report

- *Due end of September* (12 months after starting).
- The *main* report to be provided during life of project.
- Providing feedback to CRDC on achievement of objectives and milestones, any highlights and future objectives.
- Email copy of report only.

↓

Project finishes
(normally 3 year duration
and ends 30th June)

↓

3. Final Report

- *Due 3 months* after completion of project (normally end of September).
- *Travel reports are due within 2 months* after the travel has been taken.
- Postgraduates are to submit a hard copy of their Thesis and email the Plain English Summary.
- Provides information on achievement of objectives and milestones for the whole project and future research possibilities.
- Email copy of report and post 3 hard copies to CRDC.

Part 3.3 – Final Reports (due 3 months after completion of project)

(The points below are to be used as a guideline when completing your final report. Postgraduates please note the instructions outlined at the end of this Section.)

1. Outline the background to the project.

Our understanding and ability to quantify deep drainage under irrigated cotton crops is still limited. We have limited understanding of how much water is lost to deep drainage, where and how fast it moves, and how much deep drainage contributes to the groundwater beneath irrigated properties. Also, current methods like C-probes, lysimeters and neutron probes used to monitor moisture beneath a crop only measure at a single point and we have no idea how representative is that point.

Electrical imaging has been used successfully in the mining, regional groundwater, and contaminated sites industries for decades. Advances in the last decade in automated electrical imaging systems and interpretation software now allow for detailed shallow investigations to be undertaken in a timely manner.

The electrical properties of soil are dominated by clay type (and associated cation exchange capacity), clay volume, water salinity and degree of saturation. Under irrigation the dominant variable will be the volume of water. Electrical imaging should therefore be able to monitor the movement of water through the soil profile.

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

The objective of the project was to show that electrical imaging could be used to visualise the movement of water beyond the root zone.

3. Detail the methodology and justify the methodology used.

Resistivity imaging was undertaken at 5 locations under different soil and watering methodologies to show that water movement and the degree of saturation could be monitored under a range of conditions. The sites were:

- Wee Waa 1 – furrow irrigation with C-Probe monitoring
- Wee Waa 2 – furrow irrigation with C-Probe monitoring
- Wee Waa 3 – linear over-head irrigation
- Narromine – furrow irrigation with Neutron probe monitoring
- Goondiwindi – furrow irrigation with barrel lysimeters

Variations in the pre-irrigation soil moisture profile throughout the growing season were also recorded at Wee Waa site 2 and Narromine. Further details on the methodology are presented in the attached report.

4. Detail and discuss the results including the statistical analysis of results.

Please see the attached report.

5. **Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?**

Electrical imaging can be used to show the movement of water through and beyond the root zone of cotton under irrigation.

Electrical Imaging shows that deep drainage is significantly less under over-head irrigation than under furrow irrigation.

Electrical imaging shows that deep drainage is along preferential paths, most likely associated with cracks in the soil profile and small scale variation in the soil properties.

6. **Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?**

The electrical images collected to date were simply to validate the process so there is no immediate influence on the economic, environmental and social goals for CRDC. But as our ability to interpret and extend the application of electrical imaging progresses the technique will enhance the growers ability to optimise watering, which will contribute to the CRDC and CCC CRC goals of more crop per drop. Efficient water use will allow growers to plant more crops during periods of restricted water allocation.

The resistivity images enhance our understanding of the movement of water beyond the cotton plant roots, which will improve our ability to manage water and salt movement, both on and off farm.

The images will also allow farmers and others with an interest in catchment management to better understand the dynamics of water movement. This will enhance the discussion of the impact growers have within a catchment.

7. **Provide a summary of the project ensuring the following areas are addressed:**

   a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)**

   The project has validated that electrical resistivity imaging can be used to monitor the movement of water through the soil profile after irrigation. The resistivity images have shown that deep drainage occurs within the first couple of hours, and that water is moving down past 5 metres within this time interval. It has also shown that deep drainage is significant, but presently the images cannot be used to quantify the amount of water.

   b) **other information developed from research (eg discoveries in methodology, equipment design, etc.)**

   Electrical images need to be collected at a higher resolution than has been done in this study in order to compare the resistivity value to those of C-probes, neutron probes or barrel lysimeters.

   The electrical properties of the soils from the cotton districts need to be measured in detail in the laboratory so that the electrical images can be calibrated for estimating water content.

   c) **are changes to the Intellectual Property register required?**

No

8. **Detail a plan for the activities or other steps that may be taken:**

   (a) to further develop or to exploit the project technology.

   This research will be extended as part of UNSW and UTS involvement in the CCC CRC.

   (b) for the future presentation and dissemination of the project outcomes.

   Results will be presented to cotton consultants and at trade shows.

   (c) for future research.

   Our long term goals as part of the CCC CRC in collaboration with CRDC are to:

- Quantify the volume of water that is being lost to deep drainage.
- Link the results of electrical imaging to EM38 and EM31 surveys, and to point measurement systems (capacitance, neutron, Lysimeters etc).
- Develop a tomography array for monitoring moisture movements around the roots of a single cotton plant.
- Develop automated back to base systems.
- Present future research finds to the cotton consultants.
- Write a protocol for consultants.
- Demonstrate the use of electrical imaging at field days.

9. **List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)**

B.F.J. Kelly and Acworth, R.I. (2004) "Electrical Imaging of Deep Drainage", Cotton Consultants Australia Inc, AGM, Meeting, Narrabri, NSW, Australia, 18th and 19th May 2004, 6 pages.

Publication Plan:

B.F.J. Kelly and Acworth, R.I. (2006) "Cotton Growing Season Variations in Water Stored in the Soil Profile Under Irrigated Cotton, Monitored by Electrical Imaging" to be submitted to Soil Science Society of America Journal.

Acworth, R.I. and B.F.J. Kelly (2006) "Time-Lapse Electrical Imaging of Deep Drainage Under Furrow Irrigation", to be submitted to Soil Science Society of America Journal

Acworth, R.I. and B.F.J Kelly (2006) "A Comparison of Over-head versus Furrow Irrigation Deep Drainage using Electrical Imaging", to be submitted to Australian Journal of Soil Research

B.F.J. Kelly and Acworth, R.I. (2006) "Electrical Imaging of Irrigation", to be submitted to "The Australian Cotton Grower"

10. Have you developed any online resources and what is the website address?

No

11. 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 or the Australian community.

Electrical imaging has been validated as a method that can show the two dimensional movement of water through the soil profile under irrigation. Future research aims to improve the methodology so the volume of water can be quantified to depths of 10 metres, or in cubes around the roots of cotton plants.

Once we can monitor the three dimensional movement of water and salts around the base of cotton plants, then growers will be able to optimise the application of water. During drought periods and under low water allocations periods, water becomes the limiting factor in how much crop is planted and how much profit is generated. Reducing the amount of water used compared to current practices will improve a grower's capacity to maximise the return on the volume of allocated water.

Electrical imaging can also be used to validate the position of current moisture monitoring techniques. A single electrical image can show how uniform the soil profile is, and thus how representative is a sample point.

Part 4 – Final Report Executive Summary

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Electrical resistivity imaging has been validated as a technique that can show the two dimensional movement of water through the soil profile after the application of irrigation water.

Water movement can be inferred in the resistivity section by comparing resistivity images recorded before and after the application of irrigation water. As the water migrates through the soil profile the resistivity decreases (electrical conductivity increases). The movement of the water through the vadose zone has been shown to be via preferential paths, possibly related to cracks or sandier zones within the profile. Time-lapse sequences of deep drainage show that irrigation water reaches depths of 5 to 10 meters within the first few hours after watering.

Electrical images comparing the moisture content throughout the soil profile to 10 metres in October and then in February show that a substantial quantity of water is added to the profile to a depth of 6 metres throughout the growing season. Resistivity images recorded just prior to irrigation show that the roots of the cotton plants have removed significant quantities of water immediately surrounding the roots, but have little influence on the moistures content of the soil profile immediately below the root zone. The drier soil around the root zone shows up as semi-circles of higher resistivity in the resistivity images.

At some locations, after watering there is an increase in the resistivity of the soil profile between 1 to 1.5 metres. This is interpreted as fresher irrigation water flushing out more saline pore water.

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CRDC grant number UTS5

Introduction

The aim of this research project was to show that electrical imaging could be used to monitor deep-drainage under irrigated cotton. Field trials were undertaken at 5 locations in order to look at the effects of soil types and irrigation practices. The changes in the moisture content of the soil profile were also monitored throughout the season.

Equipment Used

All measurements were recorded using an ABEM Terrameter SAS 400 connected to a multi-electrode resistivity cable. The current and potential electrodes were arranged in the Wenner configuration (C1, P1, P2, C2) with the minimum spacing between the electrodes being varied from 1 to 2.5 metres. The setup of the resistivity imaging system in the field is shown in Figure 1 and a close-up of an electrode is given in Figure 2.

Figure 1: ABEM Terrameter SAS 4000. The multi-electrode resistivity imaging cable connected to the steel electrodes extends away from the meter through the centre of the background. (Image courtesy of Guy Roth and Anthony Nadelko)

Figure 2: A close-up of the multi-electrode resistivity cable connected to a steel electrode.

Electrical Properties of the Soil

The electrical conductivity of soil is primarily a function of the clay content and type, porosity, the salinity of the pore water and the degree of saturation. There are also other factors that can influence the electrical conductivity of the soil but these are not significant in the context of measuring deep drainage. For any given cotton field the only variable that will change significantly during a watering cycle is the degree of saturation. As the soil becomes saturated the electrical resistivity of the soil will decrease thus increasing its electrical conductivity.

How an Electrical Image is Recorded

An electrical resistivity image is built up by taking a series of measurements along a furrow. For any one measurement four electrodes are used (Figure 3). The electrodes are pushed into the first few centimetres of soil. An electrical current is then passed through two outer electrodes and the potential difference is measured using the inner electrodes.

Given the known input current and the measured potential then the resistivity (reciprocal of conductivity) of the soil is determined. For a given soil the resistivity is proportional to the water content; low resistivity indicates saturated soil, high resistivity indicates dry soil.

Electrical imaging uses a cable that connects a series of 32 electrodes. A computer controlled resistivity meter then automatically switches between electrodes on the cable. By sequentially selecting current and potential electrodes that are further apart the depth of investigation is increased (Figure 4). The bulk of the signal response is from an effective depth of half the electrode spacing.

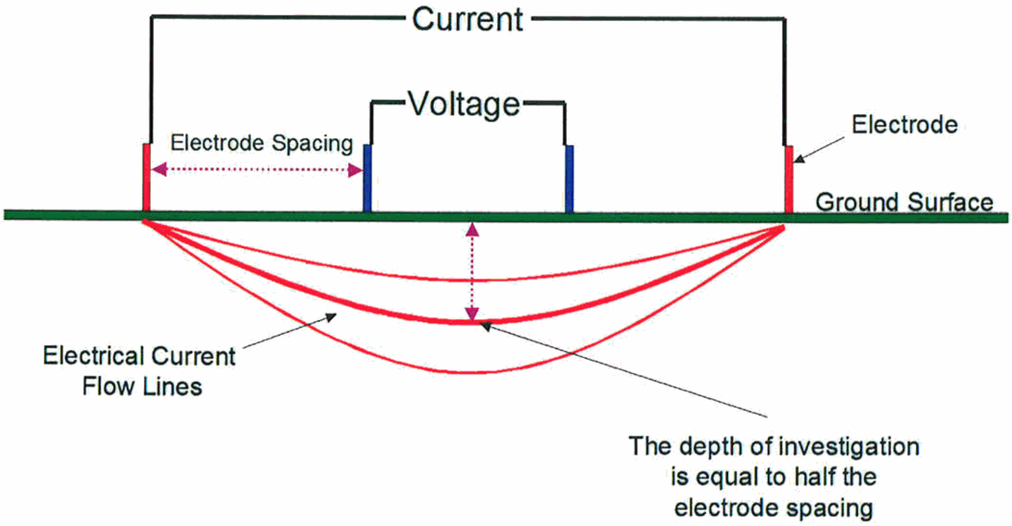

Figure 3: Geometry of the electrodes for a single resistivity measurement of the earth.

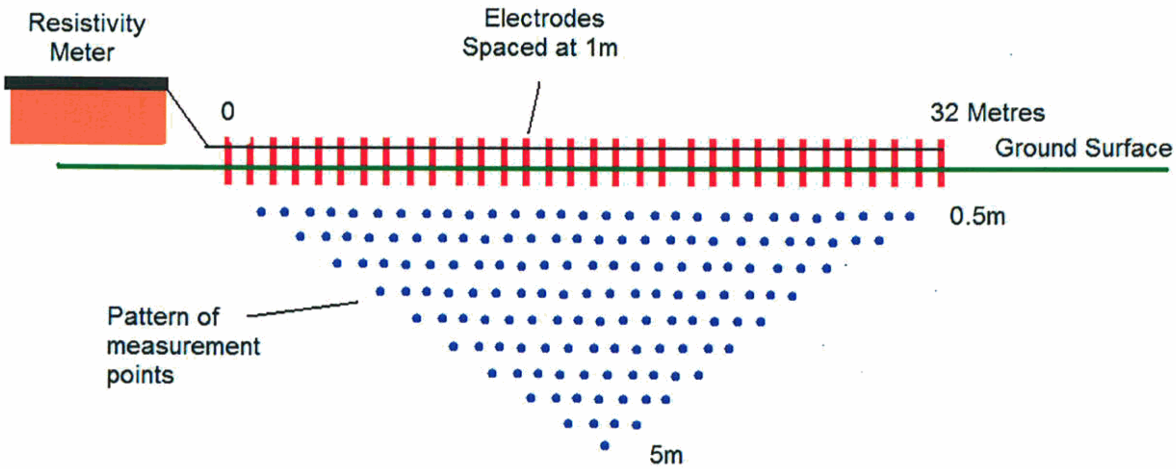

Figure 4: Multi-electrode electrical imaging array.

Modelling Apparent Resistivity Measurements

To obtain the true resistivity from the field measured apparent resistivity the field data were modelled using RES2DINV version 3.54 (www.geoelectrical.com). Details of the inversion process are described in the manual available from the web site. Briefly, the true resistivity model (bottom section in Figure 5) is adjusted automatically by the software in order to minimise the difference between the apparent resistivity field data (top section Figure 3) and the modelled apparent resistivity data (middle image Figure 3).

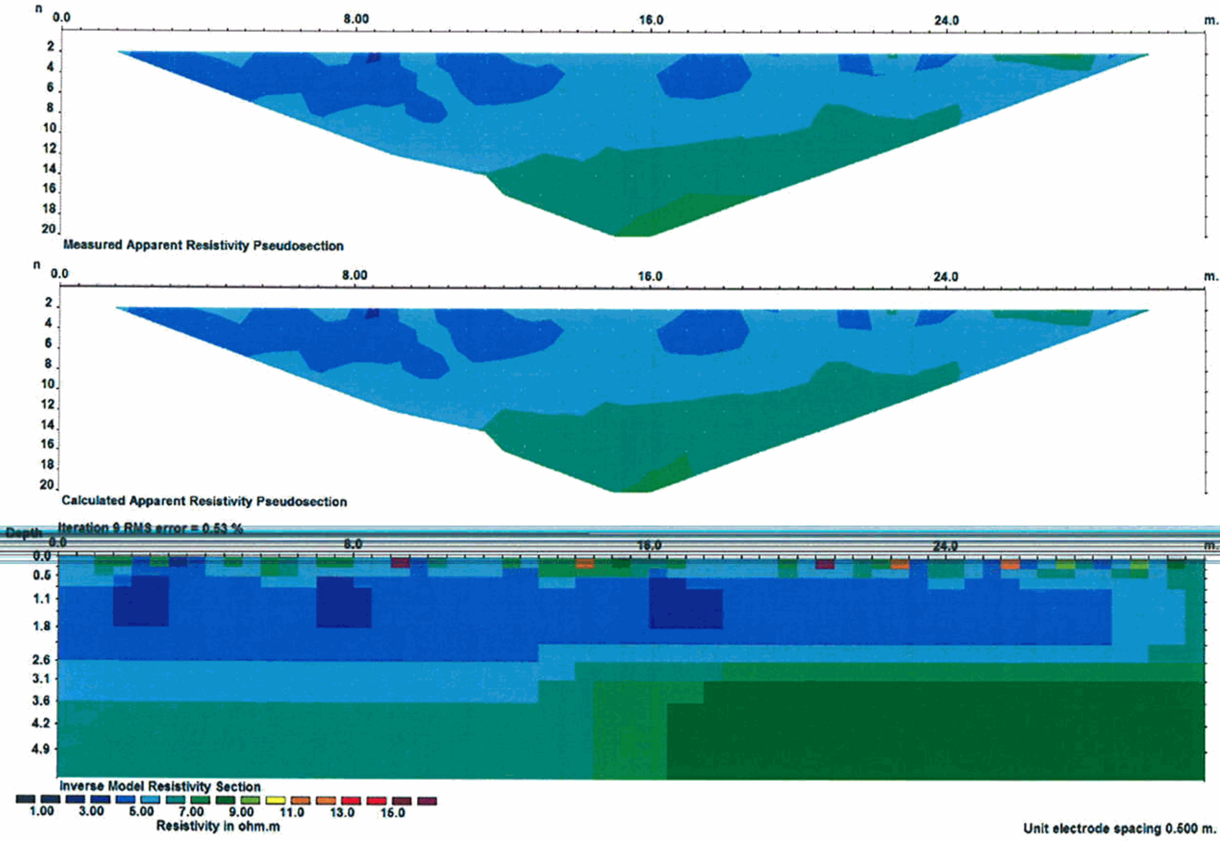

Figure 5: The top section is the apparent resistivity measured in the field, the middle section is the apparent resistivity model generated from the true resistivity model shown in the bottom section.

All resistivity imaging sections collected during the course of this research were taken along the furrows. With the exception of the survey at Wee Waa site 1, the surveys were started adjacent to the head channel. The positioning of the survey undertaken at Wee Waa site 1 is presented in Figure 5. The electrodes were placed midway between the crest and the trough of the furrows. At all sites watering was only done in every other furrow (alternate irrigation). However, in the field it was observed under furrow irrigation that the water would break through into the adjacent furrow with 10 minutes, and that all furrows eventually had water flowing.

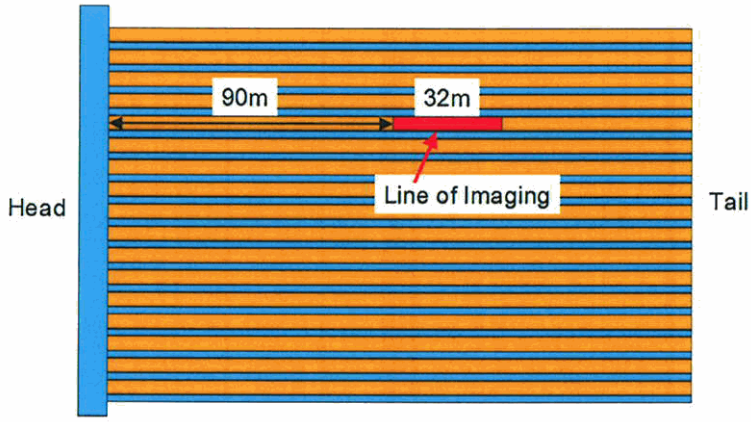

Figure 6: Overhead view of the irrigated field, showing the position of the resistivity imaging undertaken at Wee Waa site 1. The blue lines indicate the trough and the brown lines the crest of the furrows.

Wee Waa Site 1

The measurements undertaken at Wee Waa site 1 formed the basis for the first time-lapse example of measuring deep-drainage using resistivity imaging. The complete discussion on how electrical imaging was done and the results of the measurement sequence are in the attached paper:

B.F.J. Kelly and Acworth, R.I. (2004) "Electrical Imaging of Deep Drainage", Cotton Consultants Australia Inc, AGM Meeting, Narrabri, NSW, Australia, 18th and 19th May 2004, 6 pages.

A different presentation of the results, from those given in Kelly and Acworth (2004) is shown in Figure 7. The bottom section compares the electrical resistivity of the earth before and 29 hours after irrigation. The image shows the percentage of change in electrical resistivity, compared with the starting conditions. At a depth of 2.5 to 3 metres the resistivity decreased by as much as 30%. This decrease would be consistent with the degree of saturation increasing. In the interval 0 to 0.5 meters the resistivity decreased by 70%. This equates to the sediments becoming saturated.

A C-probe was located in the middle of the imaging line. Details on the C-Probe measurement are presented in the attached paper.

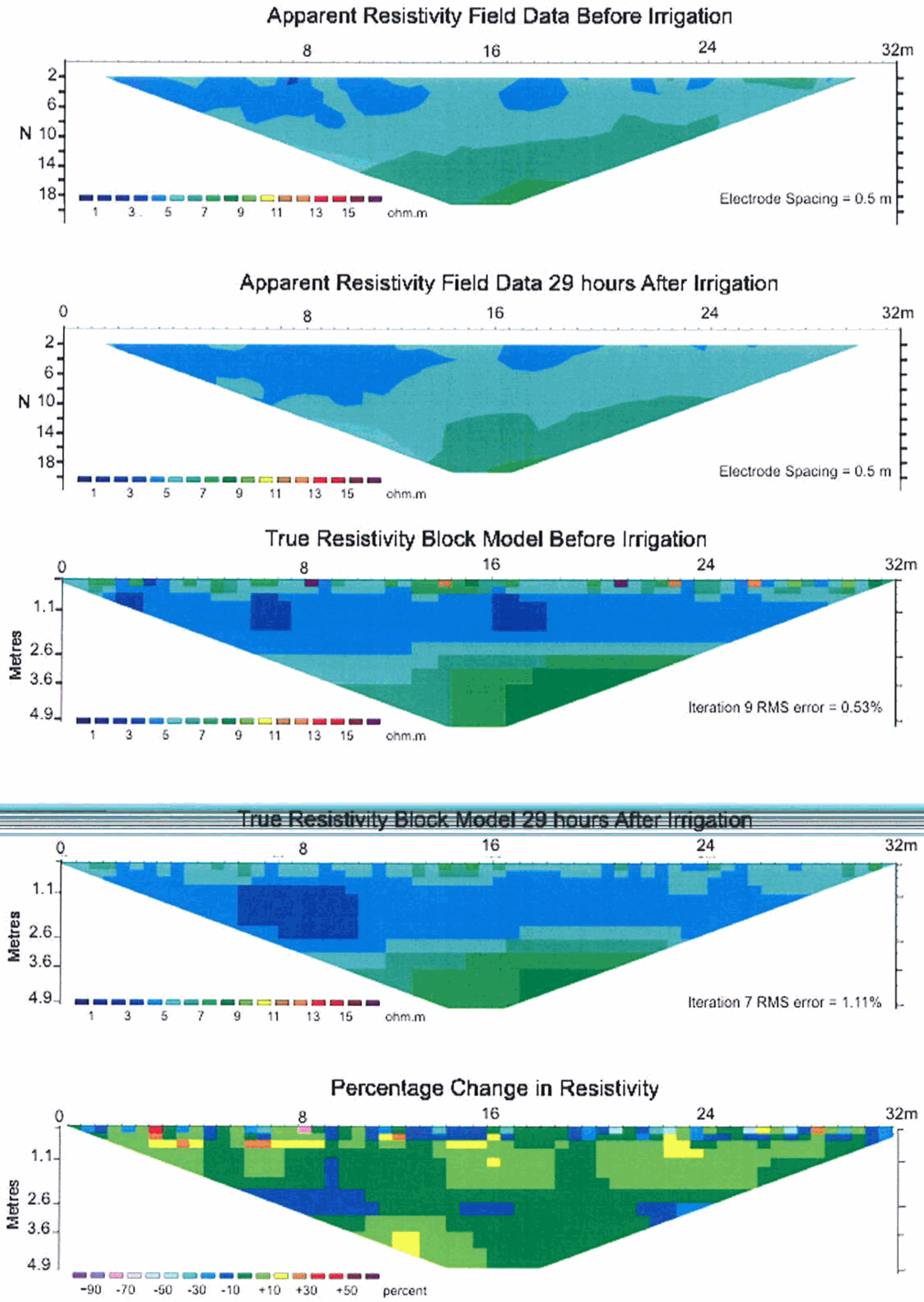

Figure 7: Wee Waa site 1, resistivity sections showing the percentage change in the electrical resistivity 29 hours after irrigation. The head ditch is to the left of the section.

Wee Waa Site 2 – Furrow Irrigation

This site is on the same property as Wee Waa site 1, but on a different field. Two parallel, but offset, 2.5m cables were used, giving an effective electrode spacing of 1.25m. Electrode 1 of cable 1 was positioned at the base of the head ditch, and the cotton plants started at electrode 6 on cable 1. The resistivity images were recorded at this location on the 26th October 2004 and from the 7th to 9th of February 2005. A C-probe was located at 49.75 metres along the section. The irrigation water had an electrical conductivity of 507 μS/cm at 25° C.

Changes in the degree of saturation after irrigation are shown in Figure 8. Large decreases in resistivity (as much as 50%) can be seen in the upper 1 metre of the section. Over the majority of the section, however, there is very little change. At this site the deep drainage is limited to 2 small zones. The first is seen at approximately 6 metres depth and runs from 15 to 35 metres, the other starts at the surface at X = 50 metres and extends downward to a depth of 3 metres at X=70 metres.

The contrast between this site, and Wee Waa site 1, highlights the problem of quantifying deep drainage. Deep drainage is not a uniform front of water moving through the soil profile. These images show that the bulk of the drainage is concentrated in small zones, most likely the large cracks that are known to occur throughout the sediment profiles.

Seasonal variation of the water stored in the soil profile and the repeatability of electrical resistivity imaging were examined by comparing measurements taken 26th October 2004 and 7th February 2005 (Figure 9). Between the two sets of measurements the electrodes were completely removed from the ground, the only reference point was a survey location marker at the head of the furrow. Comparing the October measurements to the February measurements it can be seen that the overall pattern is very similar, consisting of a highly electrically conductive layer (blue/green), overlying a slightly more resistive layer (red/purple). From nearby excavations it was observed that the upper 5 metres consists of grey cracking clay (vertosol) overlying a clayey-silty sand.

The upper 50cm of the February section shows numerous dry zones around the roots of the established cotton plants which have dried out the upper soil profile. However, there is very little change in the first 6 meters in the upper 50cm between the two sections (left of section). This is the interval with no plants between the head channel and the established crop. These images clearly show that electrical imaging can be used for monitoring moisture content around the roots of cotton plants.

In the 1 to 5 metre interval another major difference between the October and February sections can be observed. In this interval there are large zones of decreased resistivity (dark blue). This would be consistent with increased stored water in the soil profile. There is no indication of changes in resistivity below 6 metres, which would suggest that water which reaches the sandy sediments drains below the measured interval, leaving no discernable changes in moisture content.

A 4 meter interval below the root zones with increased water content represents a large volume of water and has significant water management implications that require further investigation. However, until the resistivity values have been calibrated with respect to water content the exact volume of water represented by the change in the October and February resistivity images cannot be quantified.

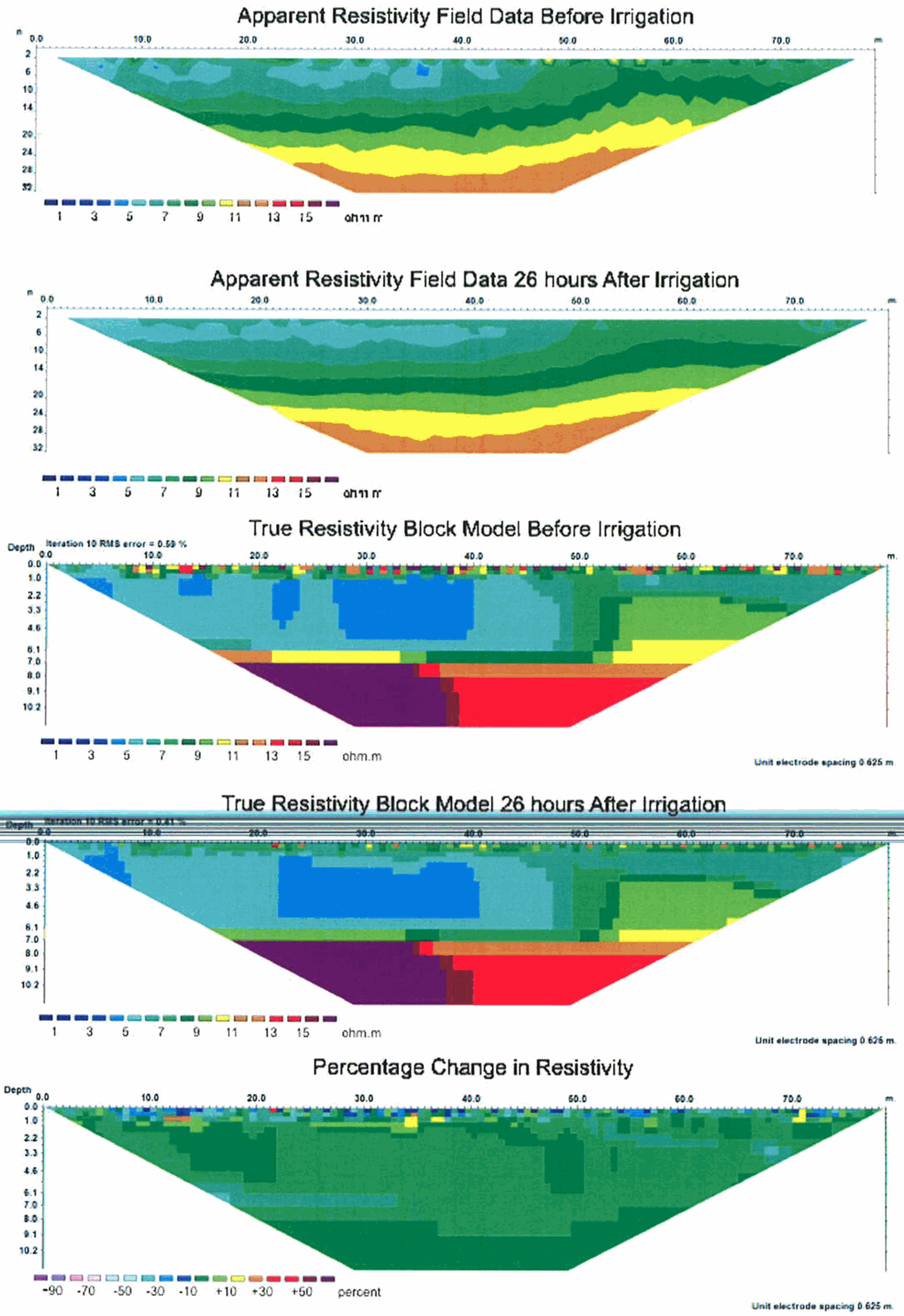

Figure 8: Wee Waa site 2, resistivity sections showing the percentage change in the electrical resistivity 29 hours after irrigation. The head ditch is to the left of the section.

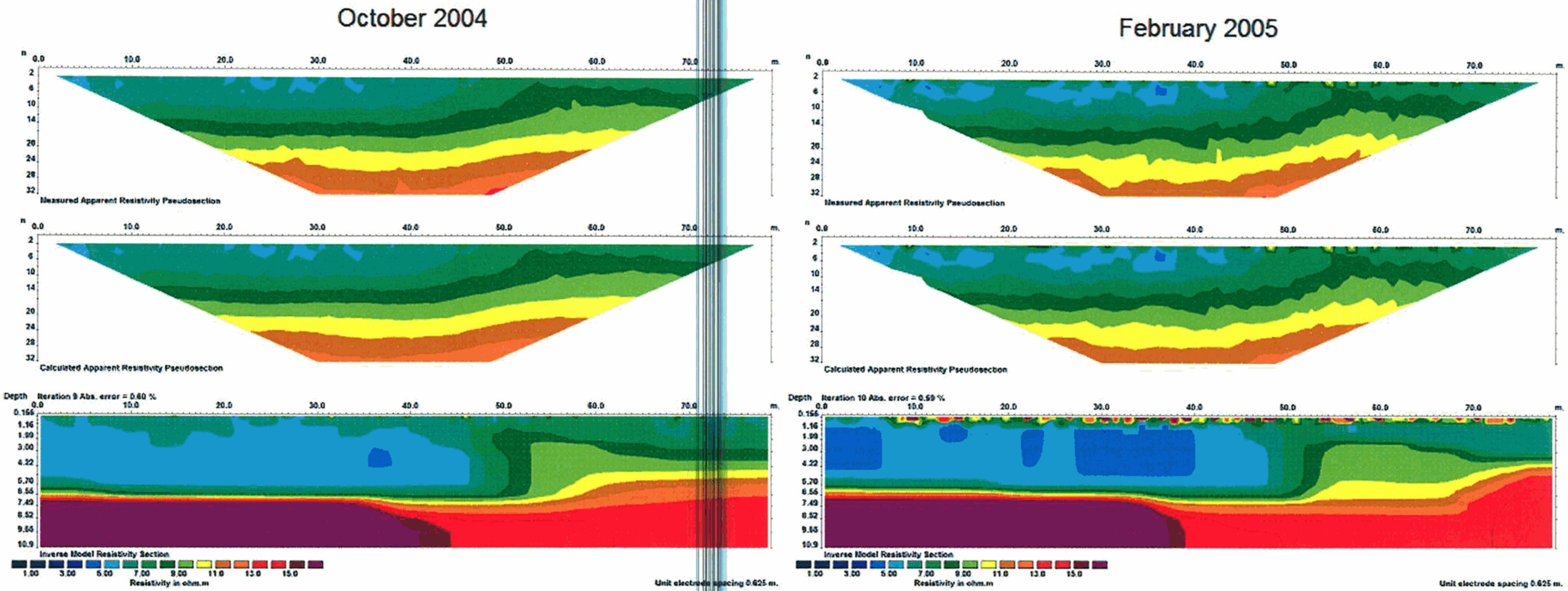

Figure 9: Wee Waa site 2 electrical imaging results repeated 3.5 months apart on the same furrow. Both sets of measurements were recorded just before irrigation. The head ditch is to the left of the section.

Wee Waa Site 3 – Overhead irrigation

This survey was undertaken on a property approximately 5km to the north of Wee Waa site 1, with very similar soils to those at Wee Waa sites 1 and 2. This location was selected to contrast drainage from overhead irrigation with furrow irrigation.

The images displayed in Figure 10 were recorded from the 15th to 17th of February 2005. The irrigation system was set up to apply 48mm of water, supplementing light rainfall on the evening between the background survey and the irrigation runs. The irrigation water had an electrical conductivity of 485 μS/cm at 25° C.

Two adjacent furrows were measured, one of which was watered directly and the adjacent furrow which was watered by leakage from the irrigated furrows. Electrodes were spaced 1 metre apart. Surveys in the irrigated furrow were recorded 30 minutes, 3.5 hours and 17.5 hours after the start of irrigation. In the adjacent furrow electrical images were recorded 1, 4 and 18 hours after irrigation. Only the pre irrigation and the final electrical images are displayed in this report.

For both survey lines there is no significant change in resistivity below 1.5 metres across the width of the sections. This suggests that no deep drainage is occurring. Limited deep drainage is indicated in the furrow adjacent to the watered furrow. There is one finger 20 metres along the survey line, where the resistivity decreased by greater than 10%. This could be water moving through a vertical crack in the soil profile. Both furrows displayed decreases in resistivity in the upper metre of the resistivity images. The maximum decrease in resistivity was 70% in the watered furrow and 60% in the adjacent furrow. This validates the procedure of watering alternate furrows. Interestingly, there were more patches in the watered line that didn't show decreases in resistivity, than in the adjacent furrow. As with other irrigated sites, there is an increase in resistivity at a depth of approximately 1 metre. It is more pronounced in these images because of the higher resolution of the survey. As mentioned above, this increase in resistivity is possibly related to fresh irrigation water diluting the saline pore water at depth. This is supported by the fact that the zone is more extended under the irrigated furrow, compared to the adjacent furrow.

Charlesworth, P (2000) "Irrigation Insights Number One: Soil Water Monitoring", Published by Land and Water Australia, 96 pages.

Dalton, P. (2000) "WATER TIGHT: Whole Farm Water Use Efficiency – Determining Your Own Water Security", Proceedings of the 10th Australian Cotton Conference, ACGRA, Brisbane. Pages 395-413.

Griffiths, D.H. and Turnbull, J (1985) "A Multi-Electrode Array for Resistivity Surveying", First Break, V. 3, N. 7, pages 16-20.

Kelly, B.F.J., (1994) "Electrical Properties of Sediments and the Geophysical Detection of Ground Water Contamination". Ph.D. Thesis, Department of Water Engineering, School of Civil Engineering, University of New South Wales, Australia, 146 pages.

Moss, J., Gordon, I. and Zischke, R. (2001) "Best Management Practices to Minimise Below Rott Zone Impacts of Irrigated Cotton", Final Report to the Murray-Darling Basin Commission (Project 16064), Department of Natural Resources and Mines, Queensland.

Raine, S.R. and Foley, J.P. (2001). "Application Systems for Cotton Irrigation – Are You Asking the Right Questions and Getting the Answers Right", In "Growing Opportunities", National Conf. Irrigation Association Australia. 11-12 July, Toowoomba. 11 pages.

Silburn, M and Montgomery, J. (2001) "Deep Drainage Under Irrigated Cotton in Australia – A Review", Cotton Consultants Associates Meeting, 21-22 June, Dalby.

Zilkche, R. and Gordon, I. (2000) "Addressing the Issues of Root Zone Salinity and Deep Drainage under Irrigated Cotton", Proceedings of the 10th Australian Cotton Conference, ACGRA, Brisbane.

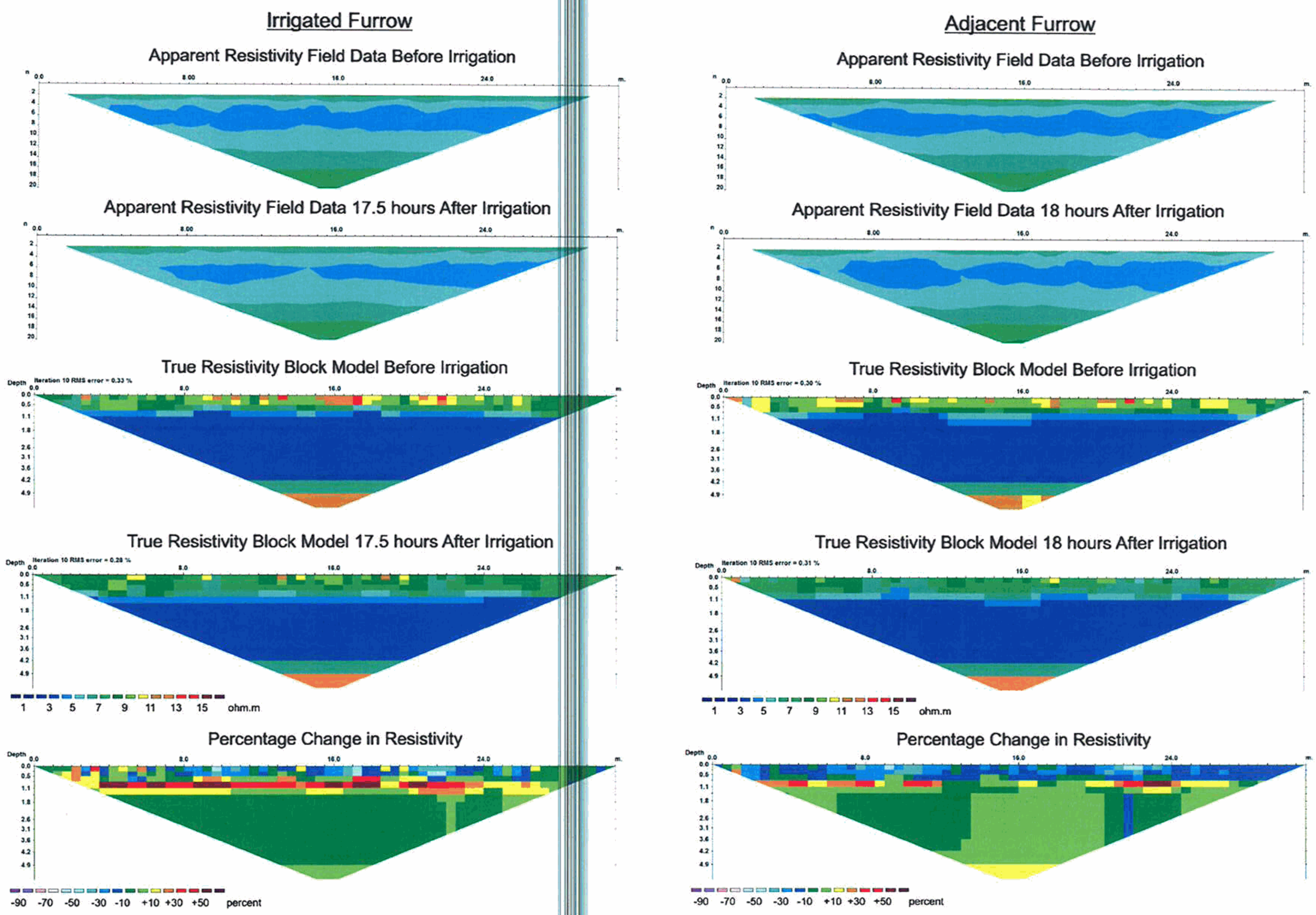

Figure 10: Electrical resistivity imaging of soil moisture changes before and after overhead linear irrigation. Sections on the left are from the watered furrow, images on the right are from the furrow adjacent to the watering lines.

Goondiwindi – Furrow Irrigation

This survey line was chosen so that resistivity images could be compared to deep drainage barrel lysimeter readings being undertaken by Des McGarry and colleagues.

Images shown here were recorded on the 9th and 11th February 2005. Two parallel, but offset, 2.5m cables were used, giving an effective electrode spacing of 1.25m. Electrode 1 of cable 1 was positioned at the base of the head ditch, and the cotton plants started at electrode 7 on cable 1. The barrel lysimeter was located at electrode 15 of cable 2 (36.25 m along the resistivity section). The electrodes were placed in the middle of the furrow that wasn't watered. But the water from the adjacent watered furrows broke through the chest between the furrows within ten minutes of the adjacent furrows being watered, and all furrows eventually had flowing water. The irrigation water had an electrical conductivity of 315 μS/cm at 25° C.

The percentage change in the resistivity images just 8 hours after the start of the watering is shown in Figure 11. Between the surface distances 20 and 30 metres and 55 to 65 meters at depths between 3 to 10 metres. In these two zones there has been a decrease in resistivity by as much as 30%. This is indicative of deep drainage. The zone of increased resistance from 34 to 36 metres cannot be explained at the moment, but could be due to equivalence in the resistivity modelling and the lack of uniqueness in inversions at depth. Given the large areas of decreased resistivity at depth at this location, it is reasonable to infer that a substantial quantity of water is being lost to deep drainage at this location.

In the upper metre the resistivity decreased by 50% as the sediments became saturated. Similar to other locations, there is a zone of increased resistivity from 1 to 1.5 metres.

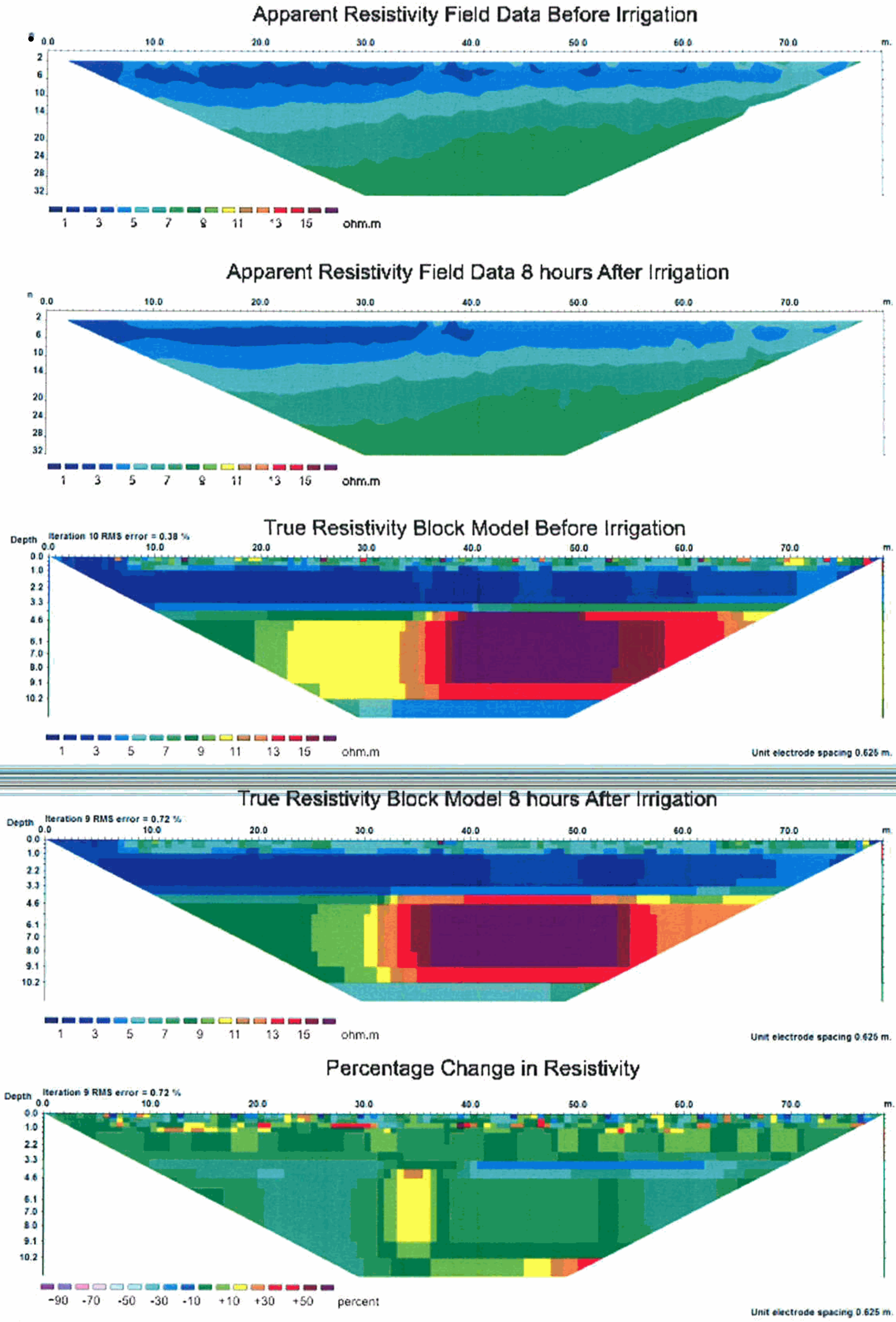

Figure 11: Goondiwindi, resistivity sections showing the percentage change in the electrical resistivity 8 hours after irrigation. The head ditch is to the left of the section.

Narromine – Furrow Irrigation

This location was selected to contrast deep drainage under soils of the Macquarie catchment with those of the Namoi and Border Rivers catchments. Also, the soil moisture content at this location is measured using soil neutron probes while at the other locations the growers use C-probes to schedule watering.

Resistivity images were recorded on the 28th of October 2004 and from the 12th to 14th of February 2005. Two parallel, but offset, 2.5m cables were used, giving an effective electrode spacing of 1.25m. Electrode 1 of cable 1 was positioned at the base of the head ditch, and the cotton plants started at electrode 5 on cable 1. The irrigation water had an electrical conductivity of 850 μS/cm at 25° C.

Seasonal changes in the soil moisture content profile at the property in the Narromine district are shown in Figure 12. The seasonal variations are significantly different from those observed in the Wee Waa district. Through most of the soil profile there is a 50% decrease is the measured resistivity. Over 8 meters of the soil profile displays an increase in moisture content between the beginning and the middle of the growing season. This represents a significant volume of water that is draining beyond the root zone throughout the season.

However, under an individual irrigation run there was only limited change in the electrical properties at depth (Figure 13), suggesting that there was no discernable change in moisture content at depth was the profile is wet to field capacity. From 0 to 1 metres the majority of the resistivity percentage change section shows a decrease in resistivity from 10 to 70%, indicating that the sediments were becoming saturated. Similar to other sites, from 1 to 1.5 meters there are zones where the resistivity increases by 10 to 50%.

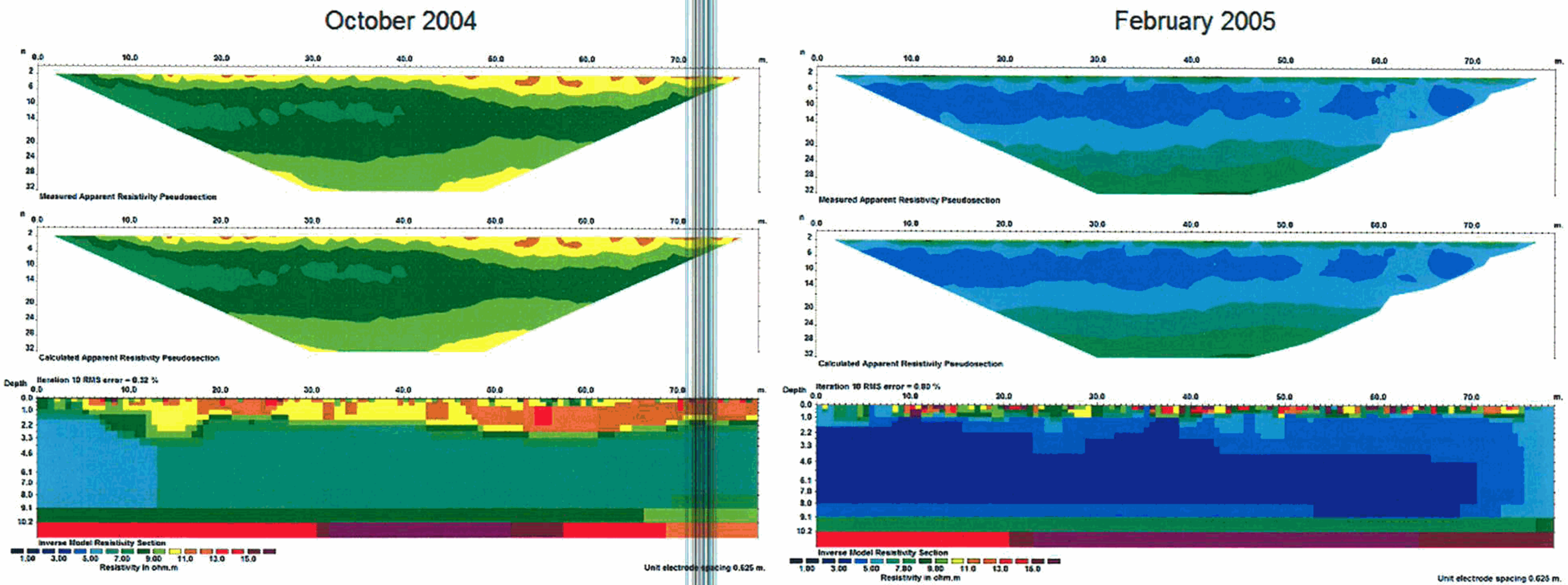

Figure 12: Electrical imaging results repeated 3.5 months apart on the same furrow, Narromine district. These measurements were recorded before irrigation. The head ditch is to the left of the section.

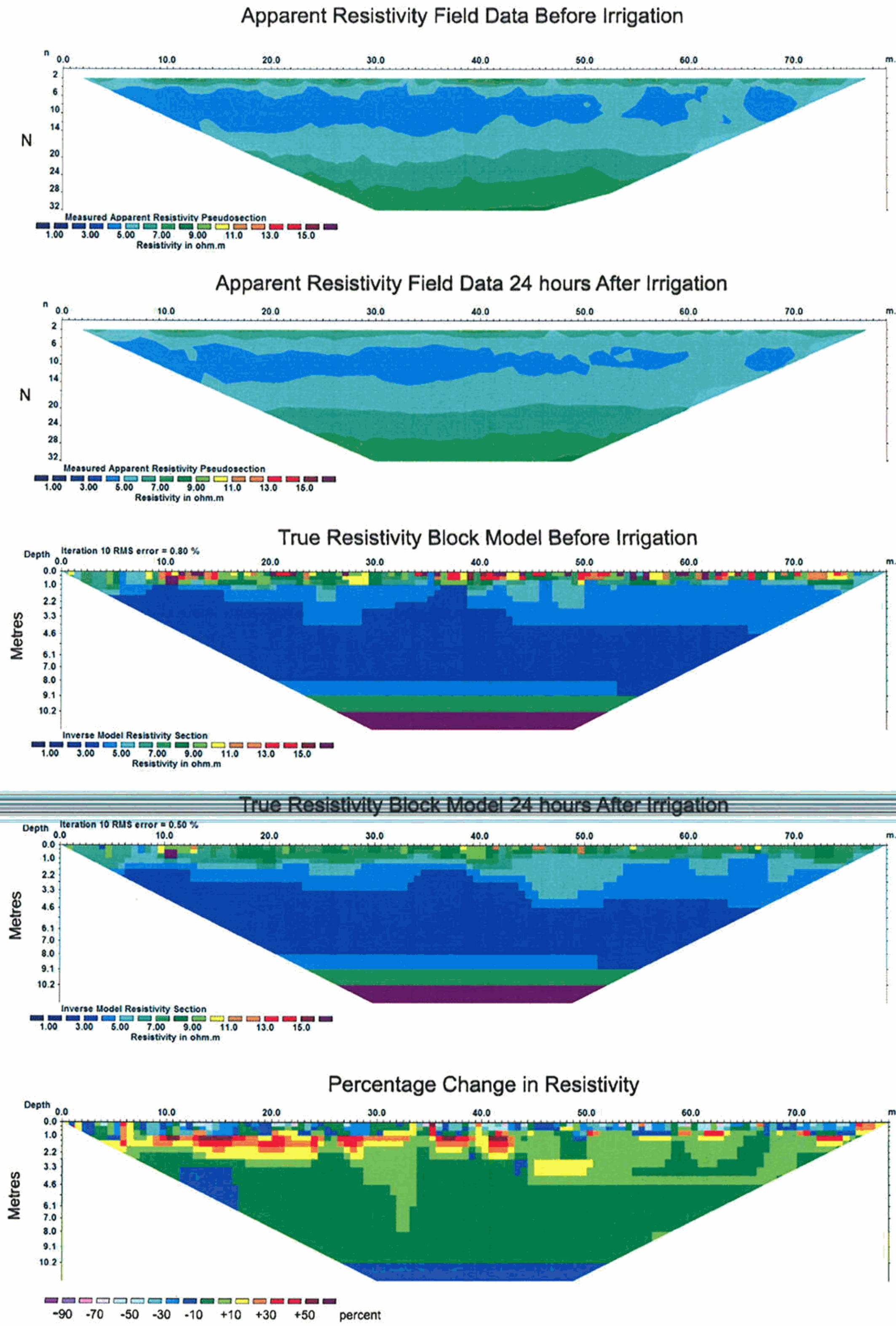

Figure 13: Narromine, percentage change in electrical resistivity after irrigation. The head ditch is to the left of the section.

ACRI – Lysimeter Furrow

A background survey was undertaken at the Australian Cotton Research Institute in August 2005. This will be used to examine changes along the monitored irrigation line as the deep drainage research continues. The survey also allows for the comparison of this site with other regions surveyed in this and future research. It was thought that the electrode spacing used (1.25 metres) would be sufficient to delineate the lysimeter trays. However, it is not possible to delineate fine features in this survey due to the electrode spacing used and the level of noise in the data collected. The electrical images show that there is a gradual change in electrical properties along the furrow. The lowest resistivity values were recorded at the head end of the field, as were the thickest sequence of clay dominated sediments. The base sediments at this site are considerably more resistive than the base sediments recorded at Wee Waa site 1, which is located to the north-west of ACRI.

Future surveys over the lysimeter need to be done at a finer spacing, at least 0.5 meters, if they are to delineate the lysimeter trays and any disturbance caused by the installation of the lysimeter or barrel lysimeters.

Further work is also needed to reference the electrical resistivity section against soil logs previously collected along the instrumented field.

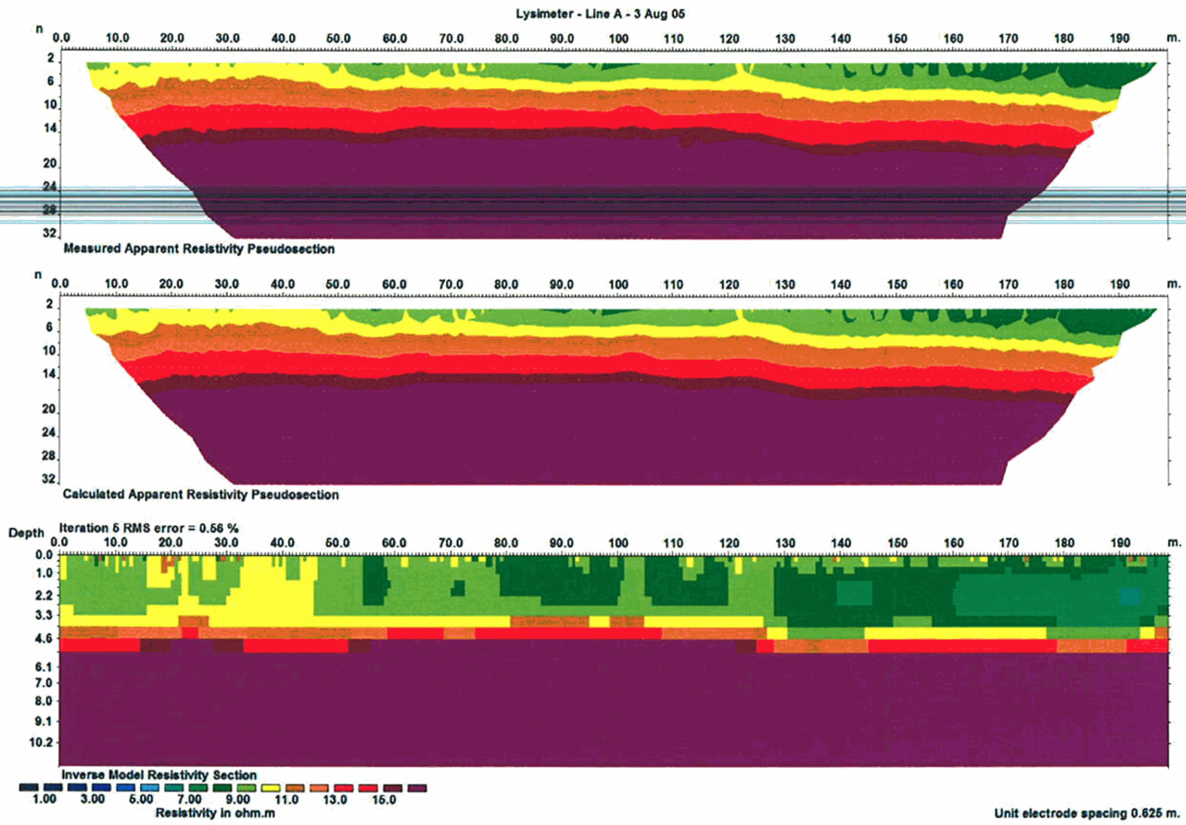

Figure 14: Resistivity imaging along the deep drainage instrumented furrow at ACRI. The tail end of the field is to the left, the head ditch to the right.

Conclusions

Electrical imaging has been used successfully to monitor water movement through the soil profile under both furrow and overhead irrigation. Electrical imaging shows that deep drainage occurs within an hour of irrigation and that water continues to move down several meters over the 24 hour interval of monitoring.

Another use of electrical imaging validated in this research project was monitoring the seasonal changes in the water content stored within the vertosols. The water content of the soils below the root zone increases throughout the season. At the case study sites this represented a 4 meter thick interval that had electrical resistivity values decrease by 10 to 20%. This is a substantial volume of water that is not accessible to the cotton plants. The management of this water needs further investigation.

The 1 to 2.5 metres spacing between electrodes used in this study is adequate for showing the large scale movement of water beneath the root zone. However, for monitoring detailed moisture content around the roots of a cotton plant the electrical imaging needs to be undertaken at a higher resolution than was done in this study.

Further work needs to be undertaken to ascertain the cause of the zone of increased resistivity in the 1 to 1.5 metre interval seen in a number of the resistivity block models. It is suggested that this may be due to fresh irrigation water flushing out saline water, where the salt has been concentrated at the base of the root system.

To be able to quantify the volume of water seen in the sections, the electrical properties of the soils need to be calibrated in the laboratory. There is reasonable uniformity in the soils so once a soil has been calibrated it should be possible to apply the relationship over a large area.

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Electrical Imaging of Deep Drainage

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Introduction

Electrical imaging has been used successfully for monitoring water quality and movement below the ground surface on a large scale for almost 20 years (Griffiths and Turnbull 1985; Acworth et al 1994; Acworth and Jankowski 1997; Acworth 1999). The methodology, however, has not been applied routinely to irrigation monitoring. Presented in this paper are the results of a field trial using electrical (resistivity) imaging for monitoring deep drainage during furrow irrigation. The electrical images show that deep drainage is significant in the grey clays (vertosols) of the Lower Namoi Valley. The results also validate that electrical imaging can provide spatial information of deep drainage. At the field trial site, deep drainage occurred in a localised zone. This highlights the problem of assuming that a single point measurement can be representative of the entire field.

Deep Drainage

Deep drainage is the water that migrates beyond the roots of the cotton plant. Over the last decade there has been a change from the belief that there is no or limited deep drainage in the grey clays common in the cotton growing districts of Australia, to an acceptance that deep drainage may be significant (Dalton 2000; Zilkche and Gordon 2000; Moss et al 2001; Silburn and Montgomery 2001; Raine and Foley 2001). These studies indicate that up to 2ML/ha/season of water may be lost to deep drainage. Thus deep drainage is a potential area to target to improve water use efficiency under furrow irrigation.

Point Measurement of Deep Drainage

There are now numerous point measurement techniques available for monitoring soil moisture and detecting deep drainage. These include various capacitance probes (EnviroSCAN, Diviner 2000 and C Probe), time domain reflectometry (Tektronix and Campbell Scientific TDR100), neutron moisture meters, or wetting front detection systems such as FullStop, and Lysimeters (Charlesworth, 2000).

With all of these methods the cost of installing a probe is expensive, or installation is difficult. Further more, these methods disturb the soil that is to be measured. These factors have typically resulted in only a limited number of measurement points being installed on a field.

Typically two or three point measurements are made in a field that could be 500 to 1000 metres long. The assumption that a limited number of measurements are representative of the whole field has not been examined in detail. Without an extensive network of measurement points, these systems cannot give a complete spatial understanding of deep drainage. From a limited number of point measurements, it is unlikely that the watering of a field is optimised for all furrows.

Electrical Properties of the Soil

The electrical conductivity of soil is primarily a function of the clay content and type, the salinity of the pore water and the degree of saturation. There are also other factors that can influence the electrical conductivity of the soil and these are reviewed by Kelly (1994). For any given cotton field the only variable that will change significantly during a watering cycle is the degree of saturation. As the soil becomes saturated the electrical resistivity of the soil will decrease; increasing electrical conductivity

How an Electrical Image is Recorded

An electrical resistivity image is built up by taking a series of measurements along a furrow. For any one measurement four electrodes are used (see Figure 1). The electrodes are pushed into the first few centimetres of soil. An electrical current is then passed through two outer electrodes and the potential difference is measured using the inner electrodes. Given the known input current and the measured potential then the resistivity (reciprocal of conductivity) of the soil is determined. For a given soil the resistivity is proportional to the water content; low resistivity indicates saturated soil, high resistivity indicates dry soil.

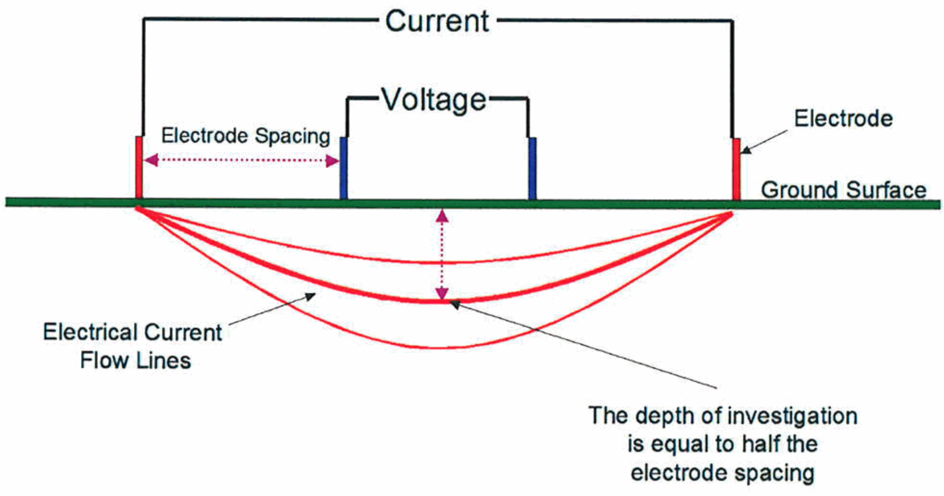

Figure 1: Geometry of the electrodes for a single resistivity measurement of the earth.

Electrical imaging uses a cable that connects a series of 32 electrodes. A computer controlled resistivity meter then automatically switches between electrodes on the cable. By sequentially selecting current and potential electrodes that are further apart the depth of investigation is increased (see Figure 2). For this trial the cable was laid out starting 90m from the head end of the field. This was done so that the electrical imaging array would be centred on a previously installed C-Probe. The electrodes were spaced at 1m intervals, allowing for a 32m long cross-section of the furrow to be imaged to a depth of approximately 5 metres.

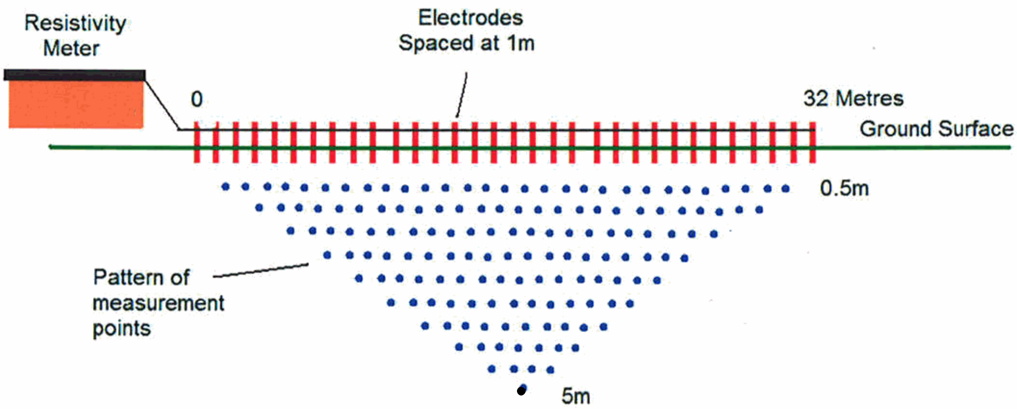

Figure 2: Multi-electrode electrical imaging array.

Results

An electrical image of the furrow just prior to the start of irrigating is presented in Figure 3. Dry soil zones, indicated by the orange/red semi-circles at shallow depths, highlight the position of some of the cotton plants. The results 5 hours after the start of irrigation are shown in Figure 4. The wetting of the upper soil is indicted by the diminishing size of the semi-circles around the roots of the plants (more of the shallow portion of the image is green). Also at a depth of 1-2 meters the saturated zone now extends across most of the section. Drainage of the water can also be seen at around 4 meters. In Figure 5, 24 hours after the start of irrigation, the movement of water beyond 5 meters can clearly be seen. Surprisingly, at the shallow depth there are still impressions of the cotton plant root zone.

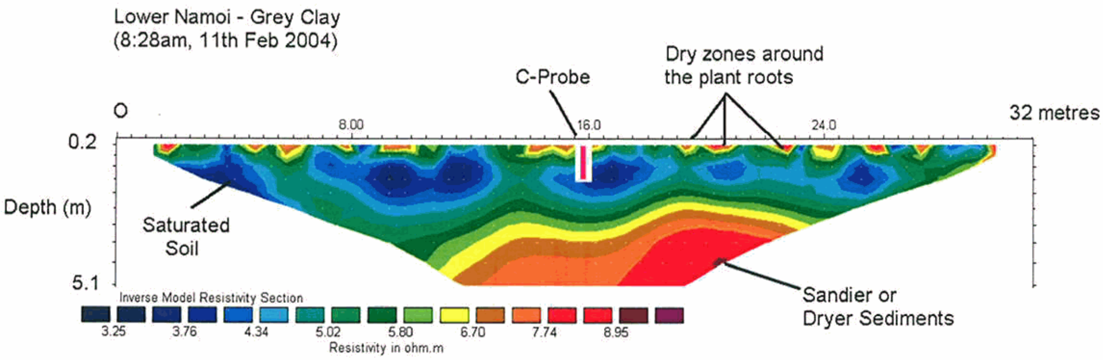

Figure 3: Electrical image just before the start of irrigation. The tail end of the field is on the right-hand side of the image.

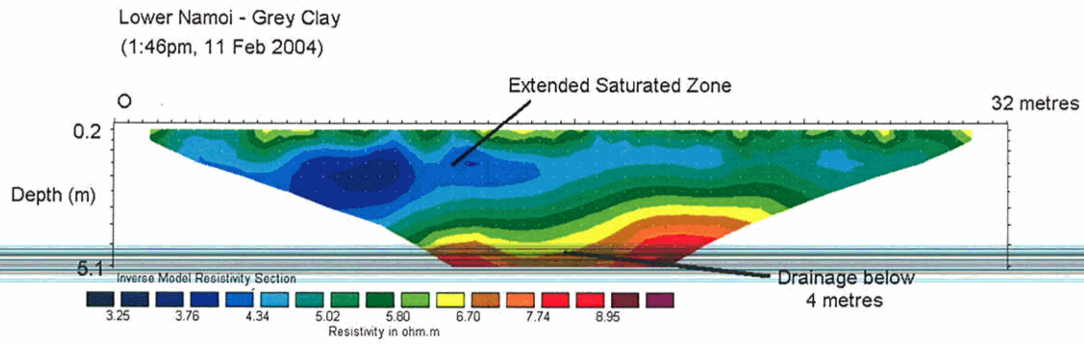

Figure 4: Electrical image approximately 5 hours after the irrigation started.

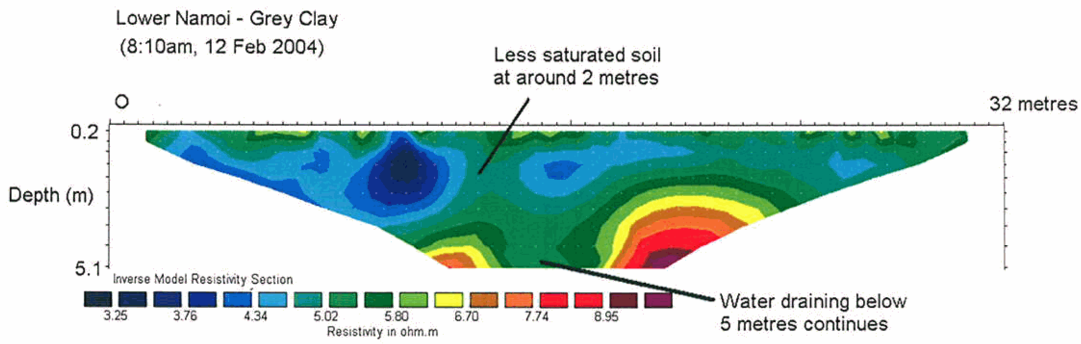

Figure 5: Electrical image approximately 24 hours after the irrigation started.

Future Research

The application of electrical imaging for monitoring furrow irrigation is in its infancy. The authors intend to extend this research with additional field trials in order to:

- examine deep drainage differences at the head and tail ends of the field under different watering schemes,
- monitor any changes in deep drainage over a growing season,
- examine variations in deep drainage with soil types,
- calibrate the resistivity images with lysimeters.

Conclusions

Electrical imaging has been shown to be able to monitor in two dimensions deep drainage under furrow irrigated cotton. The electrical imaging results show that electromagnetic and resistivity imaging surveys should be undertaken prior to selecting capacitance or neutron probe measurement points in order to place the probes in regions that are representative of the majority of the field.

Electrical imaging shows that deep drainage occurs within the first hour of irrigation, and continues at a significant rate 24 hours after irrigation. In the grey clays of the Namoi Valley the drainage occurs in zones several meters wide and the irrigation water is draining beyond 5 meters. Electrically imaging a field also gives information on the uniformity of the soil/sediment at depth along the furrow, detects major zones of infiltration associated with cracking clays or paleochannels, and differentiates between clayey and sandy soils in areas of uniform pore water salinity.

By combining the information from the electrical image section with point soil moisture measurements and electromagnetic surveys it will be possible to optimise the timing of a watering cycle for a given field. Once a field has been calibrated then the watering regime for that field should remain similar for each watering cycle.

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