DWLBC REPORT

Land Use impact on water quality and quantity in the Lower South East, South Australia

2006/25

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Land-use impact on water quality and quantity in the Lower South East, South Australia

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Resource Allocation Division
Department of Water, Land and Biodiversity Conservation

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the state. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources, it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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EXECUTIVE SUMMARY

Large-scale, essentially blue gum forestry plantations are perceived to have the potential to impact on groundwater levels and drain flows, which could potentially deprive wetlands of water. This study investigated sites in the Hundred of Nangwarry and the Wattle Range area to determine the potential impacts of land-use change, including the risk of wetlands becoming degraded due to reduced water availability and changes in water salinity.

The study was possible due to the South East Natural Resources Consultative Committee (SENRCC) who provided the major funding along with further contributions from the South East Catchment Water Management Board (SECWMB), Forestry SA and the in-kind contribution by the Department of Water, Land and Biodiversity Conservation (DWLBC) and Forestry SA.

Some of the major findings of the study are:

- Salt accumulation measurements show that both pine and blue gum may be significant users of groundwater, when overlying shallow watertables.
- Groundwater uptake for both pine and blue gum can exceed 500 mm per year in areas where the watertables are less than 5 m deep.
- Under cleared land with shallow watertables, most of the salt in the unsaturated zone is generally flushed out through the hydraulic fluctuation of the watertable.
- Water uptake by trees will result in salt accumulation in the unsaturated zone. However, there is strong evidence from this study that watertable fluctuation and fallow periods for tree rotation can result in significant flushing of salt from the unsaturated zone into the groundwater. As a consequence, the salt accumulation method used in this study may result in considerable underestimation of groundwater uptake by trees.
- The estimates of groundwater uptake for pine and blue gum sites in this study agree with those presented over the last few years for the same sites using water balance – sap flow methods.
- The presence of heavy clay or hard impermeable layers in the unsaturated zone may significantly reduce or even stop groundwater uptake by the trees.
- Recent blue gum forestry tends to have rotations averaging about 14 years and consisting of ~12 years growth and two years fallow. Accumulation of salt is likely to take place for 9–10 out of every 14 years, with at least partial flushing of salt during the remaining years.
- There will be a longer term gradual salinity increase in both the shallow groundwater and in the unsaturated zone soil water. This is the result of the overall net loss of water via transpiration from the unconfined or shallow groundwater system. The net water loss in these areas will also be reflected in lowering the watertable until a new steady state condition is reached with the surrounding land use and lateral aquifer flow.
- There is circumstantial evidence that a concentration of blue gum plantations may have contributed to a lowering of the watertable at some sites in the Wattle Range area.
- The maximum depth to watertable at these sites has reduced by almost 1 m over the past four years.
- Groundwater recharge under native vegetation is ~5–8 mm per year measured at the cored sites.

- No recharge occurs under full canopy coverage of pine and blue gum forest. Any watertable fluctuations are likely to be an aquifer hydraulic response transferred under the forest area.
- The Bakers Range Drain when flowing has a groundwater component of ~75%, with 25% surface runoff, and occurs after the watertable rises above the bottom of the drain.
- Watertable decline due to land use will reach a new equilibrium of ~4.5–5 m below ground, which may impact on drain flow in the future.
- Impact on drain flow may cause drying of the local wetlands with subsequent loss of the water dependent ecosystems.
- A groundwater numerical model, while still requiring refinement, has been developed.

1. INTRODUCTION

1.1 BACKGROUND

Concerns have been expressed in the community over the potential for large-scale forestry plantations to reduce drain flows in the Lower South East. This would potentially deprive wetlands and other down-gradient water users, particularly in the Wattle Range area, which has seen extensive blue gum development. The present study quantifies potential impacts of land-use change in the Wattle Range area, and examines the risk of wetlands becoming degraded due to reduced water availability. Potential risk arises from various water-affecting activities including forest plantations, irrigation, deep-rooted perennial (agricultural) crops, drainage and any large-scale industrial users.

An associated issue, the potential for the accumulation of salt under some land uses such as plantations and irrigated crops, has been highlighted as a risk to water quality and wetland health. Salt accumulation in the root zone might also pose a risk to the health of the plantations and crops themselves, and may occur where there is insufficient recharge to flush accumulated salts from the soil profile.

Knowledge of water use by trees in areas of the South East with shallow watertables is increasing, and there are projects both ongoing and proposed by CSIRO to further refine and assess the information on a regional scale. Detailed information is also being collected on the water budgets of various irrigated crops at a number of sites in the region; additional information is being collected on salt accumulation at some of these sites.

There is good baseline data (going back over 30 years in some areas) on the relationship between rainfall, groundwater level and surface water flows in the main drains, although all of these data had not previously been fully analysed or modelled over a long time frame.

There is limited knowledge of the importance of drains to wetlands, apart from some larger drain discharge points such as Lake George, and a URS report prepared in 2000 for the SECWMB titled ‘Groundwater dependent ecosystems’. This report examined the uncertainty over interactions between drains and wetlands, both from the point of view of the impact on wetlands of lowered water tables caused by drainage and of the importance of the surface water flows from drains and adjoining catchment areas into wetlands. Preliminary examination of the data indicated that there is a dependence of wetlands on the drain flows and groundwater elevations.

The current project proposes to examine all of these issues by developing models of water and salt balances at a broad scale. The model can then be used to predict the effects of land-use change from dryland agriculture to plantations and/or irrigation expansion on drain flows, salt accumulation and wetland health.

1.1.1 PROJECT INITIATION

SENRCC has identified and prioritised a number of projects in its four-year (2004–07) Natural Resource Management Investment Strategy plan for the South East region of South Australia (SENRCC 2003).

Among the priority issues were increasing salinity in irrigation areas, sustainable groundwater use for the unconfined aquifer, protecting groundwater dependent ecosystems, and ecosystem degradation.

Projects proposed in the strategy to address these issues were:

- Project F 2.3.5 — Baseline information for regional surface flow management strategy and operational plan. Priority A, not funded.
- Project F 3.1.2 — Minimising salt accession. Priority A, funded.
- Project F 3.4.1 — Plantation water use. Priority C, not funded.
- Project F 3.4.3 — Quantification of the implications of land uses on the water balance, South Australia and Victoria. Priority B, not funded.
- Project F 3.5.1 — Irrigate for success and sustainability. Priority A, funded.

A proposal to touch on parts of these projects and provide additional information and more confidence in the results was put forward for discussion to a number of stakeholder and NRM organisations in the region by Forestry SA. The initial proposal was developed and forwarded to SENRCC for funding.

1.1.2 FUNDING ACKNOWLEDGEMENT AND COLLABORATION

Acknowledgement and thanks are given to SENRCC for the major funding of $100 000 to the project, along with $10 000 from the South East SECWMB, $10 000 from Forestry SA, and the in-kind contribution supplied by DWLBC, CSIRO and Forestry SA.

1.2 OBJECTIVES

The objective was to create a model that will predict the impacts of land-use change on drain flows, watertable levels and salt accumulation, along with an assessment of the likely impacts on wetlands. This would enable development of land-use options that will not adversely affect wetland health and groundwater quality, and was achieved using the following objectives:

Objective 1. Within a defined study area, model the relationship between rainfall, drain flows and groundwater levels for a range of land-use change scenarios based on known or measured rates of evapotranspiration.

Objective 2. Develop a model for salt accumulation under common land uses and assess the validity of this model for predicting tree water use and longer term impacts on groundwater quality.

Objective 3. Assess potential effects of land-use change in the study area on downstream wetlands.

1.2.1 PROJECT AIMS

The aims of the project are listed below and address the required tasks outlined in the brief.

Phase 1

Phase 1 of the project comprised two main components — an assessment of the salinity risk for various land uses (irrigation, broad-scale grazing and forestry), and the determination of the water and salt balance for a pilot study area in the Wattle Range area.

Phase 1 was conducted in the following manner:

- Define the study area. This area will supply water to downstream wetlands, where there is a long recorded period of drain flows in and out of the area, and where there has recently been, or there is the potential for, large-scale land-use change.
- Collate 30 years of rainfall, drainage flows and monitoring wells in the study area (Wattle Range area). For a reasonable period of years when land use was relatively stable, examine the relationship between annual and seasonal rainfalls and drain flows and watertable levels.
- Identify wetlands within the defined study area and determine their dependence on drain flows and groundwater elevations.
- Analyse the interaction between the watertable, drain flows and wetlands.
- Undertake field investigations to quantify salt accumulation in the soil profile and upper part of the unconfined aquifer for a range of different land uses.
- Develop a model for salt accumulation under plantations and irrigation.
- Continue monitoring rainfall, watertable levels, drain flows and vegetation water use (e.g. CSIRO plantation water-use research sites) and establish further monitoring sites if required.
- Map plantation areas.
- Determine the water and salt balances for the pilot study area, and undertake a preliminary evaluation of the management implications of the current and possible future land-use scenarios.
- Develop a preferred modelling approach for the surface and groundwater resources in the pilot study area.
- Calibrate the model against existing data.
- Examine options for managing the potential impacts on wetlands under current land use, and identify appropriate mixes of future land uses to minimise impacts on wetland health.

Tasks still to be completed:

- Map irrigation sites and likely expansion scenarios.
- Develop land suitability maps for plantations and develop expansion scenarios.
- Develop expansion scenarios for deep-rooted fodder crops (lucerne and tagasaste).
- Model a range of land-use scenarios and their effect on water level, salt accumulation, groundwater quality and drain flow.

- Analyse how predicted changes in drain flows, watertable levels and salt accumulation will affect water availability and quality to wetlands down gradient of the study area under various land-use change scenarios.
- Examine the implications of large water-using factories.
- Evaluate the effectiveness of the model(s) to be used elsewhere in the region to examine the impacts of land-use change on the surface and groundwater resources.

1.3 OUTPUTS

Phase 1

The outputs for Phase 1 are:

- A salinity risk assessment for the land use in a pilot study area in the Wattle Range area.
- A water and salt balance for the pilot study area in the Wattle Range area.
- A preliminary evaluation of the management implications of the current and possible future land-use scenarios.
- Determine a preferred modelling approach to assess the impacts of land-use change in the pilot study area.

Phase 2

The outputs for Phase 2 would (subject to the results from the Phase 1 investigations) be a model(s) to quantitatively determine the impacts of land use on the water resources in the South East region.

2. STUDY AREA

Two areas in the Lower South East of South Australia were selected for an investigation of salt accumulation under different land uses (Fig. 1). The first, comprising three cored sites, is to the east and southeast of the township of Nangwarry; the second area, also comprising three locations, is close to the Bakers Range Drain ~25 km west of the township of Penola. The land uses investigated include native vegetation, dryland pasture, irrigated pasture, and pine and blue gum plantations.

The investigation was split across these areas some distance apart for two reasons:

- The need to study the potential salt load under pine trees. While extensive blue gum forests exist in the Bakers Range area, no extensive radiata pine forest is present. It was anticipated that better representative values would be gained by studying salt loads in areas with a long history of pine tree plantation.
- A spatial dimension would be added to the project by studying two areas with similar geology and depth to water. If a comparison between the two areas was made, then the results may be inferred over a greater distance.

2.1 CLIMATE

The South East region is typified by a Mediterranean climate with hot, dry summers and cool, wet winters. Annual rainfall ranges from >750 mm in the south to ~450 mm in the north. The potential annual evapotranspiration increases from ~1400 mm in the south to ~1800 mm in the north.

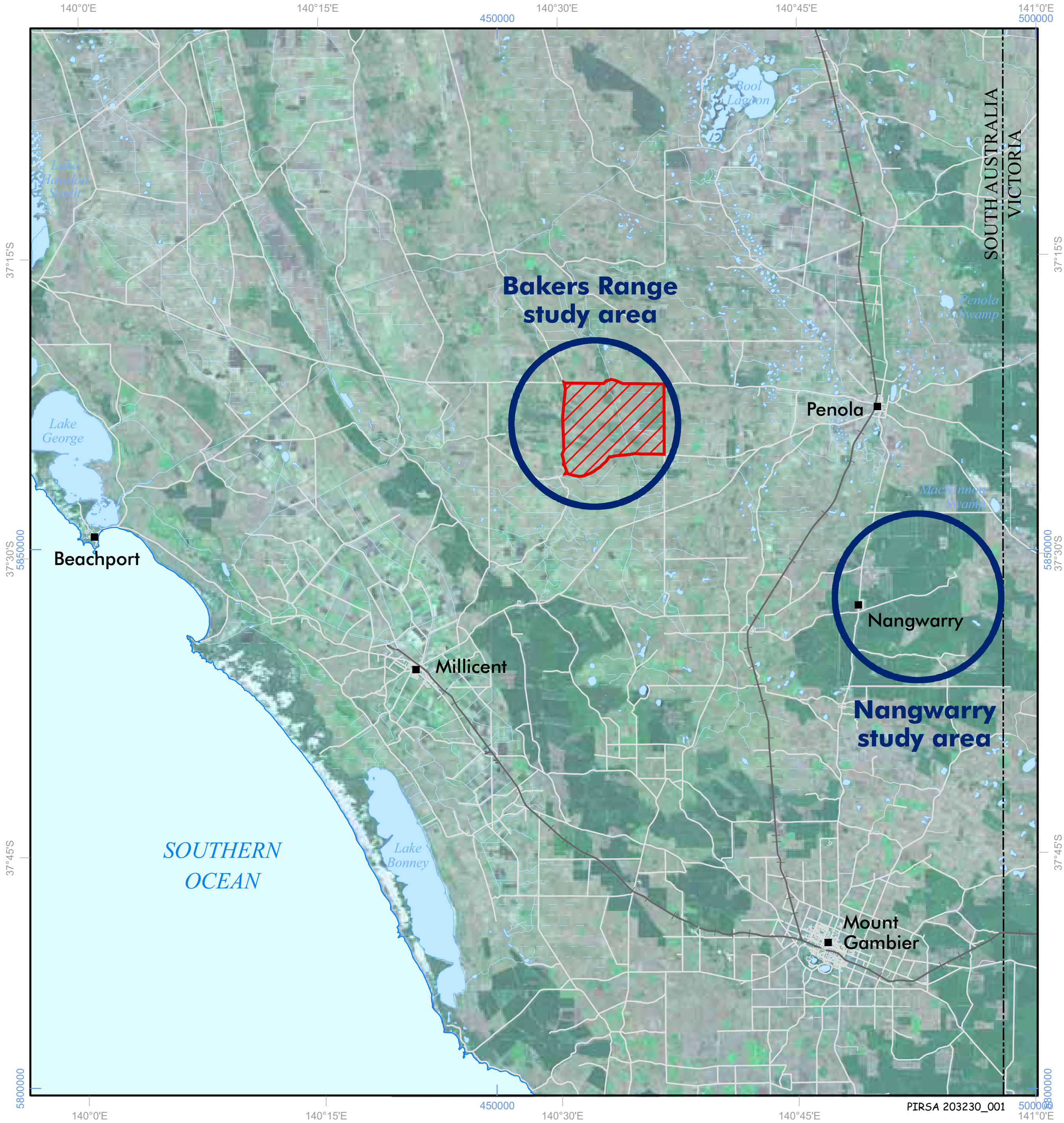
Rainfall recharge occurs to the unconfined aquifer when winter precipitation exceeds evapotranspiration and, depending on seasonal factors, can occur between May and September (Waterhouse 1977). Pan evaporation data from the Mount Gambier Bureau of Meteorology indicate an average of 133 rain days to 232 dry days over a 30-year record. The previous 10 years indicate little change in this pattern, with131 rain days to 234 dry days.

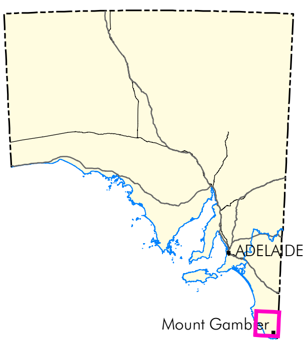
2.1.1 LONG-TERM CLIMATE PREDICTIONS

CSIRO studies on climate change in South Australia have indicated that since 1950 an increase in average temperature of 0.17°C per decade, while trends in annual rainfall since 1910 for the Lower South East have shown an overall decline (McInnes et al. 2003).

The projected changes in climatic condition from modelling results indicate an increase in the future annual average temperatures, as well as variations in seasonal temperature and rainfall across the state. Climate and hydrogeological conditions are the controlling factors of recharge, discharge, storage and groundwater fluxes. Climate change and variation will have a significant impact on groundwater resources in the South East. Variations in temperature, rainfall and evaporation will affect the amount of water that recharges to the groundwater resource, and the overall capacity of the resource.

Climate-change scenarios will be run in the model after satisfactory calibration has been achieved.





Imagery provided by
Department of Environment and Heritage –
Landsat 7 (2000)

Study area

Pilot study area

Highway

Lake

Secondary road

Subject to inundation

Railway

Watercourse

0 10 20 Kilometres

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services
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Date: May 2006

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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCALITY MAP

Figure 1

2.1.2 LOCAL RAINFALL STATIONS

Four rainfall stations with extended records are within close proximity to both study areas (Bakers Range and Nangwarry Forest areas). These stations are located at Penola PO, Kalangadoo, Lake Leake and Furner (Fig. 2).

Two automatic weather stations were set up near sites BG3 and BG4 (forested areas) to record rainfall using a tipping bucket gauge. Rainfall gauges located in an open area near each site were read every two to four weeks. Data from these stations were used for the water-balance calculation (Benyon & Doody 2004).

2.1.3 BUREAU OF METEOROLOGY

Although a number of stations collect climatic parameters in the Lower South East, the Bureau of Meteorology office adjacent to the Mount Gambier Aerodrome is the main station collecting pan evaporation data. A station in Coonawarra also collects similar data.

2.2 GEOLOGY

The geology of the Lower South East is characterised by a region of massive limestone (the Gambier Limestone), which is an extensive shallow-water shelf carbonate of Eocene to Miocene age (James & Bone 1989) deposited ~30 million to ~9 million years ago. Extensive faulting has occurred over time. Li, McGowran and White (2000) divided the Gambier Limestone into seven distinct units, which are currently being mapped through the region.

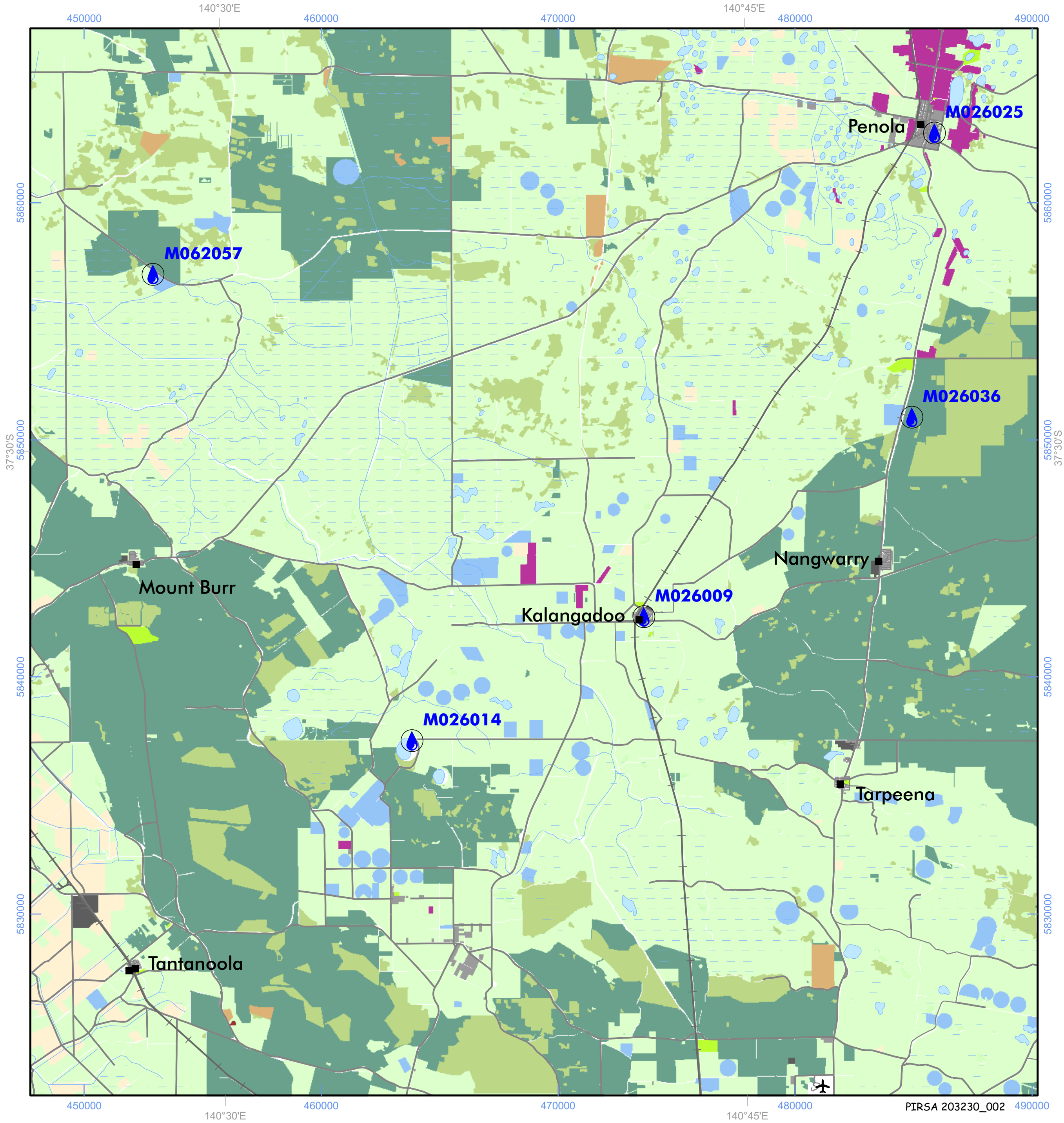
During the Pleistocene Period, ~1.6 million years ago, a number of transgressions and regressions of the sea deposited sands (now sandstone) of the Bridgewater Formation (Drexel and Preiss 1995).

As the present study concentrated on the near-surface geology, the deeper limestone units were not encountered. Table 1 shows a typical cross-section for the study area from observation well SHT013.

The majority of wells drilled throughout the study area (>90%) are completed within sandstone of the Bridgewater Formation. In some instances, wells targeting the deeper Camelback Member within the Gambier Limestone are used for irrigation supplies.

2.3 HYDROGEOLOGY

Three of the seven divisions of the Gambier Limestone in the Lower South East (highlighted in orange in Table 1) are recognised as distinct aquifer units. These are units 1 and 3 of the Green Point Member, and the deeper Camelback Member. South of the Tartwaup Fault (located close to the Mount Gambier Airport), the Camelback Member is dolomitic, but to the north it is described as a limestone and is quite often noted as green in colour. In some areas the water levels are slightly different between the aquifer units (known as a head difference), usually between Green Point unit 1 and the Camelback Member and in a downward



Rainfall station
Railway
Highway
Secondary road

Airport
Lake
Subject to inundation
Watercourses

0 5 10 Kilometres

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Date: May 2006

Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing & industrial

Mining
Nature conservation
Plantation forestry
Residential
Services

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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCATION OF BUREAU OF METEOROLOGY RAINFALL STATIONS WITHIN THE STUDY AREA

Figure 2

Table 1. Geological sequence for observation well SHT013.

Depth (m) from	to	Geological sequence	Subdivision	Description
0	4	Recent		Topsoil, sand and clay
4	14	Bridgewater Formation		Sandstone
14	66	Gambier Limestone Green Point Member	Unit 1	Porous limestone
66	90		Unit 2	Marl
90	112		Unit 3	Porous limestone
112	152		Unit 4	Marl
152	188	Gambier Limestone Camelback Member		Limestone
188	242	Gambier Limestone Greenways Member		Marly limestone
242	256	Narawaturk Marl		Marl
256	260	Mepunga Formation		Limonitic sand
260		Dilwyn Formation		Lignitic clay, sand and gravel

direction. A possible consequence of this in the Bakers Range area is that if contamination of the aquifer occurred, it has the potential to migrate downwards or become bound in the limestone marls (clays).

Additionally, in the Bakers Range area, the shallow watertables occur within Bridgewater Formation sandstone and this becomes a fourth aquifer unit. It was noted in the drilling program that in some areas the top of the unconfined aquifer is slightly confined by overlying clay. This means that when the watertable is cut, it will actually rise ~1 m.

2.4 SURFACE WATER HYDROLOGY

There is no natural drainage in the Lower South East, except the Glenelg River and coastal creeks and springs. Surface water is restricted to seasonal and some permanent swamps and wetlands. In the Bakers Range area, the man-made drains are the main surface water features; the major component of the flow is groundwater, as the drain bases are generally lower than the groundwater level during winter.

Prior to drain construction, large areas of the South East were inundated with water during winter. The Bakers Range Drain and its subsidiaries were constructed during the period 1960–67. The subsidiary drains leading into the main Bakers Range Drain include the water course ~2 km north of LDE Road, Drain B south of Phillips Road, and the private drains between LDE Road and the Penola–Millicent Rroad (B. Puddy, DWLBC, pers. comm., 2005). Bakers Range Drain runs in a south to north direction. The main and subsidiary drains carry floodwaters from the southern and eastern sections of the South East, and discharge into the east–west-orientated Drain M.

2.5 LAND USE

The pre-European settlement landscape was dominated by native vegetation. The Nangwarry area was predominantly Manna-gum (*Eucalyptus viminalis*), damp woodland, brown stringybark (*Eucalyptus baxteri*), sandy heath woodland, Hill Gum, intermittent swamp fringed by Swamp Gum (*Eucalyptus ovata*), and diverse heathy understorey or prickly tea-tree thickets. The Bakers Range study area was predominantly rough-barked Manna-gum and Swamp Gum, wet heath and open-heathy wetland or dense wetland habitat (prickly tea-tree), brown stringybark and Hill Gums on the sandy rises, with pockets of Red Gum and damp woodland (M. Bachmann, DEH, pers comm., 2005).

The landscape has undergone changes as settlement progressed and land was needed for grazing, pasture production and other irrigation activities. In the Nangwarry area, scrubland was first cleared in the mid-1920s and pine plantations followed. At present, an estimated 70–80% of this Hundred is planted with commercial forest.

Examination of aerial photography has highlighted land use changes in the Bakers Range area (Figs 3–7). The 1978 aerial photography shows that remnant native vegetations still existed west of the Bakers Range Drain. By 1987, most of the land had been cleared, with only patches of remnant native vegetation still visible. Over the past few years this has changed considerably with the advent of the blue gum industry. The main species grown is *Eucalyptus globulus*. The 1999 landscape within the pilot study area (Fig. 5) shows a small change in terms of plantation development from the 1987 landscape. The major development in forest plantation occurred between 1999 and 2005.

2.6 WETLANDS

A major requirement of this project was to study the effect that forestry may have on drain flow and hence closely related wetlands. Located alongside the Bakers Range Drain immediately north of the pilot study area are three significant wetlands — Sheepwash Swamp, Oschar Swamp and SEWCBD Swamp. These are shown in Figure 8.

Figure 3. 1978 land-use map overlain by the boundary of the pilot study area (red polygon).

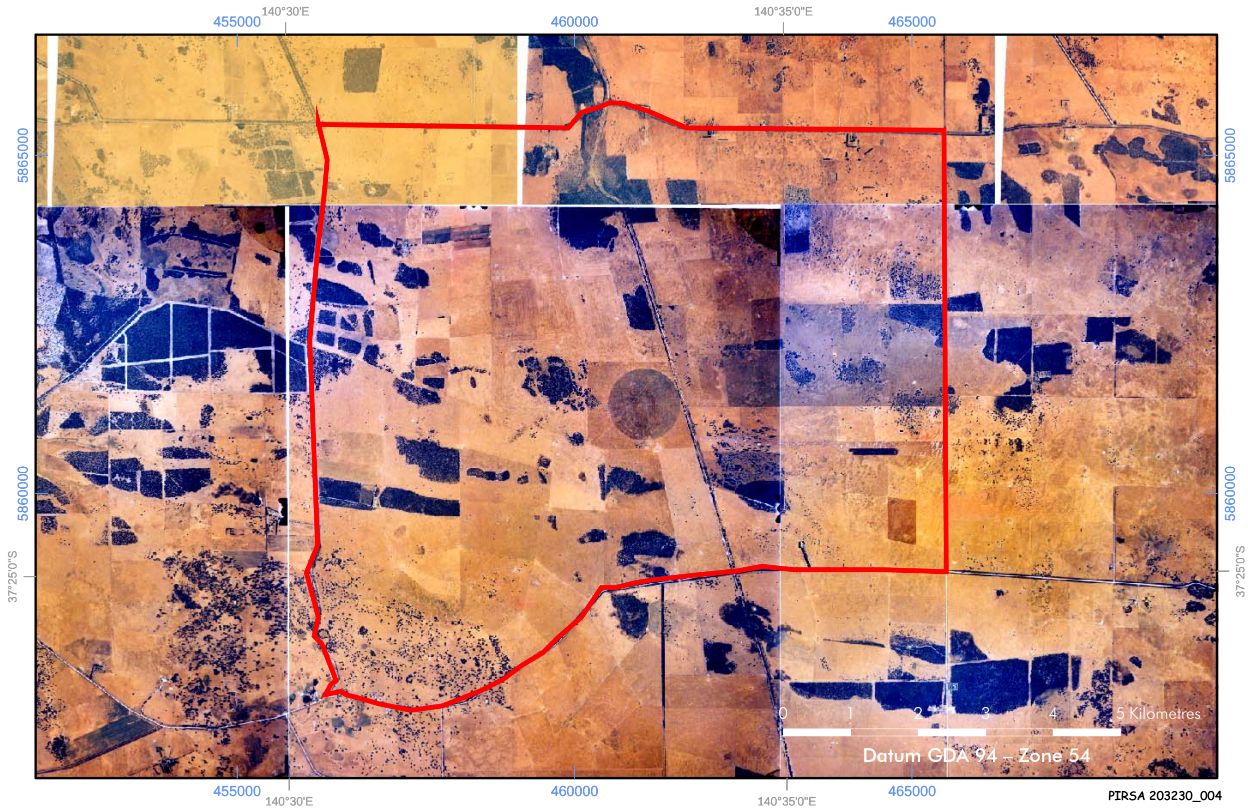


Figure 4. 1987 land-use map overlain by the boundary of the pilot study area (red polygon).

Figure 5. 1999 land-use map overlain by the boundary of the pilot study area (red polygon).

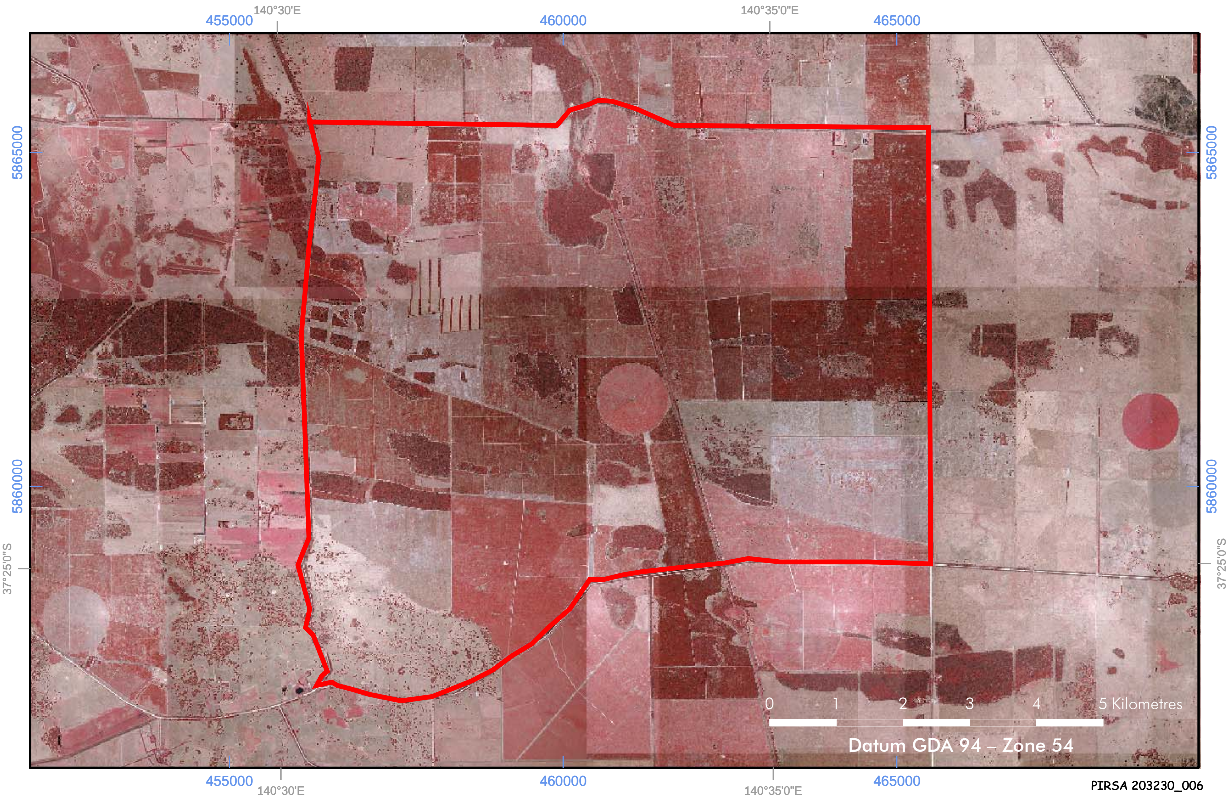


Figure 6. 2003 land-use map overlain by the boundary of the pilot study area (red polygon).

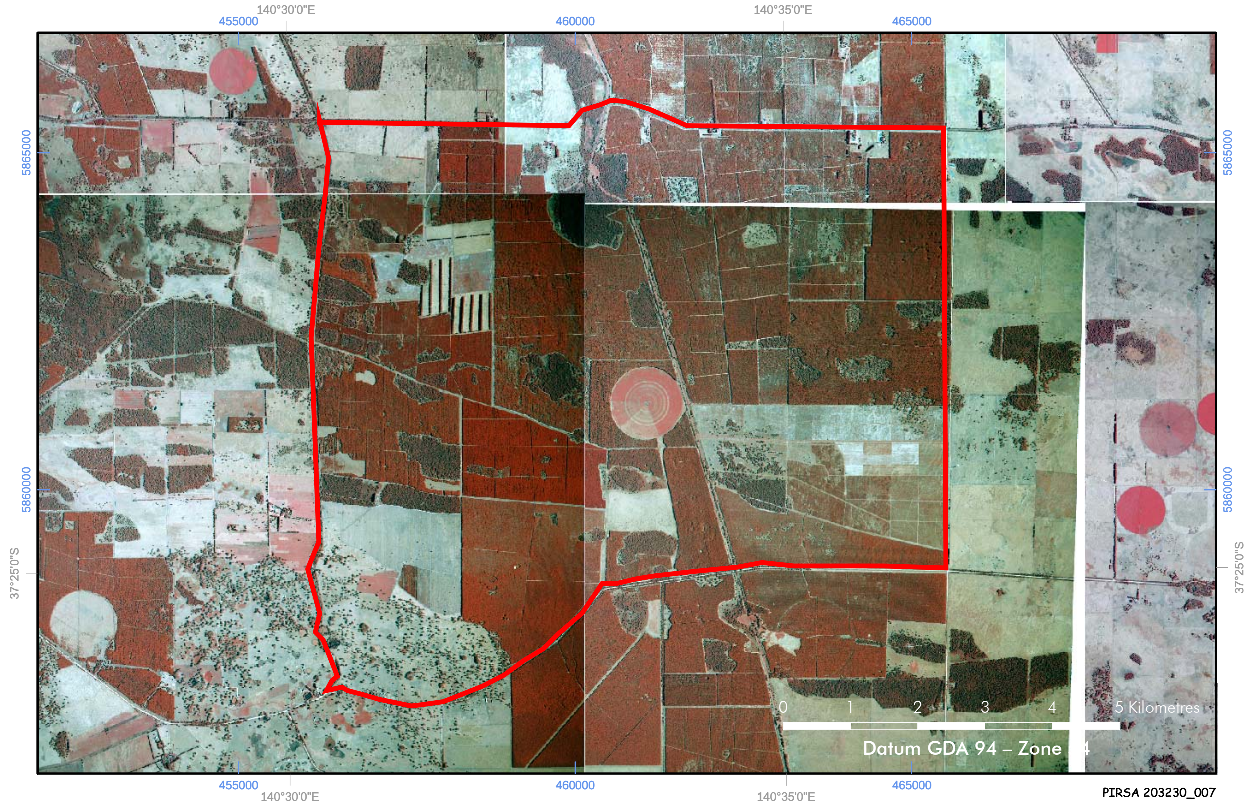


Figure 7. 2005 land-use map overlain by the boundary of the pilot study area (red polygon).

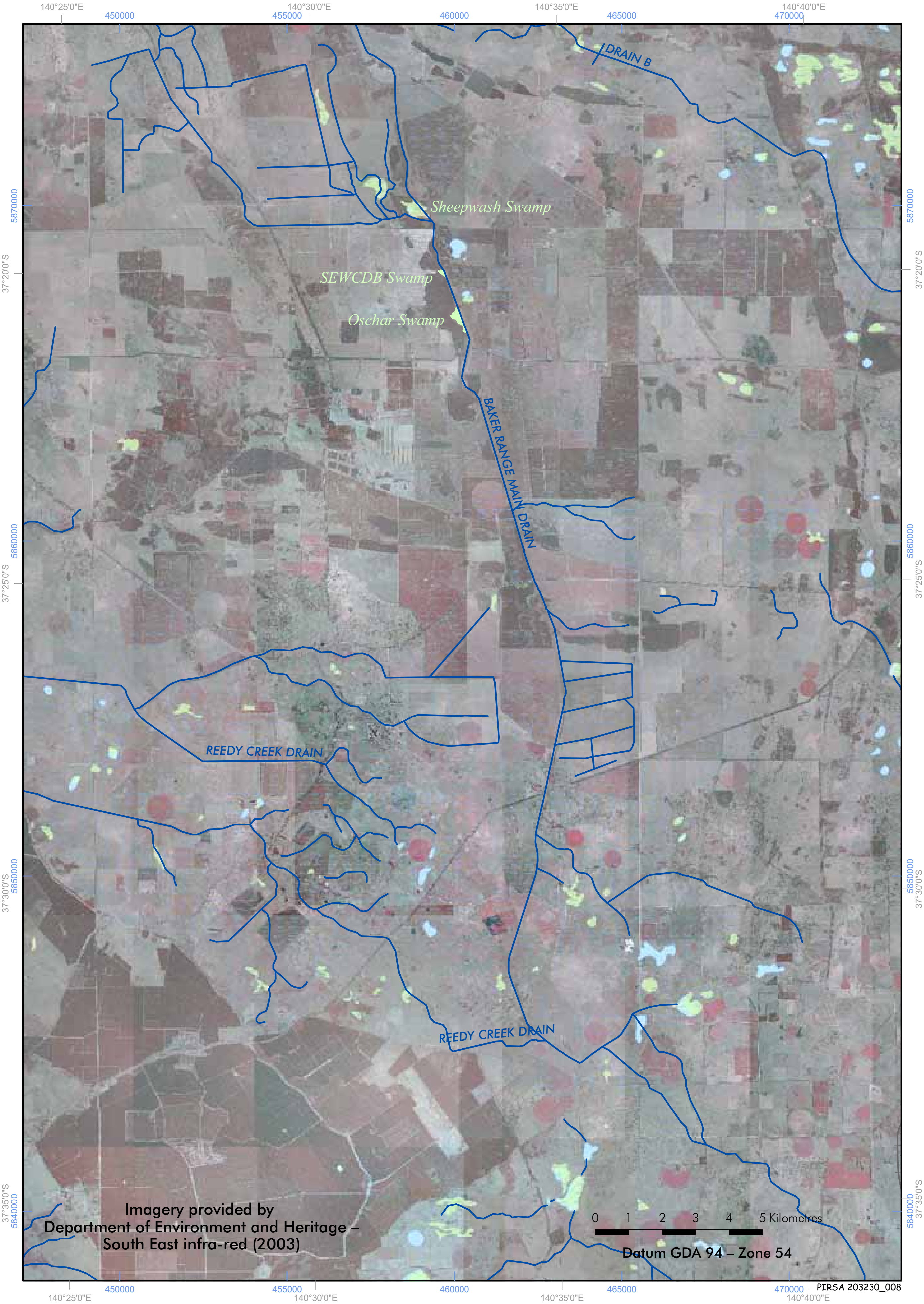


Figure 8. Infrared aerial photography of mapped wetlands (cream polygons) and drains (aqua lines) of the Bakers Range area. The three wetlands within the study area that were surveyed for the Lower South East Wetland Inventory are labelled.

3. EXISTING DATA EVALUATION

3.1 MONITORING

Government groundwater monitoring has occurred throughout the South East since the early 1970s up to the present time (Fig. 9).

Surface-water monitoring has occurred in the region over a similar time but by two different agencies. From the 1970s until the early 1990s, the Water Resources group within the SAWater (previously E&WS) southeast region monitored many of the creeks and some drains. After group abandonment, the South Eastern Water Conservation and Drainage Board (SEWCDB) continued this work, along with their own drain monitoring. The SEWCDB is now part of DWLBC.

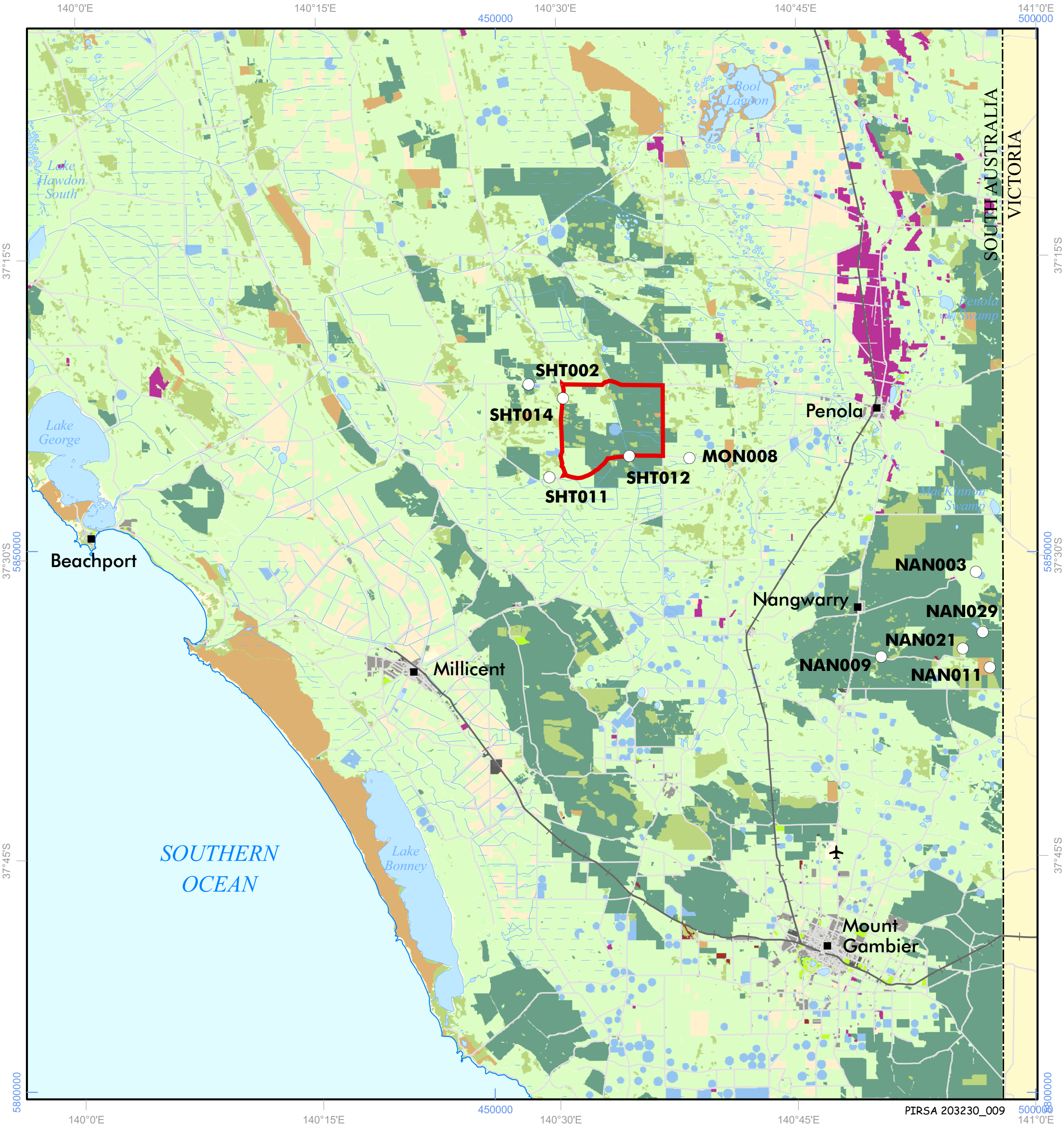
3.1.1 STANDING WATER LEVEL

The following graphs show the long-term monitoring well trends in the two areas in which the drilling operations were conducted for this study. In Figure 10, five observation wells are shown although SHT002 has an interrupted record. The water level trends have remained similar across ~30 years of monitoring; however, in wells SHT002 and SHT012, a decline not observed in the other wells has occurred since 2000. These wells are located within forested areas.

In the Nangwarry area, ~35 years of monitoring data exist. Similar trends are observed in all wells, with the main difference being in amplitude change (Fig. 11). NAN003, located in dryland pasture, shows the smallest amplitude changes but also has the greatest depth to water. Observation well NAN009 shows a watertable recovery effect after the Ash Wednesday fires similar to that observed when a pump is switched off. All show a declining watertable from 1994, although this pattern has slowed, reacting to the change in rainfall pattern since 2000.

3.1.2 SALINITY MONITORING

Salinity monitoring through most of the South East has not matched the intensity of the water level records as it is only in the last 10 years that simple technology involving 12-volt marine pumps have allowed good quality water samples to be taken. Prior to this, many samples were taken with a bailer, and were therefore biased towards sampling fresh water at the top of the aquifer. This is indicated in Figure 12, with the samples tested over the last six years having greater consistency. Groundwater salinity in the Bakers Range area varies between 800 and ~1200 mg/L.



SHT011
Observation well and number

Pilot study area
Railway
Highway
Secondary road

Airport
Lake
Subject to inundation
Watercourses

Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing and industrial

Mining
Nature conservation
Plantation forestry
Residential
Services

0 10 20 Kilometres

Projection: MGA Zone 54 Transverse Mercator
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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCATION OF OBSERVATION WELLS IN BAKERS RANGE AND NANGWARRY AREAS

Figure 9

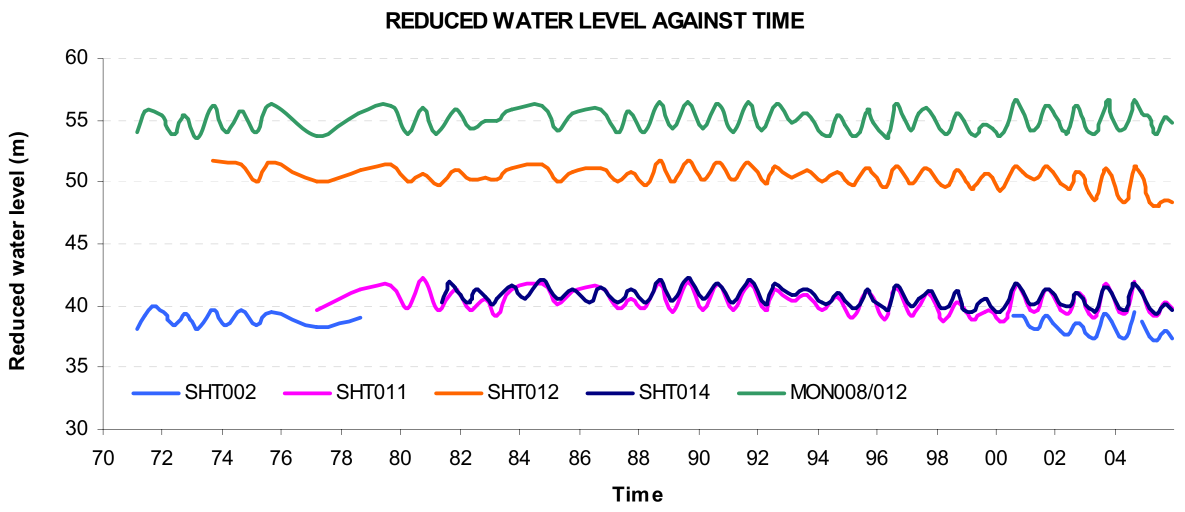


Figure 10. Hydrographs for selected observation wells in the Bakers Range Drain area.

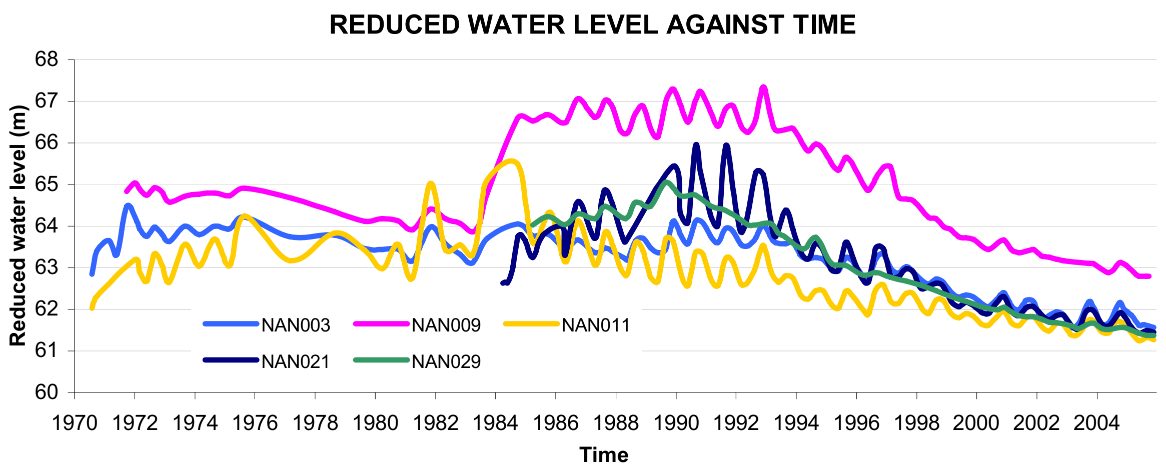


Figure 11. Hydrographs for selected observation wells in the Nangwarry area.

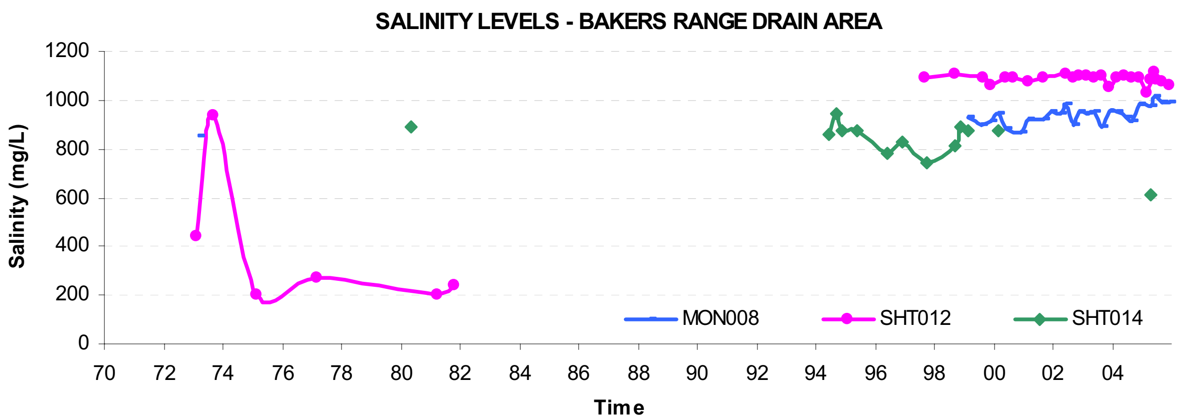


Figure 12. Salinity levels in observation wells MON008, SHT12 and SHT014 in the Bakers Range area.

In the Nangwarry area, the three wells shown in Figure 13 indicate some variation in salinity. NAN009 at the start and finish of the record shows very low salinity, but between ~1990 and 2000 values rose to ~1000 mg/L. This is attributed to the removal of the forested area after the Ash Wednesday fires, which allowed an increase in groundwater recharge to leach salt from the unsaturated zone to the watertable (Fig. 11). The salinity values in this well are lower than in other wells in the immediate area and may be influenced by a nearby swamp.

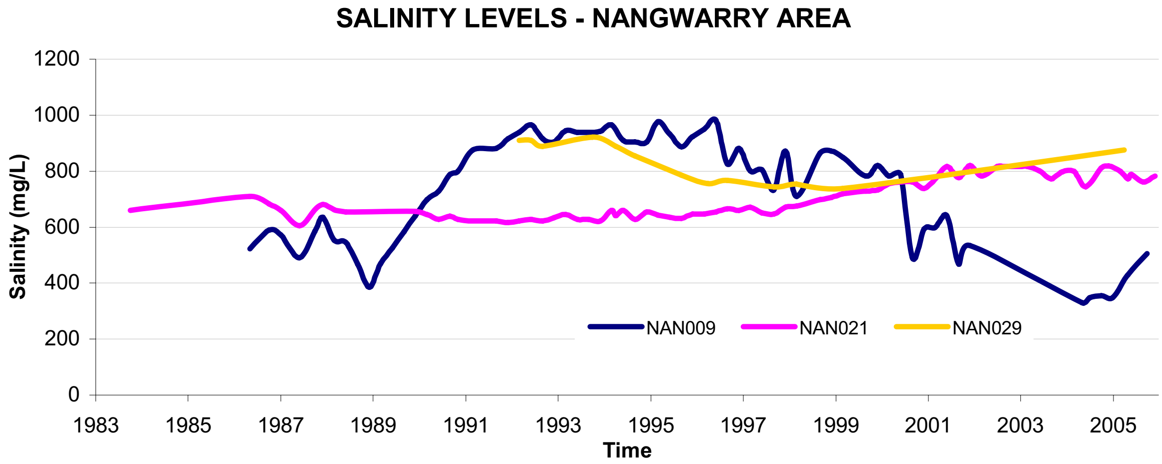


Figure 13. Salinity level in observation wells NAN009, NAN021 and NAN029 in the Nangwarry area

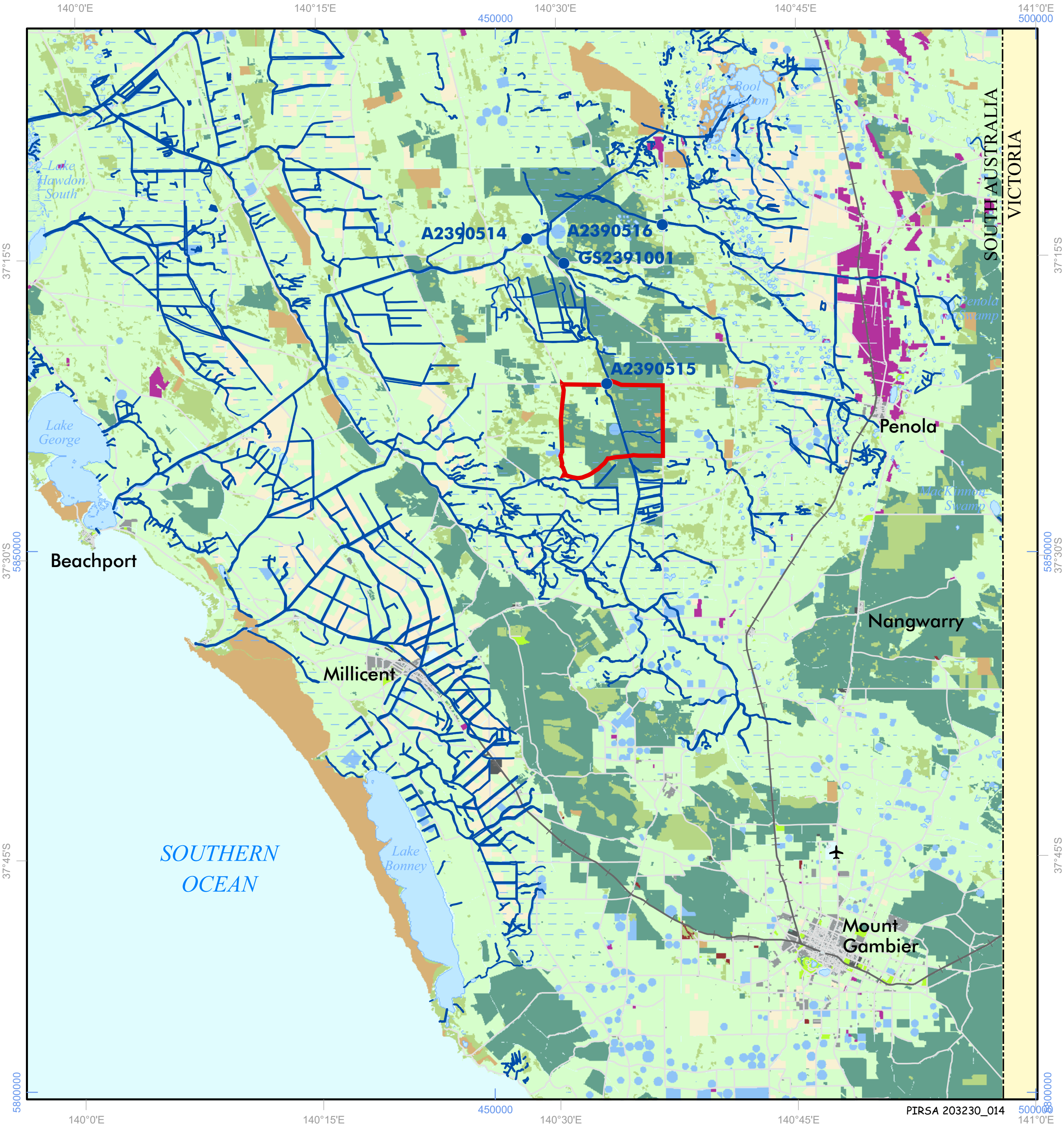
Observation well NAN021 has shown an increase in salinity from ~1995–2001, although it has stabilised in the last four years. The blue gums on this site have been through a rotation cycle that does not coincide with the salinity increase, and its cause is unclear. NAN29 has cycled in its salinity history but it is located on the edge of a forested area close to some wetlands, which may have an influence.

3.2 DRAIN FLOWS

A number of surface water monitoring stations have existed through the Bakers Range area (Table 2, Fig. 14). The two closest to the study site have a split record because the original site, located where the Penola–Robe Road crosses the Baker Range Drain, was abandoned in 1986 because of a problem with a fence line covered in vegetation hindering accurate flow measurements. A new site was selected at Phillips Road. The other two stations were located on Drains M and C.

Table 2. Surface water monitoring stations in the Bakers Range area.

Station number	Station name	Duration of record
A2390514	Drain M — Callendale	22/6/1971–18/9/1990
A2390515	Penola–Robe Road	21/6/1971–27/11/1986
A2390516	Drain C — Balma Carra	22/6/1971–21/9/1978
A2391001	Phillips Road	7/8/1990–1/9/2003



A2390514 Surface monitoring site

Pilot study area

Railway

Highway

Secondary road

Airport

Lake

Subject to inundation

Watercourses

Drain

Land use – 2003

Cropping

Grazing modified pastures

Grazing natural vegetation

Irrigated areas

Irrigated perennial horticulture

Manufacturing and industrial

Mining

Nature conservation

Plantation forestry

Residential

Services

0 10 20 Kilometres

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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCATION OF DRAINS AND SURFACE WATER MONITORING SITES WITHIN THE STUDY AREA

Figure 14

Surface water was monitored at two gauge stations along the Bakers Range Drain (Fig. 14). For gauge station A2390515 adjacent to the Penola–Robe Road, flow data are available for the period 13/7/1971–12/2/1993, when the gauge ceased operation. This site provides 21.5 years of flow data, has a catchment of 791 km^2, and is believed to be unaffected by flow-regulating structures and systems; the flow is therefore in response to natural rainfall runoff processes (Stace & Murdoch 2003). Gauge station A2391001 at Phillips Road started operation on August 1990 and has current records.

3.3 RAINFALL (SPECIFIC STATIONS)

Rainfall data have been collected at four Bureau of Meteorology (BOM) stations within and around the Bakers Range area. Most of the data are for the period 1970–2004. In groundwater studies, a technique commonly used when examining rainfall trends, especially for comparison with groundwater hydrographs, is to plot the rainfall cumulatively. It is achieved by calculating the average rainfall for the total period of the record, and then subtracting this value from the yearly totals and plotting the cumulative result. The cumulative deviation in rainfall gives a better representation of the long-term trends.

The four rainfall stations shown in Figure 15 indicate similar trends of the cumulative deviation from mean annual rainfall from the period 1970 to present. Total annual rainfall from Penola PO shows that about half of the recorded rainfall data (17 years) are below the mean annual rainfall over the last 35 years, which is clearly reflected in rainfall trends from the other stations.

The rainfall data recorded at Penola PO indicates five trends in the cumulative deviation across the 35 years of records, and these are shown in Table 3 and Figure 5 (red arrows). Three are around average to slightly above average rainfall and two are below average. The most distinct trend is from 1993–99, which shows a continuous decline indicating a series of below average annual rainfall.

Table 3. Variation in rainfall over time.

Identifier	Time period	Rainfall average (mm)
	Total Average 1970–2004	659
1	1970–1975	749
2	1976–1982	610
3	1983–1992	688
4	1993–1999	587
5	2000–2004	680

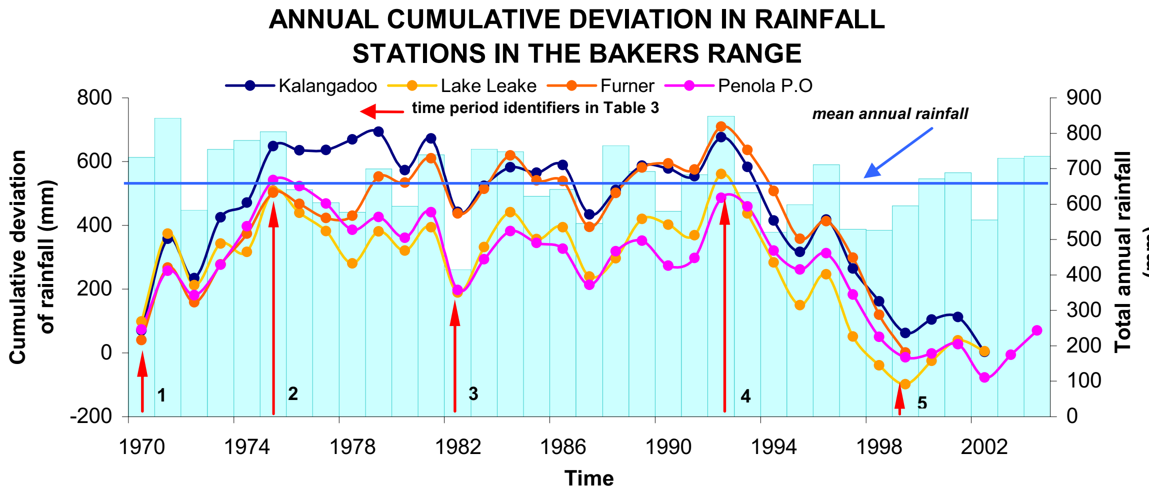


Figure 15. Annual rainfall for Penola PO station (light blue columns), and cumulative deviation from mean annual rainfall in the Bakers Range area.

3.4 PREVIOUS WATER USE DATA

Benyon and Doody (2004) reported on water use by tree plantations in the South East. The report explored the relationship between tree water use, growth and site factors such as depth to watertable. Research plots were established at six blue gum and two pasture sites, and monitored changes in soil water and plantation growth for up to three years, including monthly water balances for each site. These data were combined with previously obtained figures from another three blue gum and seven radiata pine research sites in the region. Details on the methodology used to quantify the groundwater balance and site characterisation are documented in Benyon and Doody (2004); the report can be downloaded from the Internet at http://www.ffp.csiro.au/Download/PlantationWaterUse.pdf.

In summary, the report on water use by plantations concluded that:

- The mean annual use of groundwater by eight of the nine study plots with depth to watertable less than 6 m was 435 mm/y, with 90% statistical confidence limits of ±103 mm.
- The measurements were all made in closed canopy plantations and therefore do not apply to the period before canopy closure when evapotranspiration would have been lower.
- The range of annual groundwater uptake between the eight plots was 107–671 mm/y.
- The study identified site factors influencing water use at point scale in plantations with closed canopies, including rainfall, soil depth and depth to groundwater.
- The results are only directly applicable to sites with sandy surface soils over a watertable of low salinity and high aquifer transmissivity in a Mediterranean climate.

4. PROJECT METHODOLOGY

4.1 FIELD PROGRAM

The field program was set to address the objectives of the project proposal. It included site selection for the study area, in particular the pilot study area, an electromagnetic (EM) survey, soil core sampling and analyses, measurement of tree water use, groundwater, surface water (drains) and wetland data.

4.1.1 FIELD SITE SELECTION

The criteria for site selection were discussed throughout the preparation stages of the project proposal between interested NRM and resource management groups. The following aspects were suggested for consideration:

- An area of study that has a long record of monitoring data such as water level, rainfall, drain flow and significant wetlands.
- Different types of land use — irrigated and non-irrigated pasture, softwood and hardwood plantation, and native vegetation.
- Depth to groundwater.
- Low and high elevation plantation areas.
- Age of plantations.
- Selection of an area for a computer generated model.

This was carried out by the technical group and ratified by the management committee. During the selection process, a field trip was conducted to investigate pine tree deaths thought to have been caused by salinisation. The affected areas tended to be small and not representative of what the outcomes of the project was trying to achieve. A further excursion looked at a possible area further north, close to Drain M, but this area lacked wetlands.

4.1.1.1 Definition of the pilot study area

Four study areas are discussed in this report and a definition of each is provided below to avoid confusion:

- Pilot Study Area (Fig. 1). This area was used to calculate the water and salt balances to enable comparisons to be made on how the different land uses may affect the environment, and to develop a model approach for the surface and groundwater relationship.
- Bakers Range Area — the general Bakers Range Drain area in which the drilling program took place over various land uses.
- Nangwarry Area — within the Hundred of Nangwarry where the drilling program also took place to study land uses in a deeper watertable environment. Mature and second or third rotation pine forest occurs through this area.

- Model Study Area — to model the Bakers Range environment (pilot area), the area was extended beyond the boundaries of the plantation to minimise possible simulated boundary effects surrounding the forest. The current areas will probably shrink prior to scenario modelling.

4.1.1.2 Different land-use types

Five land uses were investigated during this study:

- Native vegetation — two sites were investigated, one on POW Road near Nangwarry and another in the Bakers Range area.
- Dryland pasture — three sites adjacent to POW Road and another two in the Bakers Range area were investigated.
- Irrigated pasture — two sites in the Nangwarry and Bakers Range areas.
- Softwood plantations — two sites in the Nangwarry area.
- Blue gum plantations — three sites in the Bakers Range and one in the Nangwarry area.
- Three additional sites were added in a later stage of the project. These sites were: a pine site in the Penola forest, on second rotation, which was established in 1970; a pine site opposite the Mount Gambier airport, where higher water use has previously been measured (Benyon & Doody 2004); an 11 year old blue gum plantation near Beachport.

4.1.2 EM SURVEY

After site selection, PIRSA Rural Solutions was contracted to conduct an EM survey to detect potential areas of salinisation that the drilling program could investigate. A full report is attached in Appendix A.

The EM induction technique averages the ‘apparent’ conductivity in the soil over the surveyed area. It gives an indication of the relative variation in salinity, clay content and soil moisture. The instrument measures the apparent electrical conductivity (ECa) of the soil to a maximum depth of ~1.5 m (EM38) and 6 m (EM31).

This technique is very sensitive to salinity, less sensitive to clay content, and least sensitive to soil moisture, making it possible to interpret surveys according to the instrument response and landscape factors. However, to determine the actual soil characteristics being mapped, the EM readings must be groundtruthed using soil samples from pits, cores or augered holes.

Initially, the study sites were selected for five different types of land use, with a total of 17 investigation sites (Table 4 (A1-F17)). Between one and four EM traverses were run in each study area using Geonics EM31 and EM38 meters mounted on a quad bike. Readings were taken along forest rows approximately every 5 m and on a 10–20 m grid in the open areas. The survey was done in deep and shallow mode using EM31 and EM38 to determine the ECa variation down the profile to ~6 m.

Sixteen EM traverses (F16 and F17 were on same traverse line) were completed, of which two were in areas of native vegetation, two in pine plantations of different stand ages, six in areas where the majority of the blue gum plantations were less than eight years old (R. Benyon, CSIRO, pers. comm., 2005) and two in irrigated pasture (Table 4).

4.1.3 DRILLING AND CORING PROGRAM

After examination of the EM survey maps, the drilling sites were selected in areas that were representative of the land use.

The coring program was carried out in February 2005 under the supervision of DWLBC staff and using Drilling Solutions, an Adelaide-based company. It was necessary to use drilling methods that would not dry the soil samples or add water to them. Samples were collected at 0.5 m intervals using a split-tube wire line recovery technique mounted on an Investigator rig. Cores were collected at each of the nine study areas (A-I) and included sites in each of the land-use regimes discussed in 4.1.1.2. In total, two cores were collected in areas with native vegetation, four in areas cleared for non-irrigated pasture and two in irrigated pasture, four in pine plantations, and six in blue gum forests (Table 4).

Two sites (A2 and D9) were not included in the drilling investigation because they were not considered representative of the land-use type. Cores were logged and descriptions are attached in Appendix B. Each coring location was identified by GPS coordinates and all data were uploaded into the DWLBC database SA_Geodata. Eleven selected holes were completed as piezometers for future water level and salinity monitoring. In areas of an existing observation well, the holes were backfilled and abandoned.

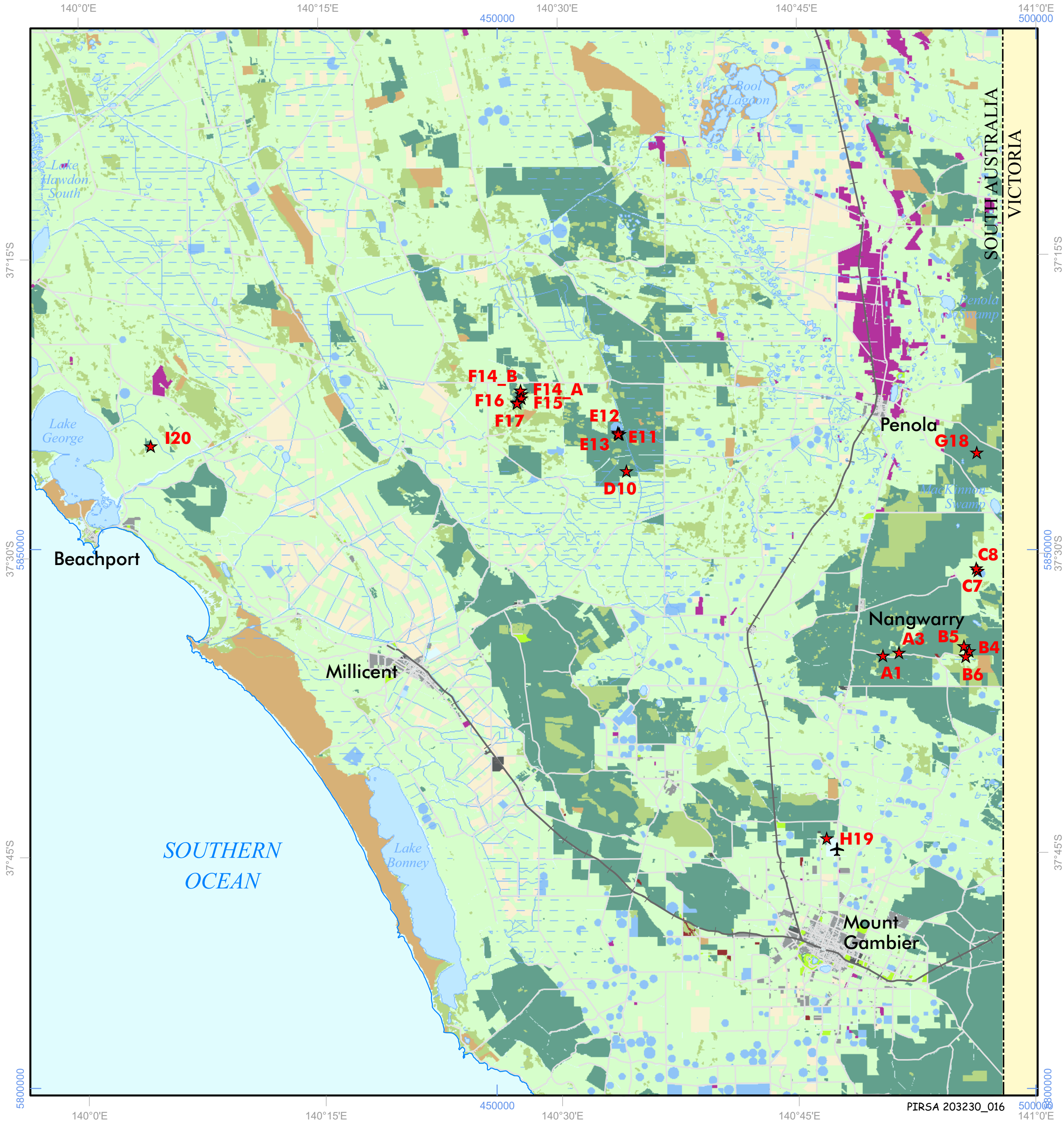
The program included 16 cored wells, and at site E11 an additional two wells were drilled to investigate salinity stratification. Three wells at the McCourts irrigation site (E) had transducers installed to record water levels, salinity and temperature to ascertain changes under the different land uses over time.

A second stage of the project had three additional sites cored in July 2005. They were located in pine forests near Penola and Mount Gambier, along with a blue gum site near Beachport. All sites had low fluctuating watertables and were considered ideal to study the salt load at each. In addition, site B6 had two wells drilled to study salinity stratification and allow future dating of the groundwater at three different depths (also utilising the original piezometer to monitor the shallow part of the watertable).

At three sites, tubes were left in the holes to sample soil gas (A1, F15 and F16). An elevated level of carbon dioxide (CO_2) concentration in soil gas can be indicative of root respiration, and therefore active tree roots. For the location of the drilling sites see Figure 16.

Cores were collected until the watertable was cut. An attempt was made to collect samples to 0.5–1.0 m below the watertable, but in most occasions this was unsuccessful due to the high moisture content making the sample unstable. At two sites (F14A and F17), the watertable was not reached due to a hard sandstone bar that resulted in coring being terminated. Samples were collected at 0.5 m intervals and aliquots placed in 500 mL glass jars that were sealed with new metal lids and tape to prevent evaporation of water from the soil.

Soil gas was collected from the three sites fitted with soil gas samplers by removing 7–10 tube volumes of gas from the tube using a syringe and then filling 10 mL pre-evacuated containers (vacutainers) with soil gas via the septa on the top of the containers. The soil gas was then transported along with the soil samples to the laboratory for analysis.



B6 ★ Soil core site
Airport
Railway
Highway
Secondary road

Lake
Subject to inundation
Watercourses

Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing and industrial
Mining
Nature conservation
Plantation forestry
Residential
Services

0 10 20 Kilometres

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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCATION OF SOIL CORE SITES

Figure 16

Table 4. Project's investigation sites.

Site	Land-use type	Hundred	Comments
A1	Pines	Nangwarry	Near observation well NAN009, prior land use was scrub. First rotation 1926. Pines burnt 1950. Second rotation 1953, and third rotation in 1988.
A2	Open natural	Nangwarry	South of NAN009, previously open pasture, covered with native ferns.
A3	Native vegetation	Nangwarry	East of NAN009, completely burnt in February 1983 fires then regenerated.
B4	Pines	Nangwarry	Southeast of NAN021, first rotation established in 1968. Heathy scrub prior to plantation.
B5	Blue gums	Nangwarry	Adjacent to NAN021, Prior land use was pasture, first rotation 1988, and second rotation in 2000.
B6	Pasture	Nangwarry	South of NAN021, open pasture.
C7	Irrigation	Nangwarry	Southeast of NAN003, irrigated pasture.
C8	Pasture	Nangwarry	Near NAN003, northeast of stockyards, open pasture.
D9	Pasture	Short	West of SHT023, mainly fern covered.
D10	Blue gums	Short	Adjacent to SHT024, planted 1998 on cleared pasture land.
E11	Blue gums	Short	South of centre pivot, planted in 1998 on cleared pasture land.
E12	Irrigation–pasture	Short	Under centre pivot, irrigated pasture.
E13	Pasture	Short	Pasture.
F14	Pasture	Short	Near CSIRO compound, open pasture.
F15	Native vegetation	Short	Bush track, land use is scrub and tree ferns.
F16	Blue gums	Short	Low ground, planted in 1998 on cleared pasture land.
F17	Blue gums	Short	High ground, planted in 1998 on cleared pasture land.
G18	Pines	Penola	At CSIRO Julia Hill site, relatively good heathy scrub in 1965 with trees. By 1968, cleared and had very low vegetation with no trees. First rotation in 1970.
H19	Pines	Young	At CSIRO airport road site, first rotation 1945. Prior land use was scrub to 1934, then pasture until pines planted. Second rotation in 1996.
I20	Blue gums	Symon	At CSIRO Beachport site, first rotation planted in 1994 on cleared pasture land.

Sites A2 and D9 were not included in the drilling program (see text for explanations).
Sites G18, H19 and I20 were added in a later stage of the project; no EM surveys were carried out at these sites.

4.1.4 TREE WATER-USE MEASUREMENTS

Monthly water balances had been measured at five blue gum sites in the Wattle Range area as well as three blue gum and seven radiata pine sites in the South East. Funding was maintained to continue monitoring to mid-2005 at two CSIRO sites in the Bakers Range study area (App. C). These sites (BG2 and BG3 in Benyon & Doody 2004) are located to the south and southeast of study site D10 (Fig. 16). Data for 2004–05 were also collected from two of the other blue gum sites in the Wattle Range (BG5 and BG6) and at one blue gum and one radiata pine site near Mount Gambier Airport (BG7 and RP2) (Fig 17). The details on measured parameters and methodology are discussed in Benyon and Doody (2004).

4.1.5 GROUNDWATER AND SURFACE WATER MONITORING

Observation well records within the study areas were analysed for trends in water levels and salinity under different land uses. Additionally wells drilled as part of the coring program completed as observation wells were monitored for both water levels and salinity.

Wells were constructed on both the western and eastern sides of the Bakers Range Drain to measure water levels, salinity and gradient flow. The program was put in place to monitor through the 2005 winter, but the drain did not flow in this time. Figure 18 provides locations.

Table 5 shows the total annual flow for gauge station A2390515 at Penola–Robe Road. The Hydstra HYBASE application was used to derive groundwater base flow and surface runoff components from the historical records at site A2390515. The HYBASE 'Filter' method was used with a standard filter factor of 0.925. An average annual total rainfall was calculated from the five stations adjacent to the catchment area of A2390515 (Fig. 2), and this average rainfall used to calculate the annual catchment coefficient figures (Stace & Murdoch 2003).

In 2004, drain flow was measured at Phillips Road, Penola–Robe Road, LDE Road, Penola–Millicent Road, and from Drain B at Coles–Killanoola road. The propeller current meter method (area velocity method) was used to calculate the flow in cubic metres per second (cumecs). The drain cross-sectional area was measured at each location and the current velocity recorded using the propeller throughout the cross-section. The flow was obtained from multiplying the area by velocity. The drain flows at these points are tabulated in Table 10, and the site locations are shown in Figure 19.

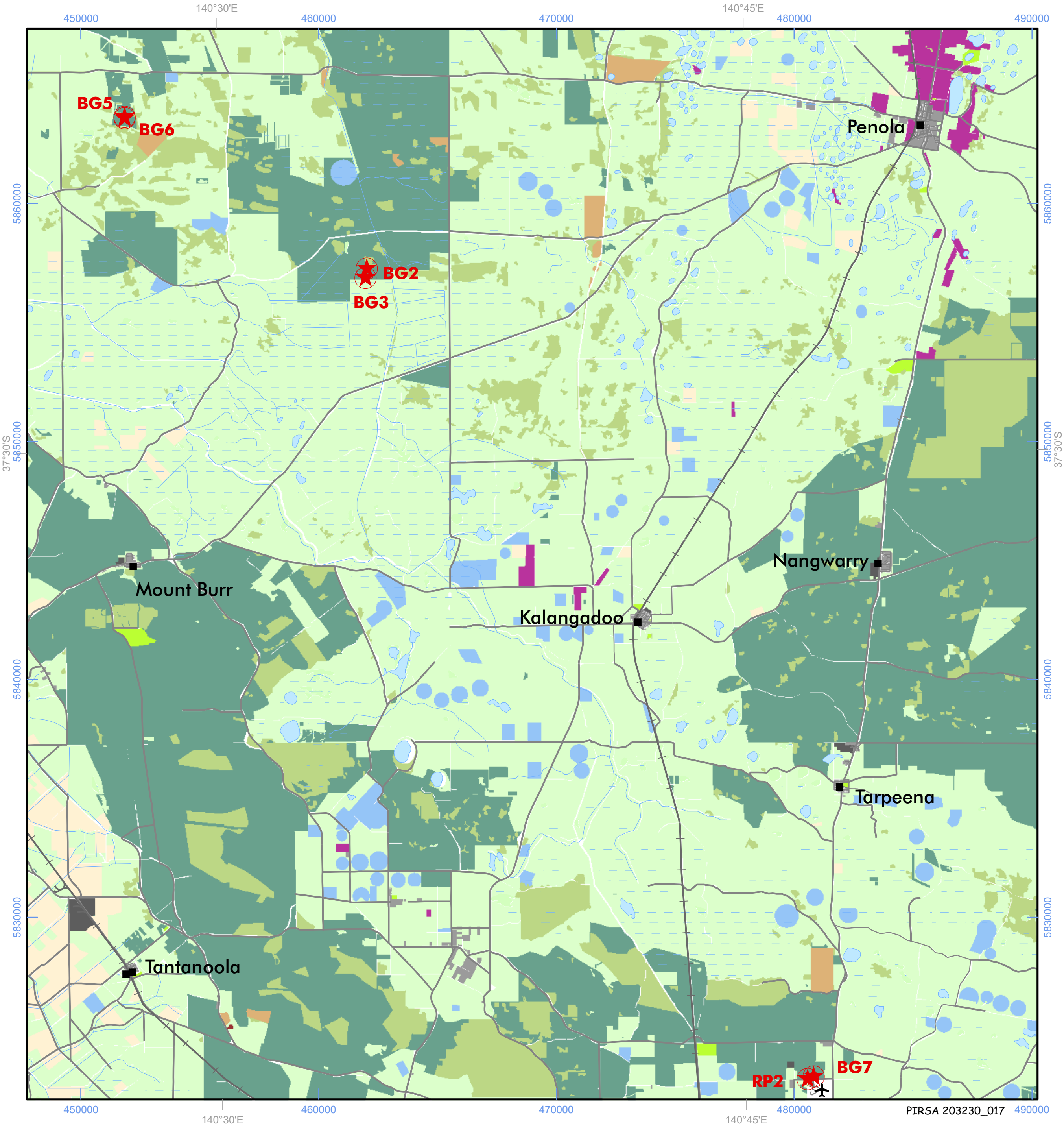
4.1.6 WETLAND ASSESSMENT

The Department for Environment and Heritage (DEH) is undertaking wetland mapping for the Lower South East Wetland Inventory (LSEWI). The aim of the project is to map all wetlands, collate existing information and collect additional baseline data to gain a better understanding of the extent, ecological character and condition of the wetlands of the Lower South East of South Australia. Physical parameters measured for the LSEWI included water conductivity, water temperature and wetland dimension. The sources of water to surveyed wetlands were also noted as accurately as possible. The project commenced in March 2004 and is due to report in June 2006.

The LSEWI project indicates that many wetlands occur within the Bakers Range study area (see App. D for details on the wetlands mapping within the study area).

4.2 LABORATORY METHODS

Core samples collected during the drilling program were analysed for soil physical and chemical properties. The soil physical properties measured were particle size analysis (PSA), soil water suction (SWS) and gravimetric water content (θ_g). Volumetric water content (θ_V) may be calculated by multiplying gravimetric water content by the mean density of the soil. Chloride concentration of the soil water $[Cl]_{SW}$ was also measured. Gravimetric water content measurements were made on all samples while SWS and chloride concentration of the soil



CSIRO research site
Railway
Highway
Secondary road
Airport
Lake
Subject to inundation
Watercourses

0 5 10 Kilometres

Projection: MGA Zone 54 Transverse Mercator
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Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing & industrial
Mining
Nature conservation
Plantation forestry
Residential
Services

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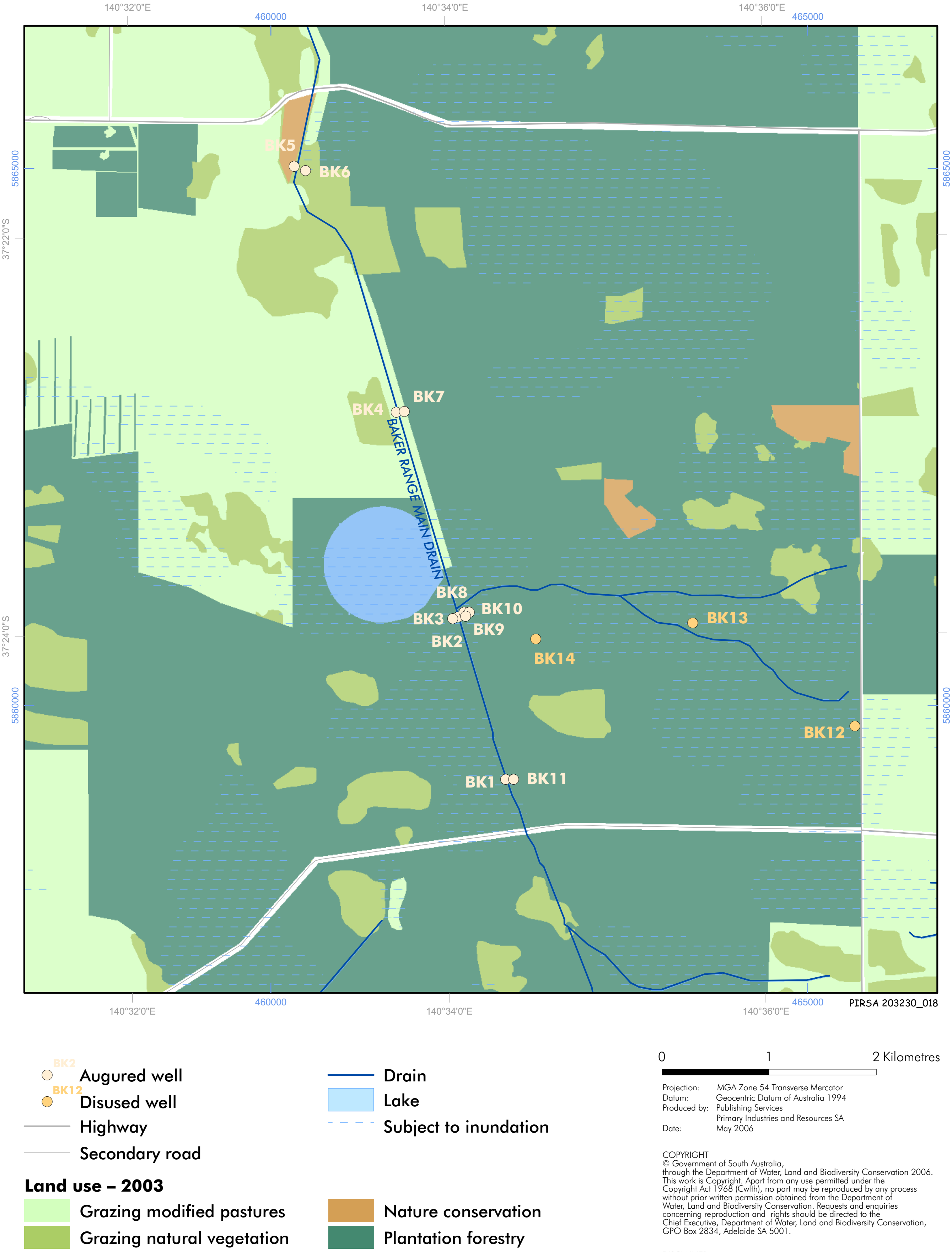
LOCATION OF CSIRO RESEARCH SITES

Figure 17



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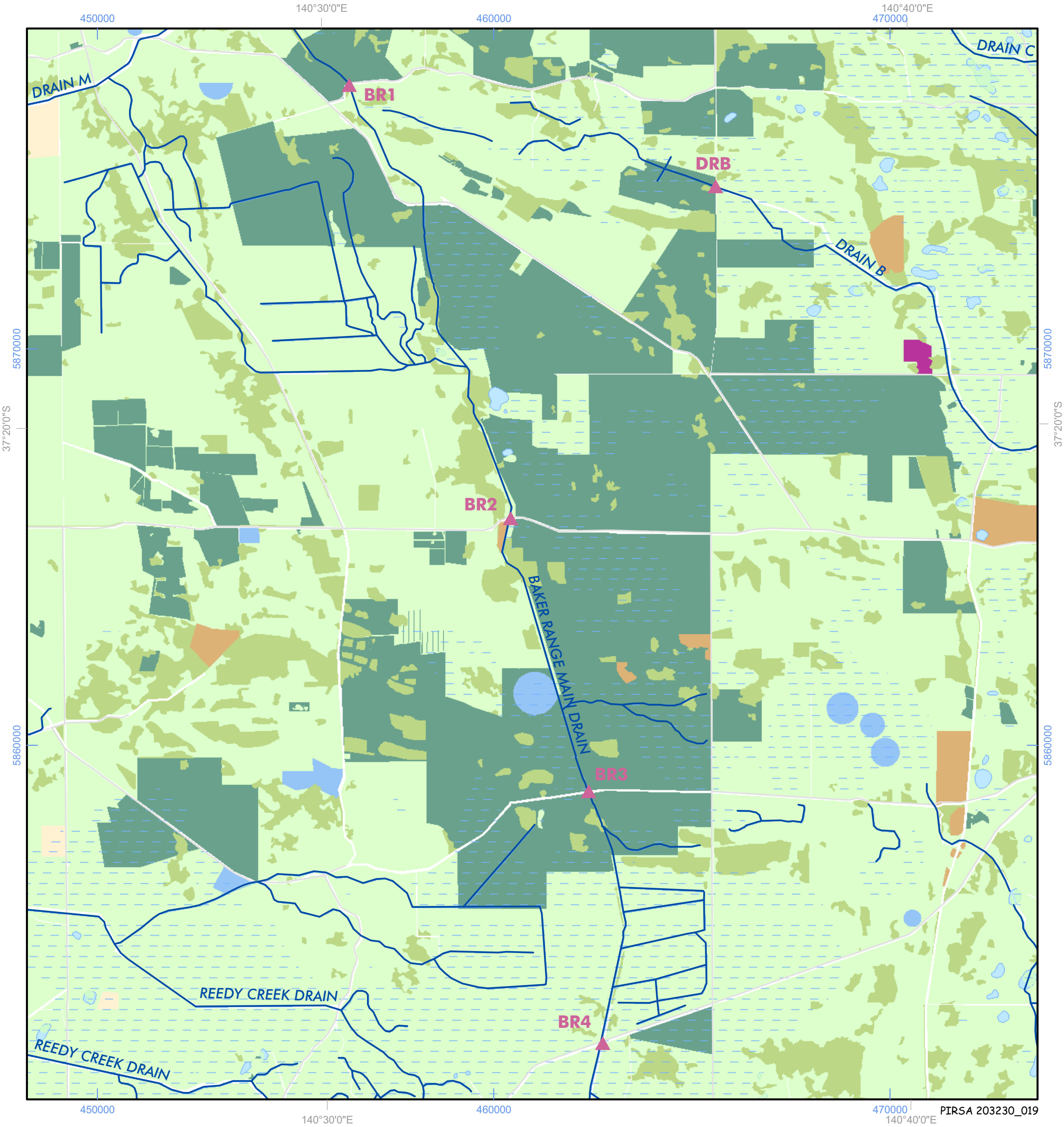
LOCATION OF MONITORING WELLS CLOSE TO THE BAKERS RANGE DRAIN

Figure 18



BR1 Drain flow site
Railway
Highway
Secondary road

Airport
Drain
Lake
Subject to inundation

Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing and industrial

Mining
Nature conservation
Plantation forestry
Residential
Services

0 2.5 5 Kilometres

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LOCATION OF DRAIN FLOW MEASUREMENTS – SEPTEMBER 2004

Figure 19

Table 5. Total annual flow at Penola–Robe Road (A2390515).

Year	**Annual total flow** (ML)	Days missing
1971	34 490	194
1972	2 056	31
1973	15 840	
1974	13 930	
1975	50 250	
1976	14 730	
1977	7 891	
1978	5 677	
1979	20 690	
1980	11 850	
1981	36 890	
1982	531.5	
1983	19 480	
1984	23 240	
1985	4 460	
1986	11 140	
1987	4 073	59
1988	25 010	
1989	49 640	
1990	19 050	
1991	19 520	
1992	24 620	
1993	18.7	323
Total	415 100	607
Minimum	18.7	
Maximum	50 250	
Mean	18 050	
Median	15 840	

Due to a number of missing days, these figures are indicative values of the total annual flow (source DWLBC surface water archive).

water measurements were made on approximately every second sample. PSA measurements were made on all core samples from the soil surface to a depth of 2.5 m and at ~2 m intervals thereafter. Description of analytical techniques is given in Appendix E.

Soil gas was collected on 20/4/2005 from the three sites fitted with soil gas samplers and then transported along with the soil samples to the laboratory for analysis.

The concentration of CO_2 in the soil gas was measured on a Europa Geo 20:20 mass spectrometer fitted with a gas sampler to allow transfer of the soil gas from the vacutainer.

4.3 ESTIMATING WATER USE

Tree water use was estimated using two independent methods. These were the water balance method (Benyon & Doody 2004) and a method utilising the accumulation of salt (measured as chloride) that takes place in the unsaturated zone when pine or blue gums are planted in areas previously under crop or pasture. These methods will be discussed in the following sections.

4.3.1 POINT WATER BALANCE

The total net rainfall, transpiration, soil evaporation, and change in volumetric water content of the root zone were measured or estimated for a 20 by 20 m plot containing ~40–50 trees at each site (Benyon & Doody 2004). The measurements took place every two to four weeks. The research plots were established at six blue gum and two pasture sites. At each site, measurements of the water balance component (net rainfall, and evapotranspiration) and change in the soil water storage were used to infer whether there was recharge to, or discharge from, the watertable under each study plot.

Rainfall was recorded continuously using a tipping bucket gauge logged by an automatic weather station near two sites (BG3 and BG4). Rainfall measurements were also made from rain gauges located in an open area near each site (within 1 km for most sites) and was read every 2–4 weeks (Benyon & Doody 2004).

As part of this project, water balance measurements were continued at two sites in the Bakers Range Drain area to mid-2005 (sites BG2 and BG3 in Benyon & Doody 2004). The details are presented in the update report in Appendix C.

4.3.2 SALT ACCUMULATION

The salt accumulation method assumes that import (accumulation) of chloride to the unsaturated zone following forestry development is the result of:

- Upward capillary flow from the groundwater, induced by tree roots in the capillary. Pure water is removed from the unsaturated zone leaving chloride behind in the soil water.
- Chloride present at low concentrations in rainfall being concentrated in the unsaturated zone as a result of infiltration and then evapotranspiration.

The following assumptions were made for the estimation of water use by trees:

- It is assumed that recharge to the groundwater ceases three years after the pines or blue gums are planted, although clearly this will be dependent on factors such as the rate of development, spacing and depth to the watertable. Three years was chosen using data from the Benyon water balance studies in the area.
- As a result of this, it is assumed that there is no loss of chloride from the unsaturated zone (as a result of recharge) for all but three years of the time when the area is forested. Clearly, this may not be the case, particularly when planting rotations result in the area being partially or completely cleared for significant periods.
- The method also assumes that there is no passage of chloride in the sap flow and subsequently via leaf fall and other dry matter (litter). Measurements of the amount of

chloride present in dry matter suggest that this is a valid assumption, unless there is significant salt stress on the pine or blue gum trees.

- The final assumption is that there is no loss (or gain) of chloride from the unsaturated zone when watertables rise and fall. In reality there is likely to be significant loss from the unsaturated zone to the groundwater by the annual watertable fluctuations. As this loss cannot be measured, it is probable that groundwater uptake using the chloride accumulation method will underestimate the chloride accumulation in the unsaturated zone and hence underestimate water use by the trees. This is the case in shallow watertable environments, particularly in areas of large watertable fluctuation.

The difference ΔCl (g/m^2)) between the chloride stored in the unsaturated zone under pine or blue gum forest (Cl_{forest} (g/m^2)) and that stored in the same unsaturated zone soils prior to planting the forests ($Cl_{cleared}$ (g/m^2)) should be the result of chloride from the groundwater (induced to move vertically upwards by tree water use) and that from rainfall. The chloride derived from groundwater can be expressed as the chloride concentration in the groundwater ($[Cl]_{gw}$) multiplied by the total amount of groundwater uptake by the trees (U_T). The chloride accumulated from rainfall (g/m^2) can be expressed as the chloride concentration in rainfall ($[Cl]_{rain}$ (g/m^3)) multiplied by the amount of rain that has fallen since the trees were planted. It is assumed that this equals the mean annual rainfall (R) multiplied by the age (A, years) of the forest. The following equation then applies:

$$\Delta Cl = Cl_{forest} - Cl_{cleared} = [Cl]_{gw}\, U_T + [Cl]_{rain}\, R\, A \qquad (1)$$

$$U_T = (Cl_{forest} - Cl_{cleared} - [Cl]_{rain}\, R\, A) / [Cl]_{gw} \qquad (2)$$

The mean annual groundwater uptake by the pine or blue gum forest (U_A m/y) can be estimated by dividing the total amount of groundwater uptake by the number of years that the tree is assumed to have been using groundwater (A-3). Hence:

$$U_A = U_T / (A-3) \qquad (3)$$

It is important to recognise that the method for determining groundwater uptake by trees is a ‘difference’ method. As such, any errors associated with measuring or estimating any of the components will impact on the final error in the groundwater uptake estimate. Furthermore, the relative error in the groundwater uptake estimate is directly proportional to the age of the plantation. As discussed in Leaney, Mustafa and Lawson (2006) in Appendix E, there will be a much larger error for the groundwater uptake estimates for the blue gum plantations (ages of 7–17 years) compared to that for the pine sites (60–79 years).

4.3.3 RECHARGE DETERMINATION

Recharge under different land uses was determined using several methods including the watertable fluctuation (WTF), water balance, chloride mass balance, and geophysical methods. Following is a discussion on the methods used in this report for the determination of recharge to the groundwater.

4.3.3.1 Watertable Fluctuation Method

This method assumes that a rise in the watertable as measured in an observation well is due to recharge. By multiplying the measured seasonal rise in the watertable observed in a well by the specific yield a recharge rate is estimated. The specific yield (Sy) is an aquifer property and is a measure of the ability of an aquifer to release groundwater from storage due to a unit decline in hydraulic head, and sometimes called effective porosity (Kruseman & deRidder 1992). The results depend on the physical properties of the aquifer. It is a reliable and effective method in shallow watertables and high winter rainfall environments (Armstrong & Narayan 1998).

When estimating recharge in a limestone environment, an Sy of 0.1 is normally used. For the study area, most water is sourced from the sandstone and an Sy of 0.1 was considered conservative. Previous work by the CSIRO (Armstrong & Narayan 1998) had shown that hydrograph records could be used to estimate the Sy for an unconfined aquifer. This technique has been further modified for the Lower South East by plotting the watertable fluctuation against rainfall greater than pan evaporation, and is shown in Figure 20. An Sy of 0.15 was calculated for a watertable rise of 1.3 m (average water fluctuation noted in the Hundred of Monbulla equates to a groundwater recharge of ~200 mm/y).

An additional technique is to assume the potential porosity calculated from the neutron log from downhole geophysics to be the equivalent of Sy. Interpretation of logs in the area has given similar values of Sy.

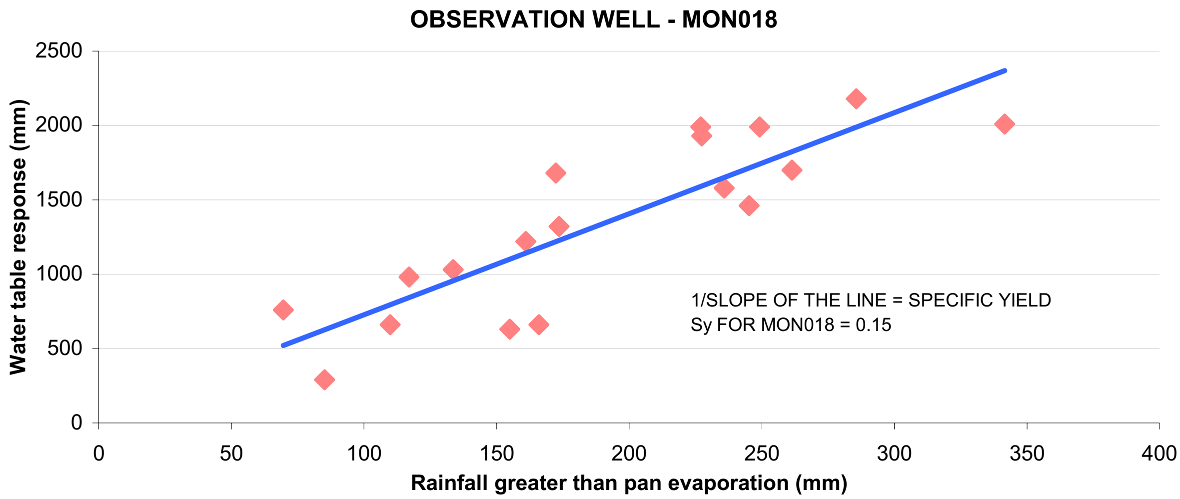


Figure 20. Calculation of specific yield from the slope of a hydrograph.

4.3.3.2 Water Balance Method

This method, detailed in Benyon and Doody (2004), uses a combination of measurements of water balance components such as net rainfall, evapotranspiration and changes in soil water storage to infer whether there was recharge to (deep drainage) or discharge (water uptake by trees) from the watertable under each study plot. Due to the sandy surface and flat to gently undulating topography, it is assumed that there was little or no net loss or gain of water from the study plots via surface or subsurface lateral flows.

The net deep drainage to, or uptake from, below the deepest soil water measurements under the plot was calculated as:

$$Q_{wt} = P - I - T - E - (S_C - S_P) \qquad (4)$$

Q_{wt} is either drainage (a positive value) or water uptake (a negative value) below the maximum depth of soil water measurement (3–6 m in most plots). P is total precipitation, representing intercepted rain that wets the exterior surfaces of the vegetation and evaporates without falling to the ground. The transpiration (T) is the water taken up through plant roots, which travels through the plant to be lost to the atmosphere via evaporation through the leaves and other plant surfaces. E is measured or estimated evaporative losses from the soil surface and leaf litter. S_C and S_P represent current volumetric water content of the root zone measured using a neutron moisture meter and the previous volumetric water content of the root zone, respectively.

4.3.3.3 Chloride Mass Balance

Using the analyses for the core samples collected under native vegetation and in cleared areas, a point estimate for recharge was made at each of the sites studied.

For native vegetation, recharge can be estimated by using the chloride mass balance technique, the same method used by Allison and Hughes (1978). This method has been used extensively over the last 30 years. It assumes that, under steady state conditions, the chloride present in the soil water below the root zone of the native vegetation is the same as that recharging the groundwater. As such, the chloride concentration of rainfall ($[Cl]_{rain}$) when multiplied by the mean annual rainfall amount (MAR) should equal the chloride concentration of soil water ($[Cl]_{sw}$) multiplied by the rate of recharge (Rech) to the aquifer.

$$[Cl]_{rain} * MAR = Rech * [Cl]_{sw} \tag{5}$$

A similar chloride mass balance approach can also be made to estimate recharge under cleared areas providing the cored site has been cleared long enough, and the recharge rates high enough, to flush out the stored salt in the unsaturated zone (see App. E for details).

Previous recharge work in the Mount Gambier region by Holmes and Colville (1970), and Allison and Hughes (1972, 1978), estimated no recharge under pine forest.

4.4 UPSCALING WATER USE

The water balance and salt accumulation methods both estimate tree water use at a point scale. For the water balance – sap flow methods, transpiration and interception are usually measured on a single tree and evaporation is estimated on an immediate area basis. Hence, the groundwater uptake measurement probably averages that over the canopy area of the tree.

For the chloride accumulation method, the chloride is measured at a point scale, being the site of the soil core. As such, there is the potential for variability in this measurement, depending on the proximity of roots to the soil sampled. As the trees grow and the root system becomes more extensive, the variability in chloride measured in a forest is likely to decrease. For this reason, greater spatial variability in groundwater uptake measurements in the younger blue gum forest could be predicted when compared to the well-established pine forest sites.

A spreadsheet approach was used to estimate the water–salt balance over a larger area (a pilot study area) using results from both methods, combined with regional groundwater data including average annual recharge, watertable response, surface water flow (drains), groundwater gradient and potentiometric surface.

A numerical modelling approach was also applied to the pilot study area to model the relationship between rainfall, drainage flow, groundwater levels, water extraction, and the impact of different land uses.

The following sections are discussions on the methodology used for assessment of the regional impact of different land uses.

4.4.1 WATER AND SALT BALANCES

Generally, over a long period of time, the volume of water and mass of salt in the aquifer will be in equilibrium under steady state conditions. Changes in land use will impact this balance. Irrigation will potentially disturb the balance in two ways — by reducing the watertable from extensive irrigation, or by raising the watertable through seepage losses and drainage below the root zones. Perennial plants and trees with deep roots that gain access to the shallow watertable will also have an impact on reducing the groundwater level through evapotranspiration. Salt from the groundwater will be recycled or accumulated in the unsaturated zone around and below the root zone. A general expression for the water balance is:

$$\text{water in} - \text{water out} = \Delta S \tag{6}$$

where ΔS is the change in groundwater storage and could be negative (water is leaving the system) or positive (water entering the system). This approach has been used to calculate the water balance for the pilot study area (Fig. 21).

In a similar way, the salt balance for the pilot study area is:

$$\text{Salt in} - \text{salt out} = \Delta\text{Salt} \tag{7}$$

where ΔSalt is the change in mass of salt stored within the pilot study area. The total calculated area was 6776 ha. The land uses include 3943 ha of hardwood (58.19%) and 858 ha of softwood plantations (12.66%). Area of remnant native vegetations is 660 ha (9.74%) and 125 ha of irrigation (1.85%) with 1190 ha of pasture (17.56%) calculated from a 2002 land-use map and adjusted to the 2005 aerial photography.

Recent work by Benyon and Doody (2004) and Benyon (2005; see App. C) estimated hardwood and softwood plantation water use at 3.5 and 2.5 ML/ha/y, respectively. Irrigation water use was calculated from 2003–04 annual water-use returns as 850 ML/y. Allowances were made for a recharge of 8 mm/y under native vegetation; this estimate is based on Leaney, Mustafa and Lawson (2006).

The 2004 and 2005 annual rainfall (data obtained from Mount Gambier BOM) of 686 and 556.8 mm, respectively, from the Penola PO station was used along with recharge estimations of 375 and 188 mm calculated from the observation well MON008 using the WTF method. This well is located slightly to the east of the pilot study area, and was used as the data from well SHT012 closer to the site was affected by land use. Salinity of the rain was estimated as 50 mg/L (chloride mass concentration in rainfall was 11 mg/L calculated from monthly rain water samples collected in Mount Gambier between September 2004 and May 2005).

Lateral through flow was calculated using the following formula:

$$Q = TWI \qquad (8)$$

T is the transmissivity of the aquifer, and a value of 1500 m^2/day was used, estimated for the Bridgewater Formation, which is considered representative of the shallow aquifer in the area. The width, W, averaged 7000 m for the inflow front and 8600 m for the outflow (Fig. 21). The hydraulic gradient (I) calculated from the potentiometric levels was 0.0012 for both inflow and outflow for the pilot area, as the potentiometric contour lines show a uniform gradient. The estimated saturated aquifer thickness was 15 m (Bridgewater Formation) with an Sy of 0.15 estimated from WTF and geophysical logs.

The total flow for the Bakers Range Drain for 2004 was 18 452 ML as measured at gauge station A2391001 at Phillips Road.

The following parameters were also used in the water and salt balance calculation for the pilot area:

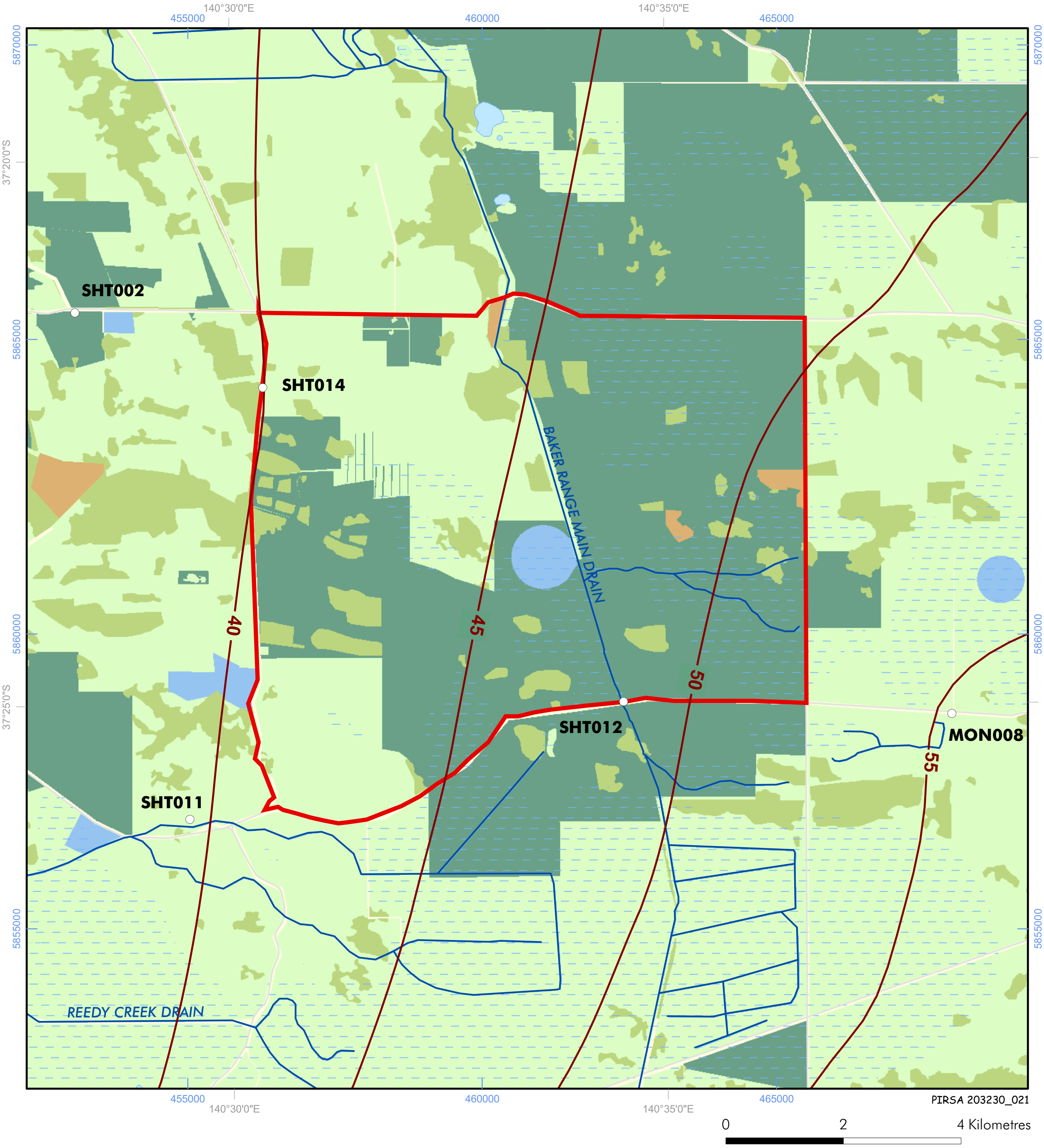
- salinity of water in storage = 1000 mg/L (estimated average salinity within the area)
- salinity of inflow = 1000 mg/L (from observation wells up-gradient)
- salinity of outflow = 750 mg/L (from observation wells down-gradient)
- salinity of drain water = 600 mg/L (average estimate based on samples collected from the drain in October 2004)
- salinity of irrigation water = 1000 mg/L
- drainage from irrigation estimated as 5% of the applied water (S. Pudney, DWLBC, pers. comm. 2006)
- salinity of water drainage from irrigation was assumed to increase by 25% from the initial salinity of the applied water.

The following land-use scenarios for water–salt balances were also calculated for the pilot study area:

- totally dryland pasture
- totally irrigated pasture
- totally planted with blue gum
- totally planted with pine
- totally planted with native vegetation.

4.4.2 NUMERICAL MODEL

One of the objectives of the project was to model, within a defined study area (pilot area), the relationship between rainfall, drain flows and groundwater levels for a range of land-use change scenarios based on known or measured rates of evapotranspiration for different land uses to identify a preferred modelling approach.



Pilot study area

40 Water level – March 2005 (mAHD)

Highway

Secondary road

SHT011 Observation well and number

Drain

Lake

Subject to inundation

Land use – 2003

Grazing modified pastures

Grazing natural vegetation

Irrigated areas

Nature conservation

Plantation forestry

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Land use impact on water quality and quantity in the Lower South East – South Australia

LOCATION OF WATER AND SALT BALANCE CALCULATION AREA (PILOT STUDY AREA) SHOWING GROUNDWATER LEVEL CONTOUR AND OBSERVATION WELLS

Figure 21

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The finite-difference groundwater flow modelling code, MODFLOW 2000 (Harbaugh et al. 2000), was used for simulating groundwater flow in the pilot study area. Pre- and post-processing were accomplished by using Groundwater Modelling System (GMS) Version 6 (Brigham Young University 2005). GMS is a commercial computer program that was used to prepare the input data set for MODFLOW and to graphically illustrate model input and output. Aquifer properties, recharge and discharge characteristics were incorporated into MODFLOW using GMS.

The intention of the modelling process was to develop a successful and properly calibrated groundwater flow model that could be used for the following reasons:

- to predict watertable variations resulting from current land use and possible future land use
- to process modelling output data in order to draw inferences concerning impact of land use on the quality and quantity of groundwater resources under various scenarios.

The model extended beyond the pilot study area and boundaries of the plantation to minimise possible simulated boundary effects surrounding the forest. The northern and southern boundaries of the study area coincide with the groundwater flow paths (Fig. 22).

The site was represented as two hydrostratigraphic units — the Bridgewater Formation and upper Gambier Limestone were combined to form one unit, with the lower Gambier Limestone represented as the second unit. These two units are directly connected hydraulically.

Geologic material underlying the lower Gambier Limestone was assumed to represent a no flow boundary. Both steady and transient state models have been constructed and are being calibrated.

Based on regional groundwater potentiometric maps, groundwater flow was assumed to be generally from the east to the west, and perpendicular to the southern and northern boundaries of the study area. Therefore, the east and west boundaries were assumed lateral inflow and outflow boundaries, and the southern and northern boundaries were assumed to be no flow.

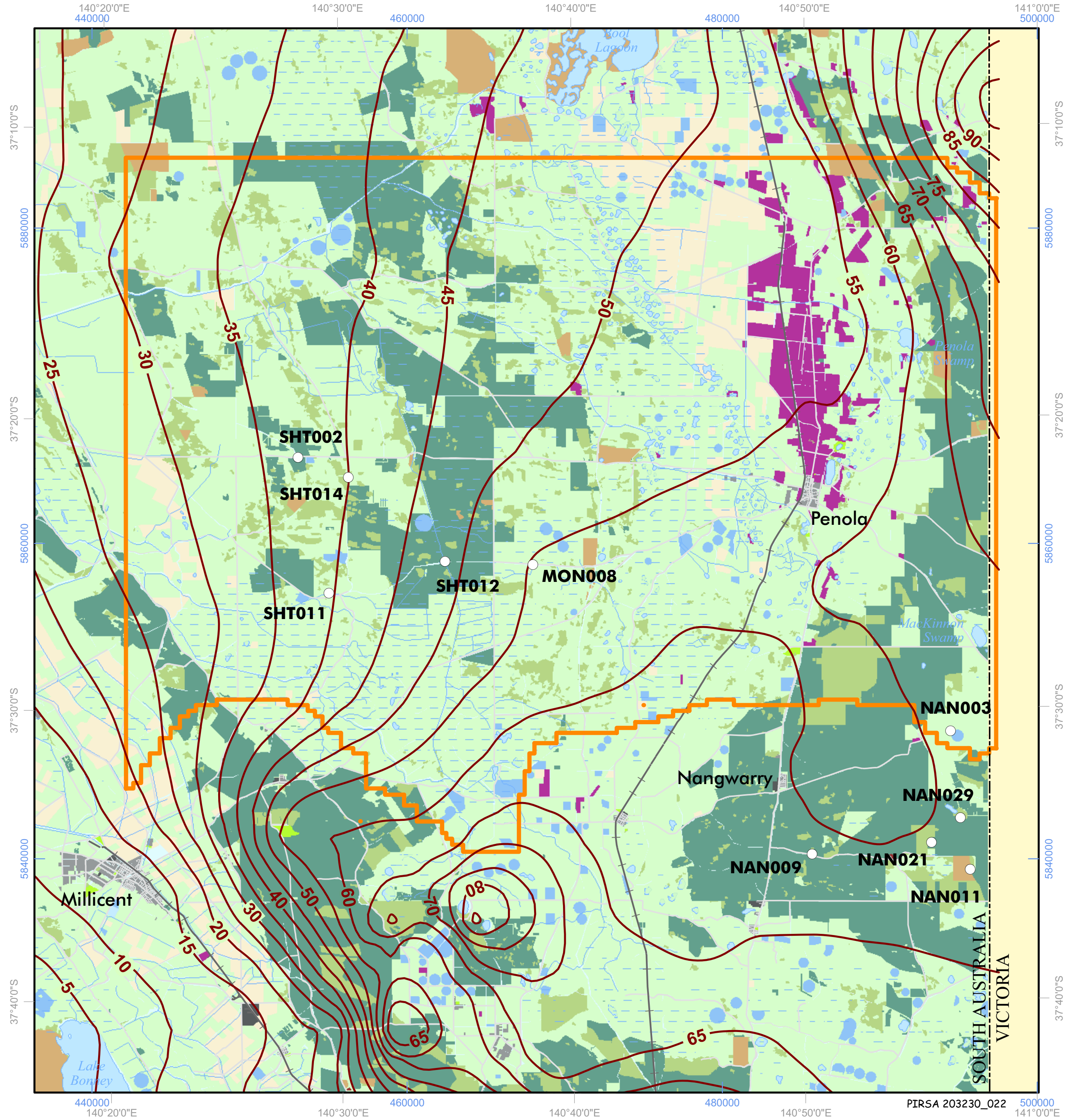
The inflow from the east and outflow at the west were simulated with constant head boundaries.

Surface-water features in the study area (the drains) were simulated as MODFLOW drain boundaries in the model. This is because it was assumed that there is no aquifer recharge from the drains, but rather groundwater only discharges to the drains when the water level is above the base of the drain.

Groundwater withdrawal from the aquifer system for irrigation and domestic purposes were simulated with the well (WEL) package in MODFLOW.

The recharge package in MODFLOW was used to simulate net real recharge, which represents net infiltration of rainfall at land surface to the aquifer system. Recharge values used in the model ranged from 0.0–200 mm/y.

Groundwater usage by plants (transpiration) was simulated with the evapotranspiration (EVT) package in MODFLOW. Evapotranspiration was applied only to areas covered by plantation forest.



Numerical model boundary

Water level – March 2005 (mAHD)

Railway

Highway

Secondary road

SHT011 Observation well and number

Lake

Subject to inundation

Watercourses

Land use – 2003

Cropping	Mining
Grazing modified pastures	Nature conservation
Grazing natural vegetation	Plantation forestry
Irrigated areas	Residential
Irrigated perennial horticulture	Services
Manufacturing and industrial	

0 5 10 15 Kilometres

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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BOUNDARY OF NUMERICAL MODEL, OBSERVATION WELLS AND WATER LEVEL CONTOURS

Figure 22

In areas where depth to water level is greater than 6 m, a transpiration rate of zero was used. Transpiration rates, which varied from zone to zone, were applied to areas where the depth to water level was less than 6 m.

Information about the hydraulic properties of the aquifers was sourced from literature. These estimates were determined from analysis of aquifer tests conducted in the unconfined limestone aquifer. Little information about vertical hydraulic conductivity is available for the various formations comprising the aquifer system, but values can be estimated from reported ratios of vertical to horizontal conductivity.

The major components of the water budget for the study area include rainfall, aquifer recharge, surface runoff, transpiration and discharges via drains and pumping wells. Surface runoff could be minimal for areas underlain by sand and average recharge rates would approach annual runoff rates in such areas.

Using simulated 1970–71 groundwater levels as initial or starting head, the transient model was calibrated to measure water levels from 1970–2004.

The estimates of recharge were obtained from salt accumulation and water balance methods. Recharge under native vegetation has been estimated at 5.5 mm/y; recharge under pasture was estimated to vary between 47–190 mm/y, with an average of 145 mm/y. Recharge under pine and blue gum plantations has been assumed to decay exponentially from 145 mm/y to 0 mm/y. In fallow years and the first year of planting, recharge was assumed to be 145 mm/y.

Evapotranspiration rates, extinction depth and the percentage of evapotranspiration applied during winter and summer months were obtained from R. Benyon (CSIRO, pers. comm., 2005). An extinction depth of 6 m was applied under all land uses. The extinction depth is interpreted in the following way. When the depth of the watertable beneath the ground surface is greater than 6 m (extinction depth), evapotranspiration from the watertable is curtailed. When the watertable is at or above the ground surface, evaporation loss from the watertable occurs at the maximum rate. The annual water-use rates in research areas covered by plantation forest was estimated to range between 107–671 mm/y for eight of nine plots by Benyon and Doody (2004).

Groundwater use estimates were used from the 2003 annual water-use returns. These values were converted into an extraction rate per parcel, with a single well assigned to each parcel. The wells were located in the centre of each parcel in the model.

The drains, which were simulated with the MODFLW drain package (DRN), required user specified values for conductance (a parameter incorporating length, width and thickness of the drain connection with the aquifer). The specified conductance for the drain was based on estimates of vertical hydraulic conductivity of the bed sediments. The values were considered to be reasonable approximations of their true values based on published values for silty, low-permeable materials. The drain width was measured at several locations along the Bakers Range Drain within the modelled area (Table 6).

Table 6. Bakers Range Drain dimensions, September 2004.

Site	**Width** (m)	**Depth** (m)
Penola–Robe Road	18.3	0.92
LDE Road	10.7	0.82
Penola–Millicent Road	10.7	1.00

The groundwater flow model was calibrated using both steady state and transient simulations of the groundwater flow system, using data collected between 1970–2005. Prior to calibration, criteria were established to evaluate the match between the simulation results and measured data. Simulation results were evaluated by comparing the water levels at observation wells to simulated variations in responses to parameter changes. Between model runs, changes were made to one parameter at a time until the simulated water level values were deemed to agree adequately with 1970–2005 measured values at several observation points.

The simulation strategy is summarised as follows:

- identification of a period in the past, during which the aquifer system was in equilibrium
- carrying out a steady state simulation for that period to obtain computed water levels that are acceptably close to the mean of the measured water levels
- using the simulated heads as initial conditions for transient simulation
- modelling all intervening stress to specified time.

5. RESULTS

5.1 FIELD PROGRAM

5.1.1 SITE SELECTION

The two regional study areas were Nangwarry and Bakers Range, with three sites at Penola Forest, Mount Gambier Airport and Beachport added for spatial distribution. The soil salinity maps generated in the EM survey were used for the site selection. Table 7 is a summary of the soil coring and site descriptions.

5.1.2 EM SURVEY

The survey results showed that all sites generally had very low apparent electrical conductivity (ECa) values <0.4 dS/m, indicating sandy soils with low clay levels. The few sites with higher ECa values to ~0.6 dS/m (D10, blue gum site) indicate some proportion of clay in the profile with possible low salinity levels. Care is required when interpreting the results as various combinations of sand, clay and salt can be misleading.

Appendix A provides the results for each site, maps showing the trace of the EM survey and the boundary used to plot the results. The maps were orientated with north to the top for easy interpretation of the coordinates.

5.1.3 DRILLING AND CORING PROGRAM

The following is a detailed description of the results from the soil coring program. Geological logs are attached in Appendix B. Figure 16 shows the location of the sites.

5.1.3.1 Study Area A

The land-use types at this site were pine forest and native vegetation. The first well was drilled on the side of a sand dune, and the second on the flat to the east. In each well the geology is slightly different, with A1 (pine plantation) having 2.5 m of sand overlying 3 m of clay, which overlies sandstone, whereas A3 (native vegetation) has 3.5 m of sand, overlying 1 m of clay overlying sandstone. The watertable is located within the sandstone. In the deeper hole, tree roots were observed all through the drilling and were still present at 9–9.5 m when the watertable was cut.

Site A1 was completed with three soil CO_2 gas tubes, while A3 was completed as an observation well. Water level and salinity data for site A1 were collected from NAN009 a short distance across the road.

5.1.3.2 Study Area B

The land-use types sampled at this site were pine plantation (B4), blue gum plantation (B5) and non-irrigated pasture (B6).

Table 7. Summary of core site details.

Site	Permit number	EC (us/cm)	Land-use type	Easting	Northing	Hundred	Total depth (m)	PVC diameter (mm)	Slotting interval (m)	Comments
A1	104327	N/A	Pines	485775	5840160	Nangwarry	10	N/A	N/A	Near NAN009; completed with soil gas sniffer. Prior land use was scrub. First rotation 1926; pines burnt in 1950. Second rotation1953, and the third rotation in 1988.
A3	104214	1295	Native vegetation	487280	5840455	Nangwarry	7.9	50	1.9–7.9	East of NAN009 — observation well. Completely burnt in February1983 fires then regenerated.
B4	104216	1660	Pines	493830	5840580	Nangwarry	8	50	5.1–8	SE of NAN021 — observation well. First rotation established in 1968. Heathy scrub prior to plantation.
B5	104215	N/A	Blue gums	493320	5841050	Nangwarry	5	N/A	N/A	Adjacent to NAN021 – Cored and abandoned. First rotation 1988, prior land use was cleared pasture. Second rotation 2000.
B6	104217	590	Pasture – north	493490	5840095	Nangwarry	8.3	50	4.3–8.3	South of NAN021 — observation well.
	108344	820	Pasture – middle	493490	5840095	Nangwarry	15	50	12.5–14	
	108345	820	Pasture – south	493490	5840095	Nangwarry	22	50	19.15–20.65	
C7	104218	965	Irrigation	494615	5848035	Nangwarry	11.9	50	5.9–11.9	Southeast of NAN003 — observation well.
C8	104219	370	Pasture	494470	5848280	Nangwarry	10.2	50	4.2–10.2	Near NAN003, northeast of stockyards — observation well.
D10	104225	N/A	Blue gums	461991	5857284	Short	4	N/A	N/A	Adjacent to SHT024 — cored and abandoned. Planted 1998 on cleared pasture land.
E11	104222	1320	Blue gums – 6 m	461325	5860723	Short	6	100	2–6	Northern hole — transducer observation well. Equipped with multi-parameter transducer (EC & water level). Planted in 1998 on cleared pasture land.
	104221 A	1375	Blue gums – 5.5 m	461328	5860721	Short	5.7	50	5.2–5.7	Southern hole — observation well. Planted in 1998 on cleared pasture land.

Site	Permit number	EC (us/cm)	Land-use type	Easting	Northing	Hundred	Total depth (m)	PVC diameter (mm)	Slotting interval (m)	Comments
	104221 B	1470	Blue gums – 6.5 m	461328	5860725	Short	6.8	50	6.3–6.8	Middle hole — observation well. Planted in 1998 on cleared pasture land
E12	104224	2480	Irrigation — pasture	461202	5860871	Short	5.9	100	1.9–5.9	Transducer observation well. Equipped with multi-parameter transducer (EC & water level).
E13	104223	1725	Pasture	461215	5860701	Short	5.9	100	1.9–5.9	Transducer observation well. Equipped with multi-parameter transducer (EC & water level).
F14 A	104220 A	N/A	Pasture — hill	452243	5864425	Short	6	N/A	N/A	Hard bar that could not be penetrated. Cored and abandoned.
F14 B	104220 B	N/A	Pasture – flat	452146	5864754	Short	4	N/A	N/A	Drilled on the flat — shallow watertable. Cored and abandoned.
F15	104226	1380	Native vegetation	452209	5864045	Short	18	50	12–18	Bush track — observation well.
F16	104227	N/A	Blue gums	451820	5863675	Short	3.5	N/A	N/A	Low ground — completed with soil gas sniffer. Planted in 1998 on cleared pasture land.
F17	104228	N/A	Blue gums	451815	5863575	Short	7	N/A	N/A	High ground — cored and abandoned. Planted in 1998 on cleared pasture land.
G18	108346	1130	Pines	494520	5859000	Penola	6.5	N/A	N/A	At CSIRO Julia Hill site, cored and abandoned. Relatively good healthy scrub in 1965 with trees. By 1968, the area had been cleared and had very low vegetation with no trees. First rotation established in 1970.
H19	108347	1700	Pines	480560	5823210	Young	6.5	N/A	N/A	At CSIRO airport road site, cored and abandoned. First rotation established in 1945. Prior land use was scrub to 1934, then pasture until pines. Second rotation in 1996.
I20	108348	N/A	Blue gums	417832	5859597	Symon	3	N/A	N/A	At CSIRO Beachport site, cored and abandoned. First rotation planted in 1994 on cleared pasture land.

N/A — the site was abandoned after coring and was not completed as a piezometer due to the existence of a nearby observation well.

All three sites had very similar geology, comprising a sand layer 0.2–0.9 m thick, overlying a clay band of 1–1.6 m thickness, overlying the sandstone. The watertable is located within the sandstone.

As an observation well (NAN021) exists at the blue gum location, the B5 well was cored and backfilled. The other two wells were completed as piezometers.

At the non-irrigated pasture site, two additional piezometers were constructed alongside well B6 as part of the second drilling phase. The three piezometers were completed at different depths below the watertable to determine if there is any salinity stratification, and for calculation of the age of the recharged water using CFC analysis.

5.1.3.3 Study Area C

The land-use types at this site were irrigated pasture (C7) and non-irrigated pasture (C8). The two sites were drilled ~100 m apart but show very different geology. The well under the irrigated site revealed ~1.5 m of sand overlying 1.5 m of clay, overlying 1.5 m of sandstone, then another 0.5 m band of clay occurs prior to the sandstone reoccurrence.

The second well drilled under non-irrigated pasture showed 10 m of sand and clay overlying the sandstone. This depth to the carbonate material is double that of the previous well, although the topography is relatively flat.

Under the irrigated site, the watertable is contained within the sandstone, whereas under the non-irrigated site it occurs within the non-carbonate clays.

5.1.3.4 Study Area D

This site studied blue gum land use (D10) and was drilled close to an existing observation well (SHT024); the well was backfilled after completion.

The geology comprised 1.5 m of sand overlying clay, with the watertable being cut at ~3.4 m, which is within the clay unit.

5.1.3.5 Study Area E

The land uses investigated at this site were blue gums (E11), irrigated pasture (E12) and non-irrigated pasture (E13).

The blue gum site investigation was completed with two additional wells finished at 5.7 and 6.8 m. The purpose was to determine if salinity stratification exists within the seasonally fluctuating watertable. Drilling at the site revealed 1 m of sand overlying 1.5 m of clay overlying another 1 m of sand prior to the sandstone.

At the non-irrigated site, drilling samples were only possible to the top of the watertable and then no returns to surface occurred. However, the geology to that point was almost identical to the blue gum site.

The irrigated pasture site seemed a little different as a drilling bit sample at the completion indicated that the material was still sandy clay. However, after examining the logs of the previous two wells, it became clear that the sandstone was intersected and that the sandy clay remained on the bit from the upper section of the hole. At this location, the watertable was cut at about the interface between the clay and sandstone at ~4.5 m below ground level.

After the watertable was cut, it rose ~1 m to <3.5 m from the ground surface. This indicates that the clay at this site is acting as a semi-confining unit.

5.1.3.6 Study Area F

The land uses studied at this site were non-irrigated pasture (F14 A and B), native vegetation (F15) and blue gums (F16 and F17).

At the non–irrigated pasture site, depth to the watertable was 20.57 m (measured in an existing CSIRO observation well alongside), which was ideal to study salt accumulation in this type of environment. Unfortunately, an extremely hard bar of sandstone occurs at 5.5–6 m, which prevented cores being recovered past this point. A second attempt further down the slope resulted in the watertable being intersected at ~3 m. An existing observation well is still current at this site and could be used to study soil-moisture content using a neutron moisture instrument. The geology in the deeper hole comprised 3.5 m of sand overlying 0.4 m of clay, overlying 0.6 m of sandstone, which overlies 0.5 m of clay prior to sandstone being encountered again. This sequence was observed in a well drilled at site C, where the carbonate deposition was interrupted.

The cored hole at the native vegetation site was completed to 18 m, with cores to 15.5 m. A 6 m sand layer overlies 1.5 m of sandy clay overlying 7 m of clay prior to the sandstone being cut at 14.5 m. The well was completed as an observation well and had three soil CO_2 gas detection tubes attached outside the casing.

Two holes were drilled at the blue gum land-use sites. A previous study by Benyon and Doody (2004) showed differing tree water use in this stand of trees. The deeper site (located on a sand dune) is underlain by a hard sandstone bar at 7 m which the drilling auger could not penetrate and it would seem the tree roots are having a similar difficulty, as the tree water use for this site is lower than the site located on the flat in a shallow groundwater environment. An existing CSIRO observation well had previously been drilled at the deeper site and had a water level of 10.56 m. At the shallow watertable site a short distance to the north, the cored well was successfully completed at 3.5 m. The logs of the two wells differ slightly, as the deeper well, which was drilled on a sand dune, had 1.3 m of sand overlying 5.7 m of sandstone. In the shallow hole, 1.5 m of sand overlies 1.5 m of clay before the sandstone is encountered.

The shallow blue gum site had two soil CO_2 gas detection tubes set in the hole, as it was being backfilled.

The geology within the sand dune system is observed to vary significantly from sand over sandstone to sand over thick clays. For this site, the watertable is within the sandstone layer.

5.1.3.7 Study Area G

The land use studied at this site was pine plantation (G18). The geology for this site is sand from ground surface to ~2.75 m. From 2.75–3 m, the sand has higher moisture content and the appearance of clay particles. Sandy clay from 3–5 m is followed by clay from 5–6.5 m.

An existing CSIRO observation well is used for water level and salinity information.

5.1.3.8 Study Area H

The land use studied at this site was pine plantation (H19). The geology at this site comprises ~1 m of sand overlying sandy clay to 1.5 m overlying 1.5 to 4 m of clay followed by limestone, then marly limestone, finishing in marl at 6.5 m. An existing CSIRO observation well is used for water level and salinity information.

5.1.3.9 Study Area I

The land use studied at this site was blue gum plantation (I20). The geology comprises 0.5 m of sand overlying sandstone. The watertable is in the sandstone. An existing CSIRO observation well is used for water level and salinity information.

5.1.4 TREE WATER-USE MEASUREMENTS

2004–05 recorded a mixture of weather conditions. Winter in 2004 was very wet, with rainfall across the region in the upper decile. Above-average rainfall occurred from June to mid-December 2004. This was followed by a dry spell of nine months. Total rainfall for the 12 months from July 2004 to June 2005 was below the long-term mean and, according to the BOM, rainfall across the Lower South East from September 2004 to August 2005 was in the lowest decile, with a severe rainfall deficit being recorded across much of the region (100–200 mm less than the long-term mean; Benyon 2005; see App. C).

Table 8 shows the results of the water balance for the CSIRO sites including the two sites funded by this project within the Bakers Range pilot study area. Discussion of the results will be covered under the water-use estimates section 5.3.

Groundwater levels at sites BG2 and BG3 have not exhibited the usual winter rise (Fig. 23). The watertable depth at 5 September 2005 was 2.9 m at site BG2 and 3.2 m at BG3. Figure 23 shows that the September 2002 depth was ~0.6 m in BG2 and 0.9 m in BG3. In early September 2005, there was more than a 200 mm soil water deficit compared to the previous three winters. This is probably largely a reflection of the low total rainfall in the past 12 months, however it might also be partly a result of lowering of the watertable due to groundwater uptake by the extensive area of blue gum plantations in this part of the Wattle Range. Most of these plantations have reached canopy closure (3–5 years old). Above-average rainfall in spring 2005 did not occur, and Benyon (2005; see App. C) anticipated in this situation it is unlikely that watertables at sites BG2 and BG3 will rise to the depths they did in winter and spring of the previous three years. If this was the case, there might be an even greater lowering of watertables over the summer of 2005–06 and autumn of 2006 than has occurred in previous years. He also suggested that it would be worthwhile continuing to monitor evapotranspiration and depth to the watertable at sites BG2 and BG3 to observe their responses.

Comparing sites BG2 and BG3 to sites BG5 (F16) and BG6 (F17), the maximum depth to groundwater has increased at BG2 and BG3 over the past four autumns, despite above-average rainfall in 2002–03 and 2003–04, whereas it has displayed no clear trend at BG5 and BG6 (Table 8). Water use at BG5 has increased each year over the past three years from 853 mm in 2002–03 to 957 mm in 2004–05. The reason for this is not known. Site BG5 used ~100 mm more groundwater in 2004–05 than it did in either of the previous two years.

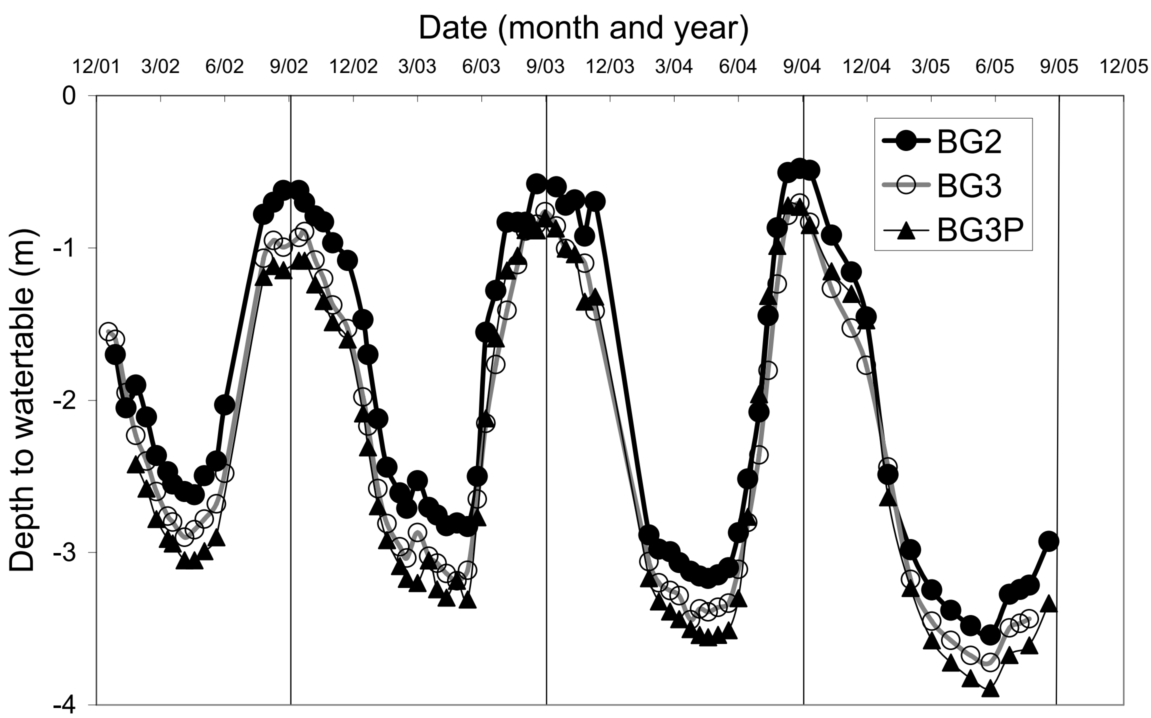


Figure 23. Depth to the water table at blue gum sites BG2, BG3 and BG3 pasture (source from Benyon, 2005; see App. C)

This is partly a result of higher total evapotranspiration (ET) and partly a result of lower rainfall. Annual water use of trees on BG6 continues to be determined largely by rainfall. Comparison of rainfall, annual evapotranspiration and net changes in soil water for each of the past three years suggest there might be a small amount of groundwater recharge at this site; however, it is not statistically significantly different to zero.

Despite having depth to groundwater of ~6 m, the radiata pine site RP2 (H19) near Mount Gambier Airport has the highest evapotranspiration observed in the region (Table 8). This site also has the longest period of measurement, with five years of water use and four years of soil water data now available. Rainfall during these five years ranged from slightly below average in 2004–05 to 15% above average in 2003–04. Annual evapotranspiration increased from ~1250 mm/y in the first two years of measurements to ~1450 mm/y in the most recent two years. Net groundwater uptake for the past three years has averaged 660 mm/y. The very high rate of evapotranspiration at this site is probably partly because it is less than 40 m from a plantation edge and therefore receives advected energy from grassland areas to the south. Annual ET in a blue gum plantation nearby is also high, averaging ~1130 mm/y over the past four years, with net groundwater uptake averaging 370 mm/y from a watertable at ~4.5 m depth (Table 8). There has been little variation between years in the maximum depth to groundwater at these two sites. It rose by ~0.6 m following the wet winter of 2004, but it was 0.3 m deeper than it would normally be in early September (Benyon, 2005).

Table 8. Annual water balances at six plantation sites in the South East.

Year	Rain	Water use	Soil water change	GWU	**Max DTW** (m)
A. BG2 (southeast of D10)					
2002	585	846			2.6
2002–03	755	908	+35	188	2.8
2003–04	765	868	-110	0	3.2
2004–05	645	763	-30	88	3.5
B. BG3 (south of D10)					
2002	574	1138			2.9
2002–03	740	1128	+37	425	3.2
2003–04	740	1204	-92	372	3.4
2004–05	628	1105	-55	422	3.7
C. BG5 (LUIWQQ SITE F16)					
2002–03	712	853	+70	211	3.5
2003–04	734	930	-30	166	3.7
2004–05	658	957	-10	289	3.6
D. BG6 (LUIWQQ site F17)					
2002–03	715	683	+21	(-11)	11.0
2003–04	734	757	-29	(-6)	11.0
2004–05	658	642	+6	(-10)	11.1
E. BG7, AIRPORT ROAD MOUNT GAMBIER					
2001–02	772	1016	+2	246	4.6
2002–03	791	1286	+40	535	4.7
2003–04	835	1128	-14	279	4.7
2004–05	711	1142	-18	413	4.5
F. RP2, AIRPORT ROAD MOUNT GAMBIER (SITE H19)					
2000–01	780	1288	?		6.1
2001–02	791	1219	0	428	6.3
2002–03	790	1388	+37	635	6.4
2003–04	835	1501	+15	681	6.4
2004–05	701	1452	-80	671	6.2

BG2 and BG3 were funded by this project. All data in mm/y (sourced from Benyon 2005; see App. C).

GWU indicates net groundwater uptake.

5.1.5 GROUNDWATER AND SURFACE WATER MONITORING

For the Bakers Range Drain, a strong relationship exists between drain flow, watertable, rainfall and the wetlands.

Figure 24 indicates the close relationship between rainfall and the watertable at observation well MON008 located alongside dryland pasture. For example, from 1994–99 the rainfall declined cumulatively by 500 mm, with an associated drop in the watertable from 1 m below ground level to ~2 m. The above-average rains after 2000 have seen a corresponding rise in watertable, with the levels generally close to ground surface. A noticeable feature of the rainfall record is that if a positive 100 mm cumulative rainfall effect occurs in a year, a strong response is noticed in the watertable.

Figure 25 compares the water levels recorded in observation well CLS009 and the total drain flow measured at the Phillips Road monitoring station on the Bakers Range Drain:

- the years 1993 to 1995 show both declining watertable and drain flow
- the three wet years through this period were 1992 (848 mm), 1996 (711 mm) and 2000 (671 mm), which have corresponding peaks in water level and drain flow
- the years 1991, 1992, 1996, 2000 and from 2002 onwards indicate that when the depth to the watertable is <0.5 m, the drain flow is at its highest
- from this it is concluded that a significant component of the drain flow is from lateral groundwater flow.

Figure 26 shows a strong relationship between above-average rainfall years and higher drain flows:

- strong drain flow occurred in 1990–92, 1996, 2000, 2001 and 2003
- the average rainfall from 1990–2004 at Penola PO was 633 mm/y
- the graph indicates that where <600 mm of rainfall has fallen, that minor to no drain flow occurs
- from this data set, drain flow under open pasture in the Bakers Range will generally occur when ~670 mm or more of rainfall occurs annually.

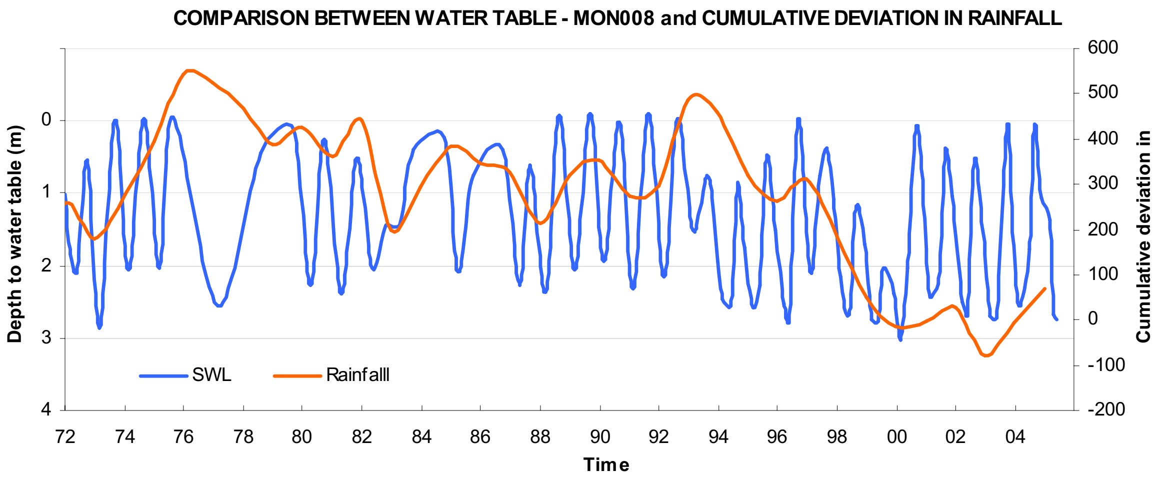


Figure 24. Hydrograph of observation well MON008 and cumulative deviation in rainfall

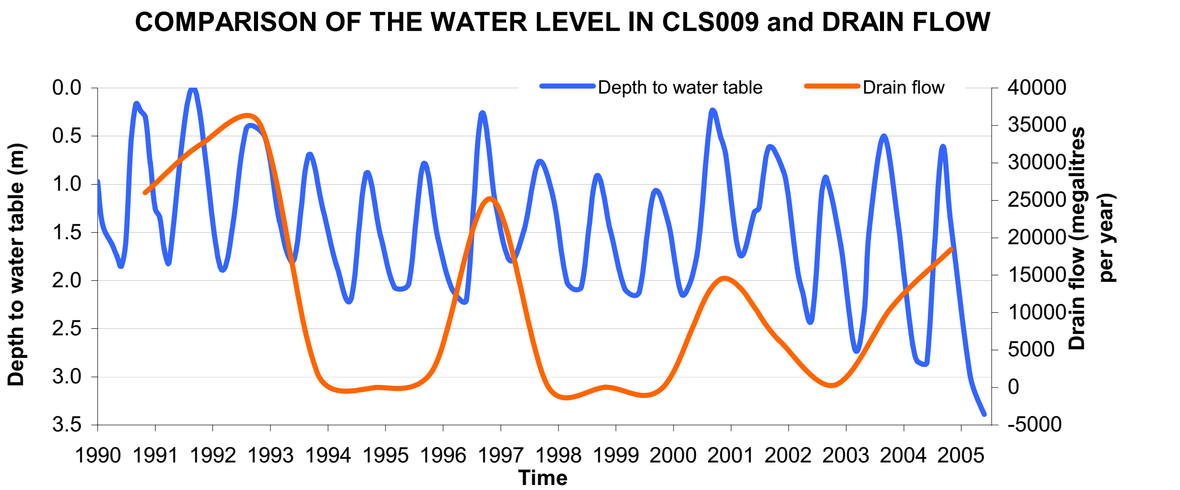


Figure 25. Water level in observation well CLS009 compared to the Bakers Range flow.

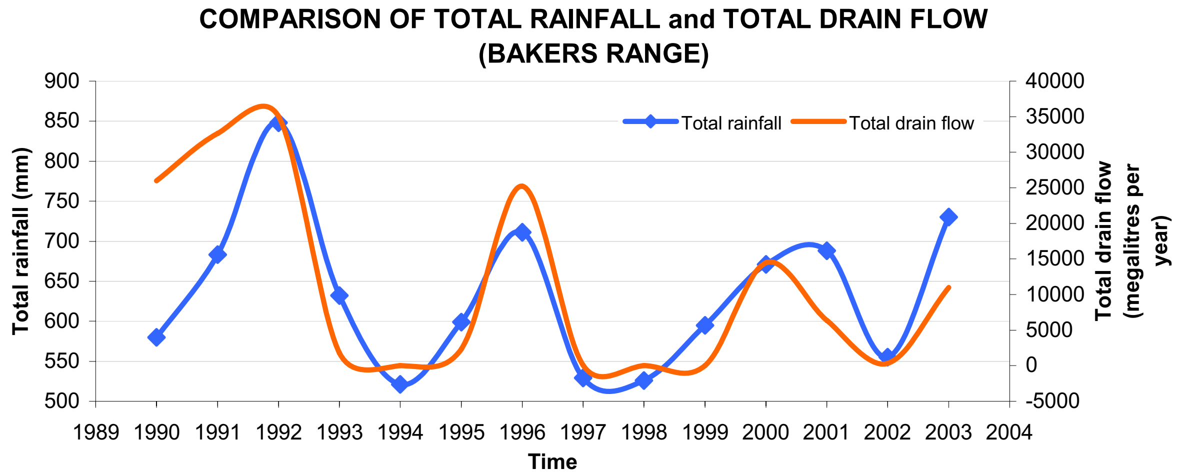


Figure 26. Total rainfall (measured at Penola PO) and the flow in the Bakers Range Drain (measured at Phillips Road).

5.1.5.1 Drain Base Flow versus Surface Flow

The results from Hydstra HYBASE application to derive groundwater base flow and surface runoff components from flow records at gauge A2390515 at Penola–Robe Road for the period 1972–92 are tabulated in Table 9. At this site, base flow is the major component (75%) of drain flow as would be expected in a situation where a drain has been excavated to below winter groundwater levels.

An Excel spreadsheet was used to calculate the annual base flow and runoff depth in millimetres over the catchment area (Stace & Murdoch 2003). Results are listed in Table 9, with total catchment discharge and rainfall plotted in Figure 27.

Table 9. Catchment flow component.

Year	Total flow discharge (mm/y)	Base flow discharge (mm/y)	Runoff discharge (mm/y)	Rainfall (mm/y)	Catchment coefficient
1972[a]	1.5	1.2	0.4	617	0.002
1973[b]	19.9	14.8	5.1	871	0.023
1974[b]	17.5	14.6	2.9	795	0.022
1975[b]	63.1	49.5	13.5	873	0.072
1976[b]	18.5	13.4	5.1	702	0.026
1977[b]	9.9	8.1	1.8	693	0.014
1978[b]	7.1	5.1	2.0	696	0.010
1979[b]	26.0	19.1	6.8	790	0.033
1980[b]	14.9	12.0	2.8	658	0.023
1981[b]	46.3	35.2	11.1	818	0.057
1982	0.7	0.6	0.1	516	0.001
1983[b]	24.4	18.3	6.1	847	0.029
1984[b]	29.2	22.2	7.0	819	0.036
1985[b]	5.6	4.4	1.2	695	0.008
1986[b]	14.0	10.1	3.9	736	0.019
1987[a]	5.1	3.8	1.3	614	0.008
1988	31.4	22.8	8.6	803	0.039
1989	62.3	47.7	14.6	803	0.078
1990	23.9	17.7	6.2	706	0.034
1991	24.5	17.8	6.6	724	0.034
1992	30.9	23.4	7.5	887	0.035
Average	22.7	17.2	5.5	746	0.029

(a) Contains missing data, (b) contains estimated data (sourced from Stace & Murdoch 2003).

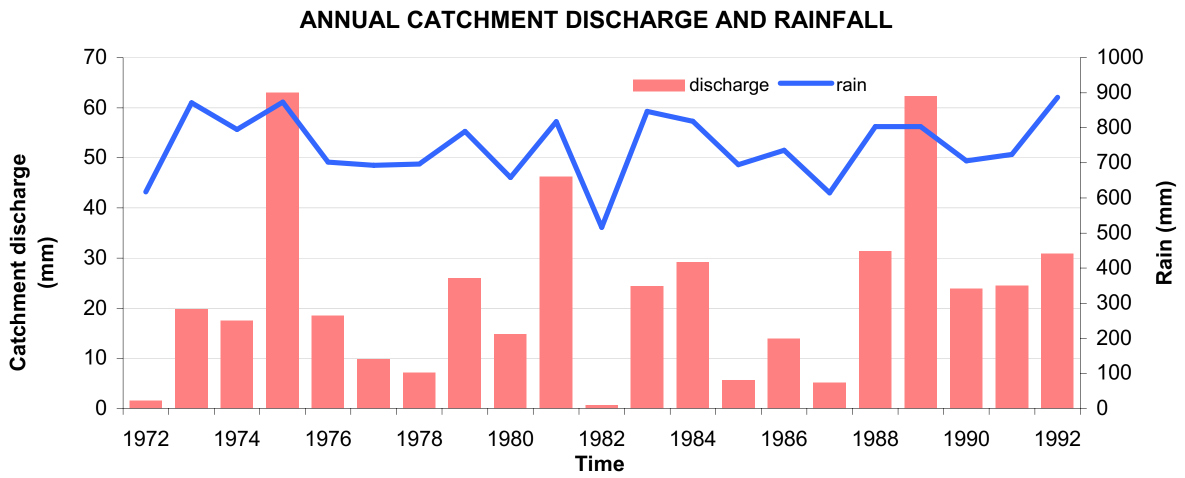


Figure 27. Catchment discharge and annual rainfall (sourced from Stace & Murdoch 2003).

Table 10 shows the results of flow measurements at different locations along the Bakers Range Drain, as estimated using the propeller current meter method.

Table 10. Records of drain flow along the Bakers Range Drain in September 2004.

Site	Date	Flow (ML/d)	Gauge no.	Comments
BRI	28/9/2004	72.06	A2391001	At Phillips Road
BR2	27/9/2004	76.87	A2390515	At Penola–Robe Road
BR3	28/9/2004	70.50		At LDE Road
BR4	28/9/2004	36.98		Penola–Millicent Road
DRB	28/9/2004	35.68		Drain B at Coles–Kilanoola Road

5.1.5.2 Drain Base – Watertable Relationship

Within the pilot study area, at the bridge on LDE Road, this relationship has been examined over a year. The three cross-sections indicate for the Bakers Range Drain that the height of the watertable is critical for the commencement of flow.

Figure 28 is a schematic diagram showing the drain and groundwater level in October 2004. Winter recharge had finished and the drain ceased flowing due to the water level dropping below the critical level. The level in the drain was measured from a point on the bridge span, which had been levelled from observation well SHT012 with no closure error. The groundwater level was taken from SHT012.

The drain level is 0.24 m lower than the watertable, which is probably related to evaporative loss. In this situation the drain is potentially gaining water from the surrounding watertable.

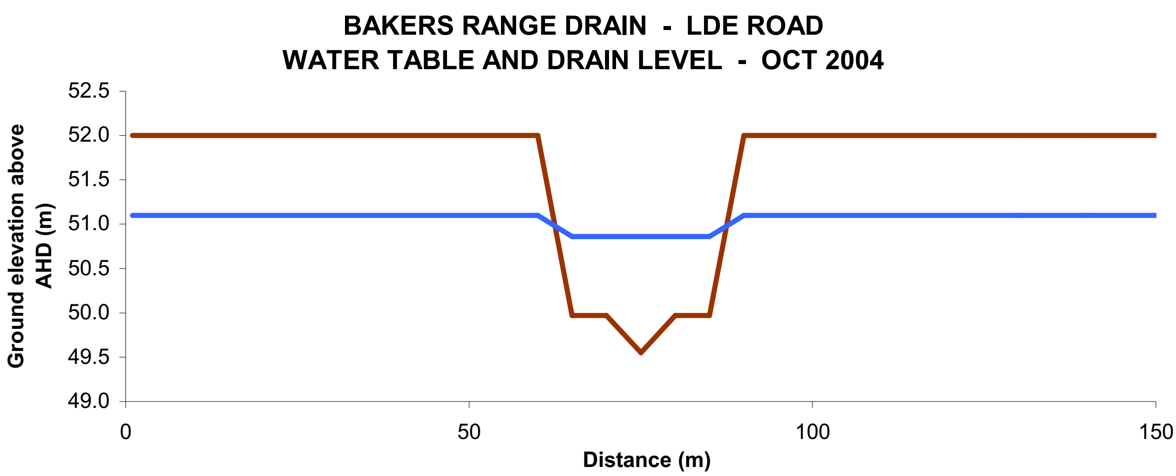


Figure 28. Watertable and Bakers Range Drain level, October 2004.

In January 2005, the groundwater level shown in Figure 29 had dropped below the base of the drain. It could not be seen in the drain at all except for a deep erosion hole below the bridge. Mounding of the water under the drain was observed as hydraulic equilibrium with the groundwater occurred. A time lag for this to occur was related to clay and silty clay in the drain base.

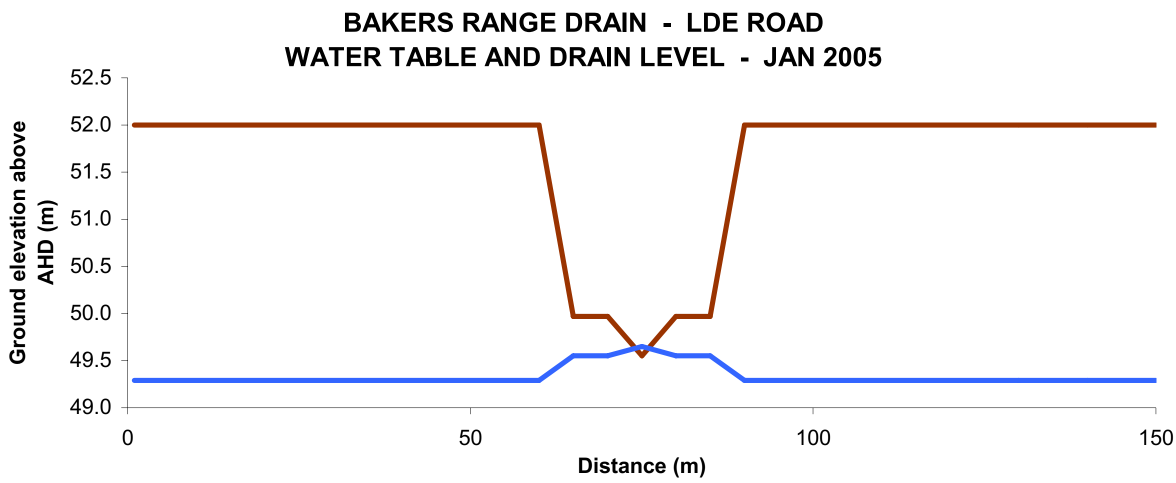


Figure 29. Watertable and Bakers Range Drain level, January 2005.

With below-average rainfall for 2005, the watertable has not risen above the base of the drain and consequently no flow has occurred. To obtain a water level below the drain, a 2.5 m augured hole was sunk into the base. The water level below the drain is only ~50 mm lower than the surrounding groundwater, which is probably the result of the water being slow to reach equilibrium in the drilled hole (Fig. 30).

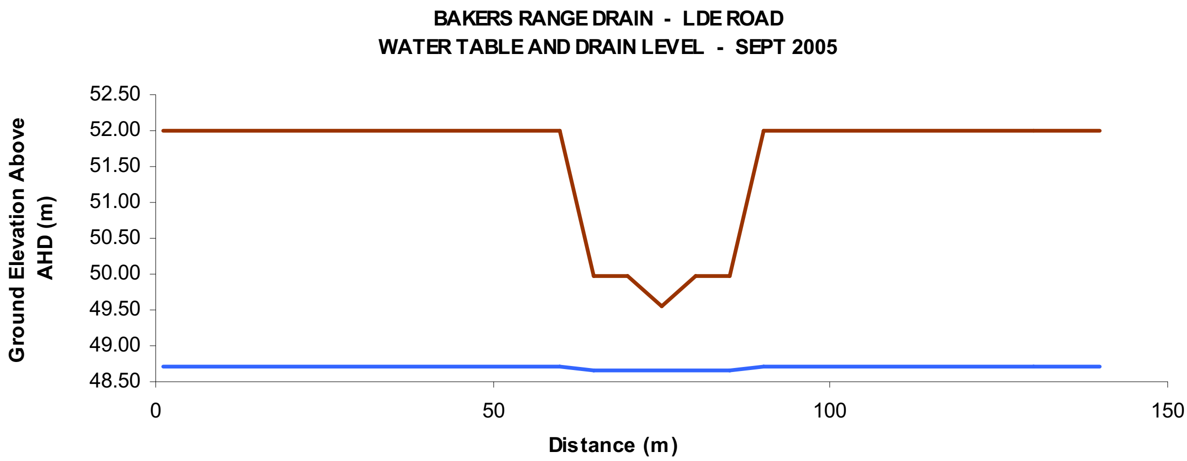


Figure 30. Watertable and Bakers Range Drain level, September 2005.

5.1.5.3 Bakers Range Area

Within the pilot study area, the major land use is blue gum forestry; changes to the watertable are examined below.

Figure 31 shows that since ~2002 a change has occurred, causing a decline in the watertable at SHT012 (see Fig. 9 for the location) not previously monitored. This observation well is located alongside Bakers Range Drain in the pilot study area. During 2000–05, rainfall has been average to above average, with the most likely cause of this decline (summer low) probably due to land-use change. A recent change has been the planting of significant areas of hardwood trees. The following observations are made for Figure 31:

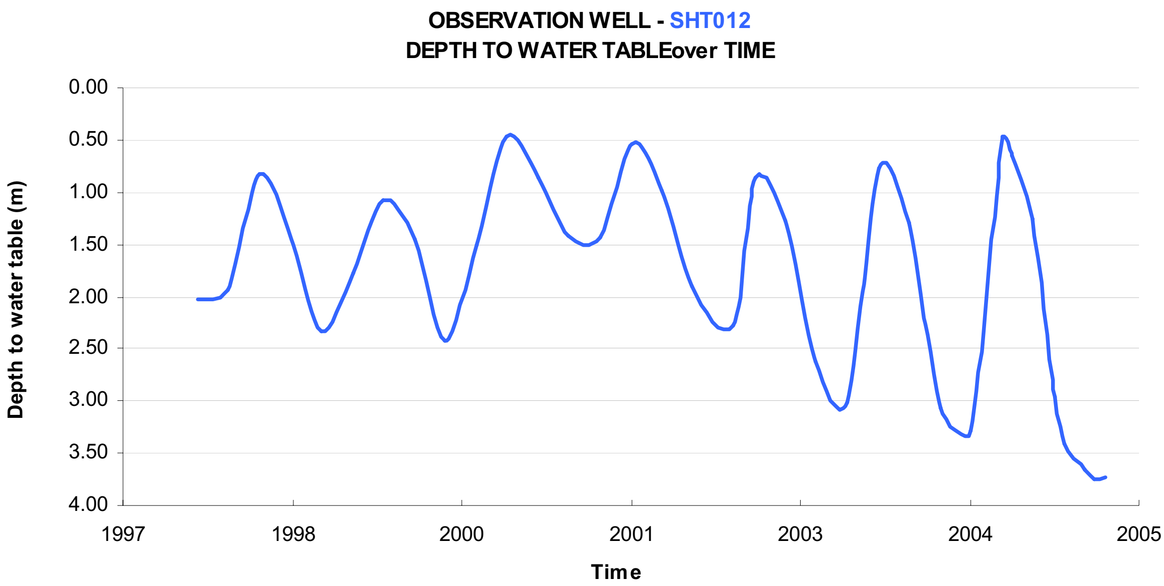


Figure 31. Depth to watertable at observation well SHT012.

- the summer water level low shows the watertable receding; at the same time, the winter high point for the watertable is similar to normal
- an increase since 2003 in hydrograph amplitude between the summer low and the winter high
- the slope of the recovery line in the graph of SHT012 has changed and is shown in Figure 32.

The following was noticed after examination of Figure 32:

- The slopes of the winter recovery period between 1998 and 2001 have comparable winter recharge recovery angles.
- In 2002, this slope became steeper or more inclined and for 2003 and 2004 has become even more acute.
- A probable explanation for this change in winter recovery angle is related to water use or more simply the effects noted in a pumping well after the pump is shut down. In an unconfined aquifer condition (which is the case in this study), the water level will be lower in the vicinity of the pumping well as the aquifer around it is dewatered. When pumping is stopped, water levels will rise in the well and the aquifer towards their pre-pumping levels (Driscoll 1989).
- As the pumping rate becomes greater, this slope will continue to increase; however, if the extraction rate remains constant, a steady state will occur as water derived from aquifer storage tries to balance the rate of extraction, and the slope will remain constant.
- Previously, recovery from winter rains in the watertable at this location occurred from March onwards, but over the last three years it has started later, from June onwards.
- A possible explanation for the changes is that during the transition from autumn to winter, groundwater use continues until the moisture levels in the unsaturated zone reach a sufficient level to sustain tree growth. Groundwater use then stops or rapidly declines.
- To gain a better understanding, it is recommended that daily rainfall be plotted against the daily water levels recorded from the transducers to show this effect.

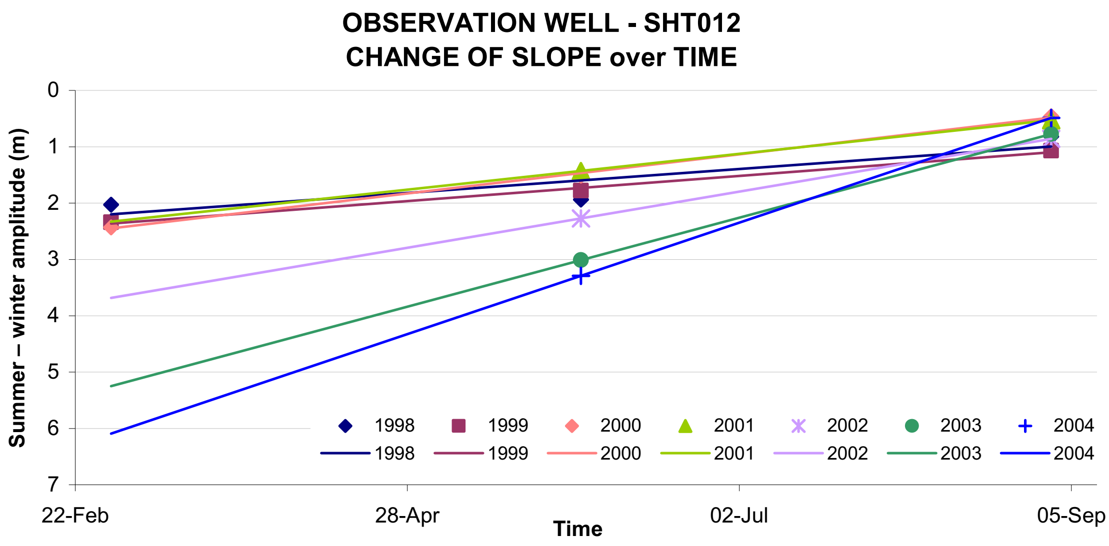


Figure 32. Changes in the slope of summer–winter water levels related to possible water use.

The trends indicated for observation well SHT012, located alongside dryland pasture (Fig. 33), are in contrast to those observed in MON008. A slight decline occurred between 1998 and 2000, which was the end of the dry rainfall period. Since 2000, the watertable has remained stable, even recovering in 2001 and 2004.

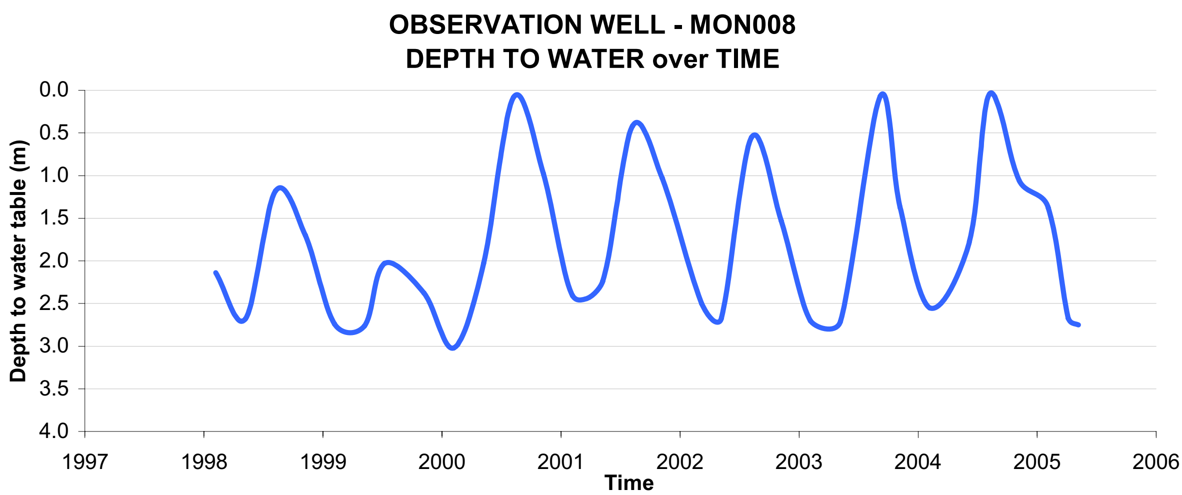


Figure 33. Depth to watertable at observation well MON008.

The figures shown above indicate changes that are occurring alongside the pilot study area. It needs to be established if these are localised effects or whether they can be identified over a larger area.

To the north of the pilot study area in the Hundred of Coles, observation well CLS009 was drilled inside blue gum forest; its watertable trend is shown in Figure 34. This shows the groundwater since 2002 declining in the same way as at SHT012, with the summer low becoming greater with time.

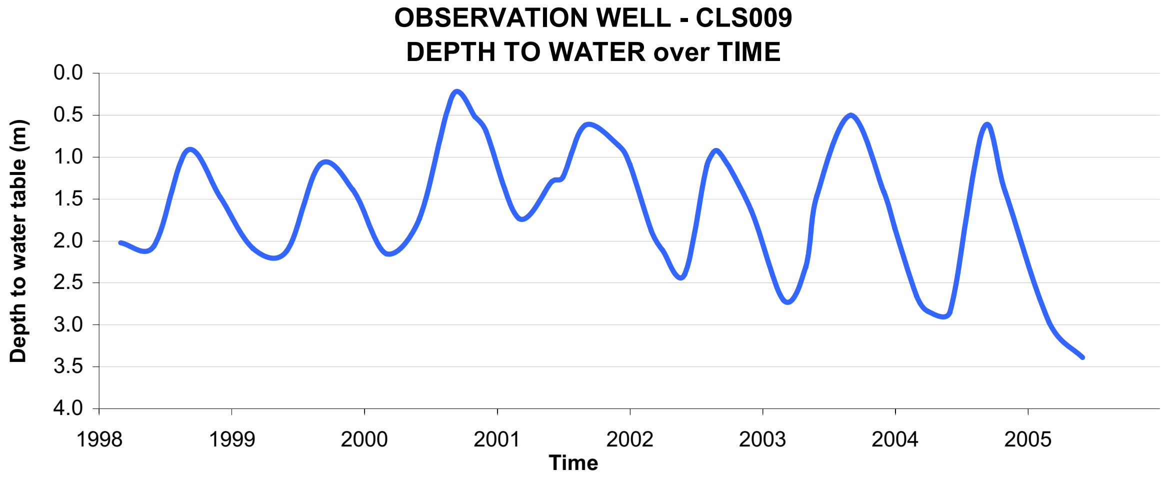


Figure 34. Depth to watertable at observation well CLS009.

Observation well KLN004, located a short distance away, is monitoring groundwater under dryland pasture. Since 2002, the summer lows of the watertable have remained stable, suggesting that the different trend is most likely related to land use (Fig. 35). An interesting observation is that the 2004 summer low for KLN004 is elevated from the 2003 summer low, and this contrasts with CLS009 which shows that the 2004 summer low has declined from the 2003 summer low.

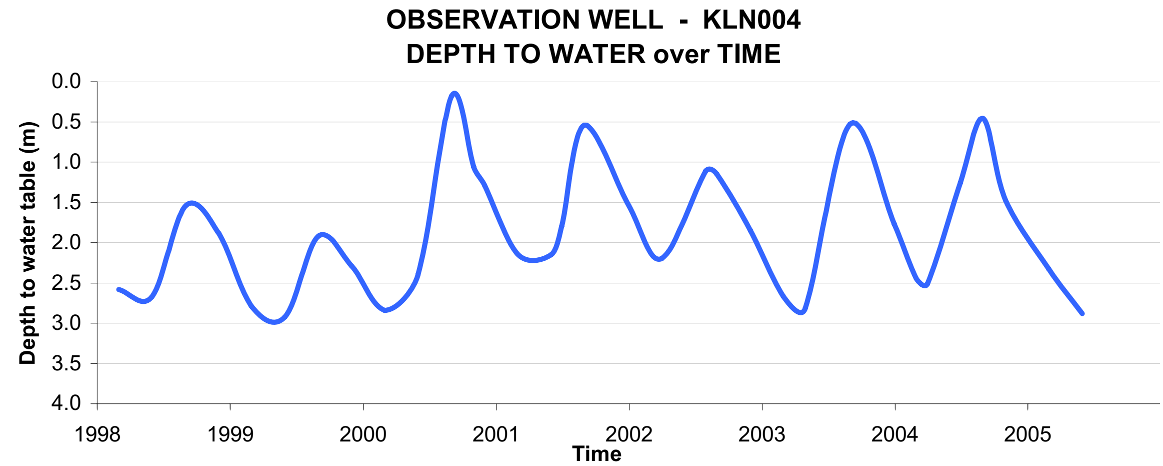


Figure 35. Depth to watertable at observation well KLN004.

5.1.5.4 Projected Watertable Levels

The graph of SHT012 (Fig. 31) indicates that the watertable alongside the pilot study area is declining at an increasing rate each summer, and may exhibit characteristics similar to that of a pumped well.

Extrapolating the watertable summer lows into the future (Figs 36–37) indicates that, for the current rate of decline, the watertable will reach a maximum level of 4–5 m below ground level.

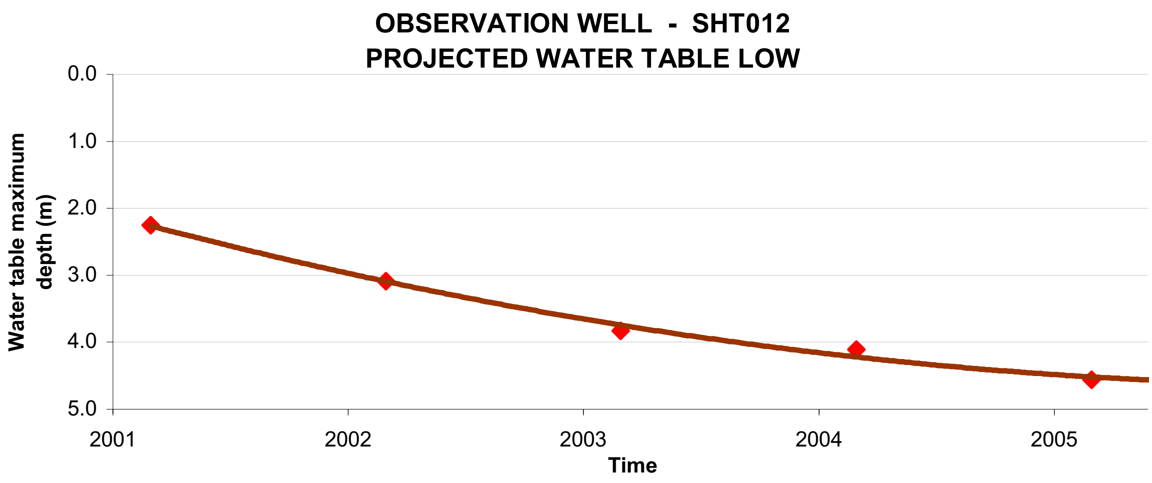


Figure 36. Observation well SHT012 — future projected watertable low.

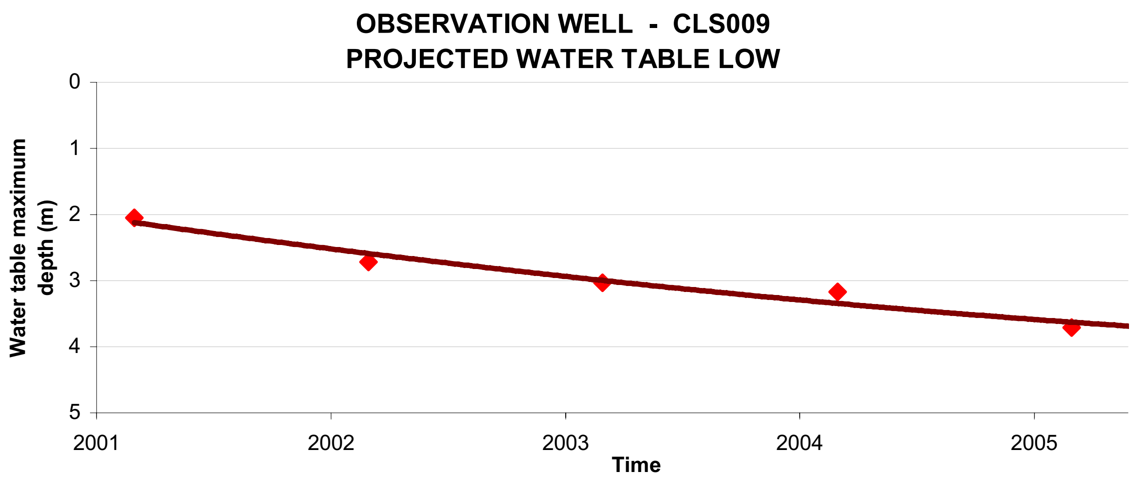
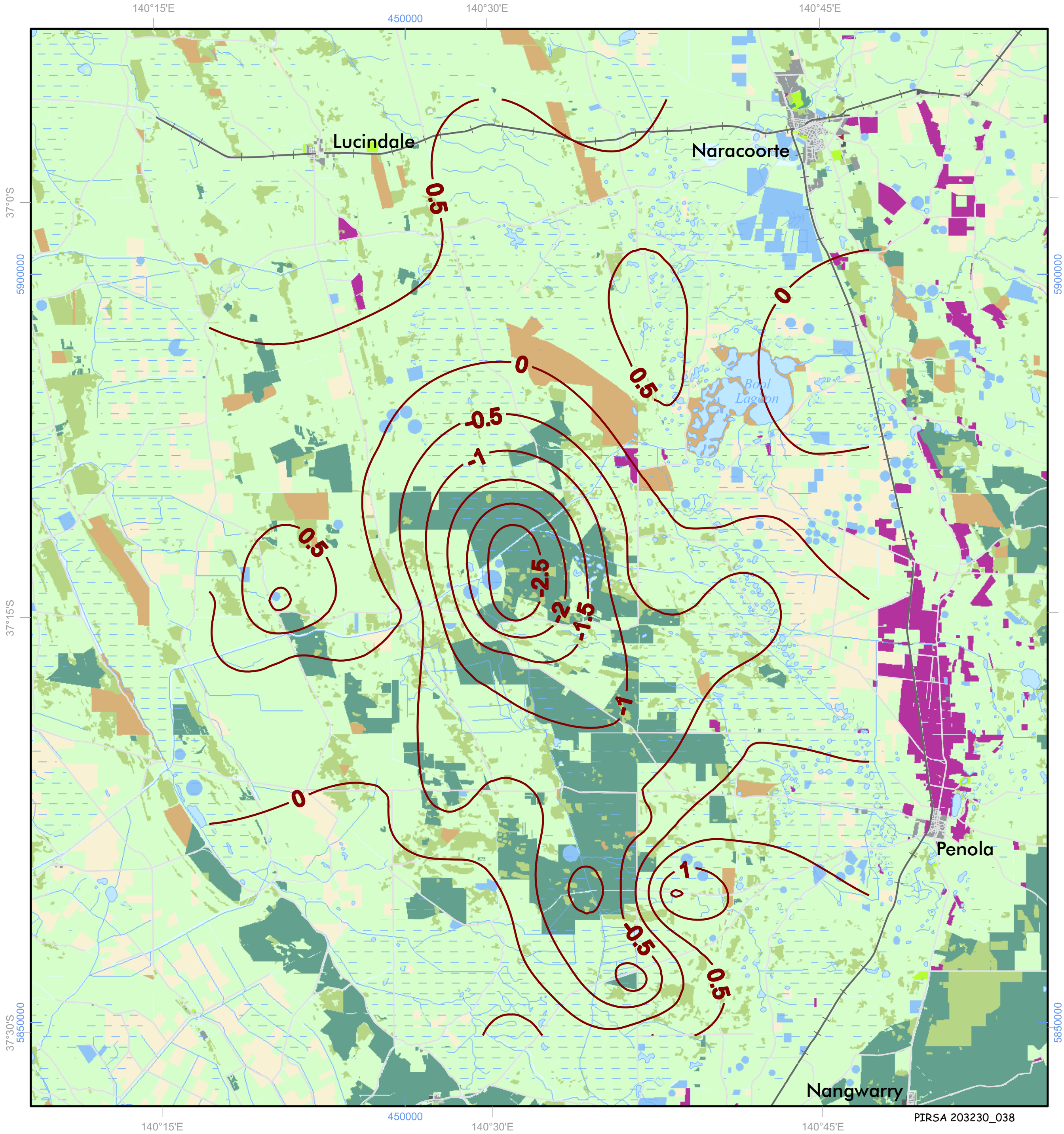


Figure 37. Observation well CCL00 9 — future projected watertable low.

If the groundwater reaches a summer lowest point of ~5 m below ground level, and a winter recovery of 3 m occurs, then the watertable in the pilot study area would still reside ~1 m below the base of the Bakers Range Drain. The extent of future impact is uncertain, however a possibility is that drain flow may not occur for average or below-average rainfall years. If rainfall is above average and drain flow occurs, it is anticipated that the flow period would be short in duration, as the watertable would only rise slightly above the base of the drain.

5.1.5.5 Regional Land-use Decline

The data indicate a relationship between land use (blue gum forestry) and groundwater in the Bakers Range area. Trend changes have been noted in the observation wells. It seems they are occurring more regionally. Figure 38 indicates a groundwater land-use effect occurring in the Bakers Range area, mapped through the Hundreds of Coles and Short. The contour boundaries, considering the constraints of the monitoring well locations, coincide with the local forestry plantations. The maximum decline in water level through this five-year period is



Water level change (m)
Railway
Highway
Secondary road
Airport
Lake
Subject to inundation
Watercourses

Land use – 2003

Cropping
Grazing modified pastures
Grazing natural vegetation
Irrigated areas
Irrigated perennial horticulture
Manufacturing and industrial
Mining
Nature conservation
Plantation forestry
Residential
Services

0 5 10 15 Kilometres

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Produced by: Publishing Services, Primary Industries and Resources SA
Date: May 2006

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Land use impact on water quality and quantity in the Lower South East – South Australia

CHANGE IN GROUNDWATER LEVEL 2000 – 2005

Figure 38

~3 m. Through the pilot study area the decline is ~0.5 m. Observation wells close to the affected area, but located adjacent to dryland pasture, are generally showing small rises in the watertable for this same time period.

5.1.5.6 Continuous Water Level and Salinity Recorders

For study site E in the Bakers Range area, the three observation wells were completed with 100 mm casing so that constant head water level and salinity recorders could be fitted. Figures 39–41 show the results recorded since February 2005.

Figure 39 shows two recovery steps occurring in the water-level record at the beginning of the winter recharge at this site. These require a more detailed study as they may indicate initial rainfall recharge followed by a drier period before recharge recommencing, or may be indicative of tree water use shut down followed by rainfall recharge. The watertable recovered ~0.8 m from winter recharge.

Water conductivity records show a number of steps and these were queried with the instrument supplier who confirmed that the instruments were properly calibrated prior to shipping. These steps coincide with data downloads, where the well is also pumped and sampled for salinity confirmation. A possible explanation is that fresh water from the upper sections may be induced into the well during pumping. The overall salinity increase may be related to flushing out some of the salt due to water-level fluctuation.

At irrigated site E12, similar trends are viewed in the watertable recovery as for E11 which will require further investigation. The watertable recovered ~1 m, a little more than for the blue gum land use.

The salinity under this site is much different, averaging ~3000 uS/cm in contrast to the blue gum site at 1320 uS/cm. An explanation for this is provided under salt balances later in this report.

The record for pasture site E13 does not show the complete recharge season due to a corruption of data in the logger. It shows a similar recharge pattern to the previous two wells but with slightly less amplitude at 0.7 m.

The salinity is less than for the irrigated site and greater than that recorded in the blue gum site.

5.1.6 WETLAND ASSESSMENT

During the winter of 2005, the Bakers Range Drain in the pilot study area did not flow. The three wetlands previously identified to the north of this area, and which are dependent on drain flow for replenishment, would have diminished further in size. Any recharge would have been derived from rainfall, but monitoring wells in the area did not recover greatly during the winter of 2005 and it can be assumed that the wetlands were affected in the same way.

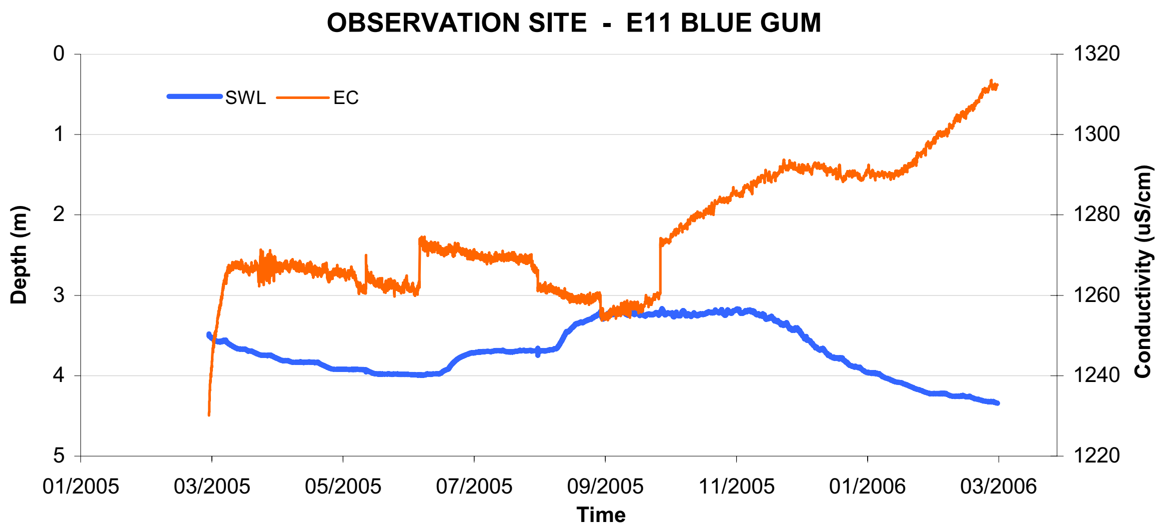


Figure 39. Water level and salinity, observation well E11 — blue gum.

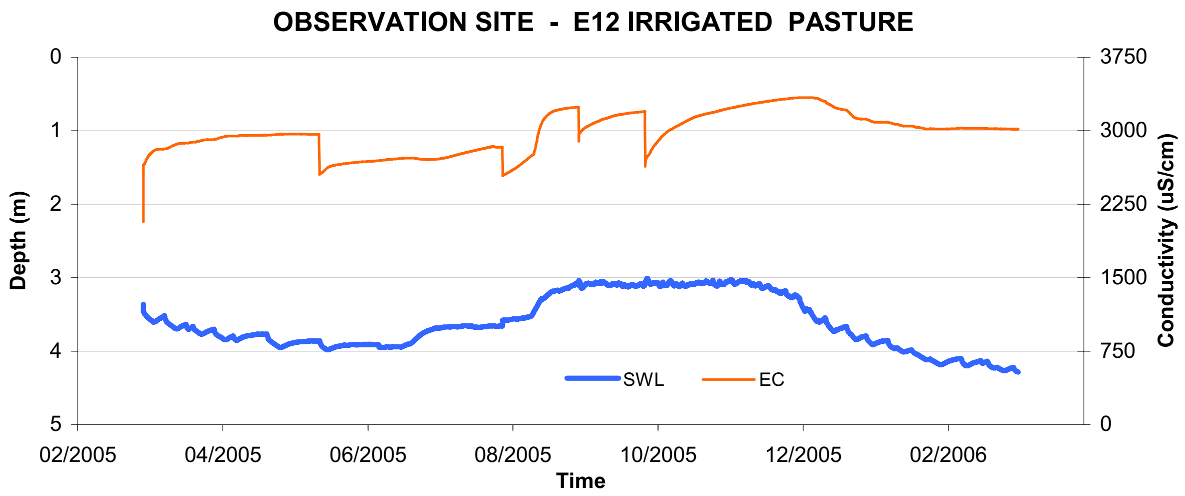


Figure 40. Water level and salinity, observation well E12 — irrigation.

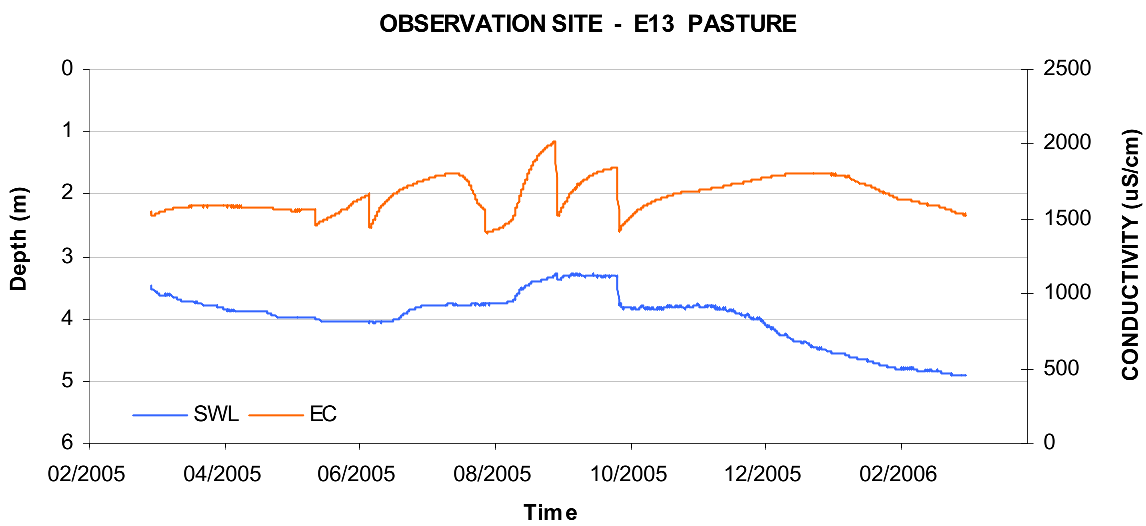


Figure 41. Water level and salinity, observation well E13 — pasture.

5.2 MEASUREMENT ON CORES AT EACH SITE

5.2.1 SOIL ANALYSES

Analyses for all of the sites are listed in Appendix B (Leaney et al. 2006). There is a 50+ fold range in gravimetric water content, θ_g (0.007–0.371 g (water)/g (dry soil)). Gravimetric water content is determined primarily by the amount of clay present in the soil and soil water suction (SWS).

5.2.1.1 Chloride Soil Water Profiles

The results of the chloride soil water ($[Cl]_{SW}$) profiles under different land-use types are presented in Figures 42–48. Soil water chloride profiles at the two native vegetation sites range from ~130–1500 mg/L (Fig. 42). At both sites, chloride soil water profile is greater for the bottom half of the unsaturated zone when compared to that for the top half. The plateau is ~1000 mg/L at both sites. This would be equivalent to a salinity of ~2000 mg/L for the soil water.

Under the pasture sites, chloride soil water profiles range from ~10–500 mg/L (Fig. 43). For most of the profile, excluding the root zone (0–2 m depth), there are very few soil samples that have chloride soil water profiles >60–80 mg/L. These types of profiles are typical of those found in areas of high drainage and shallow watertables, where the unsaturated zone has been flushed of salt accumulated under earlier native vegetation regimes.

For the sites where pine plantations have been established, chloride (salt) accumulation has recommenced. The chloride soil water profiles for the unsaturated zone at these sites range from ~100 mg/L (i.e. similar to that measured at the pasture sites) to ~9000 mg/L (Fig. 44). Usually, the largest chloride soil water profile peak is seen in the capillary zone, ~1–3 m above the watertable. At the deeper site (104327 — A1), there is an additional peak within the top few metres of the soil profile. Also shown (Fig. 45) is the chloride concentration of the soil (g_{Cl}/m^3) as a function of soil depth. The unsaturated zone soil at site 108347 (H19) has the greatest accumulation of chloride. Possible reasons for this are higher clay content at this site and incomplete flushing of the unsaturated zone during the cleared phase (Leaney et al., 2006, App. E).

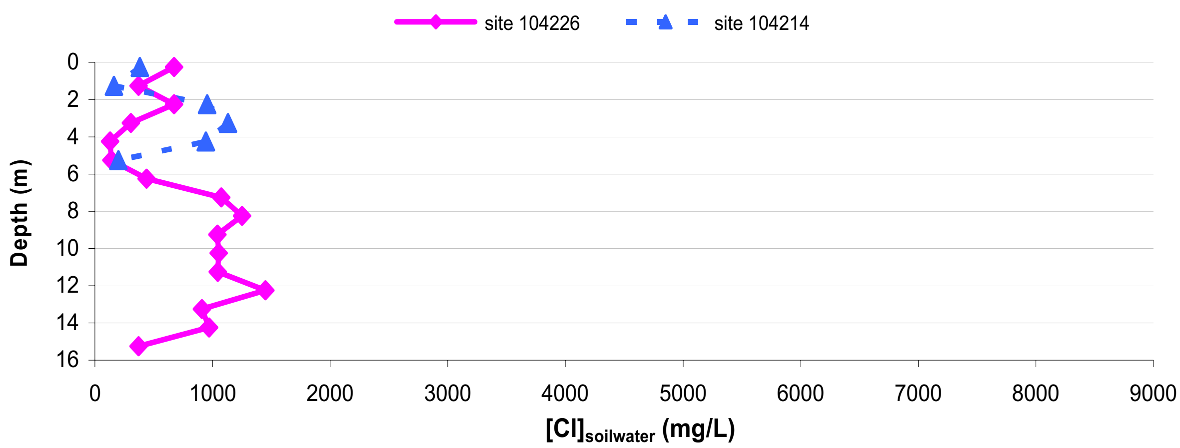


Figure 42. Soil water chloride depth profiles for areas with native vegetation.

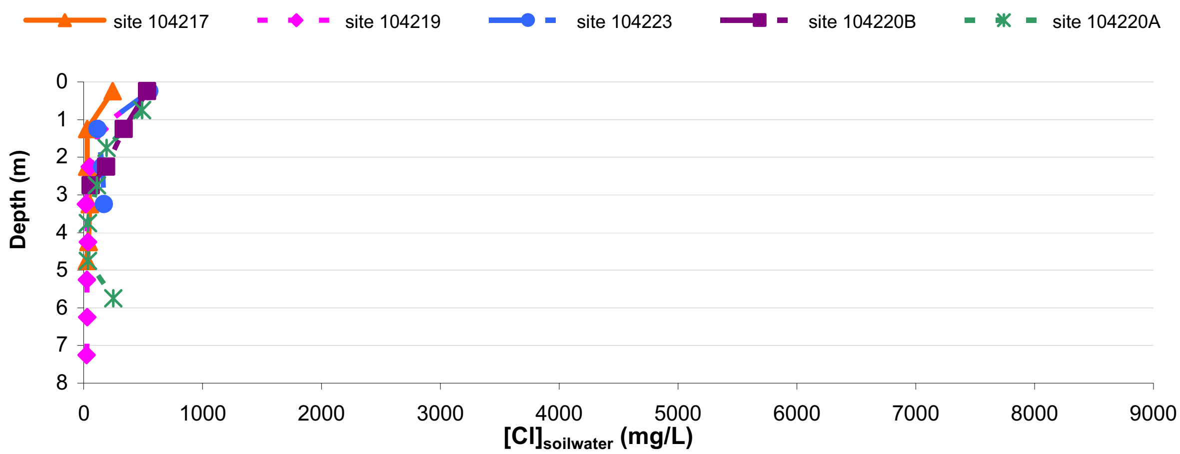


Figure 43. Soil water chloride depth profiles for cleared non-irrigated pasture.

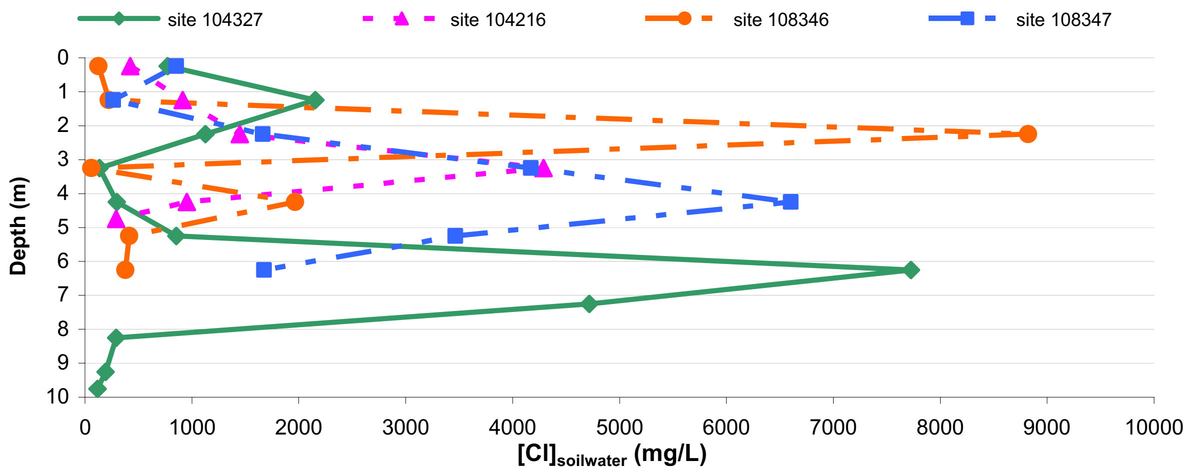


Figure 44. Soil water chloride depth profiles under pine plantations.

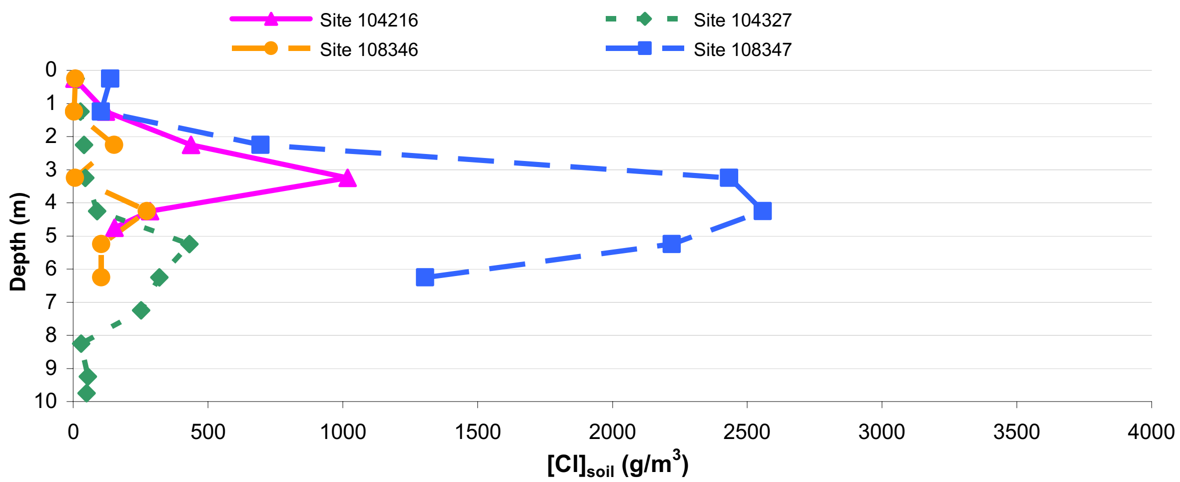


Figure 45. Soil chloride concentration (g/m^3) versus depth profiles under pine plantations.

At the blue gum sites, chloride soil water profiles for the unsaturated zone range from ~100 mg/L (similar to that measured at the pasture sites) to almost 4000 mg/L (Fig. 46). Chloride accumulation can be seen at four of the six sites 104215 (B5), 104221 (E11), 104225 (D10) and 108348 (I20). At site 108348 (I20), the chloride accumulation is greatest for the deepest sample and possibly there is more chloride in the shallow groundwater. Only a single chloride soil water profile peak is observed at these sites, similar to that seen at pine plantation site 104216 (B4) where the watertable is also ~5 m deep.

At the other two sites, chloride soil water profiles are similar to that measured at the pasture sites. Also shown (Fig. 47) are the chloride concentrations of the soil versus depth at the blue gum sites. Note that, except for site 108348 (I20), the chloride accumulation at the blue gum sites is significantly less than that at the pine sites. The main reason for this is that the pine forest has been established for much longer than the blue gum sites, and hence there has been a longer period for groundwater uptake and chloride accumulation.

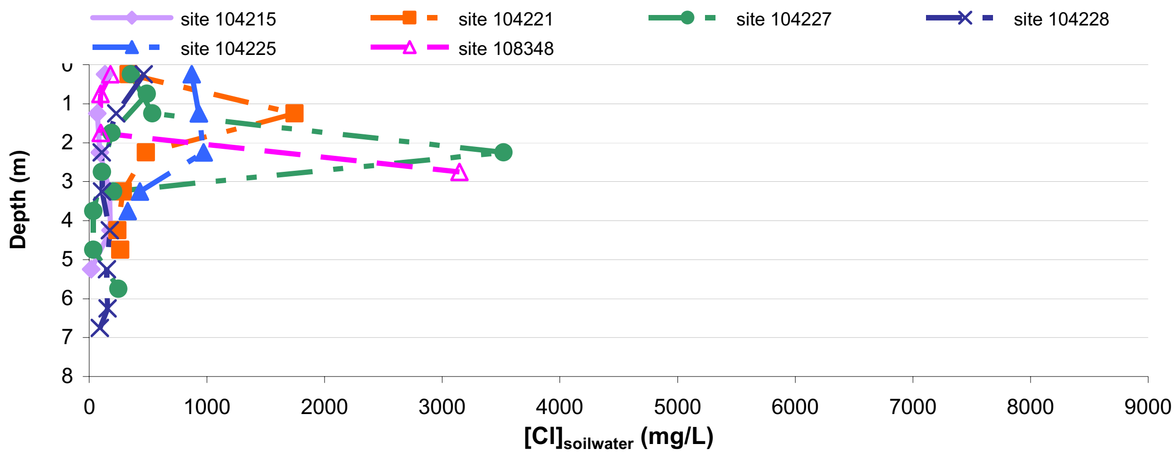


Figure 46. Soil water chloride depth profiles under blue gum plantations.

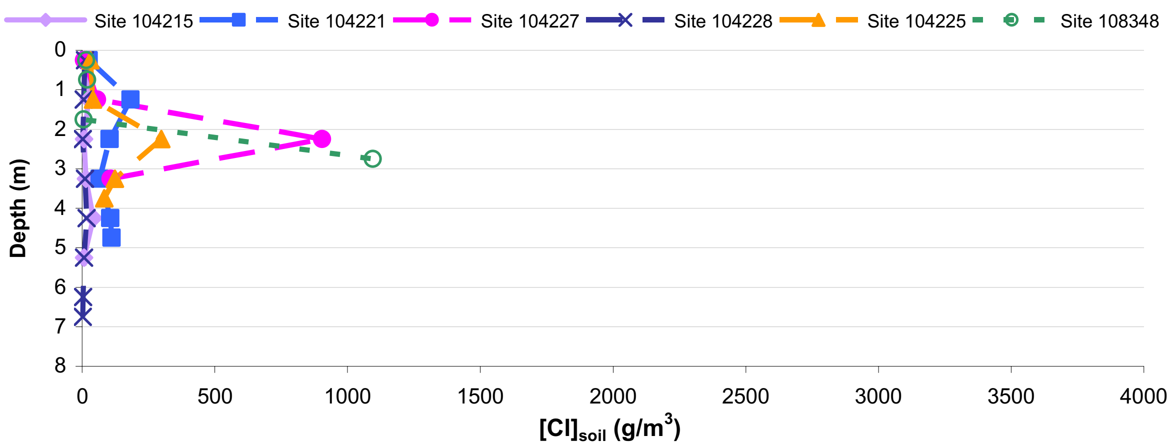


Figure 47. Soil chloride depth profiles under blue gum plantations.

Chloride accumulation is also observed in the unsaturated zones at the irrigated sites (Fig. 48). Chloride accumulation at the pine and blue gum sites arises from induced vertical movement of water upwards from the groundwater into the capillary zone. The driving force for this movement is water uptake by the trees. This is not the case for the irrigated areas. Irrigation water has 10–30 times the chloride concentration as rainfall and hence, at the irrigated sites, chloride is applied with irrigation water at the soil surface. Chloride accumulation at the irrigated sites results from removal of pure water near the surface as a result of evapotranspiration.

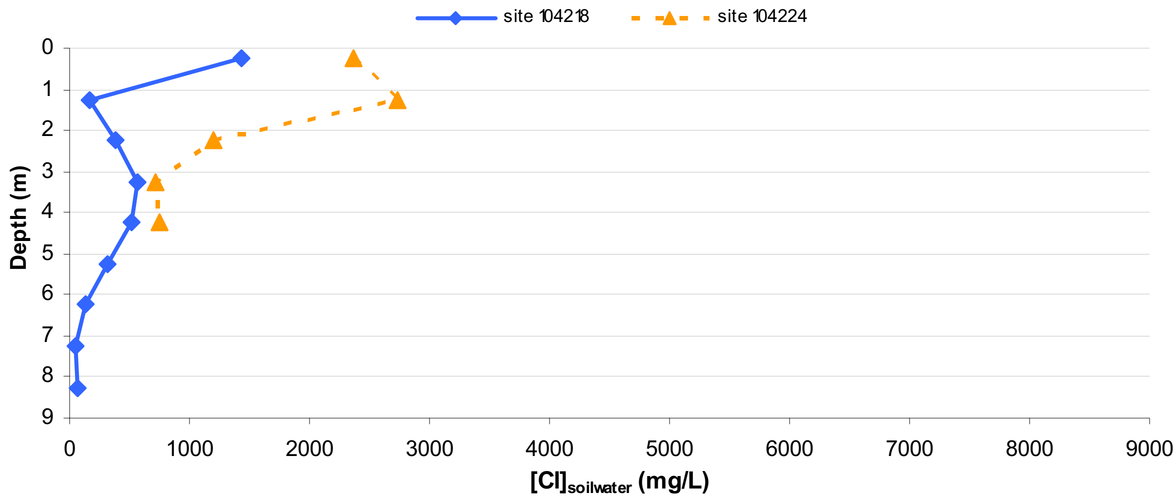


Figure 48. Soil water chloride depth profiles for irrigated areas.

5.2.1.2 Soil Water Suction Profiles

The soil water suctions (SWS) versus depth profiles are shown for all of the different land-use sites (Figs 49–53); as would be expected, the soil is close to saturation at or near the watertable (measured SWS = 5–10 kPa). The highest values measured for SWS are 2000–4500 kPa.

At both of the native vegetation sites, the SWS is high close to the soil surface (Fig. 49). For the deeper native vegetation site, SWS is also high 8–12 m from the surface but low between depths of 2–6 m below the soil surface. At the cleared sites, SWS is variable throughout most of the unsaturated zone (Fig. 50).

SWS measurements for samples collected at all of the pine sites are high for all samples excluding those collected in the capillary zone near the watertable (Fig. 51). This perhaps suggests a comprehensive root density throughout the unsaturated zone to a depth of 8–10 m under established pine trees.

There is a wide range in SWS measurements for the different blue gum sites (Fig. 52). For example, at site 108348 (I20) the unsaturated zone is near saturation (SWS is low). At site 104215 (B5), SWS is >3000 kPa at the surface and becomes progressively closer to saturation towards the watertable. At site 104228 (F17), the unsaturated zone has an SWS averaging ~1000 kPa throughout the entire profile. This site was not cored to the watertable and hence probably does not include samples from the capillary zone.

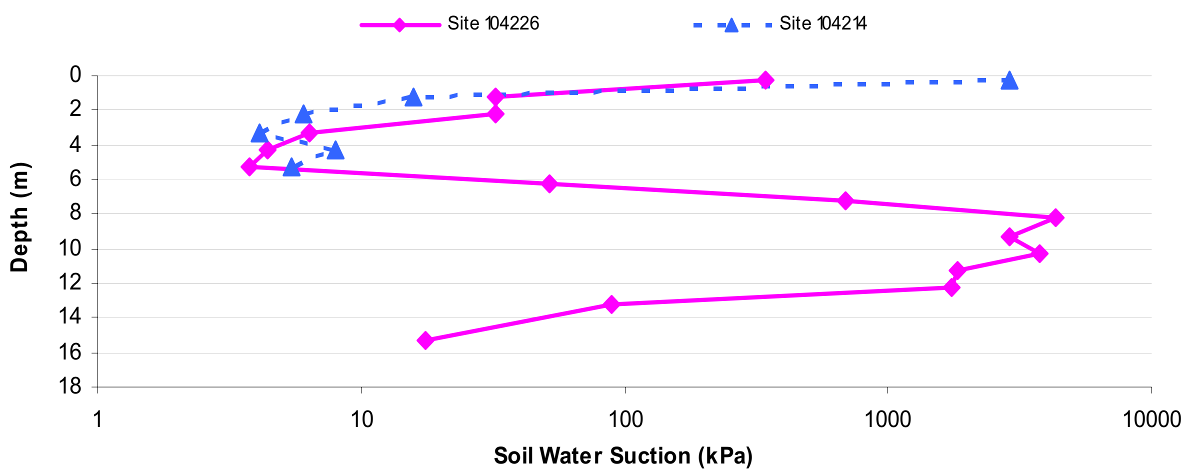


Figure 49. Soil water suction versus depth profiles for areas with native vegetation.

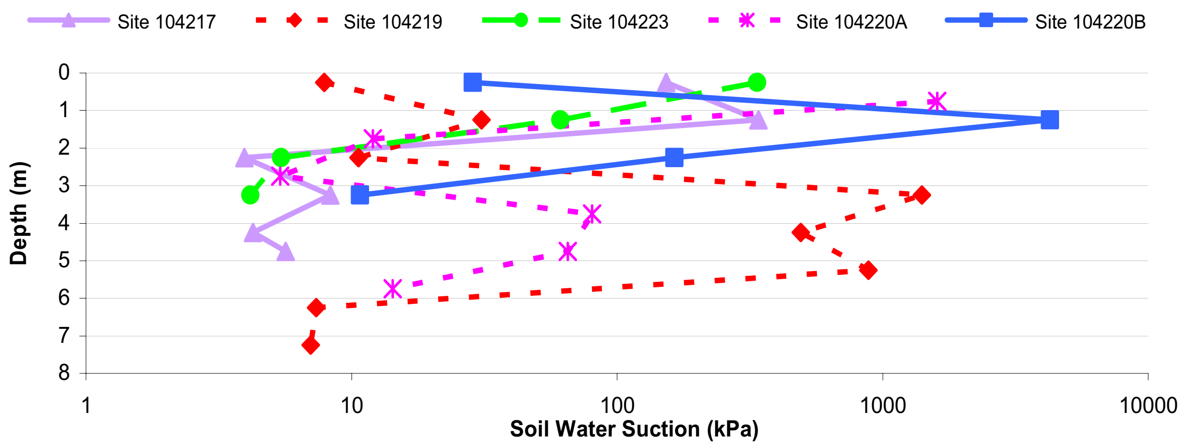


Figure 50. Soil water suction versus depth profiles for areas cleared of native vegetation and not irrigated.

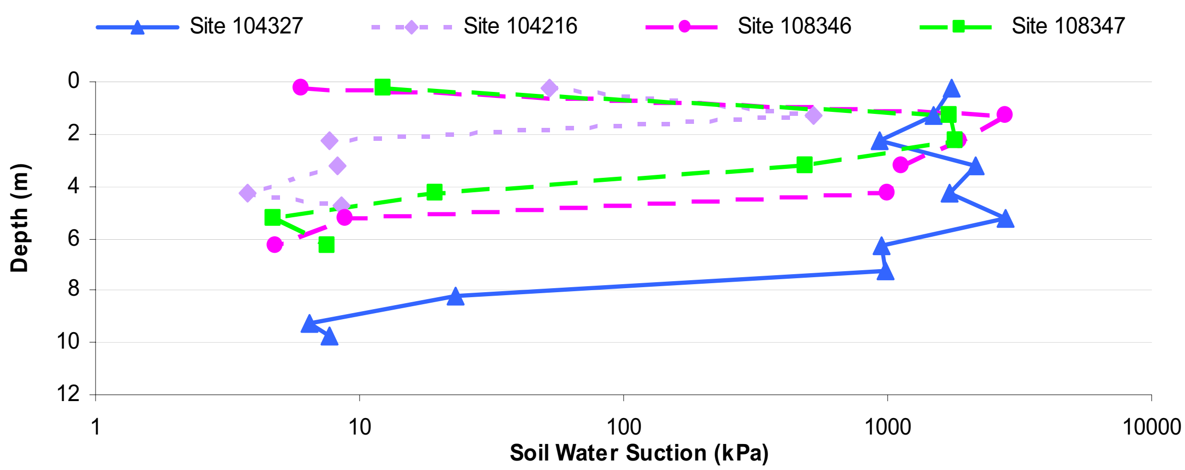


Figure 51. Soil water suction versus depth profiles under pine plantations.

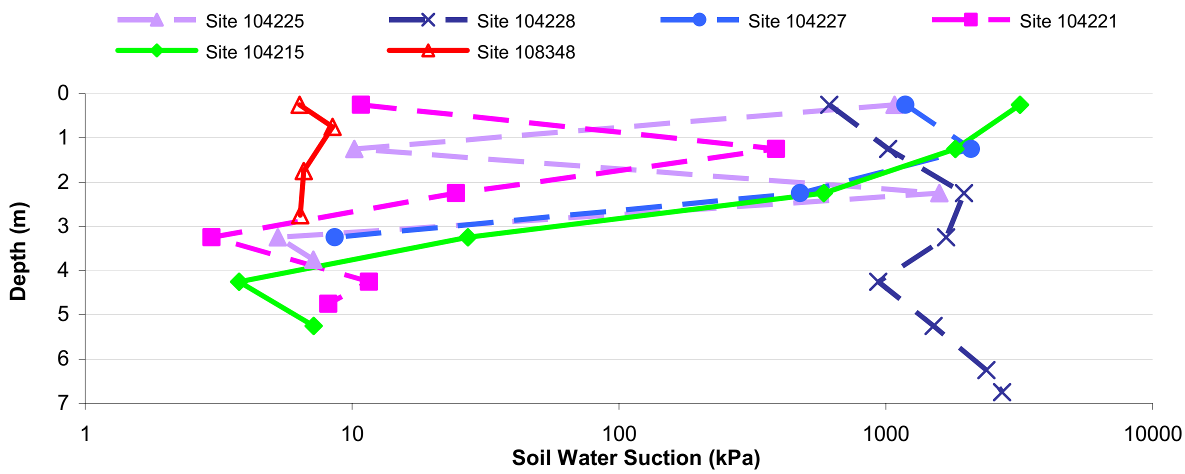


Figure 52. Soil water suction versus depth profiles under blue gum plantations.

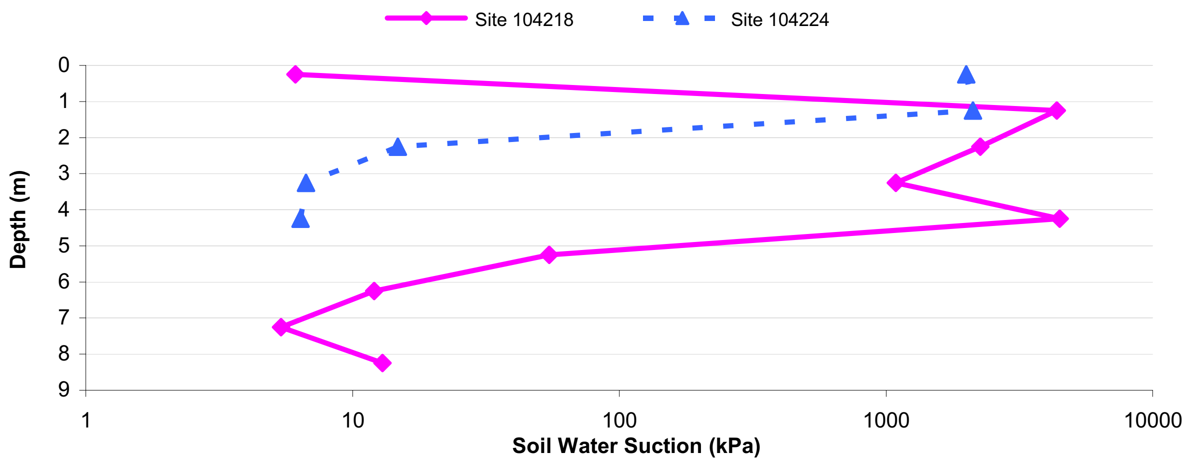


Figure 53. Soil water suction versus depth profiles for irrigated areas.

At the irrigated sites, the SWS profiles are similar to those at the cleared sites, ranging from near saturation close to the watertable to ~4000 kPa for much of the unsaturated zone (Fig. 53). Much lower values would usually be expected for the unsaturated zone soils during the irrigation season. It is possible that these soils were not irrigated for some considerable time prior to sampling, and the plants had used most of the readily available water in the root zone.

5.2.1.3 Particle Size Analysis

Particle size distribution was measured for every second soil sample collected (i.e. about one sample per metre). The fraction of clay in soil samples is often related to the amount of drainage in the soil and has often been used as a surrogate measurement for this, especially in areas cleared of native vegetation (Kennett-Smith et al. 1993). The percentage of clay in each soil sample has been plotted as a function of depth for the unsaturated zone at each of the sample sites (Figs 54–58).

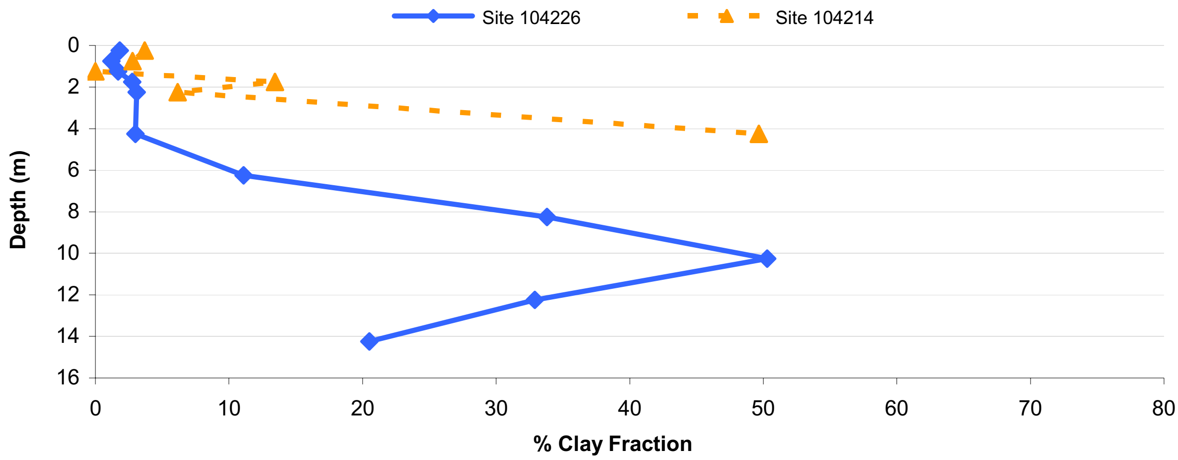


Figure 54. Percent clay versus depth profiles for areas with native vegetation.

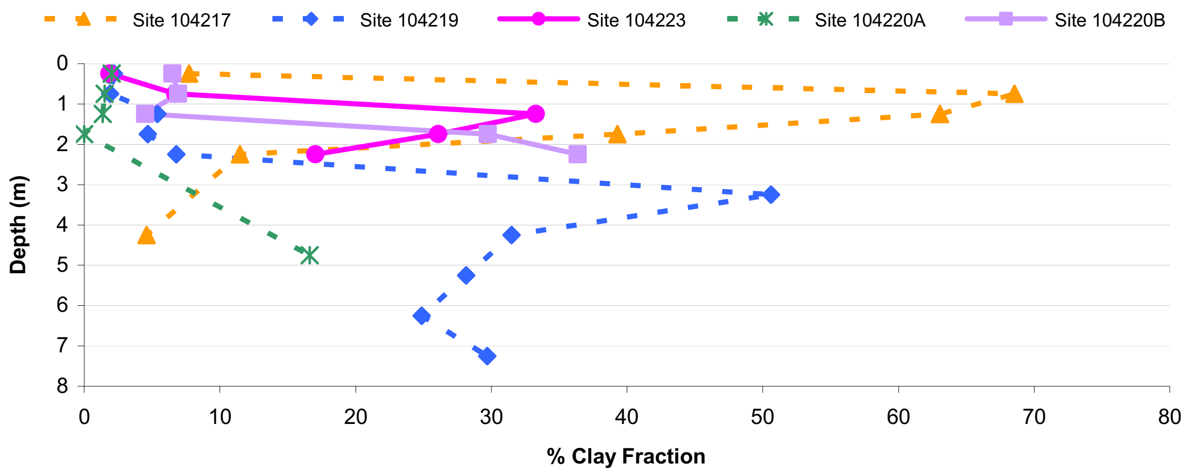


Figure 55. Percent clay versus depth profiles for areas cleared of native vegetation and not irrigated.

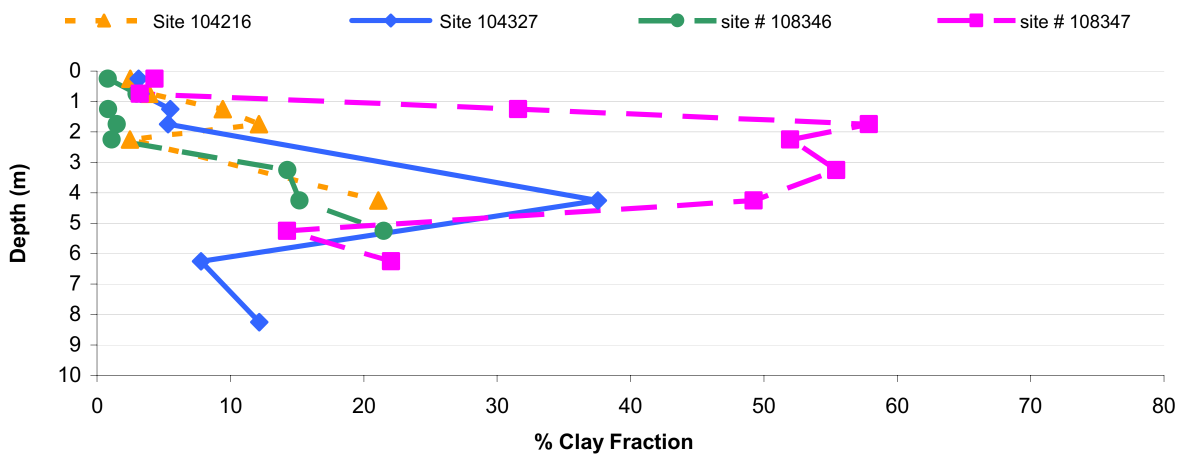


Figure 56. Percent clay versus depth profiles under pine plantations.

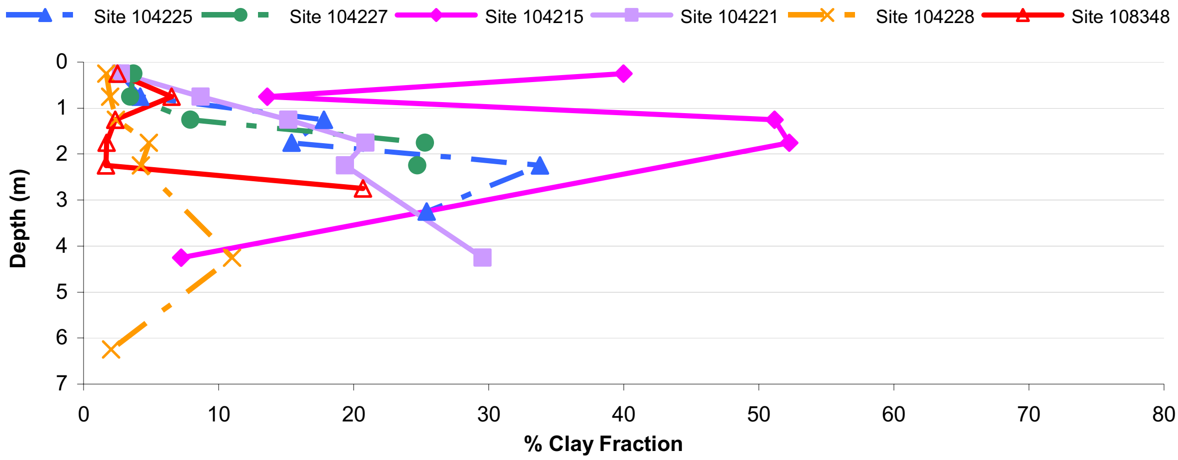


Figure 57. Percent clay versus depth profiles under blue gum plantations.

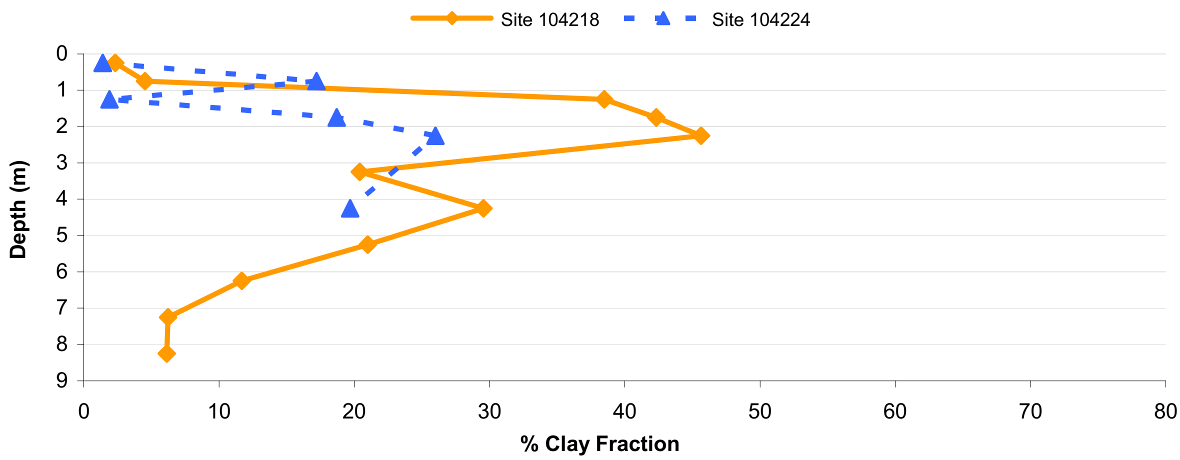


Figure 58. Percent clay versus depth profiles for irrigated areas.

In general, the surface soil is sandier (lower clay %) than that deeper in the profile. Usually, at least the top metre or two of soil has clay contents <10%, whereas this is often 50% or more deeper in the profile. The presence of heavier clay in surface soil is particularly important, as this will result in reduced rates of drainage once the area is cleared of native vegetation. Heavier clay layers deeper in the soil will not have as much impact on the rate of drainage after clearing but will increase the water storage capacity of soil in the unsaturated zone. Hence, it will take considerably longer for the salt to be flushed from heavier textured soils.

5.2.2 CARBON DIOXIDE CONCENTRATIONS IN SOIL GAS

Carbon dioxide (CO_2) is a product of root respiration. If root activity is occurring, CO_2 generated at the source of the root activity will be present at elevated concentrations in the soil. Over time, the CO_2 generated will diffuse to areas of lower CO_2 concentration. Because atmospheric CO_2 concentration is ~0.03%, this will result in a diffusion gradient from the area or areas of highest CO_2 concentration to the soil surface.

Soil gas sampling tubes were installed at three different depths (2, 4.5 and 7 m) at native vegetation site 104226 (F15), at three different depths (2.3, 5.7 and 7 m) at pine site 104327(A1), and at two depths (1.3 and 2.5 m) at blue gum site 104227 (F16; Fig. 59). The lowest CO_2 concentrations were measured for soil gas collected at the native vegetation site, with considerably higher concentrations measured for samples collected at the pine site. Only a single depth was sampled at the blue gum site, and the second sample was not tested.

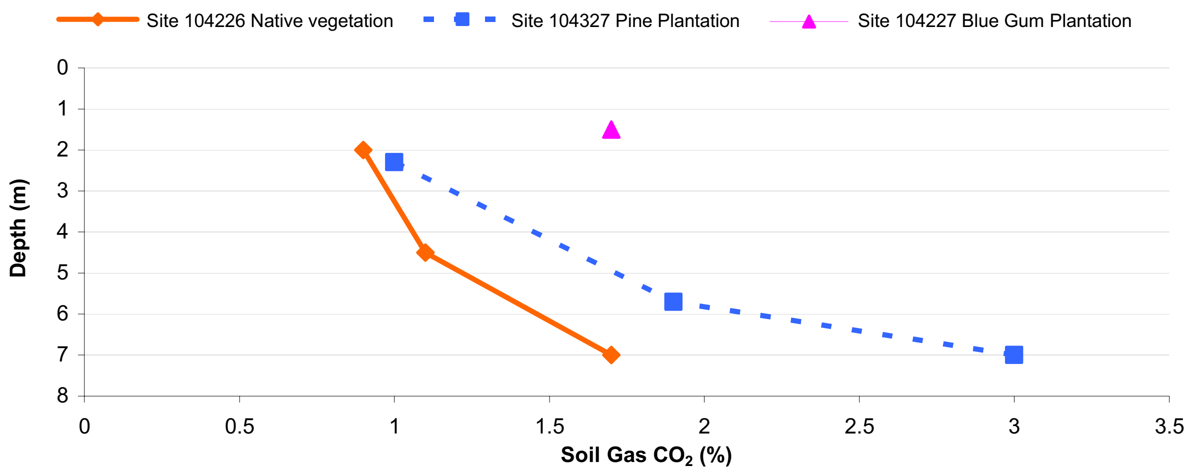


Figure 59. Soil CO_2 profiles (high soil CO_2 concentrations are indicative of root respiration).

Unfortunately, at the native vegetation site, the sampling depths are all within the top 40% of the unsaturated zone (SWL at 16.6 m). The highest concentration for soil CO_2 is 1.7% at a depth of 7 m (i.e. from the deepest soil gas collection point) and there is a gradual decrease in concentration from that depth towards the soil surface. This suggests that roots are able to remove soil water from at least this depth at this site.

At the pine site, the CO_2 concentration is greatest (3%) immediately above the watertable and decreases towards the surface. This suggests that there is considerable root activity in the capillary zone and hence groundwater uptake at this site. The CO_2 concentration of the soil gas at the blue gum site is considerably greater than that for samples collected at a similar depth at the other sites. The elevated CO_2 concentration again suggests use of groundwater at this site (SWL at 2.8 m). Unfortunately, the very different watertable depths at these sites make relative comparison of root activity difficult. Hence, all that can be said is that at each site there is evidence for water uptake from the deepest sampling point. The CO_2 concentration could also be produced from organic matter in the soil (e.g. decaying of organic matter), or CO_2 concentration in the groundwater.

5.3 WATER USE ESTIMATES

The two methods used to estimate tree water use are the water balance and the salt (as chloride) accumulation under plantation areas. Both methods are point estimates, as in both cases investigation sites were selected at different land uses. The following sections discuss the outcomes from using these two methods. Full reports on the use for these methods are listed in Appendices C and E.

5.3.1 POINT WATER BALANCE

At site BG2 (southeast of D10), the maximum depth to the watertable has increased by almost 1 m over the past four years (Table 8). It appears this may have reduced the amount of groundwater uptake. Annual net groundwater uptake was ~200 mm/y at this site for the period late spring 2001 to late autumn 2003. However, net groundwater uptake was nil in 2003–04, and 88 mm in 2004–05. The low value for 2003–04 had previously been thought to be due to high rainfall and below-average evaporative demand in that period. This is possibly a contributing factor, but in the first five months of 2005, even though only 78 mm of rain was received, net groundwater use was only 32 mm.

This plot is known to have a heavy, massive clay layer at ~2–2.5 m depth (from core analysis, the clay layer was at 1.5 m at site D10, which is ~40 m away). In the past four years, the maximum depth to groundwater has declined from only 2.6 m in autumn 2002 to 3.5 m in autumn 2005. The clay layer might be restricting root penetration to the groundwater, or restricting upward movement of groundwater to the root zone, resulting in a reduced groundwater uptake.

Site BG3 (south of D10), which is only 300 m away, also has a clay subsoil, but at slightly greater depth and not as massive as at BG2. At this site, net annual groundwater uptake over the past three years has varied by only 50 mm from year to year (Table 8) despite the maximum depth to watertable increasing from 2.9–3.7 m. Here, annual total evapotranspiration has always been close to the theoretical point potential evapotranspiration, indicating that there is little or no restriction to water uptake at this site. It is possible that at sites with medium to heavily textured clay subsoils, relatively small differences in the density or structure of the clay might have a large effect on the amount of groundwater uptake (Benyon, 2005).

5.3.2 SALT ACCUMULATION

Table 11 summarises the results for tree water use estimated using the salt accumulation method. A detailed discussion of the results at each site is provided in Appendix E.

Table 11. Summary of groundwater uptake using the salt accumulation method at pine and blue gum sites.

Site	Forest	WT depth (m)	Age/rotations (years)	GW uptake (mm/y)	Comments
A1	Pines	9	79/3	>40	
B4	Pines	4.9	37/1	>100	
G18	Pines	5	35/1	>30	
H19	Pines	6	60/2	>390	
B5	Blue gums	5	17/2	0	Groundwater use less than expected
F17	Blue gums	9.5	7/1	0	Coring ceased above WT
F16	Blue gums	2.8	7/1	>1000	Large uncertainty
E11	Blue gums	2.8	7/1	>300	Large uncertainty
D10	Blue gums	4	9/1	>300	Large uncertainty
I120	Blue gums	2.4	11/1	>>140	Large uncertainty

Groundwater use is seen at all of the pine forestry sites and at four of the six blue gum sites. For the blue gum sites, variation in local conditions such as depth to the water and presence of hard or clay layer will have an impact on the water uptake by the trees (e.g. blue gum sites F17 and B5).

A similar situation is observed at pine site (G18), where the groundwater use is considerably less than expected for a well developed pine plantation with groundwater at a depth of only 5 m.

Groundwater use for two pine sites and four blue gum sites has also been estimated using water balance – sap flow measurements (Benyon & Doody 2004; Benyon 2005; see App. C). The mean value for groundwater uptake and the study period to which the measurements apply are summarised in Table 12.

Table 12. Comparison of estimates of groundwater use by pine and blue gum using the chloride accumulation and water balance – sap flow methods.

Site	**Mean GW uptake** (mm/y) * **by Cl accumulation**	**Mean GW uptake** (mm/y) **by water balance – sap flow**
Pines		
G18	>30 (1968–2005)	0 (1997–2000)
H19	>390 (1945–2005)	600 (2001–2005)
Blue gums		
F17	0 (1998–2005)	0 (2002–2005)
F16	>1000 (1998–2005)	220 (2002–2005)
D10	>300 (1996–2005)	400 (2002–2005)
I20	>>140 (1994–2005)	640 (2000–2004)

* The mean does not include the first three years after planting nor a period of three years after each rotation.

At the pine sites, there is good agreement between the groundwater uptake estimates for the two methods. Both suggest low rates of groundwater uptake at site G18 and high rates at site H19. The results are even more interesting when one considers that they both have similar depths to the watertable. In fact, the higher rate of uptake is seen at the site with the deeper watertable. Clearly, at site G18 there is something about the soil or trees that is significantly impeding the ability for the pines to access water. The most likely reason, as suggested by Benyon and Doody (2004), is the presence of a hard layer at a depth of ~1–2 m.

There is also general agreement between the methods at two of the four blue gum sites, despite the likely large errors using the chloride accumulation method. The exceptions are at sites F16 and I20. At I20, the minimum estimate from the accumulated chloride method is considerably less than the estimate using water balance methodology. However, as discussed earlier, the estimate using chloride accumulation is likely to be a considerable underestimate at this site because sampling did not proceed far enough to define all of the chloride accumulated.

At site F16, the estimate using the chloride accumulation method is far in excess of that using the water balance method, and there are several reasons for this. The possibility of incomplete flushing of chloride from the profile prior to planting the blue gums has been discussed in Leaney, Mustafa and Lawson (2006).

5.3.3 RECHARGE DETERMINATION

The watertable fluctuation method estimated an average recharge of ~200 mm/y in the Bakers Range area, using water-level responses in observation wells MON016, MON017 and MON 018. The records extended over the period from 1981–2003.

Table 13 is a summary of the estimated recharge under native vegetation and open pasture sites calculated using the chloride mass balance.

Table 13. Summary of recharge and discharge at the sites with and without native vegetation cover.

Site	$[Cl]_{SW}$		WT depth (m)	Average % clay		Recharge or GW uptake (mm/y)
	native	*cleared*		(0–2 m)	(0–WT)	
F15	1000		16.6	2.1	14.7	low recharge or discharge
A3	1000		5.3	5.0	12.6	8 recharge
B6		30	5.2	44.7	28.1	250 recharge
C8		20	7.9	4.2	18.6	375 recharge
E13		120	3.0	17.0	17.0	65 recharge
F14 A		190	20.0	1.2	4.3	40 recharge
F14 B		30	3.5	11.9	16.8	250 recharge

The recharge under native vegetation is very low to ~8 mm/y. Recharge rates at the cleared sites using these data is estimated to range from 40–375 mm/y, with an average recharge rate of ~200 mm/y.

5.4 UPSCALING POINT — REGIONAL WATER USE

The water balance and salt accumulation methodologies used to estimate the water uptake by trees and salt accumulation under different land uses are point estimate methods. However, as long as the geological settings and depth to watertable are similar, it is possible to upscale the results across the region.

The possibility of regional upscaling is supported in Figure 38, which shows a land use impacting on the groundwater resources over ~48 km in the Bakers Range area. Additionally, the impact on groundwater salinity from irrigation practices was shown to be similar at both the Nangwarry and Bakers Range study areas over a distance of ~33 km.

The additional coring sites included in the study are some distance apart at Penola, Mount Gambier and Beachport indicated a water use by trees occurring, and if changes to this situation are observed, it will be related to a localised change in the geology, such as the existence of a hard or impermeable clay layer.

In this section, an attempt was made to upscale (test) the results from different land uses by using a water and salt balance approach and also from the numerical model.

The numerical model is showing reasonable agreement to current groundwater levels. Application of the MODFLOW groundwater flow computer model has demonstrated the capability of using the model to predict the impact of any land-use scenarios on the groundwater resources in the South East. More discussion will be presented later in this report about the numerical modelling approach to assess impact of land-use changes.

5.4.1 WATER AND SALT BALANCE

Results of the salt and water balance spreadsheet calculation for the pilot study area under current land uses are provided in Table 14. These show that the calculated water balances for 2004 and 2005 resulted in a water loss to the groundwater system. The main discussion points of the water and salt balance results are listed below.

- The water balance contains a number of estimations that best represented the system. For the calculated water loss from storage, a good agreement was noted in observation well SHT023, where a 3 m decline in the water level compared well an estimated 3.12 m decline for the year 2004 (Table 14).
- There is a considerable difference, both in salt and water balances, between 2004 and 2005. The main factors in 2004 are drain flow and tree water use having a combined impact, and in 2005 there was no flow in the drain.
- Prior to the forestry development adjacent to Bakers Range Drain, groundwater flow in the drain varied from no flow to a highest measured value of 26 266 ML in 1992. The average groundwater discharge for the 14 years of records is 8686 ML/y.
- Prior to forest plantation, water from storage was leaving the system as base flow into the Bakers Range Drain. The gauging record at Phillips Road indicated that eight of the 14 years had recorded drain flow, and shows that a water loss from the system was occurring ~50% of the time.
- For the pilot study area, drain flow and tree water use were compared. Average drain flow over a 14-year period was ~8700 ML/y. From the 2005 water balance, the forested area has an estimated water use of ~16 000 ML/y. However, in 2004 the two land uses had comparable water losses (~14 000 ML/y base flow and ~16 000 ML/y forest water use).
- In 2005, the drain did not flow and tree water use has become the dominant water loss to the system.
- There is a potential salt load stored in the unsaturated zone, which will be released upon forest harvesting. Because the watertable is relatively shallow, some of this salt will occasionally be flushed by water-level fluctuation.

Table 14. Water and salt balance for the pilot study area — current land uses.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	4 463	2 237
Recharge under native vegetation (ML/y)	52.8	52.8
Irrigation return (ML/y)	42.5	42.5
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**9 157**	**6 932**
Water out		
Hardwood discharge (ML/y)	-13 800.5	-13 800.5
Softwood discharge (ML/y)	-2 145	-2 145
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	-850	-850
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-40 897.7**	**-224 45.7**
Water balance	**-31 741**	**-15 514**
Volume of water in storage (ML)	**152 460**	**120 719**
Change in storage (m)	**-3.12**	**-1.53**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	408.2	331.296
Salt load from recharge under native vegetation (tonnes)	4.8	4.8
Salt load from irrigation return (tonnes)	53.1	55.9
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**5 065**	**4 991**
Salt out		
Salt stored under hardwood (tonnes)	-13 801	-13 801
Salt stored under softwood (tonnes)	-2 145	-2 145
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	850	895
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**-30 404**	**-19 288**
Salt balance	**-25 339**	**-14 297**
Salt in storage (tonnes)	**152 460**	**120 719**
Groundwater salinity (mg/L)	**1 053**	**1 012**

5.4.2 NUMERICAL MODEL

5.4.2.1 Calibration results

Steady-state Calibration — Simulation of March 1970–71 conditions

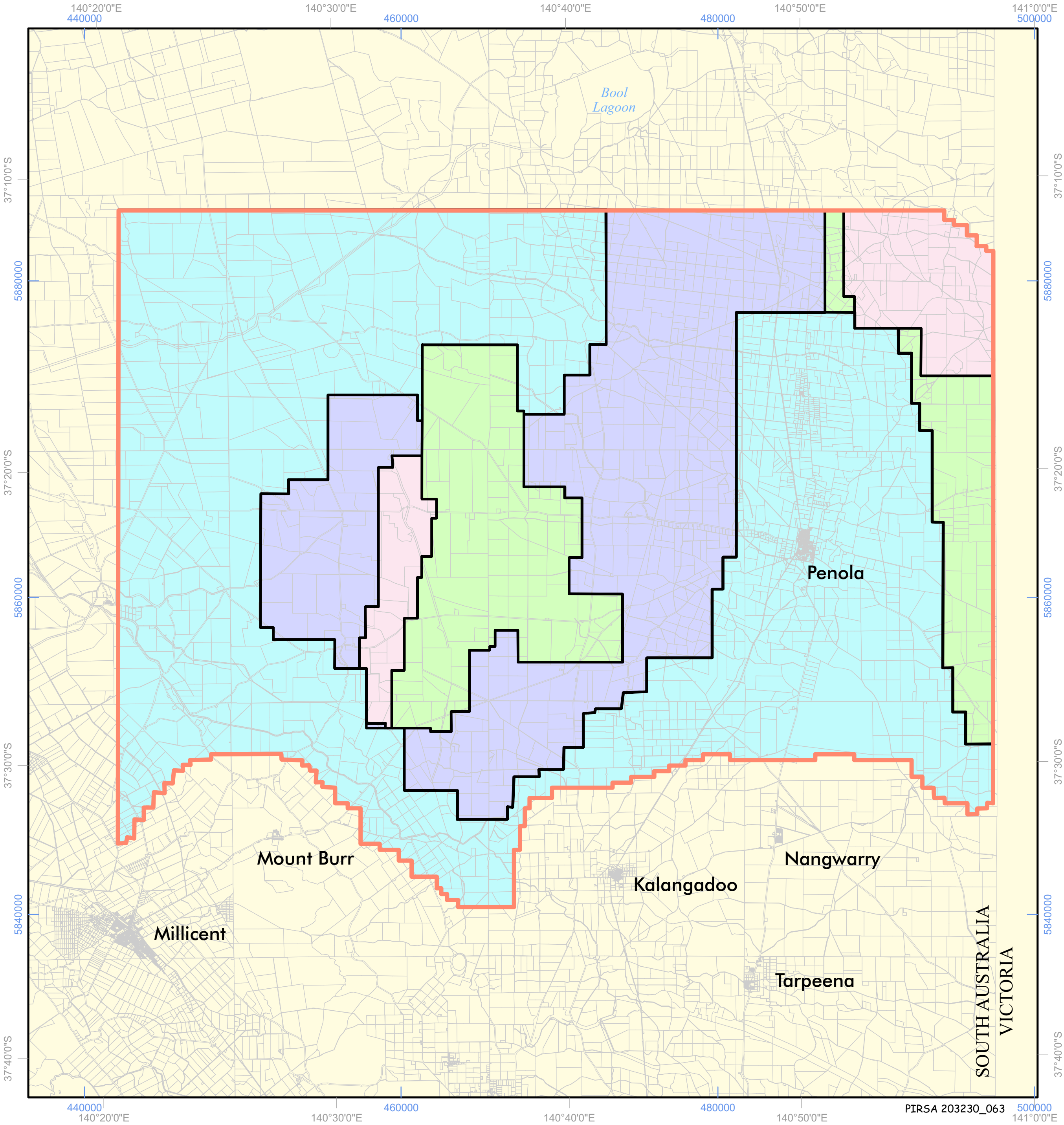
Artificial drains in the study area were constructed in the 1960s and the earliest observation well data were recorded in 1970–71. No water-level data are available prior to this time; these data therefore represent the annual average values from 1960–70. This period was selected primarily because of the availability of the data, and the steady-state model was a simulation of the assumed average annual conditions for this time.

The steady-state model calibration target was to match the calculated average annual water levels to the1970–71 observed values.

A problem was lack of information about pumping volumes, extraction well location, extraction volume and the average groundwater withdrawal from the aquifers during the years from 1970. Since groundwater was pumped from the unconfined aquifer during the 1960s and 1970s, the mean annual withdrawal rates or volume for this period was the aquifer stress required for simulations. The model was calibrated by adjusting the current extraction volume, based on the fact that groundwater from the unconfined aquifer is allocated on estimated average annual vertical recharge to the watertable. It was assumed that 81% of vertical recharge was extracted from the unconfined aquifer.

The steady-state model was calibrated by adjusting the current extraction volumes and then varying the aquifer hydraulic conductivity to obtain a close match between the simulated and observed 1970–71 groundwater level. The final calibrated hydraulic conductivity values are shown in Figures 60 and 61.

The calculated and observed 1970–71 water-level conditions are shown in Figures 62 and 63; Table 15 is an error summary for the steady-state calibration results. The root mean square error between the calculated and observed water level was 1.195 m. For the steady-state conditions, of the total inflow into Layer 1, the annual recharge accounted for ~64% (1.1 ML/d), lateral inflow (constant head) 28% (0.48 ML/d), and upward leakage from Layer 2, 8% ($8x10^{-6}$ ML/d). Of the total outflow from Layer 1, 51% (0.88 ML/d) was withdrawal by extraction wells, 22% (0.38 ML/d) lateral outflow to the adjacent aquifer, 21% (0.36 ML/d) vertical leakage to Layer 2 and 6% (0.097 ML/d) into the drains. The difference between estimated 'predevelopment' inflows and outflows is ~-0.006% of the estimated inflow.



0 5 10 15 Kilometres

K value

15 m/d

20 m/d

30 m/d

50 m/d

Numerical model boundary

Cadastre

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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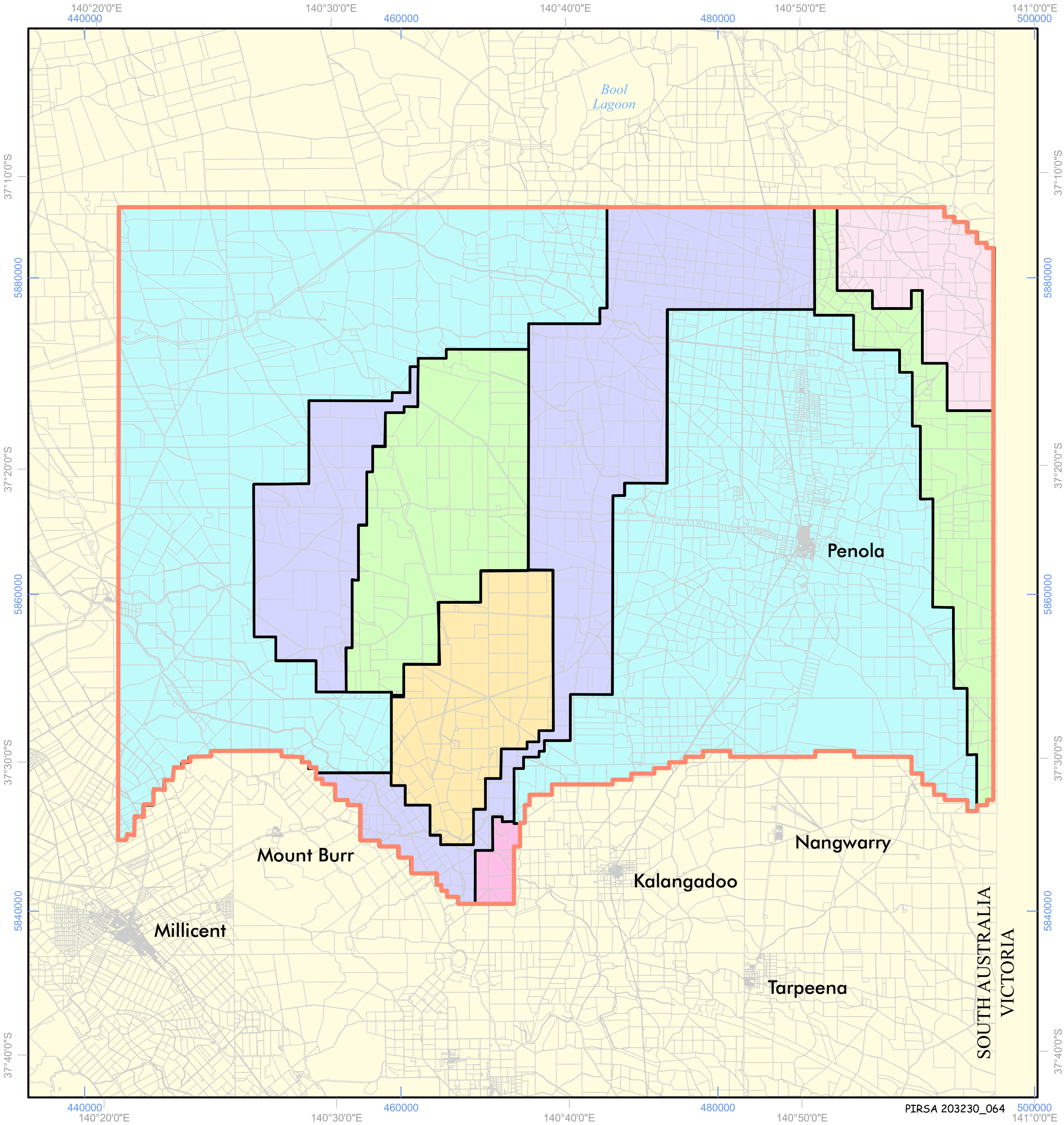
CALIBRATED HORIZONTAL HYDRAULIC CONDUCTIVITY USED IN LAYER 1

Figure 60



K value

- 15 m/d
- 20 m/d
- 25 m/d
- 30 m/d
- 50 m/d
- 55 m/d

Numerical model boundary

Cadastre

0 5 10 15 Kilometres

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CALIBRATED HORIZONTAL HYDRAULIC CONDUCTIVITY USED IN LAYER 2

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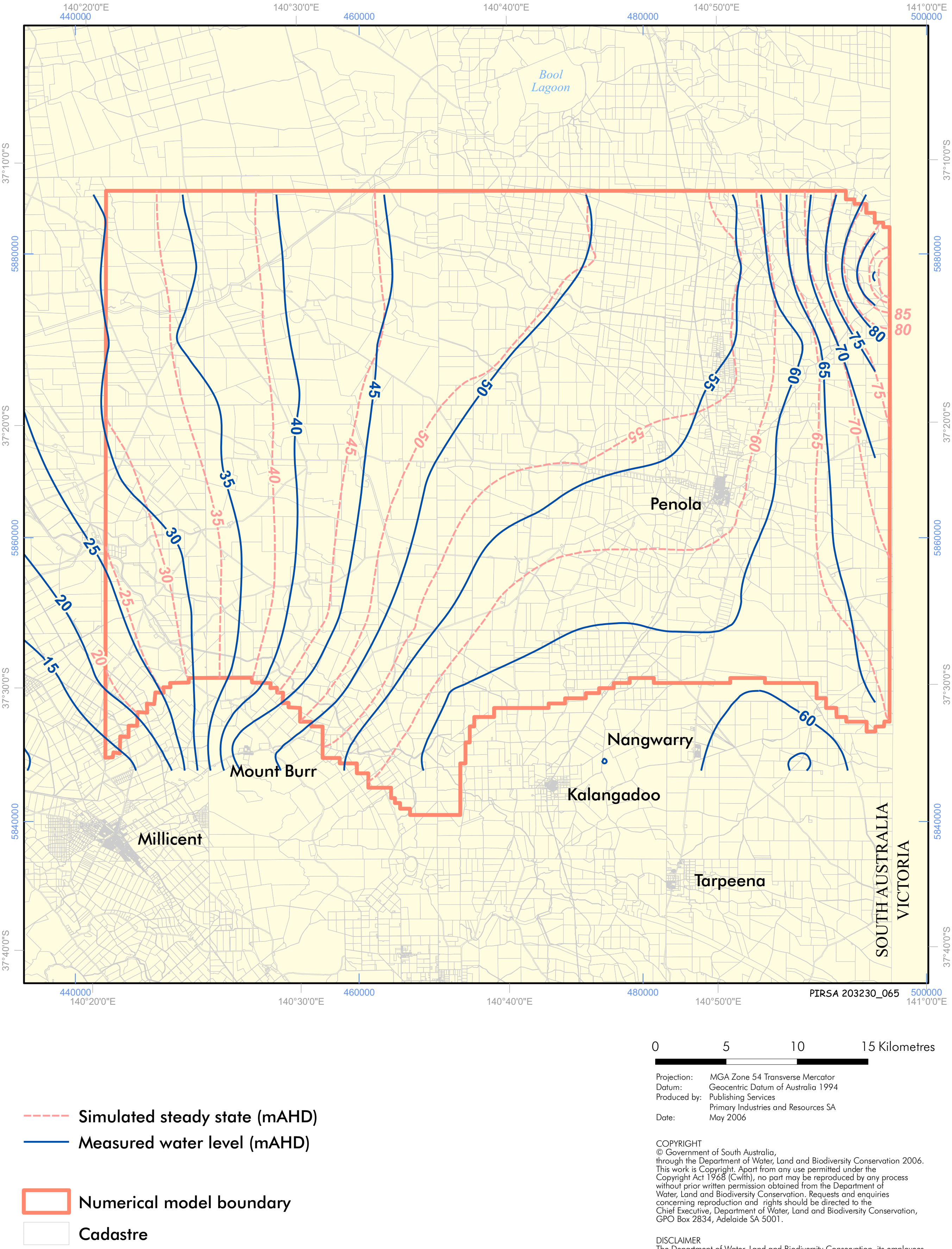
Figure 61



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COMPARISON OF SIMULATED STEADY STATE AND MEASURED WATER LEVEL

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Figure 62

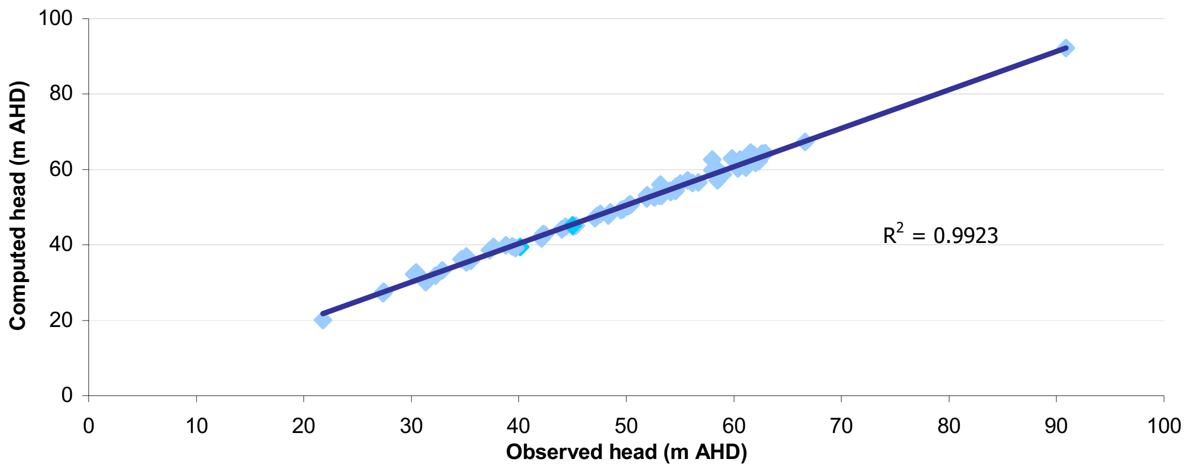

Figure 63. Steady-state simulation calibration — computed versus observed head.

Table 15. Steady-state error statistics.

Mean error	0.562
Mean absolute error	0.821
Root mean square error	1.195

5.4.2.2 Transient model calibration

After achieving a satisfactory steady-state calibration, transient groundwater conditions in the study area were modelled for 50 years between 1970–2020. The transient model was divided into two stages, and the first stage, which was run from 1970–71 through 1994–95, was used to calibrate the model. The second stage was run from 1995 through to 2004–05 and was used to validate the model. Stage one was calibrated to change water levels in response to recharge and pumping while stage two was validated to change water levels in response to recharge, pumping and evapotranspiration by tree plantations in the area. Tree plantations were established in the area in 1999.

Each year was divided into two stress periods with summer beginning in September, and made up of 232 days, while winter started in May and lasted for 133 days. These stress periods were selected so that they coincided with pumping and recharge periods, and were also linked to observation well monitoring periods. It was assumed that there is no groundwater pumping in winter months. The summer and winter stress periods were each divided into five time steps measured in days.

5.4.2.3 1970–95 Transient Model

Groundwater levels from the calibrated steady-state model were used as initial conditions for the transient simulation. The transient model was calibrated for the 1970–71 to 1994–95 seasons using available water-level data from observation wells located within the study area; Figure 64 shows the location of these wells. During the transient calibration, adjustments were made to the specific yield to achieve an acceptable match between the calculated and measured water levels. The match was obtained using specific yield values ranging from 0.07–0.15 for the unconfined aquifer (Fig. 65). The transient model was assumed calibrated when simulated water levels matched the general trend and magnitude of measured water levels (Figs 66 and 69).

A number of factors may account for variations between the simulated and measured water levels, including:

- Groundwater use in the study area is intensive during summer months, and the exact number and location of the extraction wells in the area, while known, still need to be accurately located within the model.
- Further work is required to collate available data on annual groundwater extraction volumes and rates.
- Pumping rates were determined from current allocated volume but not the actual licensed use.
- The model-simulated hydraulic heads represent long-term conditions over large areas (cell size), whereas the field-measured heads may include short-term local effects of pumping and recharge.
- In reality, the pumping rates and recharge may vary during a given stress period, but in the transient simulation, recharge and pumping rates were kept constant for the duration of the stress period.

5.4.2.4 Scenarios

The calibrated model was tested against water-level data and other stress conditions (evapotranspiration from tree plantation zones) not used in the calibration process. The calibrated model was used to reproduce 1995–2005 measured water levels at observation points under historical field conditions. The 10-year matching of the measured observation wells are shown in Figures 70–77, and validation shows how the model can simulate past conditions as a predictive tool in managing the groundwater resources in the area.

5.4.2.5 Validation results — in the absence of tree plantations

The calibrated model was used to reproduce 1995–2005 measured water levels in the absence of tree plantations. The response of the calibrated model to recharge and pumping stress from 1995–2005, in the absence of tree plantations, is shown in Figures 70–72. Apart from observation well SHT014, where the model underestimates the water levels in winter and overestimates in summer, the model clearly predicts the groundwater levels in winter but overestimates groundwater levels during summer periods at the other observation points. The potential impact of the tree plantations (cultivated from the beginning of 1999) on the groundwater resources in the study area would have been a reduction in recharge rates and an increase in plantation groundwater usage. As these conditions were not simulated or accounted for in the model, the overestimations in summer during later years could be attributed to the impact of the tree plantations. The model overestimates the summer water levels by between 0.5 and 2.1 m, or over 1.0 m on average.

0 5 10 15 Kilometres

SHT011 Observation well and number

Drain

Numerical model boundary

Cadastre

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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LOCATION OF OBSERVATION WELLS USED IN TRANSIENT MODEL CALIBRATION

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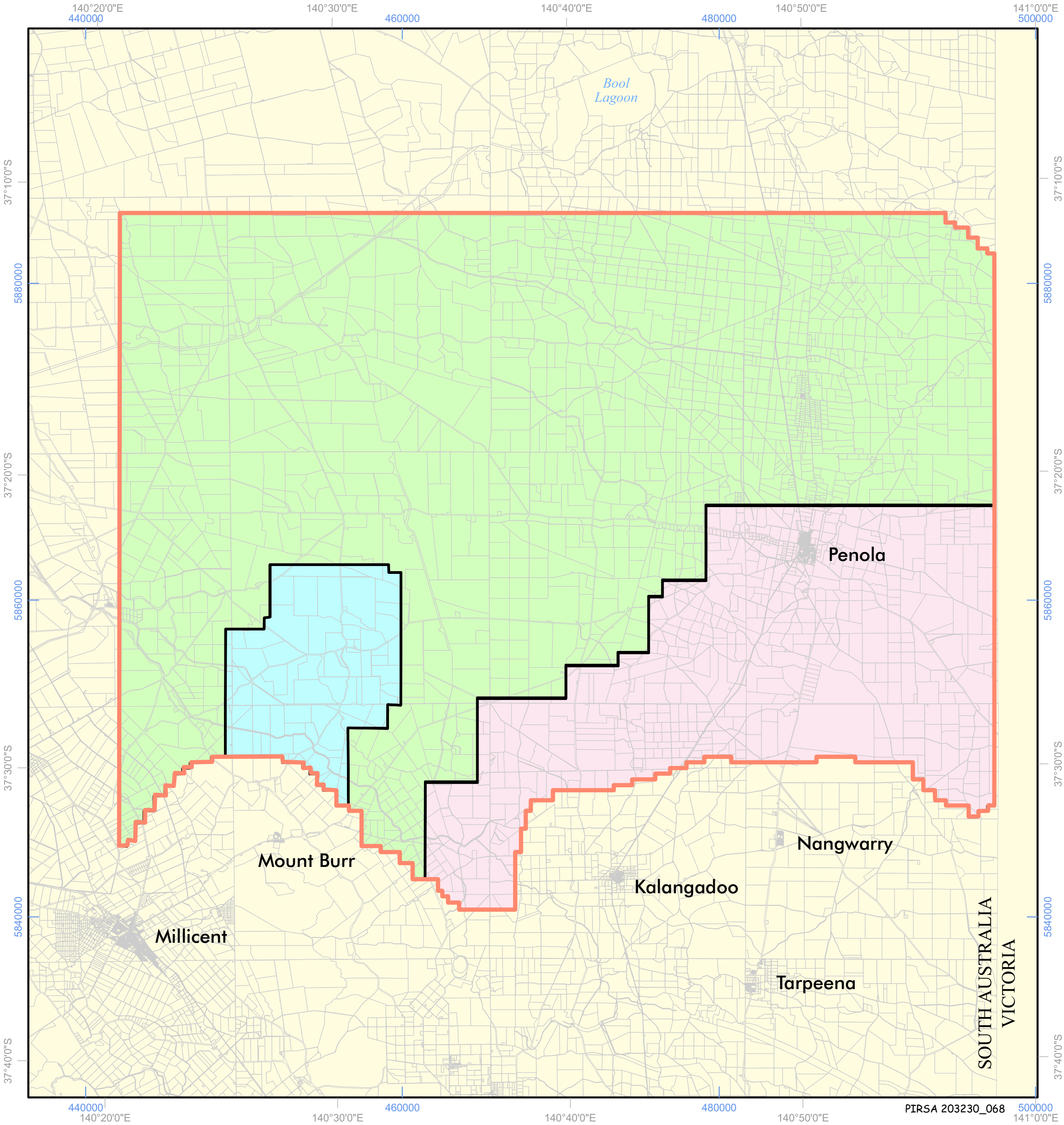
Figure 64



Specific yield

- 0.07
- 0.09
- 0.15

- Numerical model boundary
- Cadastre

0 5 10 15 Kilometres

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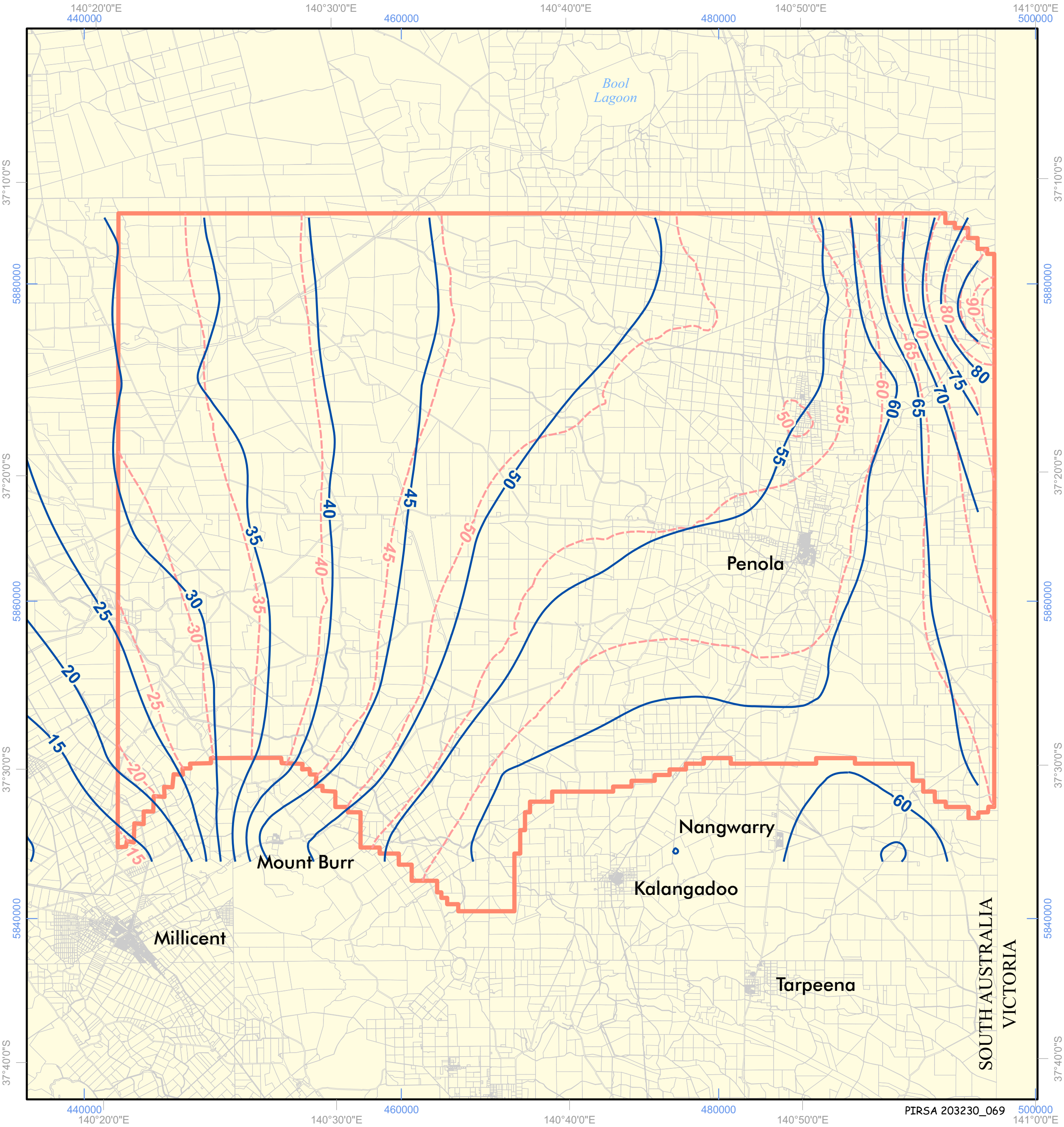
Land use impact on water quality and quantity in the Lower South East – South Australia

CALIBRATED SPECIFIC YIELD VALUE FOR UNCONFINED AQUIFER

Figure 65



0 5 10 15 Kilometres

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
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Simulated water level (mAHD)
Observed water level (mAHD)
Numerical model boundary
Cadastre

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Land use impact on water quality and quantity in the Lower South East – South Australia

COMPARISON OF WATER LEVEL SIMULATED BY THE TRANSIENT MODEL AND OBSERVED WATER LEVEL – MARCH 1971

Figure 66

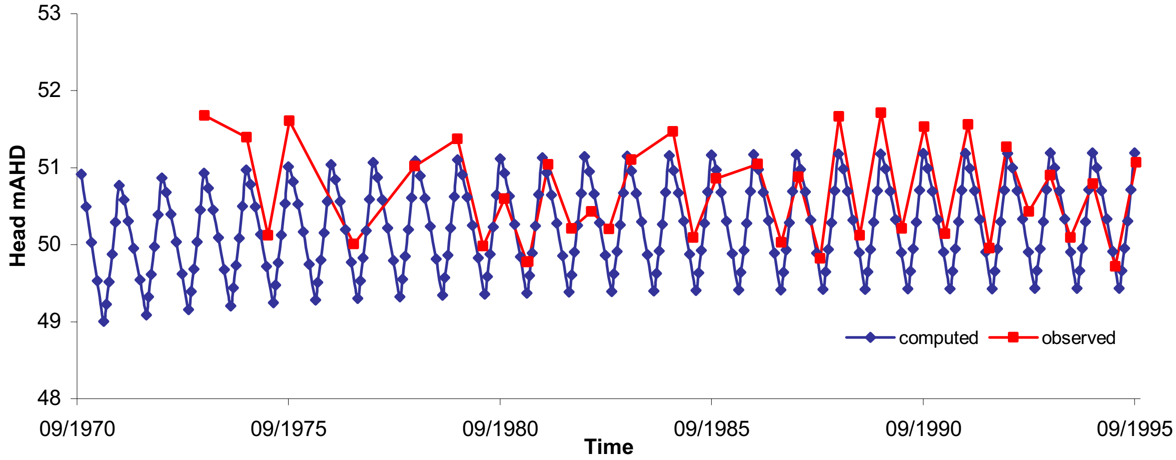


Figure 67. Observed versus simulated hydrograph at observation point SHT012.

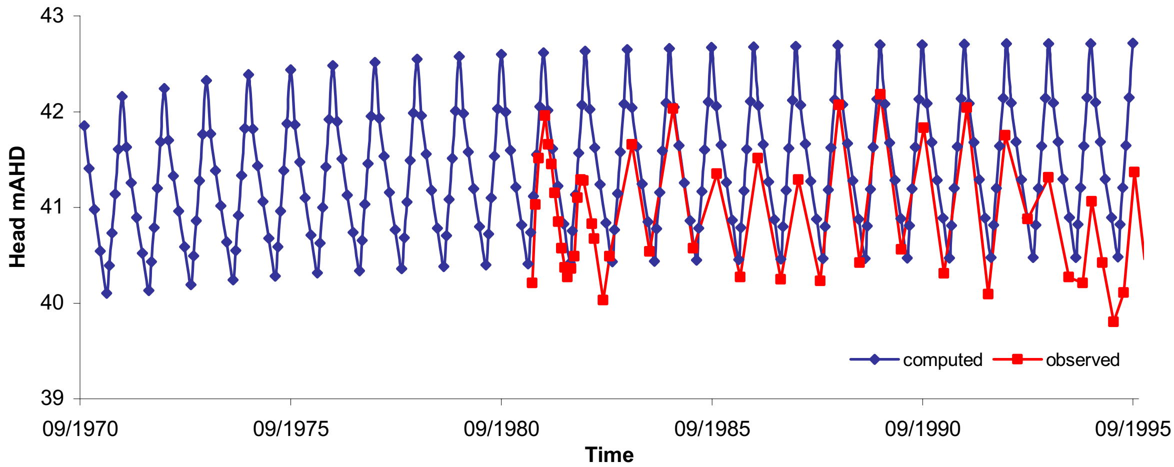


Figure 68. Observed versus simulated hydrograph at observation point SHT014.

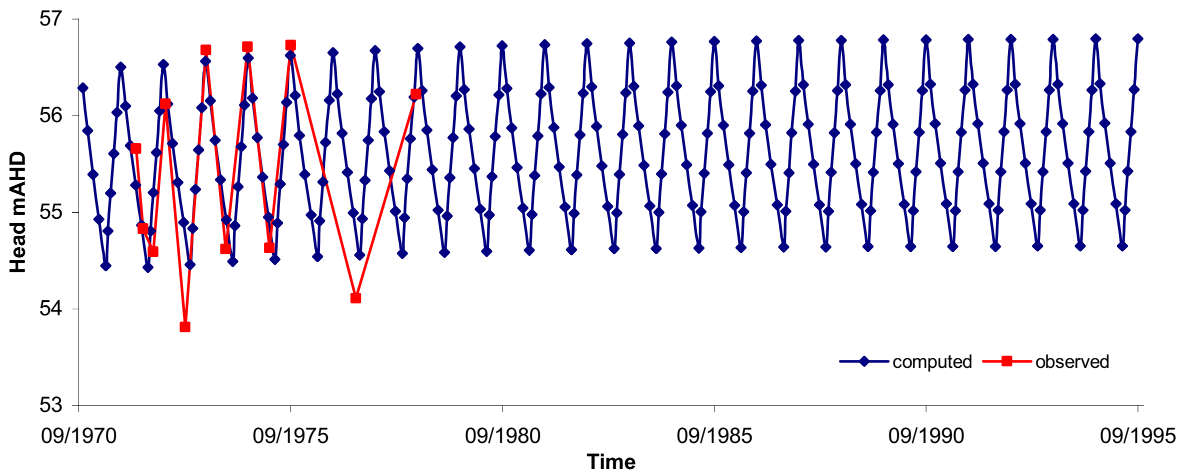


Figure 69. Observed versus simulated hydrograph at observation point MON008.

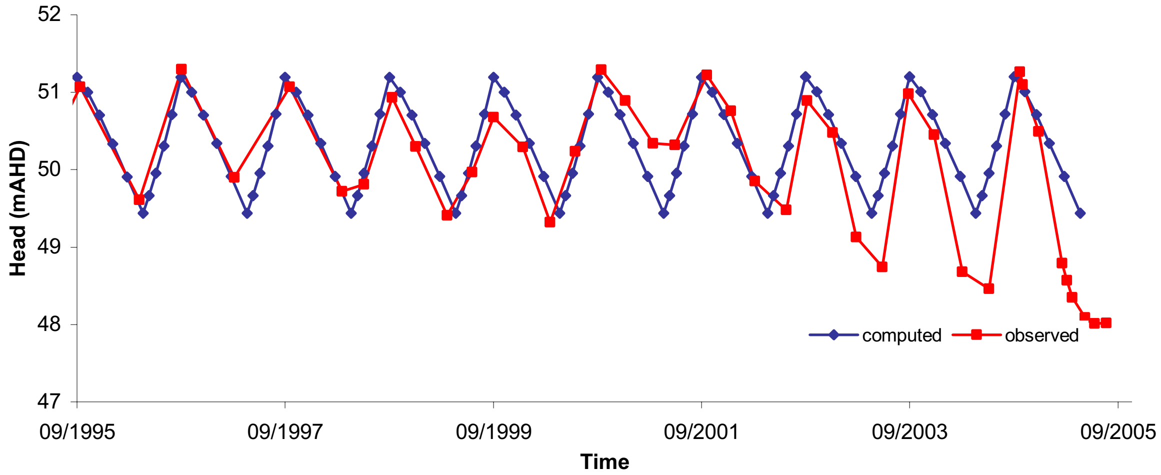


Figure 70. Model validation — observed versus simulated hydrograph at observation point SHT012 in the absence of tree plantations.

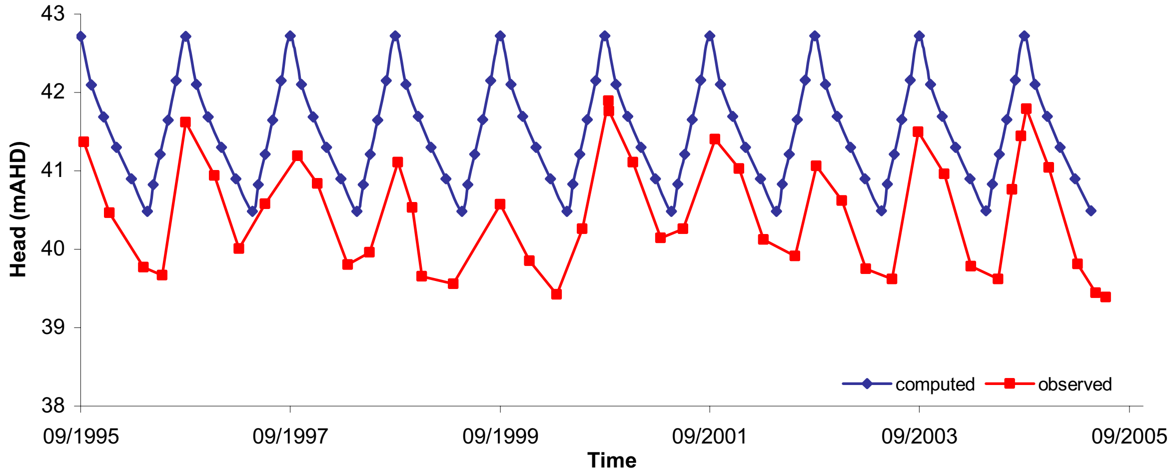


Figure 71. Model validation — observed versus simulated hydrograph at observation point SHT014 in the absence of tree plantations.

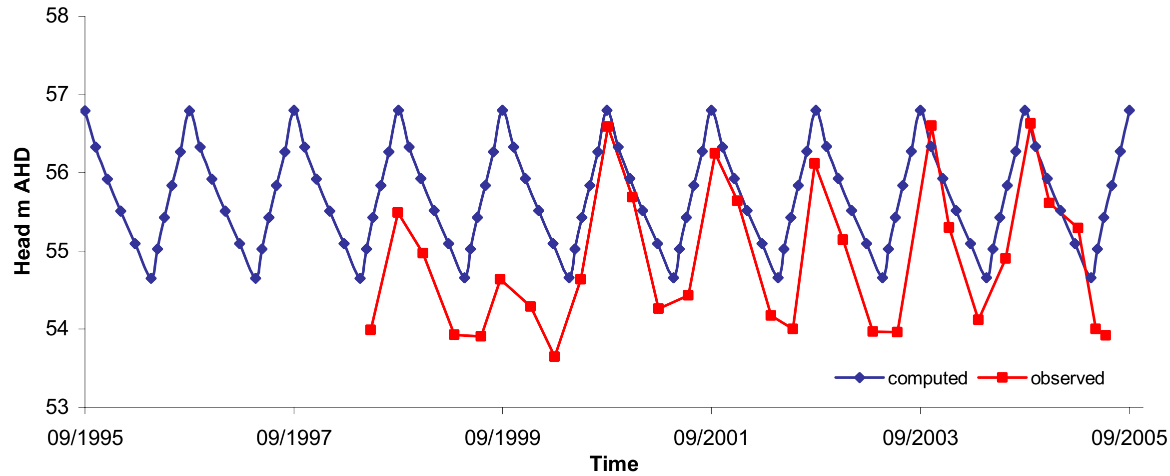


Figure 72. Model validation — observed versus simulated hydrograph at observation point MON008 in the absence of tree plantations.

5.4.2.6 Validation results — in the presence of tree plantations

In this scenario it is assumed that tree plantations were established in 1999 and recharge to the groundwater was 200 mm/y when the trees were one to two years old. It is further assumed that after two years of growth the recharge decreased exponentially from 200 mm/y from the end of the year 2000 (when the trees were about three years old) to 145 mm/y in 2005 (when the trees were seven years old) to 78 mm in 2006 (when the trees were eight years old). After eight years to the time of harvesting, recharge to the shallow aquifer in areas covered by the tree plantation is assumed to be zero. Figure 73 is a graph of recharge rate versus time since planting.

Figure 73. Annual recharge in areas of established tree plantation.

As the trees grow and the root depth reaches the capillary fringe above the watertable (which might not occur for several years after tree planting), the plantation would use groundwater. It is assumed that this use averaged 435 mm/y in areas where depth to watertable is <6 m. The trees start using groundwater after three years from planting and uptake increases from zero (from 2002) to a maximum rate of 435 mm/y when they are five years old (in 2005). This consumption would be maintained until harvesting. About 37% of tree groundwater uptake occurs in winter and 63% in summer (Fig. 74). Tables 16 and 17 summarise recharge and groundwater uptake in areas covered with tree plantations.

Table 16. Gross recharge and groundwater uptake in areas covered by tree plantations.

Year	1	2	3	4	5	6	7	8	9	10
Recharge (mm)	200	200	198	195	189	175	145	0	0	0
Groundwater uptake (mm)	0	0	0	145	290	435	435	433	435	435
Net recharge (mm)	200	200	198	50	-101	-260	-290	-435	-435	-435

Table 17. Net recharge and groundwater uptake in areas covered by tree plantations.

Year	1	2	3	4	5	6	7	8	9	10
Recharge (mm)	200	200	198	50	0	0	0	0	0	0
Groundwater uptake (mm)	0	0	0	0	101	260	290	435	435	435

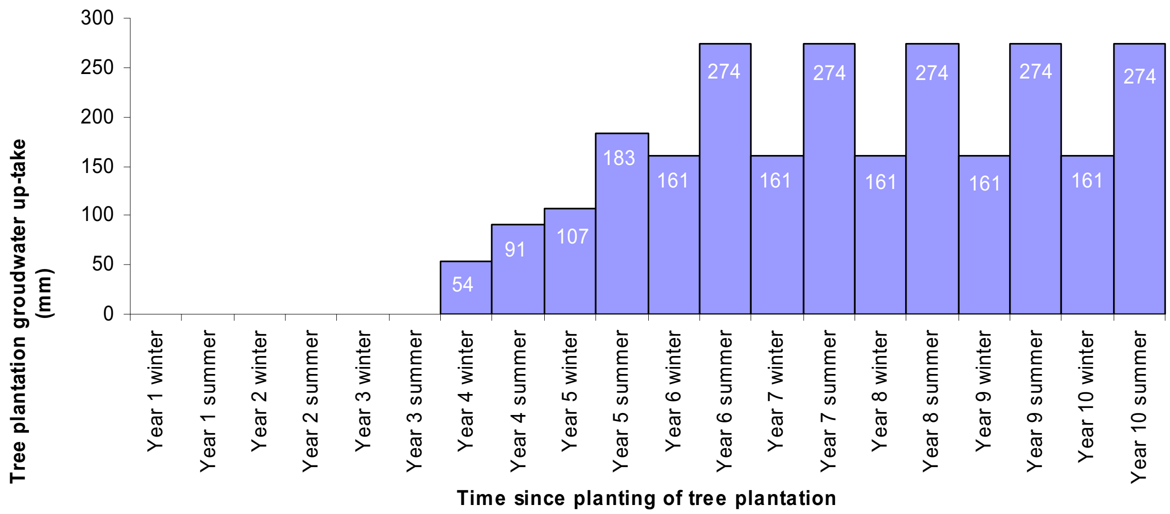


Figure 74. Tree plantation groundwater uptake.

The model-simulated impact of the tree plantation on groundwater levels in the study area is shown in Figures 75–77. These compare model-simulated hydrographs with the observed hydrographs.

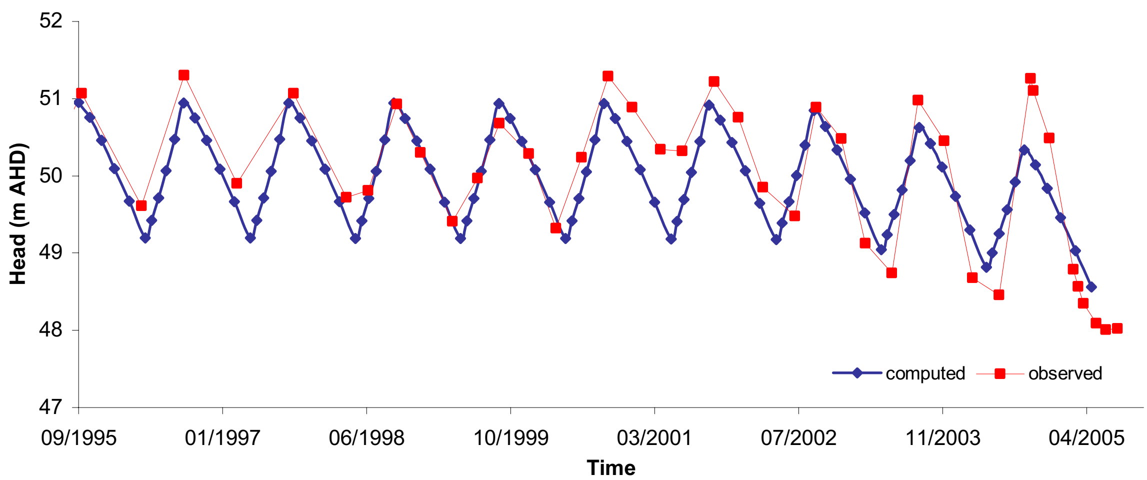


Figure 75. Model validation — observed versus simulated hydrograph at observation point SHT012 in the presence of a tree plantation.

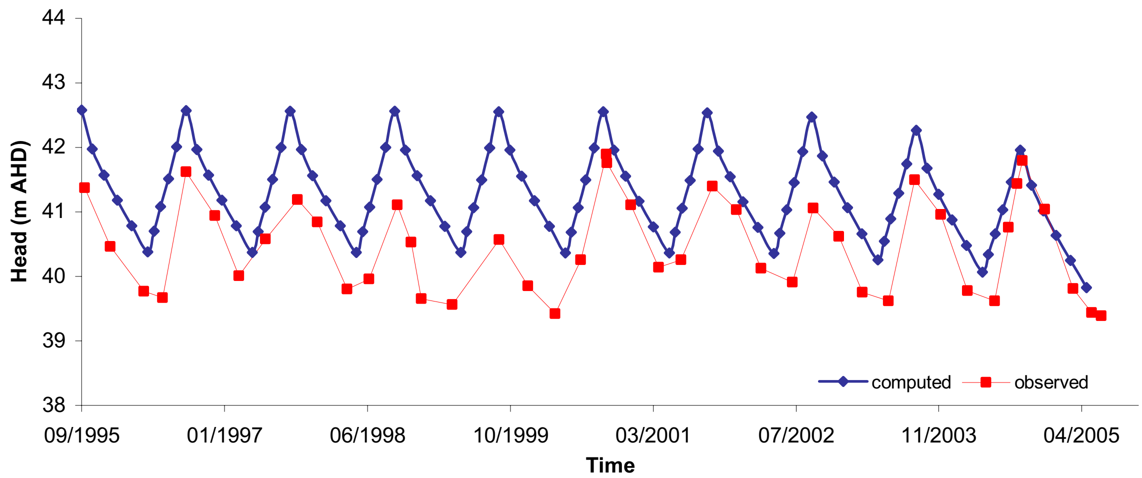


Figure 76. Model validation — observed versus simulated hydrograph at observation point SHT014 in the presence of a tree plantation.

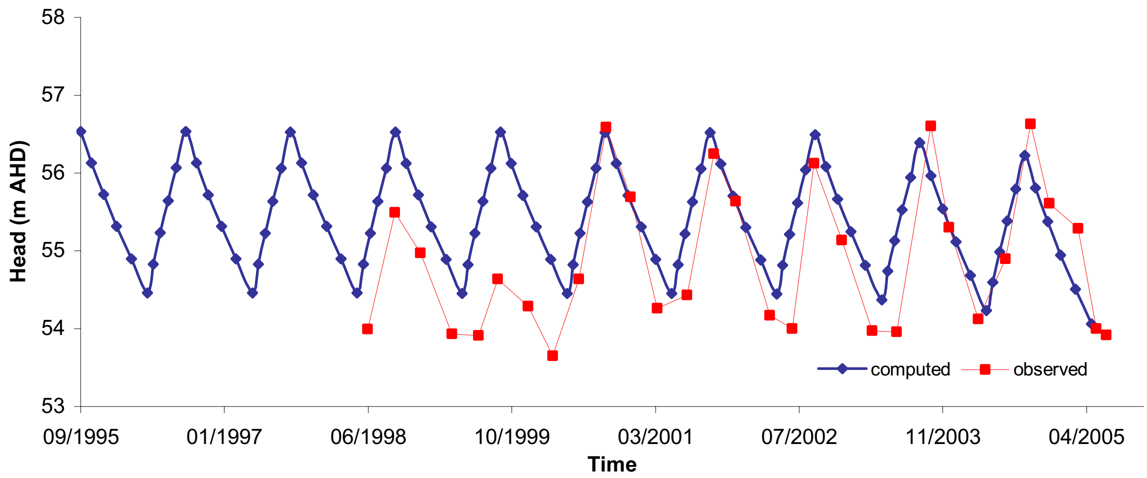


Figure 77. Model validation — observed versus simulated hydrograph at observation point MON008 in the presence of a tree plantation.

6. DISCUSSION

6.1 CONCEPTUAL MODEL

The conceptual model of the aquifer system in the study area is based on the current understanding of the geology, hydrology and hydrogeology. As a simplification, the unconfined aquifer system in the study area was divided vertically into two layers, with both simulated as convertible aquifers where they can behave as confined or unconfined depending on whether the water level is above or below the top of the aquifer.

The hydrogeology data used were obtained from various sources including CSIRO (evapotranspiration and recharge) and DWLBC (hydrostratigraphy, water level, groundwater allocation volumes). Components that affect groundwater flow and storage in the unconfined aquifer are recharge by infiltration from rainfall, recharge by infiltration of water from crop and pasture irrigation, lateral inflow from the southeastern and eastern boundaries of the modelled area, discharge of groundwater through drains and extraction wells, and discharge of water by evapotranspiration and lateral outflow through the western boundary.

Annual aquifer recharge is a function of rainfall, soil type, soil cover and land use. Recharge in the study area ranges from 5.5 mm/y in areas covered by native vegetation to >190 mm/y in areas covered by pasture. Under pine plantation and blue gum forestry, recharge could reduce from 145 mm/y to zero depending on the number of years since planting (R. Benyon and F. Leaney, pers. comm., 2005).

The groundwater contours for observation wells recorded in March 1970 and 1971 show directional flow from the east and southeast margins towards the western margins of the modelled area.

Where plantation is re-established on an existing site, there will be an exponential reduction in recharge to zero, and net increase in evapotranspiration after three to six years of planting. Increases in evapotranspiration peaks at about three or four years after planting depending on the depth to water level in the shallow aquifer.

6.1.1 CLIMATE

Climatic data was sourced from the BOM climate station close to the study area. Most stations collect only rainfall data; the Mount Gambier Airport station collects other climatic data including pan evaporation. A local BOM station in Coonawarra collects evaporation as well as rainfall data.

6.1.2 SURFACE WATER AND GROUNDWATER INTERACTION

The only running surface water is drain flow, with the groundwater base flow contributing ~75% of total flow. Hydrograph separation was used to account for the different components of the drain flow. The assessment of the surface water – groundwater interaction was based on historical and current drain flows measured at gauge stations installed at the Bakers

Range Drain. There is a strong relationship between drain flow, groundwater levels and rainfall. Drain flow commences when the groundwater level rises above the base of the drain and ceases as the water level in the surrounding aquifer declines below the base, leaving trapped water in the bottom of the drain. This water will be lost through evaporation or infiltration back into the aquifer.

6.2 WATER AND SALT BALANCES UNDER DIFFERENT LAND USES

6.2.1 WATER AND SALT BALANCE FOR THE PILOT STUDY AREA

Section 5.4.1 described the salt and water balance for the pilot study area examining the current land-use ratios. The following tables (18–22) model the pilot study area with a single land use planted through the whole area to study the way the aquifer would react.

Some of the assumptions made for the following tables are:

- groundwater gradient and lateral flows in and out of the study area remained constant
- rainfall recharge was calculated from the Penola PO record for 2004 and 2005
- the Bakers Range flow record in the drain for 2004 and 2005 were used
- application rates for water use were derived from the irrigation site adjacent to the pilot study area
- change in groundwater storage from 2004 was used to calculate the 2005 change in salinity
- change in groundwater salinity from 2004 was used to calculate the adjusted salinity for 2005
- forested areas were assumed to have reached canopy closure.

Further discussion of the results will be addressed under the following section on the impacts of land-use change.

Table 18. Water and salt balance for the pilot study area — native vegetation.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	0	0
Recharge under native vegetation (ML/y)	542	542
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**5 141**	**5 141**
Water out		
Hardwood discharge (ML/y)	0	0
Softwood discharge (ML/y)	0	0
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	0	0
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-24 102**	**-5 650**
Water balance	**-18 961**	**-509**
Volume of water in storage (ML)	**152 460**	**133 499**
Change in storage (m)	**-1.87**	**-0.05**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	0	0
Salt load from recharge under native vegetation (tonnes)	2 324	1 886
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**6 923**	**6 485**
Salt out		
Salt stored under hardwood (tonnes)	0	0
Salt stored under softwood (tonnes)	0	0
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	0	0
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**-15 309**	**-4 238**
Salt balance	**-8 386**	**2 248**
Salt in storage (tonnes)	**152 460**	**133 499**
Groundwater salinity (mg/L)	**1 079**	**1 021**

6.2.2 NON-IRRIGATED PASTURE

Table 19. Water and salt balance for the pilot study area — non-irrigated.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	25 410	12 739
Recharge under native vegetation (ML/y)	0	0
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**30 009**	**17 338**
Water out		
Hardwood discharge (ML/y)	0	0
Softwood discharge (ML/y)	0	0
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	0	0
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-24 102**	**-5 650**
Water balance	**5 907**	**11 688**
Volume of water in storage (ML)	**152 460**	**158 367**
Change in storage (m)	**0.58**	**1.15**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	2 324	1 886
Salt load from recharge under native vegetation (tonnes)	0.0	0.0
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**6 923**	**6 485**
Salt out		
Salt stored under hardwood (tonnes)	0	0
Salt stored under softwood (tonnes)	0	0
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	0	0
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**-15 309**	**-4 238**
Salt balance	**-8 386**	**2 248**
Salt in storage (tonnes)	**152 460**	**158 367**
Groundwater salinity (mg/L)	**910**	**944**

6.2.3 IRRIGATED PASTURE

Table 20. Water and salt balance for the pilot study area — irrigated.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	25 410	12 739
Recharge under native vegetation (ML/y)	0	0
Irrigation return	2 303	2 303
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**32 313**	**19 642**
Water out		
Hardwood discharge (ML/y)	0	0
Softwood discharge (ML/y)	0	0
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	-46 076	-46 076
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-70 178**	**-51 726**
Water balance	**-37 865**	**-32 085**
Volume of water in storage (ML)	**152 460**	**114 595**
Change in storage (m)	**-3.73**	**-3.16**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	2 324	1 886
Salt load from recharge under native vegetation (tonnes)	0.0	0.0
Salt load from irrigation return (tonnes)	2 879	4 850
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**9 803**	**11 336**
Salt out		
Salt stored under hardwood (tonnes)	0	0
Salt stored under softwood (tonnes)	0	0
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	46 076	46 076
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**30 767**	**41 838**
Salt balance	**40 570**	**53 175**
Salt in storage (tonnes)	**152 460**	**114 595**
Groundwater salinity (mg/L)	**1 684**	**2 033**

6.2.4 SOFTWOOD PLANTATION

Table 21. Water and salt balance for the pilot study area — softwood plantation.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	0	0
Recharge under native vegetation (ML/y)	0	0
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**4 599**	**4 599**
Water out		
Hardwood discharge (ML/y)	0	0
Softwood discharge (ML/y)	-16 940	-16 940
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	0	0
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-41 042**	**-22 590**
Water balance	**-36 443**	**-17 991**
Volume of water in storage (ML)	**152 460**	**116 017**
Change in storage (m)	**-3.59**	**-1.77**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	0	0
Salt load from recharge under native vegetation (tonnes)	0	0
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**4 599**	**4 599**
Salt out		
Salt stored under hardwood (tonnes)	0	0
Salt stored under softwood (tonnes)	-16 940	-18 224
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	0	0
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**-32 249**	**-22 462**
Salt balance	**-27 650**	**-17 863**
Salt in storage (tonnes)	**152 460**	**116 017**
Groundwater salinity (mg/L)	**1 076**	**1 001**

6.2.5 HARDWOOD PLANTATION

Table 22. Water and salt balance for the pilot study area — hardwood plantation.

Water balance		
Water in	**2004**	**2005**
Recharge under pasture (ML/y)	0	0
Recharge under native vegetation (ML/y)	0	0
Lateral flow (ML/y)	4 599	4 599
Total water in (ML/y)	**4 599**	**4 599**
Water out		
Hardwood discharge (ML/y)	-23 716	-23 716
Softwood discharge (ML/y)	0	0
Lateral flow (ML/y)	-5 650	-5 650
Irrigation pumping (ML/y)	0	0
Drainage flow (base and surface flows) (ML/y)	-18 452	0
Total water out (ML/y)	**-47 818**	**-29 366**
Water balance	**-43 219**	**-24 767**
Volume of water in storage (ML)	**152 460**	**109 241**
Change in storage (m)	**-4.25**	**-2.44**
Salt balance		
Salt in	**2004**	**2005**
Salt load from recharge (tonnes)	0	0
Salt load from recharge under native vegetation (tonnes)	0	0
Salt load from lateral flow (tonnes)	4 599	4 599
Total salt in (tonnes)	**4 599**	**4 599**
Salt out		
Salt stored under hardwood (tonnes)	-23 716	-25 625
Salt stored under softwood (tonnes)	0	0
Salt leaving in lateral flow (tonnes)	-4 238	-4 238
Salt recycled through irrigation (tonnes)	0	0
Salt out through base flow (tonnes)	-11 071	0
Total salt out (tonnes)	**-39 025**	**-29 863**
Salt balance	**-34 426**	**-25 264**
Salt in storage (tonnes)	**152 460**	**109 241**
Groundwater salinity (mg/L)	**1 080**	**994**

6.3 IMPACTS OF LAND-USE CHANGE

6.3.1 SMALL SCALE

The small-scale pilot study area in the Bakers Range was selected as it was known to supply water to wetlands down gradient, it has a long recorded period of drain flows in and out of the area, and has been under significant land-use change over the past few years (1998–2005). No comparative analysis has been made between each land use in Tables 18–22. These are two-year snapshots of what may occur if the complete pilot study area was planted with a single land use. To compare each land use, the calculations would need to run a 37-year cycle, to the end of a pine plantation rotation.

6.3.1.1 Native Vegetation

Water level

The current water level mirrors the situation under natural or pre-European conditions, except for the drain flow from Bakers Range. Because the drain was removing water in 2004, a decline in the watertable is calculated. For 2005, with no drain flow and slightly below-average rainfall, only a small decline in water level was anticipated.

Salinity

A small increase is anticipated for salinity under native vegetation. This may be because only a small recharge occurs and so salt is also stored in the unsaturated zone. Under natural conditions it may take a bushfire or land clearing to free this salt load.

6.3.1.2 Pasture

Water level

The calculations indicate watertable rises of 0.58 and 1.15 m across the two years. The reason for this is that no water use is assigned under this land use and therefore the winter rainfall recharge contributes to a water level rise, as seen in many areas of the South East. The drain drawdown effect for this land use is 0.57 m.

Salinity

Because rainfall recharge is refreshing the aquifer, and only minor salt is stored in the unsaturated zone, the groundwater salinity is decreasing. This occurs in many areas of the South East under shallow watertable environments during winter.

6.3.1.3 Irrigated Pasture

Water level

With the whole of the pilot study area theoretically under irrigation, the results show that, after two years of pumping, the watertable has declined a combined 6.89 m for a pumping rate about twice that of the forestry land uses. This would be a major decline in the water level in a sandstone aquifer assumed as 15 m thick. With the same amount of water being irrigated in 2004 and 2005, but with the drain failing to flow in the second year, it has been calculated that the drawdown in the watertable due to drainage discharge is 0.57 m.

Once again for both pumping years there is a strong salinity increase. From an initial pumped salinity of 1000 mg/L after two years, this has increased to 2033 mg/L. Salt flushing is common under irrigated sites but, unlike forestry, any residual salt stored in the unsaturated profile is generally leached into the watertable after the winter opening rains begin recharging the aquifer.

6.3.1.4 Hardwood

Water level

A slightly higher drawdown than that seen for irrigated pasture is observed under hardwood plantation. This is due to a higher drain effect of 1.80 m (as for softwood plantation), but mainly due to no rainfall recharge being assigned under mature forest. Irrigated pasture has been assigned almost twice the water use, but also receives recharge during the winter months.

Salinity

Groundwater salinity changes very little because of no returning water from the unsaturated zone. Similar to a softwood plantation, the salt is stored in the unsaturated profile, but for a shorter period of ~10–12 years. It is when the forest is harvested that the groundwater salinity will rise when the stored salt load is released.

6.3.1.5 Softwood

Water level

For 2004, with drain flow and tree water use, a watertable decline of ~3.6 m is calculated. In 2005, with no drain flow, the decline reduced, but a drain effect of up to 1.80 m of groundwater drawdown can be assumed after examination of both years.

Salinity

In the first year, the salinity shows a slight increase and then in the second year it is in balance. However, salinity under a pine plantation is only observed after ~30 years of accumulated salt (after canopy closure) in the unsaturated profile is moved into the aquifer upon harvesting of the forest.

6.3.2 REGIONAL AND SUB-REGIONAL SCALE

The additional three cored sites added to the study at Penola, Mount Gambier and Beachport were to assist in the broadening of the area of interpretation. Two of these were reacting differently to other shallow watertable sites and the technical group felt it was important to understand why. Two of the sites had forestry with low water use, one with large water use as well as low watertable fluctuation, and all in a relatively shallow watertable environment.

A lack of watertable fluctuation in shallow groundwater areas may be indicating the presence of impeding layers (heavy clay or hard bars) as in the Penola Forest. It has been known for some time that the clay layer in the South East plays an important role, not only in the effect it may exert on forestry but also on groundwater recharge. Currently, the clay layers are being mapped as part of the South East stratigraphic study, and once this is completed the data can be used to assist in resource management.

Numerical modelling could be used to assess the impact of land-use changes on the water resources over sub-regional to regional scale. This process requires more information and a good understanding of the groundwater system. Discussion on the results, required information and limitation of the model approach are presented in section 6.3.3 of this report.

6.3.2.1 Temporal and Spatial Variability in Groundwater Uptake

There is a potential for temporal and spatial variation in groundwater uptake in pine and blue gum forests. In general, it would be expected to see lower rates of groundwater uptake for wetter years and vice versa. The groundwater uptake estimates made using the chloride accumulation method were over a timeframe that had close to average rainfall. On the other hand, most of the water balance measurements were made during 2000–05, a period where rainfall was ~10% greater than average. Hence, even higher rates of groundwater uptake in average or below-average rainfall years could be expected.

The differences seen between the minimum estimates of groundwater uptake using the chloride accumulation method and those made using the water balance method would be even greater than the values reported in Leaney et al. (2006). In other words, it is highly likely that the chloride accumulation method significantly underestimates groundwater uptake, particularly in areas with varying watertable depth.

At pine site G18, when rainfall was ~10% lower than average, it is probable that the estimate using water balance methodology for 1997–2000 was more than that for an average year at that site. However, given that there is no groundwater uptake estimated at this site (Table 12), whatever is causing the low rate of groundwater use at this site is clearly having a much greater impact than the temporal variability in rainfall.

Spatial variability is also likely to impact on groundwater uptake measurements using both the methodologies. For the water balance – sap flow methods, transpiration and interception are usually measured on a single tree and evaporation is estimated on an immediate area basis. Hence, the groundwater uptake measurement probably averages that over the canopy area of the tree.

For the chloride accumulation method, the chloride is measured at a point scale, being the site of the soil core. As such, there is the potential for variability in this measurement, depending on the proximity of roots to the soil sampled. As trees become more advanced and the root system more extensive, the variability in chloride measured in a forest is likely to decrease. Greater spatial variability in groundwater uptake measurements could be anticipated in the younger blue gum forest compared to the well-established pine forest sites. This may explain the high rate of groundwater uptake estimated using the chloride accumulation method at site F16.

Evidence has been seen of spatial variation in groundwater uptake as a result of the presence of hard layers and/or heavy clay layers that do not allow, or at least restrict, root penetration (App. E). This was observed at pine site G18 (heavy clay layer) and at blue gum site F17 (hard impenetrable layer). The spatial extent and distribution of these layers is currently unknown.

One of the main limitations of the chloride accumulation method for estimating water uptake by trees is the estimation used for chloride stored in the unsaturated zone soils prior to planting the forests ($Cl_{cleared}$). An overestimate in this value will result in an underestimate in the amount of chloride that has accumulated since the trees were planted and hence an underestimate in the amount of groundwater uptake by the trees. Likewise, an underestimate for $Cl_{cleared}$ will result in overestimating change in chloride and hence water uptake.

6.3.2.2 Salt Accumulation

There is clear evidence that most salt present in the unsaturated zone under native vegetation is flushed from the system within a decade or two after the area is cleared. This is because the study site is in a high rainfall area and the surface soils are predominantly sandy. There is also clear evidence that both pine trees and blue gums do use groundwater and, as a result, accumulate salt in the unsaturated zone.

Well-established pine trees can use groundwater (and accumulate salt in the unsaturated zone) in areas with watertables at least 9 m deep. In general, however, the amount of groundwater used and therefore the amount of salt accumulated is greater in areas with shallower watertables.

There is no evidence of chloride accumulation at blue gum site F17 where the watertable is considerably deeper than at the other blue gum sites. This could be due to the presence of a hard layer that restricts water uptake by the trees. However, it appears as though the rate of chloride accumulation at the blue gum sites is at least as high as at the pine sites, presumably as a result of being established in general on areas with shallower watertables.

It is likely that heavy clay or a hard layer is stopping the roots accessing the watertable at pine site G18 and blue gum B5. At these sites, clearly there is no likelihood of salt accumulation in the unsaturated zone.

Indirect evidence that salt may be partially flushed from the profile on a regular basis comes from the observation that groundwater uptake as determined by chloride accumulation tends to be less than that determined by water balance calculations.

Further flushing of salt from the unsaturated zone is also likely to occur during the interval between rotations and during the first few years of tree growth. For blue gum forestry, the rotations are likely to be of the order of every 14 years (12 years growth and two years between rotations). Hence, accumulation of salt is likely to take place for maybe 9–10 out of every 14 years, with at least partial flushing of salt during the remaining years. It is therefore likely that the concentration of salt in the unsaturated zone soil water and in the shallow groundwater will cycle from high to lower concentrations.

The degree of flushing will depend on factors such as soil texture in the unsaturated zone, the watertable depth and amount of rainfall between rotations. In addition to the salinity cycling, there will, however, also be a longer term gradual salinity increase in both the shallow groundwater and in soil water in the unsaturated zone. This is the result of the overall net loss of water via transpiration from the unconfined or shallow groundwater system. Variations in rainfall will obviously impact on this general trend along with other factors such as aquifer flow velocity.

6.3.3 MODELLING WATER AND SALT BALANCES

Creation of the numerical model has proceeded smoothly, with reasonable agreements between actual and predicted groundwater levels, showing that the concepts included into the model are correct. To run land-use scenarios was a requirement of phase two of this project, yet the model is almost developed to that stage now. It could run predictive phases, but it can be further developed by addition of the following:

- Examination of the model boundaries and excluding the Coonawarra area will assist greatly by eliminating the need to estimate 1970 irrigation use.
- There is an ability to add better aquifer properties such as transmissivity, permeability and specific yield through interrogation of the departmental database.
- While the model boundaries are extensive, the predictive scenarios to the actual water levels have taken place close to the pilot study area. It is felt the model will work better on a regional scale by adjusting this aspect to include all of the area inside the boundaries.
- The residual error has been improved and could be improved further after the additional data mentioned above are included.
- Seasonal changes in groundwater recharge from rainfall were not simulated and a fixed average annual recharge value of 200 mm/y was used. Recharge rates for any particular year or groups of years could be added to the model in the future.
- The model would be improved by further work in actual irrigation pumping locations and application rates. The current pumping rates were determined from licensed allocated volumes but not the actual extraction data.
- The model used groundwater allocation data that was based on the crop area ratio system, which could be improved with further work.

7. PRELIMINARY EVALUATION OF MANAGEMENT IMPLICATION

In natural resource management, a consideration is balancing competing demands for the utilisation of the resource. This study shows that different land uses will have an impact on the groundwater resource, wetlands and water-dependent ecosystems in the study area. The salt–water balance indicates that there is a potential salt storage that will be leached into the groundwater upon tree harvesting, which will have a negative impact not only on the resources but also on future plantations. The following discussion highlights some of the implications.

7.1 WETLANDS

Preliminary assessment of wetlands in the pilot study area indicates that some of these are strongly dependent on the drain flow. Hydrograph separation of the drain flow showed that a significant component is groundwater. Examination of the groundwater hydrograph (SHT 012) showed an impact due to land use on the watertable.

A continuous water-level decline to below the drain base may have ramifications for the future health of these wetlands.

A management option may be the use of buffering systems around wetlands. If the wetland occurs within the forested area, a buffering system probably will not be effective, but may present a management opportunity if it is located close to a forest boundary.

Small wetlands dependent on declining drain flow may be retained by the construction of wells equipped with either a windmill or solar pump. The advantage is the ability to manage the wetland throughout the year by retaining winter water levels irrespective of climate. By maintaining moist clays the ecosystem can be retained.

7.2 NATIVE VEGETATION

These stands tend to be sparser than commercial forests and the result of this study indicates a small groundwater recharge occurs under them.

In shallow watertable environments native vegetation is also a groundwater user, and both a recharge and discharge rate may require consideration when assessing vertical recharge rates for resource evaluation.

7.3 NON-IRRIGATED PASTURE

In shallow watertable areas under open pasture between 100 and 300 mm of recharge occurs. If no other land uses are present, drains have been required to remove excess recharge water. However, as other land uses are introduced to a management zone, this recharging area becomes more critical to maintain aquifer heads and groundwater flushing.

The pasture areas are the major recharge mechanism for the groundwater. Maintenance of water levels within management areas may require that the land use be split into percentages, so that the recharge volumes are in some equilibrium with the discharge rates. Management areas of significant forestry in shallow watertables tend to have negative water balances.

7.4 IRRIGATED PASTURE

This study shows an increase in groundwater salinity under the two irrigated study sites. With large-scale irrigation occurring in the Lower South East, much of it over shallow groundwater aquifers, the risk of groundwater salinisation is an impact that needs to be considered. Both irrigation efficiency and drainage require a better understanding.

Salt stored in the unsaturated zone under irrigated pasture is leached into the groundwater through irrigation drainage and rainfall recharge. Efficient irrigation practices will reduce excess salt being stored in the unsaturated zone and so control drainage water moving salt into the aquifer.

One aim of this study was to examine deep-rooted perennials including lucerne and tagasaste, etc. This is still to be addressed due to the lack of records about major or long-term irrigation activities of such deep-rooted perennial in the study areas. An observation well located at Site C7 is further investigating the potential impact.

7.5 FORESTED AREA

For forested areas, there is a build up of salt in the unsaturated zone. Flushing of this salt occurs after tree clearing, but not all the salt is removed prior to replanting (estimation is 70–80%). A longer fallow period would remove more salt.

An example of this salt retention in the unsaturated profile is that after 140 years of rotation within blue gum plantation the salt concentration in the unsaturated soil water could be doubled. For example, the 20% retained in the soil water profile after the first rotation continues to accumulate after the subsequent harvesting periods.

In major areas of blue gum plantation after canopy closure it is anticipated that a decline in the water level of ~3 m could occur (Fig. 38). Resource managers need to assess if this is an acceptable decline.

All land-use sites need to be assessed on individual characteristics. An example is that at some sites within the study area little water use occurred under plantation due to either heavy clays or hard bars of sandstone.

A management option is to instigate planning processes where in shallow watertable environments trees are planted over heavy clays, which will reduce water use. This may also hinder tree growth.

To plant over heavy clays may lead to the need for greater areas being planted to achieve economic viability.

Pine plantations can access watertables at up to 9 m depth.

7.6 GROUNDWATER NUMERICAL MODELLING

The use of the MODFIOW package tends to be a preferred approach for modelling the relationship between rainfall, groundwater levels, and drain levels and flow. It is also used to assess the impact of land use on groundwater and surface water resources.

It could be used for different scenarios of land-use changes. It is believed by the authors that this approach will become a valuable option for resource management for this area after the model is refined through improved input data.

The model set up has been accomplished and existing data were used to run some scenarios ahead of schedule to test the validity of the results. An important consideration is to run a refined model under phase two of this project.

7.7 GENERAL COMMENTS

For planning purposes, sites could be assessed on geological stratigraphy. An example is that at some sites within the study area, clay or hard bars of sandstone limit water use within forested areas. An understanding of the stratigraphy could be accomplished using the existing well logs to interpolate the data, filling in gaps using a hand auger, or by use of geophysical methods such as electromagnetic (TEM).

8. CONCLUSIONS AND RECOMMENDATIONS

The results from the work carried out in this project show the potential impact from different land uses on the groundwater and the flow into the drains in the Bakers Range area. This impact will consequently affect any groundwater dependent ecosystems that are reliant on the drain flow and the level of the water table.

Development of a numerical model to predict the regional impact of changes in the land use on the water resource is possible using MODFLOW modelling software. Further work is needed to obtain more accurate parameters required for the improvement of the preliminary model.

Following are the key conclusions and recommendations:

- Results from chloride accumulation measurements show that both pine and blue gum may be significant users of groundwater.
- Groundwater uptake by both pine and blue gum can exceed 500 mm/y in areas where the watertable is <5 m deep.
- In shallow watertable areas, most of the salt in the unsaturated zone is flushed out generally through the hydraulic fluctuation of the watertable.
- Groundwater uptake by trees clearly will result in chloride accumulation in the unsaturated zone. However, there is strong evidence from this study that watertable fluctuation and fallow periods for tree rotation can result in significant flushing of salt from the unsaturated zone into the groundwater. As a result, the chloride accumulation method used in this study may result in considerable underestimation of groundwater uptake by trees.
- The estimates of groundwater uptake for pine and blue gum sites in this study agree well with estimates presented over the last few years for the same sites using water balance – sap flow methods. This provides additional confidence in the use of both methods, particularly because the two methodologies used are entirely independent.
- Although groundwater uptake by trees is normal rather than the exception in this area, the presence of heavy clay or hard impermeable layers in the unsaturated zone may significantly reduce or even stop groundwater uptake by the trees. The results from this study confirmed little or no groundwater uptake at two sites where such layers were present.
- Recent blue gum forestry tends to have rotations averaging ~14 years and consisting of ~12 years growth and two years fallow. This being the case, accumulation of salt is likely to take place for maybe 9–10 out of every 14 years with at least partial flushing of salt during the remaining years. It is likely that the concentration of salt in the unsaturated zone soil water will cycle from high to lower concentrations. The shallow groundwater will also cycle from high to low salinity but as a mirror image to the unsaturated zone.
- However, in addition to the salinity cycling, there will also be a longer term gradual salinity increase in both the shallow groundwater and in the unsaturated zone soil water. This is the result of the overall net loss of water via transpiration from the unconfined or shallow groundwater system. The net water loss in these areas will also be reflected in lowering the watertable until a new steady state situation is reached with the surrounding land use and lateral aquifer flow.

- It is concluded from circumstantial evidence that at sites BG2 and BG3 in the Wattle Range area, a concentration of blue gum plantations in the order of several thousand hectares, which are now mostly 3–5 years old, may have contributed to a lowering of the watertable. The maximum depth to the watertable each year at these sites has reduced by almost 1 m over the past four years. At site BG2, lowering of the watertable to below a dense clay layer might have reduced net groundwater uptake in the past two years. Continuation of plantation water-use measurements at this site, and the nearby site BG3, until at least winter 2006 would provide important data on the effect of lowering the watertable on rates of groundwater uptake.
- Groundwater recharge under native vegetation is ~5–6 mm/y measured at the cored sites.
- No recharge occurs under pine and blue gum forest. Any watertable fluctuations are likely to be an aquifer hydraulic response transferred under the forest area.
- Open pasture area groundwater recharge is 100–300 mm/y.
- Blue gum forest in the study area is creating a cone of drawdown from water use.
- The Bakers Range Drain when flowing, has a groundwater component of ~75% and surface runoff of 25%; flow occurs after the watertable rises above the bottom of the drain.
- Watertable decline due to land use will reach a new equilibrium of ~4.5–5 m below ground, which may cease drain flow in the future.
- A result of ceased drain flow will be drying of the local wetlands with subsequent loss of the water dependent ecosystems.
- Carbon dioxide tubing left in three wells has indicated active tree roots at the watertable.
- A groundwater monitoring network to monitor drain–groundwater interaction has been put in place.
- The investigation drilled additional wells that may help to spatially extend the ability of the model to predict groundwater reaction through similar geological conditions in the South East.
- A groundwater computer model, while still requiring some refinement, has been developed.
- Salinity variability in both areas of study requires a better understanding.
- Salinity stratification occurs within the study area.

8.1 RECOMMENDATIONS

- Funding be sought to implement the work outlined in section 1.2.1 — tasks still to be completed.
- The NRM Board be made aware that some types of land use is dropping groundwater levels, which will in the future probably inhibit the ability of the Bakers Range Drain to flow. The drain did not flow in 2005, which will probably lead to the drying of close proximity wetlands.
- Investigate the Bakers Range Drain to the south of the study area to better understand how the up-gradient portion influences flow further north.
- For stage two of the study, the sandstone and limestone stratigraphy for the model area should be mapped.

- The database be investigated for driller's pump tests within the model boundaries that will better indicate transmissivity and permeability figures.
- The daily rainfall should be plotted against the daily water levels recorded from the data loggers to show if tree groundwater use ceases after a certain moisture level has occurred in the unsaturated zone.
- Further study should be done on the salinity variations noted for Sites A to F.
- The groundwater monitoring program should be reviewed so that watertable changes due to land-use effects are adequately covered.
- Establish an appropriate distribution regime of land use activity to balance groundwater recharge, evaporations and environmental water requirements.

APPENDICES

A. SENRCC ELECTROMAGNETIC INDUCTION SURVEY

SENRCC Electromagnetic Induction Survey Nangwarry – Wattle Range area, SA

November, 2004

Terry Evans

Rural Solutions SA

RURAL SOLUTIONS SA

SaltSmart
Smart solutions for better management

SENRCC
Electromagnetic Induction Survey
Nangwarry – Wattle Range area, South Australia

November, 2004

Terry Evans

Rural Solutions SA
Research Rd
Nuriootpa, SA
08 8568 6400

CONTENTS

SaltSmart™ Mapping using EM surveys - an introduction

SaltSmart™ surveys use electromagnetic induction instruments made by Geonics Limited, Canada. The instruments used for this survey were the Geonics EM31 and EM38 meters mounted on a quad bike. These instruments measure the apparent electrical conductivity (ECa) of the soil to a maximum depth of about 1.5 metres (EM38) and 6 metres (EM31). The electromagnetic induction (EM) readings are referred to as “apparent” conductivity as it is averaging the variations in the soil over the survey depth. In this way it gives an indication of the relative variation in salinity, clay content and soil moisture across the survey area.

In operation, the instruments have two coils, a transmitter and receiver, separated by one metre in the EM38 and 3.6 metres for the EM31. The transmitter emits a small electromagnetic signal that radiates down through the soil. As this signal passes through conductive material in the soil (moisture, ionic particles and metal) an eddy current is induced which generates a secondary signal which is detected by the receiver. The strength of the secondary signal is proportional to the amount of conductive material in the soil.

The sensitivity of the EM instruments varies depending on the make-up of the soil profile and the dipole orientation (mode) in which it is used. When used in “horizontal mode” for shallow surveys, the EM38 is most sensitive to ECa changes to a depth of around 75cm. In “vertical mode” for deep surveys the EM38 is relatively insensitive to surface layers and more sensitive to ECa in the deeper layers to a maximum of 150cm. In effect, shallow EM38 surveys pick up the topsoil layers in which plants are growing and the deep surveys pick up the soil layer below the root zone of shallow rooted plants.

Similarly, the shallow mode for the EM31 measures ECa to about 3 metres and the zone from 3 to 6 metres in deep mode. This can used to measure the ECa in the rootzone of deep rooted plants.

In practice, EM is very sensitive to salinity, less sensitive to clay content and least sensitive to soil moisture, making it possible to interpret surveys according to the instrument response and landscape factors. Typically, soils have complex and varied structures which can change over a few metres. EM is able to map these variations at a much finer grid spacing than is economically possible with soil pits. However, to determine the actual soil characteristics being mapped, the EM readings must be ground-truthed using soil samples from pits, cores or augered holes. The number of sample points required depends on the desired accuracy and the variability of the soil as shown by the EM survey. For intensive land use, one sample point per 2 or 3 ha may be required, while in broad scale farming, one sample point per 10 or 20 ha may be deemed sufficient. Samples should be taken to 6 metres when the EM31 is used and 1.5 metres for the EM38, or as deep as possible.

The major soil factors affecting plant growth are salinity, sodicity and compaction which all affect drainage. The most accurate method to physically measure soil electrical conductivity is by using a saturated extract (ECe), which is an indirect measure of soil properties. Where soil salinity levels are significantly high, the ECa values from the EM instruments have a positive correlation with soil ECe, which is a useful method of calibrating the instruments and mapping soil factors.

The conductivity readings from the surveys are reported in deciSiemens per metre (dS/m), which is equivalent to milliSiemens per centimetre (mS/cm). This is the same unit used to measure the ECe, which gives a measure of the actual soil salinity that the plant must grow in.

As a general guide, ECa values up to 0.2 or 0.3 dS/m indicate soils with very little salt content, usually with a sandy texture. ECa values between 0.2 and 0.6 dS/m I the normal range for “healthy” soil and indicates increasing clay content and some salt. Some very heavy clays can have high ECa values with a low salt content, but this is uncommon. Above 0.6 dS/m salt is a significant component of the soil and over 1.0 dS/m the salt will have some impact on plant growth and yield, depending on the sensitivity of the plant. These levels of salinity indicate there is substantial salt storage in the soil profile. It must be emphasized that soil samples must be taken to ground-truth the ECa values measured in a survey.

Surveyed areas

The EM surveys of the areas near Nangwarry and Wattle Range, South Australia, were done on November 15th, 16th and 17th, 2004. Readings were taken along forest rows every 5 metres (approximately) and on a 10 to 20 metre grid in the open areas. The survey was done in deep and shallow mode using the EM31 and EM38 to determine the ECa variation down the profile to about 6 metres.

GPS and Coordinate system

The geographic coordinates of the EM readings were recorded with a differential GPS. When post-processed with base station data this can give a relative positional accuracy of approximately +/- 2.5 cm horizontally and +/-5 cm vertically. GPS accuracy is determined by satellite coverage and a clear view of the sky. Within forests the satellite signals can be blocked which has a major impact on the accuracy of readings. The elevations are much more affected by poor satellite reception and therefore the surface contours have not been plotted, but can be supplied if required. For this reason it is not possible to guarantee the accuracy of readings taken in this survey, however every attempt has been made to obtain reasonable GPS readings.

The EM31 was mounted next to the GPS receiver on a quad bike and the EM38 was mounted on a sled which trailed behind the GPS by 2 metres. This offset the horizontal position of the EM38 readings by 2 metres, however this has little effect on the EM maps as the readings were averaged over a 5 metre radius.

The coordinate system used is the Map Grid of Australia (GDA94) using the AUSGEOID98 model which displays elevations as heights above mean sea level (mASL).

Results

Maps of survey sites and locations
The areas are shown for each site showing the trace of the EM survey and the boundary used to plot the results. The maps were oriented with north to the top for easy interpretation of the coordinates.

EM38 surveys
The EM survey maps show the horizontal ("shallow") mode and vertical ("deep") modes of the EM38 and EM31 meters to examine the surface and deeper layers of the soil to about 6 metres. The elevations were recorded with a differential GPS and post processed with base-station data to give a relative accuracy within 10 cm where possible. Due to the poor satellite reception within the forest areas, the vertical accuracy was reduced or non-existent. Surface contour maps have not been included, but can be supplied if required. Horizontal accuracy was less affected by poor coverage, and is reasonably accurate.

The maps were oriented to maximize the use of space on the page. When rotated more than 90 degrees from the normal north orientation the grids are still displayed, but the coordinate values are not. The coordinate values can, however be obtained from the location maps.

The colour scales used on the maps are specific to each map as the range of readings was too wide to have a common scale. The colour changes are therefore relative and the results need to be interpreted carefully. The wide range is due to the large variation in soil texture from the surface to deeper layers. In most of the surveys, the soils were generally sandy topsoils over subsoils with a higher clay content. This difference is less apparent in the EM31 readings due to its deeper penetration.

For a given meter, the readings in shallow and deep mode are comparable and show relative variation with depth. Unless the soil profile is relatively uniform, the readings from EM38 and EM31 meters should not be directly compared with each other as they are measuring different layers. The surveys need to be ground-truthed to calibrate the readings.

All sites generally had very low ECa values less than 0.4 dS/m indicating sandy soils with low clay levels. The few sites with higher ECa values to about 0.6 dS/m indicate some proportion of clay in the profile with possible low salinity levels. Care is required when interpreting the results as various combinations of sand, clay and salt can produce misleading results. A range of zones in each surveyed area must be sampled to ground-truth the ECa readings.

Sites A1, A2 and A3
The three surveyed areas had very low readings less than 0.4 dS/m, except for a small area in A3 Deep EM31 with higher readings. The variation in ECa can probably be attributed to sandy soils with a generally increasing, but variable, clay content.

An increase in ECa with depth is often observed and usually indicates a general increase in clay content with depth. As ECa increases, the possibility of salinity being present increases.

Sites B4, B5 and B6
All these sites had very low ECa values consistent with sandy soils with variable clay content down the profile.

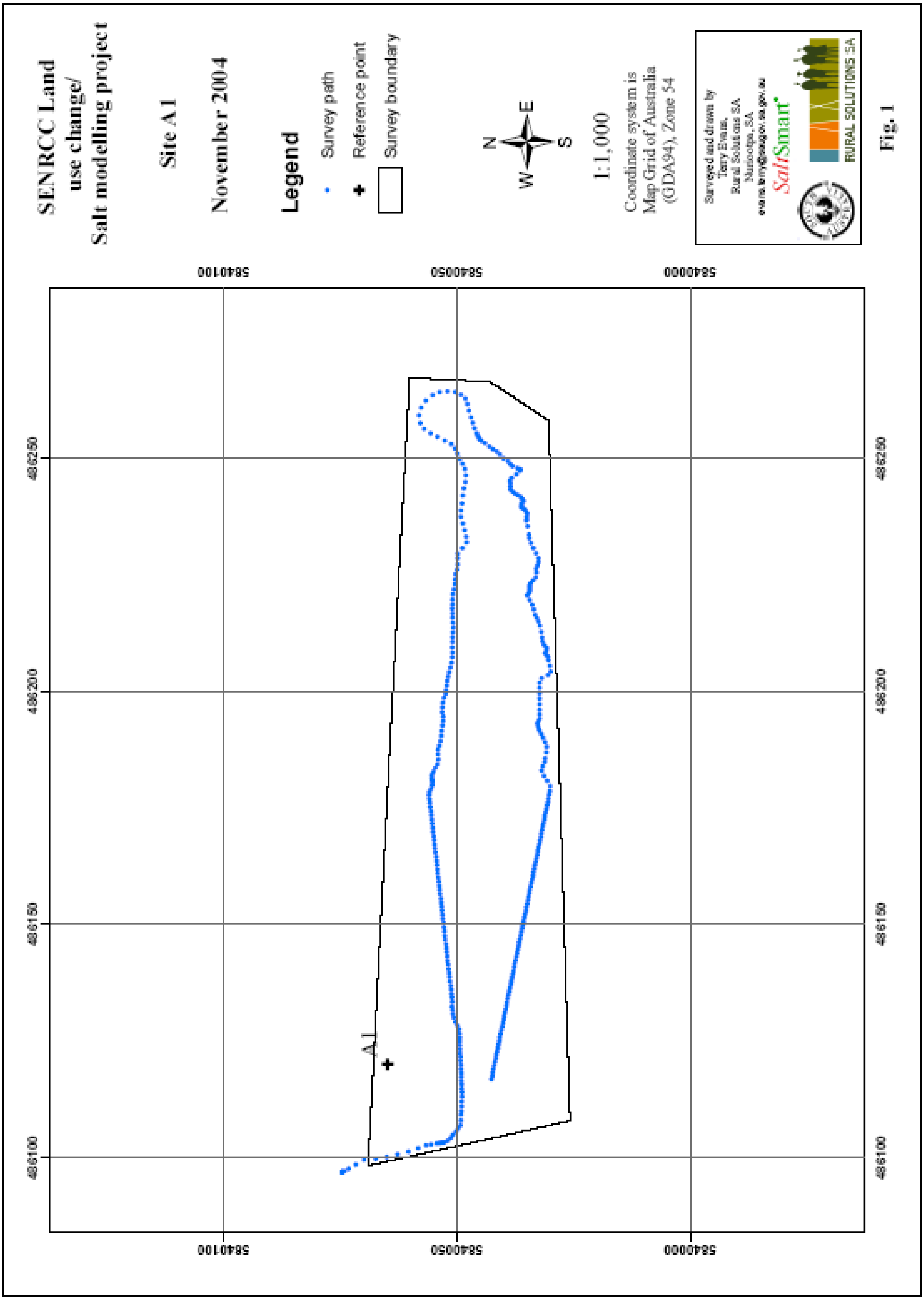
Sites C7 and C8
All these sites had very low ECa values consistent with sandy soils with variable clay content down the profile.

Sites D9 and D10
There were generally low ECa values in sites, except an area at the western end of D10 with the ECa increasing with depth to over 0.6 dS/m. This probably indicates a deep sandy clay profile with a low to moderate salinity level. Sampling to depth is required to determine the actual salt and clay content.

Sites E11, E12 and E13
All these sites had very low ECa values consistent with sandy soils with variable clay content down the profile.

Sites F14, F15, F16 and F17
All these sites had very low ECa values consistent with sandy soils with variable clay content down the profile.

Conclusion
The survey results showed very low ECa values indicating that the soil profiles were sandy with low clay levels. Sandy soils are very well drained, so it is possible that any salt in the soil profile may leach to greater than the 6 meter depth than the EM survey can detect. It is advisable to sample selected areas within these sites to determine if there is any salt accumulation below 6 meters.



SENRCC Land use change/ Salt modelling project
Site A1
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:1,000
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA, Naracoorte, SA
SaltSmart
486100
486150
486200
486250
5840000
5840050
5840100
A1

Fig. 1

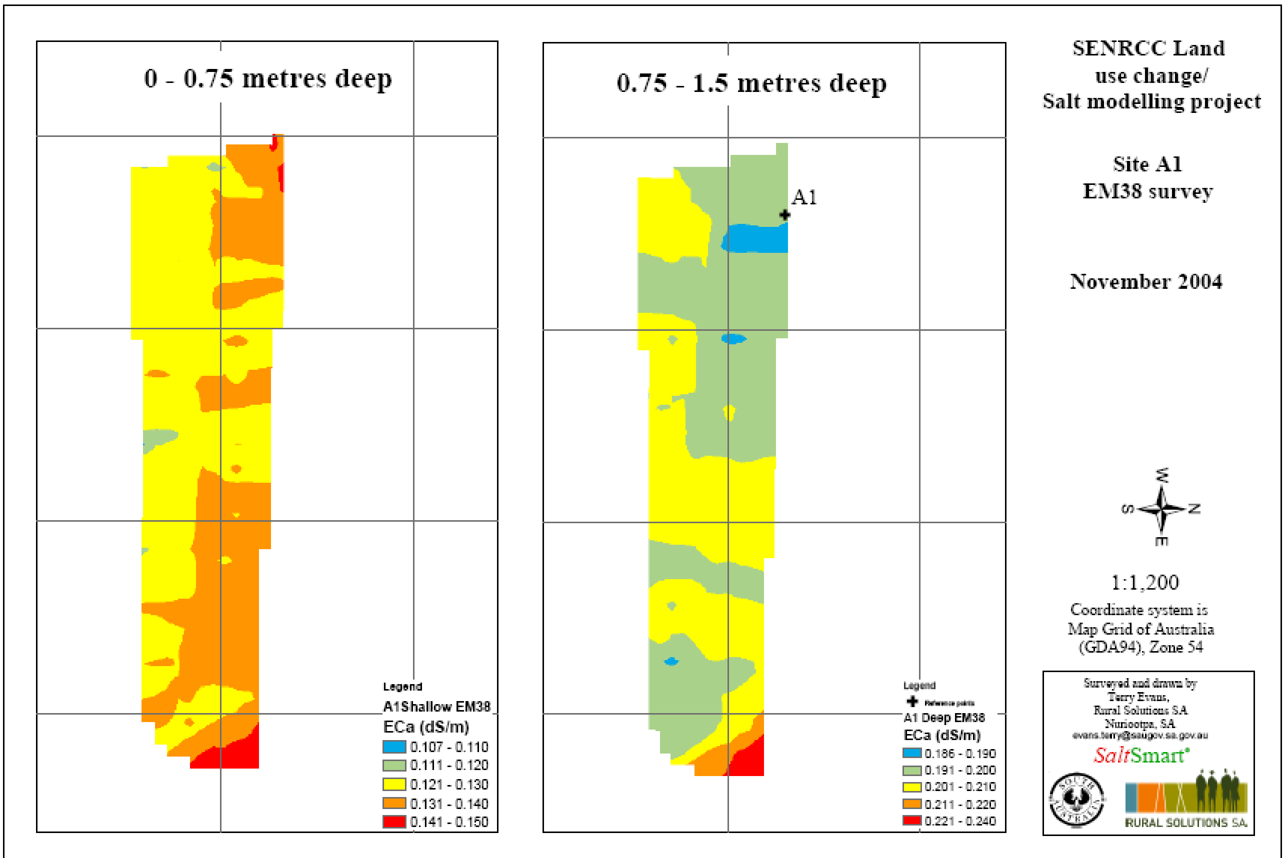

0 - 0.75 metres deep
Legend
A1Shallow EM38
ECa (dS/m)
0.107 - 0.110
0.111 - 0.120
0.121 - 0.130
0.131 - 0.140
0.141 - 0.150
0.75 - 1.5 metres deep
A1
Legend
A1 Deep EM38
ECa (dS/m)
0.186 - 0.190
0.191 - 0.200
0.201 - 0.210
0.211 - 0.220
0.221 - 0.240
SENRCC Land
use change/
Salt modelling project
Site A1
EM38 survey
November 2004
W
S
N
E
1:1,200
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
0
25
50
75
100
Metres

Fig. 2

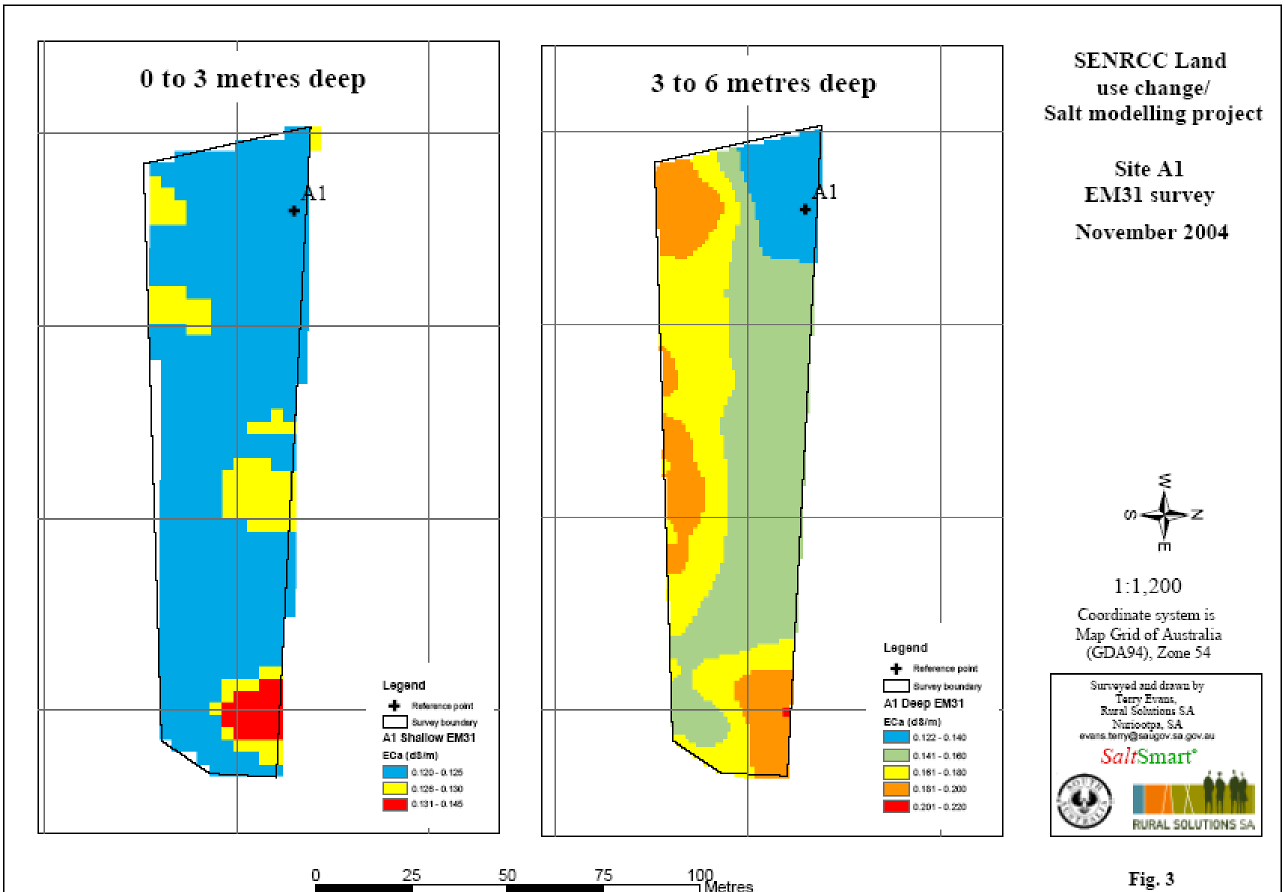
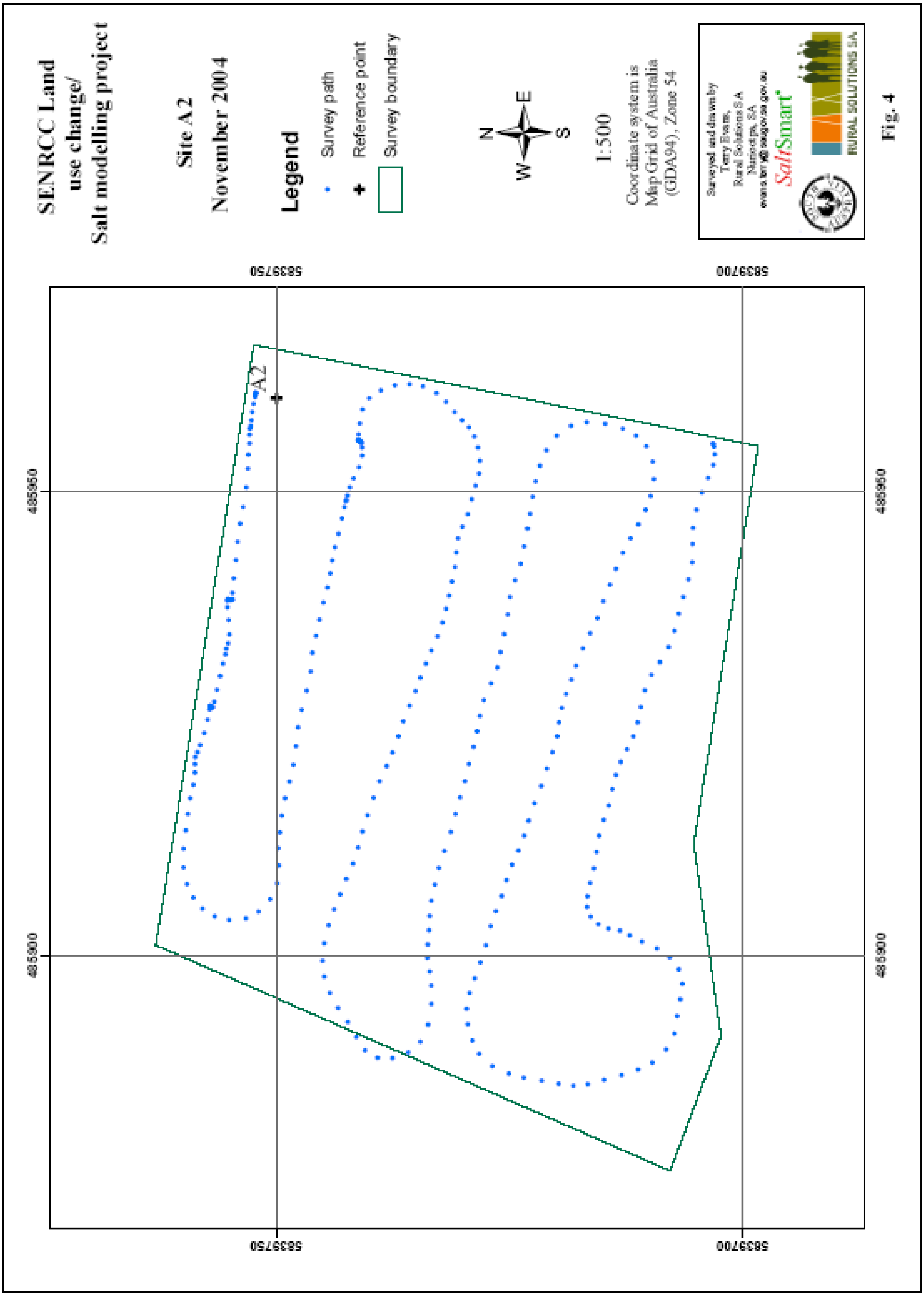

0 to 3 metres deep
A1
Legend
Reference point
Survey boundary
A1 Shallow EM31
ECa (dS/m)
0.120 - 0.125
0.126 - 0.130
0.131 - 0.145
3 to 6 metres deep
A1
Legend
Reference point
Survey boundary
A1 Deep EM31
ECa (dS/m)
0.122 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
SENRCC Land
use change/
Salt modelling project
Site A1
EM31 survey
November 2004
W
S
N
E
1:1,200
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
0
25
50
75
100
Metres

Fig. 3


SENRCC Land use change/ Salt modelling project
Site A2
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
SaltSmart
RURAL SOLUTIONS SA
A2
485950
485900
5839750
5839700
Fig. 4

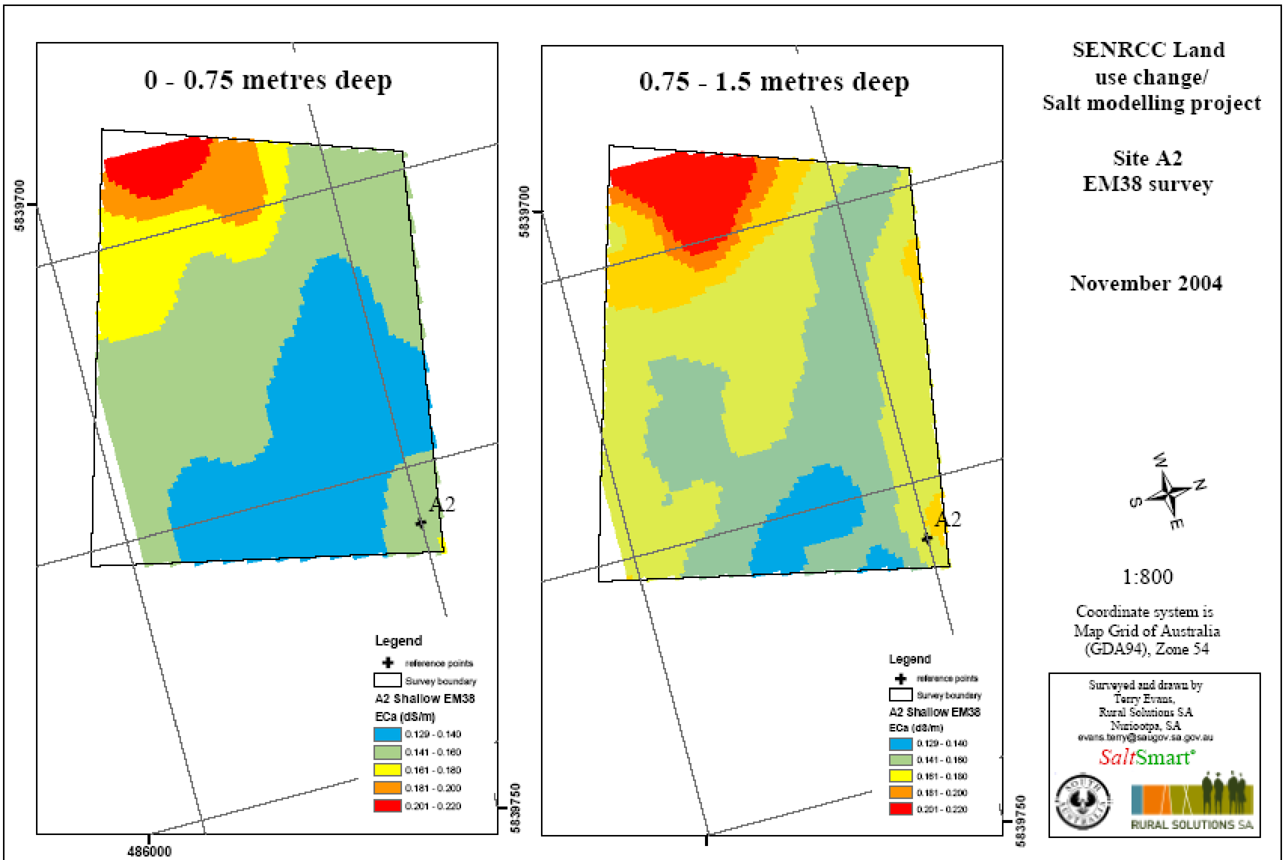

0 - 0.75 metres deep
0.75 - 1.5 metres deep
A2
5839700
5839750
486000
Legend
reference points
Survey boundary
A2 Shallow EM38
ECa (dS/m)
0.129 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0
25
50
75
100
Metres
SENRCC Land use change/ Salt modelling project
Site A2
EM38 survey
November 2004
W
N
S
E
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

Fig. 5

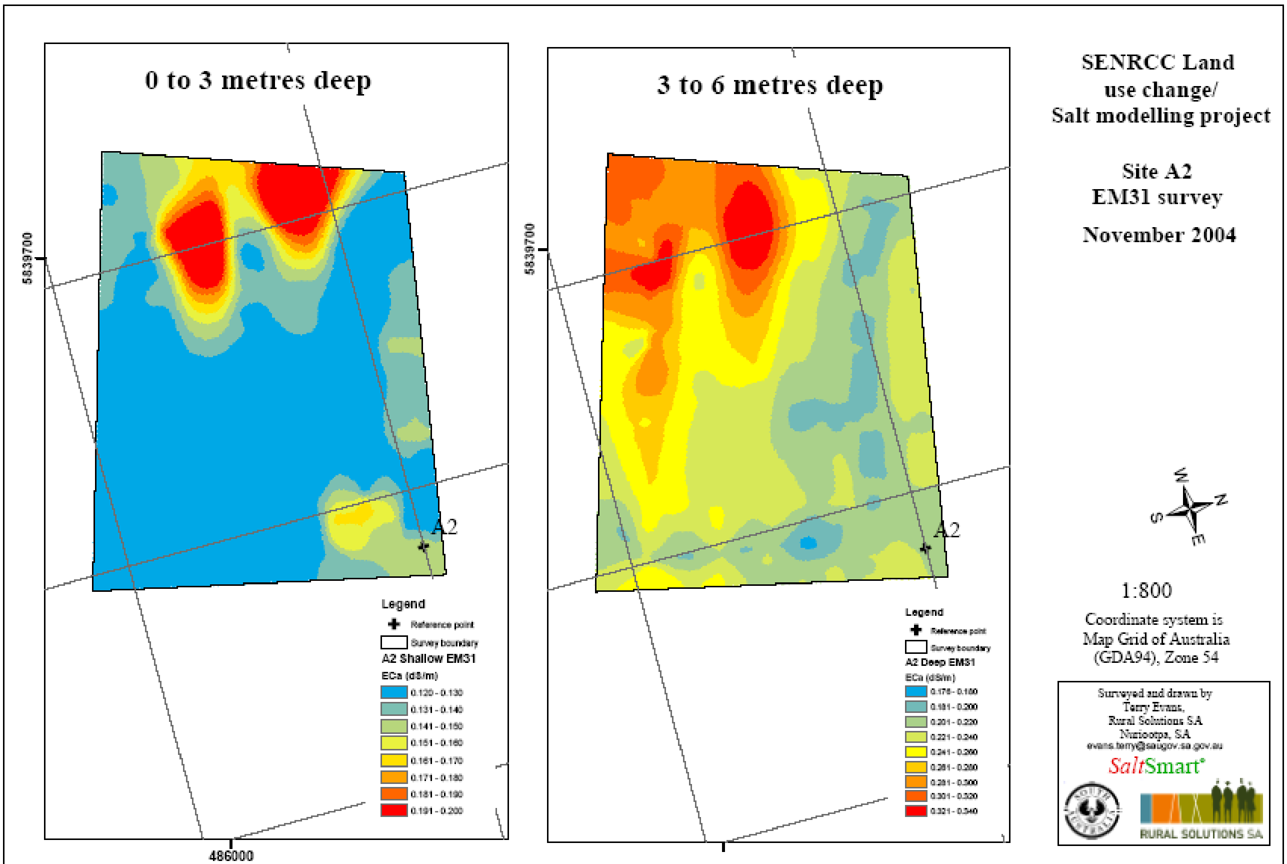
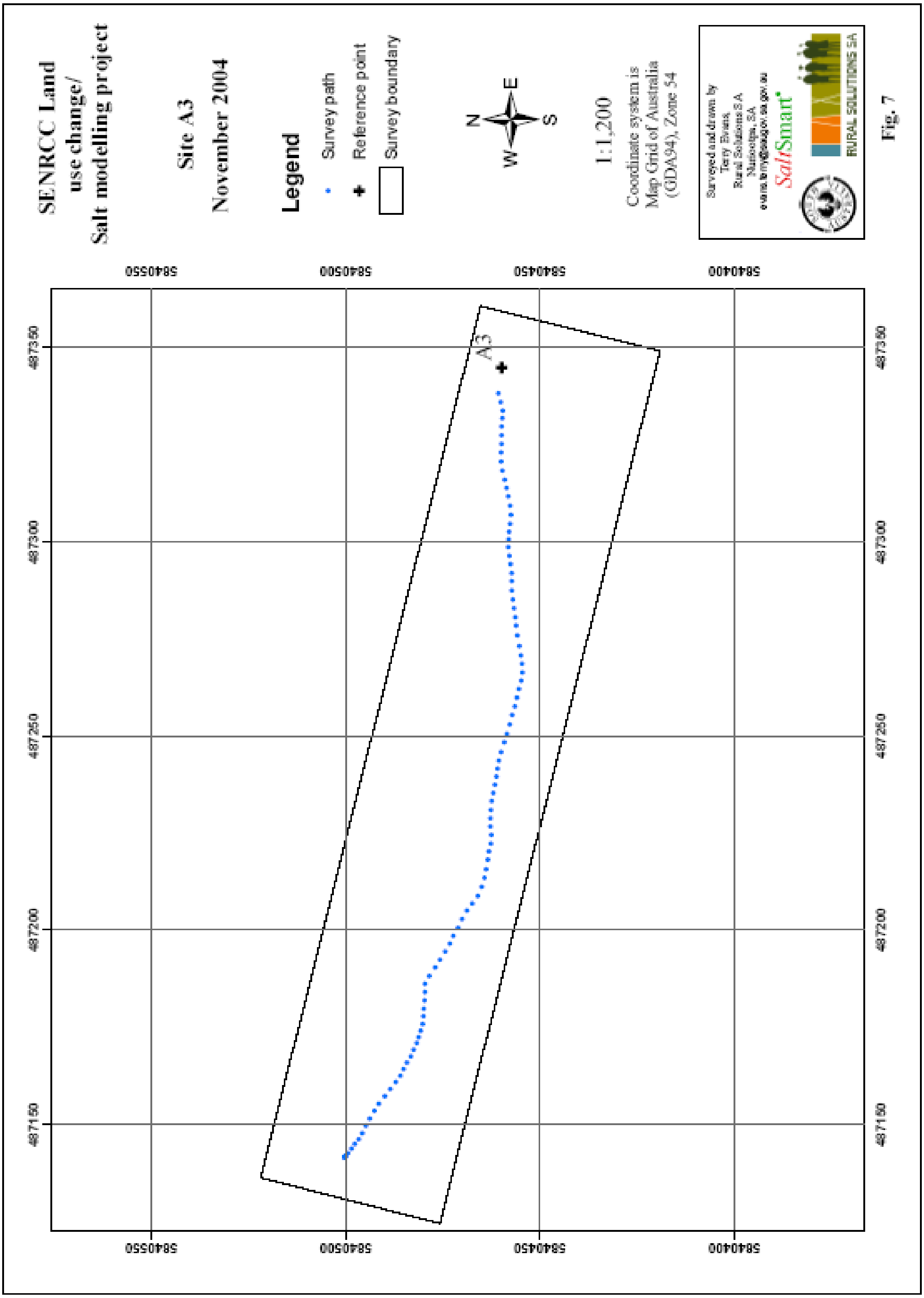
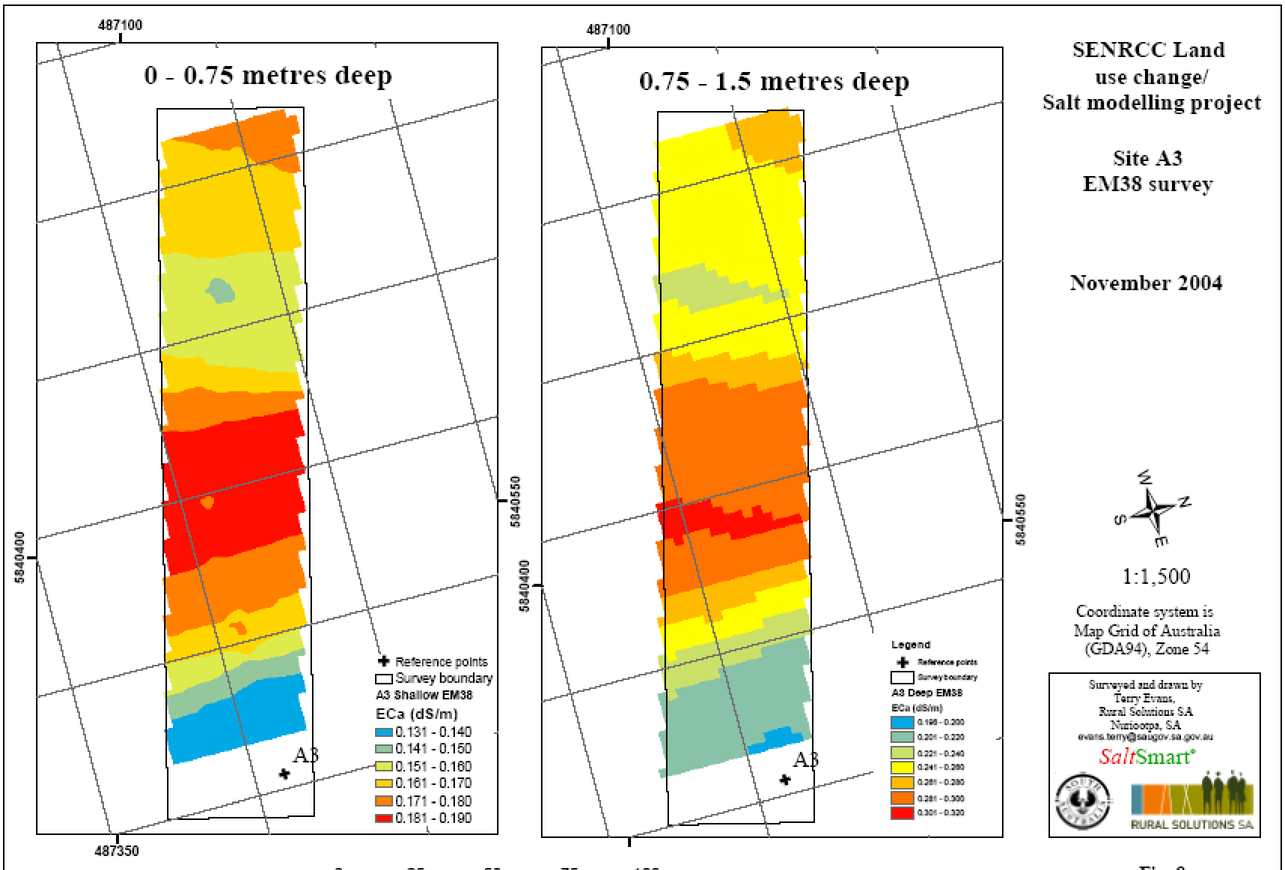

0 to 3 metres deep
3 to 6 metres deep
A2
5839700
486000
Legend
Reference point
Survey boundary
A2 Shallow EM31
ECa (dS/m)
0.120 - 0.130
0.131 - 0.140
0.141 - 0.150
0.151 - 0.160
0.161 - 0.170
0.171 - 0.180
0.181 - 0.190
0.191 - 0.200
A2 Deep EM31
0.176 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0
25
50
75
100
Metres
SENRCC Land use change/ Salt modelling project
Site A2
EM31 survey
November 2004
W
N
S
E
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

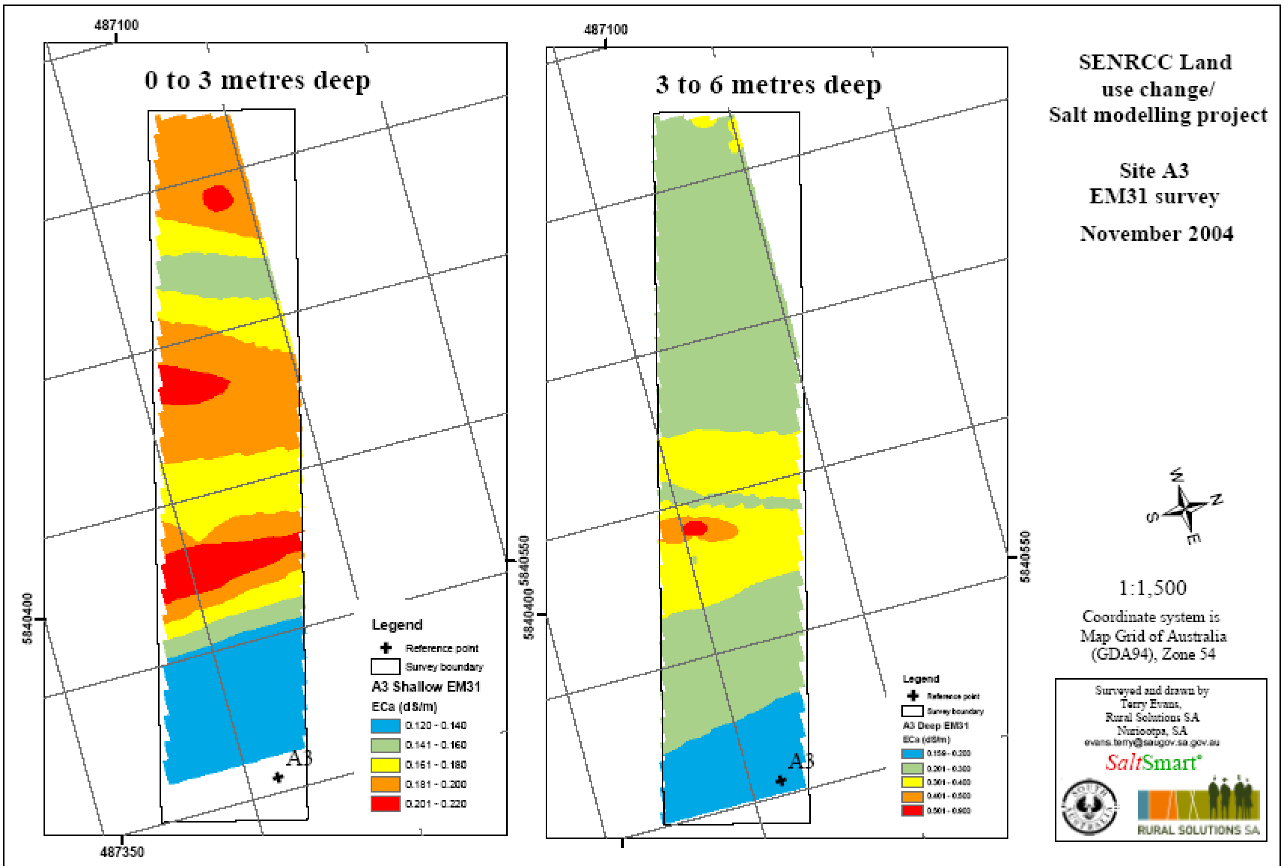
Fig. 6


SENRCC Land
use change/
Salt modelling project
Site A3
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:1,200
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
A3
5840550
5840500
5840450
5840400
487150
487200
487250
487300
487350
Fig. 7



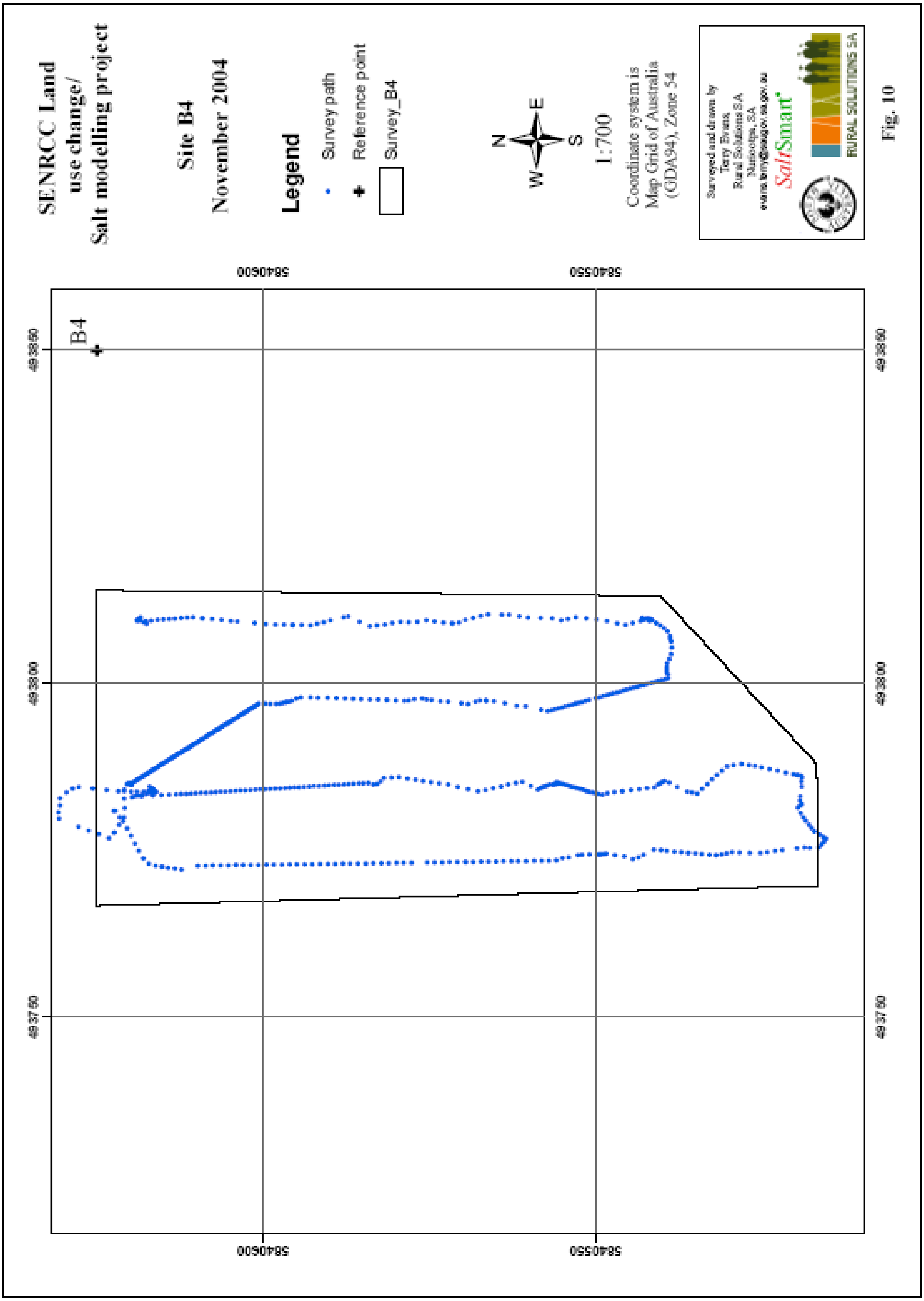
0 - 0.75 metres deep
0.75 - 1.5 metres deep
487100
487350
5840400
5840550
A3
Reference points
Survey boundary
A3 Shallow EM38
ECa (dS/m)
0.131 - 0.140
0.141 - 0.150
0.151 - 0.160
0.161 - 0.170
0.171 - 0.180
0.181 - 0.190
Legend
A3 Deep EM38
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site A3
EM38 survey
November 2004
1:1,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 8



0 to 3 metres deep
3 to 6 metres deep
487100
487350
5840400
5840550
A3
Legend
Reference point
Survey boundary
A3 Shallow EM31
ECa (dS/m)
0.120 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
A3 Deep EM31
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site A3
EM31 survey
November 2004
1:1,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 9


SENRCC Land use change/ Salt modelling project
Site B4
November 2004
Legend
Survey path
Reference point
Survey_B4
N
E
S
W
1:700
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by
SaltSmart
RURAL SOLUTIONS SA
Fig. 10
B4
5840600
5840550
493850
493800
493750

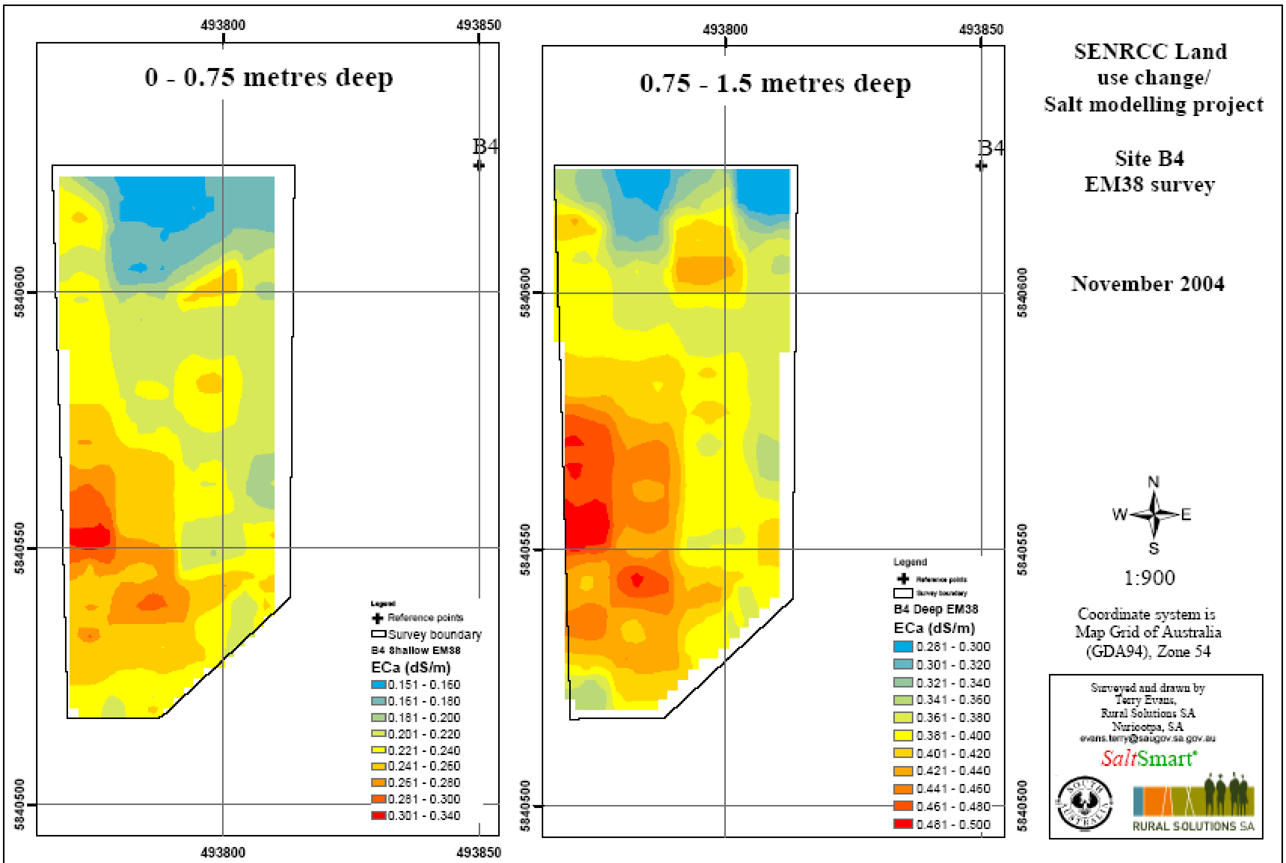

0 - 0.75 metres deep
0.75 - 1.5 metres deep
493800
493850
5840600
5840550
5840500
B4
Legend
Reference points
Survey boundary
B4 Shallow EM38
ECa (dS/m)
0.151 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.340
B4 Deep EM38
ECa (dS/m)
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
0.381 - 0.400
0.401 - 0.420
0.421 - 0.440
0.441 - 0.460
0.461 - 0.480
0.481 - 0.500
0
25
50
75
100
Metres
SENRCC Land
use change/
Salt modelling project
Site B4
EM38 survey
November 2004
N
W
E
S
1:900
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 11

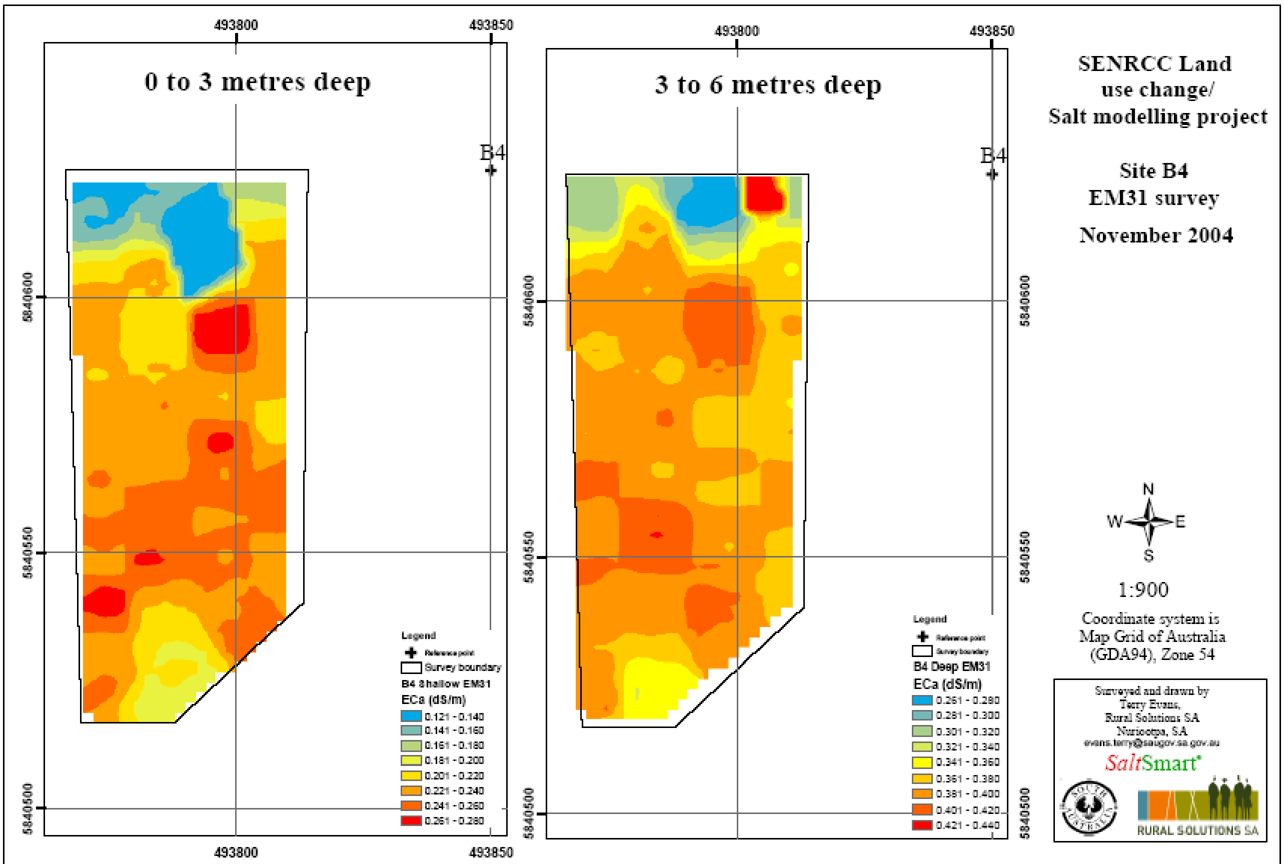

0 to 3 metres deep
3 to 6 metres deep
493800
493850
5840600
5840550
5840500
B4
Legend
Survey boundary
B4 Shallow EM31
ECa (dS/m)
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
B4 Deep EM31
ECa (dS/m)
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
0.381 - 0.400
0.401 - 0.420
0.421 - 0.440
0
25
50
75
100
Metres
SENRCC Land
use change/
Salt modelling project
Site B4
EM31 survey
November 2004
N
W
E
S
1:900
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 12

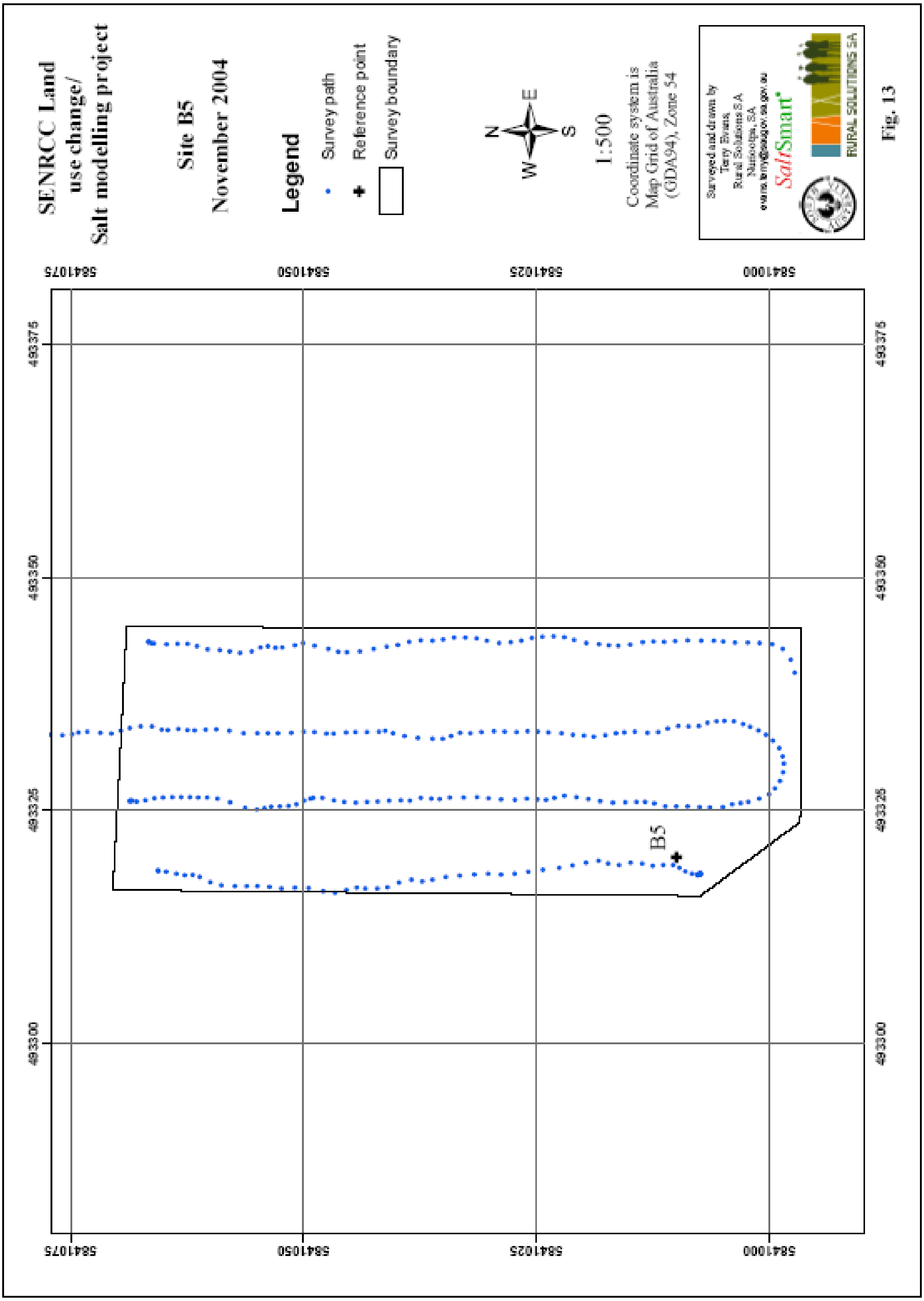

SENRCC Land use change/ Salt modelling project
Site B5
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
SaltSmart
RURAL SOLUTIONS SA
B5
584075
584050
584025
584000
493375
493350
493325
493300

Fig. 13

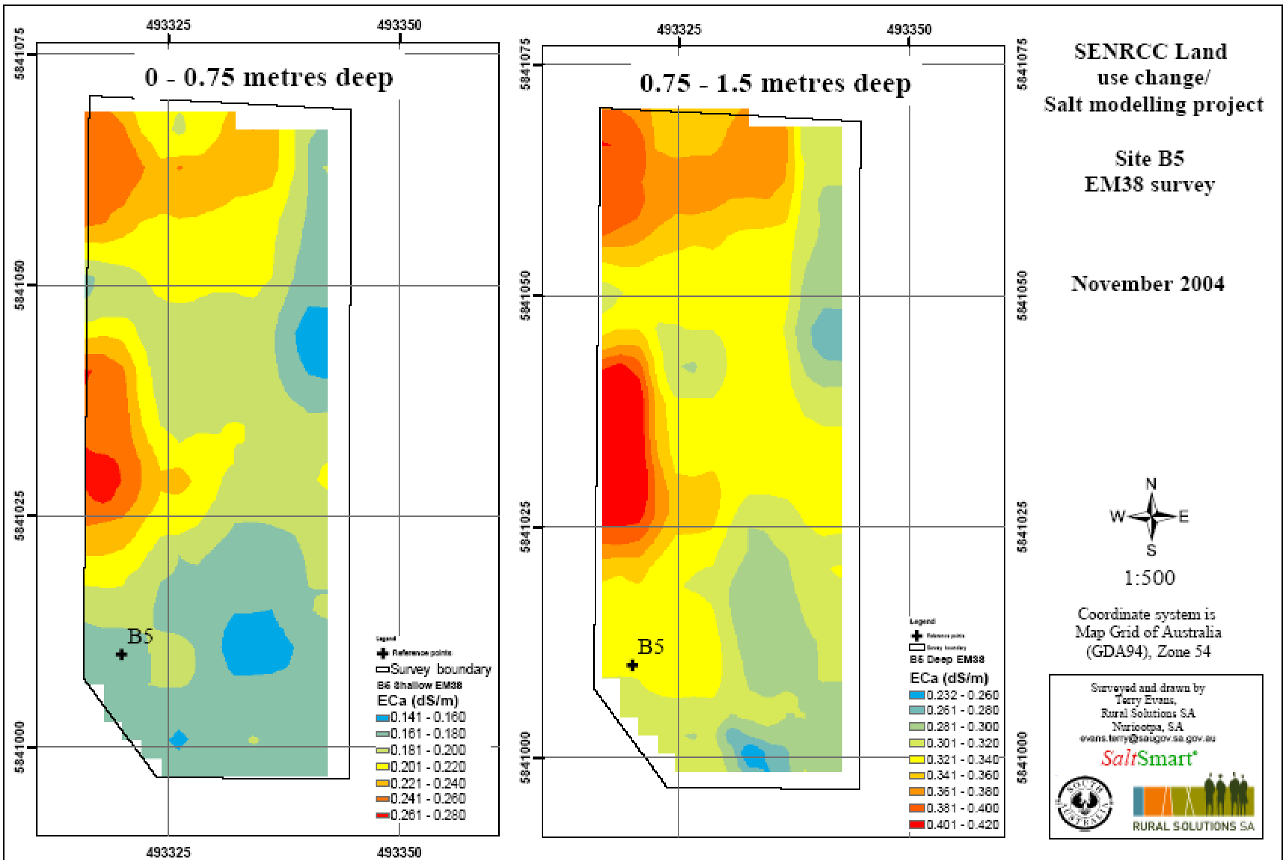

0 - 0.75 metres deep
0.75 - 1.5 metres deep
493325
493350
5841075
5841050
5841025
5841000
B5
Reference points
Survey boundary
B5 Shallow EM38
ECa (dS/m)
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
B5 Deep EM38
ECa (dS/m)
0.232 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
0.381 - 0.400
0.401 - 0.420
0
10
20
30
40
Metres
SENRCC Land
use change/
Salt modelling project
Site B5
EM38 survey
November 2004
N
W
E
S
1:500
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 14

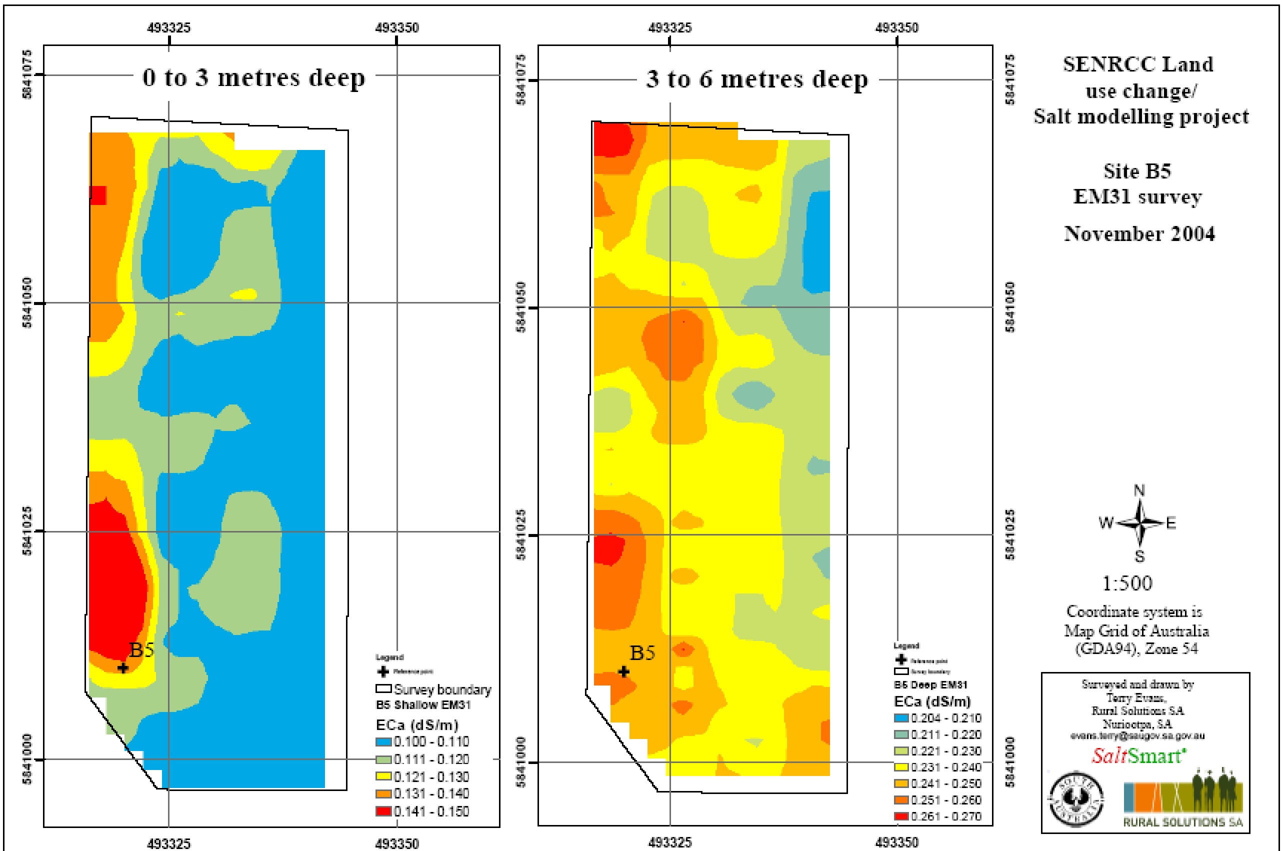

0 to 3 metres deep
3 to 6 metres deep
493325
493350
5841075
5841050
5841025
5841000
B5
Survey boundary
B5 Shallow EM31
ECa (dS/m)
0.100 - 0.110
0.111 - 0.120
0.121 - 0.130
0.131 - 0.140
0.141 - 0.150
B5 Deep EM31
ECa (dS/m)
0.204 - 0.210
0.211 - 0.220
0.221 - 0.230
0.231 - 0.240
0.241 - 0.250
0.251 - 0.260
0.261 - 0.270
0
10
20
30
40
Metres
SENRCC Land
use change/
Salt modelling project
Site B5
EM31 survey
November 2004
N
W
E
S
1:500
Coordinate system is
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Fig. 15

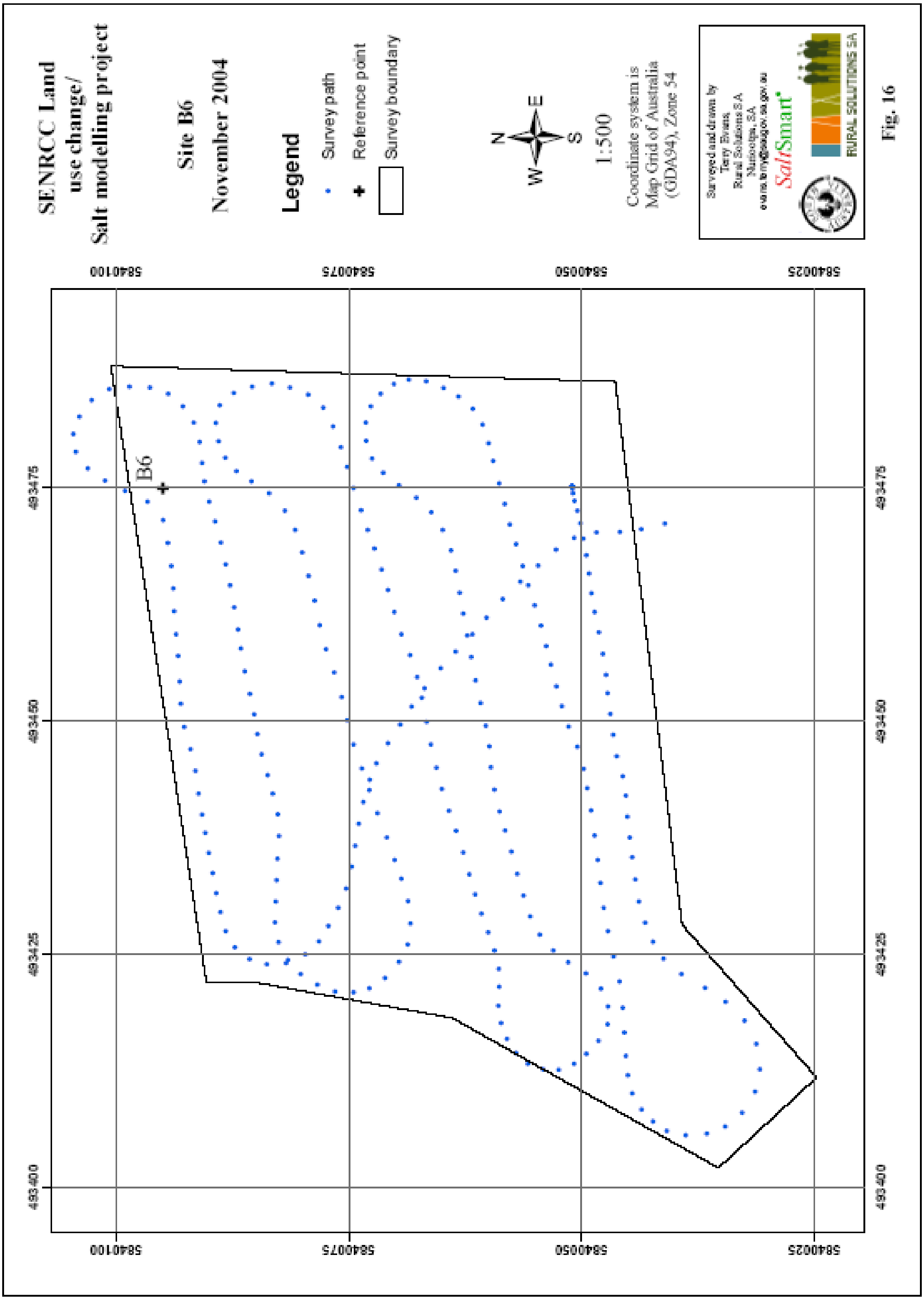
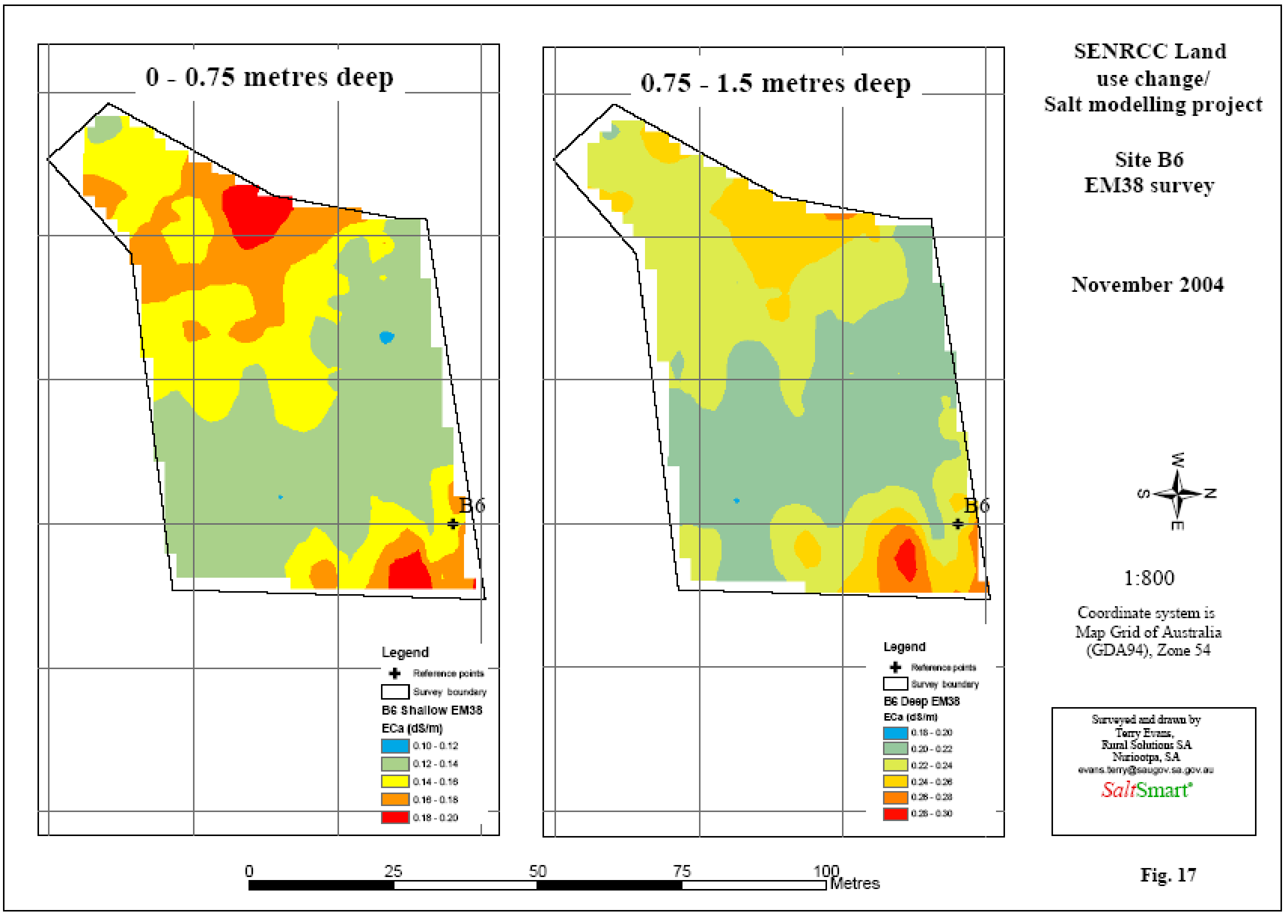

SENRCC Land use change/ Salt modelling project
Site B6
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
B6
5840100
5840075
5840050
5840025
493475
493450
493425
493400

Fig. 16


0 - 0.75 metres deep
0.75 - 1.5 metres deep
B6
B6
Legend
Reference points
Survey boundary
B6 Shallow EM38
ECa (dS/m)
0.10 - 0.12
0.12 - 0.14
0.14 - 0.16
0.16 - 0.18
0.18 - 0.20
Legend
Reference points
Survey boundary
B6 Deep EM38
ECa (dS/m)
0.18 - 0.20
0.20 - 0.22
0.22 - 0.24
0.24 - 0.26
0.26 - 0.28
0.28 - 0.30
SENRCC Land
use change/
Salt modelling project
Site B6
EM38 survey
November 2004
W
S
N
E
1:800
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
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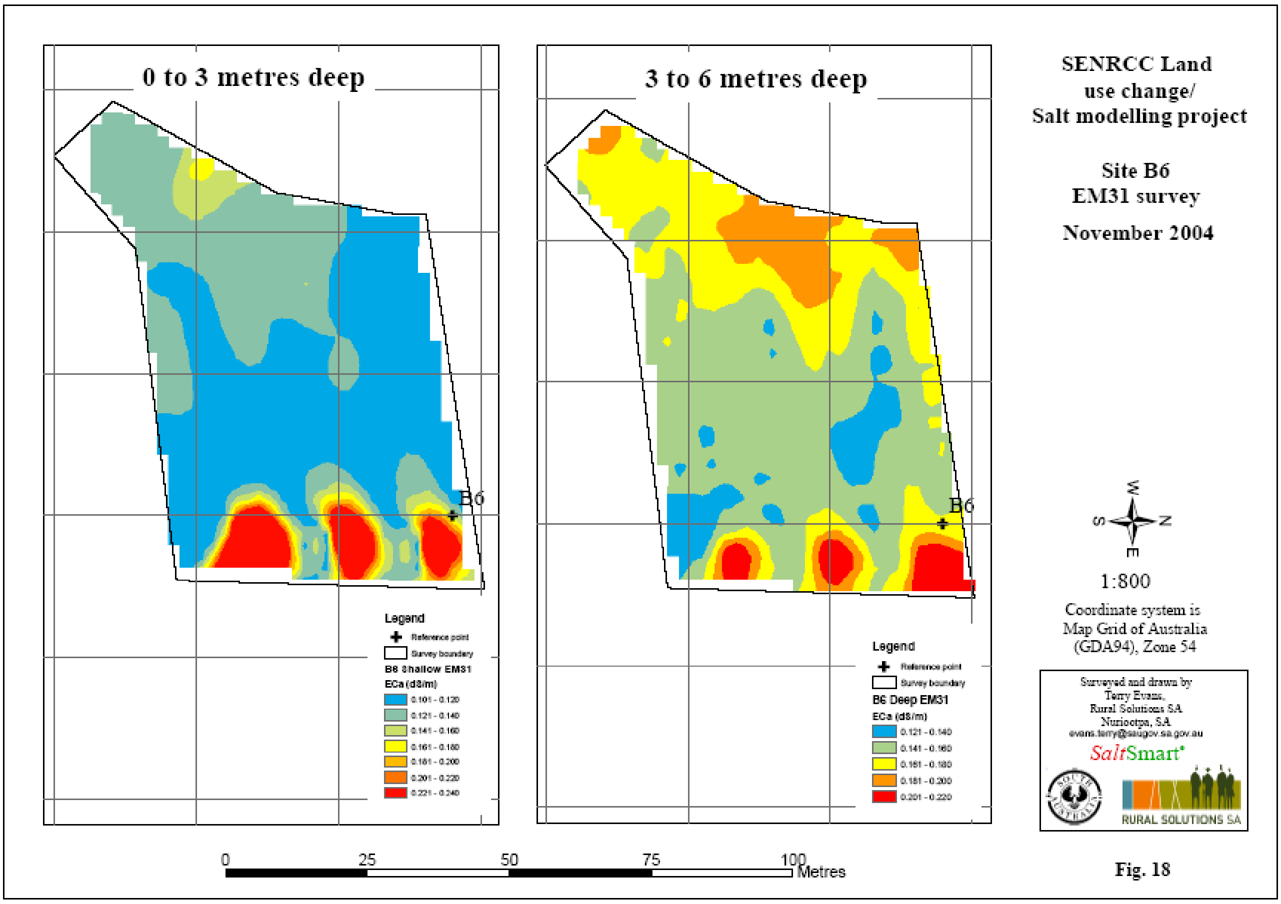
Nuriootpa, SA
evans.terry@saugov.sa.gov.au
SaltSmart
0
25
50
75
100
Metres
Fig. 17


0 to 3 metres deep
3 to 6 metres deep
B6
B6
Legend
Reference point
Survey boundary
B6 Shallow EM31
ECa (dS/m)
0.101 - 0.120
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
Legend
Reference point
Survey boundary
B6 Deep EM31
ECa (dS/m)
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
SENRCC Land
use change/
Salt modelling project
Site B6
EM31 survey
November 2004
W
S
N
E
1:800
Coordinate system is
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(GDA94), Zone 54
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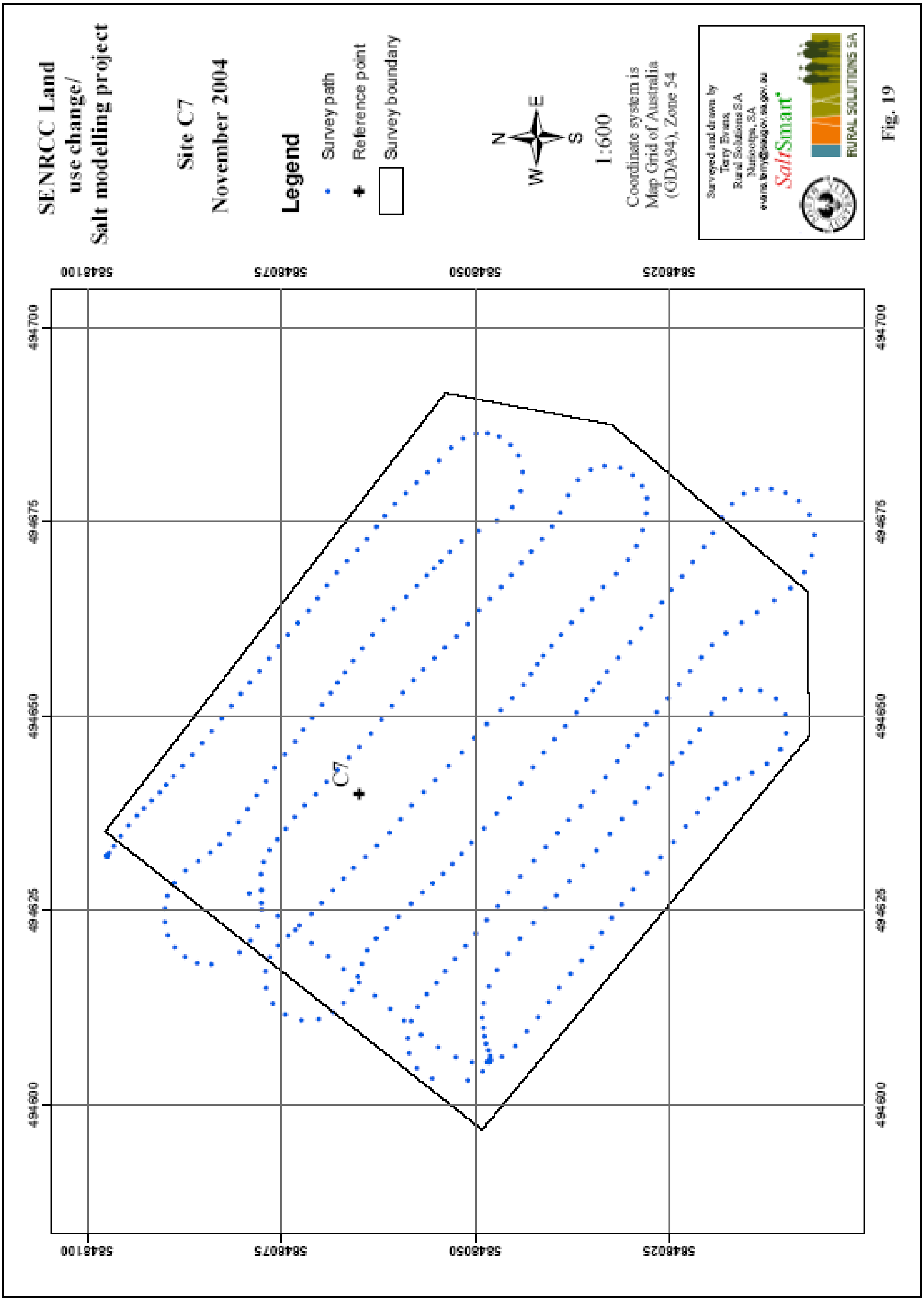
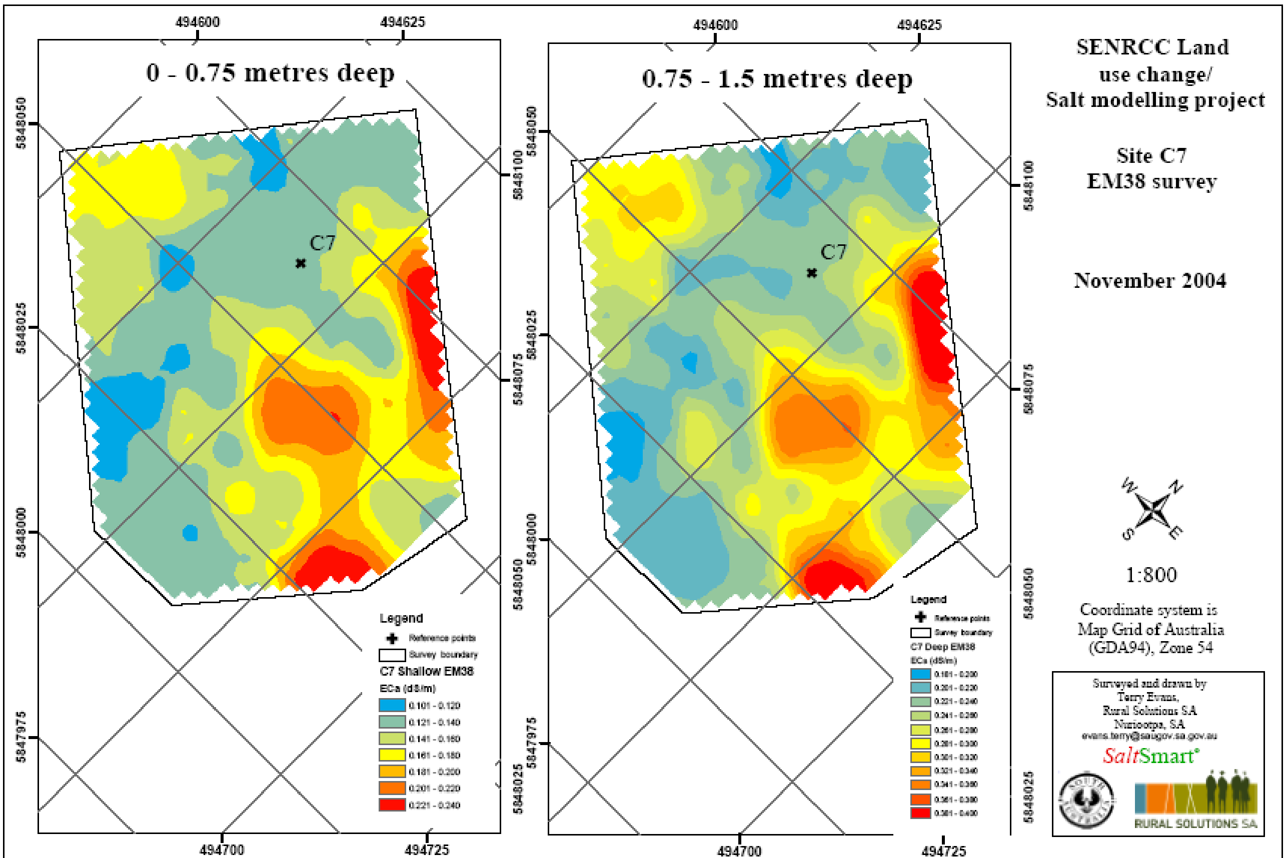
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
0
25
50
75
100
Metres
Fig. 18


SENRCC Land use change/ Salt modelling project
Site C7
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
C7
5848100
5848075
5848050
5848025
494700
494675
494650
494625
494600
Fig. 19


0 - 0.75 metres deep
0.75 - 1.5 metres deep
C7
SENRCC Land use change/ Salt modelling project
Site C7
EM38 survey
November 2004
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
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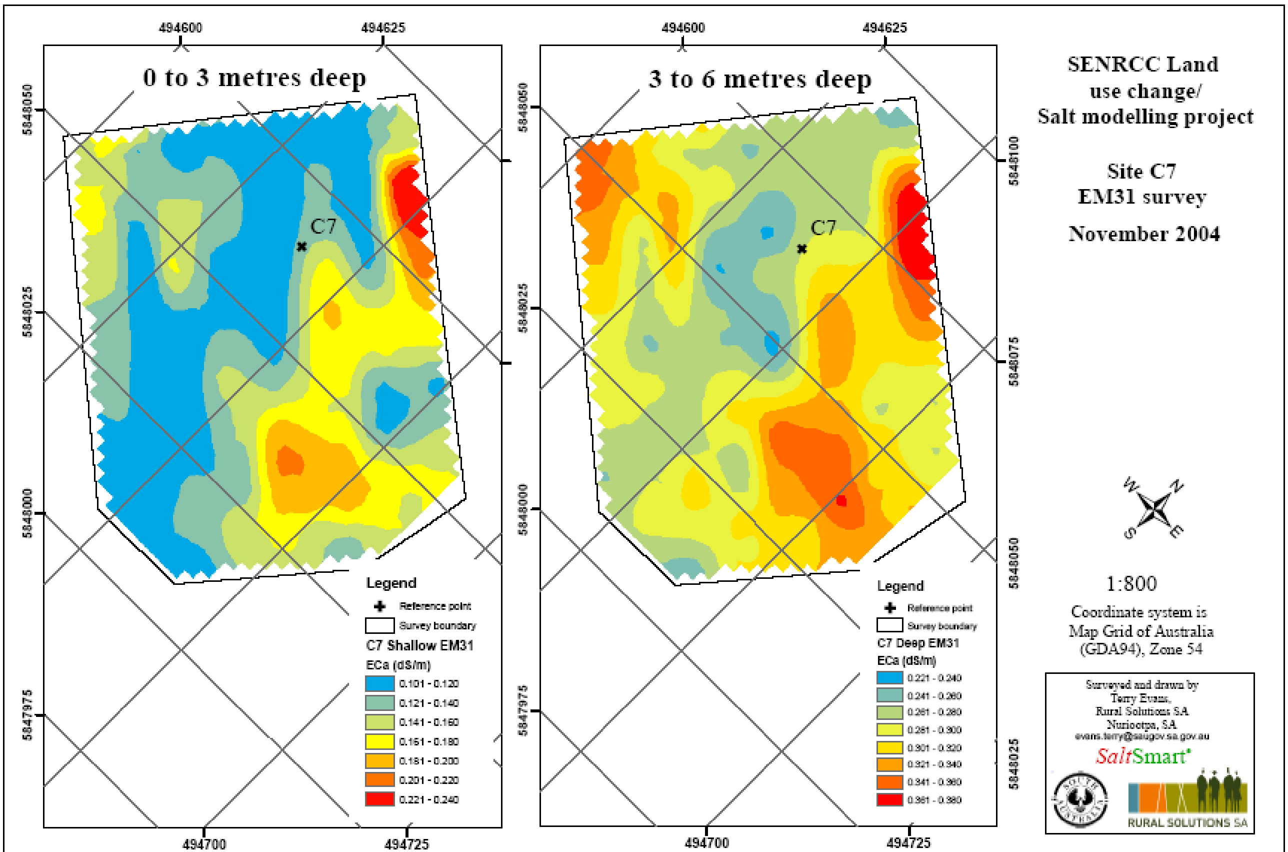
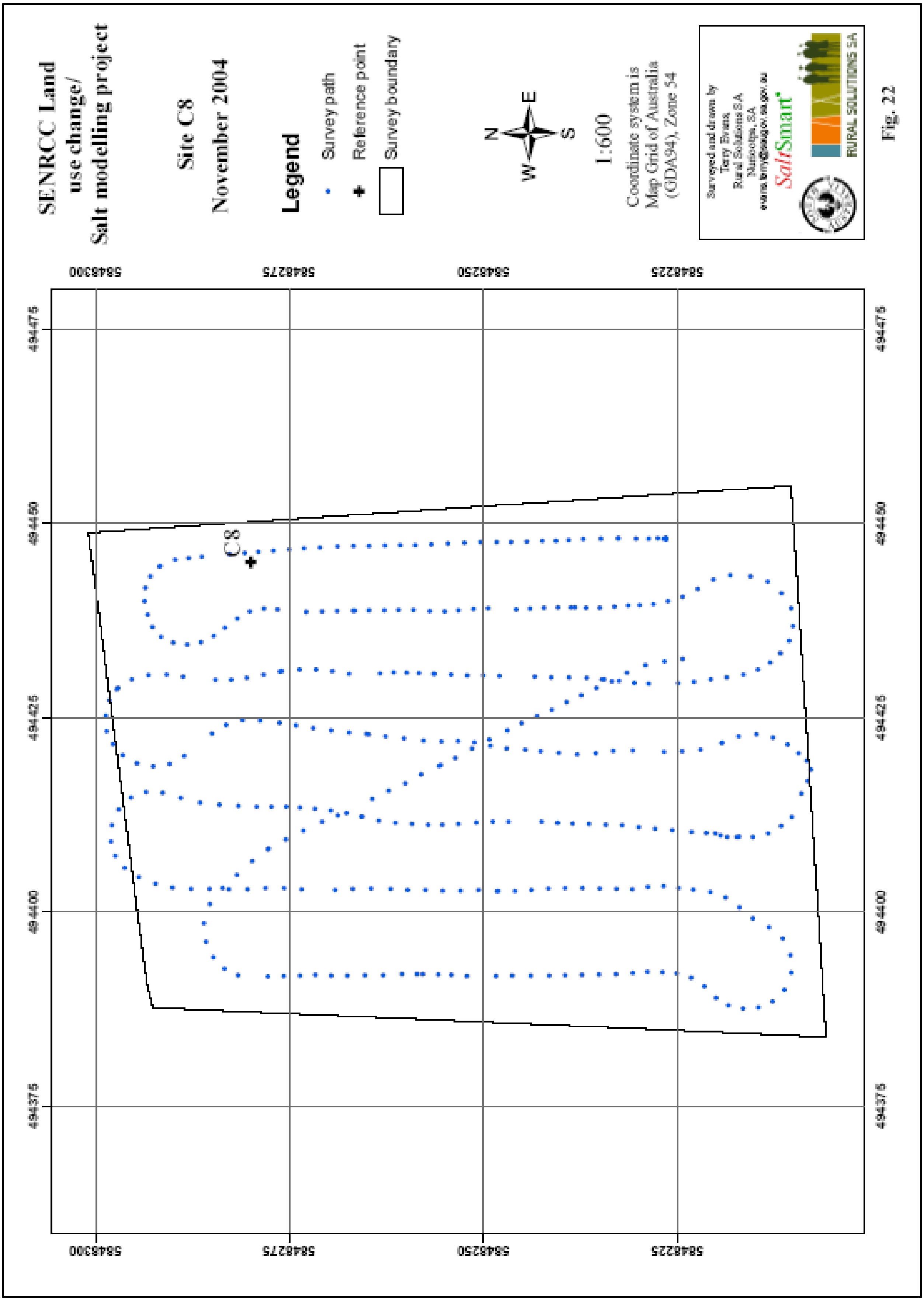
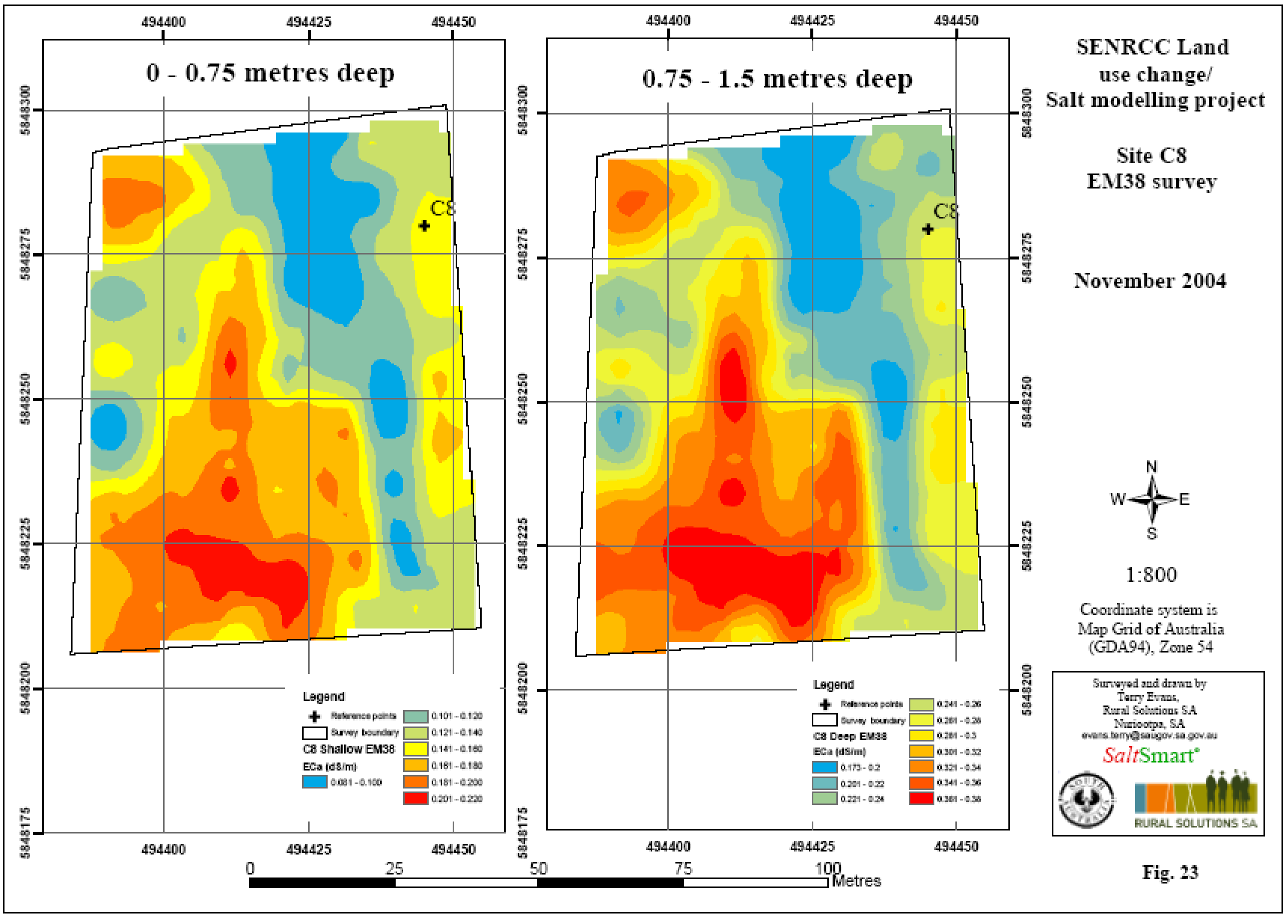
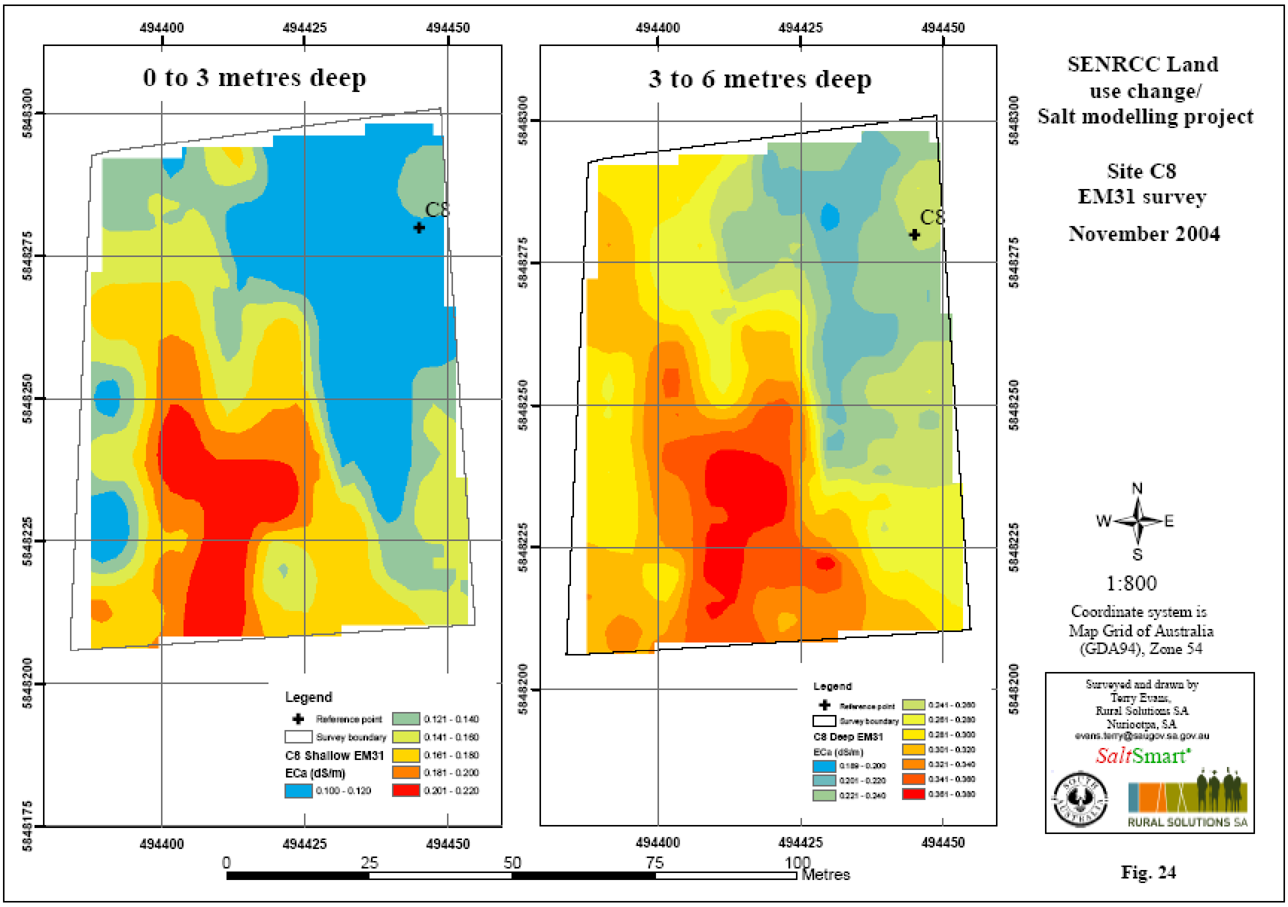
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
Legend
Reference points
Survey boundary
C7 Shallow EM38
ECa (dS/m)
0.101 - 0.120
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
C7 Deep EM38
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
0.381 - 0.400
494600
494625
494700
494725
5848050
5848025
5848000
5847975
5848100
5848075
0
25
50
75
100
Metres
Fig. 20


0 to 3 metres deep
3 to 6 metres deep
C7
SENRCC Land use change/ Salt modelling project
Site C7
EM31 survey
November 2004
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Nuriootpa, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
Legend
Reference point
Survey boundary
C7 Shallow EM31
ECa (dS/m)
0.101 - 0.120
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
C7 Deep EM31
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
494600
494625
494700
494725
5848050
5848025
5848000
5847975
5848100
5848075
0
25
50
75
100
Metres
Fig. 21


SENRCC Land use change/ Salt modelling project
Site C8
November 2004
Legend
Survey path
Reference point
Survey boundary
N
E
S
W
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
C8
5848300
5848275
5848250
5848225
494475
494450
494425
494400
494375
Fig. 22


0 - 0.75 metres deep
0.75 - 1.5 metres deep
494400
494425
494450
5848300
5848275
5848250
5848225
5848200
5848175
C8
Legend
Reference points
Survey boundary
C8 Shallow EM38
ECa (dS/m)
0.081 - 0.100
0.101 - 0.120
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
C8 Deep EM38
0.173 - 0.2
0.201 - 0.22
0.221 - 0.24
0.241 - 0.26
0.261 - 0.28
0.281 - 0.3
0.301 - 0.32
0.321 - 0.34
0.341 - 0.36
0.361 - 0.38
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site C8
EM38 survey
November 2004
N
W
E
S
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Fig. 23


0 to 3 metres deep
3 to 6 metres deep
494400
494425
494450
5848300
5848275
5848250
5848225
5848200
5848175
C8
Legend
Reference point
Survey boundary
C8 Shallow EM31
ECa (dS/m)
0.100 - 0.120
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
C8 Deep EM31
0.189 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.341 - 0.360
0.361 - 0.380
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site C8
EM31 survey
November 2004
N
W
E
S
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by
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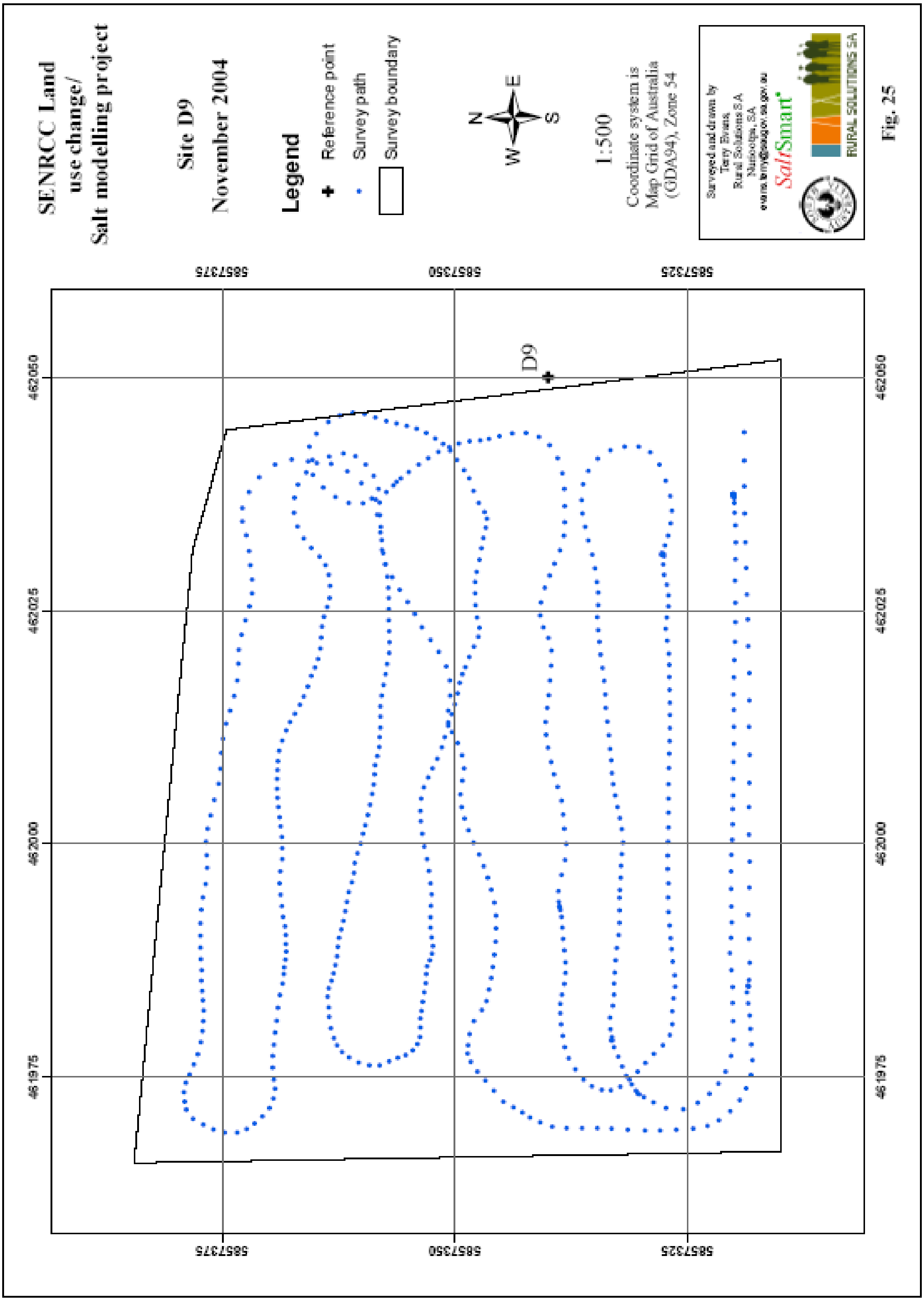
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Fig. 24


SENRCC Land use change/ Salt modelling project
Site D9
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
D9
5857375
5857350
5857325
462050
462025
462000
461975
Fig. 25

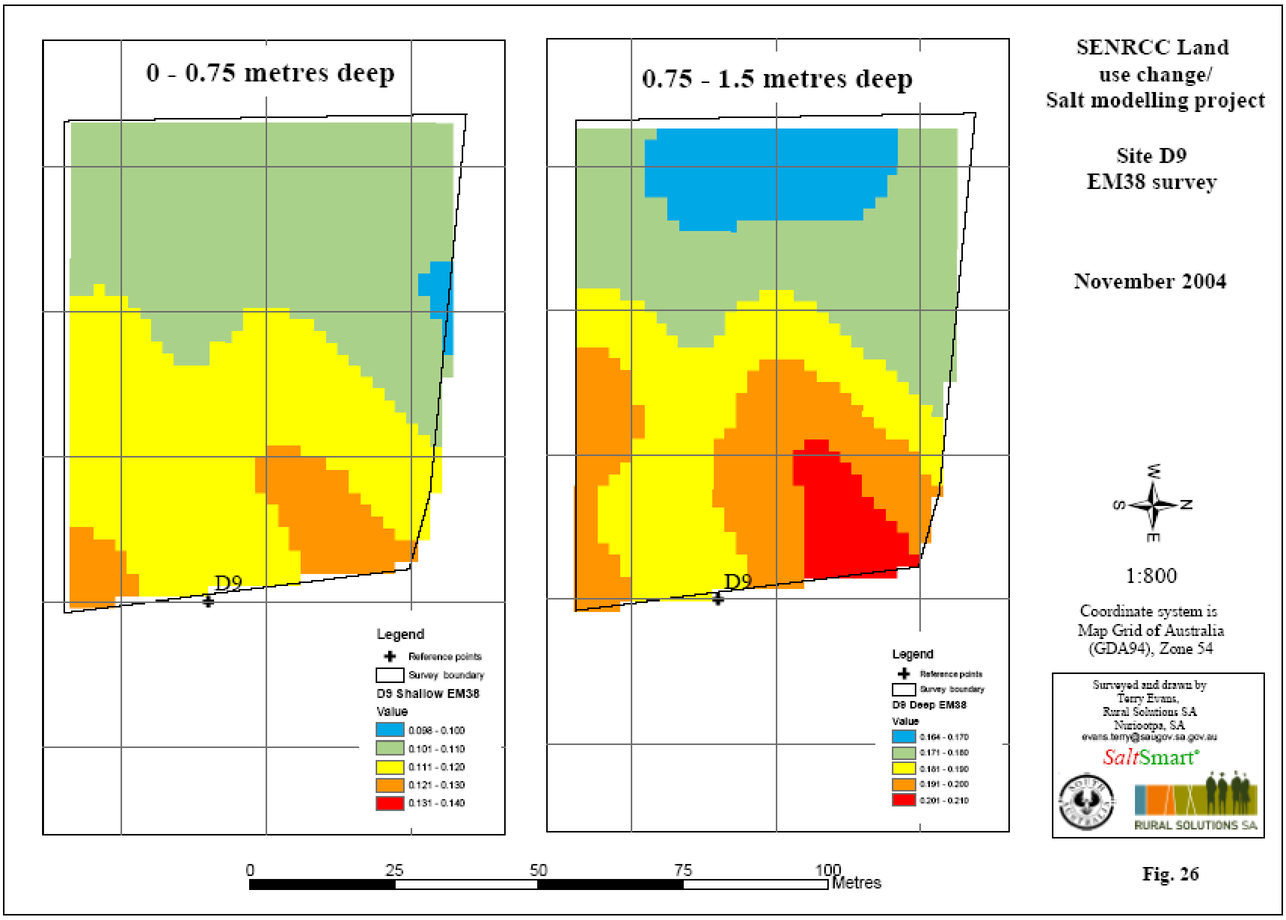
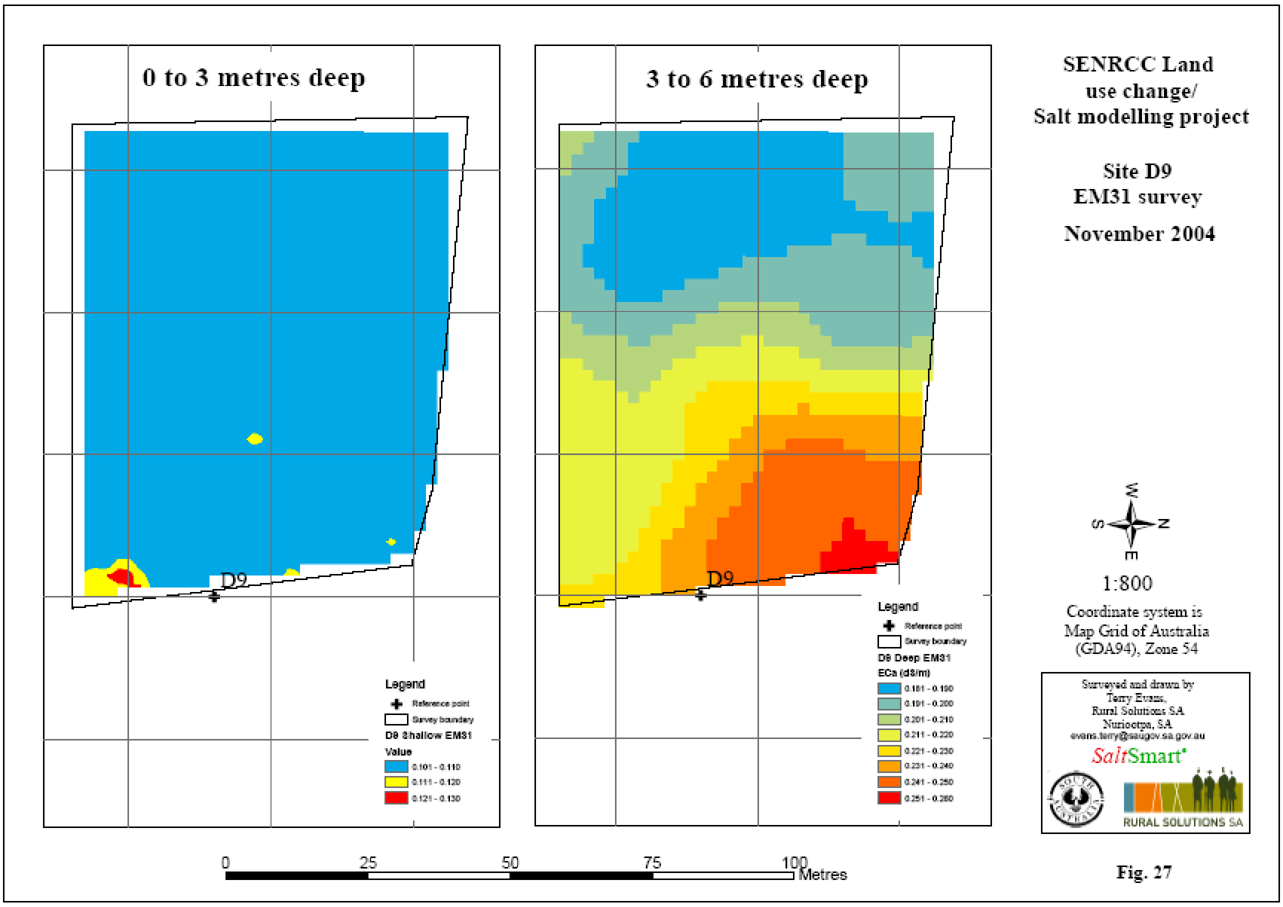

0 - 0.75 metres deep
0.75 - 1.5 metres deep
D9
Legend
Reference points
Survey boundary
D9 Shallow EM38
Value
0.098 - 0.100
0.101 - 0.110
0.111 - 0.120
0.121 - 0.130
0.131 - 0.140
D9 Deep EM38
0.164 - 0.170
0.171 - 0.180
0.181 - 0.190
0.191 - 0.200
0.201 - 0.210
SENRCC Land
use change/
Salt modelling project
Site D9
EM38 survey
November 2004
W
S
N
E
1:800
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
0
25
50
75
100
Metres

Fig. 26


0 to 3 metres deep
3 to 6 metres deep
D9
Legend
Reference point
Survey boundary
D9 Shallow EM31
Value
0.101 - 0.110
0.111 - 0.120
0.121 - 0.130
D9 Deep EM31
ECa (dS/m)
0.181 - 0.190
0.191 - 0.200
0.201 - 0.210
0.211 - 0.220
0.221 - 0.230
0.231 - 0.240
0.241 - 0.250
0.251 - 0.260
SENRCC Land
use change/
Salt modelling project
Site D9
EM31 survey
November 2004
W
S
N
E
1:800
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
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Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA
0
25
50
75
100
Metres

Fig. 27

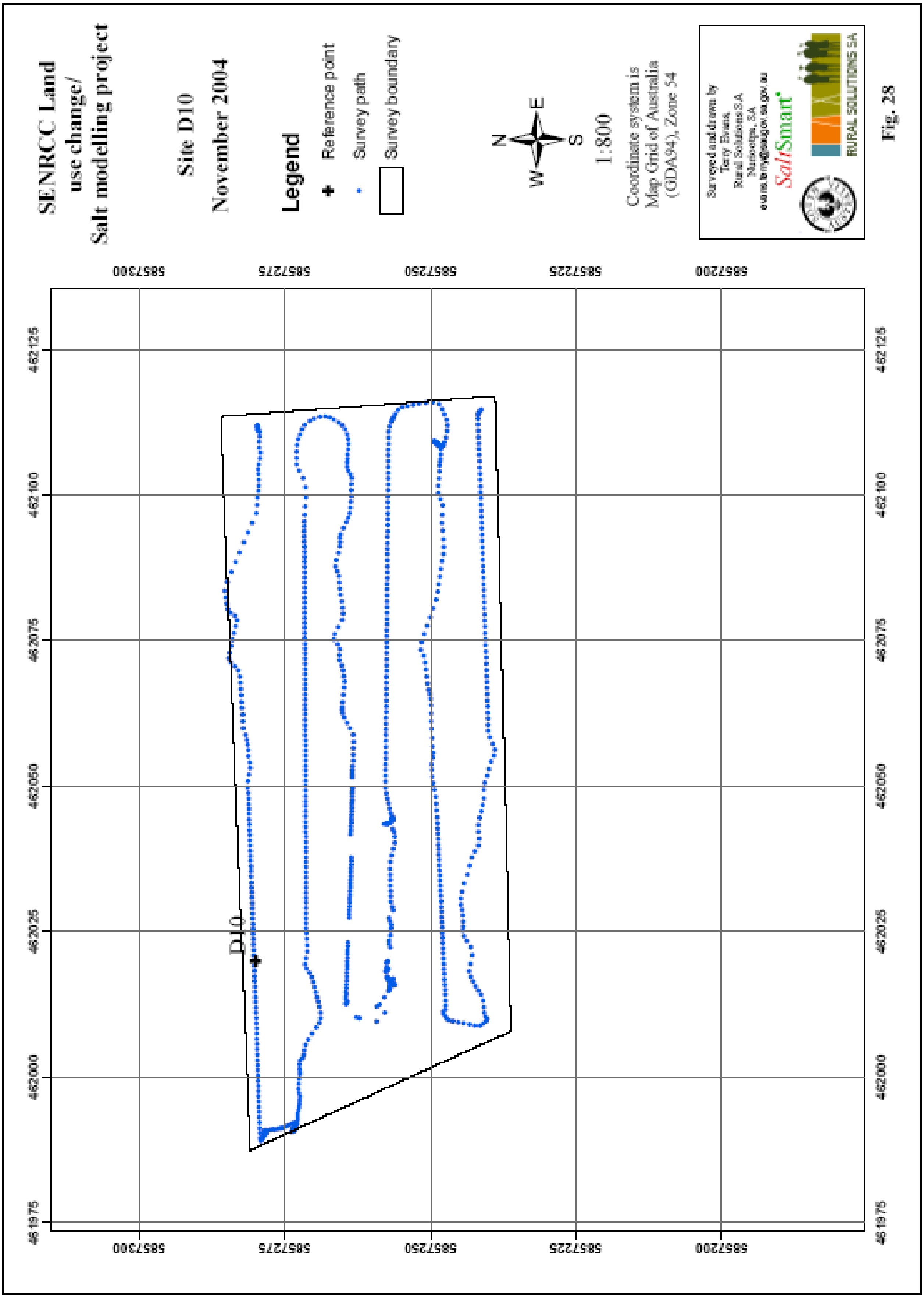
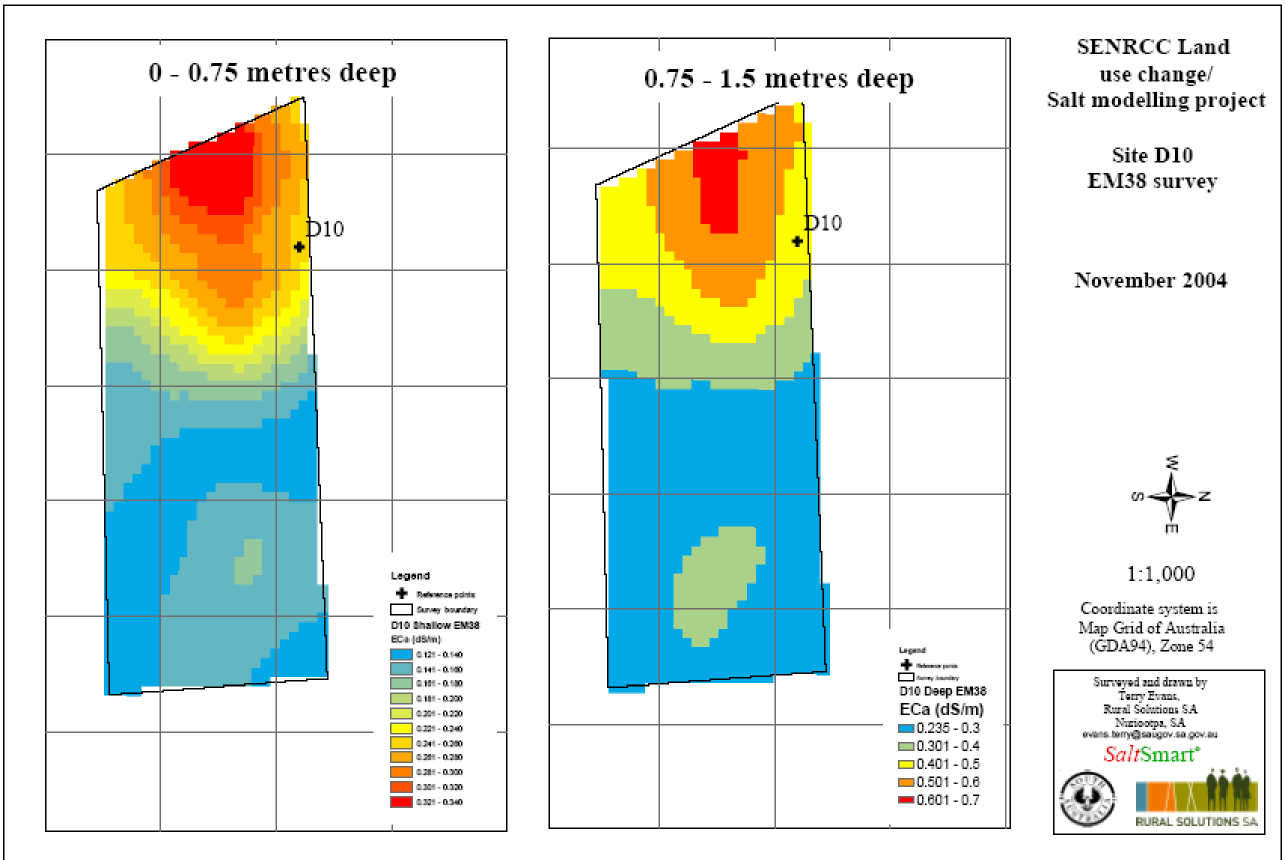
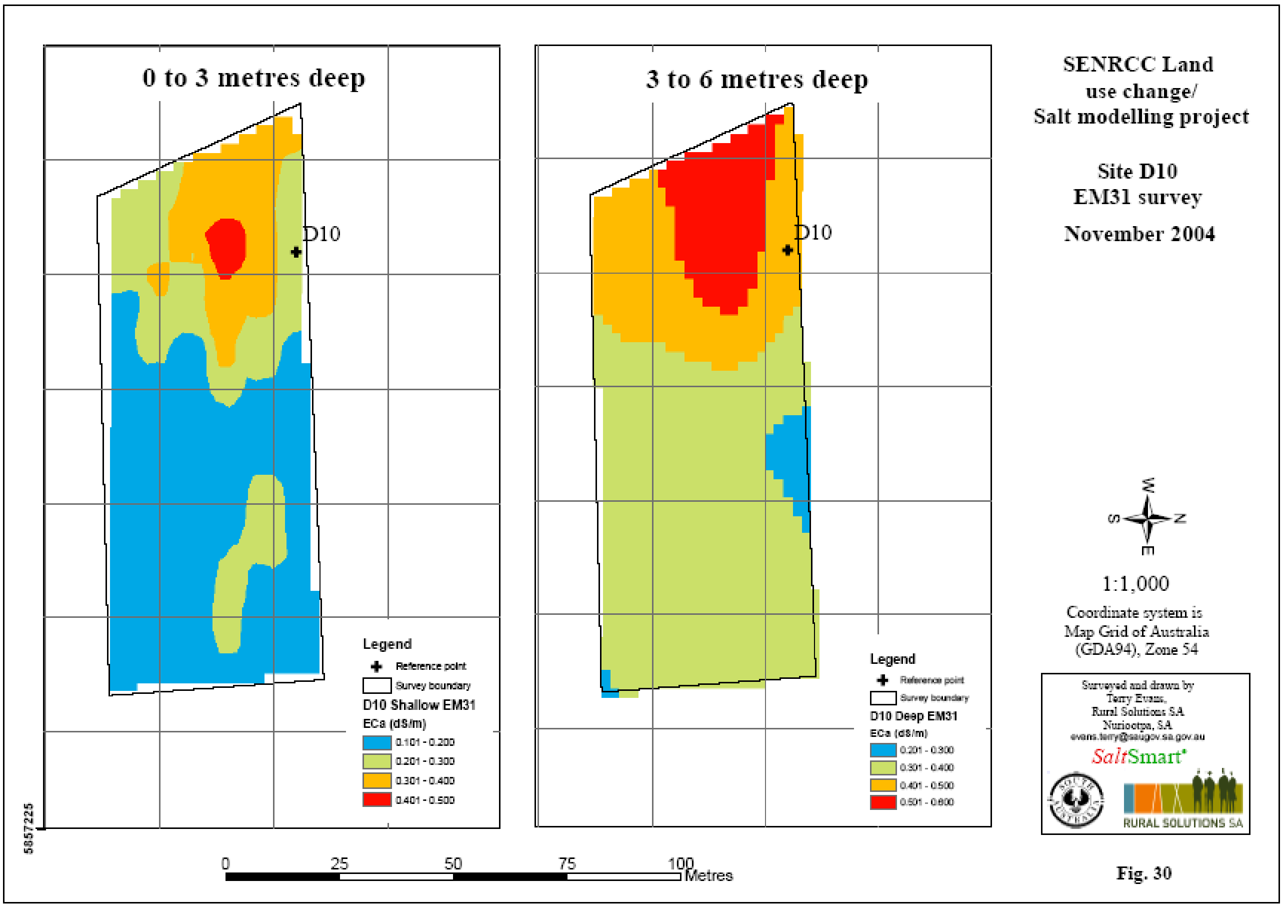

SENRCC Land use change/ Salt modelling project
Site D10
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
D10

Fig. 28



0 - 0.75 metres deep
D10
Legend
Reference points
Survey boundary
D10 Shallow EM38
ECa (dS/m)
0.121 - 0.140
0.141 - 0.160
0.161 - 0.180
0.181 - 0.200
0.201 - 0.220
0.221 - 0.240
0.241 - 0.260
0.261 - 0.280
0.281 - 0.300
0.301 - 0.320
0.321 - 0.340
0.75 - 1.5 metres deep
D10
D10 Deep EM38
ECa (dS/m)
0.235 - 0.3
0.301 - 0.4
0.401 - 0.5
0.501 - 0.6
0.601 - 0.7
0
25
50
75
100
Metres
SENRCC Land
use change/
Salt modelling project
Site D10
EM38 survey
November 2004
W
S
N
E
1:1,000
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

Fig. 29



0 to 3 metres deep
D10
Legend
Reference point
Survey boundary
D10 Shallow EM31
ECa (dS/m)
0.101 - 0.200
0.201 - 0.300
0.301 - 0.400
0.401 - 0.500
3 to 6 metres deep
D10
Legend
Reference point
Survey boundary
D10 Deep EM31
ECa (dS/m)
0.201 - 0.300
0.301 - 0.400
0.401 - 0.500
0.501 - 0.600
5857225
0
25
50
75
100
Metres
SENRCC Land
use change/
Salt modelling project
Site D10
EM31 survey
November 2004
W
S
N
E
1:1,000
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
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Rural Solutions SA
Nuriootpa, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

Fig. 30

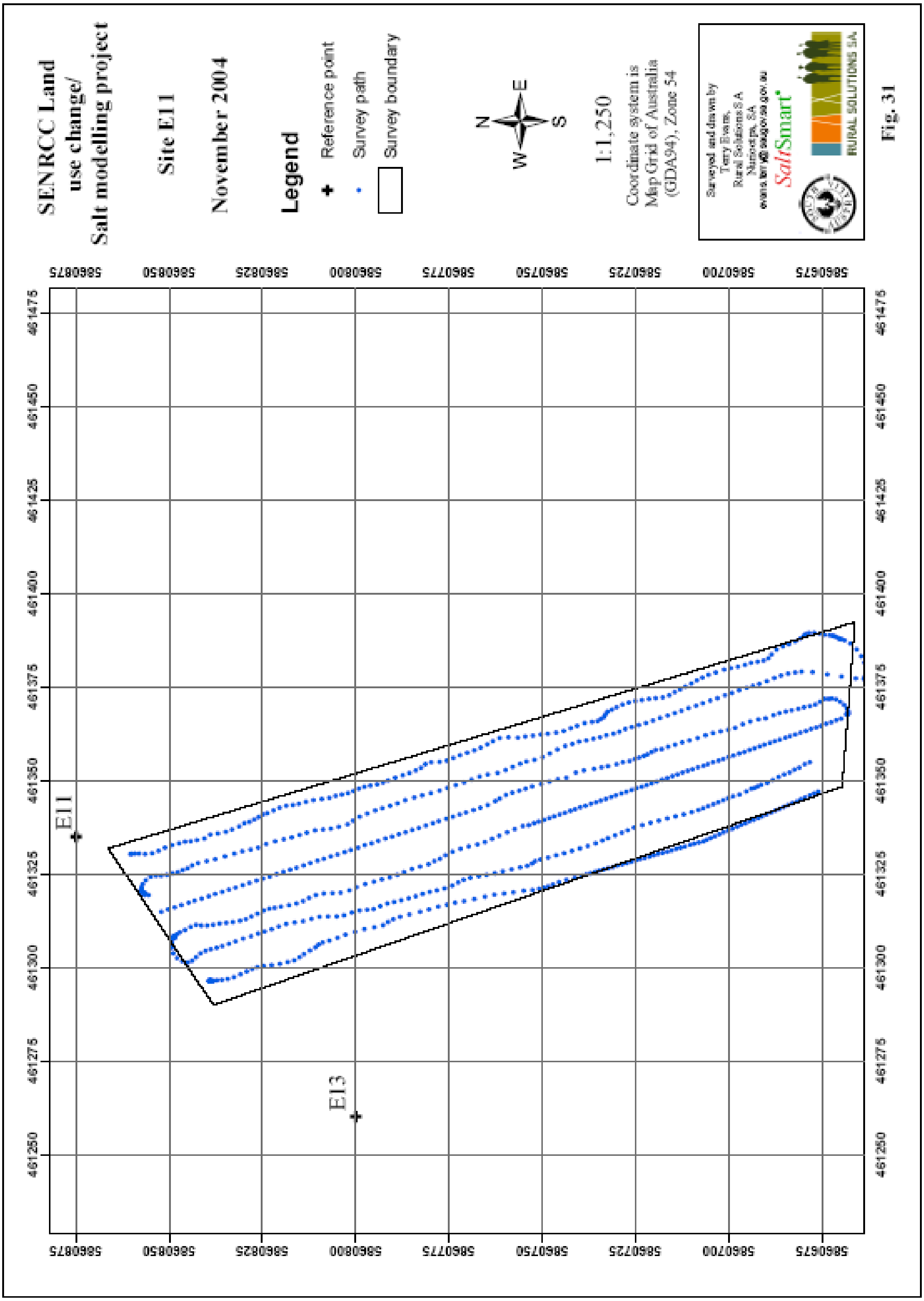

SENRCC Land use change/ Salt modelling project
Site E11
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:1,250
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
E11
E13
461250
461275
461300
461325
461350
461375
461400
461425
461450
461475
5860675
5860700
5860725
5860750
5860775
5860800
5860825
5860850
5860875

Fig. 31

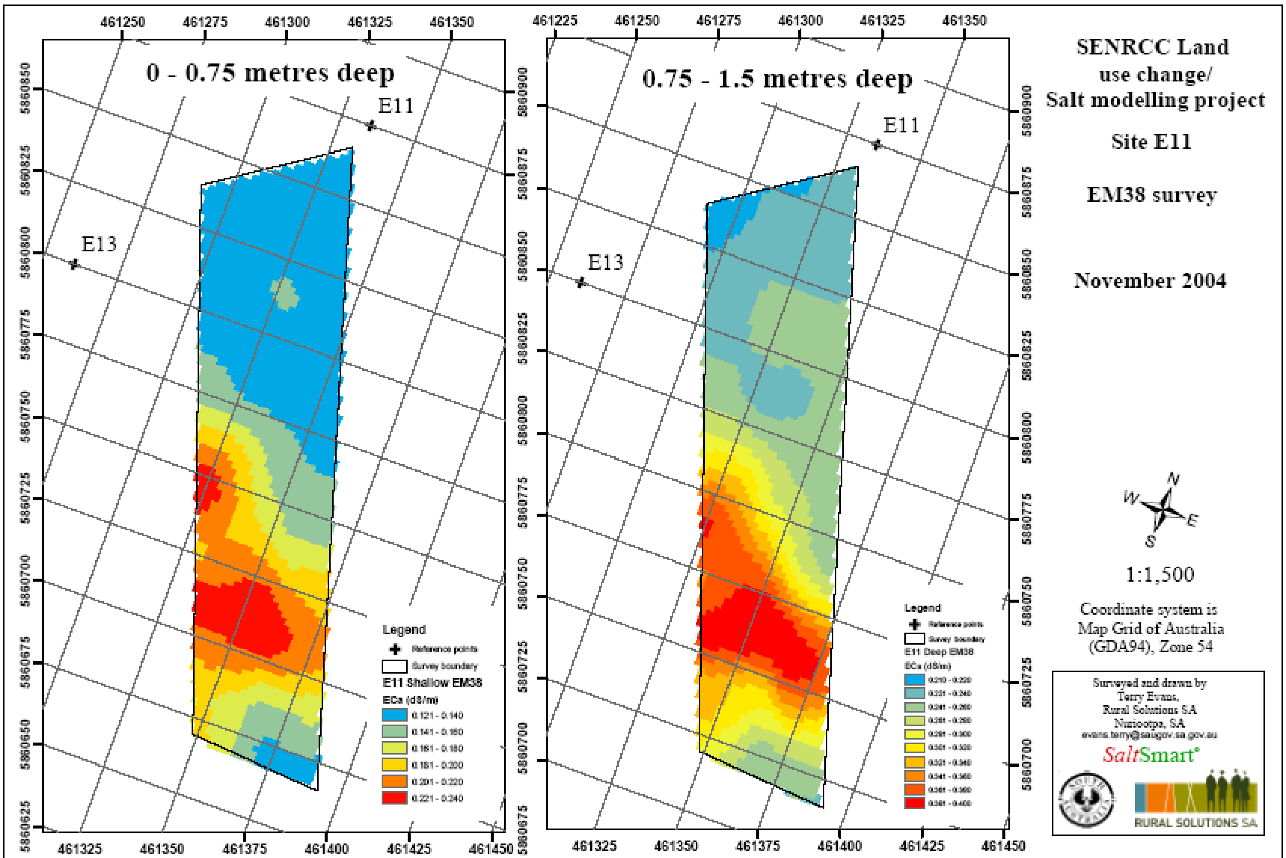

0 - 0.75 metres deep
0.75 - 1.5 metres deep
E11
E13
Legend
E11 Shallow EM38
E11 Deep EM38
ECa (dS/m)
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site E11
EM38 survey
November 2004
1:1,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 32

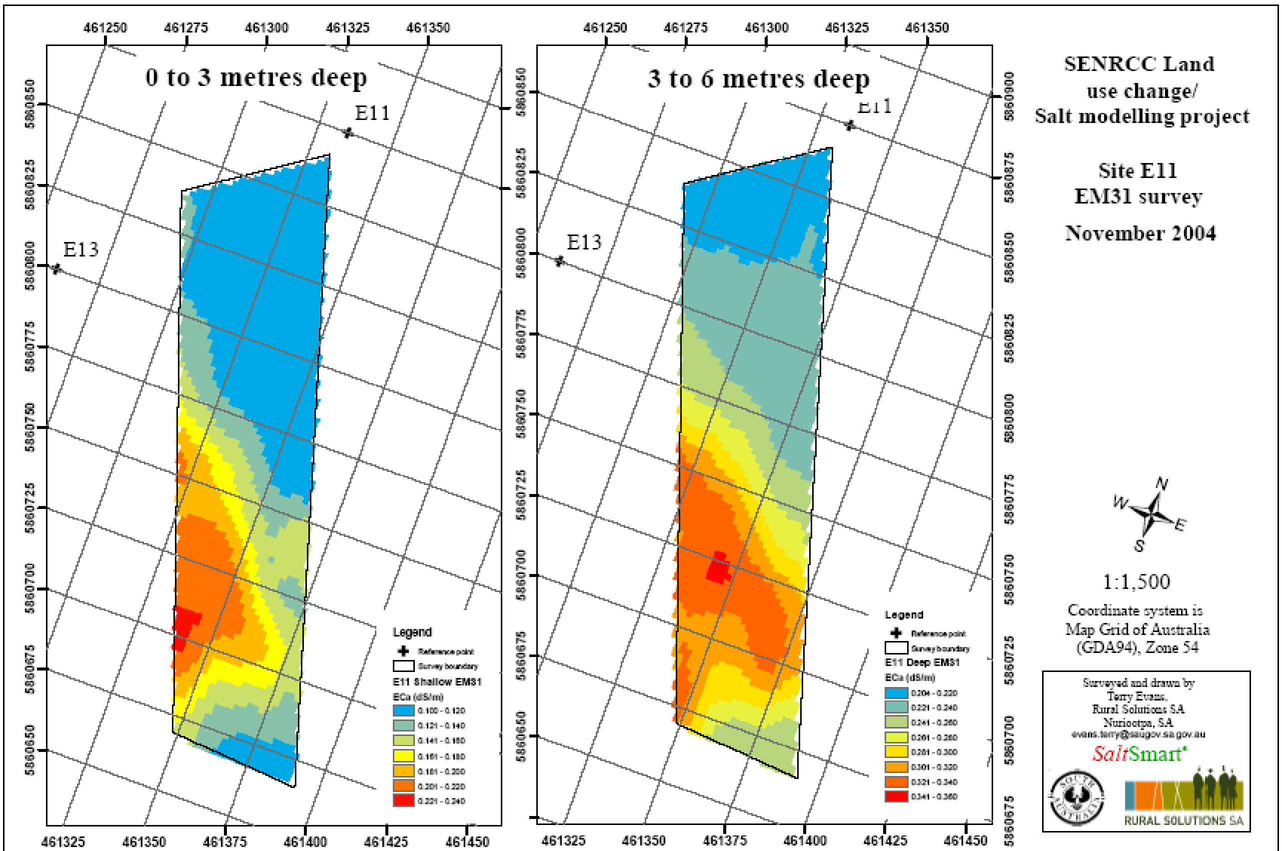
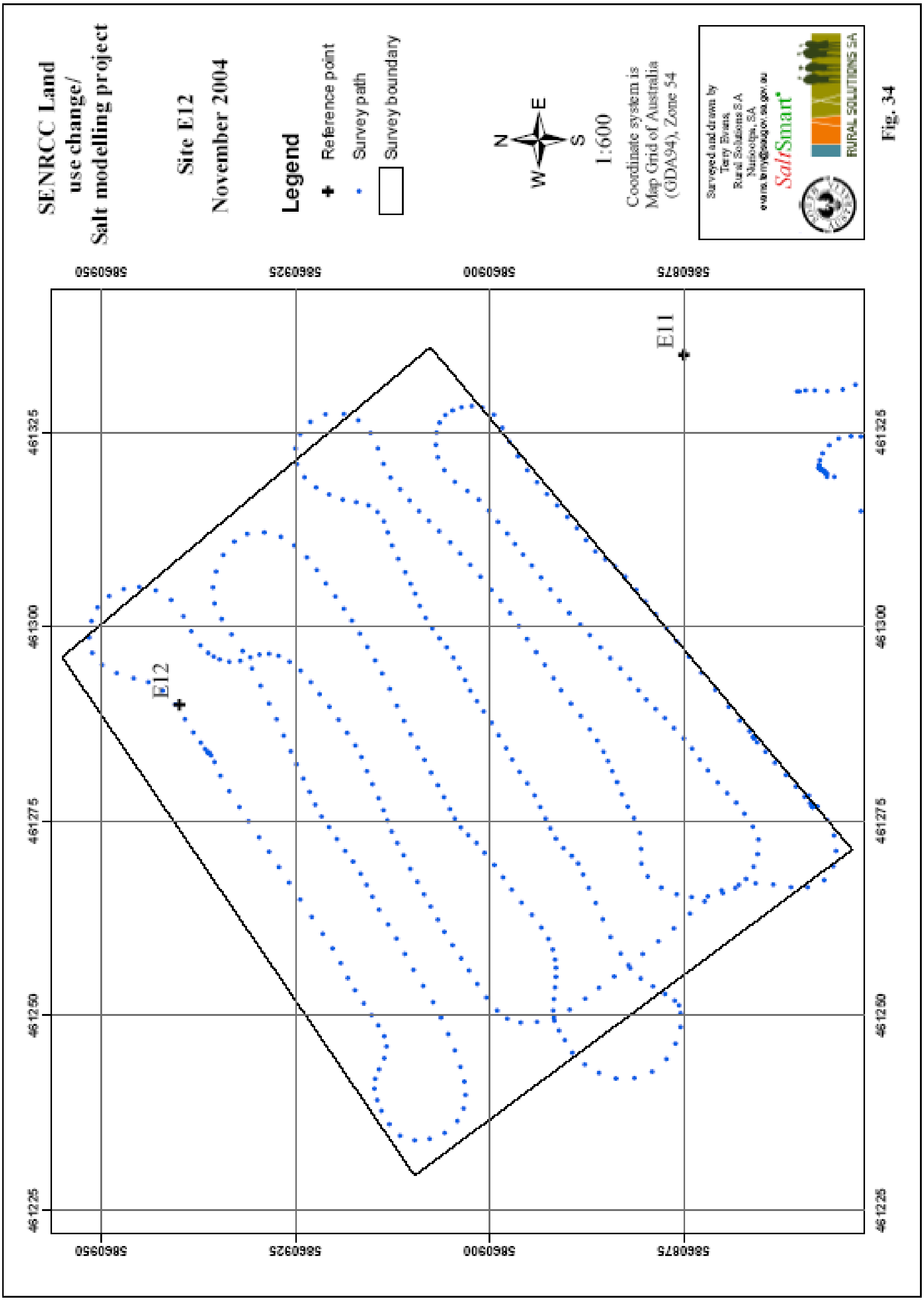

0 to 3 metres deep
3 to 6 metres deep
E11
E13
Legend
E11 Shallow EM31
E11 Deep EM31
ECa (dS/m)
0 25 50 75 100 Metres
SENRCC Land use change/ Salt modelling project
Site E11
EM31 survey
November 2004
1:1,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 33


SENRCC Land use change/ Salt modelling project
Site E12
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
E11
E12
5860950
5860925
5860900
5860875
461225
461250
461275
461300
461325
Fig. 34

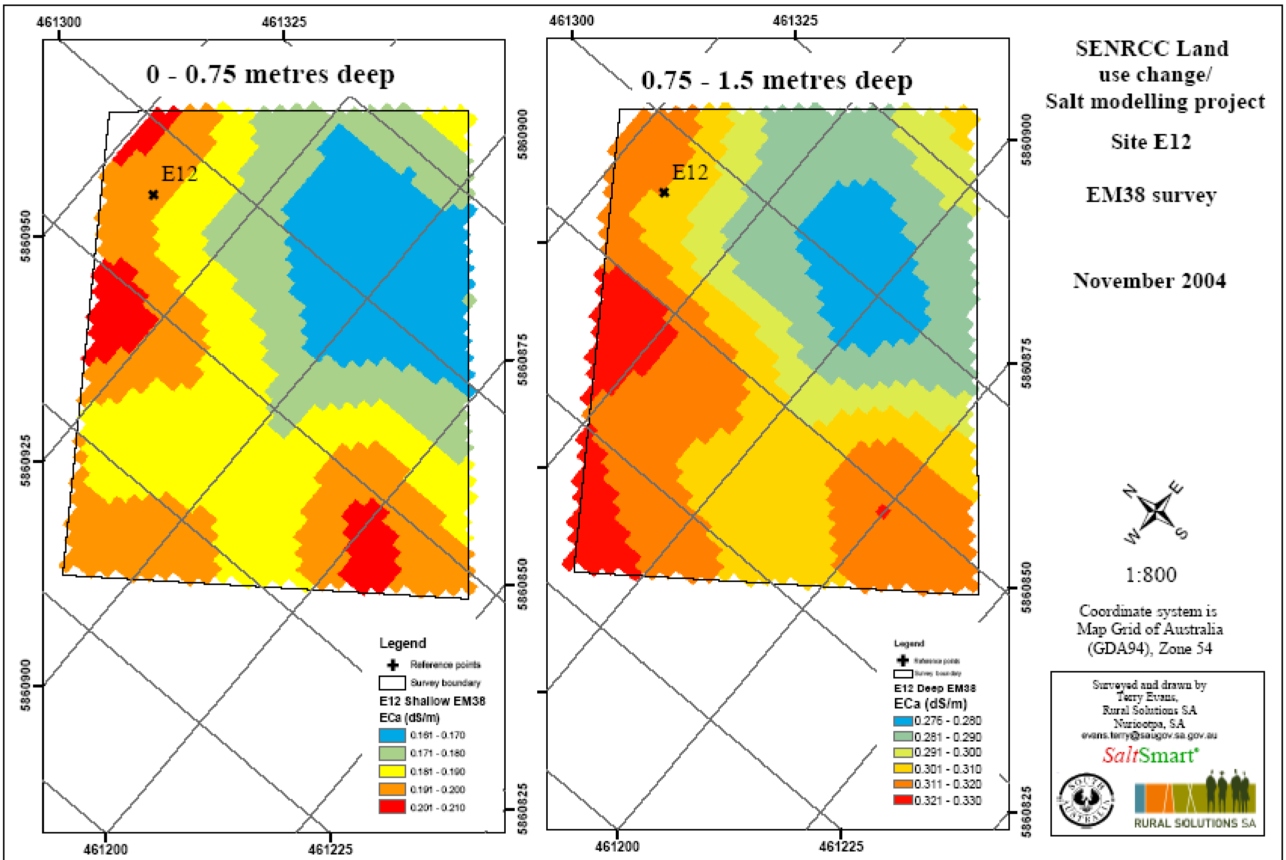

0 - 0.75 metres deep
0.75 - 1.5 metres deep
E12
SENRCC Land use change/ Salt modelling project
Site E12
EM38 survey
November 2004
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
Reference points
Survey boundary
E12 Shallow EM38 ECa (dS/m)
0.161 - 0.170
0.171 - 0.180
0.181 - 0.190
0.191 - 0.200
0.201 - 0.210
E12 Deep EM38 ECa (dS/m)
0.276 - 0.280
0.281 - 0.290
0.291 - 0.300
0.301 - 0.310
0.311 - 0.320
0.321 - 0.330
Metres

Fig. 35

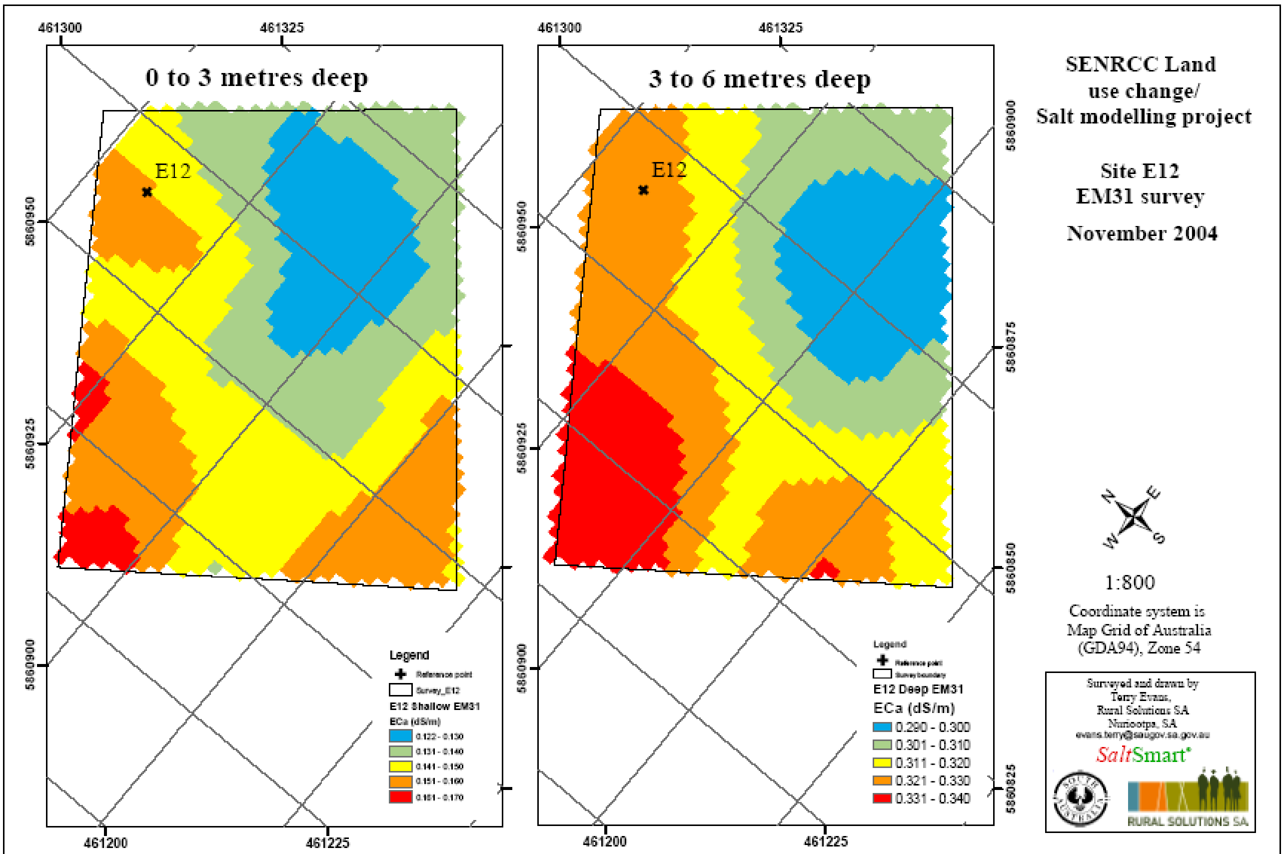
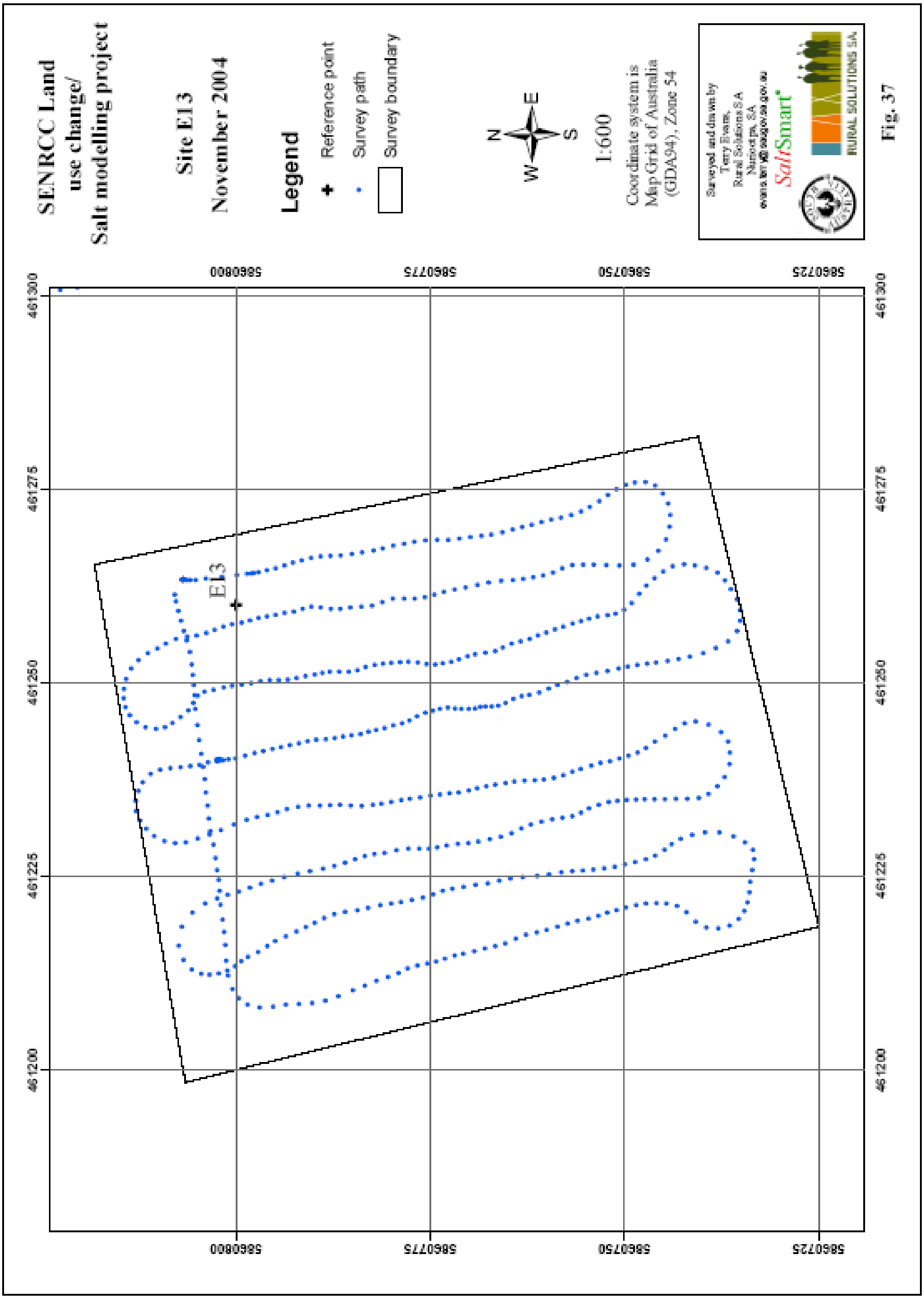

0 to 3 metres deep
3 to 6 metres deep
E12
SENRCC Land use change/ Salt modelling project
Site E12
EM31 survey
November 2004
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
E12 Shallow EM31 ECa (dS/m)
0.122 - 0.130
0.131 - 0.140
0.141 - 0.150
0.151 - 0.160
0.161 - 0.170
E12 Deep EM31 ECa (dS/m)
0.290 - 0.300
0.301 - 0.310
0.311 - 0.320
0.321 - 0.330
0.331 - 0.340
Metres

Fig. 36


SENRCC Land use change/ Salt modelling project
Site E13
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
E13
461300
461275
461250
461225
461200
5860800
5860775
5860750
5860725
Fig. 37

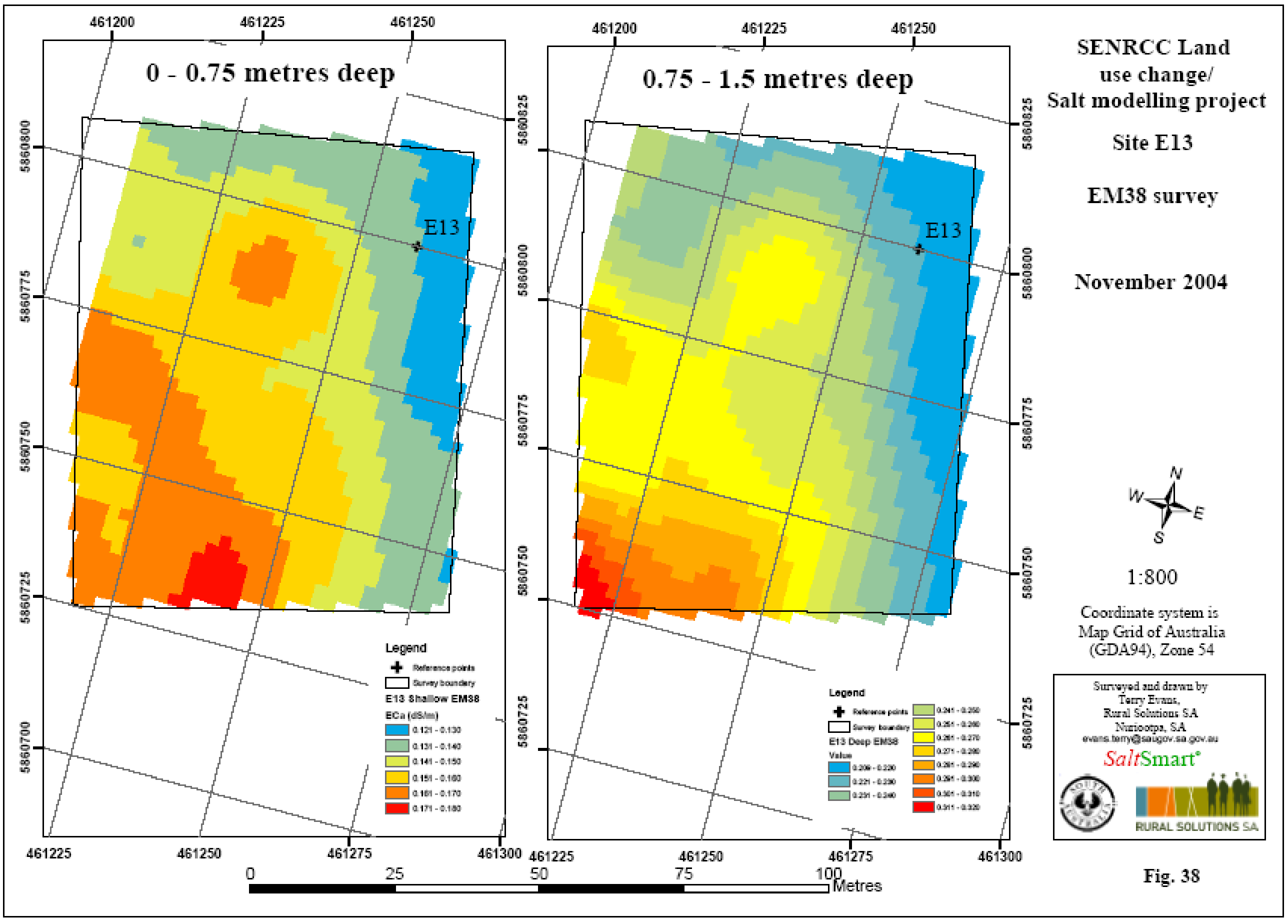

0 - 0.75 metres deep
0.75 - 1.5 metres deep
E13
SENRCC Land use change/ Salt modelling project
Site E13
EM38 survey
November 2004
N
W
E
S
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
Metres

Fig. 38

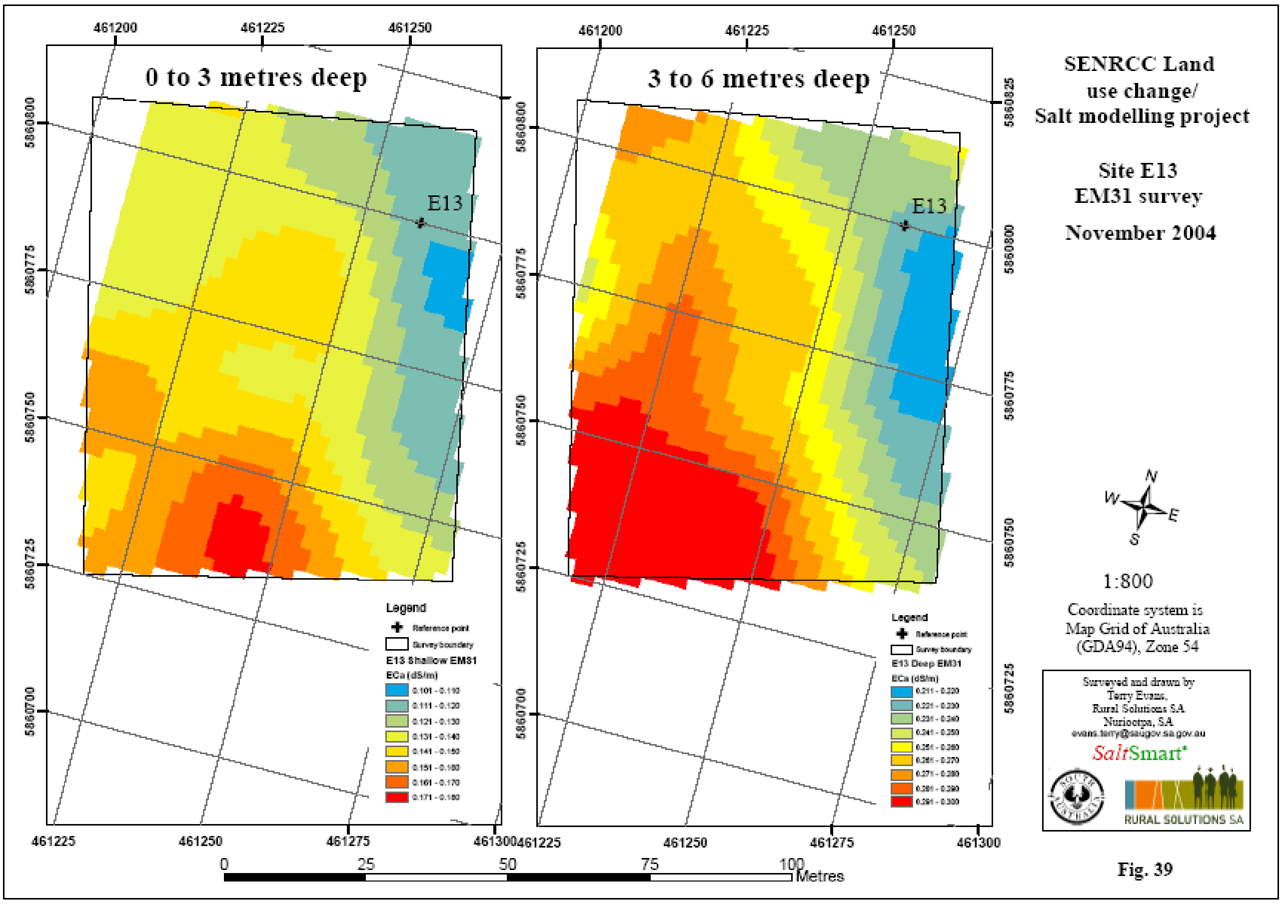
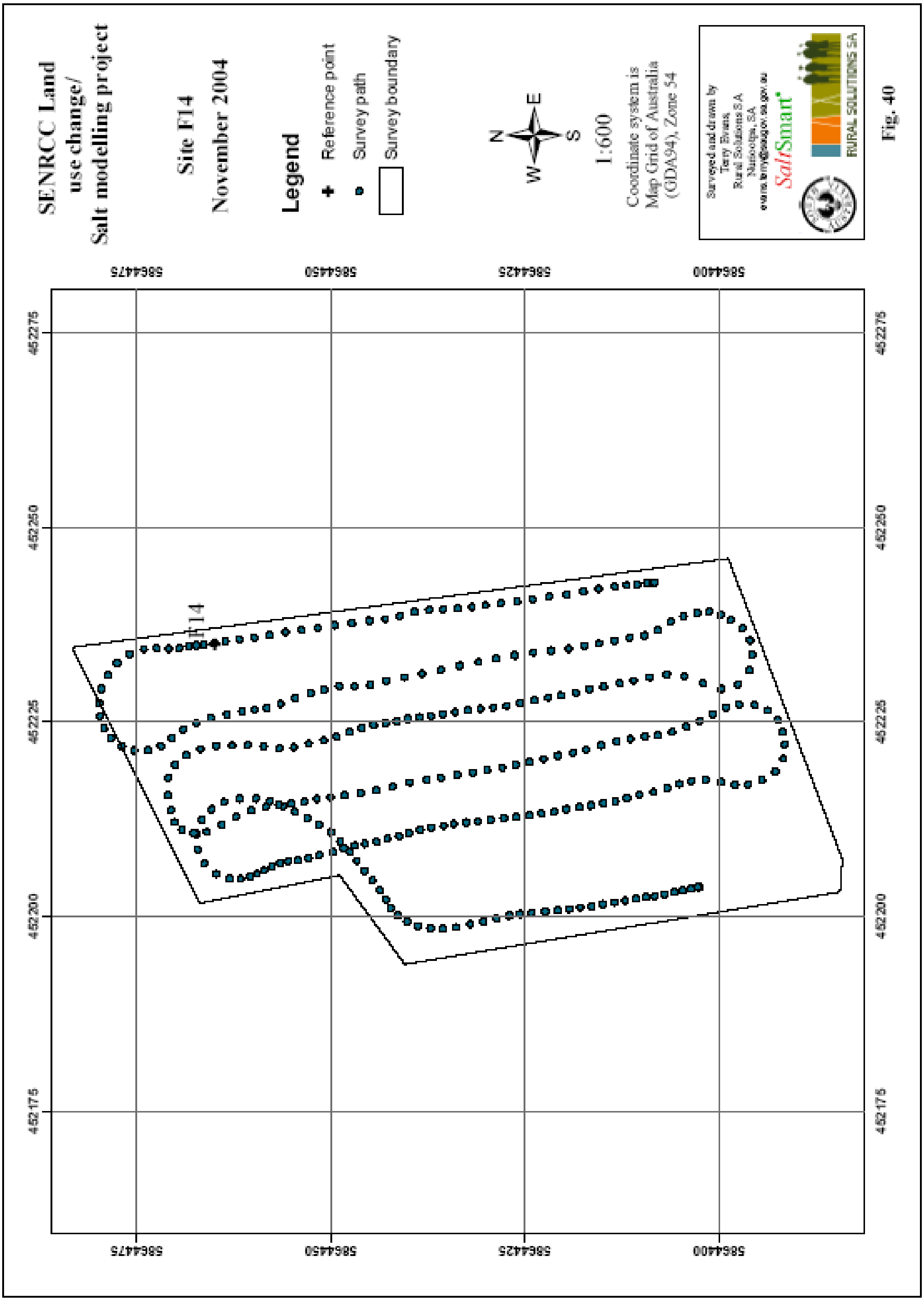

0 to 3 metres deep
3 to 6 metres deep
E13
SENRCC Land use change/ Salt modelling project
Site E13
EM31 survey
November 2004
N
W
E
S
1:800
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
Metres

Fig. 39


SENRCC Land use change/ Salt modelling project
Site F14
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
F14
452275
452250
452225
452200
452175
5864475
5864450
5864425
5864400
Fig. 40

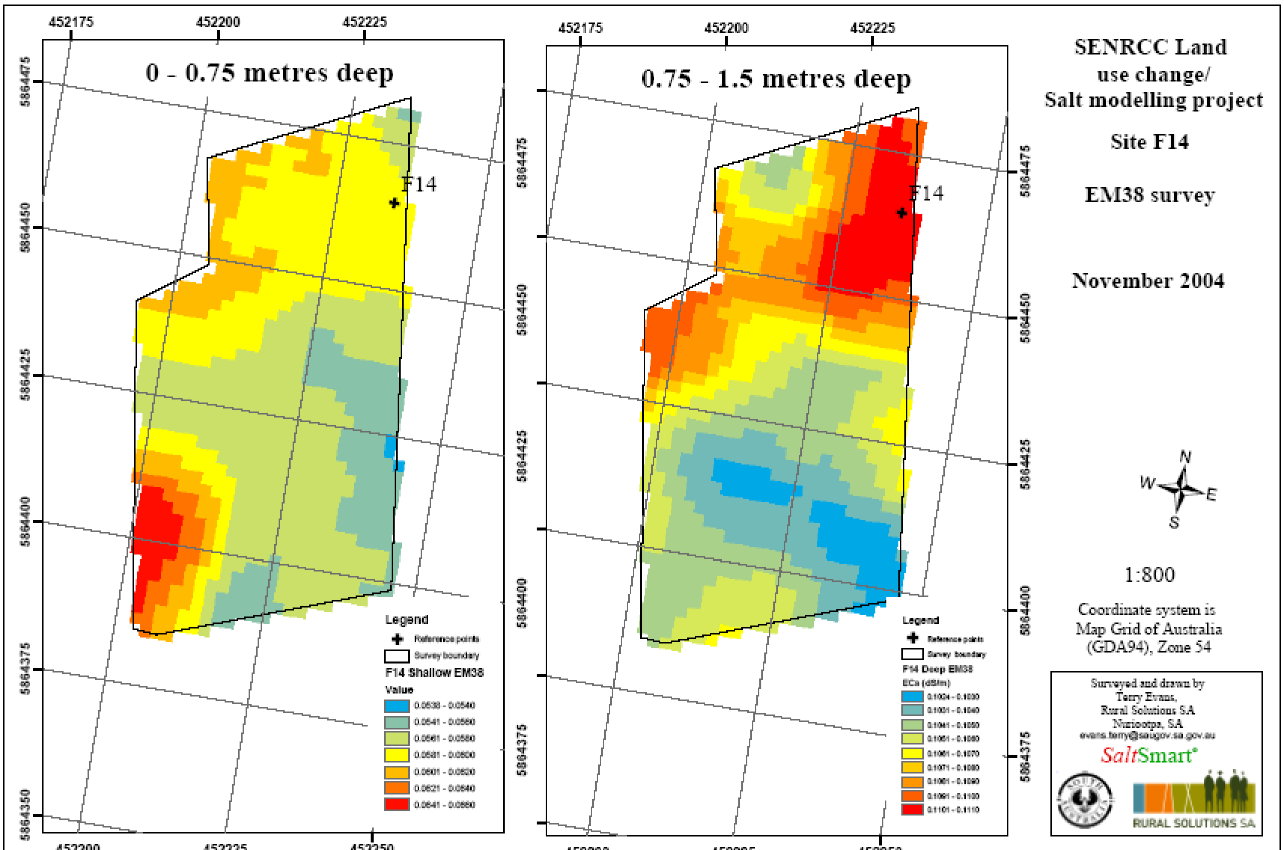

0 - 0.75 metres deep
0.75 - 1.5 metres deep
F14
SENRCC Land
use change/
Salt modelling project
Site F14
EM38 survey
November 2004
1:800
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
F14 Shallow EM38
F14 Deep EM38
Metres

Fig. 41

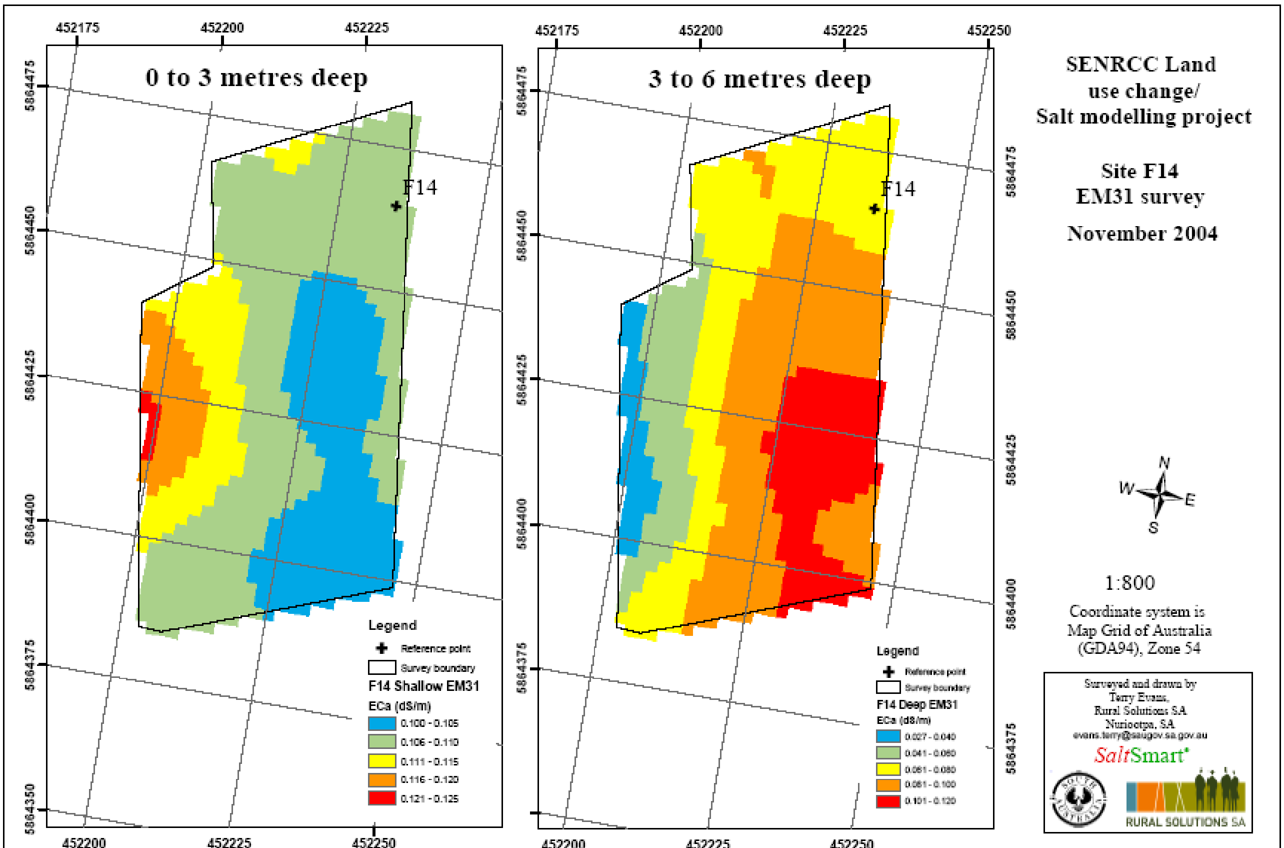
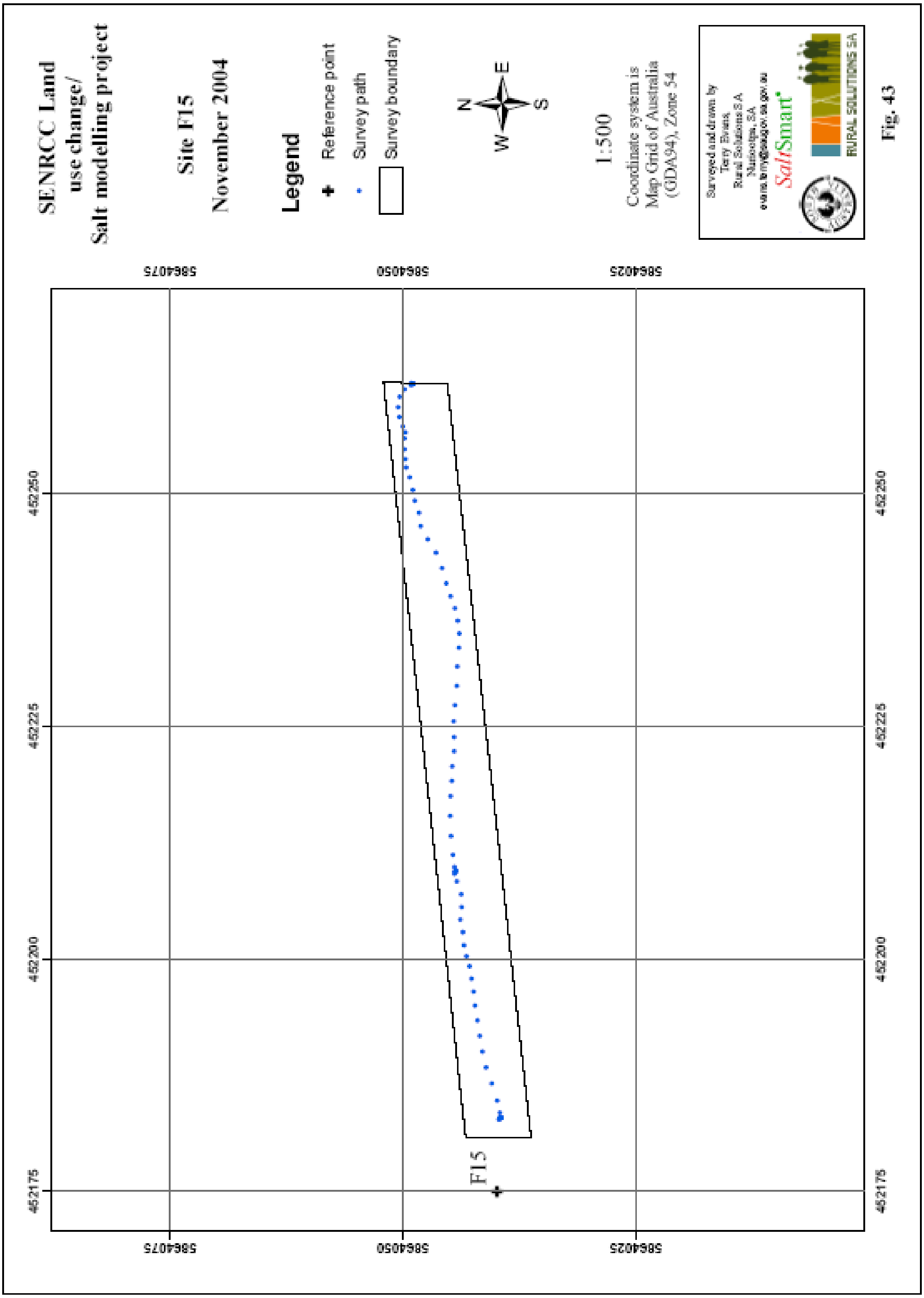

0 to 3 metres deep
3 to 6 metres deep
F14
SENRCC Land
use change/
Salt modelling project
Site F14
EM31 survey
November 2004
1:800
Coordinate system is
Map Grid of Australia
(GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Nuriootpa, SA
SaltSmart
RURAL SOLUTIONS SA
Legend
Reference point
Survey boundary
F14 Shallow EM31
ECa (dS/m)
0.100 - 0.105
0.106 - 0.110
0.111 - 0.115
0.116 - 0.120
0.121 - 0.125
F14 Deep EM31
Metres

Fig. 42


SENRCC Land use change/ Salt modelling project
Site F15
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
Fig. 43
F15
452175
452200
452225
452250
5864025
5864050
5864075

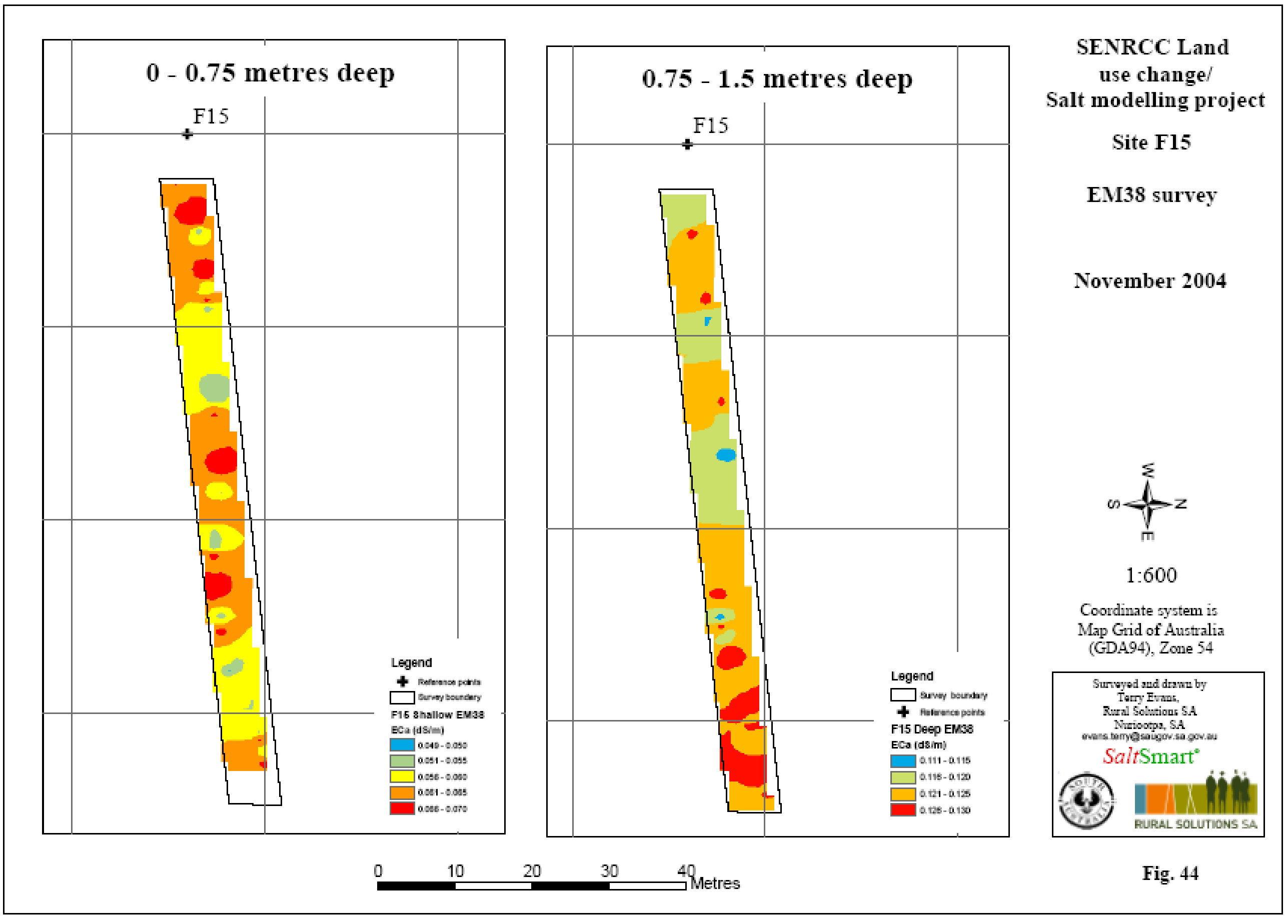
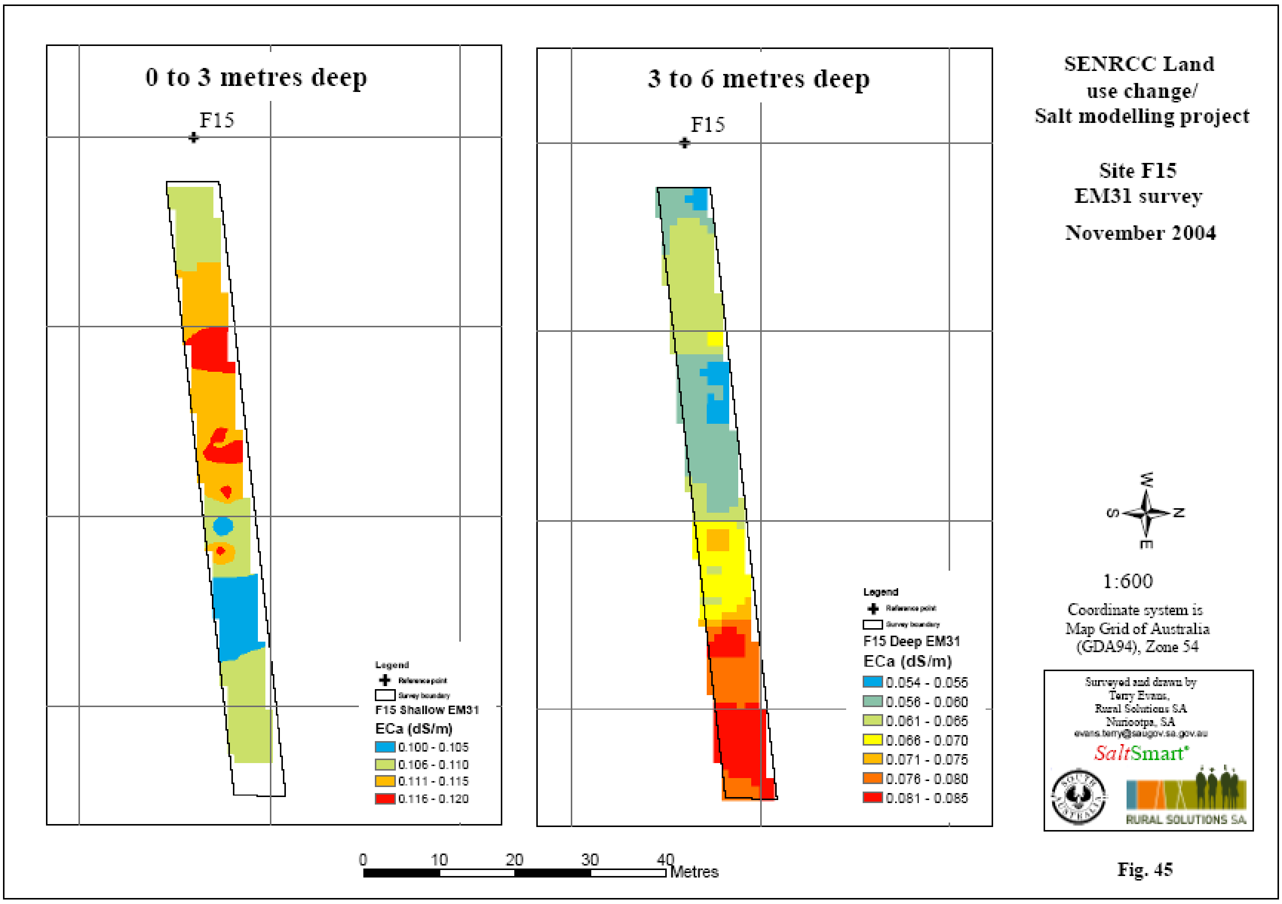

0 - 0.75 metres deep
F15
Legend
Reference points
Survey boundary
F15 Shallow EM38
ECa (dS/m)
0.049 - 0.050
0.051 - 0.055
0.056 - 0.060
0.061 - 0.065
0.066 - 0.070
0.75 - 1.5 metres deep
F15
Legend
Survey boundary
Reference points
F15 Deep EM38
ECa (dS/m)
0.111 - 0.115
0.116 - 0.120
0.121 - 0.125
0.126 - 0.130
0
10
20
30
40
Metres
SENRCC Land use change/ Salt modelling project
Site F15
EM38 survey
November 2004
W
S
N
E
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by
Terry Evans,
Rural Solutions SA
Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

Fig. 44


0 to 3 metres deep
F15
Legend
Reference point
Survey boundary
F15 Shallow EM31
ECa (dS/m)
0.100 - 0.105
0.106 - 0.110
0.111 - 0.115
0.116 - 0.120
3 to 6 metres deep
F15
Legend
Reference point
Survey boundary
F15 Deep EM31
ECa (dS/m)
0.054 - 0.055
0.056 - 0.060
0.061 - 0.065
0.066 - 0.070
0.071 - 0.075
0.076 - 0.080
0.081 - 0.085
0
10
20
30
40
Metres
SENRCC Land use change/ Salt modelling project
Site F15
EM31 survey
November 2004
W
S
N
E
1:600
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by
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Rural Solutions SA
Naracoorte, SA
evans.terry@saugov.sa.gov.au
SaltSmart
RURAL SOLUTIONS SA

Fig. 45

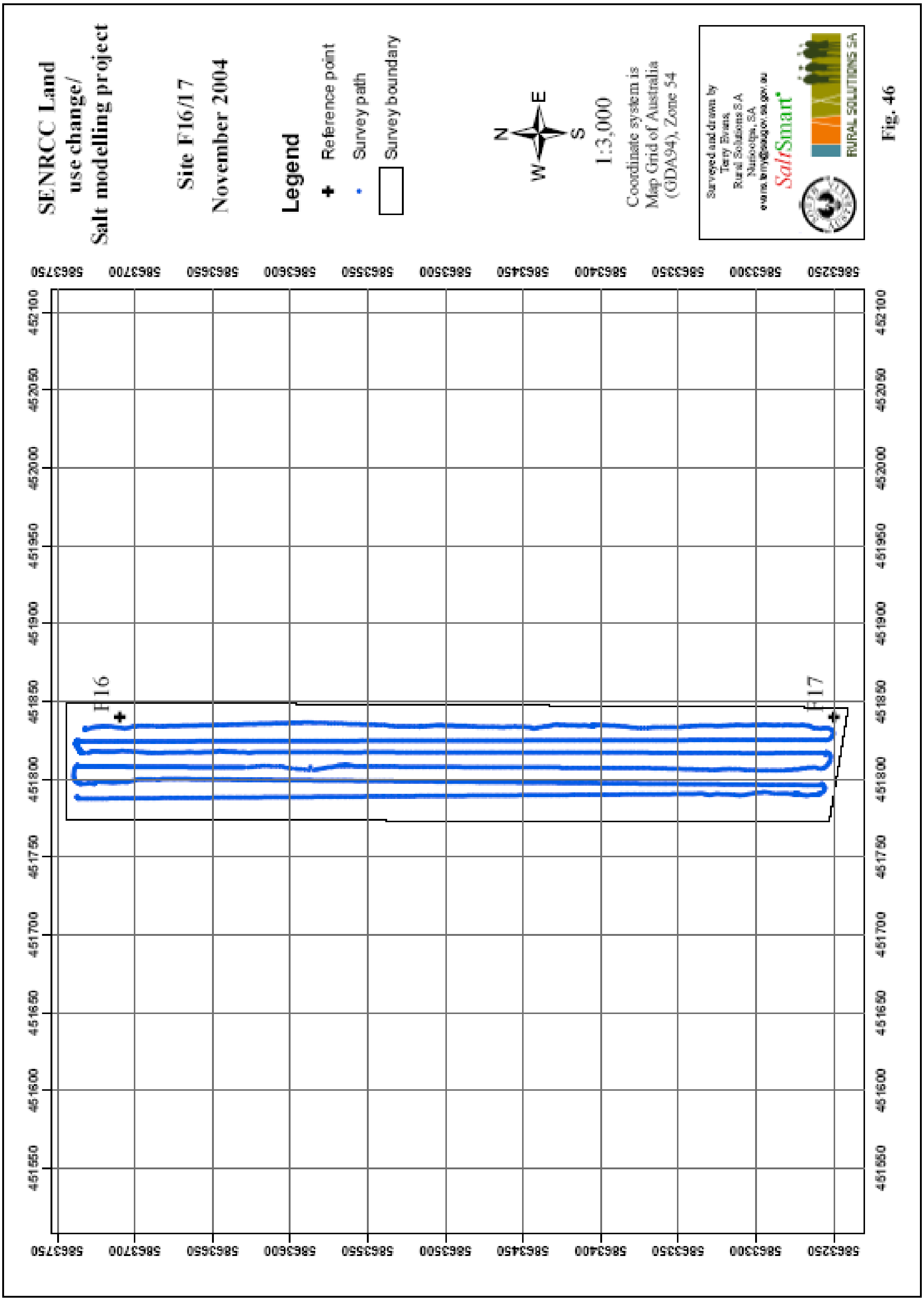

SENRCC Land use change/ Salt modelling project
Site F16/17
November 2004
Legend
Reference point
Survey path
Survey boundary
N
E
S
W
1:3,000
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA
F16
F17

Fig. 46

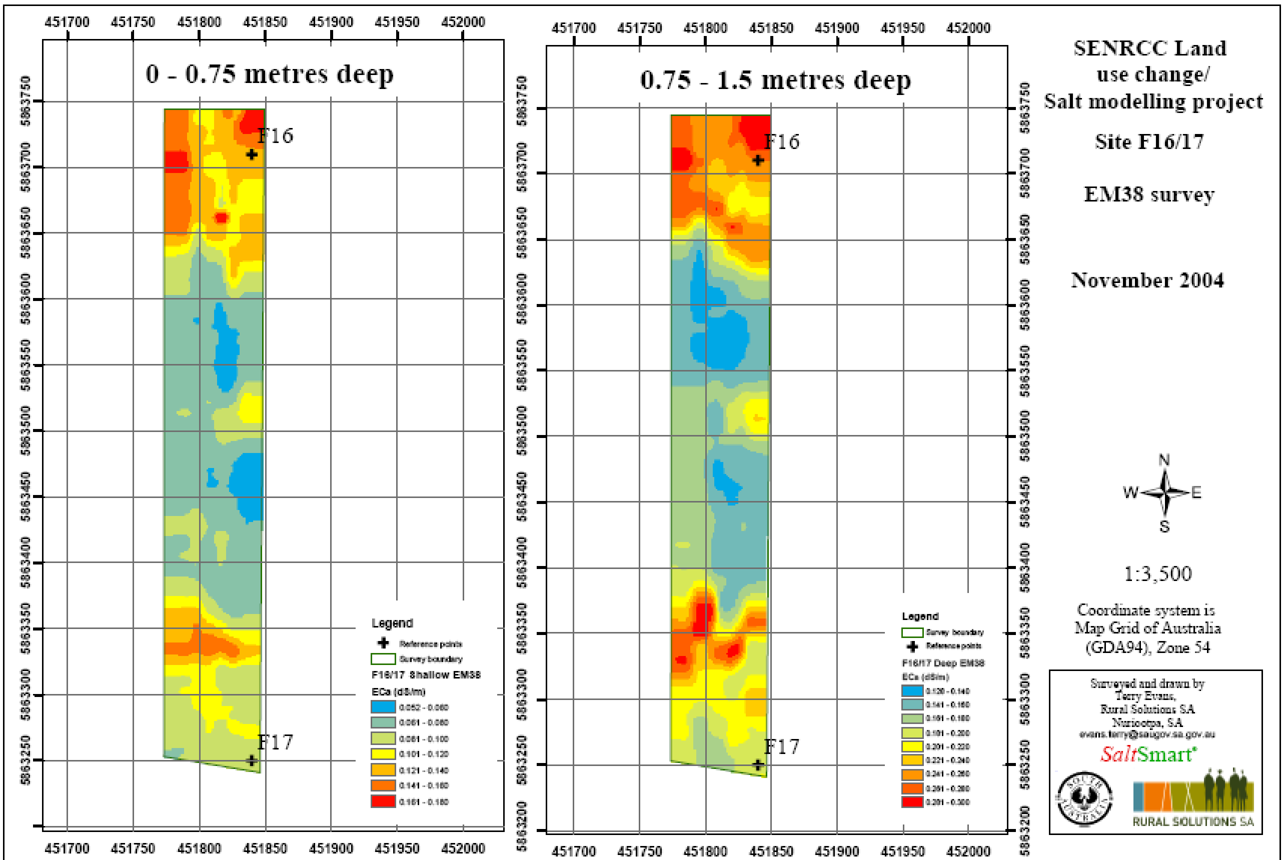

0 - 0.75 metres deep
0.75 - 1.5 metres deep
F16
F17
Legend
Reference points
Survey boundary
F16/17 Shallow EM38
ECa (dS/m)
F16/17 Deep EM38
ECa (dS/m)
0 50 100 150 200 Metres
SENRCC Land use change/ Salt modelling project
Site F16/17
EM38 survey
November 2004
N W E S
1:3,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

Fig. 47

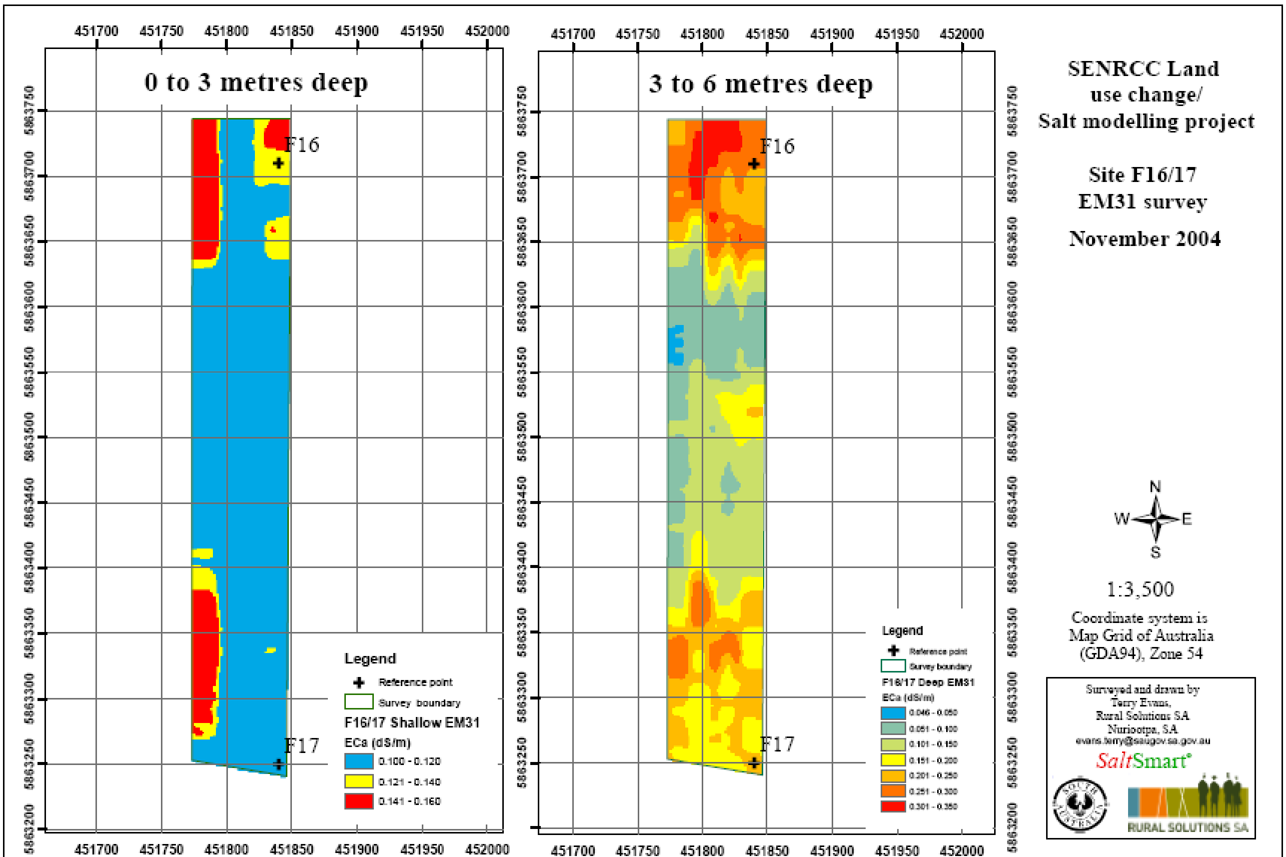
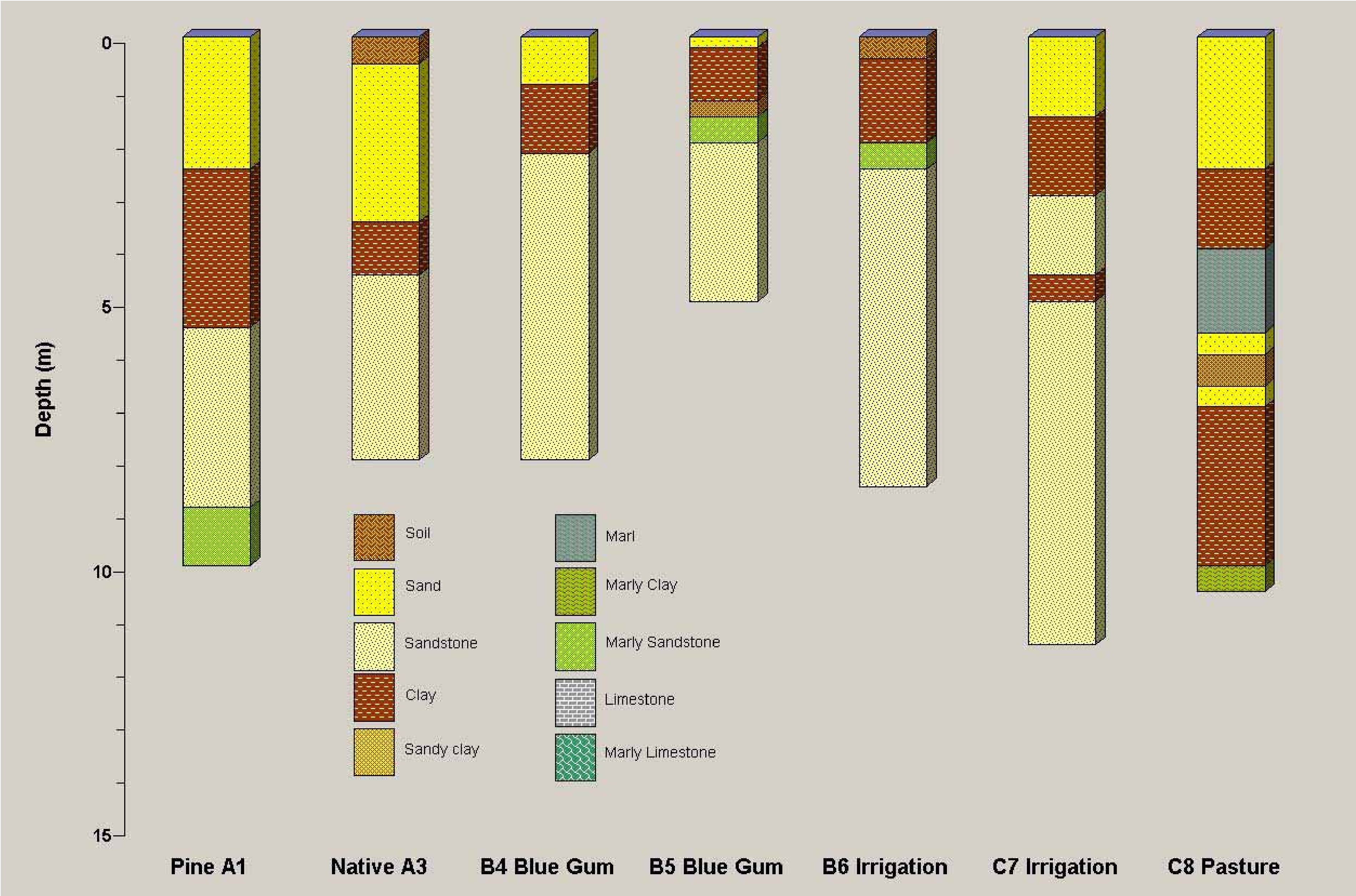

0 to 3 metres deep
3 to 6 metres deep
F16
F17
Legend
Reference point
Survey boundary
F16/17 Shallow EM31
ECa (dS/m)
0.100 - 0.120
0.121 - 0.140
0.141 - 0.160
F16/17 Deep EM31
ECa (dS/m)
0 50 100 150 200 Metres
SENRCC Land use change/ Salt modelling project
Site F16/17
EM31 survey
November 2004
N W E S
1:3,500
Coordinate system is Map Grid of Australia (GDA94), Zone 54
Surveyed and drawn by Terry Evans, Rural Solutions SA Naracoorte, SA
SaltSmart
RURAL SOLUTIONS SA

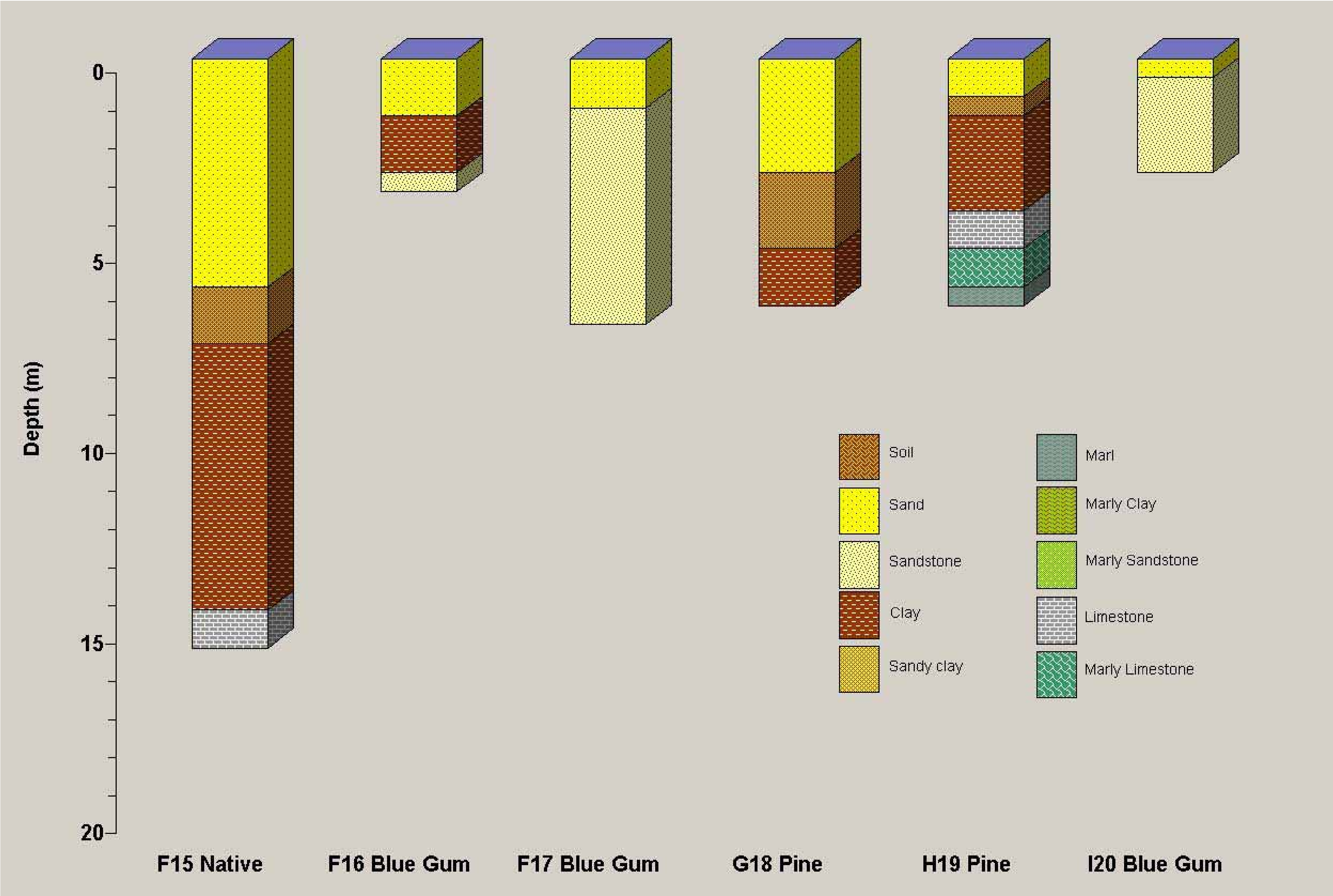
Fig. 48

B. WELL LOGS



Depth (m)
0
5
10
15
Pine A1
Native A3
B4 Blue Gum
B5 Blue Gum
B6 Irrigation
C7 Irrigation
C8 Pasture
Soil
Sand
Sandstone
Clay
Sandy clay
Marl
Marly Clay
Marly Sandstone
Limestone
Marly Limestone

0
5
10
Depth (m)
Soil
Sand
Sandstone
Clay
Sandy clay
Marl
Marly Clay
Marly Sandstone
Limestone
Marly Limestone
D10 Blue Gum
E11 Blue Gum
E12 Irrigation
E13 Pasture
F14A Pasture
F14B Pasture



Depth (m)
0
5
10
15
20
F15 Native
F16 Blue Gum
F17 Blue Gum
G18 Pine
H19 Pine
I20 Blue Gum
Soil
Sand
Sandstone
Clay
Sandy clay
Marl
Marly Clay
Marly Sandstone
Limestone
Marly Limestone

C. WATER USE BY PLANTATIONS IN THE WATTLE RANGE: UPDATED RESULTS FOR 2004–05

Water use by plantations in the Wattle Range: updated results for 2004/05

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9 September 2005

Introduction

This report updates results of plantation water use studies conducted in the lower South East of South Australia in the past year, since the publication of a report on plantation water use in the region by Benyon and Doody (2004).

Up to September 2004, monthly water balances had been measured at five blue gum sites in the Wattle Range and at three other blue gum and seven radiata pine sites in the South East (Benyon and Doody 2004). As part of the LUIWQQ project, water balance measurements were continued at two of the Wattle Range sites to mid 2005 (sites labelled BG2 and BG3 in the Benyon and Doody 2004 report). Data for 2004/05 were also collected from two of the other blue gum sites in the wattle range (sites BG5 and BG6) and at one blue gum and one radiata pine site near Mount Gambier Airport (sites BG7 and RP2). Site characteristics and the methods used to quantify the groundwater balance at these sites were described in detail in the Benyon and Doody (2004) report, which can be down loaded from the internet at http://www.ffp.csiro.au/Downloads/PlantationWaterUse.pdf

Updated water balances for the six sites

Annual rainfall, water use, net change in soil water and net groundwater uptake for the past 3 or 4 years at each site is detailed in Table 1. The maximum depth to groundwater occurring each year is also shown.

The 2004/05 year contained a mixture of weather conditions. Winter of 2004 was very wet, with rainfall across the region in the upper decile. Above-average rainfall occurred from June to mid December 2004. This has been followed by a dry spell of 9 months. Total rainfall for the 12 months from July 2004 to June 2005 was below the long-term mean and, according to the Bureau of Meterology, rainfall across the lower South East for the past 12 months, from September 2004 to August 2005, was in the lowest decile, with a severe rainfall deficit being recorded across much of the region (100-200 mm less than the long-term mean).

Some interesting observations have emerged at site BG2 (LUIWQQ southeast of site D10). Over the past 4 years, maximum depth to the water table (usually occurring in late autumn each year) has increased by almost 1 m. It appears this may have reduced the amount of groundwater uptake. In the first 18 months of monitoring at this site (late spring 2001 to late autumn 2003), annual net groundwater uptake was about 200 mm year^{-1} (Table 1A). More recently, however, net groundwater uptake has been nil in 2003/04, and 88 mm in 2004/05. We had previously hypothesised the low value for 2003/04 was due to high rainfall and below average evaporative demand in that period. This is possibly a contributing factor. However, in the first 5 months of 2005, even though only 78 mm of rain was received, net groundwater use was only 32 mm.

This plot is known to have a heavy, massive clay layer at around 2-2.5 m depth. In the past 4 years, the maximum depth to groundwater has declined from only 2.6 m in autumn 2002 to 3.5 m in autumn 2005. The clay layer might be restricting root penetration to the greater groundwater depth, or restricting upward movement of groundwater to the root zone, resulting in reduced groundwater uptake.

Site BG3, only 300 m away, also has a clay subsoil, but at slightly greater depth, and not as massive as at BG2. At this site, net annual ground water uptake over the past 3 years has varied by only 50 mm from year to year (Table 1B) despite the maximum depth to water table increasing from 2.9 to 3.7 m. At this site, annual total evapotranspiration has always been close to the theoretical point potential evapotranspiration as defined by Wang *et al* (2001), indicating there is little or no restriction to water uptake at this site. It is possible that at sites with medium to heavy textured clay sub-soils, relatively small differences in the density or structure of the clay might have a large effect on the amount of groundwater uptake. In previous research in the Riverina, massive clay subsoils prevented trees accessing groundwater from less than 3 m depth, whereas at locations with lighter textured soils, ground water uptake rates similar to those observed at sites in the South East were recorded (Polglase *et al*. 2002).

As a result of the dry autumn and winter in 2005, groundwater levels at Sites BG2 and BG3 have not exhibited the usual winter rise (Fig. 1). As at 5 September 2005, depth to the watertable was 2.9 m at site BG2 and 3.2 m at site BG3. In the previous 3 years in early September it was at about 0.6 m depth in BG2 and 0.9 m depth in BG3. In early September 2005, there was more than a 200 mm soil water deficit compared with the previous three winters. This is probably largely a reflection of the low total rainfall in the past 12 months, however it might also be partly a result of lowering of the watertable due to groundwater uptake by the extensive area of blue gum plantations in this part of the Wattle Range. At 3 to 5 years old now, most of these plantations have reached canopy closure. Unless there is above-average rainfall in spring 2005, it seems unlikely water tables at sites BG2 and BG3 will rise to the depths they have in winter and spring of the previous three years. If this is the case there might be even greater lowering of watertables over summer 2005/06 and autumn 2006 than has occurred in previous years. It would be worthwhile continuing to monitor evapotranspiration and depth to the water table at sites BG2 and BG3 to observe their responses to the lowered water tables.

Comparing sites BG2 and BG3 with sites BG5 and BG6, maximum depth-to-groundwater has increased at BG2 and BG3 over the past 4 autumns, despite above average rainfall in 2002/03 and 2003/04 (Table 1 A & B), whereas it has displayed no clear trend at BG5 and BG6 (Table 1 C & D). Water use at BG5 has increased each year over the past 3 years from 853 mm in 2002/03 to 957 mm in 2004/05. The reason for this is not known. Site BG5 used approximately 100 mm more groundwater in 2004/05 than it did in either of the previous 2 years. This is partly a result of higher total evapotranspiration and partly a result of lower rainfall. Annual water use of BG6 continues to be determined largely by rainfall. Comparison of rainfall, annual evapotranspiration and net changes in soil water for each of the past 3 years suggest there might be a small amount of ground water recharge at this site; however it is not statistically significantly different from zero.

Despite having depth-to-groundwater of approximately 6 m, the radiata pine site (RP2) near Mount Gambier Airport has the highest evapotranspiration observed in the region (Table 1F). This site also has the longest period of measurement, with 5 years of water use and 4 years of soil water data now available. Rainfall during these 5 years ranged from slightly below average in 2004/05 to 15% above average in 2003/04. Annual evapotranspiration increased from approximately 1250 mm year^{-1} in the first 2 years of measurements to around 1450 mm year^{-1} in the most recent 2 years. Net groundwater uptake for the past 3 years has averaged 660 mm year^{-1}. The very high rate of evapotranspiration at this site is probably partly because it is less than 40 m from a plantation edge and therefore receives advected energy from grassland areas to the south. Annual ET in a blue gum plantation nearby is also high, averaging about 1130 mm year^{-1} over the past 4 years, with net groundwater uptake averaging 370 mm year^{-1} from a watertable at about 4.5 m depth (Table 1E). There has been little variation between years in the maximum depth to ground water at these two sites. It rose by about 0.6 m following the wet winter of 2004 but is currently about 0.3 m deeper than it would normally be in early September.

An earlier conclusion that current annual stem growth rates were only moderately-well correlated with current annual transpiration has not changed with the additional data from the six sites. For the five blue gums sites for which measurements have continued during 2004/05, between-site variation in current annual stem volume growth accounted for only 40% of the between-site variation in current annual transpiration (Fig. 2). Sites BG5 and BG6 illustrate this point well. For the period June 2004 to May 2005, transpiration at BG5 totalled 675 mm and stem volume growth was 25 m^3 ha^{-1}. In contrast, at BG6, a substantially higher current rate of stem growth (33 m^3 ha^{-1} year^{-1}) would suggest a higher rate of transpiration, yet observed transpiration at BG6 in the same 12 month period was actually substantially lower (515 mm). For each m^3 of stem volume growth, BG5 transpired 27 mm, compared to only 16 mm for BG6. Values for the other four sites for the same period were 25 mm m^{-3} at BG2 compared to only 15 mm m^{-3} at BG3 and 22 mm m^{-3} at both BG7 and RP2.

Conclusions and recommendations

There is circumstantial evidence that at sites BG2 and BG3 in the Wattle Range, a concentration of blue gum plantations in the order of several thousand hectares, which are now mostly 3 to 5 years old, may have contributed to lowering of the watertable. The maximum depth to the water table each year at these sites has reduced by almost 1 m over the past 4 years. At one of the sites (BG2) lowering of the watertable to below a dense clay layer might have reduced net groundwater uptake in the past 2 years. Continuation of plantation water use measurements at this site, and the nearby site BG3, until at least winter 2006 would provide important data on the effect of lowering the watertable on rates of groundwater uptake.

References

Benyon RG, Doody TM (2004) Water Use by Tree Plantations in South East South Australia. (CSIRO Forestry and Forest Products Technical Report Number 148: Mount Gambier)

Polglase PJ, Theiveyanathan S, Benyon RG, Falkiner RA (2002) Irrigation management and groundwater uptake in young tree plantations growing over high watertables. (Rural Industries Research and Development Corporation: Canberra)

Wang QJ, Chiew FHS, McConachy FLN, James R, de Hoedt GC, Wright WJ (2001) Climatic atlas of Australia: evapotranspiration (Bureau of Meteorology: Australia)

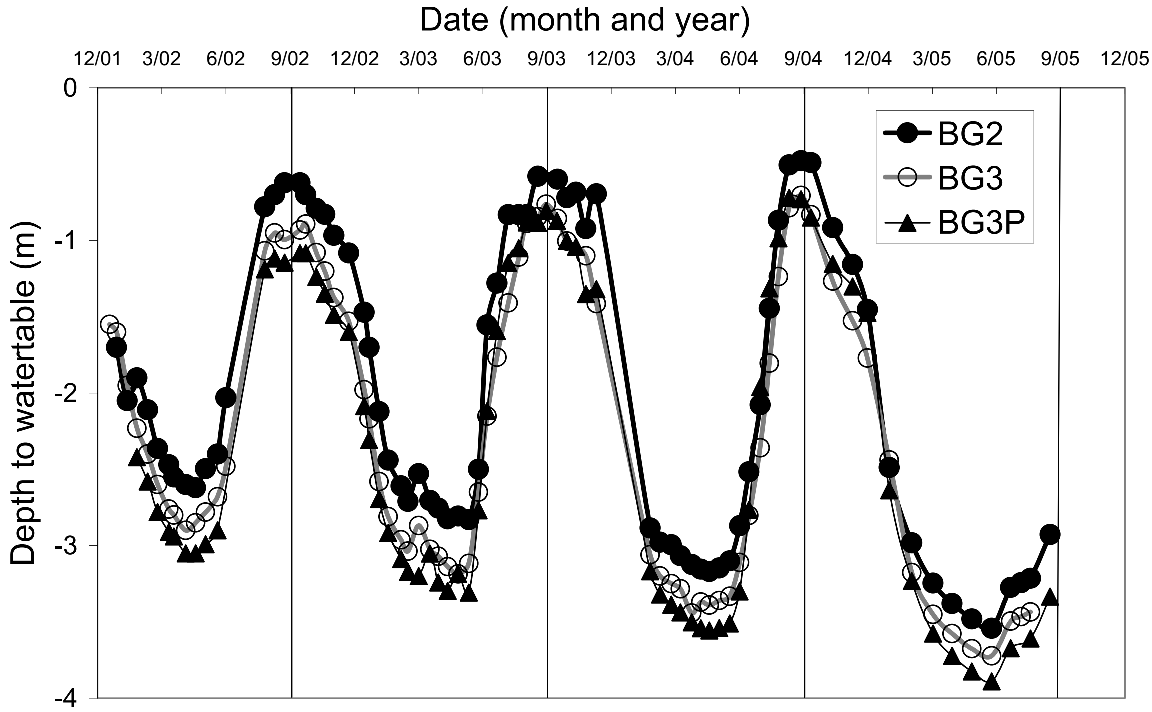

Figure 1. Depth to the water table at McCourt's tree farm at sites BG2, BG3 and BG3 pasture.

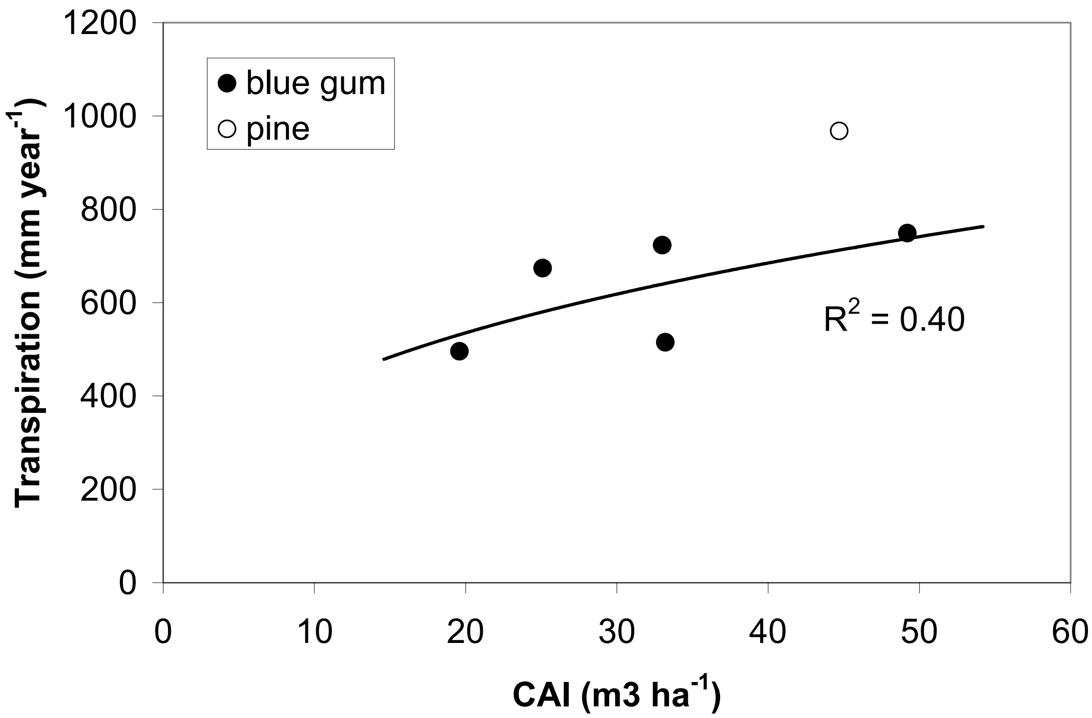

Figure 2. The relationship between annual transpiration and stem volume growth for the 12 months from June 2004 to May 2005.

Table 1. Annual water balances at six plantation sites in the South East. Site descriptions and methods used to determine net water balances can be found in a report by Benyon and Doody (2004), which can be viewed on the internet at http://www.ffp.csiro.au/Downloads/PlantationWaterUse.pdf. In the table, GWU indicates net groundwater uptake.

A. BG2 (LUIWQQ southeast of site D10)

Year	Rain	Water use	Soil water change	GWU	Max DTW (m)
2002	585	846			2.6
2002/03	755	908	+35	188	2.8
2003/04	765	868	-110	0	3.2
2004/05	645	763	-30	88	3.5

All data in mm $year^{-1}$

B. BG3 (LUIWQQ south of site D10)

Year	Rain	Water use	Soil water change	GWU	Max DTW (m)
2002	574	1138			2.9
2002/03	740	1128	+37	425	3.2
2003/04	740	1204	-92	372	3.4
2004/05	628	1105	-55	422	3.7

All data in mm $year^{-1}$

C. BG5 (LUIWQQ site F16)

Year	Rain	Water use	Soil water change	GWU	Max DTW (m)
2002/03	712	853	+70	211	3.5
2003/04	734	930	-30	166	3.7
2004/05	658	957	-10	289	3.6

All data in mm $year^{-1}$

D. BG6 (LUIWQQ site F17)

Year	Rain	Water use	Soil water change	WU>6m	Max DTW (m)
2002/03	715	683	+21	(-11)	11.0
2003/04	734	757	-29	(-6)	11.0
2004/05	658	642	+6	(-10)	11.1

All data in mm $year^{-1}$

E. BG7, Airport Road Mt Gambier

Year	Rain	Water use	Soil water change	GWU	Max DTW (m)
2001/02	772	1016	+2	246	4.6
2002/03	791	1286	+40	535	4.7
2003/04	835	1128	-14	279	4.7
2004/05	711	1142	-18	413	4.5

All data in mm $year^{-1}$

F. RP2, Airport Road Mt Gambier

Year	Rain	Water use	Soil water change	GWU	Max DTW (m)
2000/01	780	1288	?		6.1
2001/02	791	1219	0	428	6.3
2002/03	790	1388	+37	635	6.4
2003/04	835	1501	+15	681	6.4
2004/05	701	1452	-80	671	6.2

All data in mm $year^{-1}$

D. LAND-USE IMPACTS ON WATER QUALITY AND QUANTITY — IDENTIFICATION OF WETLANDS WITHIN THE STUDY AREA

Land Use Impacts on Water Quality and Quantity

Identification of Wetlands Within the Study Area

Wetland mapping undertaken by the Department for Environment and Heritage (DEH) for the Lower South East Wetland Inventory (LSEWI) indicates that many wetlands occur within the study area of the Land Use Impacts on Water Quality and Quantity (LUIWQQ) study (Fig. 1). Wetland mapping is incomplete at the time of writing and further work may alter the extent and distribution of wetlands within the study area. Field surveys of a limited number of wetlands were undertaken as part of the LSEWI. Wetlands determined *a priori* as being in good condition were surveyed preferentially. Within the LUIWQQ study area three wetlands were surveyed for the LSEWI; Sheepwash Swamp, SEWCDB Swamp and Oschar Swamp (Fig. 1). The data collected for each survey is held in the South Australian Wetland Inventory Database (SAWID)managed by DEH. A selection of the survey data for each wetland is presented here. The overall condition of wetlands surveyed for the LSEWI was assigned as pristine, intact, moderate, degraded, severely degraded or completely degraded.

Sheepwash Swamp (see Fig. 2)

Conductivity:	739 μS cm^{-1} (14/10/2004)
Water regime:	semi-permanent
Water sources:	drain water, groundwater, local runoff
Overall condition:	intact
Comments:	Relatively large (32.3 ha) wetland that fills via surface flow within Baker Range Drain. When full the wetland supports many waterfowl. Threatened flora also occurs. At the end of the dry season the area of surface water shrinks to approximately 100 m in diameter. This semi-permanent core area is highly likely to be groundwater dependent and provides important refuge habitat for strictly aquatic organisms.

SEWCDB Swamp (see Fig. 3a)

Conductivity:	530 μS cm^{-1} (8/11/2004)
Water regime:	seasonal
Water sources:	drain water, groundwater, local runoff
Overall condition:	intact
Comments:	Small (3.1 ha) wetland immediately adjacent to the Baker Range Drain. Hydrological restoration works completed in late 2004 permit water to flow from the drain into the wetland but prevent flow in the reverse direction.

Oschar Swamp (see Figs. 3b and 4)

Conductivity:	515 μS cm^{-1} (14/10/2004)
Water regime:	seasonal
Water sources:	drain water, groundwater, local runoff
Overall condition:	intact
Comments:	Medium sized (12.8 ha) wetland immediately adjacent to the Baker Range Drain. Hydrological restoration works completed in late 2004 permit water to flow from the drain into the wetland but prevent flow in the reverse direction.

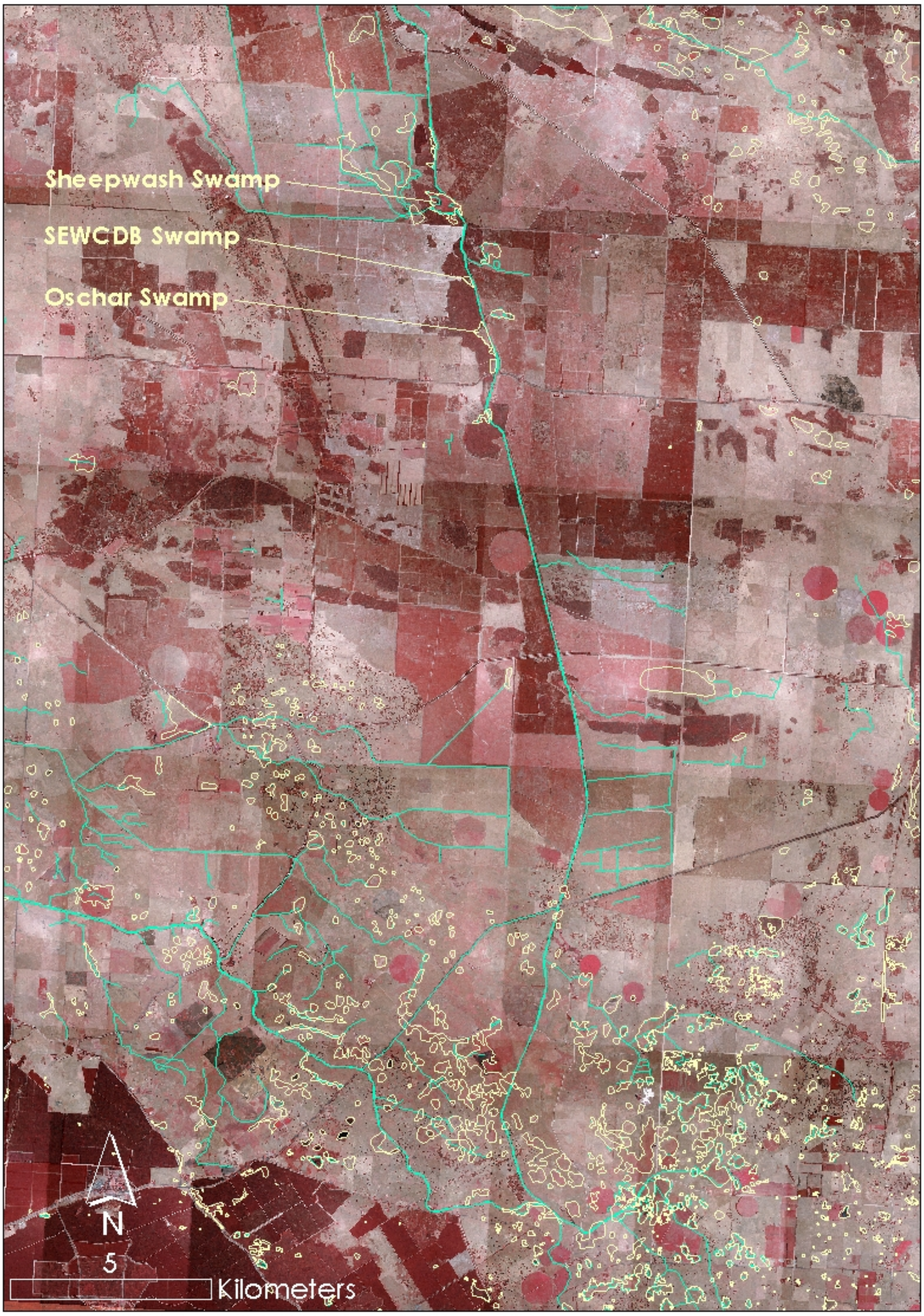

Fig. 1. Infra-red aerial photography, mapped wetlands (cream polygons) and drains (aqua lines). The three wetlands within the study area that were surveyed for the Lower South East Wetland Inventory are labelled.

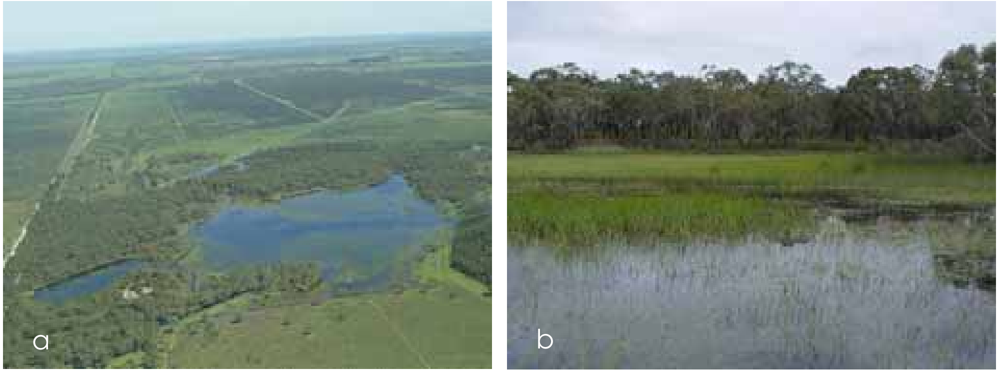

Fig. 2. (a) Aerial view of Sheepwash Swamp when full, 1 October 2004 and (b) southern basin of Sheepwash Swamp, 14 October 2004.

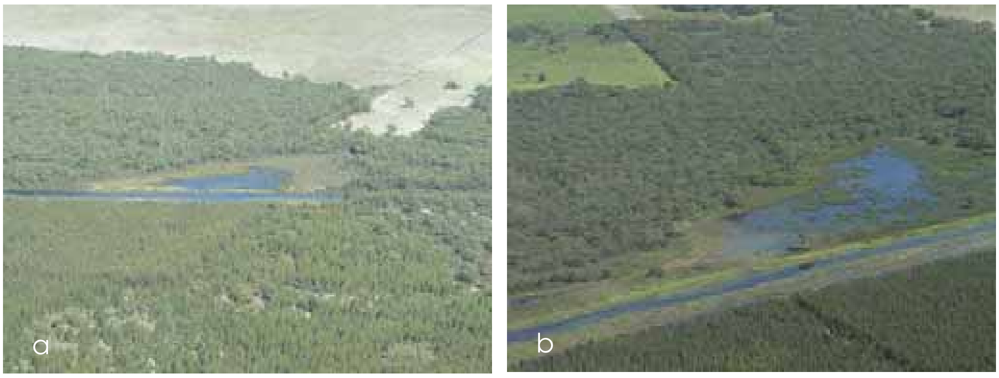

Fig. 3. Aerial views of (a) SEWCDB Swamp and (b) Oschar Swamp, 1 October 2004.

Fig. 4. (a) Flow control structure at Oschar Swamp completed December 2004 that permits flow from Baker Range Drain into wetland (foreground) but prevents flow in the reverse direction, and (b) view of Oschar Swamp, 14 October 2004.

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E. SALT ACCUMULATION AND WATER BALANCE UNDER DIFFERENT LAND USE IN THE BAKERS RANGE AREA

Salt Accumulation and Water Balance Under Different Land Use in Bakers Range Area

Leaney, F.W., Mustafa, S. and Lawson, J.
CSIRO Science Report 05/06

Government of South Australia
Department of Water, Land and Biodiversity Conservation

SENRCC
South East Natural Resource Consultative Committee

ForestrySA

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Cover Photograph:

Designed by Saad Mustafa using photos from the study area.

Salt Accumulation and Groundwater Uptake by Pine and Bluegum Forests in Bakers Range

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Executive Summary

The results from chloride profiles of the unsaturated zone indicate that, on average, recharge under native vegetation is probably less than 10 mm yr^{-1}. However, in some areas with native vegetation where the watertable is shallow, there may be lengthy periods where there is net uptake of groundwater rather than net recharge. Clearing native vegetation and replacing it with pasture results in recharge rates increasing markedly. In some areas, the estimated rate of recharge under pasture is ~350 mm yr^{-1}. The increased recharge flushes salt present in the unsaturated zone into the groundwater, thereby flushing the unsaturated zone of most of its salt.

Results from this study show that if pine or bluegum forests subsequently develop on cleared land, there is clear evidence of renewed salt/chloride accumulation in the unsaturated zone. The amount of accumulated salt far exceeds that accountable from rainfall alone and therefore must come from another source. The obvious source is salt present in groundwater. The mechanism for salt concentration is trees extracting water from the capillary zone and leaving the salt behind. Groundwater is then induced to move vertically upwards as the soilwater suction in the capillary zone increases.

The amount of salt accumulation under Pine and Bluegum forests suggest that these trees can be significant users of groundwater. This study has shown that pine trees are able to extract water from the groundwater capillary zone in areas where the groundwater depth is at least ten metres. The Bluegum trees studied were shown to access groundwater to depths of at least four metres. At the sites studied, the difference in the groundwater accessibility between Pines and Bluegums is primarily associated with the age of the forest. In addition to the forest age, however, groundwater uptake is also strongly related to the depth of the watertable. The average groundwater uptake estimates in this report are based on the amount of chloride in the unsaturated zone relative to that in the groundwater for the life of the Pine or Bluegum forest. Groundwater uptake for both Pine and Bluegum can exceed 500 mm yr^{-1} in areas where the watertable is less than 5 metres deep.

Despite the salt accumulation observed in the unsaturated zone of these forests, there is evidence from this study that watertable fluctuation and fallow periods for tree rotation can result in significant flushing of salt from the unsaturated zone into the groundwater. As a result, the chloride accumulation method used in this study may result in considerable underestimation of groundwater uptake by trees.

The estimates of groundwater uptake for Pine and Bluegum sites in this study agree well with estimates presented over the last few years for the same sites using water balance/sap flow methods. This provides additional confidence in the use of both methods, particularly because the two methodologies used are entirely independent.

Although groundwater uptake by trees is the norm rather than the exception in this area, the presence of heavy clay or hard impermeable layers in the unsaturated zone may significantly reduce or even stop groundwater uptake by the trees. The results from this study confirmed little or no groundwater uptake at two sites where such layers were present.

Recent Bluegum forestry tends to have rotations averaging about 14 years and consisting of approximately 12 years growth and 2 years fallow. This being the case, accumulation of salt is likely to take place for maybe 9-10 out of every 14 years with at least partial flushing of salt during the remaining years. Hence, it is likely that the concentration of salt in the unsaturated zone soilwater will cycle from high to lower concentrations. The shallow

groundwater will also cycle from high to low salinity but out of phase with that of the unsaturated zone.

However, in addition to the salinity cycling, there will also be a longer term gradual salinity increase in both the shallow groundwater and in the unsaturated zone soilwater. This is the result of the overall net loss of water via transpiration from the unconfined/shallow groundwater system. The net water loss in these areas will also be reflected in lowering watertable until a new steady state situation is reached with the surrounding land use and lateral aquifer flow.

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1. Introduction

1.1. Background

Concerns have been expressed over the potential for land use changes, such as rapid expansion of large scale forestry plantations, increased irrigation, more widespread planting of deeper rooted perennials in agriculture, or building of high water -using processing facilities to reduce drain flows or watertable levels in the lower South East, particularly in the Wattle Range. These developments might adversely affect water dependent ecosystems (eg wetlands) and other existing water users. It is felt that urgent action is required to quantify potential impacts of land use change in the Wattle Range area, to minimise the risk of wetlands becoming degraded due to reduced water availability.

An associated issue, the potential for accumulation of salt under some land uses such as plantations and irrigated crops, has also been flagged as a risk to water quality and wetland health. Salt accumulation in the root zone might also pose a risk to the health of the plantations and crops themselves.

1.2. Study Areas

For the salt accumulation study two regional areas within the lower South East of South Australia were selected (Figure 1). Three study areas are located to the east and south east of the township of Nangwarry; along with another three close to the Bakers Range drain which is situated about 25 kilometres west of the township of Penola. The study areas cover different types of land use, including native vegetation, dryland pasture, irrigated pasture, Pine and Bluegum plantations.

The study area has been split across two areas some distance apart for two reasons:

- The need to study the potential salt accumulation located under Pine trees. While extensive Bluegum forests exist in the main study area of Bakers Range Drain, no extensive radiata Pine forest exists. It was felt that by studying salt accumulation in areas with a long history of Pine tree history, better representative values would be gained.
- A spatial dimension is added to the project by studying two areas with similar geology and depth to water characteristics. If it is possible to make a comparison between the two areas then the results can be inferred over a greater distance.

A second stage was added to the project with three extra study areas cored for examination. These study areas were located in Pine forests near Penola and Mount Gambier along with a Bluegum site near Beachport. All three had low fluctuating watertables and seemed ideal to study the salt load at each.

In addition, a study area previously cored in the Nangwarry part of the program had two additional wells drilled to allow future dating of the groundwater at three different depths (also utilizing the original piezometer as a shallow part of the watertable). Annual rainfall, as recorded at the Penola Post Office, has varied from ~410 to ~850 mm yr^{-1} since 1970 with an average of 660 mm yr^{-1} (Figure 2). Rainfall for the study areas is winter dominant. The depth to the unconfined watertable aquifer in the wells drilled as part of the program ranged from a little over 3 metres to over 16 metres on the top of one dune (Figure 3). The water levels quoted are the drilling values recorded in summer time. All wells drilled as part of this program intersected the sandstone of the Bridgewater Formation, which while hydraulically connected to the deeper Gambier Limestone, may exhibit different transmissivities and hydraulic conductivities. Some water levels were actually contained within the clay layer and moved significantly upwards after being cut.

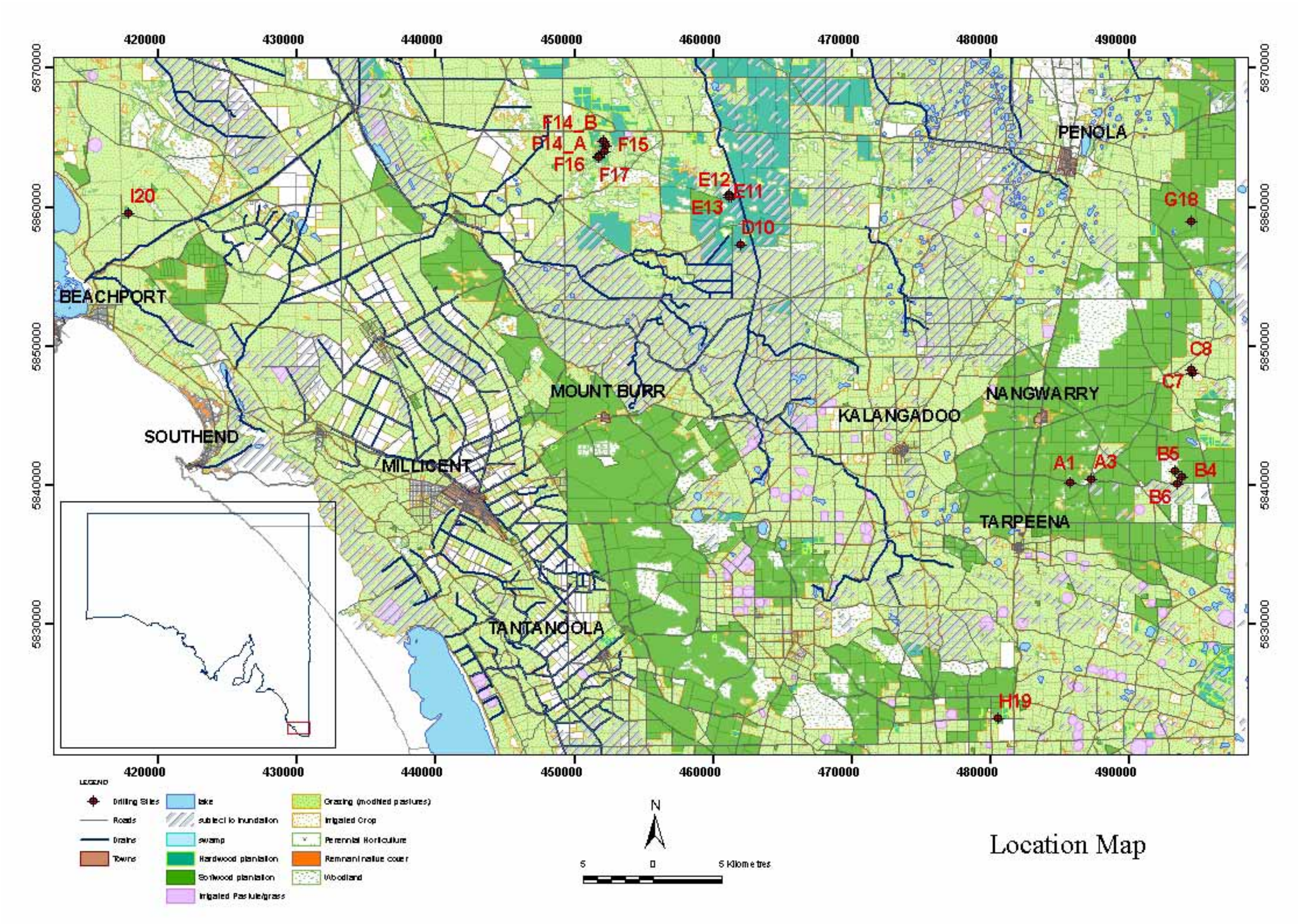

Figure 1. Site map showing the location of the study areas and sites at each.

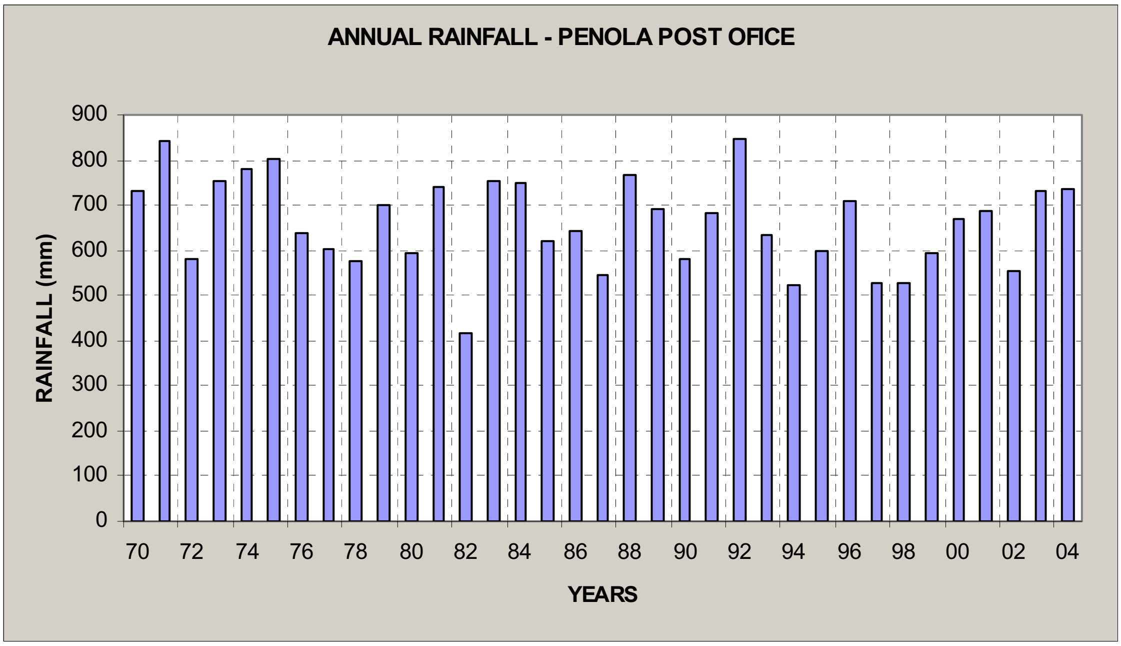

Figure 2. Annual rainfall recorded at Penola post office since 1970

Historically, the interest for the establishment of softwood plantations in the South East of South Australia began as early as 1903, because of extensive areas of suitable land. Early planting encountered problems, which were slowly overcome. Between 1926 and 1937 the provision of funds at low interest rates encouraged about 20,200 ha to be planted in this period. During this period also saw a number of private companies become involved in the industry (Vear, 1975).

Native vegetation for the Nangwarry study was predominantly Manna-gum (*Eucalyptus viminalis*), damp woodland, brown stringybark (*Eucalyptus baxteri*), sandy heath woodland, Hill Gum, and intermittent swamp fringed by Swamp Gum (*Eucalyptus ovata*), diverse heathy understorey or prickly tea-tree thickets. The Baker Range study area was predominately Rough-barked Manna-gum/Swamp Gum, wet heath and open-heathy wetland or dense wetland habitat (prickly tea-tree), brown stringybark and Hill Gums on the sandy rises, with pockets of Red_gum and damp woodland (Mark Bachmann, Perss Comm. 2005)

In the Nangwarry area at study site A, scrub land was cleared in 1926 with first rotation of Pine following, and at study site B, heathy scrub was cleared prior to 1968 and Pine was planted on the site. At the present time 70% to 80% of the Hundred of Nangwarry is planted with Pine forest. Land use in the Bakers Range area has changed considerably over the past few years with the advent of the Bluegum industry. The main species being grown are (Eucalyptus globulus). More detailed histories of the land use changes at each of the sites are given later in this report

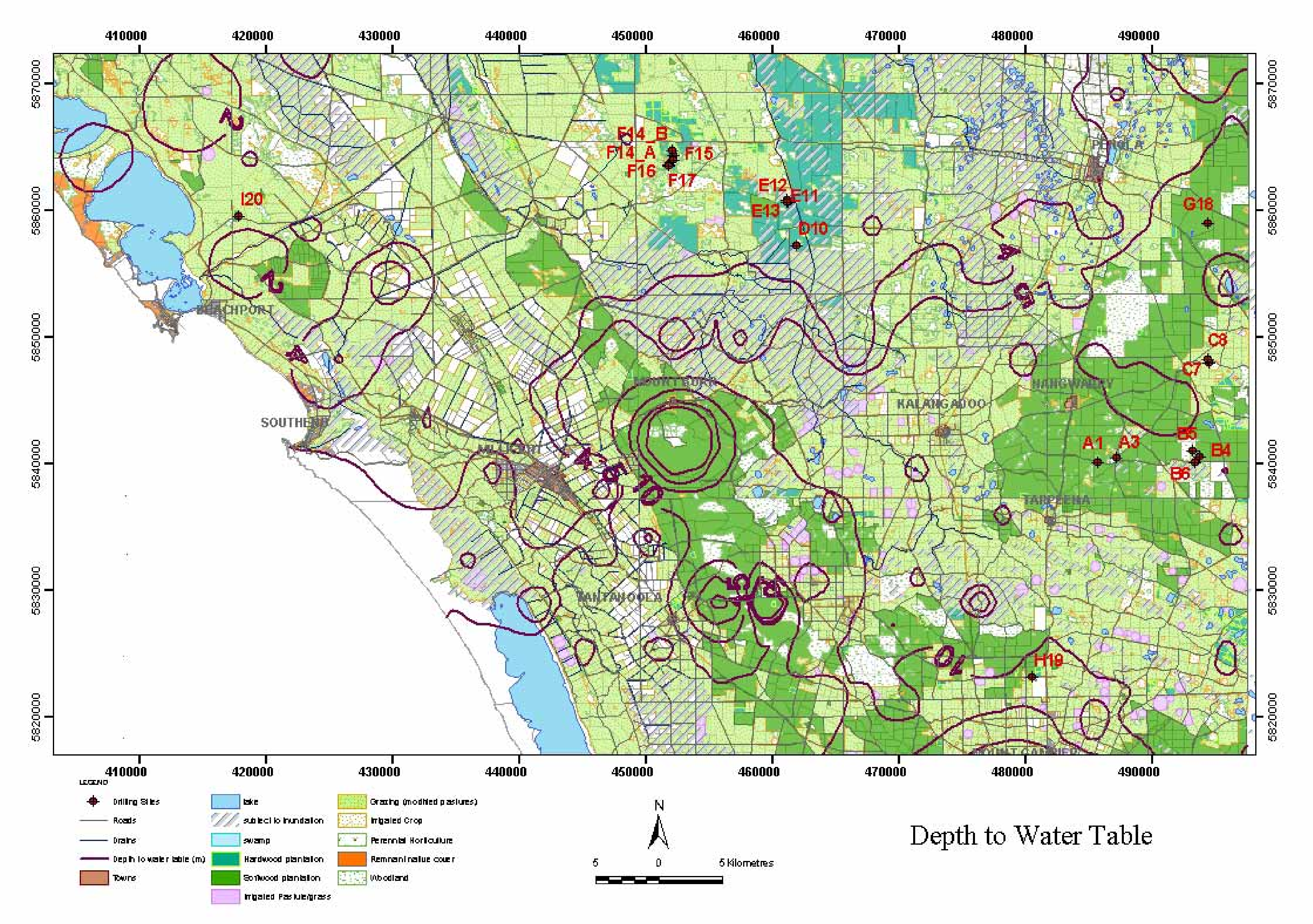

Figure 3. Standing water level for the unconfined aquifer and land use for the area..

1.3. Recharge, Salt Accumulation and Land Use Change

In any environment, the amount of water that passes below the root zone of plants (termed drainage) is determined by several factors such as rainfall, vegetation cover, soil type and depth to water. If there are no impeding layers that cause perching or lateral movement of water, the drainage reaches the watertable and is then classed as recharge. Drainage water and water that recharges the aquifer can range from being very fresh (approaching rainfall salinities) to the salinity of sea-water or greater. The reason for this is that small amounts of salt are present in rainfall. This salt is concentrated by evaporation of rainfall at or near the soil surface and by transpiration throughout the root zone of vegetation. This results in an accumulation of salt in the unsaturated zone below the root zone and above the watertable. The water present in the unsaturated zone is termed “soilwater”.

In general, for areas with similar rainfall, deep-rooting vegetation tends to result in lower rates of drainage below the root zone and more saline soilwater than shallow rooting vegetation (eg crops or pastures). However, other factors, and in particular, surface soil type, also have a major influence. Areas with heavier textured surface soils tend to hold recent rainfall events so that maximum water is removed by evaporation and transpiration and, hence, result in more saline soilwater. What this essentially means is that, providing an area has had a particular land use for an extended period, recharge to the aquifer, the salt store in the unsaturated zone and the salinity of recharge water will all be in a steady state situation.

If any of the factors affecting drainage change, so will the steady state. During this “transient state”, the soilwater salinity will change. In addition, after various lag times, the recharge to the aquifer and the salinity of the water recharging the aquifer will also change. This process has been described and modelled many times for different land-use changes (Cook et al, 1993, 2004; Leaney and Herczeg, 1999; Leaney et al, 2003, 2004)

Aim of this study

For the study area, there have been several land use changes (as described above), with the most recent being the development of Bluegum plantations. The aims of this study are:

- Determine the water and salt store in the unsaturated zone under areas with native vegetation, pasture/crop cover, Pine plantation and Bluegum plantation.
- Determine whether there is any evidence of groundwater use by the Bluegum, Pine plantation, and native vegetation.
- If Bluegum plantations are extracting groundwater estimate the rate at which this is occurring.

The methodology used involves interpretation of soilwater chloride (in mg L^{-1}) profiles for the unsaturated zone at a number of different sites. Chloride is used because it is a conservative tracer that remains in solution to high concentrations. It is indicative of the salinity of the soilwater and groundwater. In general, an approximation of salinity (in mg L^{-1}) can be estimated for sodium chloride dominant waters by assuming double the chloride concentration measured in the soilwater or groundwater. This is a reasonable approach for meteorically derived water. However, most groundwater in the area contains high concentrations of calcium and bicarbonate ions and hence the salinity is often 4-8 times that of chloride.

2. Study Areas, Sampling and Analysis

2.1. Description of Study Areas

Initially, the study sites were selected for four different types of land use and 5 study areas (A-F). Between one and four EM traverses were run in each study area using Geonics EM31 and EM38 meters mounted on a quad bike. Readings were taken along forest rows approximately every 5 metres and on a 10 to 20 metre grid in the open areas. The survey was done in deep and shallow mode using the EM31 and EM38 to determine the apparent electrical conductivity (Ec_a) variation down the profile to about 6 metres.

In total, there were 16 EM traverses of which two were in areas of native vegetation, 4 were in areas cleared of native vegetation, two were in Pine plantations of different stand ages, 6 were in areas with the majority of the Bluegum plantations were less than 8 years old (Richard Benyon, pers comm.) and two were in irrigation areas (Table 1). After preliminary viewing of the EM survey maps, drilling sites were selected in areas that, from the EM map, appeared to be representative of the study area and land-use at each site (not shown here). The EM survey maps and preliminary interpretation of the data is given in the companion report (Mustafa et al., 2005). As discussed earlier, a further three study areas (G-I) were subsequently sampled to allow comparisons of groundwater use estimated using the chloride accumulation method and by the more conventional water balance approach.

A detailed description of each study area follows along with a summary in Table 1.

Study Area A

The land uses in this study area were Pine Forest (Site P/N104327) and Native Vegetation (Site P/N104214).

The first well was drilled on the side of a sand dune (Pine site), and the second (Native Vegetation) drilled on the flat to the east. In each well the lithology is slightly different with P/N104327 having 2.5 metres of sand over 3 metres of clay over sandstone, whereas P/N104214 shows 3.5 metres of sand over 1 metre of clay over sandstone. The watertable is located within the sandstone. In the deeper, pine site hole, active tree roots were observed all through the drilling and were still present at 9 to 9.5 metres which is the top of the watertable.

Site P/N104327 was completed with soil gas sampling tubes. These consist of lengths of 6 mm nylon tube inserted in the hole prior to back filling so that one end of the tube is located at the depth where soil gas is to be sampled and the other end protrudes from the soil surface. The end in the soil is fitted with a plug of glass wool to prevent the tube being blocked by soil. At this site, the ends of the tubes were placed at depths of 2.3 m, 5.7 m and 7.0 m below the soil surface. Site P/N104214 was completed as an observation well.

Study area B

The land uses studied at this study area were Bluegums (site P/N104216), Pine Trees (site P/N104215) and non-irrigated Pasture (site P/N104217).

All three sites in this area had very similar lithology. This was a Sand layer varying from 0.2 to 0.9 metres thick, overlaying a Clay band of 1 to 1.6 metres thickness, which then overlay the Sandstone. The watertable is located within the Sandstone.

As an observation well (Nan21) exists at the Bluegum location, this well was cored and backfilled. The other two wells were completed as observation wells.
At the non-irrigated pasture site, two additional piezometers, P/N108344 and P/N108345, were constructed alongside P/N104217 The three piezometers were all in an area of non-

irrigated pasture and were completed at different depths below the watertable to ascertain if there is any salinity stratification and to allow future dating of the groundwater.

Study area C

The land uses studied at this study area were Irrigated Pasture (site P/N104218) and non-irrigated Pasture (site P/N104219).

These two sites were drilled close together but show very different geology. The well under the irrigated site has a slightly unusual log that shows about 1.5 metres of sand overlaying 1.5 metres of clay overlaying 1.5 metres of sandstone. Unusually below this a 0.5 metres band of clay occurs prior to the sandstone reoccurrence.

The second well, drilled under non-irrigated pasture (P/N104219), shows 10 metres of intermingled sands and clays overlaying the sandstone. This depth to the carbonate material is double that of the previous well for no real topographic difference.

Under the irrigated site the watertable is contained within the Sandstone, whereas under the non-irrigated site it occurs within the non-carbonate clays.

Study area D

The site studied in this study area was planted with Bluegum (Site P/N104225). It was drilled close to an existing observation well (SHT 24) and so was backfilled after completion.

The lithology at this site was 1.5 metres of sand overlaying clay, with the watertable within the clay unit, at about 3.4 metres.

Study area E

The land uses at this study area were Bluegums (site P/N104222), non-irrigated Pasture (site P/N104223) and irrigated Pasture (site 104224). Initially 6 wells were planned for this study area, however, after understanding the site conditions, this was reduced to 5 holes.

The lithology differed at this study area from hole to hole. P/N104222 drilled at the Bluegum location showed 1 metre of sand overlaying 1.5 metres of clay overlaying another metre of sand prior to the sandstone. At the non-irrigated site P/N 104223, samples were only possible to the top of the watertable and then no returns to surface occurred. However the geology to that point was almost identical to the Bluegum site. The irrigated Pasture site seemed a little different as a bit sample at the completion of drilling indicated that the material was still sandy clay. However after examining the logs of the previous two wells it is now concluded that sandstone was cut and that the sandy clay stayed on the bit from higher in the hole.

At this location the watertable was reached at about the interface between the clay and the sandstone at around 4.5 metres. After the water was reached it rose about a metre, to less than 3.5 metres from the ground surface. This indicates that the clay at this site is acting as a semi-confining unit.

At the Bluegum site two extra wells were drilled and completed at 5.5 metres and 6.8 metres, to examine if salinity stratification is occurring through the profile.

Study area F

The land uses at this study area are non-irrigated Pasture (site P/N104220A and P/N104220B), Native vegetation (site P/N104226) and Bluegums (site P/N104227 and site P/N104228).

At the non–irrigated pasture site (P/N 104220A) depth to the watertable was 20.57 metres, which was ideal to study salt accumulation in this type of environment. Unfortunately an extremely hard bar of sandstone occurs at 5.5 to 6 metres, which prevented cores being recovered past this point. A second attempt (P/N 104220B) further down the slope resulted in the watertable being intersected at about 3 metres. An existing observation well is still current at this site and could be used to study soil moisture content by using a neutron probe. The geology in the deeper hole shows 3.5 metres of sand overlaying 0.4 metres of clay overlaying 0.6 metres of sandstone which overlays 0.5 metres of clay prior to sandstone being encountered again. This sequence was also observed in a well drilled in study area C, where the carbonate deposition was interrupted.

The cored site in the native vegetation was drilled to 18 metres with cores to 15.5 metres. A 6 metre sand band overlays 1.5 metres of sandy clay overlaying 7 metres of clay prior to the sandstone being cut at 14.5 metres. The well was completed as an observation well, and had three soil gas detection tubes attached outside the casing.

For the Bluegum land use, two holes were drilled. An existing observation well had previously been drilled at the deeper site and had a water level of 10.56 metres. Unfortunately at 7 metres a very hard bar stopped the coring reaching the watertable. At the shallow watertable site a short distance to the north, the cored well was successfully completed at 3.5 metres. The logs of the two wells differ slightly, as the deeper well (P/N 104228) had 1.3 metres of sand overlaying 5.7 metres of sandstone. In the shallow hole (P/N 104227) 1.5 metres of sand overlays 1.5 metres of clay before the sandstone is encountered.

The geology within the sand dune system is observed to vary significantly from sand over sandstone to sand over thick clays. Any differences in the results should be compared back to this geology difference.

For this site the watertable is within the sandstone layer.

Study area G

The land use studied at this site is Pine Tree plantation (P/N 108346). The geology for this site is sand from ground surface to about 2.75 metres. From 2.75 metres to 3 metres the sand has higher moisture content and the appearance of clay particles. Then from 3 to 5 metres is sandy clay followed by clay from 5 to 6.5 metres.

An existing observation well is used for water level and salinity information.

Study area H

The land use studied at this site was Pine Tree Plantation (P/N 108347). The geology at this site was about one metre of sand overlaying sandy clay to 1.5 metres. From 1.5 metres to 4 metres is clay followed by Limestone, then marly limestone, finishing in Marl at 6.5 metres.

An existing observation well is used for water level and salinity information.

Study area I

The land use studied at this site was Bluegum plantation (P/N 108348). The geology encountered at this site was 0.5 metres of sand overlaying sandstone.

At this site the watertable is in the sandstone formation. An existing observation well is used for water level and salinity information.

Table 1 Summary of Core Site Details

Site	Permit Number	EC (us/cm)	Land Use Type	Easting	Northing	Hundred	Total Depths (m)	PVC Diameter (mm)	Slotting Interval (m)	Comments
A1	104327	N/A	Pines	485775	5840160	Nangwarry	10	N/A	N/A	Near NAN009 - completed with soil gas sniffer. Prior land use was scrub. First rotation 1926; pines burnt in 1950. Second rotation 1953, and the third rotation in 1988
A3	104214	1295	Native Veg	487280	5840455	Nangwarry	7.9	50	1.9 to 7.9	East of NAN009 - Observation well. Completely burnt in February1983 fires then regenerated
B4	104216	1660	Pines	493830	5840580	Nangwarry	8	50	5.1 to 8	SE of NAN021 - Observation well. First rotation established in 1968. Heathy scrub prior to plantation
B5	104215	N/A	Blue Gums	493320	5841050	Nangwarry	5	N/A	N/A	Adjacent to NAN021 - Cored and abandoned. First rotation 1988, prior land use was cleared pasture. Second rotation 2000
B6	104217	590	Pasture - North	493490	5840095	Nangwarry	8.3	50	4.3 to 8.3	South of NAN021 - Observation well
	108344	820	Pasture - Middle	493490	5840095	Nangwarry	15	50	12.5 to 14	
	108345	820	Pasture - South	493490	5840095	Nangwarry	22	50	19.15 to 20.65	
C7	104218	965	Irrigation	494615	5848035	Nangwarry	11.9	50	5.9 to 11.9	SE of NAN003 - Observation well
C8	104219	370	Pasture	494470	5848280	Nangwarry	10.2	50	4.2 to 10.2	Near NAN003, NE of stockyards - Observation well
D10	104225	N/A	Blue Gums	461991	5857284	Short	4	N/A	N/A	Adjacent to SHT024 - Cored and abandoned. Planted 1998 on cleared pasture land
E11	104222	1320	Blue Gums 6.0m	461325	5860723	Short	6	100	2 to 6	Northern hole - Transducer Observation well. Equiped with multi parameter Transducer (EC & water level). Planted 1998 on cleared pasture land
	104221 A	1375	Blue Gums - 5.5m	461328	5860721	Short	5.7	50	5.2 to 5.7	Southern Hole - Observation well. Planted 1998 on cleared pasture land
	104221 B	1470	Blue Gums - 6.5m	461328	5860725	Short	6.8	50	6.3 to 6.8	Middle hole - Observation well. Planted 1998 on cleared pasture land
E12	104224	2480	Irrigation-Pasture	461202	5860871	Short	5.9	100	1.9 to 5.9	Transducer Observation well. Equiped with multi parameter Transducer (EC & water level)
E13	104223	1725	Pasture	461215	5860701	Short	5.9	100	1.9 to 5.9	Transducer Observation well. Equiped with multi parameter Transducer (EC & water level)
F14 A	104220 A	N/A	Pasture - Hill	452243	5864425	Short	6	N/A	N/A	Hard bar couldn't penetrate. Cored and abandoned
F14 B	104220 B	N/A	Pasture - Flat	452146	5864754	Short	4	N/A	N/A	Drilled on the flat - shallow water table Cored & abandoned
F15	104226	1380	Native Veg	452209	5864045	Short	18	50	12 to 18	Bush track - Observation well
F16	104227	N/A	Blue Gums	451820	5863675	Short	3.5	N/A	N/A	North end coordination - completed with soil gas sniffer. Planted 1998 on cleared pasture land
F17	104228	N/A	Blue Gums	451815	5863575	Short	7	N/A	N/A	South end coordination - cored and abandoned. Planted 1998 on cleared pasture land
G18	108346	1130	Pines	494520	5859000	Penola	6.5	N/A	N/A	At CSIRO Julia Hill site, Cored and abandoned. Relatively good Heathy scrub in 1965 with trees. By 1968 the area had been cleared and had very low vegetation with no trees. First rotation establised in 1970
H19	108347	1700	Pines	480560	5823210	Young	6.5	N/A	N/A	At CSIRO Airport road site, Cored and abandoned. First roration establised 1945. Prior land use was scrub to 1934, then pasture until pines. Second rotation 1996
I20	108348	N/A	Blue Gums	417832	5859597	Symon	3	N/A	N/A	At CSIRO Beachport site, Cored and abandoned. First rotation, planted 1994 on cleared pasture land

N/A - the site was abandoned after coring and was not completed as a piezometer due to the existence of a nearby observation well.

2.2. Sampling Soil and Soil Gas from the Unsaturated Zone

The initial drilling program, carried out in February 2005, had 16 cored wells and another two wells completed at different depths to compare possible salinity stratification. Of these 11 wells were completed as piezometers for future water level and salinity readings. Three wells at the McCourt's irrigation site (study area E) had transducers installed to record both water levels and salinity. This is to ascertain any differences occurring under different land uses over longer time periods. Also at three sites, tubes were left in the holes in an attempt to sample soil gas (Table 1). An elevated level of CO_2 concentration in soil gas is indicative of root respiration, which in turn, is indicative of active tree roots. For the location of the drilling sites see Figure 1. Soil samples from a further 3 cores were collected in a subsequent drilling program in July 2005.

For this project, it was necessary to use drilling methods that would not dry soil samples during sampling or add water to the soil samples. At the cored well sites, samples were collected using a split-tube wire line recovery technique mounted on an Investigator rig. Drilling was contracted to Drilling Solutions under the supervision of DWLBC staff. Cores were collected at each of the 9 study areas (A-I) and included sites in each of the land-use regimes discussed above. In total, there were two cores collected in areas with native vegetation, 4 in areas cleared non-irrigated pasture and 2 in irrigated pasture, four in Pine plantations, 6 in Bluegum forests (Table 1).

Cores were collected to the watertable. In general an attempt was made to collect sample to 0.5-1.0 m below the watertable, however in most occasions this was unsuccessful due to the high moisture content making the sample unstable. At two sites, the watertable was not reached due to the existence of a hard soil layer that resulted in coring being terminated at these sites (P/N 104220A and P/N 104228). Soil samples were collected at 0.5 m intervals and aliquots placed in 500 ml glass jars that were sealed with new metal lids to prevent evaporation of water from the soil.

Soil gas was collected from the three sites fitted with soil gas samplers by removing 7-10 tube volumes of gas from the tube using a syringe and then filling 10 ml pre-evacuated containers (vacutainers) with soil gas via the septa on the top of the containers. The soil gas was then transported along with the soil samples to the laboratory for analysis.

2.3. Analyses

The soil physical properties measured in this study were particle size analysis (PSA), soilwater suction (SWS) and gravimetric water content (θ_g). Volumetric water content (θ_V) may be calculated by multiplying θ_g by the mean density of the soil. Chloride concentration of the soilwater, $[Cl]_{soilwater}$ was also measured. θ_g, measurements were made on all samples while SWS and $[Cl]_{soilwater}$ measurements were made on approximately every second sample. PSA measurements were made on all core samples from the soil surface to a depth of 2.5 m and at approximately 2 m intervals thereafter. A brief description of analytical techniques is given in **Appendix A.**

The concentration of CO_2 in the soil gas was measured on a Europa Geo 20:20 mass spectrometer fitted with a gas sampler to allow transfer of the soil gas from the vacutainer to the mass spectrometer.

3. Results

3.1. Soil Analyses

Analyses for all of the sites are listed in **Appendix B**. There is a 50+ fold range in θ_g (0.007 - 0.371 g(water)/g(dry soil)). θ_g is determined primarily by the amount of clay present in the soil (see particle size analysis) and soilwater suction, both of which are discussed later in this report.

3.1.1. [Cl]soilwater Profiles

Soilwater chloride, $[Cl]_{soilwater,}$ profiles at the two native vegetation sites range from ~130 – 1500 mg L^{-1} (Figure 4). At both sites, $[Cl]_{soilwater}$ is greater for the bottom half of the unsaturated zone than for the top half and increases at greater depth to a maximum value of ~1000 mg L^{-1} before decreasing closer to the watertable. This value is referred to at the plateau $[Cl]_{soilwater}$ and would be equivalent to a total salinity of ~2000 mg L^{-1} for the soilwater. For ease of comparison, $[Cl]_{soilwater,}$ profiles for the different land uses are presented on the same X,Y scale as the native vegetation profile.

Under the pasture sites, $[Cl]_{soilwater}$ ranges from ~10 – 500 mg L^{-1} (Figure 5). For most of the profile, excluding the root zone (0-2m depth), there are very few soil samples that have $[Cl]_{soilwater}$ greater than 60-80 mg L^{-1}. These types of profiles are typical of those found in areas of high drainage and shallow watertables where the unsaturated zone has been flushed of salt accumulated under earlier native vegetation regimes (see discussion section).

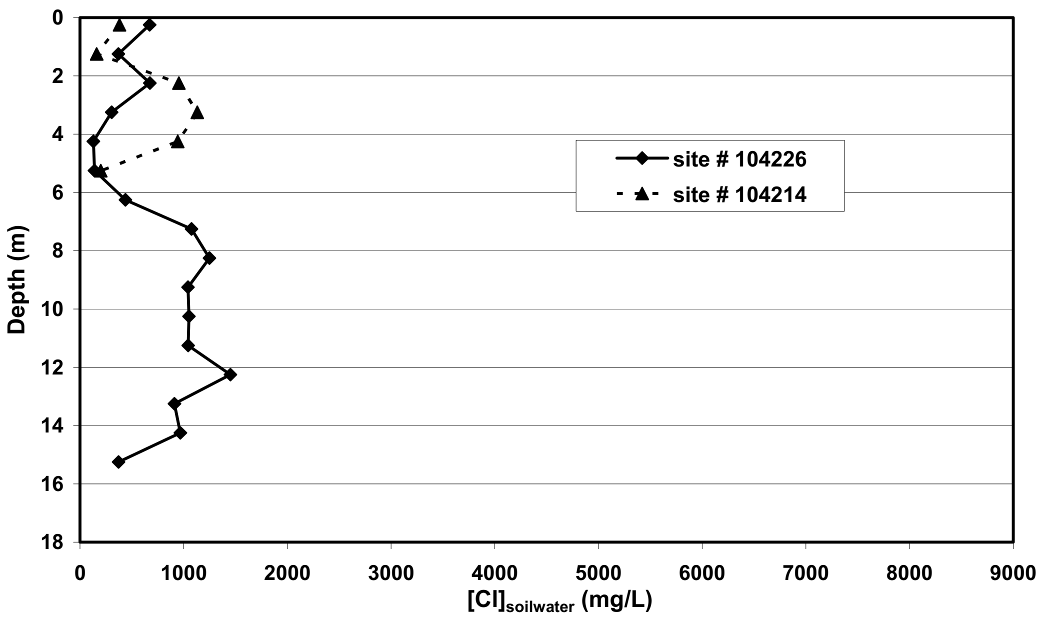

Figure 4. Soilwater chloride depth profiles for areas with native vegetation

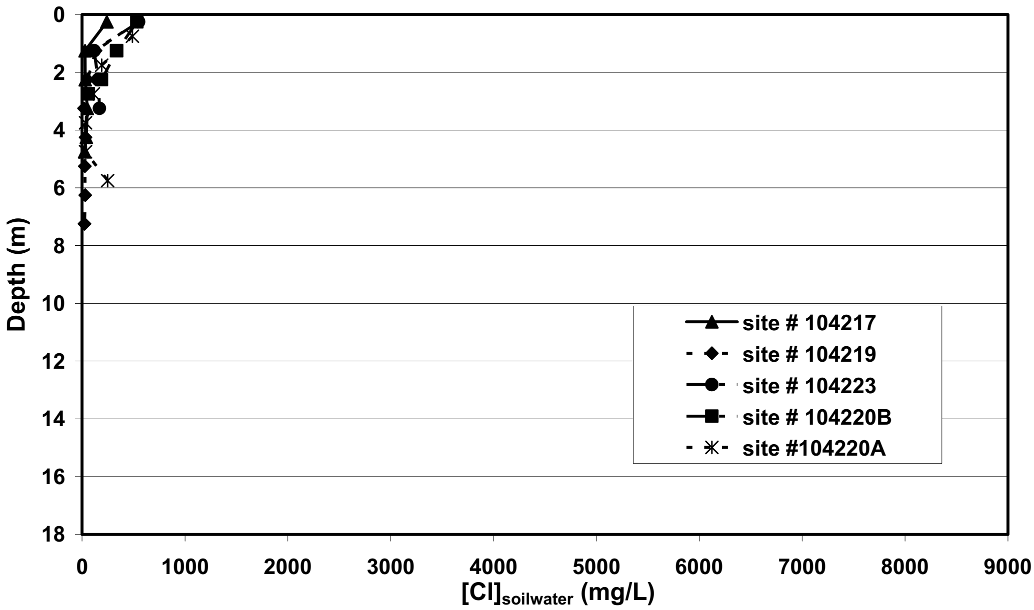

Figure 5. Soilwater chloride depth profiles for areas cleared of native vegetation and not irrigated

For the sites where Pine plantations have been established, chloride (salt) accumulation has recommenced. The $[Cl]_{soilwater}$ for the unsaturated zone at these sites range from ~100 mg L^{-1} (ie similar to that measured at the pasture sites) to ~9 000 mg L^{-1} (Figure 6). Usually, the largest $[Cl]_{soilwater}$ peak is seen in the capillary zone, ~1 – 3 m above the watertable. At the deeper site, (104327), there is an additional $[Cl]_{soilwater}$ peak within the top few metres of the soil profile.

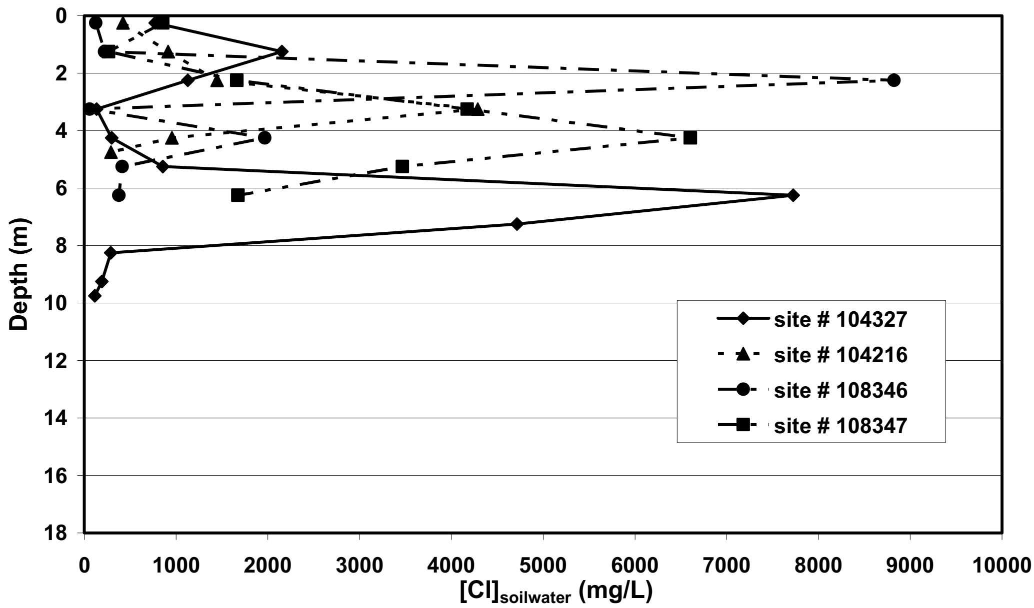

Figure 6. Soilwater chloride depth profiles under Pine plantations

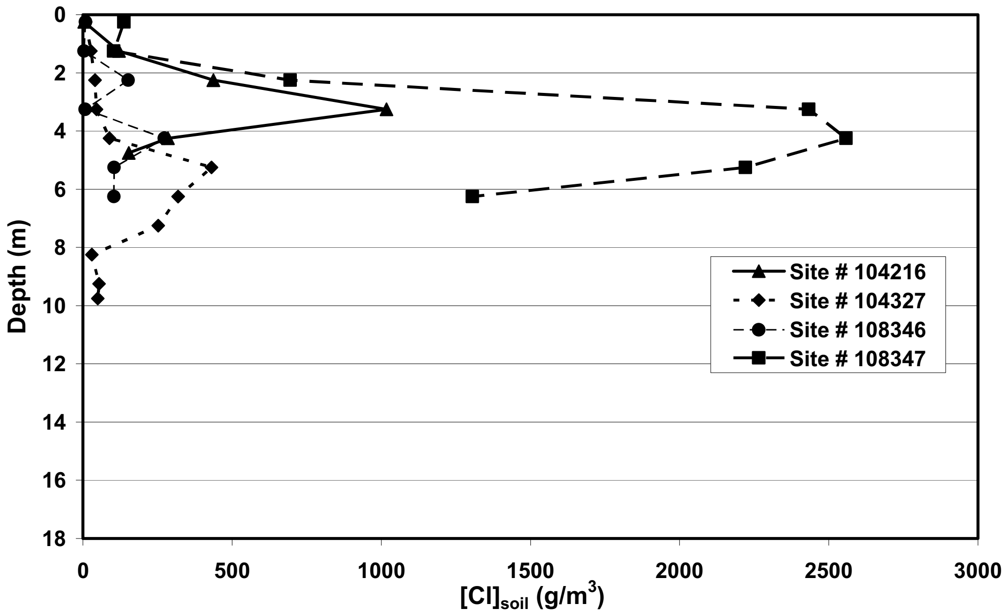

Figure 7. Soil chloride concentration (g m-3) vs depth profiles under Pine plantations

Also shown (Figure 7) is the chloride concentration of the soil (g_{Cl} m^{-3}) as a function of soil depth. The unsaturated zone soil at site 108347 has the greatest accumulation of chloride. Reasons as to why this may be the case are discussed in later sections of this report.

At the Bluegum sites, $[Cl]_{soilwater}$ for the unsaturated zone range from ~100 mg L^{-1} (similar to that measured at the pasture sites) to almost 4 000 mg L^{-1} (Figure 8). Chloride accumulation can be seen for samples at 4 of the 6 sites (104215, 104221, 104225 and 108348). At site 108348, the chloride accumulation is greatest for the deepest sample and possibly there is more chloride in the shallow groundwater. Only a single $[Cl]_{soilwater}$ peak is observed at these sites, similar to that seen at site 104216 (Pine plantation) where the watertable is also around 5 m deep.

At the other two sites, $[Cl]_{soilwater}$ is similar to that measured at the pasture sites. Also shown (Figure 9) are the chloride concentrations of the soil against depth at the Bluegum sites. Note that the chloride accumulation at the Bluegum sites is significantly less than that at the Pine sites. The main reason for this is that the Pine forest have been established for much longer than the Bluegum sites and hence there has been a longer period for groundwater uptake hence chloride accumulation.

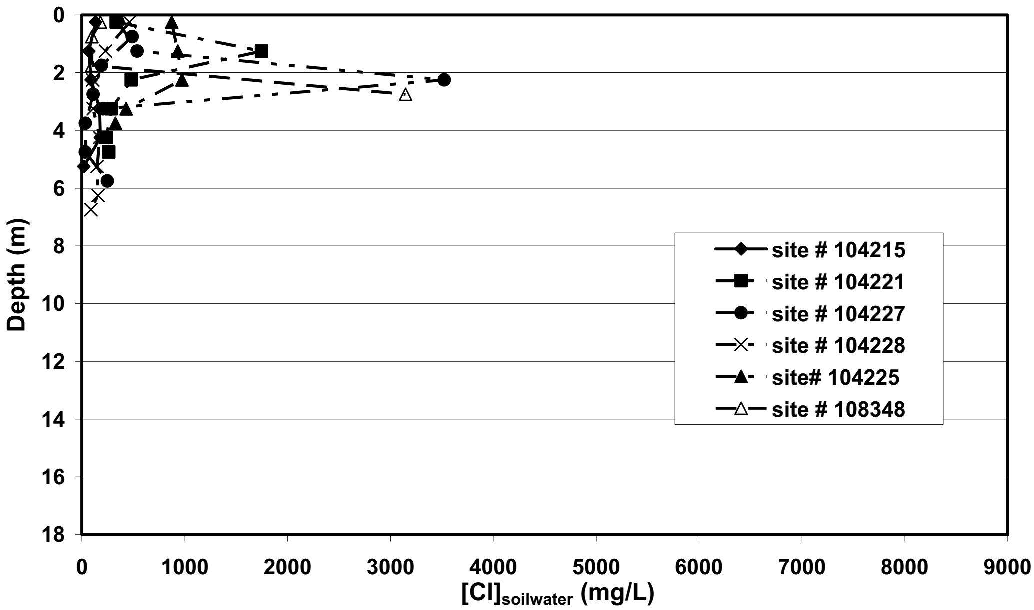

Figure 8. Soilwater chloride depth profiles under Bluegum plantations

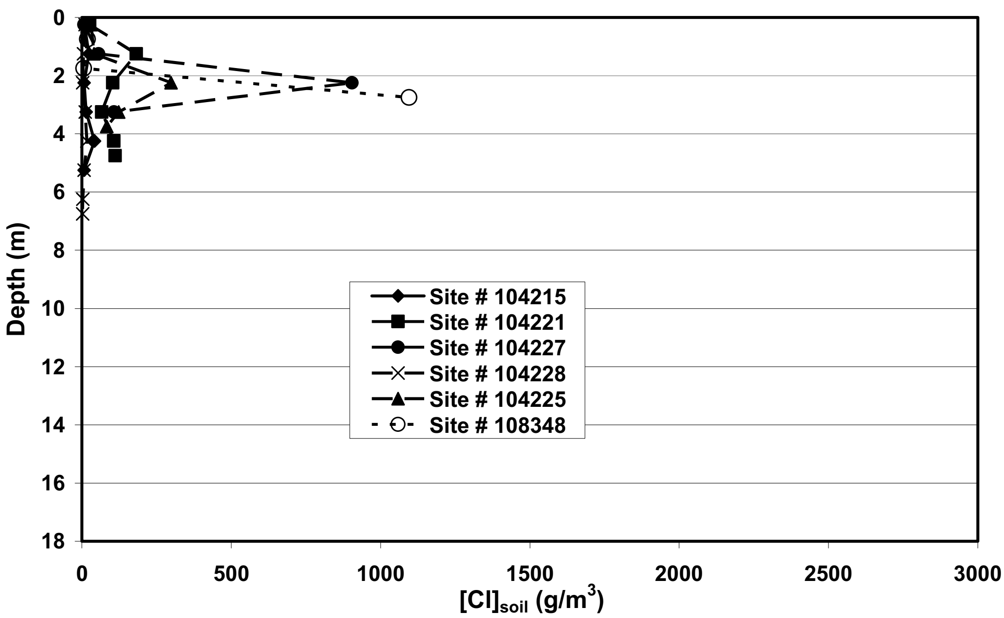

Figure 9. Soil chloride depth profiles under Bluegum plantations

Chloride accumulation is also observed in the unsaturated zones at the irrigated sites (Figure 10). Chloride accumulation at the Pine and Bluegum sites arises from induced vertical movement of water upward from the groundwater into the capillary zone. The driving force for this movement is water uptake by the trees. This is not the case for the irrigated areas. Irrigation water has 10-30 times the chloride concentration as rainfall and hence, at the irrigated sites, chloride is applied with irrigation water at the soil surface. Chloride accumulation at the irrigated sites results from removal of pure water near the surface as a result of evapo-transpiration.

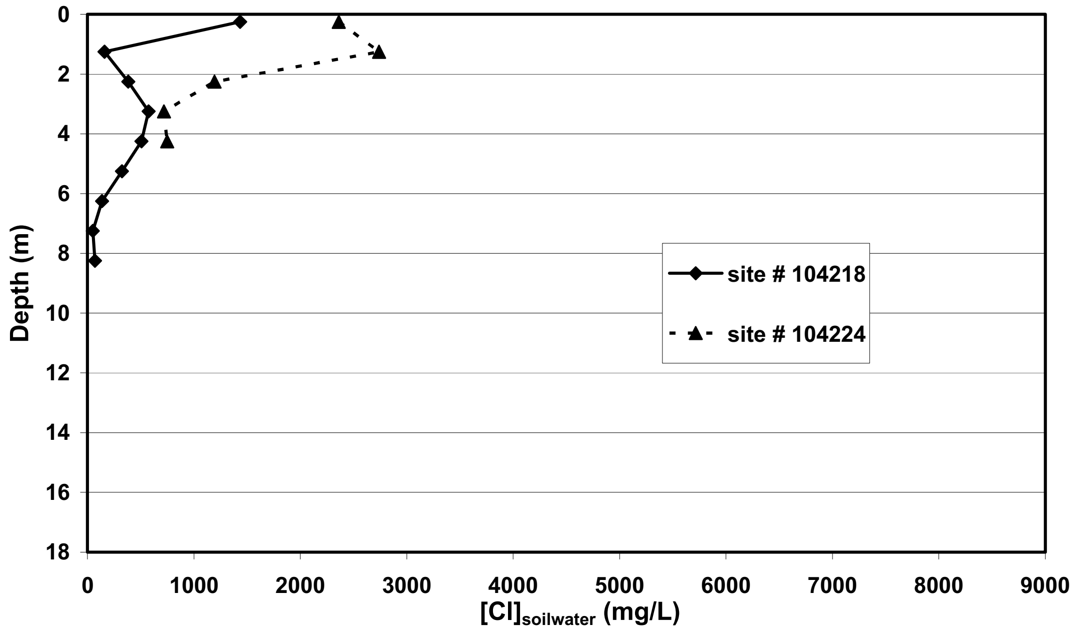

Figure 10. Soilwater chloride depth profiles for irrigated areas

3.1.2. Soilwater Suction Profiles

Soilwater suction as measured using the filter paper technique (see Appendix) is plotted against depth profiles for all of the different land use sites (Figures 11-15) As would be expected, the soil is close to saturation at or near the watertable (measured soilwater suction = 5-10 kPa). The highest values measured for soilwater suction are 2000 -4500 kPa.

At both of the native vegetation sites, the soilwater suction is high close to the soil surface (Figure 11). For the deeper native vegetation site, soilwater suction is also high 8-12 m from the surface but low between depths of 2-6 m below the soil surface. At the cleared sites, soilwater suction is variable throughout most of the unsaturated zone (Figure 12).

The soilwater suction measurements for samples collected at all of the Pine sites are high for all samples excluding those collected in the capillary zone near the watertable (Figure 13). This perhaps suggests a comprehensive root density throughout the unsaturated zone to a depth of 8-10m under established Pine trees.

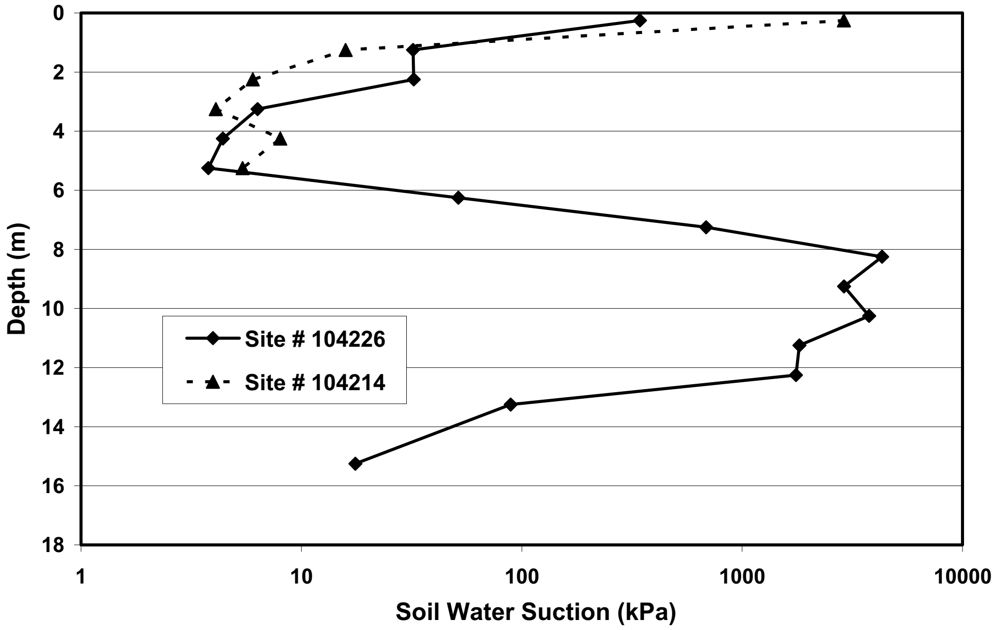

Figure 11. Soilwater suction vs depth profiles for areas with native vegetation

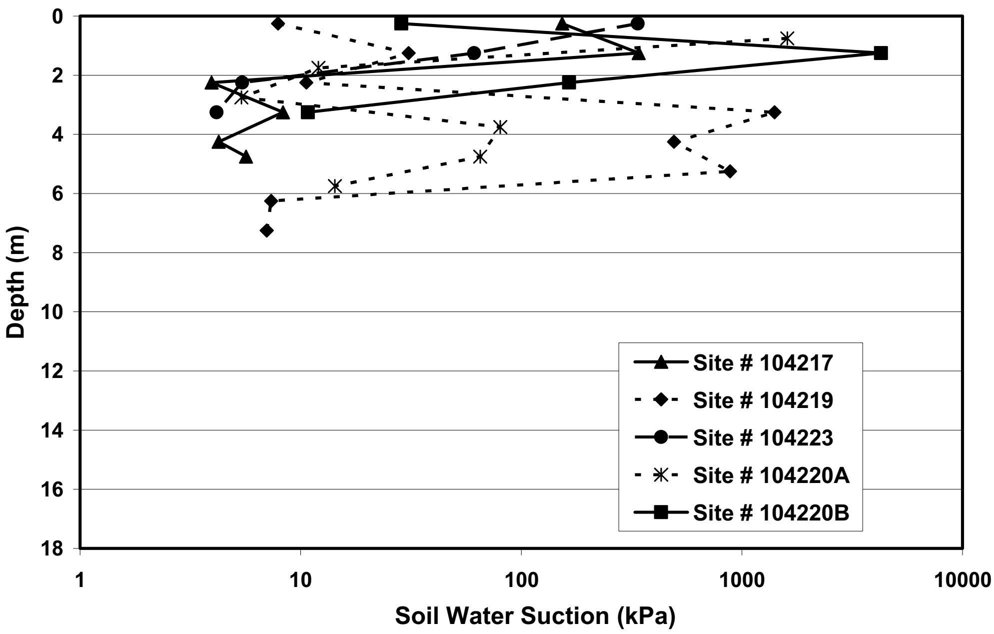

Figure 12. Soilwater suction vs depth profiles for areas cleared of native vegetation and not irrigated

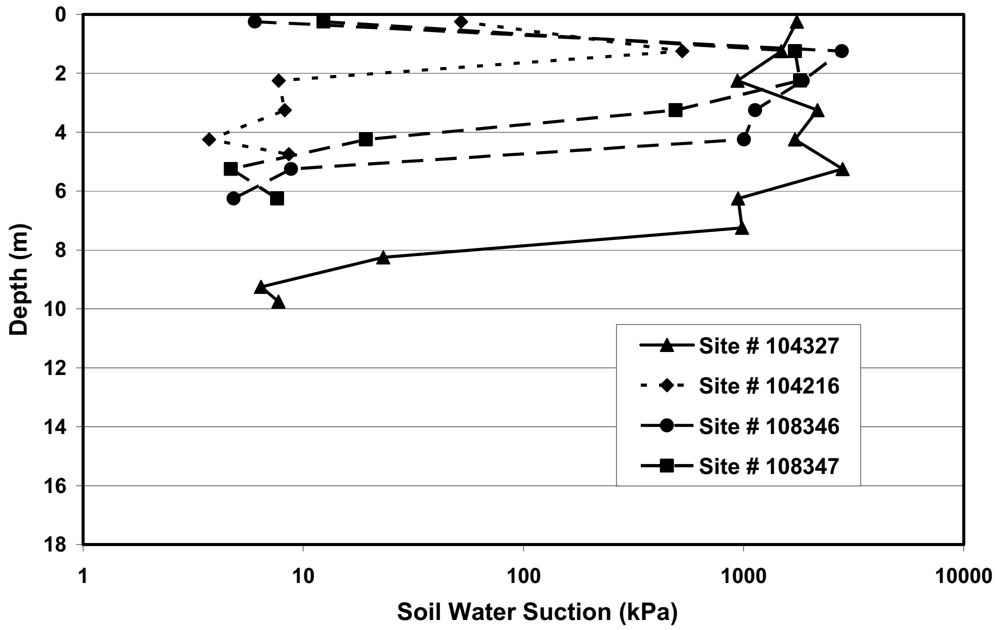

Figure 13. Soilwater suction vs depth profiles under Pine plantations

At the Bluegum sites, there is quite a range in soilwater suction measurements for the different sites (Figure 14). For example, at site 108348 the unsaturated zone is near saturation (soilwater suction is low) throughout the unsaturated zone. At site 104215, the soilwater suction is >3000 kPa at the surface and gets progressively closer to saturation towards the watertable. At site 104228, the unsaturated zone has a soilwater suction averaging ~1000 kPa throughout the entire profile. This site was not cored to the watertable and hence probably does not include samples from the capillary zone.

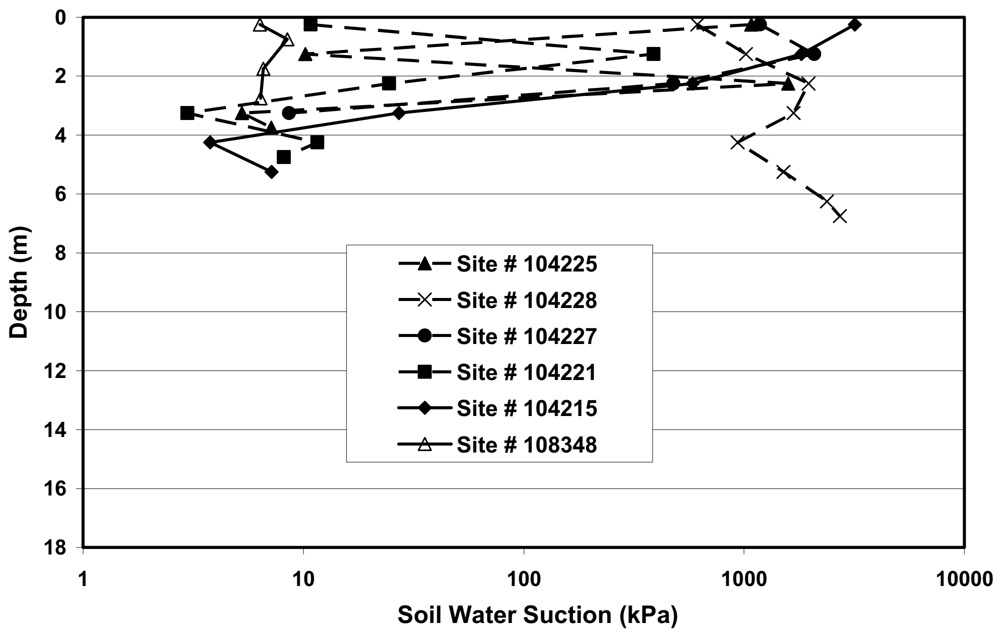

Figure 14. Soilwater suction vs depth profiles under Bluegum plantations

At the irrigated sites, the soilwater suction profiles are similar to those at the cleared sites, ranging from near saturation close to the watertable to ~4000 kPa for much of the unsaturated zone (Figure 15). Usually during the irrigation season, much lower values would be expected for the unsaturated zone soils. I suspect that It is probable that these soils were not irrigated for some considerable time prior to sampling and most of the readily available water in the root zone has been used by the plants.

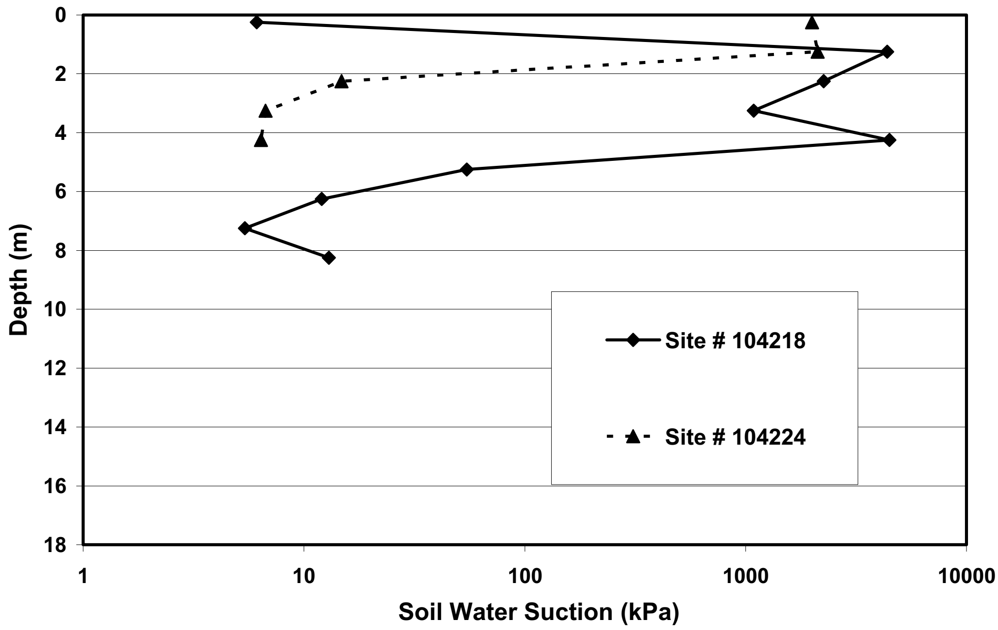

Figure 15. Soilwater suction vs depth profiles for irrigated areas

3.1.3. Particle Size Analysis

Particle size distribution was measured for every soil sample from the surface to a depth of two metres (ie two samples per metre) and every second soil sample thereafter (ie ~ one sample per metre). The results for all analyses are given in Appendix B. The fraction of clay in soil samples for the surface two metres of the soil profile is often related to the amount of drainage in the soil and has been used as a surrogate measurement for this, especially in areas cleared of native vegetation (Kennett-Smith et al. 1993). The percentage of clay in each soil sample has been plotted as a function of depth for the unsaturated zone at each of the sample sites (Figures 16-20).

In general, the surface soil is sandier (lower % clay) than that deeper in the profile. Usually, at least the top metre or two of soil has clay contents less than 10 %, whereas deeper in the profile, the clay contents are often 50 % or greater. The exception to this is at site P/N 104215 where the near surface soil has a clay content of 40% and the clay persists throughout the unsaturated zone. A possible implication of this on the potential for groundwater uptake is discussed later.

The presence of heavier clay in surface soil is particularly important, as they will result in reduced rates of drainage once the area is cleared of native vegetation. Heavier clay layers deeper in the soil will not have as much impact on the rate of drainage after clearing but will increase the water storage capacity of soil in the unsaturated zone. Hence, it will take considerably longer for the salt to be flushed from heavier textured soils than sandier soils. The implications of this with regard to salt accumulation in the unsaturated zone and estimation of groundwater use by Pine and Bluegum forest is discussed later in this report.

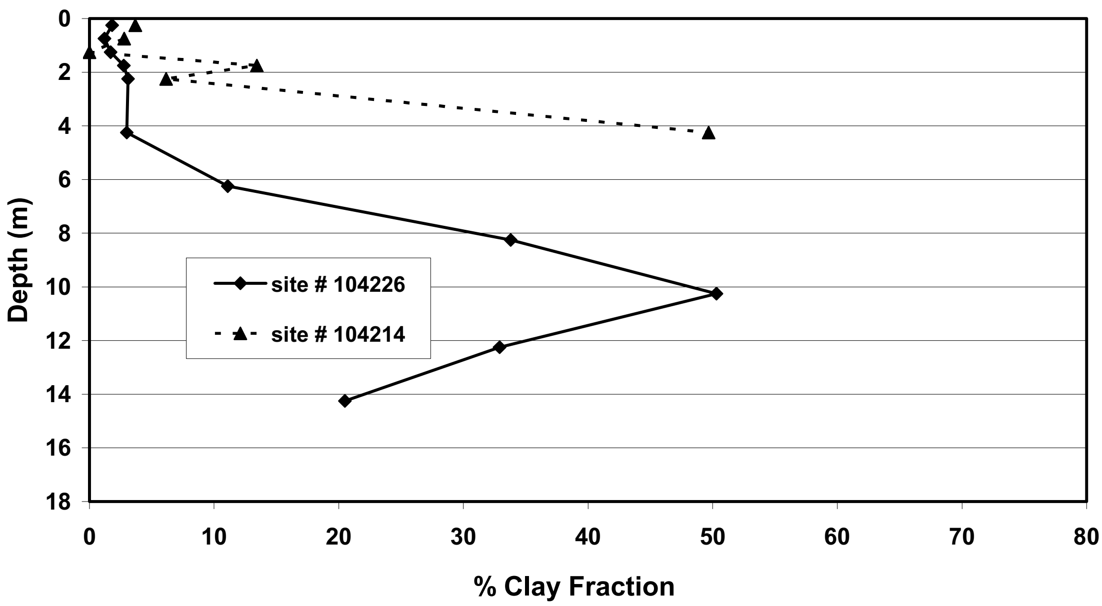

Figure 16. Percent clay vs depth profiles for areas with native vegetation

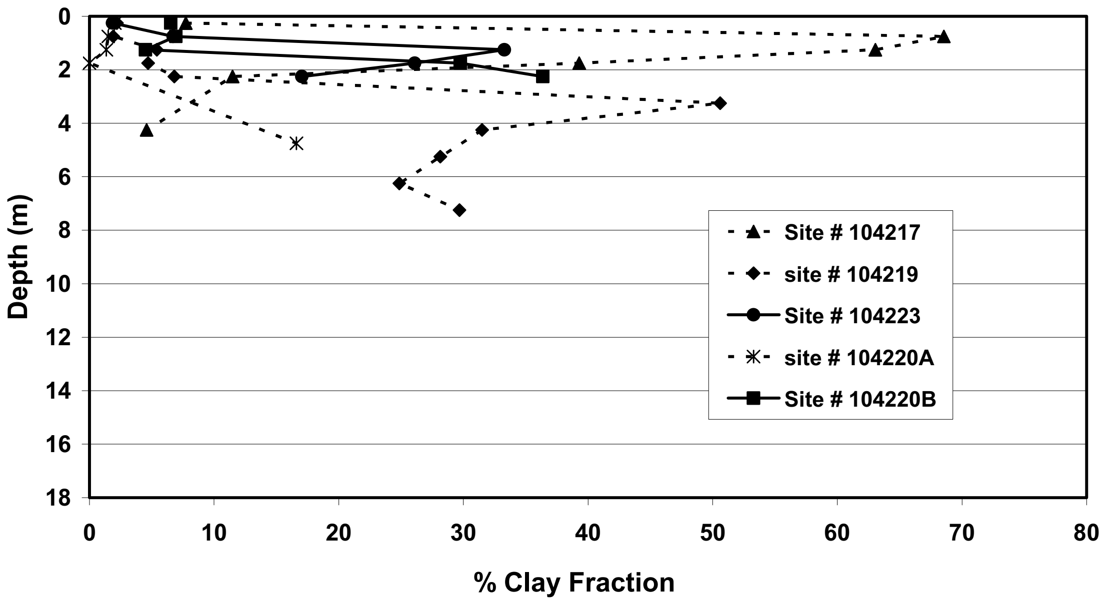

Figure 17. Percent clay vs depth profiles for areas cleared of native vegetation and not irrigated

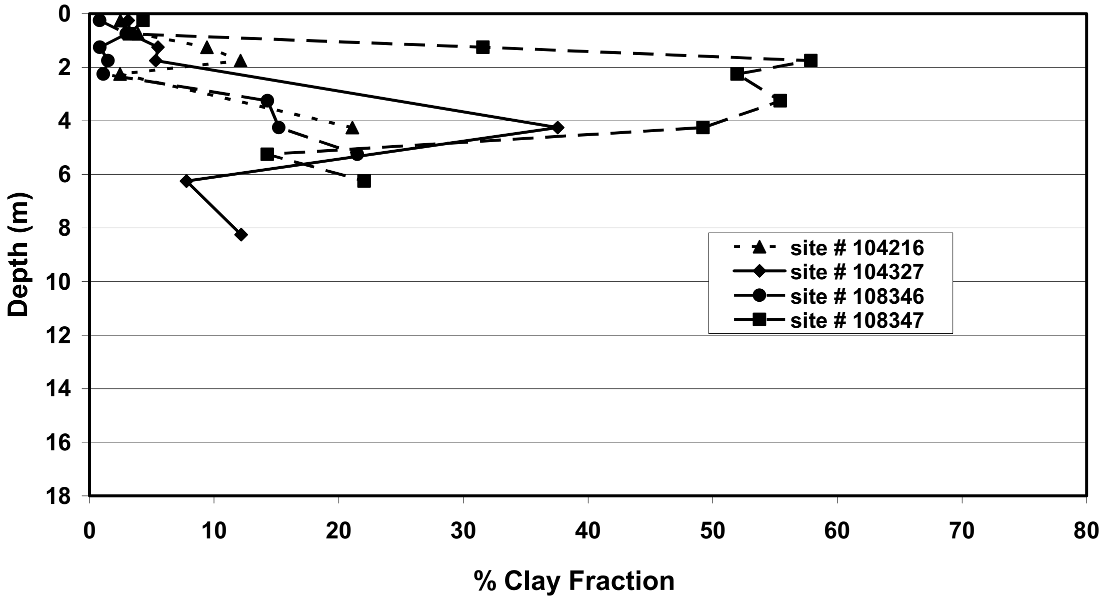

Figure 18. Percent clay vs depth profiles under Pine plantations

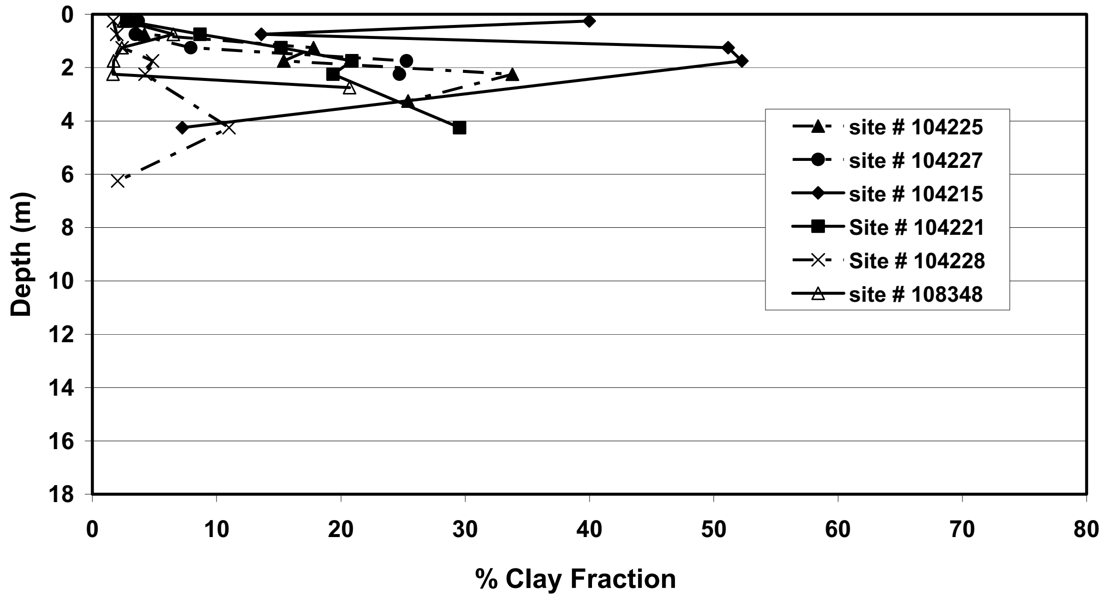

Figure 19. Percent clay vs depth profiles under Bluegum plantations

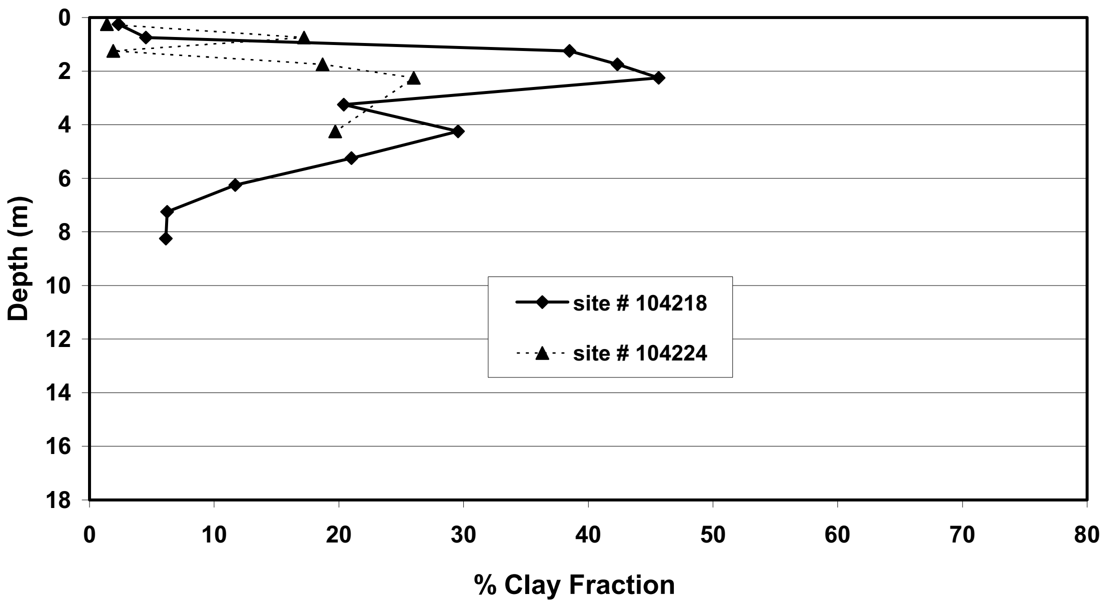

Figure 20. Percent clay vs depth profiles for irrigated areas

3.2. CO_2 Concentrations in Soil Gas

CO_2 is a product of root respiration. If root activity is occurring, CO_2 generated at the source of the root activity will be present at elevated concentrations in the soil. Over time, the CO_2 thus generated will diffuse to areas of lower CO_2 concentration. Because atmospheric CO_2 concentration is ~0.03%, this will result in a diffusion gradient from the area or areas of highest CO_2 concentration to the soil surface.

Soil gas sampling tubes were installed at three different depths (2, 4.5 and 7 m) at native vegetation site 104226, at three different depths (2.3, 5.7 and 7 m) at Pine site 104327 and at one depth (1.7 m) at Bluegum site 104227 (Figure 21). The lowest CO_2 concentrations were measured for soil gas collected at the Native vegetation site with considerably higher concentrations measured for samples collected at the Pine site. Only a single depth was sampled at the Bluegum site.

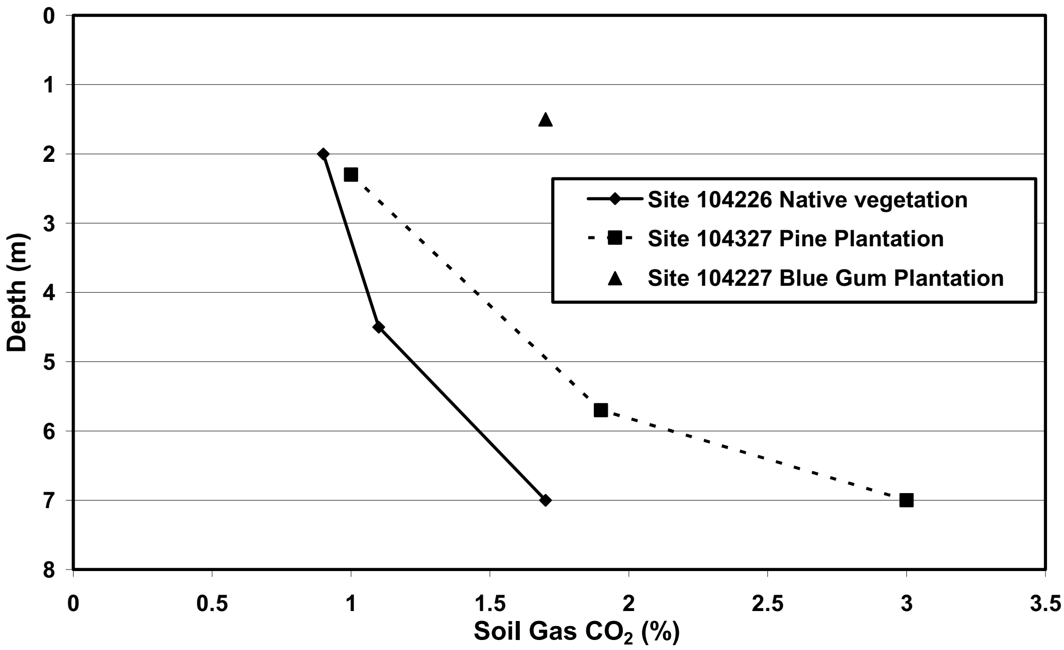

Figure 21. Soil CO2 profiles (High soil CO2 concentrations are indicative of root respiration).

Unfortunately, at the native vegetation site, the sampling depths were all within the top 40% of the unsaturated zone (SWL at 16.6 m). The highest concentration for soil CO_2 is 1.7 % at a depth of 7 m (ie from the deepest soil gas collection point). There is a gradual decrease in CO_2 concentration from that depth towards the soil surface. This suggests that roots were able removing soilwater from at least this depth at this site.

At the Pine site, the CO_2 concentration was greatest (3%) immediately above the watertable and decreases towards the surface. This suggests that there is considerable root activity in the capillary zone and hence, groundwater uptake at this site. The CO_2 concentration of the soil gas at the Bluegum site is considerably greater than that for samples collected at a similar depth at the other sites. The elevated CO_2 concentration again suggests use of groundwater at this site (SWL at 2.8 m) . Unfortunately, the very different watertable depths at these sites make relative comparison of root activity difficult. Hence, we suggest that all that can be said is that, at each site there is strong evidence for water uptake from the depth of the deepest sampling point.

4. Estimating Recharge and Groundwater Uptake Following Land Use Change

4.1. Recharge and Land use Change

The first estimates for recharge in the Mt Gambier region under different types of landuse commenced in the late 1960s (eg Holmes and Colville, 1970) using water balance/lysimetry studies. They estimated recharge to the aquifer under grassland to be between 25 and 134 mm yr^{-1} and no recharge under Pine forest. Further studies followed using techniques such as groundwater dating using tritium and chloride mass balance (Allison and Hughes, 1972 & 1978). The researchers concluded that recharge under native vegetation was initially low but, after clearing, increased by 2-3 orders of magnitude to 80-260 mm yr^{-1} depending on the soil type and hydrologic unit. They also confirmed that, where Pine was replanted, the recharge reduced dramatically to zero within a few years. Little indication was made at that stage for potentially large net water loss from the groundwater in these areas as a result of groundwater use by the Pine plantations.

Over the course of the next few decades, it became clear that groundwater use by Pine plantations was more likely a probability rather than a possibility and the challenge was to quantify the amount used and the factors that determine it. This culminated in the development of medium term water balance studies at different sites by CSIRO Division of Forestry and Forest Products, starting in the late 1990s and continuing to the present (Benyon and Doody, 2004; Benyon, 2005).

Using the analyses for the core samples collected under native vegetation and in cleared areas, we can make point estimates for recharge at each of the sites studied. At the native vegetation sites, recharge can be estimated by using the chloride mass balance technique, the same method used by Allison and Hughes (1978). This method has been used extensively over the last 30 years. It basically assumes that, under steady state conditions, the chloride present in the soilwater below the rootzone of the native vegetation is the same as that recharging the groundwater. As such, the chloride concentration of rainfall, $[Cl]_{rain}$ when multiplied by the mean annual rainfall amount, *MAR* , should equal the chloride concentration of soilwater, $[Cl]_{sw}$ multiplied by the rate of recharge, *Rech*, to the aquifer.

$$Rech = MAR * [Cl]_{rain} / [Cl]_{sw} \quad (1)$$

In the recharge study by Allison and Hughes (1978), no measurements of $[Cl]_{rain}$ were available so an estimate of ~7 mg L^{-1} (for site 3 in Allison and Hughes, 1973) was calculated from the empirical relationship between $[Cl]_{rain}$ and distance from the coast developed by Hutton (1976). During 2005, rainfall has been collected at Mt Gambier by Mr. Mustafa (of the Department of Water, Land and Biodiversity Conservation, DWLBC) and the samples analysed for chloride concentration. The precipitation weighted mean chloride concentration was measured at 11 mg L^{-1}, about 50 % greater than that previously estimated.

The $[Cl]_{sw}$ for the unsaturated zone under native vegetation reaches a plateau value of ~1000 mg L^{-1} (Figure 4). Using $[Cl]_{sw}$ = 1000 mg L^{-1}, MAR = 750 mm yr^{-1} and for $[Cl]_{rain}$ = 11 mg L^{-1}, recharge under mallee vegetation would be approximately 8 mm yr^{-1} at the two sites studied. It is worth noting that both of these sites had quite sandy surface soil. During coring, live roots were found throughout the unsaturated zone at site 104214. In addition, analysis of soil gas at that site showed higher levels of CO_2 close to the watertable than towards the top of the profile. This suggests that, at least at some times, the roots are active at that depth and some groundwater uptake is taking place, even with the watertable at a depth of ~6 m. If this is the case, the chloride in the unsaturated zone may in fact be derived both from above (rainfall) and below (groundwater uptake). Hence, a small amount of groundwater uptake may also be the case at this site.

A similar chloride balance approach can also be made to estimate recharge under cleared areas providing the cored site has been cleared long enough and the recharge rates high enough, to flush out the stored salt in the unsaturated zone. The minimum values of *$[Cl]_{sw}$* measured at the cleared sites range from ~20 to ~190 mg L^{-1} (Table 2). Recharge rates at the cleared sites, using these data are estimated to range from 40 – 375 mm yr with an average recharge rate of ~200 mm yr^{-1}.

Table 2. Summary of recharge and discharge at the sites with and without native vegetation cover

Site #	$[Cl]_{sw}$ Native cleared	WT (m)	Average % clay (0-2m) (0-WT)	Recharge/gw uptake mm yr^{-1}
104226	1000 …….	16.6	2.1 14.7	low recharge/discharge
104214	1000 …….	5.3	5.0 12.6	8 recharge
104217	…… 30	5.2	44.7 28.1	250 recharge
104219	…… 20	7.9	4.2 18.6	375 recharge
104223	…… 120	3.0	17.0 17.0	65 recharge
104220A	…… 190	20.0	1.2 4.3	40 recharge
104220B	…… 30	3.5	11.9 16.8	250 recharge

4.2. Groundwater Uptake by Forestry

4.2.1. Methodology

Estimates of groundwater uptake by forestry in the area are limited (Benyon and Doody, 2004; Benyon, 2005). Over the last 10 years, groundwater use estimates in Pine and Bluegum plantations have been made at ~20 sites in SE South Australia using water balance/sap flow methodology. The age of the Pine and Bluegum stands were up to 79 and 17 years respectively although the older sites had several rotations (discussed below). The watertable depths ranged from 2.4 to ~10 m .

For the sites currently forested with Pine or Bluegum, there have been several changes to land use over the last century. For each landuse change, there will be corresponding changes in recharge to the groundwater and, in some case, the potential for groundwater use by the vegetation. Each of these changes will also have an impact on the salinity of the soilwater (presented here using the conservative tracer [Cl].) The methodology, and results, when using $[Cl]_{sw}$ measurements to estimate recharge under native vegetation and under pasture were presented in the previous section of this report.

In this report, we estimate groundwater uptake using an entirely different methodology to the water balance studies used previously. The method utilises the accumulation of salt (measured as chloride) that takes place in the unsaturated zone when Pine or Bluegums are planted in areas previously under crop or pasture. The method assumes import (accumulation) of chloride to the unsaturated zone following forestry development is the result of

i) upward capillary flow from the groundwater induced by tree roots in the capillary. Pure water is removed from the unsaturated zone leaving chloride behind in the soilwater.
ii) chloride present at low concentrations in rainfall being concentrated in the unsaturated zone as a result of infiltration and then evapotranspiration.

We assume that recharge to the groundwater ceases three years after Pines/Bluegum are planted although clearly this will be dependent on factors such as the rate of development of the Pine trees or Bluegum, the spacing of the trees and depth of the watertable. The time of three years was chosen following discussions with Richard Benyon (CSIRO Forestry) using results from his water balance studies in the area. As a result of this assumption, we assume that there is no loss of chloride from the unsaturated zone (as a result of recharge) for all but three years of the time when the area is forested. Clearly, this may not be the case, particularly when planting rotations result in the area being partially or completely cleared for significant periods.

The method also assumes that there is no passage of chloride in the sap flow and subsequently via leaf fall and other dry matter (litter). Measurements of the amount of chloride present in dry matter suggest that this is a valid assumption, unless there is significant salt stress on the Pine/Bluegum trees. The final assumption is that there is no loss (or gain) of chloride from the unsaturated zone when watertables rise and fall. In reality there is likely to be significant loss from the unsaturated zone to the groundwater by the annual watertable fluctuations. As this loss cannot be measured, it is probable that groundwater uptake using the chloride accumulation method will underestimate the chloride accumulation in the unsaturated zone and hence under estimate water use by the trees. This is particularly the case in shallow watertable environments, particularly in areas of large watertable fluctuation.

Assuming the above, the difference, ΔCl (g m^{-2}), between the chloride stored in the unsaturated zone under Pine or Bluegum forest, Cl_{forest} (g m^{-2}), and that stored in the same unsaturated zone soils prior to planting the forests ($Cl_{cleared}$ g m^{-2}), should be the result of chloride from the groundwater (induced to move vertically upwards by tree water use) and that from rainfall. The chloride derived from the groundwater can be expressed as the chloride concentration in the groundwater, $[Cl]_{gw}$, multiplied by the total amount of groundwater uptake by the trees, $U_{T.}$ The chloride accumulated from rainfall (g m^{-2}) can be expressed as the chloride concentration in rainfall $[Cl]_{rain}$ (g m^{-3}), multiplied by the amount of rain that has fallen since the trees were planted. We have assumed that this equals the mean annual rainfall, R, multiplied by the age, A (yrs), of the forest. The following equation then applies:

$$\Delta Cl = Cl_{forest} - Cl_{cleared} = [Cl]_{gw} U_T + [Cl]_{rain} R \; A \qquad (2)$$

Or, by rearranging the equation, the groundwater uptake over the life of the forest can be estimated by the following.

$$U_T = (Cl_{forest} - Cl_{cleared} - [Cl]_{rain} R \, A) / [Cl]_{gw} \qquad (3)$$

The mean annual groundwater uptake by the Pine or Bluegum forest, U_A (m yr^{-1}), can be estimated by dividing the total amount of groundwater uptake by the number of years that the tree is assumed to have been using groundwater (A-3). Hence;

$$U_A = U_T / (A-3) \qquad (4)$$

It is important to recognise that the method described here for determing groundwater uptake by trees is a “difference” method. As such, any errors associated with measuring or estimating any of the components will impact on the final error in the groundwater uptake estimate. Furthermore, the relative error in the groundwater uptake estimate is directly proportional to the age of the plantation. Hence, as discussed below, there will be a much larger error for the groundwater uptake estimates for the Bluegum plantations (A = 7-17 years) compared to that for the Pine sites (60-79 years).

4.2.2. *Estimating Soilwater Chloride ($Cl_{cleared}$) of Cleared Land*

One of the main limitations to this method for estimating U_T is the estimation used for $Cl_{cleared.}$ An overestimate in this value will result in an underestimate in the amount of chloride that has accumulated since the trees were planted and hence an underestimate in the amount groundwater uptake by the trees. Likewise an underestimate for $Cl_{cleared}$ will result in overestimating ΔCl and hence $U_{T.}$

$Cl_{cleared}$ can not be measured retrospectively for sites currently planted. Hence, if we want to use measured values for $Cl_{cleared}$, we will need to analyse samples for Cl from the unsaturated zone soil at a site earmarked for forestry, wait several years after forestry development and then resample. Because the method relies on a difference between the initial and final amounts of chloride in the unsaturated zone, the error associated with U_T and hence U_A will decrease for older forests (with more accumulated chloride) than for younger forests. This is therefore not a realistic option with current timeline limitations.

The alternative is to use our best understanding and knowledge to estimate what $Cl_{cleared}$ would have been at each of the sites. To do this, we need to know $[Cl]_{sw}$ and the water content of the unsaturated zone. We can measure what the water content of the soil is at the time of sampling and this itself is a reasonable first approximation of what it would have been prior to forestry. However, soil profiles under cleared conditions usually have higher water contents than the same profiles under forestry. This can also be seen (Fig 12) for soilwater suction profiles with cleared sites in general having lower soilwater suction than forested sites (Figures 13&14). For the unsaturated zone soil profiles in the study area (average clay content ~20%), we estimate that the water content of soils under cleared sites would be approximately 25% greater than that under forested sites. This is the average difference in water content observed for soils having similar clay contents but with soilwater suctions equivalent to those under forested and cleared sites respectively (see Leaney et al, 1999, Fig. 14 for data set). Hence, a better estimate of the water content for soils under cleared conditions would be approximately 1.25 that for the same soil under forestry.

When estimating $[Cl]_{sw}$, we are fortunate that, for this area, sites cleared of native vegetation for several decades have very little chloride store (ie $[Cl]_{sw}$ is very low, Fig. 5). In areas currently forested that were cleared several decades before planting, it is valid to use an average value for $[Cl]_{sw}$. For our study sites, the average for $[Cl]_{sw}$ is ~100 mg L^{-1} and this is used in the following sections.

Unfortunately, not all of the study sites under Pine or Bluegum experienced an extended period of clearing prior to the trees being planted. Hence, we need to determine what is the minimum clearing time required to flush the salt from the profile and hence provide a “clean slate” for chloride accumulation. This is best estimated by considering the amount of water in the unsaturated zone profile, the amount of time cleared and the likely recharge rate to determine whether or not at least one complete pore volume of soilwater has been flushed from the unsaturated zone into the soilwater.

Because all of the sites have different history for clearing, period of forestry, depth to water and soil type, we discuss each of the sites separately below.

Site 104327 (A1) Pine Plantation

Pines at this site were first planted in 1926 with a second rotation in 1953 and a third rotation in 1988. It is believed that the pine trees were first planted soon after the land was cleared of the native scrub. However, records of this are not clear and there may have been a short period of time (maybe a year) in which the ground was reasonably bare. Furthermore, it would have taken a few years for the Pine trees to establish following each rotation. During that time, recharge would slowly reduce from perhaps 200 mm yr^{-1} to zero and eventually see a net groundwater withdrawal by the trees. We suggest that maybe up to 1500 mm of recharge took place during the three periods where Pines were either absent or immature.

In addition to this, the Pine trees were burnt in 1950 and not replanted until 1953. Assuming three years of relatively bare earth with recharge at ~200 mm yr^{-1} suggests 600 mm more recharge during this time, resulting in a total amount of recharge of 2100 mm.

The depth to groundwater at site 104327 is ~9 m with ~1.3 m of water stored in the unsaturated zone. Hence, as the combined recharge periods are likely to have flushed 1.5 times the volume of water present in the unsaturated zone, we could assume complete flushing of the profile and assume $[Cl]_{sw}$ is 100 mg L^{-1} at this site. Using this value and the methodology above, we would estimate ΔCl = 1080 g m^{-2}, of which about half (545 g m^{-2}) is derived from groundwater.

$[Cl]_{gw}$ was not measured at this site but from EC measurements at the closest bores and using the regional relationship between EC and [Cl], we estimate it to be ~230 mg L^{-1}. Using this value, we would suggest uptake of groundwater by the trees to be approximately 40 mm yr^{-1} for 70 of the last 79 years since the Pine trees were planted. In actual fact, because of the partial flushing of chloride from the profile at the start of each rotation this is likely to be a significant underestimate of Cl_{forest} and hence a significant underestimate of the groundwater uptake at this site.

Site 104216 B4 Pine Plantation

Pines at this site were planted in 1968 and are still in their first rotation. The best information on the previous land use for this site is from aerial photos taken in 1968 (S. Shaw, pers. comm.) The aerial photo shows sparse tussocky low vegetation and the southern part of the area clearly had inundation from the swamp to the south. With this vegetation condition, the assumption of complete flushing is likely to be valid. In fact, because of the flooding, $[Cl]_{sw}$ is likely to be even lower than that for pasture sites. We have used a value of $[Cl]_{sw}$ = 50 mg $L^{-1,}$ halway between that in rainwater and the value we have used for soilwater under a cleared site, in estimating groundwater uptake at this site.

Using this value and the methodology above, we estimate ΔCl = 1860 g m^{-2}, of which 1390 g m^{-2}) is derived from groundwater. The measured value for $[Cl]_{gw}$ is 230 mg L^{-1}. Using this value, groundwater uptake by the trees is estimated to be ~100 mm yr^{-1} for 34 of the last 37 years since the Pine trees were planted. The standing water level (SWL) at this site is about ~4.5 m with an annual fluctuation of the order of ±0.3 m Although the watertable fluctuation at this site is less than at many of the other sites, there is still a strong probability for removal of chloride from the unsaturated zone as a result of watertable fluctuations. This will result in an underestimate of chloride accumulation. Hence, the groundwater uptake estimate of 100 mm yr^{-1} at this site should be considered a minimum value.

Site 108346 G18 Pine Plantation

Pines at this site were planted in 1970 and are still in their first rotation. As for site 104216, the best information on the previous land use for this is from aerial photos. At this site aerial photos are available for 1965 and 1968 (S. Shaw, pers. comm.) The

1965 aerial photo show relatively good scrub, including some trees. By 1968, the area had been cleared with very low vegetation and no trees. Hence, one can assume a period of between 2 and 5 years clearing prior to planting the Pine trees.

If we assume similar rates of recharge for cleared areas and areas with young trees as used at site 104327, we suggest that 900-1500 mm of recharge took place prior to planting. The depth to groundwater at this site is 5 m with ~0.9 m of water stored in the unsaturated zone. Hence, because 1-1.5 pore volume of water is likely to have been flushed from the unsaturated zone during the cleared phase, we assume complete flushing of the profile and assume $[Cl]_{sw}$ is 100 mg L^{-1} at this site. Using this value and the methodology above, we would estimate ΔCl = 600 g m^{-2}, of which slightly more than half (350 g m^{-2}) is derived from groundwater.

The measured value for $[Cl]_{gw}$ is 330 mg L^{-1}. Using this value, groundwater uptake by the trees is estimated to be 30 mm yr^{-1} for 32 of the 35 years since the Pine trees were planted. However, as suggested for site 104216, this should be considered to be a minimum estimate given the potential for flushing chloride from the unsaturated zone as a result of groundwater fluctuations.

Site 108347 (H19) Pine Plantation

At this site, the scrub was cleared in 1934 and was under pasture until planted to Pines in 1945. A second rotation of Pines was made in 1996. This suggests that there was a period of 11 years where at least 2 m of recharge flushed the unsaturated zone prior to planting the Pines (using the same recharge rates as for the previous pasture/young tree sites).

The depth to groundwater at this site is ~6 m.Because the clay content is high at this site, θ_g, averages ~0.3 and there was ~2.7 m of water stored in the unsaturated zone. This is at least double that at the other Pine sites with sandier soils and θ_g usually ~0.1 to 0.15. Using estimates of 2 and 3 m for recharge and water storage, we suggest only two thirds of the unsaturated zone is likely to have been flushed of salt during the cleared phase. Hence, we have used $[Cl]_{sw}$ = 400 mg L^{-1} in our calculations for $Cl_{cleared}$. This value assumes a 2:1 weighting of $[Cl]_{sw}$ for cleared (100 mg L^{-1}) and native vegetation (1000 mg L^{-1}) land use respectively (ie 400 = 0.67*100 + 0.33*1000).

Using this value for $[Cl]_{sw}$ and the methodology above, we estimate ΔCl = 7780 g m^{-2}, of which nearly all (7340 g m^{-2}) is derived from groundwater. The measured value for $[Cl]_{gw}$ at this site is 354 mg L^{-1}. Using this value, groundwater uptake by the trees is estimated to be 390 mm yr^{-1} for 54 of the 60 years since the Pine trees were planted. However, for the same reasons as suggested at the other sites (watertable fluctuations and flushing during rotations) this should be considered to be a minimum estimate of groundwater uptake at this site.

Bluegum Plantations

The development of Bluegum forest in the lower south east of SA is much more recent than that of Pine forest. The oldest Bluegum forest in this study is site 104215, planted in 1988 with a second rotation in 2000. Of the other sites, 104221, 104227 and 104228 were all planted in 1998, site 104225 was planted in 1996 and site 108348 was planted in 1994. All Bluegum sites are believed to have been developed in areas that had been cleared of native vegetation for decades prior to planting the Bluegum trees.

At two sites, 104215 and 104228, there is no evidence of accumulated salt, above that expected for pasture, in the unsaturated zone. In the case of 104215, this may be the result of whatever salt was in the unsaturated zone at the end of the first rotation

(1999) being flushed out. There is about a metre of water in the unsaturated zone at site 104215. This is about double that expected to be flushed by recharge between the1st and 2nd rotation. Hence, unless recharge is more than expected at this site, chloride accumulation should be observed. Some suggestions as to why this may not be the case are discussed in the next section.

At site 104228, it was not possible to core to the watertable. Dry cemented layers stopped drilling at a depth of ~7m. This is probably a few metres above the watertable, which, from other bores in the area is likely to be at a depth of 9-10 m. Hence, it is not possible to say whether or not there is chloride accumulated immediately above the watertable. Nevertheless, the absence of accumulated chloride above that expected under pasture is consistent with no groundwater uptake by the Bluegum.

Site 104227 shows the most chloride accumulation in the unsaturated zone for all of the Bluegum sites. This site has a large accumulation of chloride at a depth of ~ 2.5 m, immediately above the 3-3.5 m watertable. This is also one of the youngest Bluegum forests. Using the same methodology as used for the Pine sites, the estimate of groundwater use at this site is >1000 mm yr^{-1}. Groundwater uptake estimates at sites 104225 and 104221 are >300 mm yr^{-1}. The estimated minimum groundwater uptake at site 108348 is >>140 mm yr^{-1}. The minimum value is likely to be a large underestimate. Most of the chloride at this site was measured for the deepest sample collected and there is likely to be considerable more chloride over the next metre or two (ie at the depth of the fluctuating watertable).

As is the case for estimates of groundwater use at the Pine sites, the estimates at the Bluegum sites are likely to be minimum values. However, in addition, because of the limited age of the Bluegum forests, the errors associated with estimating groundwater uptake for all Bluegum sites are large (probably of the same order of magnitude as the estimate itself). Estimates of groundwater uptake by Pine and Bluegum forest from this current study are summarised in Table 3.

Table 3. Summary of groundwater uptake at Pine and Bluegum sites (current study).

Site #	Forest	WT Depth (m)	Age/ Rotations yrs	GW uptake mm yr^{-1}	Comments
104327	Pine	9	79/3	>40	
104216	Pine	4.9	37/1	>100	
108346	Pine	5	35/1	>30	
108347	Pine	6	60/2	>390	
104215	Bluegum	5	17/2	0	gw use < expected
104228	Bluegum	9.5	7/1	0	Coring ceased above WT
104227	Bluegum	2.8	7/1	>1000	Large uncertainty
104221	Bluegum	2.8	7/1	>300	Large uncertainty
104225	Bluegum	4	9/1	>300	Large uncertainty
108348	Bluegum	2.4	11/1	>>140	Large uncertainty

5. Discussion

5.1. Groundwater Uptake

Groundwater use, as evidenced by chloride accumulation in the unsaturated zone, is seen at all of the Pine forestry sites and at 4 of the 6 Bluegum sites. At site 104228, the watertable is ~9.5 m deep and the Bluegums were only planted 7 years ago. Hence, groundwater uptake is not expected at this site. At site 104215, groundwater uptake and chloride accumulation would be expected given the results at the other sites and the fact that Bluegums were first planted ~17 years ago and the watertable is only ~5 m deep.

A possible reason why this is not the case may be related to the presence of heavy clay throughout the unsaturated zone at this site that may be preventing the Bluegums utilising the groundwater. This would result in less vigorous growth compared to that seen at most other sites. It was noted that the growth at this stand was poor compared to other stands of similar age. A similar situation is observed at Pine site 108346, where the groundwater use is considerably less than expected for a well developed Pine plantation with groundwater only at a depth of only 5 m. Benyon (pers comm.) reports the presence of a hard layer that he believes is likely to restrict root penetration at the Pine site.

An alternative explanation may be that there was higher than predicted rates of flushing at this site for the years 2000-2005 and any chloride accumulated was flushed into the groundwater. The annual rainfall during this time was 10% higher than average with that immediately after tree removal almost 20% higher. Chloride, accumulated from the first rotation may have been flushed out of the unsaturated zone during this wetter period and there has been insufficient time (and no need) for the trees to start using groundwater and start accumulating significant amounts of chloride after that time.

There is a considerable range in estimates of groundwater uptake at the Pine sites ranging from >30 to > 390 mm yr^{-1}. Unfortunately, all estimates of groundwater uptake must be considered as minimum values and it is not possible to estimate the extent to which they underestimate the correct value. At the Bluegum sites, there are large errors associated with the groundwater uptake estimates in addition to the requirement for these to be considered minimum values.

5.1.1. Comparison with Estimates from Water Balance Studies

Six of the sites where groundwater uptake has been measured using the chloride accumulation method (two Pine sites and four Bluegum sites) have also had estimates using water balance/sap flow measurements (Benyon and Doody, 2004; Benyon, 2005). The mean value for groundwater uptake and the study period to which the measurements apply are summarised in Table 4.

It is important to realise that the cumulative chloride and water balance/sap flow methodology used to estimate groundwater uptake are entirely independent. The only commonality is that they are both “difference” methods. For the water balance methodology, groundwater uptake is not measured directly but is estimated from the difference between input (rainfall) and output (evapo-transpiration and recharge). Any errors in the measured components will result in the same error in the estimate of groundwater uptake.

Table 4 Comparison between estimates of groundwater use by Pine and Bluegum using the chloride accumulation and water balance/sap flow methods.

Site	Mean GW Uptake (mm yr^{-1}) * by Cl accumulation.	Mean GW Uptake (mm yr^{-1}) By water balance/sap flow
Pine		
108346 G18	>30 (1968-2005)	0 (1997-2000)
108347 H19	>390 (1945-2005)	600 (2001-2005)
Bluegum		
104228 F17	0 (1998-2005)	0 (2002-2005)
104227 F16	>1000 (1998-2005)	220 (2002-2005
104225 D10	>300 (1996-2005)	400 (2002-2005)
108348 I20	>>140 (1994-2005)	640 (2000-2004)

*the mean does not include the first three years after planting nor a period of three years after each rotation.

For the chloride accumulation method, chloride accumulation is determined by the difference in the amount of chloride in the unsaturated zone after forestry less that present before forestry. Again, any errors in the estimation of either of these will impact directly on the error of the groundwater uptake estimate. The advantage of estimating groundwater uptake by both methods is that, if they agree, there is added confidence in the overall groundwater uptake estimate at each site measured. Moreover, agreement will result in greater confidence of each of the methodologies used.

At the Pine sites, there is good agreement between the groundwater uptake estimates for the two methods. Both methods suggest low rates of groundwater uptake at site 108346 and high rates at site 108347. The results are even more interesting when one considers that they have similar depths to the watertable. In fact, the higher rate of uptake is seen at the site with the deeper watertable. Clearly, at site 108346, there is something about the soil or trees at that site that is significantly impeding the ability for the Pine trees to access water. The most likely reason, as suggested by Benyon and Doody, 2004~~,~~ is the presence of a hard layer at a depth of ~ 1-2 m at that site.

There is also general agreement between the methods at three of the four Bluegum sites. This is despite the likely large errors using the chloride accumulation method at these sites. The exceptions are at sites 104227 and 108348. At site 108348, the minimum estimate from the accumulated chloride method is considerably less than the estimate using water balance methodology. However, as discussed earlier, the estimate using chloride accumulation is likely to be a considerable underestimate at this site because sampling did not proceed far enough to define all of the chloride accumulated.

At site 104227, the estimate using the chloride accumulation method is far in excess of that using the water balance method. There are several reasons why this may be the case. We have already discussed the possibility of incomplete flushing of chloride from the profile prior to planting the Bluegum but there are other possible explanations, as discussed below.

5.2. Temporal and Spatial Variability in Groundwater Uptake

So far in this report, no mention has been made of the potential for temporal and spatial variation in groundwater uptake in Pine and Bluegum forests. In general, one would expect to see lower rates of groundwater uptake for wetter years and vice versa. The groundwater uptake estimates made using the chloride accumulation method were made over a timeframe that had close to average rainfall. On the other hand, most of the water balance measurements were made during 2000-2005, a period where rainfall has been approximately 10% greater than average. Hence, one could expect even higher rates of groundwater uptake in average or below average rainfall years.

This being the case, the difference seen between the minimum estimates of groundwater uptake using the chloride accumulation method and the estimates made using the water balance method would be even greater than reported in this report. In other words, it is highly likely that the chloride accumulation method significantly underestimates groundwater uptake, particularly in areas with varying watertable depth.

The exception to this was the timeframe for the water balance studies at site 108346 when rainfall was ~10% lower than average. It is probable that the estimate using water balance methodology for 1997-2000 would be more than that for an average year at that site. However, given that the there is no groundwater uptake estimated at this site, whatever is causing the low rate of groundwater use at this site is clearly having a much greater impact than the temporal variability in rainfall.

Spatial variability is also likely to impact on groundwater uptake measurements using both the water balance and chloride accumulation methodologies. For the water balance/sap flow methods, transpiration and interception are usually measured on a single tree and evaporation is estimated on the surrounding area. Hence, the groundwater uptake measurement averages that over the canopy area of the tree.

For the chloride accumulation method, the chloride is measured at a point scale, being the site of the soil core. As such, there is the potential for variability in this measurement, depending on the proximity of roots to the soil sampled. As trees get more advanced and the root system more extensive, the variability in chloride measured in a forest is likely to decrease. For this reason, one could foresee greater spatial variability in groundwater uptake measurements in the younger Bluegum forest than the well established Pine forest sites. The high rate of groundwater uptake estimated using the chloride accumulation method at site 104227 may be an example of this, and suggests that for large scale estimates, more cores would improve the estimates.

We have also presented evidence of spatial variation in groundwater uptake as a result of the presence of hard layers and/or heavy clay layers that do not allow or, at least, restrict root penetration. This was observed at Pine site 108346 (hard impenetrable layer) and at Bluegum site 108228 (heavy clay layer). The spatial extent and distribution of these layers is currently unknown, and ought to be established, either using drilling or geophysical techniques, in order to improve the estimates over wider regions.

Salt Accumulation

One of the aims of this project was to determine the amount of salt stored in the unsaturated zone under different types of land use. There is clear evidence that, because the study region has a high rainfall and the surface soils are predominantly sandy, most salt present in the unsaturated zone under native vegetation is flushed

from the system within a decade or two after the area is cleared. There is also clear evidence that both Pine trees and Bluegums use groundwater and, as a result, accumulate salt in the unsaturated zone.
Furthermore, there is evidence that well established Pine trees can use groundwater (and accumulate salt in the unsaturated zone) in areas with watertables at least 9 m below the surface. In general, however, the amount of groundwater used and therefore the amount of salt accumulated is greater in areas with shallower watertables. Soilwater chloride concentrations in the watertable capillary zone under Pine trees have been measured at up to 8 000 mg L^{-1} (~16 000 mg L^{-1} Total Dissolved Salts).

At the more recently developed Bluegum sites, soilwater chloride concentrations have been measured at up to 4000 mg L^{-1}. There is no evidence of chloride accumulation at the Bluegum site 104228 where the watertable is considerably deeper than the other Bluegum sites. Whether or not groundwater uptake and chloride accumulation would take place if the Bluegums were to continue to grow for a further decade or two cannot be answered from the data available. However, it appears as though the rate of chloride accumulation at the Bluegum sites is at least as high as the Pine sites, presumably as a result of being established in general on areas with shallower watertables.

Although groundwater uptake and chloride accumulation by both Pine and Bluegum generally increases in areas of shallow watertables, there are obvious exceptions (Pine site 108346 and Bluegum site 104215). As discussed before, it is likely that heavy clay or a hard layer is stopping the roots accessing the watertable at both of these sites. At these sites, clearly there is no likelihood of salt accumulation in the unsaturated zone.

Whilst salt accumulation does appear to be the norm rather than the exception, there is also a strong suggestion that some of this salt may be partially flushed from the profile on a regular basis. The process likely to be driving this is associated with watertable fluctuations that would tend to seasonally flush some of the salt stored in the bottom of the capillary zone. The indirect evidence that this may be occurring comes from the observation that groundwater uptake as determined by chloride accumulation tends to be less than that determined by water balance calculations.

Further flushing of salt from the unsaturated zone is also likely to occur during the interval between rotations and during the first few years of tree growth. For Bluegum forestry, the rotations are likely to be of the order of every 14 years (12 years growth and 2 years between rotations). Hence, accumulation of salt is likely to take place for maybe 9-10 out of every 14 years with at least partial flushing of salt during the remaining years. This being the case, it is likely that the concentration of salt in the unsaturated zone soilwater and in the shallow groundwater will cycle from high to lower concentrations.

This cycling between groundwater uptake and unsaturated zone flushing is shown schematically in Figure 22. The degree of flushing will depend on factors such as the texture of the soil in the unsaturated zone, the watertable depth and the amount of rainfall between rotations. In addition to the salinity cycling, there will, however, also be a longer term gradual salinity increase in both the shallow groundwater and in the soilwater in the unsaturated zone. This is the result of the overall net loss of water via transpiration from the unconfined/shallow groundwater system. Variations in rainfall will obviously impact on this general trend along with other factors such as aquifer flow velocity.

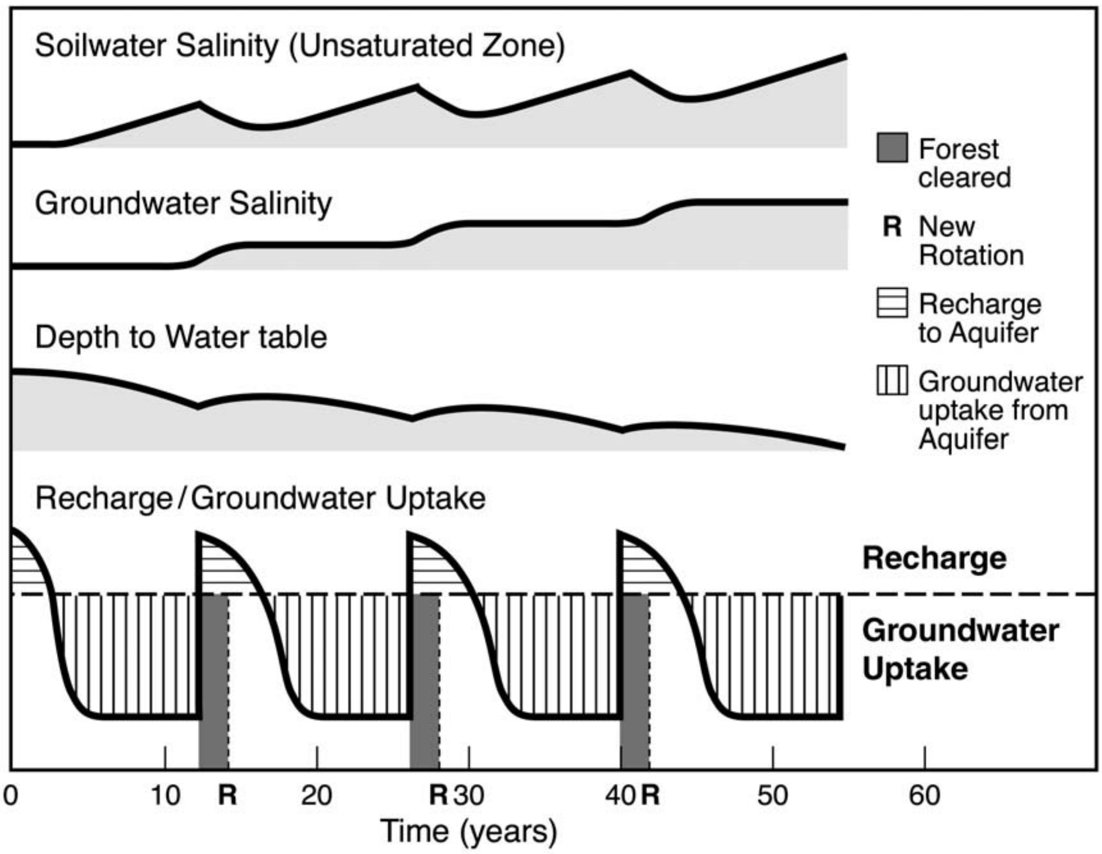

Figure 22. Schematic of the expected changes to standing water level, and soilwater and groundwater salinity in Bluegum forests with 14 year rotation.

6. Conclusions

The results from chloride accumulation measurements show that both Pine and Bluegum may be significant users of groundwater. Pine trees are able to extract water from the groundwater capillary zone in areas where the groundwater depth is at least ten metres. The Bluegum trees studied were shown to access groundwater to depths of at least four metres. At the sites studied, the difference in the groundwater accessibility between Pines and Bluegums is primarily associated with the age of the forest. In addition to the forest age, however, groundwater uptake is also strongly related to the depth of the watertable. The groundwater uptake for both Pine and Bluegum can exceed 500 mm yr^{-1} in areas where the watertables are less than 5 metres deep.

Groundwater uptake by trees clearly will result in chloride accumulation in the unsaturated zone. However, there is strong evidence from this study that watertable fluctuation and fallow periods for tree rotation can result in significant flushing of salt from the unsaturated zone into the groundwater. As a result, the chloride accumulation method used in this study may result in considerable underestimation of groundwater uptake by trees.

The estimates of groundwater uptake for Pine and Bluegum sites in this study agree well with estimates presented over the last few years for the same sites using water balance/sap flow methods. This provides additional confidence in the use of both methods, particularly because the two methodologies used are entirely independent.

Although groundwater uptake by trees is the norm rather than the exception in this area, the presence of heavy clay or hard impermeable layers in the unsaturated zone may significantly reduce or even stop groundwater uptake by the trees. The results from this study confirmed little or no groundwater uptake at two sites where such layers were present.

Recent Bluegum forestry tends to have rotations averaging about 14 years and consisting of approximately 12 years growth and 2 years fallow. This being the case, accumulation of salt is likely to take place for maybe 9-10 out of every 14 years with at least partial flushing of salt during the remaining years. Hence, it is likely that the concentration of salt in the unsaturated zone soilwater will cycle from high to lower concentrations. The shallow groundwater may also cycle from high to low salinity but out of phase with the unsaturated zone.

However, in addition to the salinity cycling, there will also be a longer term gradual salinity increase in both the shallow groundwater and in the unsaturated zone soilwater. This is the result of the overall net loss of water via transpiration from the unconfined/shallow groundwater system. The net water loss in these areas will also be reflected in lowering watertable until a new steady state situation is reached with the surrounding land use and lateral aquifer flow.

7. Further Work

This study was initiated as a pilot study primarily to determine whether there was likely to be accumulation of salt in the unsaturated zone under Pine and Bluegum forest and whether it would be possible to use this data to estimate groundwater uptake by the trees. As such, the limited amount of sampling available has meant that spatial variations in groundwater uptake have not been adequately addressed. In particular, the spatial variation in groundwater uptake that is likely within a single plantation due to factors such as distance from individual trees and the presence of hard impenetrable layers or heavy clay layers needs to be studied in more detail.

It would also be interesting analyse the soilwater salinity profiles at sites where the timber growth is higher than expected and alternatively lower than expected to correlate growth to groundwater uptake and factors such as the presence of heavy clay or hard impenetrable layers that may reduce vertical root progression.

This study also identified the likely flushing of salt from the unsaturated zone as a result of both annual watertable fluctuations and the interval between tree felling and re-establishment of the next tree rotation. To address this, it would be useful to sample cores periodically from a single site over at least one rotation. By doing this, it would be easier to quantify the vertical scale presented in the schematic of surface and groundwater salinity increase with time (Figure 22). Sites chosen for this study could provide the basis for this future work.

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Appendix A

Analytical Methods For Soil Analyses

Gravimetric water content

Calculated from the difference in weight of the soil sample and the sample dried at 105 ^{0}C for 24 h divided by the dry weight of soil.

Soilwater chloride concentration (as per Taras *et al*., 1975)
The amount of chloride in the soil (soil chloride ie. mg of Cl per kg of dry soil) was determined by extracting the chloride from soil samples using a 5:1 dilution with water. Soilwater chloride (mg of Cl per Litre of water) was calculated by dividing the soil chloride by the gravimetric water content.

Soilwater potential (as per Greacen *et al*., 1987)
Soilwater potential measurements were made by placing 3of 55 mm Whatman 42 filter papers at 3 levels in a 500 ml glass jar filled with soil compacted using a rubber plunger. The SWP of the soil equilibrates with the filter paper. The amount of water in the filter paper indicates the SWP of the filter paper and hence, the soil.

Particle size analysis (as per Lewis 1983)

The percentage of different particle size fractions was determined using the method developed by Bowman and Hutka, 2002 using air dried soil samples that had been treated with 6% hydrogen peroxide solution to remove any cementing organic matter. If carbonate were also present the sample was reacted with a calculated volume of 1M acetic acid to remove the carbonate cementing before washing to remove calcium and magnesium salts and dispersing with an alkaline polyphosphate solution. Sand is considered to be coarser than 0.02 mm, silt between 0.02 and .002 mm and clay to be finer than 0.002 mm (2000 micron).

Appendix B

Measurements from soil cores

	A1 Site 104327		Pines	
DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.008	770	1700	56.9 : 39.1 : 4.0
0.5 – 1.0	0.007			56.5 : 39.2 : 4.2
1.0 – 1.5	0.008	2150	1500	63.2 : 29.0 : 7.8
1.5 – 2.0	0.030			65.9 : 25.6 : 8.5
2.0 – 2.5	0.024	1130	940	
2.5 – 3.0	0.137			
3.0 – 3.5	0.226	130	2200	
3.5 – 4.0	0.161			
4.0 – 4.5	0.199	300	1700	30.5 : 28.6 : 40.9
4.5 – 5.0	0.224			
5.0 – 5.5	0.336	850	2800	
5.5 – 6.0	0.017			
6.0 – 6.5	0.028	7700	940	24.8 : 54.7 : 20.6
6.5 – 7.0	0.034			
7.0 – 7.5	0.036	4700	990	
7.5 – 8.0	0.084			
8.0 – 8.5	0.069	290	23	16.3 : 56.6 : 27.1
8.5 – 9.0	0.090			
9.0 – 9.5	0.188	190	6.4	
9.5 – 10.0	0.288	120	7.7	

	A3 Site 104214		Native Vegetation	
DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.031	380	2900	66.7 : 28.0 : 5.3
0.5 – 1.0	0.008			60.6 : 35.7 : 3.7
1.0 – 1.5	0.018	160	16	60.8 : 36.1 : 3.1
1.5 – 2.0	0.071			51.1 : 33.7 : 15.2
2.0 – 2.5	0.036	950	6.0	61.1 : 32.0 : 6.9
2.5 – 3.0	0.064			
3.0 – 3.5	0.075	1130	4.1	
3.5 – 4.0	0.324			
4.0 – 4.5	0.371	940	8.0	7.9 : 36.7 : 55.4
4.5 – 5.0	0.217			
5.0 – 5.5	0.273	200	5.4	

B4 Site 104216 Pines

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	65.2 : 31.4 : 3.3
0.0 – 0.5	0.007	420	52	54.3 : 39.5 : 6.1
0.5 – 1.0	0.007			41.2 : 38.0 : 20.8
1.0 – 1.5	0.088	910	530	40.1 : 33.0 : 27.0
1.5 – 2.0	0.237			69.9 : 26.8 : 3.3
2.0 – 2.5	0.201	1450	7.7	
2.5 – 3.0	0.177			
3.0 – 3.5	0.158	4300	8.3	
3.5 – 4.0	0.157			
4.0 – 4.5	0.199	950	3.7	42.6 : 34.9 : 22.4
4.5 – 5.0	0.353	290	8.6	

B5 Site 104215 Bluegums

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.043	130	3200	7.7 : 48.6 : 43.6
0.5 – 1.0	0.271			25.6 : 53.9 : 20.5
1.0 – 1.5	0.234	68	1800	17.5 : 25.2 : 57.3
1.5 – 2.0	0.085			6.5 : 32.5 : 61.0
2.0 – 2.5	0.055	90	580	
2.5 – 3.0	0.056			
3.0 – 3.5	0.055	170	27	
3.5 – 4.0	0.137			
4.0 – 4.5	0.156	180	3.8	46.1 : 39.3 : 14.6
4.5 – 5.0	0.242			
5.0 – 5.5	0.277	17	7.2	

B6 Site 104217 Pasture North

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.076	240	150	60.6 : 29.3 : 10.0
0.5 – 1.0	0.311			14.7 : 14.9 : 70.4
1.0 – 1.5	0.331	29	340	8.3 : 20.7 : 71.0
1.5 – 2.0	0.233			27.5 : 28.8 : 43.7
2.0 – 2.5	0.197	31	3.9	37.0 : 46.9 : 16.1
2.5 – 3.0	0.086			
3.0 – 3.5	0.081	51	8.3	
3.5 – 4.0	0.102			
4.0 – 4.5	0.086	42	4.3	51.6 : 38.3 : 10.0
4.5 – 5.0	0.183	26	5.7	64.5 : 30.2 : 5.3

C7 Site 104218 Irrigation

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.056	1400	6.1	68.9 : 28.0 : 3.1
0.5 – 1.0	0.023			63.3 : 30.6 : 6.1
1.0 – 1.5	0.146	160	4400	41.7 : 17.4 : 40.9
1.5 – 2.0	0.152			37.5 : 14.6 : 47.9
2.0 – 2.5	0.205	380	2300	39.3 : 10.4 : 50.3
2.5 – 3.0	0.258			
3.0 – 3.5	0.104	570	1100	66.8 : 11.2 : 22.0
3.5 – 4.0	0.059			
4.0 – 4.5	0.131	510	4500	63.2 : 5.4 : 31.4
4.5 – 5.0	0.126			
5.0 – 5.5	0.093	320	55	52.6 : 23. : 24.0
5.5 – 6.0	0.092			
6.0 – 6.5	0.131	140	12	33.8 : 49.9 : 16.3
6.5 – 7.0	0.122			
7.0 – 7.5	0.111	50	5.4	34.7 : 56.1 : 9.3
7.5 – 8.0	0.192			
8.0 – 8.5	0.251	70	13	38.8 : 52.5 : 8.7

C8 Site 104219 Pasture

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.046	540	7.9	60.7 : 35.7 : 3.6
0.5 – 1.0	0.013			57.1 : 39.3 : 3.6
1.0 – 1.5	0.018	130	31	54.5 : 34.8 : 10.7
1.5 – 2.0	0.089			58.7 : 34.2 : 7.1
2.0 – 2.5	0.059	52	11	57.6 : 33.9 : 8.5
2.5 – 3.0	0.247			
3.0 – 3.5	0.285	18	1400	25.3 : 9.2 : 65.5
3.5 – 4.0	0.348			
4.0 – 4.5	0.196	35	490	41.5 : 12.3 : 46.2
4.5 – 5.0	0.209			
5.0 – 5.5	0.181	26	880	66.9 : 4.3 : 28.8
5.5 – 6.0	0.059			
6.0 – 6.5	0.246	31	7.4	28.7 : 44.3 : 27.0
6.5 – 7.0	0.257			
7.0 – 7.5	0.246	24	7.0	49.2 : 20.2 : 30.6

D10 Site 104225 Bluegums

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.024	870	1100	78.6 : 17.0 : 4.4
0.5 – 1.0	0.054			75.2 : 17.2 : 7.6
1.0 – 1.5	0.029	930	10	63.3 : 15.3 : 21.4
1.5 – 2.0	0.083			68.1 : 12.4 : 19.5
2.0 – 2.5	0.204	970	1600	53.5 : 9.2 : 37.3
2.5 – 3.0	0.133			
3.0 – 3.5	0.191	430	5.3	65.3 : 7.6 : 27.1
3.5 – 4.0	0.171	330	7.2	

E11 Site 104221 Bluegums

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.051	340	11	83.8 : 12.4 : 3.7
0.5 – 1.0	0.080			72.4 : 14.3 : 13.3
1.0 – 1.5	0.070	1750	390	71.6 : 9.3 : 19.0
1.5 – 2.0	0.127			71.3 : 6.5 : 22.2
2.0 – 2.5	0.143	480	25	71.6 : 6.5 : 21.9
2.5 – 3.0	0.170			
3.0 – 3.5	0.155	290	3.0	
3.5 – 4.0	0.139			
4.0 – 4.5	0.298	240	11	56.3 : 11.8 : 31.9
4.5 – 5.0	0.282	260	8.2	

E12 Site 104224 Irrigation

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.035	2350	2000	84.2 : 13.7 : 2.1
0.5 – 1.0	0.004			63.1 : 14.2 : 22.7
1.0 – 1.5	0.073	2750	2100	79.0 : 16.3 : 4.7
1.5 – 2.0	0.115			69.5 : 8.4 : 22.1
2.0 – 2.5	0.140	1200	15	64.0 : 8.1 : 27.9
2.5 – 3.0	0.148			
3.0 – 3.5	0.196	720	6.7	
3.5 – 4.0	0.185			
4.0 – 4.5	0.196	750	6.4	66.0 : 12.7 : 21.3

	E13 Site 104223		Pasture	
DEPTH (m)	θ_g	**$[Cl]_{SW}$**	**SW Suction**	**Sand:Silt:Clay**
		(mg/L)	kPa	
0.0 – 0.5	0.018	550	340	85.8 : 11.5 : 2.7
0.5 – 1.0	0.077			75.2 : 13.4 : 11.4
1.0 – 1.5	0.186	120	61	56.7 : 7.4 : 35.9
1.5 – 2.0	0.160			65.2 : 7.7 : 27.0
2.0 – 2.5	0.158	160	5.4	73.9 : 7.5 : 18.6
2.5 – 3.0	0.184			
3.0 – 3.5	0.182	170	4.2	

	F14A Site 104220A		Pasture-Hill	
DEPTH (m)	θ_g	**$[Cl]_{SW}$**	**SW Suction**	**Sand:Silt:Clay**
		(mg/L)	kPa	
0.0 – 0.5	0.017	490	1600	81.0 : 16.8 : 2.2
0.5 – 1.0	0.007			84.1 : 14.2 : 1.7
1.0 – 1.5	0.011		12	85.9 : 12.7 : 1.4
1.5 – 2.0	0.023	190		85.2 : 12.5 : 2.3
2.0 – 2.5	0.032		5.4	
2.5 – 3.0	0.040	110		
3.0 – 3.5	0.058		80	
3.5 – 4.0	0.173	34		
4.0 – 4.5	0.090		65	
4.5 – 5.0	0.096	35		72.1 : 10.6 : 17.3
5.0 – 5.5	0.043		14	
5.5 – 6.0	0.041	250		

	F14B Site 104220B		Pasture-Flat	
DEPTH (m)	θ_g	**$[Cl]_{SW}$**	**SW Suction**	**Sand:Silt:Clay**
		(mg/L)	kPa	
0.0 – 0.5	0.046	530	29	79.7 : 11.9 : 8.5
0.5 – 1.0	0.040			73.0 : 17.0 : 10.1
1.0 – 1.5	0.066	340	4300	76.4 : 17.0 : 6.6
1.5 – 2.0	0.149			43.9 : 22.0 : 34.0
2.0 – 2.5	0.181	190	160	35.3 : 24.2 : 40.5
2.5 – 3.0	0.302	60	11	

F15 Site 104226 Native Vegetation

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.012	670	340	81.4 : 16.7 : 2.0
0.5 – 1.0	0.007			77.2 : 21.4 : 1.4
1.0 – 1.5	0.010	370	32	79.0 : 18.9 : 2.1
1.5 – 2.0	0.018			80.5 : 16.5 : 3.0
2.0 – 2.5	0.028	670	32	81.0 : 14.7 : 4.3
2.5 – 3.0	0.024			
3.0 – 3.5	0.031	310	6.3	
3.5 – 4.0	0.035			
4.0 – 4.5	0.041	130	4.4	73.2 : 22.3 : 4.5
4.5 – 5.0	0.043			
5.0 – 5.5	0.043	140	3.8	
5.5 – 6.0	0.046			
6.0 – 6.5	0.062	440	52	67.0 : 18.0 : 15.0
6.5 – 7.0	0.180			
7.0 – 7.5	0.126	1070	690	
7.5 – 8.0	0.149			
8.0 – 8.5	0.125	1250	4300	46.8 : 16.5 : 36.7
8.5 – 9.0	0.215			
9.0 – 9.5	0.335	1040	2900	
9.5 – 10.0	0.214			
10.0 – 10.5	0.220	1050	3800	36.2 : 10.0 : 53.8
10.5 – 11.0	0.231			
11.0 – 11.5	0.153	1040	1800	
11.5 – 12.0	0.227			
12.0 – 12.5	0.189	1450	1800	56.2 : 8.7 : 35.1
12.5 – 13.0	0.159			
13.0 – 13.5	0.083	910	89	
13.5 – 14.0	0.312			
14.0 – 14.5	0.155	970		40.0 : 32.9 : 27.1
14.5 – 15.0	0.183			
15.0 – 15.5	0.198	370	18	

	F16 Site 104227		Bluegums	
DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	75.3 : 19.9 : 4.7
0.0 – 0.5	0.013	350	1200	72.7 : 22.9 : 4.5
0.5 – 1.0	0.013			67.5 : 21.4 : 11.1
1.0 – 1.5	0.070	540	2100	59.6 : 12.5 : 27.8
1.5 – 2.0	0.136			46.9 : 24.6 : 28.5
2.0 – 2.5	0.171	3500	500	
2.5 – 3.0	0.174			
3.0 – 3.5	0.351	200	8.6	

	F17 Site 104228		Bluegums	
DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.015	460	6.1	85.8 : 12.1 : 2.2
0.5 – 1.0	0.022			86.4 : 11.1 : 2.5
1.0 – 1.5	0.017	230	4400	85.2 : 12.1 : 2.7
1.5 – 2.0	0.021			65.6 : 25.5 : 8.9
2.0 – 2.5	0.017	110	2300	66.3 : 26.7 : 7.0
2.5 – 3.0	0.017			
3.0 – 3.5	0.066	110	1100	
3.5 – 4.0	0.086			
4.0 – 4.5	0.063	170	4500	71.7 : 15.2 : 13.1
4.5 – 5.0	0.079			
5.0 – 5.5	0.034	150	55	
5.5 – 6.0	0.015			
6.0 – 6.5	0.014	160	12	84.0 : 12.4 : 3.5
6.5 – 7.0	0.017	90	5.4	

	G18 Site 108346		Pines	
DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.047	130	6.0	98.3 : 0.8 : 0.8
0.5 – 1.0	0.061			94.3 : 2.8 : 3.0
1.0 – 1.5	0.011	220	2800	97.2 : 2.0 : 0.8
1.5 – 2.0	0.010			97.1 : 1.4 : 1.5
2.0 – 2.5	0.011	8800	1850	96.0 : 2.8 : 1.1
2.5 – 3.0	0.024			
3.0 – 3.5	0.086	60	1100	85.2 : 0.5 : 14.3
3.5 – 4.0	0.136			
4.0 – 4.5	0.093	1970	1000	79.7 : 5.1 : 15.2
4.5 – 5.0	0.156			
5.0 – 5.5	0.169	410	8.8	76.7 : 1.8 : 21.5
5.5 – 6.0	0.175	370	4.8	

H19 Site 108347 Pines

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)		
0.0 – 0.5	0.1072	850	12	94.5 : 1.2 : 4.3
0.5 – 1.0	0.0503			95.5 : 1.2 : 3.2
1.0 – 1.5	0.2592	260	1700	66.5 : 1.9 : 31.6
1.5 – 2.0	0.3023			36.0 : 6.2 : 57.9
2.0 – 2.5	0.2785	1650	1800	40.3 : 7.7 : 52.0
2.5 – 3.0	0.4002			
3.0 – 3.5	0.3887	4150	490	32.5 : 12.1 : 55.4
3.5 – 4.0	0.1683			
4.0 – 4.5	0.2582	6600	19	43.3 7.5 : 49.2
4.5 – 5.0	0.2460			
5.0 – 5.5	0.4272	3450	4.7	49.9 : 35.8 : 14.3
5.5 – 6.0	0.4630			
6.0 – 6.5	0.5195	1650	7.6	28.5 : 49.5 : 22.0

I20 Site 108348 Bluegums

DEPTH (m)	θ_g	$[Cl]_{SW}$	SW Suction	Sand:Silt:Clay
		(mg/L)	kPa	
0.0 – 0.5	0.0570	180	6.4	96.4 : 1.1 : 2.5
0.5 – 1.0	0.1303			89.8 : 3.7 : 6.5
1.0 – 1.5	0.0562	96	8.5	96.4 : 1.3 : 2.4
1.5 – 2.0	0.0445			97.7 : 0.6 : 1.7
2.0 – 2.5	0.0574	97	6.6	98.1 : 0.2 : 1.7
2.5 – 3.0	0.2322	1095	6.4	74.6 : 4.7 : 20.7

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Act (the). In this document, refers to the *Natural Resources Management Act* (South Australia) *2004*.

Adaptive management. A management approach, often used in natural resource management, where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Algal bloom. A rapid accumulation of algal biomass (living organic matter) which can result in deterioration in water quality when the algae die and break down, consuming the dissolved oxygen and releasing toxins.

Ambient. The background level of an environmental parameter (e.g. a background water quality like salinity).

Anabranch. A branch of a river that leaves the main stream.

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, confined. Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test. A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Arid lands. In South Australia, arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broad acre cropping.

Artesian. Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

Artificial recharge. The process of artificially diverting water from the surface to an aquifer. Artificial recharge can reduce evaporation losses and increase aquifer yield. *(See recharge, natural recharge, aquifer.)*

Barrage. Specifically, any of the five low weirs at the mouth of the River Murray constructed to exclude sea water from the lower lakes.

Base flow. The water in a stream that results from groundwater discharge to the stream. (This discharge often maintains flows during seasonal dry periods and has important ecological functions.)

Basin. The area drained by a major river and its tributaries.

Benchmark condition. Points of reference from which change can be measured.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the ecosystems *(see ecosystem)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Biota. All of the organisms at a particular locality.

Bore. *See well.*

Buffer zone. A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses).

Catchment. That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the *Water Resources Act 1997*.

Codes of practice. Standards of management developed by industry and government, promoting techniques or methods of environmental management by which environmental objectives may be achieved.

Cone of depression. An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells due to declining water levels or water quality.

Conjunctive use. The utilisation of more than one source of water to satisfy a single demand.

Council of Australian Governments (COAG). A council of the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association which exists to set national policy directions for Australia.

CWMB. Catchment Water Management Board.

Dam, off-stream dam. A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted, or pumped, from a watercourse, a drainage path, an aquifer or from another source. An off-stream dam may capture a limited volume of surface water from the catchment above the dam.

Dam, on-stream dam. A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water.

Dam, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

Diffuse source pollution. Pollution from sources such as an eroding paddock, urban or suburban lands and forests; spread out, and often not easily identified or managed.

District Plan. (District Soil Conservation Plan) An approved soil conservation plan under the repealed *Soil Conservation Act 1989*. These plans are taken to form part of the relevant regional NRM plans under the transitional provisions of the *Natural Resources Management Act 2004* (Schedule 4 – subclause 53[4]) until regional NRM plans are prepared under Chapter 4, Part 2 of the Act.

Domestic purpose. The taking of water for ordinary household purposes, and includes the watering of land in conjunction with a dwelling not exceeding 0.4 ha.

Domestic wastewater. Water used in the disposal of human waste, personal washing, washing clothes or dishes, and swimming pools.

DSS (decision support system). A system of logic, or a set of rules derived from experts, to assist decision making. Typically they are constructed as computer programs.

DSS. Dissolved suspended solids.

DWLBC. Department of Water, Land and Biodiversity Conservation. Government of South Australia.

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment.

Ecosystem services. All biological, physical or chemical processes that maintain ecosystems and biodiversity, and provide inputs and waste treatment services that support human activities.

Effluent. Domestic wastewater and industrial wastewater.

EIP. Environment improvement program.

EMLR. Eastern Mount Lofty Ranges.

Entitlement flows. Minimum monthly River Murray flows to South Australia agreed in the Murray-Darling Basin Agreement 1992.

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.

Environmental water requirements. The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

EP. Eyre Peninsula.

EPA. Environment Protection Agency.

Ephemeral streams and wetlands. Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion. Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

ESD. Ecologically sustainable development *(see above for definition)*.

Estuaries. Semi-enclosed waterbodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences, and experience periodic fluctuations and gradients in salinity.

Eutrophication. Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom.)*

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

Fishway. A generic term describing all mechanisms that allow the passage of fish along a waterway. Specific structures include fish ladders (gentle sloping channels with baffles that reduce the velocity of water and provide resting places for fish as they 'climb' over a weir) and fishlifts (chambers, rather like lift-wells, that are flooded and emptied to enable fish to move across a barrier).

Floodplain. Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the Water Resources Act 1997; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development Act 1993*, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

Flow bands. Flows of different frequency, volume and duration.

GAB. Great Artesian Basin.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GIS (geographic information system). Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL. *See gigalitre.*

Greenhouse effect. The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere, such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

Geological features. Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Greywater. Household wastewater excluding sewage effluent. Wastewater from kitchen, laundry and bathroom.

Groundwater. *See underground water.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Heavy metal. Any metal with a high atomic weight (usually, although not exclusively, greater than 100), for example mercury, lead and chromium. Heavy metals have a widespread industrial use, and many are released into the biosphere via air, water and solids pollution. Usually these metals are toxic at low concentrations to most plant and animal life.

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrography. The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere. *(See hydrogeology.)*

Hyporheic zone. The wetted zone among sediments below and alongside rivers. It is a refuge for some aquatic fauna.

Indigenous species. A species that occurs naturally in a region.

Industrial wastewater. Water (not being domestic wastewater) that has been used in the course of carrying on a business (including water used in the watering or irrigation of plants) that has been allowed to run to waste or has been disposed of or has been collected for disposal.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or mechanical means.

Irrigation. Watering land by any means for the purpose of growing plants.

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Lake. A natural lake, pond, lagoon, wetland or spring (whether modified or not) and includes: part of a lake; a body of water declared by regulation to be a lake; a reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land. Whether under water or not and includes an interest in land and any building or structure fixed to the land.

Land capability. The ability of the land to accept a type and intensity of use without sustaining long-term damage.

Leaching. Removal of material in solution such as minerals, nutrients and salts through soil.

Licence. A licence to take water in accordance with the Water Resources Act 1997. *(See water licence.)*

Licensee. A person who holds a water licence.

Local water management plan. A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

Macro-invertebrates. Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

Model. A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Mount Lofty Ranges Watershed. The area prescribed by Schedule 1 of the regulations.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

NHMRC. National Health and Medical Research Council.

NHT. Natural Heritage Trust.

Natural resources. Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Natural Resources Management (NRM). All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Occupier of land. A person who has, or is entitled to, possession or control of the land.

Owner of land. In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Palaeochannels. Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

Pasture. Grassland used for the production of grazing animals such as sheep and cattle.

Percentile. A way of describing sets of data by ranking the data set and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability. A measure of the ease with which water flows through an aquifer or aquitard.

Personal property. All forms of property other than real property, for example shares or a water licence.

Phreaphytic vegetation. Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phytoplankton. The plant constituent of organisms inhabiting the surface layer of a lake; mainly single-cell algae.

PIRSA. (Department of) Primary Industries and Resources South Australia.

Pollution, diffuse source. Pollution from sources that are spread out and not easily identified or managed (e.g. an eroding paddock, urban or suburban lands and forests).

Pollution, point source. A localised source of pollution.

Potable water. Water suitable for human consumption.

Potentiometric head. The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

Precautionary principle. Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Prescribed area, surface water. Part of the state declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

Prescribed water resource. A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

Property right. A right of ownership or some other right to property, whether real property or personal property.

Proponent. The person or persons (who may be a body corporate) seeking approval to take water from prescribed water.

PWA. Prescribed Wells Area.

PWCA. Prescribed Watercourse Area.

PWRA. Prescribed Water Resources Area.

Ramsar Convention. This is an international treaty on wetlands titled ‘The Convention on Wetlands of International Importance Especially as Waterfowl Habitat’. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran, in 1971, hence its common name. The Convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Recharge area. The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

Reclaimed water. Treated effluent of a quality suitable for the designated purpose.

Rehabilitation (of waterbodies). Actions that improve the ecological health of a waterbody by reinstating important elements of the environment that existed prior to European settlement.

Remediation (of waterbodies). Actions that improve the ecological condition of a waterbody without necessarily reinstating elements of the environment that existed prior to European settlement.

Restoration (of waterbodies). Actions that reinstate the pre-European condition of a waterbody.

Reticulated water. Water supplied through a piped distribution system.

Riffles. Shallow stream section with fast and turbulent flow.

Riparian landholder. A person whose property abuts a watercourse or through whose property a watercourse runs.

Riparian rights. These were old common law rights of access to, and use of water. These common law rights were abolished with the enactment of the Water Resources Act 1997, which now includes similar rights under s. 7. Riparian rights are therefore now statutory rights under the Act. Where the resource is not prescribed (Water Resources Act 1997, s. 8) or subject to restrictions (Water Resources Act 1997, s. 16), riparian landholders may take any amount of water from watercourses, lakes or wells without consideration to downstream landholders, if it is to be used for stock or domestic purposes. If the capture of water from watercourses and groundwater is to be used for any other purpose then the right of downstream landholders must be protected. Landholders may take any amount of surface water for any purpose without regard to other landholders, unless the surface water is prescribed or subject to restrictions.

Riparian zone. That part of the landscape adjacent to a water body that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses.

Seasonal watercourses or wetlands. Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter/spring period, although there may be some flow or standing water at other times.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

Stock Use. The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Stormwater. Runoff in an urban area.

Surface water. (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

Taxa. General term for a group identified by taxonomy — which is the science of describing, naming and classifying organisms.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Total kjeldhal nitrogen (TKN). The sum of aqueous ammonia and organic nitrogen. Used as a measure of probable sewage pollution.

Transfer. A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period.

Underground water (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Wastewater. *See domestic wastewater, industrial wastewater.*

Water affecting activities. Activities referred to in Part 4, Division 1, s. 9 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based. An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water use year.

Water allocation plan (WAP). A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water licence. A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Water service provider. A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse. A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Water-dependent ecosystems. Those parts of the environment, the species composition and natural ecological processes, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water-use year. The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

Well. (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

Wetlands. Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic/intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed 6 m.

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