SALINITY IMPACT ON LOWER MURRAY HORTICULTURE

MILESTONE 3 REPORT (DEP 15 PROJECT)

Tapas K Biswas, Gerrit Schrale, Graeme Sanderson[1] and John Bourne[2,3]

Water Resources & Irrigation, SARDI Sustainable Systems & Technologies
GPO Box 397, Adelaide SA 5001
[1]NSW DPI Dareton Agricultural Research Station, PO Box 62, Dareton, NSW 2717
[2]DWLBC Irrigation Programme, GPO Box 2834, Adelaide 5001

[3]**TriState Salinity Project Team:** Jahangir Alam, Bill Ashcroft, Tapas Biswas, Ann-Maree Boland, John Bourne, Masoud Edraki, Stuart Putland, Graeme Sanderson, Maxine Schache, Gerrit Schrale, Rob Stevens, Mike Treeby, Julio Vargas and Rob Walker

June 2005

DEP15 Project: Salinity Impacts on Lower Murray Horticulture
Milestone 3 Report

Cover page: A fully instrumented drip irrigated vineyard at the Loxton Research Centre in the Riverland. Instruments in the picture includes; capacitance probes, tensiometers, gypsum blocks, soil solution extractors, full and long stops


FullStop wetting front detector

Acknowledgement

Rob Thomas, SARDI Chief scientist for logistic support
Murray Chapman, NPSI coordinator, for valuable comments
John Hutson, Flinders University, for assistance in LEACHM modelling tools
Tony Meissner, MDBC, for providing Mallee soil moisture characteristics data
Tony Adams, PIRSA-ICMS, for IRES module
Project Management Team for tireless efforts during various phases of this study
Steering Committee members[1] for valuable advice and encouragement
Funding from various sources[2] is thankfully acknowledged.

[1]**STEERING COMMITTEE:**

SA Growers:	Brian Caddy (vines), PO Box 420, Barmera SA 5345
Vic Growers:	Jim Grant, Area Manager, Vineyards, Berringer Blass Wine Estates, Merbein, VIC 3502
NSW Growers:	Col Thomson (citrus) PO Box 19, Curlwaa NSW 2648
Industry Groups:	MVCB: Peter Morrish, Murray Valley Citrus Board, POB 1384, Mildura 3502
HAL:	Leigh Sparrow, Horticulture Australia Ltd, TIAR, PO Box 46, Kings Meadow, TAS 7249
NPSI:	Murray Chapman, NPSI Program Coordinator, RMB 2040, Baddaginnie VIC 3670
RMCWMB:	John Johnson, General Manager, RMCWMB, PO Box 1374, Berri SA 5343
DPI-Vic:	Greg Buchanan, DPI-Vic, Sunraysia Horticultural Centre, PO Box 905, VIC 3502
Mallee CMA:	Ian Ballantyne, Mallee Catchment Management Authority, DPI-Vic, Mildura Vic 3502
LMCMA:	Bill Tatnell, NSW Dept of Infrastructure, Planning & Natural Resources, Buronga, NSW
DPI-NSW:	Eddie Parr, NSW Department Primary Industries, LMB 21, Orange NSW 2800
SARDI:	Rob Thomas, Chief Scientist, Sustainable Systems, SARDI, GPO Box 397, Adelaide 5001
MDBC:	Bob Newman, MDBC Salinity Program Coordinator, 57 Powel St, Berri SA 5343
DWLBC:	Phil Cole, Salinity Program Leader, DWLBC, GPO Box 2834, Adelaide 5001

[2]**FUNDING AGENCIES*:***
Land & Water Australia (NPSI-National Programme for Sustainable Irrigation)
Murray-Darling Basin Commission (MDBC)
River Murray Catchment Water Management Board (RMCWMB).

Executive Summary

Improved irrigation management in the Lower Murray horticultural districts has raised field application efficiency (FAE) from about 50 to 85% during the past 2 decades. Consequently the drainage volumes have reduced from about 50 % to 15% of applied water. Under steady state conditions, the salinity in the root zone can be predicted from irrigation water salinity and the leachate (the extra irrigation water applied which drains out of the base of the root zone). This prediction assumes that the extra water applied for leaching uniformly displaces the (saline) soil water as 'piston' flows. However, there is anecdotal evidence that the root zone salinity is often greater than expected. The discrepancy between observed and expected soil salinity may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone.

A 'Tri-State Salinity' syndicate of Government agencies from western NSW, Victoria and South Australia (with support from federal agencies) was formed to generate the knowledge for managing root zone salinity hazards by undertaking a 3 year laboratory and field scale study. In addition to assessing the risk of salinity accumulation under precision irrigation, the project team is working on strategies for minimising production losses.

First year field data (Milestone 1 & 2 investigations) a from vineyards and citrus orchards in the Riverland and Sunraysia regions showed that the average leaching fraction is often less than 15% and salt is accumulating in the root zone. This is particularly of concern when the average leaching efficiency at 14 surveyed properties was 65% and where only <5% of total applied water is flushing the root zone during the irrigation season. For the reader's convenience, the executive summary of the Milestone 1 & 2 reports is reproduced in Appendix 1.

This Milestone 3 report describes the interim progress against set outcomes & deliverables of the Tri-State Salinity project, presented in the Table below. This mainly includes:

i) Site instrumentation and real time data logging for soil moisture and salinity
ii) Refinement of methodology and protocol for water, soil, soil solution, hydraulic parameters and plant tissue sampling and monitoring;
iii) Trends in root zone drainage and salt accumulation during summer irrigation;
iv) Simulation and prediction of irrigation water quality impacted rootzone salt build up using 2D vadose zone models;
v) Communication through various avenues to different audiences; and
vi) Future directions

One of the spin-offs of the project has been the assessment of deep percolation in the Bookpurnong Lock 4 district. Deep drainage (DD) is the prime important factor influencing off-site impact of irrigation on the local landscape. In the Riverland DD becomes recharge to the underlying highly saline aquifers and accelerates the natural saline seepage into the Murray River. A 'curtain' of salinity interception wells protects the River water quality by intercepting the enhanced saline groundwater discharge into the River. To design efficient salinity mitigation works we need to quantify the deep drainage component on a property scale, which can then be integrated to district scale.

Several attempts have been made to quantify deep drainage with a varying degree of success and failure. Indirect measurements such as water balance, natural tracer and salt balance are point measurements and hence do not allow for spatial and temporal variability. On the other hand, direct measurements including drainage capture by disturbed soil profile and drainage meter are often expensive and demand excessive time from growers busy during the irrigation season.

In modern horticultural districts there are usually large networks of capacitance probes used for irrigation scheduling. In this paper we present a new method for assessing DD from data generated by these multi-sensor capacitance probes. In this method DD is estimated by using Darcy's flux equation. A water content –suction (θ-ψ) relationship was developed from data generated by two sensors, located just below the root zone.

The DD estimates were compared with results from two other (independent) methods for vineyards in Loxton (SA) and Irymple (Vic), and citrus in Dareton (NSW):

- chloride tracer technique which involves extracting soil water solution from the bottom of the root zone, and
- seasonal water tracing technique (I2003 method) which involves real time soil water storage derived from irrigation records, crop types, climatic data and crop coefficients.

The DD estimate shows considerable daily and seasonal variations of drainage rate for an under cover sprinkler irrigated citrus property in Dareton, NSW. The cumulative drainage from irrigation and rainfall was 250 mm (2.5 ML/ha) during the entire year.

In general, DD was much less under the drip system. Less than 10% of applied water was found to leave the root zone during the grape growing season, which resulted in salt build up in root zone even at the current river water salinity of 300 EC.

Using the data from a drip irrigation vineyard at Loxton in the Bookpurnong Lock-4 district, the output of a two-dimensional numerical flow/transport model (LEACHM-TRANSMIT) simulation run at 800 EC irrigation showed that 2t salt/ha could accumulate in 1 m root zone during a normal grape growing season under drip irrigation. If irrigated with 800EC during a drought year, this could increase soil EC to 5 dS/m, at which up to 60% yield loss may occur.

Chloride and sodium content of petioles and leaves at flowering and harvest, and berries at harvest were measured to assess the salt injury to the plants. Grape varieties sampled included Chardonnay and Colombard on either Ramsey rootstock or vines on their own roots. For citrus, only the leaf was analysed for chloride and sodium content. When compared against the acceptable limit, no significant salt problem was identified from the chloride and sodium analysis of either grape or citrus material from this survey.

Outcomes and generic deliverables set for Milestone 3

Due date/ Item No	Deliverables during Milestone 3	Outcomes	Quick Reference
1	Collection of second seasons data and samples	√	Chapter 2 &3
2	Simulations run and analysed	√	Chapter 2 &3
3	Sustainable Irrigation Projects receiving input as appropriate for their project (as defined in milestone 3)	√	Chapter 4
4	At least one Steering Committee meeting with year1 data analysis reported and discussed by the Committee	√	5th May 2005 Mildura
5	Work plan continues with all priority stakeholders participating.	√	Chapter 4

Milestone 3 Highlights in a Nutshell

i. Under the drip system, less than 10% of applied water is leaving the root zone during the grape growing season.

ii. Less than 10% root zone drainage under precision irrigation resulted in salt build up in root zone even at the current river water salinity of 300 EC.

iii. Model simulation run at 800 EC irrigation showed that 2t salt/ha could accumulate in 1 m root zone during a normal grape growing season under drip irrigation.

iv. If irrigated with 800EC in a drought year, this could increase soil EC to 5 dS/m, at which up to 60% yield loss may occur.

v. Fruit and leaf analysis showed no significant salt problem for either grape or citrus during 2004-2005 except for Irymple drip site which recorded very high amount of sodium in both the leaf petiole and berry juice.

vi. Solution extractors, developed by this project, are being adopted by the PIRSA-ICMS/RMCWMB to estimate deep percolation in the Bookpurnong Lock 4 irrigation district.

vii. DPI-Vic's dairy project and vegetable growers from the Adelaide hill expressed keen interest in the solution extractor to monitor salts and nutrients in the root zone.

viii. Submitted a summer studentship completion report on deep drainage work to CRC-IF.

ix. A Chinese PhD student from Wuhan University has begun work to assist the modelling approach within the project in a collaborative arrangement.

x. Eight articles have been published including 2 refereed conference articles and 4 media articles in SA, Vic and NSW rural newspapers.

CONTENTS

List of Tables

List of Figures

1. TRISTATE SALINITY PROJECT - MILESTONE 3[1]

Irrigated horticulture in the Lower Murray (Riverland-Sunraysia) region contributes a 'gate-value' of about $ 2.5 billion a year to the national economy. As a consequence of improved irrigation practices over the years, there is a risk emerging of a salinity build-up in the root zone, threatening the sustainability of this region. During the past two decades the water use efficiency (WUE) of irrigated horticulture in this region has gradually increased from about 50 to 80% as a consequence of improved irrigation systems and management. With the objective to manage the irrigation impact on the river water quality and health of the floodplains, the River Murray Catchment Water Management Board introduced an 85% target of WUE in the current Water Allocation Plan.

However it is recognised that some drainage water must displace the residual salts of the irrigation water and thus avoid a salinity build up in the root zone causing crop yield losses.

In the Lower Murray Region the irrigation water salinity is typically about 0.4 dS m^{-1} and with 15% leaching the average salinity (ECe) in the root zone should be around 0.6 dS m^{-1}. However field surveys indicate that the root zone salinity is often greater than 1.3 dS m^{-1} with considerable variance. The discrepancy between observed and expected soil salinity may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone (Bouwer, 1969).

In order to understand and manage this salinity hazard, a 'Tri-State Salinity' syndicate of Government agencies from western NSW, Victoria and South Australia (with support from federal agencies) was formed to undertake a 3 year laboratory and field scale study popularly known as the "TriState Salinity Project" or the DEP15 project for the lower Murray irrigated permanent horticulture.

1.1 Objectives

The DEP 15 project has been developed to test the hypothesis that: *'a depressed leaching efficiency (LE) in the Lower Murray irrigation districts raises the root zone salinity and that improved water use efficiency (WUE) may have an upper limit determined by paddock's LE and its variance'*.

The project activities were grouped into two distinctive stages that spread over 6 milestone activities, to deliver an outcome that could assess the risk of irrigation water-induced salinity on Lower Murray horticulture. The specific objectives were to:

1. Determine/update the salinity relationships for irrigated horticulture along the Lower Murray: Riverland, Sunraysia and western NSW;
2. Determine the variability of EC (soil water) and leaching efficiency in the field under known soil conditions and irrigation management;

[1] Elaborate description of work plan and associated reviews were presented in Milestone 2 report

3. Simulate the performance of horticultural crops under different scenarios of River Murray salinity at Morgan; and
4. Provide input to the implementation of the Salinity Strategy and Integrated Catchment Management Plan of the Murray-Darling Basin.

This report forms the deliverables of Milestone 3 activities listed in Table 1. Two previous reports submitted to the funding agencies contained the outputs of Milestone 1 and 2 activities.

Table 1. Outcomes and generic deliverables set for Milestone 3

Due date/ Item No	Deliverables during Milestone 3	Outcomes	Quick Reference
1	Collection of second seasons data and samples	√	Chapter 2 &3
2	Simulations run and analysed	√	Chapter 2 &3
3	Sustainable Irrigation Projects receiving input as appropriate for their project (as defined in milestone 3)	√	Chapter 4
4	At least one Steering Committee meeting with year1 data analysis reported and discussed by the Committee	√	5th May 2005 Mildura
5	Work plan continues with all priority stakeholders participating.	√	Chapter 4

2. FIELD SITE, INSTRUMENTATION AND METHODOLOGY

2.1 Field sites

Four representative field sites as shown in Figure 1, spread over the Riverland and Sunraysia regions were selected. These sites were representative of vines and citrus crops in the Riverland and Sunraysia regions.

1. Loxton Riverland irrigation district, SA: Colombard grape on Ramsey rootstock on a light sandy clay loam soil and drip irrigated based on neutron probe's moisture record;
2. Loxton Riverland, SA: Chardonnay grape on Ramsey rootstock on a sandy loam soil irrigated with a mini sprinkler system based on neutron probe's moisture record;
3. Dareton, Coomealla irrigation district, NSW: Nova Mandarin on sandy loam soil under mini sprinkler irrigation system scheduled at tensiometer and enviroscan readings;
4. Irymple, Sunraysia irrigation district, VIC: Chardonnay wine grape on Ramsey a deep sandy loam soil and drip irrigated based on capacitance probe readings.

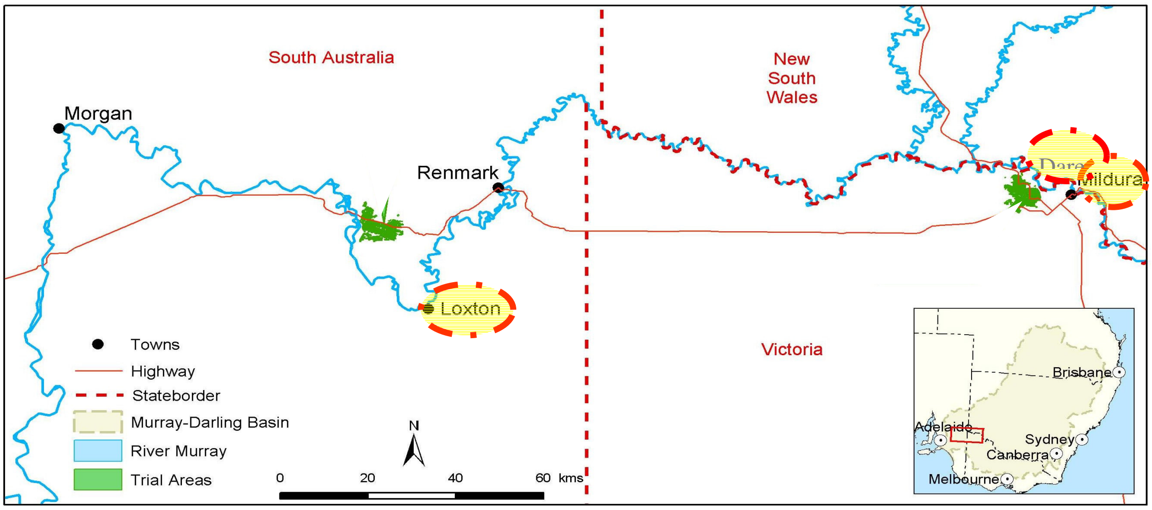


Figure 1. DEP 15 project sites (yellow circles)

2.2 Instrumentation[2]

Each site is instrumented with the following soil water and salinity monitoring equipment:

1. Soil solution extractors (ceramic suction tube) at 3 depths: 0.30m 0.60m and 0.90m and having 3 replications. Initially 0.25,0.5 and 1m was proposed but when the project team agreed on an average root zone of 0.90m, a small adjustment of the original theoretical depths was made.
2. Watermark tension blocks: (4 depths x 2 replications): Due to the irregularity of tension block readings from the Dareton site, especially for the first year it was

[2] Detailed descriptions of these instruments were reported in Milestone 2 report.

decided to install the block at both the sites in Loxton. Any calibration done from these sites will then be used for other two sites.

3. EnviroScan capacitance probe (5 depths multi sensors): Installed at each site, two TRISCAN (SENTEK, 1997) probes having moisture sensors at 0.1,0.3,0.6,0.9,1.2,and 1.5m depths and salinity sensors at 0.1, 0.3, 0.6 and 0.9 m. In addition the drip irrigated Loxton site now has extra 4 EnviroScan probes with 5 sensors installed to capture the spatial variability.
4. Drainage meter (DM) just below the root zone (0.9 m): DM is yet to come from CSIRO L&W Griffith Laboratory. Paul Hutchinson indicated that only two DMs could be available in August 2005. Due to this difficulty LongStops from CSIRO L&W were installed at Loxton sites to estimate deep drainage.
5. FullStop & LongStop: Wetting front detectors (Stirzaker, 2003) were placed directly under a dripper at a depth of 0.3 m for shallow detector, and 0.6 m for the deep detector. Whereas under the canopy sprinkler irrigation site the detectors were installed at 0.5 m radius of the jet. Paired LongStops with a tube length of 0.60m were installed at a depth of 0.9 m, the cut-off line of the root zone. If the data from these detectors are reliable and interpretable then these detectors will be extended to the sites in Vic and NSW.
6. Loggable tensiometer: For measuring matric potential or suction, 4 log tensiometers were installed at 0.3m, 0.6m 0.9m and 1.2m depths on a circular line 0.15 m away from the dripper. The readings from the bottom two sensors, located just below the root zone will be used to calibrate the capacitance probe's sensors readings from the same depths.

2.3 EM Survey and soil coring for ground truthing

Except for the Dareton (NSW) site where an EM38 survey was conducted in 2003, the remaining three sites were EM-surveyed during July-August 2004 for both EM_h and EM_v. Using a 50mm hand auger, soil cores at 0.3m intervals to up to 1.5 m were drawn from 9 locations at each paddock immediately after the EM survey. The sampling locations were randomly selected from easting and northing coordinates from the survey grids. All samples were measured for bulk density and moisture content. Sub samples were air dried and passed through 2mm sieve before analysing for saturated paste extract EC and chloride concentration. Particle size analysis (sand, silt and clay %) was carried out for a composite sample from each paddock. The EM readings together with soil analysis data were used to identify the most appropriate site for instrumentation, where the variability due to salinity was minimum.

2.4 Real time water and salinity monitoring instruments

A schematic diagram of several instruments within and below the root zone is presented in Figure 2. Whereas Figure 3 presents a fully instrumented drip irrigated vineyard at the Loxton Research Centre in the Riverland. Instruments in the picture include; capacitance probes, tensiometers, gypsum blocks, soil solution extractors, full and long stops. A detailed description of these instruments is presented in the Milestone 2 report.

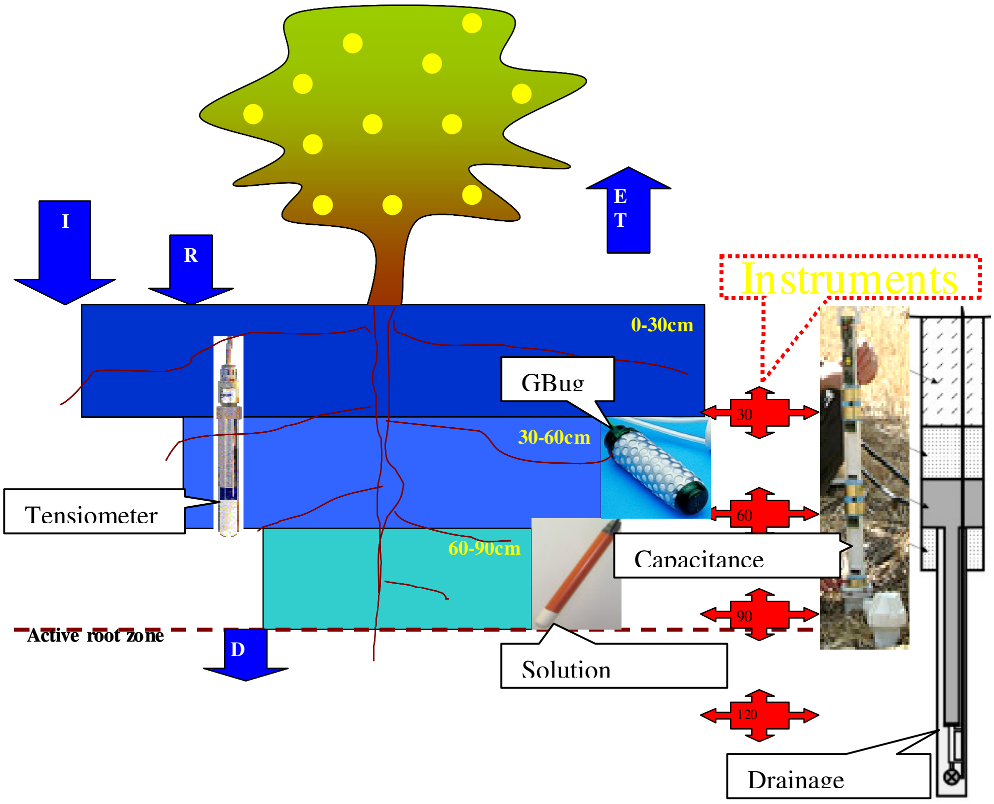


Figure 2. Schematic presentation of root zone and soil moisture monitoring equipment

Figure 3. A fully instrumented drip irrigated vineyard at the Loxton Research Centre in the Riverland. Instruments in the picture include; capacitance probes, tensiometers, gypsum blocks, soil solution extractors, full and long stops

2.5 Field Sampling and Methodologies

2.5.1 Soil and water sampling and analysis

2.5.1.1 Water salinity

Records of irrigation and rainfall depths combined with measures of Cl concentration in the irrigation water and published analysis of Cl in rainfall at Mildura and Loxton (Blackburn and McLeod 1983) were used to calculate a volume weighted chloride concentration for the applied water (Clw). A relationship between Cl concentration in river water and its salinity (EC) was developed by regressing measurements of Cl in water at Merbein against corresponding measures of EC for data from the period 1980 through to 1998. Currently the conversion equation is:

Cl (mg/L)=217*dS/m -4.77; $r^2 = 0.89$ (n=94)

2.5.1.2 Soil solution EC and Chloride

Soil solutions were collected from solution extractors using a suction of 70kPa from 0.3m, 0.6m and 0.9m depths once a week following irrigation during current (2005) irrigation season. The solutions were stored in a refrigerator before analysis for ECsw. ECsw measurement was used as surrogate measure of Cl_e using a recently developed conversion relationship. Currently the conversion equation is:

Cl (mg/L)=348*ECsw(dS/m) -138.4; $r^2 = 0.99$ (n=55)

Soil was sampled from throughout the root zone and below the rootzone. Soil samples were dried at 40^o C and passed through 2mm sieve before analysis. Saturated soil pastes were prepared from soil. The chloride concentration in the extract (Cle) was measured with a Buchler chloridometer. The EC of the extract was expressed in dS/m at 25^o C. Particle size analysis (sand, silt and clay %) was carried out for a composite sample from each paddock. A sub sample of saturated extracts was tested for pHe, metalloids & metals.

The chloride concentration in the soil water (Clsw) was estimated as twice that in the saturated paste extract (Clsw = 2*Cle) (Ayers and Westcot, 1985).

2.5.2 Leaching fraction and root zone drainage (DD) estimation

2.5.2.1 Seasonal water balance using soil water trace method

Leaching fraction was estimated using this technique (I2003 method) developed by ICMS (Tony Adams, *pers.comm*), which involves real time soil water storage derived from soil texture, irrigation records, crop types, climatic data and crop coefficients. Relative soil water deficit or excess is calculated from the daily irrigation and rainfall volume combined with evapotranspiration (ET). Any excess is accounted for the deep drainage.

2.5.2.2 Chloride Tracing Technique

Chloride tracer technique estimates the deep drainage by measuring ratio of Cl_{iw} and Cl_{dw}; where Cl_{iw} = chloride concentration in irrigation water Cl_{dw}= Chloride concentration of soil water drawn from the bottom of freely draining root zone.

Hence deep drainage (DD) or leaching fraction (LF) = Cl_{iw}/Cl_{dw} which is approximately $EC_{iw}/EC_{sw.}$ EC_{sw} was measured by extracting soil water solution from the bottom of the root zone under 70 kPa suction. This requires a manual extraction and measurement at each site. It not only provides daily data if monitored every day, but also draws out the water at a root equivalent suction (70 kPa). In an ideal situation, these figures will work better over time. This would account for variations in rainfall, human activity, plant activity and plant root depth.

2.5.2.3 Water Balance Technique using hourly data from capacitance probe

Along with irrigation application and rainfall data, this method uses total root zone θ_v (mm) derived from the hourly measurements of capacitance probe. An example of such a probe with 5 sensors, located in a citrus orchard at Dareton, NSW is given below.

Root zone: 90cm		Sensor Depth (cm)					Total root	Average
Date	Time	10	30	50	80	110	zone water content (mm)	root zone θ_v (%)
11/12/2002	8:52	13.67	16.39	13.25	22.96	13.56	148.30	16.5

The capacitance probe at this site has sensors at 5 depths, where each sensor represents a 10 cm soil layer. It is noted that these sensors have not yet been calibrated and hence the results are subject to some degree of error.

Hence the measured θ_v represent 5-15, 25-35, 45-55, 75-85, 105-115 cm of soil layers respectively. The data for 20, 40, 60, 70, and 90 cm have been interpolated from averaging the appropriate depths. Therefore, the total water content for the root zone is estimated as 13.67*1.5+ (13.67+16.39)/ 2 + 16.39+ (16.39+13.25)/ 2 + 13.25+ (13.25+22.96)/ 2*2 + 22.96+ (22.96+13.56)/ 2*0.5 = 148.30 mm.

Field capacity (FC), estimated either visually from water content data or from soil texture, is used as upper threshold limit for soil water holding capacity. Any amount exceeding this limit is subjected to leaching immediately after cessation of irrigation or rainfall. Due to visual judgement for moisture content and feel methods for soil texture, these FCs are subject to a degree of error and careful interpretation is needed. Total drainage was calculated as the sum of leaching throughout individual events.

2.5.2.4 Capacitance probe technique using Darcy equation

The multisensor capacitance probe is a popular field technique, which allows an automated continuous measurement of soil water content. The method is based on dielectric property of soil water and measures the frequency change induced by the changing permittivity of the soil permeated by the fringing fields of the capacitor sensor (Paltineanu and Starr 1997, Sentek, 1997). By simple conversion of hourly raw data for separate layers to daily total soil profile water contents (mm) along with rainfall and irrigation volumes and field capacity estimation (FC) the leaching fraction estimation (LF) or deep drainage is estimated. A detailed procedure is recorded in the Milestone 2 report (Biswas *et al.* 2005).

In order to accommodate spatial and temporal variability during stage 2 work, each hourly estimation of deep drainage were recorded from 12 capacitance probes using remote telemetry technology. The probes will be calibrated at a site and DD from capacitance probe log data will be estimated for a given period of time, Δt by using equation:

$$DD = k(\theta)\frac{\Delta(h+z)}{\Delta z}\Delta t$$

where, $k(\theta)$ (cm d^{-1}) is the unsaturated hydraulic conductivity at the water content θ (cm^3 cm^{-3}) of the soil layer below the rooting zone, Δh is the pressure head gradient, Δz is the distance between the bottom of the root zone and the immediate next depth's soil moisture monitoring points. The relationship between $k(\theta)$ and θ will be established by using van Genuchten (1980)'s analytical expression:

$$k(\theta) = k_s S_e^{1/2}\left[1-(1-S_e^{1/m})^m\right]^2$$

where k_s is the saturated hydraulic conductivity (cm d^{-1}), $S_e = \frac{\theta-\theta_r}{\theta_s-\theta_r}$, θ_s (cm^3 cm^{-3}) is the water content at saturation, θ_r is the residual water content, θ is the water content at which k will be estimated and m is a fitting parameter. When the water content at a given depth is known, the pressure head h, at that location will be estimated as:

$$|h| = \frac{1}{\alpha}\left[(S_e)^{-1/m}-1\right]^{1/n} \therefore\ n = 1/(1-m), m<1$$

where, α is a fitting parameter.

Representative θ_s, θ_r, m and α were derived from an existing PIRSA soil moisture release curve database of 300 Mallee soils (Meissner, 2004) whereas, k_s was estimated by using a USDA soil moisture characteristics model (Saxton *et al.* 1986) that required soil texture data as input.

2.5.3 Leaching efficiency

With a given salinity of applied water, the leaching fraction necessary to produce the actual value of linear average soil salinity (Clsw) was calculated iteratively by substituting various leaching fractions into the spreadsheet. This spreadsheet is based on the Ayers and Westcot (1985) adaptation of the 40-30-20-10 extraction pattern with a vertical pattern of extraction set from site specific data. This model assumes that the water draining below the root zone carries its full quota of salt. The leaching efficiency (LE*estimated*) was defined as the ratio of this leaching fraction to the leaching fraction determined from measures of water use efficiency.

2.5.4 Citrus leaf, grapevine petiole and berry sampling and analysis

Citrus leaves were generally collected during February from the mid section (leaf 3 or 4) of hardened, non fruiting spring flush growth. Sampling occurred at shoulder to eye height around the tree. Approximately 5 leaves removed per tree and 20 trees sampled per block (100 leaves). Leaves were washed to remove surface contaminants. The samples were dried at 60ºC before grinding in a hammermill and sub sampling for analysis.

Vine petioles (leaf stalks) were collected opposite a bunch when flowering is 50% - 75% complete. Petioles were selected close to the base of shoots. The typical sampling time in the Sunraysia region is early to mid November. Samples were collected early in the morning before leaves become stressed. Care was taken to not sample immediately after overhead/sprinkler irrigation. Recommended 100 petioles were collected per block for a representative sample. Petioles were washed to remove surface contaminants and dust. Samples were dried at 60ºC then ground in a hammermill and sub sampled for analysis. Analysis of above plant tissues was carried out according to the procedure adopted by Loxton Laboratory.

Approximately 100 representative berries were collected at harvest, weighed and sent to the ACML laboratory for analysis of sodium and chloride content.

2.6 Analytical and numerical Modelling

Several water-soil salinity relationship models are being used for leaching fraction and leaching efficiency calculation. The common inputs for these prediction were Clw and leaching fraction. Three estimates of Clsw were obtained by using:

i. Prendergast (1993) derivation of the Rhoades (1974) formula (ClswGHD),
ii. Hoffman and van Genuchten (1983) algorithm (Clsw40-30-20-10), and
iii. Ayers and Westcot (1985) with substitution for site specific extraction patterns (ClswSSEP

Van-Genuchten model was used for θ-ψ relationships and hydraulic properties. Darcy's steady state flow equation was used for drainage flux calculation in addition to lamped water balance models. A numerical 2D model LEACHM-TRANSMIT (Hutson and Wagenet, 1995) was used for modelling water and salt transport in the root zone. This model uses Richard's flow equation along with convection-advection equation for salt movement.

2.7 Statistics

During the development of this project, a statistician from the SA Biometrics centre has been consulted for the design of experimental plans, sampling methods, data recording and statistical analysis. Relevant Paired T-tests and calculation of Pearson correlation coefficients were undertaken with the Statistix® program and S-STAT®. Corresponding graphical analysis has been carried out by Sigma-Plot®.

3 RESULTS AND DISCUSSION

3.1 Estimation of root zone salinity using water and soil EC measurements

Soil Cl concentration and associated leaching efficiency of 14 properties surveyed during 2003-2004 are presented in Table 2. Root zones were between 50 and 120 cm deep. The seasonal irrigation depths for the citrus crops ranged from 588 to 1646 mm; the associated total rainfall ranged from 235 to 284 mm. The vines had seasonal irrigation depths ranging from 440 to 1133 mm and total rainfall from 153 to 303 mm. The mean measured value of soil salinity (Cl_{sw}) was at least 2-fold higher than the values estimated by application of a range of irrigation water to soil salinity conversion formulae (GHD, 1999, Hoffman and van Genutchen, 1983, and Ayers and Westcot, 1985). The mean leaching efficiency of 0.63 at these sites was significantly less than unity ($P < 0.01$) and had a large coefficient of variation (77%).

The leaching in-efficiency and its large variation are likely due to local characteristics and their spatial variability. In order to gain temporal variation of both leaching fraction and leaching efficiency four representative sites were selected. The major criteria were that the sites should have at least 12 years of irrigation and more that 3 meters water table depths (see Schrale and Biswas, 2004 and Biswas *et al.* 2005).

All sites were EM38 surveyed from where representative cores were taken for ECe measurement. Despite long-term irrigation practices in this region, the paddocks were quite variable in apparent EC values. This was possibly due to natural variation. The EM38 vertical (EM_v) profiles for site 1 and 2 from Loxton Research Farm are presented in Fig 4 whereas Fig 5 shows the Emv profile for site 4 from Irymple, Vic.

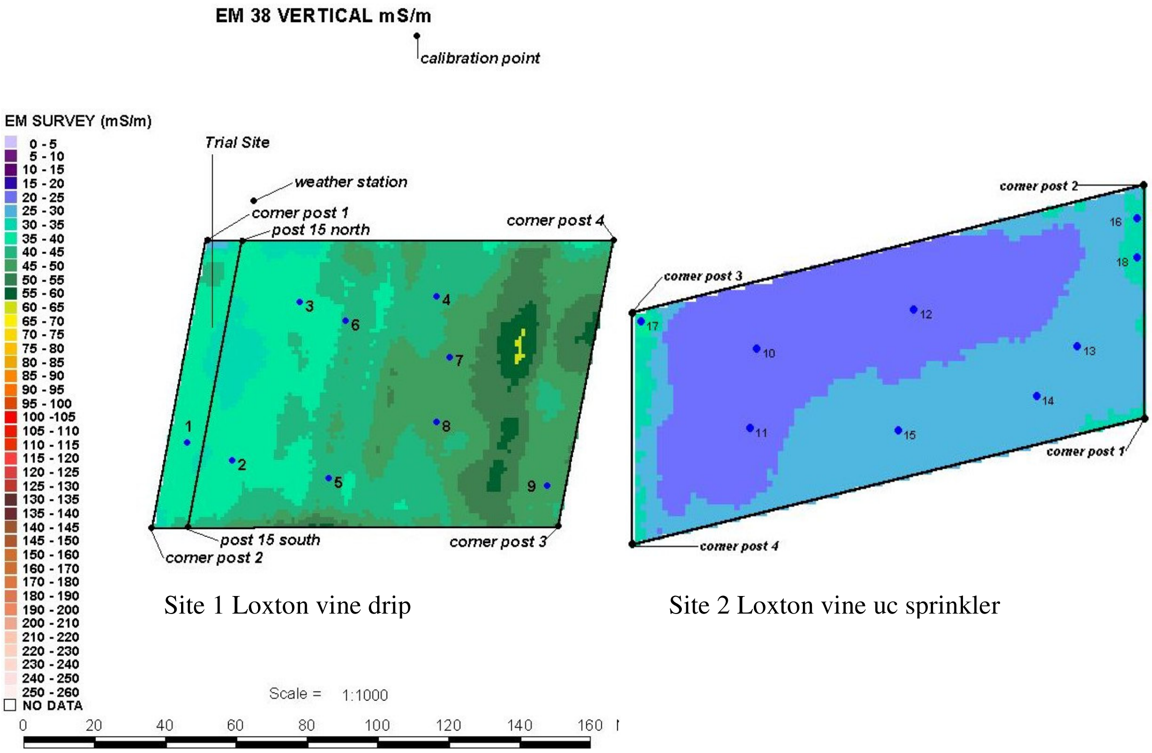


Figure 4. Riverland site's EMv profile: site 1 (Loxton F Block) with drip irrigation and site 2 (Loxton C Block) with undercover (uc) sprinkler irrigation

These profiles demonstrate the heterogenous nature of the paddocks where EC_v varied between 20 and 75 mS/m (100mS/m=1dS/m).

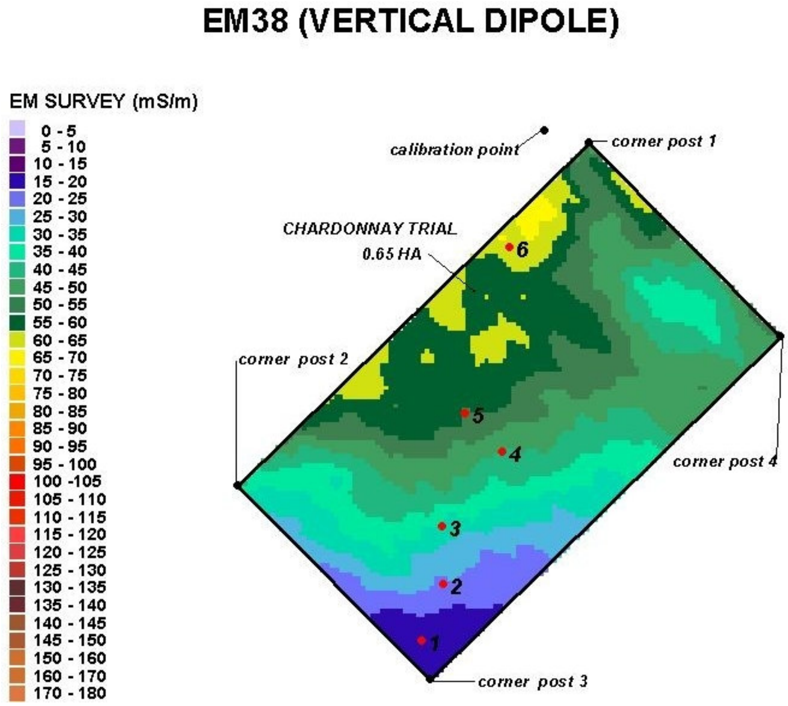


Figure 5. EMv profile of site 4 (Irymple Chardonnay Block) with drip irrigation

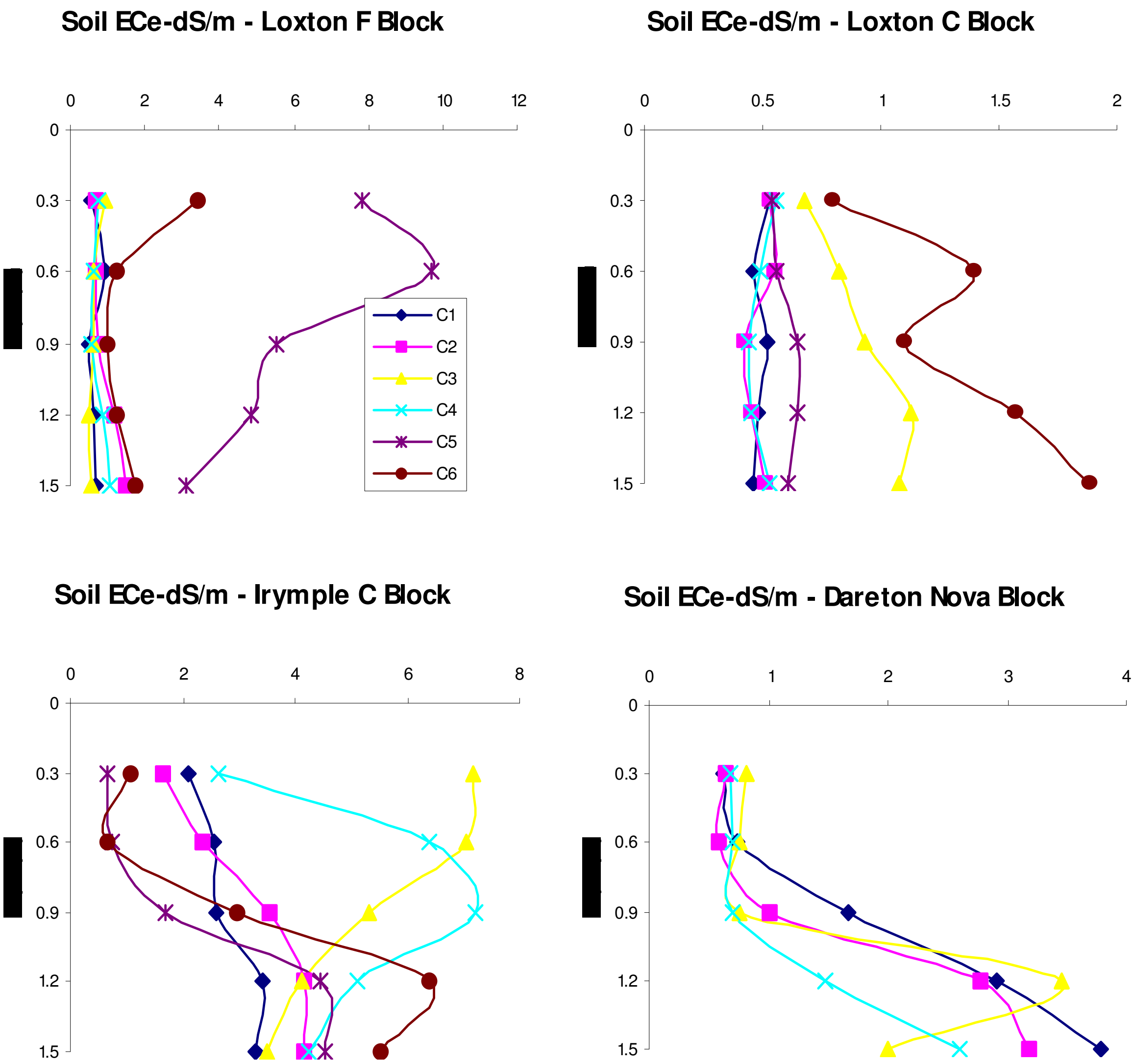
For ground truthing, several soil core samples were collected from the paddock and measured for saturated paste extract (ECe). In general attempts were made to select sampling locations whose ratio were <1.0 and had a maximum spread. A recent review on EM38 by (Vlotman, 2000) has reported that if the ratio of Em_h/Em_v is less 1.05 then the profile is considered as a leached profile. The EM_h/EM_v ratios for this site were less than 1.05 confirming that 40 years of irrigation activities leached salt from the root zone profile.

Table 2. Volume weighted Cl concentration in water applied in 12 months preceding soil sampling, Cl concentrations in the saturated paste extracts (Cle), Cl concentrations in the soil solution (Clsw), leaching fraction and leaching efficiency (Cl in mmol/L)

Site ID	Year of soil sample	Location	Clw	Cle linear average	Clsw linear average	Leaching fraction (1-WUE)	Clsw (GHD, 1998)	Clsw [40-30-20-10]	Clsw (site specific extraction pattern)	Leaching efficiency
DarSat	2004	Sunraysia	0.76	0.68	1.36	0.40	1.33	1.32	1.53	1.17
DarSulSpr	2004	Sunraysia	0.57	0.61	1.23	0.25	1.43	1.29	1.45	1.24
DarSulDrip	2004	Sunraysia	0.49	10.01	20.02	0.30	1.06	1.01	0.98	0.00[A]
DarNav	2004	Sunraysia	0.71	2.29	4.58	0.43	1.18	1.19	1.18	0.1
KeeWash	2004	Sunraysia	0.7	1.48	2.96	0.32	1.44	1.39	1.35	0.25
SCNav	2004	Sunraysia	0.69	1.31	2.62	0.26	1.66	1.53	1.62	0.47
DarNova	2004	Sunraysia	0.7	0.90	1.79	0.23	1.85	1.65	1.88	1.08
KeeNav	2004	Sunraysia	0.61	0.87	1.73	0.28	1.38	1.29	1.46	0.77
FarnChar	2004	Sunraysia	0.49	6.67	13.34	0.22	1.36	1.20	1.28	0.05
S11	2003	Riverland	1.87	17.75	35.51	0.10	10.29	6.85	8.78	0.13
S15	2003	Riverland	1.97	24.87	49.74	0.18	6.46	5.34	M	M
S37	2003	Riverland	1.84	8.04	16.08	0.04	23.92	10.33	15.13	0.91
S42	2003	Riverland	1.9	6.58	13.17	0.10	10.45	6.96	6.76	0.35
S72	2003	Riverland	2.01	4.19	8.38	0.07	15.36	8.75	9.23	1.18
S37	2004	Riverland	1.46	9.50	19.00	0.05	15.33	7.42	10.49	0.4
S42	2004	Riverland	1.46	1.93	3.85	0.11	7.37	5.10	4.92	1.54
S72	2004	Riverland	1.58	5.08	10.15	0.08	10.67	6.45	6.73	0.52
Mean			1.17	6.04	12.09	0.20	6.62	4.06	4.69	0.63

[A] value < 0.00

Figure 6 shows saturated paste EC for all four experimental sites in SA, VIC and NSW and corresponding coring points. We selected instrumentation sites for example, between post 13 and 15 corresponding soil cores 1 and 2 that meets our requirement of nearly an uniform section in the paddock. Similarly, instrumentation location for rest of



the three sites were carefully selected so that we get a fairly leached root zone.

Figure 6. Changes in soil ECe with depth at four experimental sites.

3.2 Relationship between soil solution chloride and solution EC

Due to the large volume of soil and water samples, the measurement of Cl for individual samples is very expensive and time consuming in comparison to EC measurement. An attempt was made to find out whether there exists a relationship between soil or water Cl to the corresponding EC measurements. Figure 7 shows that for 55 soil samples analysed from this project there is a strong relationship between soil solution EC (measured as ECe) and Cl giving goodness of fit r^2 =0.99. Similarly, river water Cl data from MDBC an equally strong relationship was noticed. This indicates that EC can be a surrogate measure for Cl particularly for soil samples.

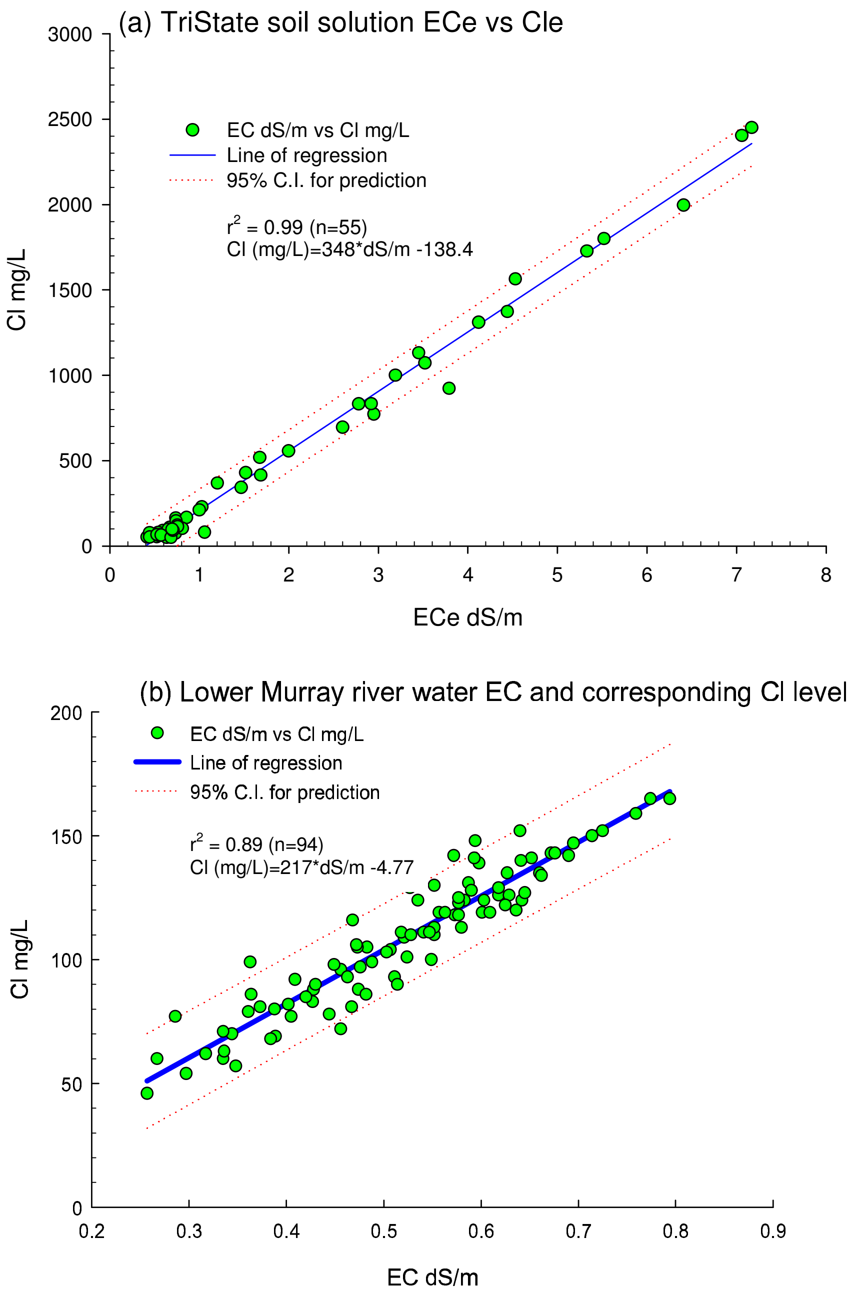


Figure 7. Relationship between EC and Cl for soil saturated paste extracts and irrigation water

3.3 Solution extractors for monitoring root zone salinity

Of the two methods available to extract a sample of soil water solution at depth (suction and Full-Stop indicators), the solution extraction is possibly the more accurate in obtaining a representation of true soil water EC within the root zone. In general an increase in the EC of soil water was observed with depths at each site (see figures 8, 9 and 10). It supported views that the percolation of water down through the soil profile resulted in the increase of EC by way of evaporation and uptake of water by plant root. Most importantly, the data collected over the growing season shows the influence of irrigation and rainfall on the real time changes in solution EC (also called EC_{sw}).

The Full-Stop wetting front detector (Stirzaker, 2003) is a method to indicate when the 'root zone is Full of water', and consequently when to Stop irrigating. It provides a visual indicator for the arrival of a wetting front, and a travel time for the arrival to take place at consecutive depths. The removal and repacking of soil for the fitment of the instrument is however disruptive to the normalised wetting pattern for the soil, and for the purpose of this report, the solutions obtained were not further analysed. With the increased hydraulic conductivity of the repacked soil, the contact time between soil particles and water molecules is obviously reduced to reflect a slightly different signature than soil that has not been disrupted to the same extent. Contact time has been reduced hence the solubility of the soil has also been affected. In contrast to this however, the system is still a useful indicator in most situations and environments, and the use is quite high. The Angas-Bremer Water Board has been using these instruments with success in the implementation of new irrigation policies.

The samples of the extraction method were drawn from all locations for the generation of results. The time frame between extraction and sampling from the solution extractors is a definite limiting factor in the accuracy of EC and or Cl value, hence in-situ field measurement practices have been adopted by field staff to reduce error. The EC_{sw} under Drip peaked to 20 dS/m at 90 cm (root zone depth) whereas it rarely crossed 1.5 dS/m under the under cover sprinkler. According to Mass and Hoffman, 1977 the threshold EC_{sw} for grape is 2.1 dS/m whereas for citrus it is 1 dS/m, beyond which any increase in EC_{sw} will incur yield loss. Hence, as shown in Fig 8 and 9 the uc sprinkler irrigated vine and citrus sites recorded EC_{sw} much below the threshold limit and as such posses no risk to yield. By contrast, the topsoil of drip vine site at Irymple (Fig 10) is sitting on or just above the yield reduction threshold EC_{sw} where as the deeper soil is most likely unsuitable for the root growth and may incur yield loss.

Water draining below the root zone for the drip was generally 10% or less of applied water. This is far lower than the accepted value of 0.15. As shown in Figs 8 and 9 the average EC_{sw} of soil solution at depth 90 cm under sprinkler system is much lower than drip (Fig 10) giving rise to a high leaching volume of water. In general, the LF appears to be inadequate under the drip to leach salt out of root zone, whereas uc sprinkler maintained sufficient leaching and thus low soil water EC_{sw} even at the bottom of the root zone.

With the salt concentrations in the Murray River still increasing as a delayed effect of past vegetation clearing the increasing Cl will be directly transferred to irrigation sites, and hence the root zone. The solution extraction technique will be useful for monitoring the soil profile-leaching fraction, as a function of the increasing irrigation salinity over longer time periods.

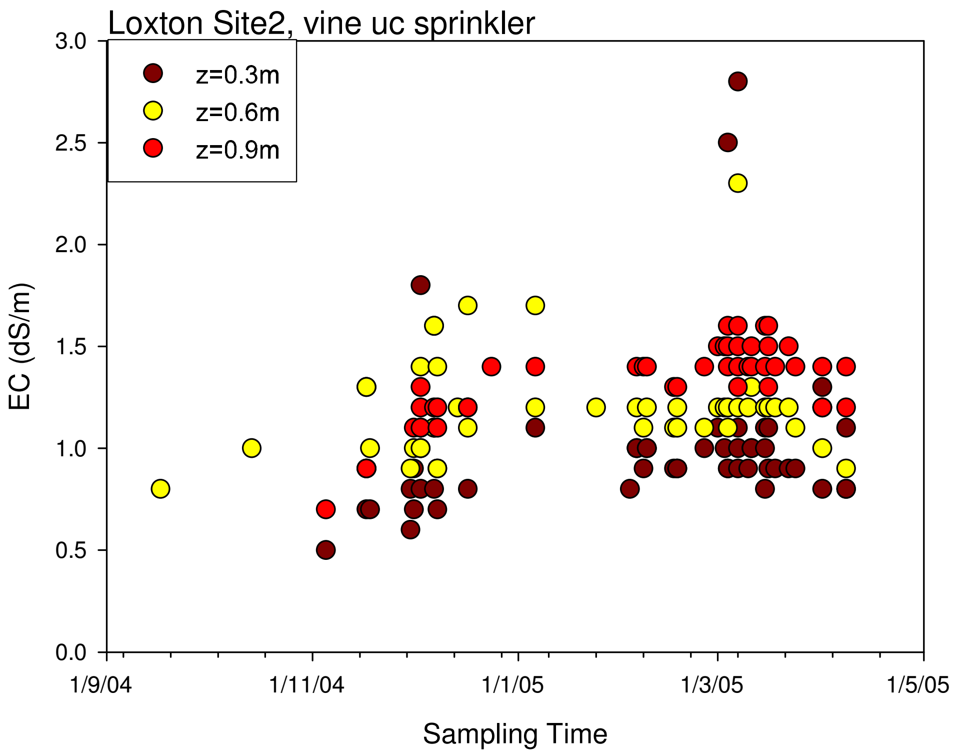


Figure 8. Changes in root zone soil water salinities during irrigation season under a uc sprinkler irrigated vineyard in Loxton, SA

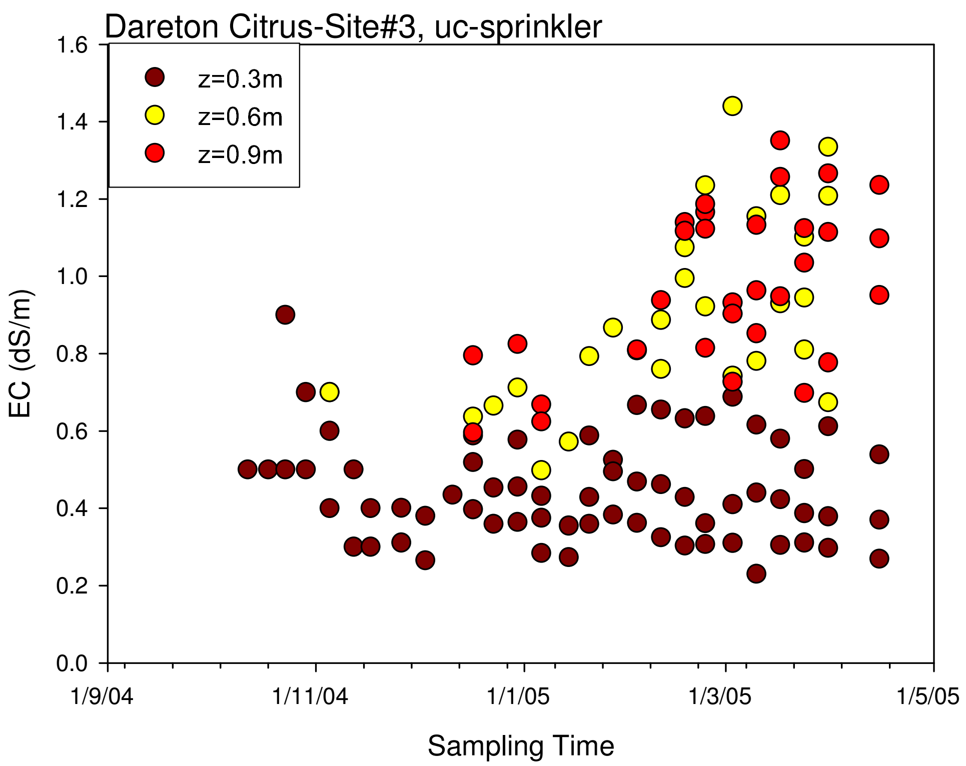


Figure 9. Changes in root zone soil water salinities during irrigation season under a uc sprinkler irrigated citrus orchard in Dareton, NSW

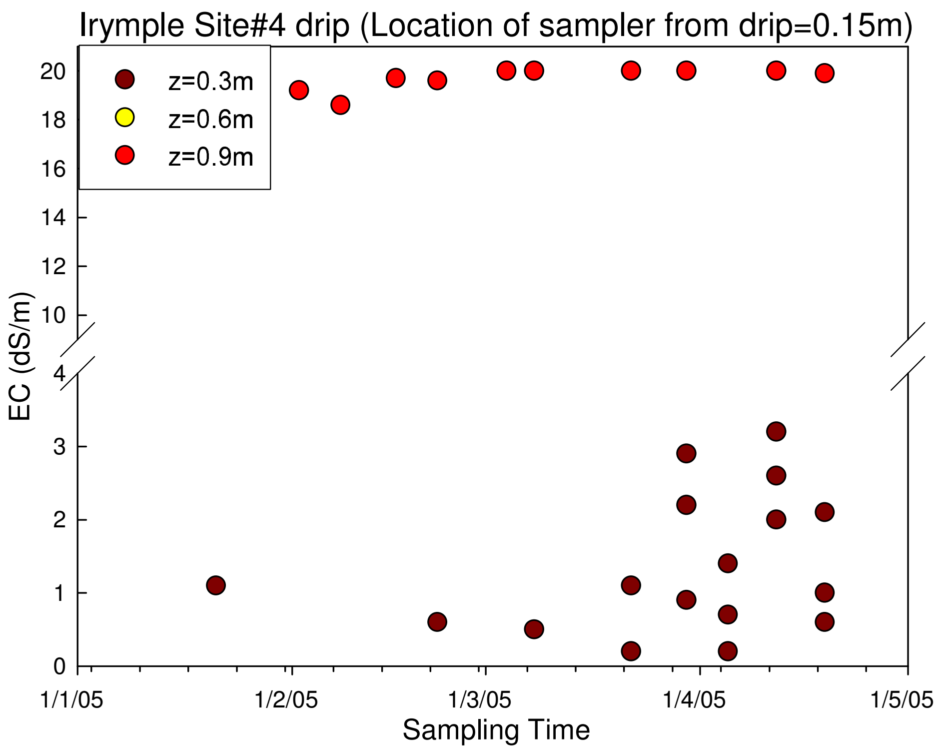


Figure 10. Changes in root zone soil water salinities during irrigation season under a drip irrigated vineyard at Irymple, Vic

3.4 Root zone drainage volume assessment

3.4.1 Seasonal water balance using soil water trace method

Figure 11 presents the water mass balance data from July 2004 to March 2005 where citrus received nearly 10 ML of water per hectare compared to 7 ML for vine under the same system of irrigation. By contrast, the drip system received almost half the citrus requirement. During the same time DD or root zone drainage varied from as low as 4% to a maximum of 35% of applied water. Interestingly, the under cover system in vines resulted in highest volume of DD, when one would expect to get highest from citrus. The rainfall pattern shows that Loxton received 100 mm more rainfall than Dareton, which might explain the high DD under the uc sprinkler.

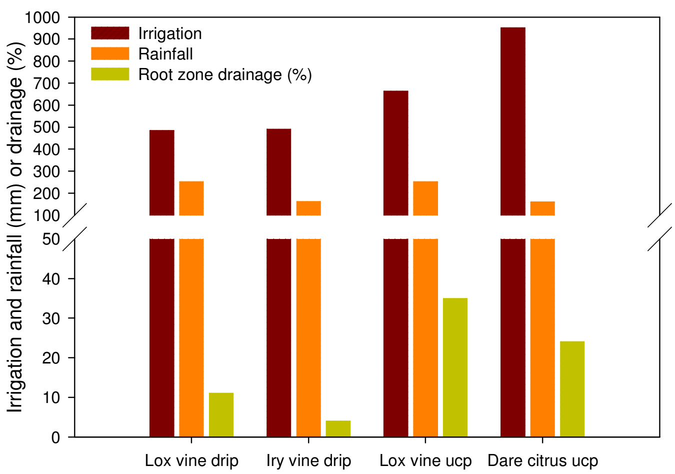


Figure 11. Deep drainage from orchards under different irrigation systems (2004-05)

In general 10% or less DD is occurring under the drip system compared to 24% for citrus and 35% for grapes irrigated by uc sprinkler. In other words, the WUE under the drip is 90-95%. This raises the question of how this high WUE is leading to long term salt accumulation in the root zone and its effect on yield loss.

3.4.2 Chloride Tracing Technique

As discussed in the solution extraction section 3.3, leaching fraction or DD calculated using natural chloride tracer in the soil solution and is given in the Table 3. Solution Cl data were collected between December 2004 and April 2005. This estimate of DD estimation is based on the average EC or Cl concentration in the irrigation and the soil solution drawn from the bottom of root zone (90 cm). The drip vineyard at Loxton didn't produce any leachate (DD) below the root zone where the solution extractors were installed 15 cm away from the dripper. Similarly, Irymple site, which had about 100 mm less rainfall, produced only 1 % of applied water as DD.

Both these sites are irrigated very frequently with lesser amount of water at each irrigation event. The measured soil water tension did not show much fluctuations (fall and rise) with irrigation events at 60, 90 and 120cm depths as it showed for uc sprinkler sites. This suggests that water probably did not enter to a deeper depth due to lighter irrigation.

The result confirms the general observation made by the water balance technique that a negligible leaching is occurring under the drip compared to the uniform uc sprinkler irrigation, irrespective of crop types. However, as expected Loxton vine property on a sandy loam soil generated highest volume of DD; 21% out of 912 mm applied water. Similarly, there was more 17% DD under the Dareton citrus property, for which salt may not be an issue as long as minimum LF of 0.15 (15% DD) is maintained. As a result, the general concern for precision drip irrigation is that if winter rainfall is not effective in leaching the salt from the root zone, management of root zone salt is going to be a major issue.

Table 3. Estimated DD (Sep 04-Apr 05) from soil Cl tracing technique

Site	Irrigation (mm)	Rainfall (mm)	DD (%)
Loxton vine drip	510	177	ND[a]
Irymple vine drip	343	116	1 (±0.02; n=10)[b]
Loxton vine uc sprinkler	735	177	21 (±3; n=53)
Dareton citrus uc sprinkler	912	102	17 (±4; n=31)

[a]ND=Not detected [b]value in parenthesis indicates standard deviation (SD) and n= sample size

3.4.3 Capacitance probe method

3.4.3.1 Hourly soil water balance method

Table 4 gives crops, irrigation systems, FC, root zone depths and DD for 13 irrigated properties ranging from sandy to clay loam in texture. Estimated field capacities ranged from 13 to 32% (v/v). The seasonal irrigation depths for the citrus crops ranged from 588 to 1646 mm; the associated total rainfall ranged from 235 to 284 mm. The vines had seasonal irrigation depths ranging from 440 to 1133 mm and total rainfall from 153 to 303 mm. The vines had seasonal irrigation depths ranging from 440 to 1133 mm and total rainfall from 153 to 303 mm.

Annual DD estimated using capacitance probe data for θ_v from vineyard and citrus sites during and between two irrigation seasons (2002-2004) varied from 181 to 569 mm or 19 to 43% of applied water.

Table 4. Leaching fractions from horticultural properties in Riverland and Sunraysia region

Site	Crop and irrigation system	FC	Root zone	Irrigation	Rain	DD
		%	(cm)	mm	mm	mm
1	Dareton navel citrus -Drip	13	90	1040	284	569
2	Dareton Satsuma ctrus-uc* Sprinkler	18	90	1003	284	515
3	Dareton Mintill vines Drip	18.2	100	588	284	262
4	Dareton Mintill vines Sprinkler	18.5	90	440	284	181
5	Keenan citrus -uc Sprinkler	20	110	1646	284	618
6	Wingara shiraz vines-SS** Drip	20	90	560	228	276
7	Dareton Nova citrus-uc Sprinkler	21	90	1197	284	341
8	Robertson1 vines-ucSprinkler	21	60	638	272	282
9	Keenan navel citrus-uc Sprinkler	24	90	588	235	230
10	Sam Cross citrus-uc Sprinkler	30	60	1056	272	345
11	Farnsworth vines-uc Sprinkler	31	65	686	284	213
12	Robertson2 vines-ucSprinkler	32	60	641	272	274
13	Peter Hammond citrus-uc Sprinkler	32	50	826	303	215

3.4.3.2 θ-ψ Relationship and Darcy's Flux method

Data from the EnviroScan (ES)© probe was retrieved through telemetry from Loxton drip irrigated vine site (F Block) for the period between 22nd November 2004 and the 2nd March 2005. The period was 99.7 days, and received a total 392.60mm from irrigation (277.20mm) and rainfall (115.40mm). A typical moisture profile reading of ES is presented in Figure 12. At the study depths below the root-zone, both probes East and West have recorded very minimal water content. At the prevailing water contents, we are able to say that minimal, if any, drainage will be occurring due to the large matric potential and resulting low unsaturated hydraulic conductivity.

Van Genuchten parameters were derived for F Block from the average values obtained by analysing 14 soil samples at depths between 90 and 150cm. The parameters are:

Alpha (α) =	0.244	(SD ± 0.108)
Mu (m) =	0.17769	(SD ± 0.04033)
θ_s =	0.3455	(SD ± 0.016)
θ_r =	0.0787	(SD ± 0.0249)

n = 1.28185 (SD ± -0.05912)
L = 0.5

Average clay, sand and silt %age of 25.83, 64.83 and 9.3 respectively resulted in K_{sat} of 0.3317cm/hr (SD ±.1065) when SMC soil program (Saxton *et.al*, 1986) was used.

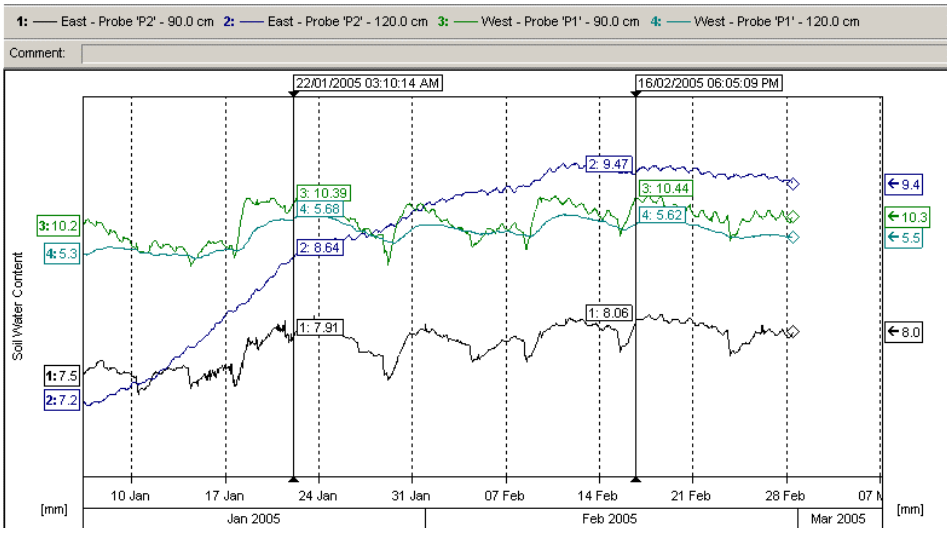


Figure 12. A typical moisture profile reading by the EnviroScan probe.

Figure 13 depicts the real time DD occurring with associated Rainfall and Irrigation events during Nov 2004 to March 2005 under the Loxton drip irrigated vineyard. Relatively high rainfall events occurring in mid December 2004 of 50mm resulted in an increased drainage possibility at a rate of between 0.02 and 0.04mm/d.

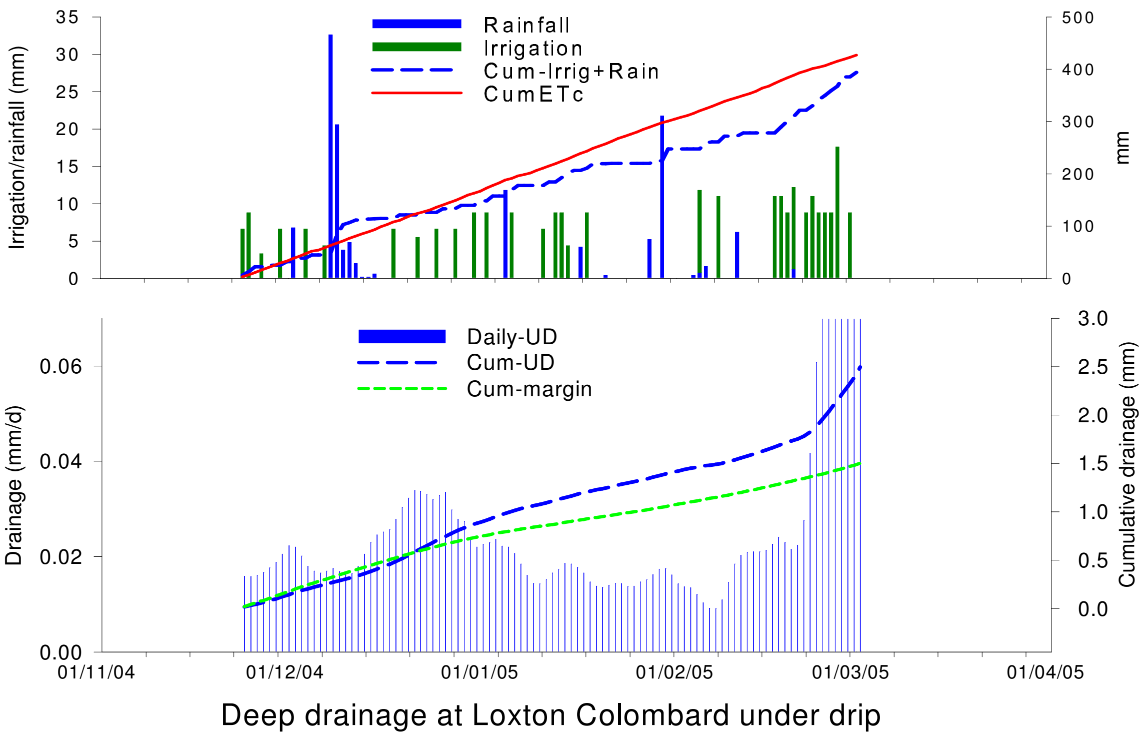


Figure 13. Deep drainage under a drip irrigated vineyard at Loxton, SA during 2004-05 summer irrigation period as influenced by applied water volume and evapotranspiration.

Towards the end of the period, successive irrigation events of just over 10mm application with higher frequency applications, increased the DD occurrences to over 0.06mm/d. Overall water balance (Fig 13) calculated from ET demand minus total irrigation and rainfall was found negative, which meant that there were less water available to plant. This resulted in negligible DD (<1%) confirming the finding of Cl tracing data.

The DD estimated using the capacitance probes water content data, coupled with the van Genuchten expressions and Darcy's law, is therefore extremely useful in supporting point-to-point flux estimations over fluctuating water contents in real time. Due to time implications, a complete season of irrigation from all sites was not as yet available. In order to analyse the effects that rainfall and climatic variation had upon the total DD estimated under the two irrigation types, a complete season of comparative data is required.

The concept of monitoring temporal changes in the unsaturated hydraulic conductivity is of high importance in the estimation of DD. Wetting periods are not homogeneous events that result in a foundational K_{unsat}. The incorporation of this concept has been reflected in the initial results of capacitance theory, suggesting that less DD may be occurring than what was originally estimated by the both the Water Balance Methods.

3.5 Modelling the processes of root zone salinity

Using the data from a drip irrigated Loxton Colombard vineyard in the Bookpurnong Lock-4 district, the output of a two-dimensional numerical flow/transport model (LEACHM-TRANSMIT) is presented in Fig 14. A model simulation run for 278 days with the current river water salinity of 300 EC suggests that at less than 10% root zone drainage, under precision irrigation, about 130 kg salt is likely to accumulate in the root zone during a single irrigation season. Although this may sound little for a single season a long-term accumulation will give rise to hyper saline root zone unsuitable for grape.

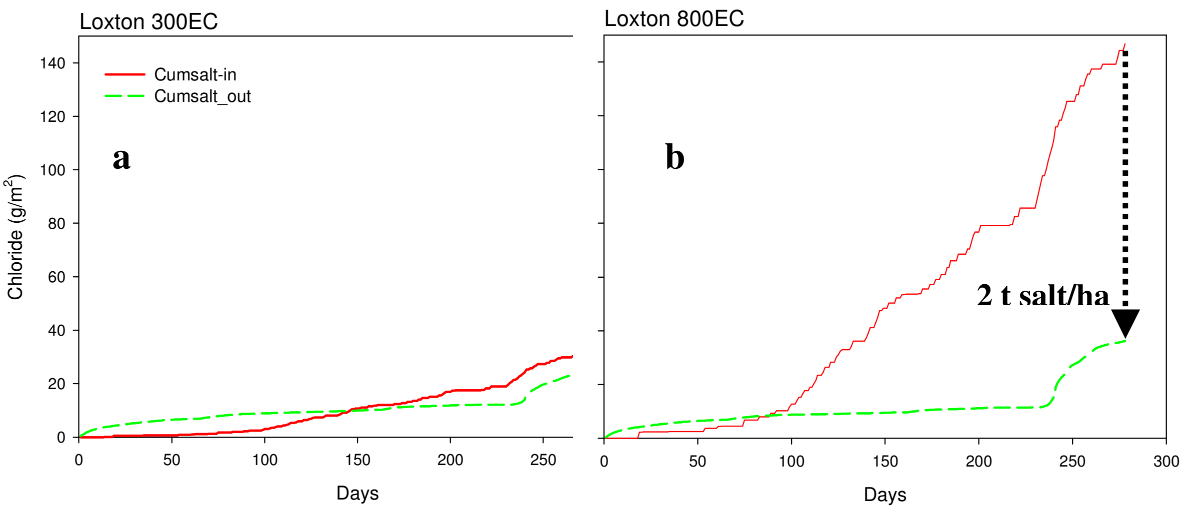


Figure 14. Model prediction of salt builds up in the root zone with two different ECs of river water (a) 300EC (0.3 dS/m) and (b) 800EC (0.8 dS/m)

When simulated with 800 EC irrigation water (Morgan limit), as shown in Fig 14b, the result clearly showed that 2t salt/ha could accumulate in 1 m root zone during a normal grape growing season under drip irrigation. When temporal change in soil EC was plotted against the depth, we obtained a contour map, as in Fig 15, where box Figure inside the contour map shows the existing profile EC at the start of the experiment. As demonstrated in Fig 15, 800 EC water and a drought year could increase topsoil EC to 5 dS/m, at which up to 60% yield loss may occur when plotted in the classical soil EC and yield loss relationship (Mass and Hoffman, 1977).

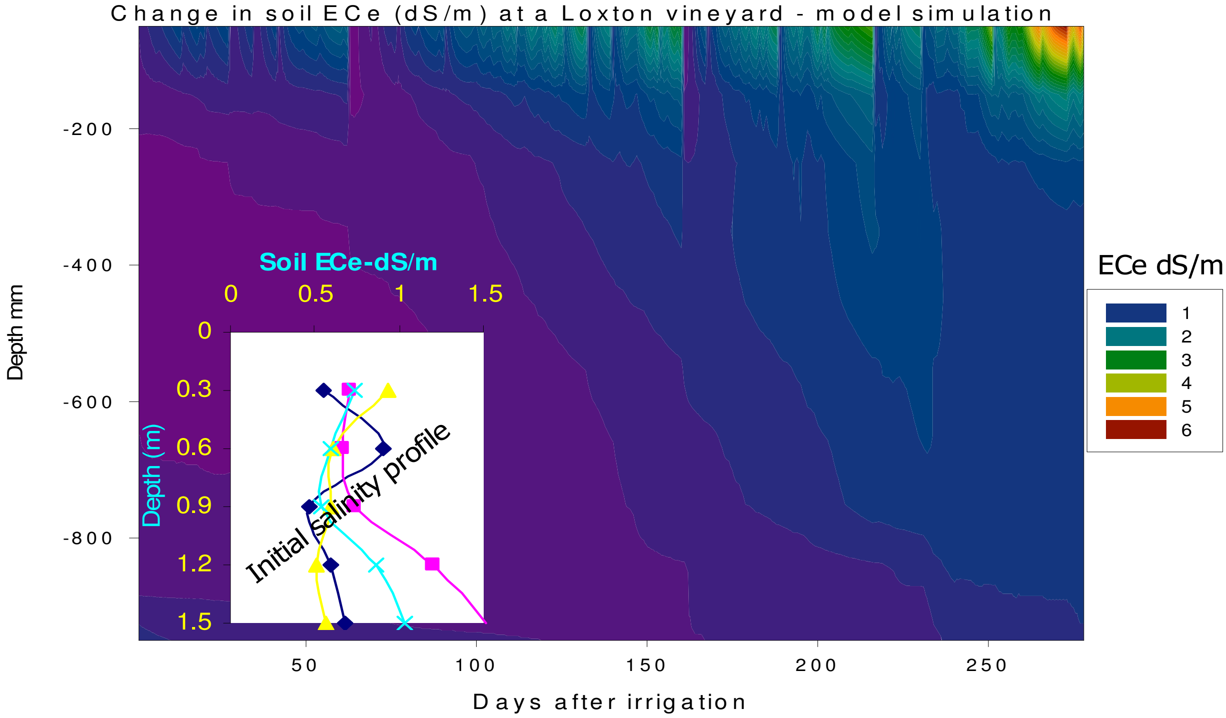


Figure 15. Soil ECe in the root zone during a single season if river water salinity reaches 800 EC (0.8 dS/m)

3.6 Effect of salinity on plant nutrition and fruit quality

Recent salinity survey work has been done in a range of Sunraysia vineyards to assess the chloride and sodium content of petioles and leaves at flowering, veraison and harvest, and berries at harvest. Grape varieties sampled included Chardonnay, Shiraz and Sultana on either Ramsey rootstock or vines on their own roots. The irrigation systems were drip, low level sprinkler and overhead sprinkler. An equivalent combination from the survey work has been compared with DEP15 grape sites 1, 2 and 4 for chloride and sodium in the petiole and berry at harvest (Table 5).

The survey results in brackets (bold) are drawn from an average of 2 seasons' results (2000/01- 2001/02). Since, Colombard grape was not a part of the Sunraysia survey, it is compared with a Chardonnay site on Ramsey rootstock in a sandy loam soil and drip irrigated with 4ML/ha/yr.

Table 5. Elemental analysis of leaf petiole and berry juice of grapes grown with moderately saline water in Loxton (SA) and Irymple (Vic)

Element	*Site1*			*Site2*			*Site4*		
	Flowering (2004)	*Harvest (2005)*	*Comment*	*Flowering (2004)*	*Harvest (2005)*	*Comment*	*Flowering (2004)*	*Harvest (2005)*	*Comment*
Nitrate – N (mg/kg)	250	220		920	440		1900	300	
Nitrogen (%)	0.74	*		1.0	*		1.4	*	
Phosphorus (%)	0.5	0.21		0.27	0.14		0.23	0.08	
Potassium (%)	2.8	1.1		2.5	4.2		2.4	1.4	
Calcium (%)	1.7	2.8		1.6	1.8		1.6	2.1	
Magnesium (%)	0.65	1.5		0.54	0.82		0.5	0.86	
Sodium (%)	0.11	0.46	**(0.91)**[A]	0.07	0.14	**(0.55)**	0.12	1.1	**(0.91)**
Chloride (%)	0.20	0.99	**(1.31)**	0.15	0.35	**(1.44)**	0.73	1.5	**(1.31)**
Zinc (mg/kg)	33	41		68	142		59	79	
Manganese (mg/kg)	24	46		33	44		307	1078	
Iron (mg/kg)	25	28		20	35		20	28	
Copper (mg/kg)	19	51		14	66		25	17	
Boron (mg/kg)	32	27		44	43		61	48	
Sulphur (%)	0.05	*		0.11	*		0.08	*	
Berry Cl (mg/l)		39c	**(85)**		*	**(61)**		80	
Berry Na (mg/l)		38d	**(56)**		*	**(91)**		78	

[A] Figures in the parenthesis represent the Sunraysia survey average survey result, whereas wine Cl standard =394 mg/l and wine Na Standard =606 mg/l

For all sites the petiole samples were collected first at the flowering time in early Nov 2004 followed by a harvest sample in March 2005. Berries were collected at harvest and analysed for Na and Cl only. The elemental constituents of the petiole and berry samples are presented in the Table 5. There were no significant salt problems identified from the chloride and sodium analysis of grape material from this survey.

Chloride and sodium result from reflects the management issues such as water quality and volume applied. When compared to the Sunraysia comparative survey result, the salt concentration in the plant at both the Loxton sites were low warranting no immediate salinity risk issue. However, no berry testing was done at loxton uc sprinker vine site but it would be expected that the chloride and sodium levels in the berry at harvest would be significantly lower than those from the comparative Sunraysia vineyard.

By contrast, Irymple drip irrigated vine site recorded higher than expected petiole salt levels and ultimately led to highest Na reading in the berry at harvest. This conforms the inadequacy of root zone salt leaching, which led to high EC_{sw} reading amongst all the vine sites surveyed.

Table 6 presents the elemental analysis of Nova mandarin citrus leaves from the Dareton site. The sandy loam soil type at the trial site is alkaline but leaf calcium levels are now in the marginal category for citrus. The 3 leaf calcium nitrate sprays during the season, prior to leaf sampling, have not been reflected in the petiole results. Heavy crop load in 2004 probably caused the 'export' of calcium from the orchard in harvested fruit. A specific calcium spray product (Caltrac – Phosyn Chemicals) will be applied as well as the calcium nitrate sprays for rind condition in the 2005-06 season.

The lower manganese, zinc and iron levels are a reflection of the moist alkaline soil conditions in the trial area causing 'lock–up' of these elements in the soil. This is a typical feature of citrus grown on this soil type. The leaf nutrient spray program for these elements will be increased over the spring to autumn growing period.

Table 6. Elemental analysis of citrus leaf (Nova mandarin) at Dareton (NSW) site

Element	*2004*	*2005*	*Comment 2005*
Nitrate – N (mg/kg)	390	*	
Nitrogen (%)	2.4	2.4	Adequate – low end of range
Phosphorus (%)	0.12	0.13	Adequate
Potassium (%)	1.3	1.7	High
Calcium (%)	3.8	2.7	Marginal
Magnesium (%)	0.37	0.31	Adequate
Sodium (%)	0.02	0.02	Low
Chloride (%)	0.08	0.05	Low
Zinc (mg/kg)	144	52	Adequate
Manganese (mg/kg)	100	24	Marginal
Iron (mg/kg)	67	49	Marginal
Copper (mg/kg)	9	8	Adequate
Boron (mg/kg)	63	50	Adequate
Sulphur (%)	0.20	*	

The chloride and sodium levels have remained very low in 2005, which is a reflection of the low salinity irrigation water, high water volume (13Ml/ha/yr) under-tree sprinkler application and low soil electrical conductivity (EC) in the rootzone.

Internal fruit quality at harvest on 15/6/2005 recorded Juice%: 48, ºBrix (sugar): 11.2. Acid %: 0.93 and Brix to Acid ratio: 12:1. Yield on citrange rootstock was 29.7kg/tree in 2005 (30% of 2004 yield) due to spring hedging and topping of the block to shape, allow access and re-invigorate the trees for future cropping seasons. Fruit was not sold commercially from the trial in 2005.

4 SUMMARY REPORT ON COMMUNICATION

A formal communication strategy has been prepared by the project team, and is updated regularly. The strategy has identified three main target audiences; project partners and funding organisations, additional key technologists and policy makers, and finally key local irrigator, community and industry groups.

Key messages have been presented to each of these audiences by a range of techniques; including communication within the project, technical presentations and publications, and media articles or interviews.

The strategy was endorsed by the PSC at its meeting in Oct 04, who noted;

- The significant effort made by the PMC in setting up the project, and the thorough review carried out in phase 1 leading to a program of field-work.
- The wide range of initial technical presentations to key stakeholders.
- Excellent internal communication between the project partners and team members.
- In the case of this project, branding should be in the form of acknowledgement of partner's logos rather than a specific project logo.

During the first 18 months of the project, communication activities have been primarily about awareness of the potential problem of low leaching efficiency.

Results of the first season's field measurements will become available in the next month or so, requiring a review of future communication activities including;

- Review of key stakeholder/target audience lists and key messages for different audiences. To date only a limited number of the initial proposed stakeholders have received information about the project.
- Planning of future technical presentations.
- Wider involvement of key local irrigators in the project through seminars and field day events.

A specific meeting for the PMC needs to be convened to concentrate on this future planning.

The following table out-lines communication activities to date. Activities in *italics* have been carried out since the last milestone report.

Target Audience	Strategy	Activity
Project partners and funding organizations	Communication within the project	a) Bi-monthly project team meetings held at the Sunraysia Horticultural Centre Mildura, Loxton Research Centre, and Dareton Research Station NSW. b) Project team members attended Environmental Risk Assessment workshop at Mildura, hosted by NPSI, to assess a methodology for estimating environmental impact of the project. c) Three project steering committee meetings, held at Mildura, and an additional meeting by telephone hook-up. *d) Fachou Zhou a Chinese PhD student from Wuhan University has begun work to assist the modeling approach within the project in a collaborative arrangement between SARDI and Wuhan University, May 2005.*
	Technical presentations and publications	a) Presentations to: -2003 NPSI Investors Forum, Shepparton, Sep 2003. -NPSI Management Committee Meeting, Mildura, Sep 2004. -CRC –IF Conference, Sydney, Sep 2004 -2004 NPSI Investors Forum, Barossa Valley, Oct 2004. -ANCID 2004 Conference, Barossa Valley, Oct 2004. *- CRC-IF Winter Zone Advisory Group, Melbourne, April 2005.* *-IAA Conference, Townsville, May 2005.* *- Regional forum of the Institute of Public Administration, Berri, May 2005* *-River Murray Catchment Water Management Board, Berri, June* 2005. b) Posters prepared for - 2003 ANCID Conference - 2004 ANCID Conference. c) Stage 1 Report (2003-2004) distributed to partners and funders, Aug 2004. d) *Milestone 2 report distributed to partners and funders*

Additional key technologists and policy makers	Technical presentations and publications	a) Above list of presentations to Project Partners and Funding organisations would have included additional key technologists group. b) *Specific presentations to additional key technologists;* *-CRC-IF Program 3, Practice and Technology of Irrigation, Brisbane June 2005 – presentation of site instrumentation and modeling approach used in the project.*
	Media program	a) Tri-state salinity project coloured flyer distributed, 2004. b) *NPSI Irrigation Update Volume 4, May 2005. Article on "Addressing the silent time bomb".*
Key local irrigator, community and industry groups	Technical presentations and publications	a) AGM of the SA Murray Irrigators Inc at Mypolonga, in November 2004, on "Irrigation Performance and Rootzone Salinity Management". b) *Suction cup lysimeters used at project trial sites promoted to vegetable growers on the Northern Adelaide Plains.* *c) Presentation to SA Minister for the River Murray and local growers, Bamera, June 2005.*
	Media program	a) SA Stock Journal 23/9/04. "Tackling the silent time bomb". b) Murray Pioneer 1/10/04. "Tackling the salt time bomb". c) Loxton News 20/10/04. "Tackling the silent time bomb". d) RMCWMB In the Basin newsletter, Issue 4 Dec 2004. "Tackling rootzone salinity in the Riverland and Sunraysia". *e) Sunraysia Daily 12 Jan 2005, "Tackling salinity in Sunraysia and the Riverland".* *f) WIN TV – Riverland . Interview about the project, Jan 2005.* *g) ABC Radio Country Hour. Interview on Salinity Impact on Lower Murray Horticulture, May 2005.*

5. CONCLUSION

i. Under the drip system, less than 10% of applied water is leaving the root zone during the grape growing season
ii. Less than 10% root zone drainage under precision irrigation resulted in salt build up in root zone even at the current river water salinity of 300 EC
iii. Model simulation run at 800 EC irrigation showed that 2t salt/ha could accumulate in 1 m root zone in a normal grape growing season under drip irrigation
iv. If irrigated with 800EC in a drought year, this could increase soil EC to 5 dS/m, at which up to 60% yield loss may occur
v. Fruit and leaf analysis showed no significant salt problem for either grape or citrus during 2004-2005 except for Irymple drip site, which recorded very high amount of sodium in both the leaf petiole and berry juice.
vi. Solution extractors, developed by this project, are being adopted by the PIRSA-ICMS/RMCWMB to estimate deep percolation in the Bookpurnong Lock 4 irrigation district
vii. DPI-Vic's dairy project and vegetable growers from the Adelaide hill expressed keen interest in the solution extractor to monitor salts and nutrients in the root zone
viii. Submitted a summer studentship completion report on deep drainage work to CRC-IF
ix. A Chinese PhD student from Wuhan University has begun work to assist the modeling approach within the project in a collaborative arrangement
x. Eight articles have been published including 2 refereed conference articles and 4 media articles in SA, Vic and NSW rural newspapers.

6 FUTURE DIRECTION

i. Collection of full season data for model simulation to predict long term scenarios.
ii. Economic analysis of root zone salinity related crop loss in Riverland and Sunraysia.
iii. Continue providing environmental indicators input to CRCIF sustainable irrigation challenge project.
iv. Continue interaction with priority stakeholders and industry groups.
v. Provide input to and interact with related projects such as, 'BPL4 Deep Drainage' and 'CMA Irrigation Management Impact'.

7 REFERENCES

Ayers, R. S., and D. W. Westcot. (1985). Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. (FAO: Rome.)

Biswas TK, Schrale G, Bourne J (2005) 'Salinity Impact on Lower Murray Horticulture - DEP15 Project Milestone 2 Report.' Water Resources & Irrigation, SARDI, Adelaide SA 5001

Blackburn, G., and S. McLeod. (1983). Salinity of atmospheric precipitation in the Murray-Darling drainage division. *Australian Journal of Soil Research* 24, 411-34.

Bouwer, H. (1969). Salt balance, irrigation efficiency and drainage design. *American Society Civil Engineers Journal of Irrigation and Drainage Division.* 95:153-170.

GHD (Gutteridge, Haskins and Davey) (1999). Murray-Darling Basin Commission Salinity Impact Study. (Gutteridge, Haskins and Davey Pty Ltd, Melbourne.)

Hoffman, G.J., and , M. Th. van Genuchten. (1983). Soil properties and efficient water use: water management for salinity control. *In* Limitations to Efficient Water Use in Crop Production (eds. Taylor, H.M, Jordan, W.R. and Sinclair, T.R.) pp 73-85 ASA, CSSA, SSSA Madison, Wisconsin.

Hutson, J.L. and R.J. Wagenet. (1995). A multiregion model describing water flow and solute transport in heterogeneous soils. *Soil Sci Soc Am J.* 59:743-751.

Maas, E.V. and G.J. Hoffman. (1977). Crop salt tolerance-current assessment. *American Society Civil Engineers Journal of Irrigation and Drainage Division*. 103 (IR2):115-134.

Meissner, T. (2004). Relationship between soil properties of Mallee soils and parameters of two moisture characteristics models. (Super Soil 2004-3rd AusNZ Soils Conference, Univ Sydney: ASSSI, P.O. Box 1349, WARRAGUL VIC 3820)

Paltineanu I.C., Starr J.L. (1997). Real-time soil water dynamics using multisensor capacitance probes: Laboratory calibration. *Soil Sci. Soc. Am. J.;*61: 1576-1585.

Prendergast, J.B. (1993). A model of crop yield response to irrigation water salinity: theory, testing and application. *Irrigation Science* 13:-157-164

Rhoades, J.D. (1974). Drainage for salinity control. *In*: van Schilfgaarde J (Ed) Drainage for agriculture pp 433-461. Am. Soc. Agronomy. USA.

Saxton KE, Rawls WJ, Romberger JS, Papendick RI (1986) Estimating generalized soil-water characteristics from texture. *Soil Sci Soc Am J*. 50, 1031-1036.

Schrale, G.S. and T.K. Biswas. (2004). Salinity Impact on Lower Murray Horticulture -Stage 1 Report. Water Resources & Irrigation, SARDI Sustainable Systems, GPO Box 397, Adelaide SA 5001.

SENTEK. (1997). EnviroSCAN. Hardware manual ver.3.0. Sentek Pty. Ltd, 77 Magill Rd, Adelaide 5069.

Stirzaker, R.J. (2003). When to turn the water off: scheduling micro-irrigation with a wetting front detector. *Irrigation Science.* 22:177-185.

Van Genuchten, M.Th. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Sco. Am.J.* 44:892-898

Vlotman, W.F. (2000). EM38 WORKSHOP PROCEEDINGS (ed: W.F. Vlotman). New Delhi, Feb 4. ILRI, The Netherlands.

Appendix 1. Milestone 1 -Executive summary

Background

Irrigated horticulture in the Lower Murray (Riverland-Sunraysia) region contributes a 'gate-value' of about $ 2.5 billion a year to the national economy. As a consequence of improved irrigation practices over the years, there is a risk emerging of a salinity build-up in the root zone, threatening the sustainability of this region.

Irrigation of virgin land results in leaching antecedent salts from the upper soil strata, while irrigation water itself also contains some salt. Ultimately the salinity of the root zone will be in equilibrium with the salinity of the irrigation water. In the Lower Murray region irrigation water contains a significant amount of salt. This implies that saline drainage must occur for irrigation to be sustainable.

During the early years of irrigation in the Riverland average annual applications were of the order of 10 to 20 ML/ha. Field application efficiencies were very low which meant that large amounts went to drainage and no build-up of salinity in the root zone occurred. To prevent water-logging in the soil profile, especially where low permeable Blanchetown clay was present, tile drainage was installed during the 1950's and 1960's.

During the past two decades the water use efficiency (WUE) of irrigated horticulture in this region has gradually increased from about 50 to 80% as a consequence of improved irrigation systems and management. Under steady state conditions, the salinity of the root zone can be predicted from irrigation water salinity and the leaching fraction (portion of water applied at the surface which flows out of the base of the root zone).

In the Lower Murray Region the irrigation water salinity is typically about 0.4 dS m^{-1} and with 15-20% leaching the average salinity (ECe) in the root zone should be around 0.6 dS m^{-1}. Field surveys however indicate that the root zone salinity is often greater than 1.3 dS m^{-1} with considerable variance. This value is well above the threshold for salinity damage to vines and citrus. Stevens (2002)[3] states that this discrepancy between observed and expected soil salinity may be due to a portion of the extra water applied for leaching moving rapidly through the larger soil pores without removing any salt from the root zone. On the other hand, the portion of water moving through the finer pores displaces effectively the (saline) soil water as a piston flow. As a result, the leachate is a mixture of irrigation water that has passed unchanged and of displaced soil solution. Van der Molen (1973)[4] described this salt transport process with the term 'leaching efficiency' ie the portion of irrigation water that completely mixes with the soil solution.

With the objective of managing the impact of irrigation on river water quality and health of the floodplains, the River Murray Catchment Water Management Board introduced an 85% target of WUE in the current Water Allocation Plan. Insufficient leaching at that target may result in high levels of root zone salinity and subsequent yield losses for the local horticultural crops.

In order to understand and manage this salinity hazard, a 'Tri-State Salinity' syndicate of Government agencies from western NSW, Victoria and South Australia (with support from federal agencies) was formed to undertake laboratory and field scale studies for irrigated horticulture in this region for three years starting at the end of 2003.

---

[3] Stevens, R.M. (2002). Australian Grapegrower & Winemaker. 466:71-76

[4] Van der Molen, W.H. (1973) Salt Balance and Leaching Requirement. pp 59-100. In: Drainage Principles and Applications. Publication 16 Vol 2. International Institute for Land Reclamation and Improvement. Wageningen, Netherlands.

Objectives

This project has been developed to test the hypothesis that: *'a depressed leaching efficiency (LE) in the Lower Murray irrigation districts has been raising the root zone salinity and that any improved water use efficiency (WUE) may have an upper limit determined by paddock's LE and its variance'*.

The project objectives are:

i. Determine/update the salinity relationships for irrigated horticulture along the Lower Murray: Riverland, Sunraysia and western NSW;
ii. Determine the variability of EC (soil water) and leaching efficiency in the field under known soil conditions and irrigation management;
iii. Simulate the performance of horticultural crops under different scenarios of River Murray salinity at Morgan; and
iv. Provide input to the implementation of the Salinity Strategy and Integrated Catchment Management Plan of the Murray-Darling Basin.

Meanwhile MDBC (subject to funds being available) has requested an economic assessment of the significance of leaching efficiency on modern (& efficient) irrigated horticulture in the Lower Murray region. An economic framework has been developed and an initial assessment using data available for irrigated areas, crop types and soil conditions has been carried out.

The project activities are spread over two distinctive stages to deliver a series of outcomes that could assess the risk of irrigation water-induced salinity on Lower Murray horticulture.

Stage 1 outputs

1. Five literature reviews on the salinity relationships for the commonly grown crops in the Lower Murray region: grape, citrus, stone fruit, vegetables (asparagus, carrot, tomato) and melon (Appendix 1)
2. A review on the need for leaching efficiency for a sustainable irrigation (Appendix 2)
3. A detailed methodology for interpretation of capacitance sensor data for estimating the leaching fraction and soil water extraction patterns in Sunraysia-Riverland (Appendix 3)
4. Field estimation of the leaching efficiency and its variance based on irrigation and soil chloride data from 23 properties in the region (Appendix 4)
5. Gap analysis of the irrigation and salinity relationships used in GHD's report estimating economic losses due to changing River Murray salinity (Appendix 5)
6. Economic assessment of salinity impact on lower Murray horticulture based on variation in River Murray salinity scenarios (Appendix 6)
7. A detailed field experimental plan for scientific measurement of water and salt flux in the lower Murray region (Appendix 7)
8. Communication plan for the project including a summary on the SARDI website (Appendix 8) (http://www.sardi.sa.gov.au/pages/horticulture/viti/sustainable/salinity.htm)

Stage 1 Finding

The literature reviews of major crop responses to root zone salinities showed that since the work on crop salinity tolerances by Maas and Hoffman (1977)[5], no significant changes been reported except for vines grown on grafted rootstocks (Walker and Stevens, 2004)[6].

The leaching review highlights that the inefficient leaching of salts from the root zone may be occurring due to preferential flow (i.e., bypass of soil matrix through soil macro-pores). In soils with a low leaching efficiency, less than the expected amount of salt is displaced from the root zone. This risk salt accumulation in the root zone is inherently greater under current irrigation practices with a high WUE.

The leaching review identified that the rate of salt removal from the root zone was found to vary for the different leaching strategies, and, where possible, leaching should be only practiced in winter when plant water use and soil evaporation is low and higher leaching efficiencies can be achieved.

The Stage 1 field studies at 23 sites showed that the upper range of average soil ECe in both Sunraysia and the Riverland were well above the threshold for salinity damage to vines and citrus. The average leaching efficiency was 0.65 with a large range in the values measured. Root zone leaching according to the piston flow concept, as often anticipated to occur, has a leaching efficiency of unity.

The stage 1 findings clearly show the need for further investigations into leaching processes.

[5] Maas,EV. & Hoffman, GJ (1977). Crop salt tolerance-current assessment. ASCE J. Irrig & Drainage Div. 103 (IR2):115-134

[4] Walker, R. & Stevens, R. (2004). Recent developments in the understanding of the effects of salinity on grapevines.

Appendix 2. Milestone 2 -Executive Summary

During the past two decades improvements in horticultural irrigation systems and their management have raised water use efficiency (WUE)[7] from about 50 to 85% in this region. As a consequence the drainage volumes have been reduced from about 50 % of water applied to 15%. Under steady state conditions, the salinity in the root zone can be predicted from irrigation water salinity and the leaching fraction (portion of water applied at the surface which drains out of the base of the root zone). This prediction assumes that the extra water applied for leaching uniformly displaces the (saline) soil water as a 'piston' flow.

In the middle of the Lower Murray Region irrigation water salinity is typically about 0.4 dS m-1. With 15-20% leaching, the average salinity (ECe) in the root zone should be around 0.6 dS m-1. Field surveys however, indicate that the root zone salinity is often greater than 1.3 dS m-1 with considerable variance. The discrepancy between observed and expected soil salinity may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone. As a result, the leachate is a mixture of irrigation water that has passed unchanged and of displaced soil solution. Van der Molen (1956)8 described this bi-pathway water and salt transport process and used the term 'leaching efficiency' to describe the ratio of the volume of drainage flowing by piston flow to the total volume of drainage.

A 'Tri-State Salinity' syndicate of Government agencies from western NSW, Victoria and South Australia (with support from federal agencies) was formed to generate the knowledge on managing this salinity hazard by undertaking a 3 year laboratory and field scale studies for irrigated horticulture in this region.

From the Stage 1 investigations, summarised in Milestone 1 report, it was found that the extra irrigation water applied for leaching the residual salt from the root zone of vineyards and orchards in the Sunraysia and Riverland area did not remove the anticipated quota of salt. For the reader's convenience, the executive summary of the Milestone 1 report is reproduced in Appendix 1. Besides the preliminary communication plan and a framework for economic loss analysis, Stage 1 outcomes included development of Stage 2 work plan and identification of possible "bolt on" projects for the Murray Mallee region to jointly combat the challenges of root zone salinity issues in permanent horticulture. Appendix 2 incorporates the minutes from the Steering Committee meeting held on 28th Oct 2004, which complemented the DEP15 project team for heading in the right direction.

This Milestone 2 report summarises the interim progress against outcomes & deliverables set for Milestone 2 of the Tri-State Salinity project, presented in Table 1 below. This mainly includes:

i. Independent reviews of the Stage 2 work plan and the team's response to the suggestions made;
ii. Identification of representative sites for the study area across three States for instrumentations and telemetry;
iii. Draft methodology and protocol for water, soil, soil solution, hydraulic parameters and plant tissue sampling and monitoring;
iv. Interim observations and future direction;

---

[7] Water use efficiency is a broad term and in this paper it is used specifically to indicate field application efficiency

[8] Van der Molen, W.H. (1973) Salt Balance and Leaching Requirement. pp 59-100. In: Drainage Principles and Applications. Publication 16 Vol 2. International Institute for Land Reclamation and Improvement. Wageningen, Netherlands.

v. Communication through various avenues to different audiences (Appendix 3); and
vi. A revised draft of root zone salinity related economic loss analysis of Lower Murray Horticulture (Appendix 4).

Milestone 2 Highlights in a Nutshell

i. Developed and manufactured a new device: a soil solution extractor for determining the chemical composition of soil water available for plant uptake.
ii. Installed forty eight extractors in root zones at our four vine and citrus calibration sites in SA, NSW and Vic
iii. Trained DPI-Vic and NSW-DPI and PIRSA-ICMS staff in the use of soil solution extractors; these devices are now also used in the NPSI/HAL funded project on Open Hydroponic Systems.
iv. Our preliminary survey of 14 properties indicates that salt displacement from root zone by leaching is less than expected leaching, however our results have a considerable variance (75% cv).
v. Our actually measured Leaching Fraction at a citrus property near Dareton is about 20%; this is twice the value used by MDBC for water balance modelling of irrigation districts.
vi. Project staff discovered an unpublished database on soil water release curves for nearly 300 Mallee soils from PIRSA lab work undertaken in the 1980s.
vii. Project won a CRC-IF funded, summer internship for a Flinders University student: Nicolas Kruger
viii. Our method for deep drainage assessment (See Milestone 1 report) has been adopted by RMCWMB for the Bookpurnong-Lock 4 project.
ix. Assisted the GWRRDC-funded 'Clean & Green Viticulture' project for monitoring nutrient and pesticide leaching from vineyards.
x. Seven articles on our project published including 3 media articles in SA, Vic and NSW rural newspapers.