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Salinity Impact on Lower Murray Horticulture

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SALINITY IMPACT ON LOWER MURRAY HORTICULTURE [DEP-15 PROJECT]



FINAL REPORT

For LWA (through NPSI), MDBC and SAMDB Natural Resource Board

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Cover page: A drip irrigated vineyard (left) and sprinkler irrigated citrus orchard (right) in a Riverland irrigation district (Bookpurnong-Lock 4).

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I. Background

In the past decade, growers in the semi-arid region of the Lower Murray River have converted to pressurised irrigation systems. The drivers for this conversion have been: (i) Grape growing under controlled water stress for better quality wine, (ii) A 'wine boom' which has enabled progressive growers to change over to precision irrigation and (iii) Growing competition for high-security irrigation water for permanent horticulture.

Irrigation water contains dissolved salts that can accumulate in the root zone as evapotranspiration (E_t) removes irrigation water and leaves the salts behind. Even though there is still a leaching fraction, it is unclear how efficiently the residual salt is being displaced from the soil profile in this semi-arid region with low rainfall. Under steady state conditions, root zone salinity can be estimated from salinities of the irrigation water and the leachate (i.e. extra irrigation water applied which drains out of the base of the root zone). With River Murray water salinity of about 0.4dS/m, a 15% leaching fraction or deep drainage is likely to give a root zone salinity of 0.6 dS/m. This algorithm assumes that the leaching water uniformly displaces the (saline) soil water as 'piston' flow, but this is unlikely to occur because of the presence of macropores that allow bypass flow. (Bouwer 1969) described bypass water movement and associated salt transport and introduced the term of 'leaching efficiency' (LE) as a ratio of the volume of drainage flowing by piston flow to the total volume of drainage.

Several growers from those regions have reported high levels of sodium and chloride in leaf, grape and reduction in wine quality. There is also some evidence of tree mortality. Insufficient leaching of residual salts is threatening the sustainability of horticulture (\$2 billion/year) in the lower Murray region of Victoria, NSW and SA.

In response, a 'tri-state' salinity project (called DEPI5) was initiated with funding from Land & Water Australia, (through the National Program for Sustainable Irrigation), the Murray-Darling Basin Commission, and the River Murray Catchment Water Management Board (RMCWMB).

In addition to biophysical and economic modeling of salinity impacts in the region, the project team has developed three practical tools and a draft best management practice (BMP) guidelines for growers to measure deep drainage and manage the root zone salinity hazard. The 3 tools are: Deep Drainage Estimation from Capacitance Probe Logs, Soil Water Extractor for monitoring root zone salinity and a new method for assessing Leaching Efficiency in the field.

2. Project Objectives

The project was developed to test the hypothesis: 'a depressed leaching efficiency (LE) in the Lower Murray irrigation districts raises the root zone salinity and, improved water use efficiency (WUE) has an upper limit determined by that field's LE and its variance'. 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;
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 also overarches the suite of milestone reports prepared to generate the new knowledge for managing root zone salinity hazards and to assess the risk of salt accumulation under precision irrigation, with a goal to deliver strategies for minimising yield losses. Five

previous reports submitted to the funding agencies contained the outputs of Milestone 1,2, 3, 4 and 5 activities respectively. These reports are: (Biswas *et al.* 2005a; Biswas *et al.* 2005b; Schrale and Biswas 2004; Biswas *et al.* 2005c; Biswas *et al.* 2006b).

3. Methods & Findings

3.1 Regional background

Figure 1 shows a cross section of the study region. The soil generally comprises the Woorinen Sands (generally alkaline) underlain by carbonate layer subsoils and low permeable clays (Blanchetown Clay). The natural saline groundwater discharge into the River Murray is accelerated by excess drainage from irrigated lands. In the past decade precision irrigation (i.e. right amount at the right time) has been widely promoted to minimise excess drainage from

permanent horticulture. However, precision irrigation and inadequate leaching lead to salt build up in a plant's root zone (Stevens 2002). Therefore it is important to maintain sufficient drainage from the root zone to keep the root zone salinity at acceptably low levels, but at the same time not dramatically increase groundwater discharge into the River Murray.

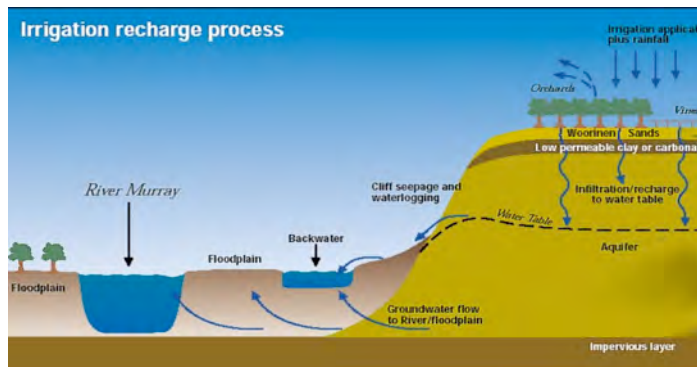
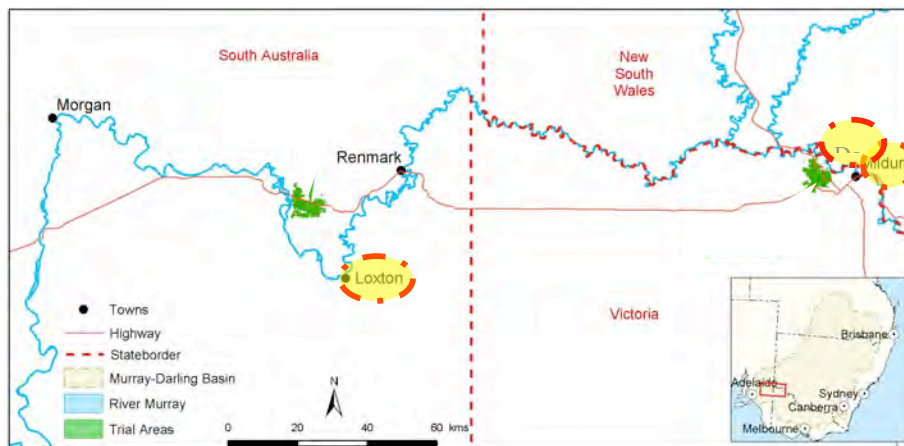


Figure 1. Regional geological profile of Lower Murray

3.2 Stages of Investigations

Stage 1 investigations involved a desktop review of crop salinity tolerance and a soil salinity survey of 14 properties in Sunraysia and the Riverland. A (40-30-20-10) water extraction model (Ayars and Westcott 1985) was used to calculate leaching efficiency, from data on irrigation, leaching fraction and chloride profiling. The Stage 1 outcomes clearly showed that a strategy was needed to manage root zone salinity under precision irrigation.

During Stage 2, to thoroughly study water and salt movement in the root zone, 4 representative sites (Figure 2) across NSW, Vic and SA were fully instrumented where long-term and reliable irrigation, weather and management data were available. These sites have water tables deeper than 3 m and represented typical vineyard and citrus orchard



management in the Riverland and Sunraysia regions. Detailed information on crop, variety, rootstocks used, planting year, soil types, irrigation system and water salinity for the four sites is listed in

Table 1.

Figure 2. Regional geological profile of Lower Murray

To address the spatial variability of the paddocks with respect to instrumentation location, an EM38 survey was undertaken that uses electromagnetic resonance imaging to map the paddocks into units of greater or lesser salinity. The EM readings together with soil analysis data were used to identify the most appropriate location or patch within the paddock for instrumentation, where the variability due to salinity in the rooting depth was minimum. Under the drip, the SWE was installed around the dripper at $\frac{1}{4}$ the dripper spacing away to accommodate the spatial variability.

Irrigation records were collected from the farm managers whereas weather data including rainfall were collected from weather stations located within the research farms where these sites were established. For Loxton and Irymple sites potential evapotranspiration (ET_o) were calculated using FAO 56 method (Allen *et al.* 1998) whereas Dareton site used FAO 24 method. (Doorenbos and Pruitt 1977).

Table 1. Location and description of field sites

Field Site	Irrigation District	Property	Crop	Variety	Rootstock	Planting Year	Soil Type	Water Quality	Irrigation System
1	Bookpurnong Lock 4, SA	Loxton Research Centre	Wine Grapes	Colombard	Ramsey	1985	Sandy Loam	~0.4dS/m	Conventional Drip
2	Bookpurnong Lock 4, SA	Loxton Research Centre	Wine Grapes	Chardonnay	Ramsey	1985	Sandy Loam	~0.4dS/m	Under Canopy Sprinkler
3	Sunraysia, NSW	NSW DPI- Dareton	Mandarin	Nova	Citrango	1987	SL-SCL	~0.2dS/m	Under Canopy Sprinkler
4	Sunraysia, Vic	Vic DPI Irymple	Wine Grapes	Chardonnay	Ramsey	1995	SCL-CL	~0.2dS/m	Conventional Drip

Besides regular soil coring and plant sampling, the main instruments used within and below the active rooting depth for water and solute data collection at these sites are listed in Table 2.

Table 2. Instruments installed and their purpose

Instrument	Brief description and purpose
SARDI Soil Water Extractor (SWE)	Ceramic suction device to collect soil water sample for salinity and nutrient assessment
Wetting Front Detector (WFD)' also called FullStop (Stirzaker 2003)	Its is a buried funnel-shaped device used to indicate wetting front and passively collect soil water sample(<2 kPa suction) for salinity and nutrient assessment
LongStop	To collect wetting front below 4 kPa at a certain depth
Loggable Tensiometer (UMS-T8)	To measure soil water suction at 90 and 120cm depths and log the data at given intervals
TriScan (Sentek)	Integrated salinity and moisture sensing device using capacitance sensors
Enviroscan (Sentek)	Similar to above without salinity sensors
GBLites and Heavies	To measure soil water content by resistance where GBLite is specially designed for sandy soil conditions.

3.3 Biophysical assessment of irrigated salinity in Sunraysia & Riverland

Despite the relatively low salinity of the River Murray water in the past five years, growers practicing precision irrigation expressed concern about the gradual, but visual accumulation of salinity in the root zone of drip irrigated vineyards, in particular.

3.3.1 Salinity & Leaching Efficiency survey of major irrigated crops

Leaching efficiency is the efficiency at which drainage water mixes with the soil solution (Bouwer 1969) and is often assumed as 100% when every millimetre (mm) of water passing below the root zone carries completely mixed soil water.

Measurement of the electrical conductivity (EC) of soil began in 2002/03 irrigation season at 3 properties in the Lower Murray and during 2003/04 another 11 properties were included in the Stage I salinity survey. The depth of water applied to the citrus crops ranged from 588 to 1646 mm; the seasonal total rainfall ranged from 235-284 mm. The vines had seasonal irrigation depths ranging from 440 to 1133 mm and total rainfall from 153 to 303 mm. It was found that the mean soil salinity (C_{lsw}) was at least 2-fold higher than the values estimated by using different formulae for irrigation water to soil salinity conversion (GHD, 1999, Hoffman and van Genuchten, 1983, and Ayers and Westcot, 1985). The Stage I results presented in Table 3 show that the mean

leaching efficiency was 63% at these sites i.e., significantly less than unity ($P < 0.01$) but had a large coefficient of variation (77%).

Table 3. Volume weighted Cl concentration in water (Clw) applied in 12 months preceding soil sampling, Cl concentrations in the soil solution at base of root zone (Clswb), leaching fraction and leaching efficiency.

No of farms surveyed	Years under irrigation	Clw mmol/L	Clsw mmol/L	Leaching = I-FAE Clw/Clswb	Fraction or Predicted Clsw mmol/L	Leaching Efficiency
14	>45	1.2	12	0.2	4.1 – 5.1**	63%

* estimated as twice the Cl concentration in the saturated paste extracts **P=0.01 paired t-test between Clsw and predicted Clsw

It was concluded that besides the large coefficient of variation, conventional methods of estimating leaching efficiency are laborious, expensive and require specialised skills and equipment. There are several experimental (Bouma and Dekker 1981) and modelling approaches (Clothier and White 1981; Clothier and Green 1994; Thorburn and Rose 1990) to quantify bypass flow which gives an idea of short-circuiting of the leaching water. The utility of these approaches is limited due either to difficulties in applying results in the field or the models require specific data and expertise which often beyond growers' capabilities.

Recognising the need for an inexpensive and simple method for estimating LE, the DEPI5 researchers developed a technique for measuring LE by using simple tools such as SWE (Soil Water Extractor - suction cup) and the wetting front detector (WFD). Following each irrigation and rainfall event, salt concentrations in both the SWE and WFD were recorded for a year under drip and sprinkler irrigated vineyards. Interestingly, salt concentration in WFD as a whole was lower than that the SWE. Figure 3 presents the changes in salinity readings in both the tools installed at the 0.3 and 0.6 m depths in a drip irrigated vineyards in the Riverland.

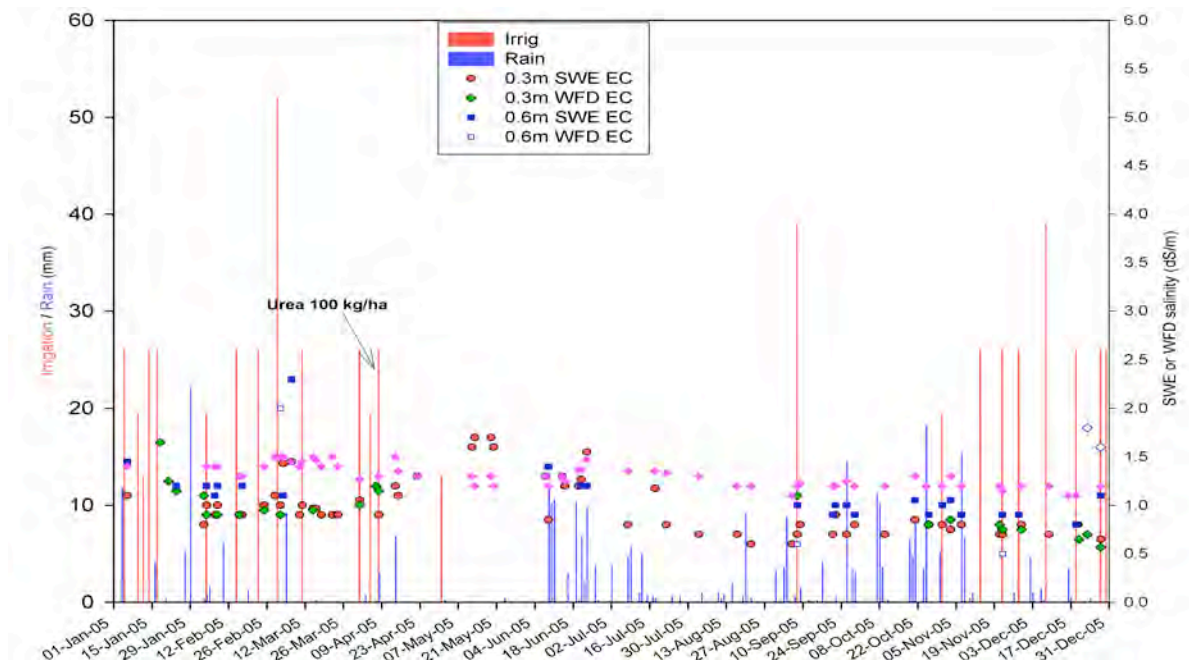


Figure 3. Salinities measured by SWE and WFD in an under canopy sprinkler irrigated Chardonnay vineyard. Irrigation/rainfall (left y axis); SWE and WFD salinities (right y axis).

It is assumed that the WFD is sampling both matrix and bypass flow and that the SWE being under suction is sampling the matrix (residual) soil water. This method is only valid when wetting fronts are regularly passing at the depth of measurement, such that salinity conditions in the soil above the devices are fairly uniform. The leaching efficiency was estimated by comparing the

chloride concentration in WFD water with that of the SWE water.. Leaching efficiency, expressed as percentage, can be written as:

$$LE = \left[1 - \frac{[Cl_{SWE} - Cl_{WFD}]}{[Cl_{SWE}]}\right] \times 100 \quad [1]$$

where,

Cl_{SWE} = Chloride concentration (mg/L) in soil water extracted by SWE

Cl_{WFD} = Chloride concentration (mg/L) in soil water captured by WFD.

Because electrical conductivity is easily measured and linearly related to salt concentration, soil water EC (EC_{sw}) measurement was used as surrogate measure of Cl_{SWE} using a conversion relationship from 55 soil water samples collected from the field. The relationship was:

$$Cl_{SWE} \text{ (mg/L)} = 348 * EC_{sw} \text{ (dS/m)} - 138.4; \quad r^2 = 0.99 \text{ (n=55; p=0.05)} \quad [2]$$

Equation [1] was used to calculate a complete set of LE calculated for 0.3 and 0.6m soil depths under both drip and sprinkler, listed in Table 4. The LE values under drip varied between 48 and 85% giving an average of 65%. A 65% LE for the drip implies that at least one third of leachate is non-mixed irrigation water which bypassed without removing salt from the soil. While studying bypass fluxes of 35 irrigated soils in Queensland, Thorburn and Rose (1990) reported highest value of 33% for 0.3 m soil depth, giving rise to 67% LE assuming that bypass volume does not participate in salt leaching. This is particularly of concern when the leaching fraction is only 10-15% of total applied water.

At the same time, the sprinkler LE estimated for the topsoil layer varied between 70 and 107% giving an average of 90%. Given that the initial hypothesis of wetting fronts passing regularly both the SWE and WFD, there were times when WFD recorded higher EC readings than SWE after fertiliser application. As a consequence LE values exceeded 100%. The result shows that LE measured during the same period for drip at 0.6m were higher than the top 0.3m layer. The average LE value for the subsurface layer (0.6m) was 79% with a range from 67% to 104%. As macropores only conduct water for short times, plant's uptake of water from macropores is negligible. Analogous to this results, Thorburn and Rose (1990) concluded that bypass flux, a cause for leaching inefficiency, decreases with increasing soil depths, eventually becoming zero at the end of bypass flow path.

Table 4. A comparison of leaching efficiencies for two different irrigation systems

Irrigation Type	Irri	Rain (mm)	ETo	Soil Type	Depth (m)	Mean LE (%)	Range (%)
Drip	593	334	1367	Light Sandy Loam	0.3	65	48-85
				Sandy Clay Loam	0.6	79	67-104
Sprinkler	598	334	1367	Fine Sandy Loam	0.3	93	70-107
				Sandy Clay Loam	0.6	NA	-

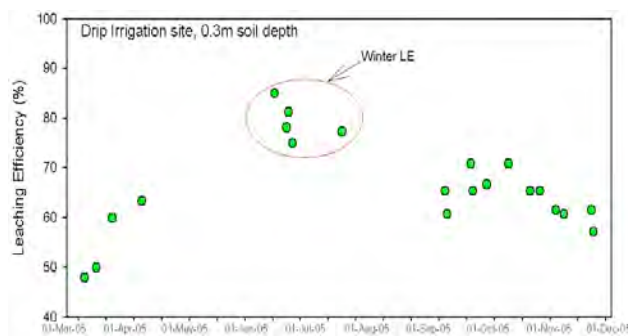


Figure 4. Regional geological profile of Lower Murray

Figure 4 gives seasonal changes of LE in a drip irrigated vineyard where the highest LE was measured in winter when plants are inactive, soil is moist, and ET is minimum. This implies that LE of a permanent horticulture planting may be governed by the irrigation type, evapo-transpiration, rainfall and its intensity and distribution, cover crop and associated crop management practices.

Winter (June & July) seems to be the best time when a supplementary leaching irrigation is likely to maximise salt displacement from the root zone with minimum drainage volume. In a laboratory

study using intact soil cores from the same site, (Kies 2006) found that using same volume of irrigation intermittent application was more efficient to leach salt than continuous (see Table 5). The measured leaching of 0.3g/L extra salt by intermittent application is equivalent to approximately 0.5 ton per ha, equating about 10% increase in salt leaching.

Table 5. Comparison of salt leaching by continuous and intermittent leaching irrigation

Core #	Total volume drained (L)	Continuous EC (dS/m)	TDS (g/L)	Intermittent EC (dS/m)	TDS (g/L)
1	3.5	2.125	4.8	2.289	5.2
2	3.5	2.097	4.8	2.237	5.1
3	3.5	2.163	4.9	2.296	5.2

3.3.2 Effects of irrigation systems on root zone salt accumulation

Lower Murray growers tend to apply the next irrigation when the soil water potential has reached 40 – 60 kPa. . Monitoring salt in the soil is generally done by soil coring once or twice a year. This type of information gives only a snap-shot of the soil salinity at that time, and the laboratory results often come too late for preventing sodium and chloride to enter the fruit or berry. Soil coring is also time consuming and expensive. Although there are several tools (e.g. resistance, capacitance, passive and suction lysimeters) available, these devices are often expensive and require specialised skills.

3.3.3 New DEPI5 Salt Watch Tool

Recognising the need for an inexpensive and simple tool for real time monitoring of soil water salinity (Biswas 2006) developed a modified porous ceramic cup device called soil water extractor (SWE), that samples soil water under a suction of 60-70 kPa created by a 60 mL plastic syringe. Although there are several devices (eg., resistance, capacitance, passive and suction lysimeters) available, these are often expensive and require specialised skills. This inexpensive device, when permanently installed, enables growers to track the salinity within the rooting depth throughout the year by sampling at any time.



Using SWE at 0.3, 0.6 and 0.9 m soil depths installed 0.15 m away the dripper (dripper spacing 0.6m) Figure 5 presents one year root zone salinity changes within a drip irrigated vineyard growing high yielding (~30 t/ha) Colombard variety in a sandy loam soil since 1985. The EC readings from SWE were found to be twice the saturated soil paste EC (ECe) having regression equation:

$$EC_{sw} \text{ (dS/m)} = 1.9 * EC_e \text{ (dS/m)} + 0.6, r^2 0.94 \text{ (n=9; p=0.05)} \quad [3]$$

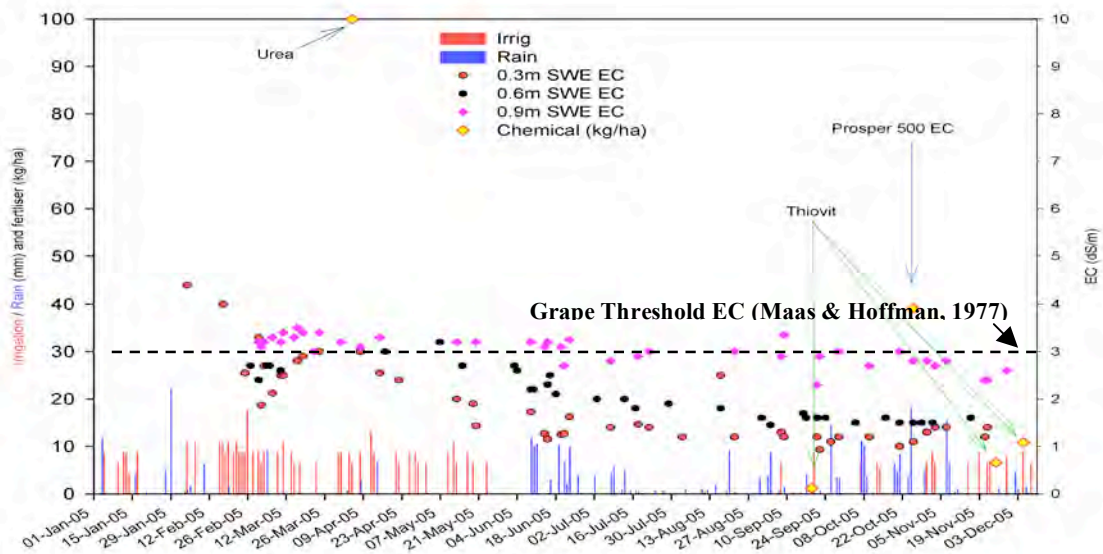


Figure 5. Salinities measured by SWE in a drip irrigated vineyard. Irrigation/rainfall, fertilizers and chemicals (left y axis); SWE salinities (right y axis).

Coupled with high water demand by plants summer irrigation increased average salinity up to 3 dS/m which fell below 2dS/m at the end of winter. The above average annual rainfall of 334 mm during 2005 in the Riverland was sufficient to leach the irrigation-induced salinity from the root zone. On a similar soil when irrigated with under canopy mini sprinkler system, a chardonnay vineyard recorded root zone salinity between 1-2 dS/m during summer irrigation period which the fell below 1 dS/m with winter rainfall. Two years of SWE data on seasonal changes of mean soil water salinities from Sunraysia (western NSW and Vic) and SA- Riverland showed that the average soil salinity under the drip was always higher than the sprinkler. Two important processes for salt accumulation under the drip are: a non-uniform irrigation application and associated salt leaching efficiency of the profile.

Grapes are a crop that is moderately sensitive to salinity. Saline root zone can depress plant growth through two effects. A droughting (osmotic) effect, which occurs because the buildup of salts within the soil make it harder for the grapevine to extract water for plant growth, and a toxic effect, which is caused by the chloride and sodium ions in water entering and accumulating in the plant to concentrations that are poisonous to plant metabolism.

The threshold salinity expressed in saturated soil paste extract EC (EC_e) for grape is 1.5 dS/m (Maas and Hoffman 1977). The threshold is the maximum EC_e value that a crop can tolerate without a potential yield decline. The salinity tolerance for grapevines was reassessed under Australian conditions (Walker and Stevens 2004), where for an own rooted vine the value was raised to 1.8 dS/m. From equation [3], where SWE EC (EC_{sw}) is twice the EC_e , we get threshold EC_{sw} for own rooted grapes is 3.6 dS/m.

Two years SWE data on seasonal changes of mean soil water salinities from four sites across NSW, Vic and SA is summarised in Table 6. The salinity under drip was always higher than the sprinkler. Both top and sub soil salinities for all sites ranged between 0.5-2.9 dS/m. Deep soil (90cm) salinity ranged from 1-3 dS/m, except in the Irymple vineyard where 90 cm recorded 19 and 7.5 dS/m for the two consecutive seasons. Water table depth at the Irymple site was 3 m deep, which has contributed to the high salinity at 90 cm depth. Due to drought that lowered the water table combined with higher volume of irrigation in 2006 that lead to salt leaching the salinity fell to almost one-third of the salinity readings of previous year.

Table 6. Seasonal changes of mean soil water salinities from four sites across NSW, Vic and SA

Site#	Irri System	Season	2004-2005			2005-2006		
			Soil water EC			Soil water EC		
			30 cm	60 cm	90 cm	30 cm	60 cm	90 cm
1. LRC Colombard	Drip	Winter	NA			1.52 (0.07)	2.29 (0.11)	3.05 (0.05)
		Summer	2.87(0.26)	2.29 (0.27)	3.26 (0.04)	1.51 (0.10)	1.57 (0.02)	2.41 (0.10)
2. LRC Chardonnay	Sprinkler	Winter	NA			1.14 (0.09)	1.08 (0.14)	1.26 (0.03)
		Summer	0.98 (0.23)	1.22 (0.07)	1.33 (0.03)	0.80 (0.03)	0.94 (0.02)	1.16 (0.02)
3. Dareton Nova Mandarin	Sprinkler	Winter	NA			0.35 (0.02)	0.93 (0.04)	0.95 (0.01)
		Summer	0.51 (0.03)	0.88 (0.05)	0.96 (0.04)	0.41 (0.02)	0.98 (0.03)	1.08 (0.03)
4. Irymple Chardonnay	Drip	Winter	NA			1.08 (0.42)	0.55 (0.15)	7.34 (2.59)
		Summer	0.91 (0.22)	NA	19.12 (0.36)	0.24 (0.04)	1.00 (na)***	7.50 (na)

¹ For this exercise, 'summer' refers to the growing season for deciduous crops or peak irrigation season (1st of September until the 30th of April). 'Winter' refers to the 1st of May until the 31st of August.

**Figure in parenthesis indicates SEM (Std Error Mean)

***SEM was unable to be calculated as there was only 1 sample taken

In this study, the average root zone salinity tolerance for own rooted grapevines has been accepted as 3.6 dS/m when measured by SWE. For citrus this value is 3.4 dS/m. Examining the seasonal variability of EC_{sw} data reported in Table 6 for two consecutive years, the average root zone salinities eg, at 60cm depths present no risk of yield loss except for the Irymple site during 2004-05 summer and 2005-06 seasons.

Grape's salt tolerance needs critical look given that in most cases yield but quality is the criterion and hence typical Maas & Hoffman threshold values may not valid anymore. A new threshold criterion needs to be established based on quality, eg Cl and Na content of fruit juice. The European Union and Australian bilateral agreement on wine requires wine to contain less than 394 mg/L of sodium. The maximum Cl concentration permitted is 606 mg/L (equivalent to 1000 mg/L, when expressed as NaCl). Also, a limit of 60 mg/L of free sodium, defined as the difference between sodium and chloride levels in the wine, applies in Germany. Australian wine has been denied access to the German market because of sodium content greater than 400 ppm (Australian Wine and Brandy Corporation 2001). Secondly, the salinity impact varies with the EC during the season; probably more importantly, the impact depends on at what crop physiological stages the salinity spike(s) occur.

It is recommended to monitor soil water salinity to avoid salinity risk, especially in dry years or when the irrigation water salinity increases. During droughts years or immediately after floodplain overflow the river water salinity often tends to rise and in some instances it may reach 1 dS/m at Morgan, SA. High water use efficiency coupled with poor quality irrigation water and low LE will necessitate the use of SWE or some other form of root zone salinity monitoring devices that allow continual root zone soil water sampling in order to prevent yield loss and wine quality deterioration.

When soil cores were sampled along and between the rows, the drip irrigated root zone showed a clear-cut differences in the soil paste salinity (EC_e) readings along the row when measured by taking 150 cm deep soil cores to in Dec and June. In winter (June) there was uniform displacement of salts throughout the profile while in summer (Dec) there was a distinct build up of salts at around 60 cm and half way between dripper emitters. None of the measured EC_e exceeded 1.8 dS/m threshold EC_e value of grape.

3.3.4 What soil water salinity means to horticultural crops

Salt tolerance levels shown in Table 7 below should be used as a guide. They may require adjustment depending on management, irrigation water salinity, soil salinity and leaching efficiency.

Table 7. Average root zone salinity threshold of soil water (EC_{sw}) extracted by SWE**

Tree crops	Varieties	Threshold salinity (EC _{sw}) at which yield decline starts

Almond	All	3
Apricot	All	3.2
Grape ^{\$\$} -own rootstocks (Sensitive)	Sultana, Shiraz, Chardonnay, Pinot Noir, Riesling, Semillon, Merlot, Cabernet Franc, Cabernet Sauvignon, Grenache. Rootstocks: 3309, 1202C, K51-40	3.6
Grape- Moderately sensitive)	Colombard on own roots. Rootstocks: 5BB, 5C Teleki, Richter 110, Richter 99, K51-32	5
Grape- Moderately tolerant	Rootstocks: Rupestris St. George, Ruggeri 140, Schwarzmann, 101-14, Ramsey	6.6
Grape- Tolerant	Rootstocks: 1103 Paulsen	11
Orange	All	3.4
Peach	All	3.4
Plum	All	3.0
Pear	All	2.0

**Soil water salinity was found to be twice the EC of saturated soil paste extract (ECe).

\$\$Grape ECe data from Walker, R and Stevens, R. (2004). In 'Salinity Impacts on Lower Murray Horticulture' Stage I Report. SARDI, GPO Box 397, Adelaide 5001. This study relates salinity tolerance to ECe only.

3.3.5 Leaching requirement

In order to maintain acceptable yields it is necessary to leach the residual salts from the root zone. For example, the salinity threshold for an own rooted grape is 1.8 dS/m (Walker and Stevens 2004). Since electrical conductivity (EC) of soil solution (EC_{sw}) = 2xECe; if average EC_{sw} is greater than 3.6 dS/m, there is a need for additional water for leaching in order to maintain maximum yield. The leaching requirement (LR) is the extra water needed for leaching and is expressed as a fraction or percentage of the total water penetrating the soil. Its equation is expressed as follows:

$$LR = \frac{D_{d^*}}{D_a} = \frac{C_a}{C_{d^*}} = \frac{EC_a}{EC_{d^*}} = \frac{EC_a}{EC_{sw^*}} = \frac{EC_a}{2.24 * EC_{swT}} \quad [4]$$

where D_{d^*} = required depth of drainage; D_a = depth of applied (irrigation + rainfall); C_a = salt content of applied water; C_{d^*} = required salt content of drain water; EC_a = electrical conductivity of applied water, EC_{d^*} = required electrical conductivity of drain water, which is equal to required electrical conductivity of soil water (EC_{sw}) measured at the bottom of root zone by extracting water from suction cup. Under normal irrigation and rooting pattern where typical extraction pattern is 40-30-20-10 ((Ayars and Westcott 1985) EC_{sw} at the bottom of root zone is related to threshold EC (EC_{swT}) whereby $EC_{sw} = 2.24 * EC_{swT}$. Because electrical conductivity is easily measured and linearly related to salt concentration, the LR can easily be expressed as a ratio of electrical conductivities. The unit for EC is dS/m.

If Irrigating grapes with 1 dS/m then the LR required to achieve threshold average root zone salinity of soil water (3.6dS/m) is 0.124. The total water requirement (WR) needed to achieve a typical LR depends on crop evapotranspiration according to: $WR = \frac{ET}{(1-LR)}$ [5]

Assuming the annual ET of grape in the Lake district is 1200 mm, then total irrigation and rainfall equals 1200/(1-0.124), or 1370 mm. Since rainwater contributes to the overall soil EC, any measurable rain needs to be taken into account when assessing the leaching requirement.

3.4 Leaching Fraction (Deep Drainage) under pressurised irrigation system

High water use efficiency results in less irrigation water draining below the crop root zone, which is referred to as deep drainage (DD). There is a compelling need to develop a set of practical tools and methods for growers to monitor and quantify deep drainage.

3.4.1 Measuring deep drainage

Three methods were used to try to determine the amount of water draining from the root zone. These were:

1. calculation of seasonal water balance using soil water trace
2. simple chloride trace;
3. capacitance probe method using Darcy's equation.

Method 1 was based upon the water balance tool known as IRES (Irrigation Recording & Evaluation System) developed by a previous MDBC funded project "I2003"(Adams *et al.* 2006). This involves estimating real time soil water status 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.

Method 2 assumes that the ratio of deep drainage to the amount of water applied is equivalent to the ratio of the chloride (Cl) concentration in irrigation water to the Cl concentration in drainage water. By using Cl tracing method, the deep drainage (DD) equation can be written as:

$$DD = \frac{Cl_{iw}}{Cl_{dw}} \quad [6]$$

Where Cl_{iw} is Cl concentration (mg/L) in irrigation water and Cl_{dw} is Cl concentration (mg/L) in drainage water at the bottom of root zone, which was 90cm for this experiment. Knowing the EC of irrigation water (EC_{iw}) and soil solution EC (EC_{sw}) retrieved by SWE in the field the amount of deep drainage can be estimated using EC to Cl conversion equation. A relationship between Cl concentration in river water (Cl_{iw}) and its salinity (EC_{iw}) was developed by regressing measurements of Cl in water at Merbein against corresponding measures of EC from 1980 to 1998. The conversion equation is:

$$Cl_{iw} \text{ (mg/L)} = 217 * EC_{iw} \text{ (dS/m)} - 4.77; \quad r^2 = 0.89 \text{ (n=94; p=0.05)} \quad [7]$$

Soil water EC (EC_{sw}) was used as a surrogate measure of Chloride in soil water (Cl_{SWE}) using a conversion relationship given in equation [2].

Using all methods 1 & 2, the deep drainage results from four trial sites are summarised in Table 8 along with irrigation, rainfall, ETo and irrigation water salinities for 2 years. For Loxton and Irymple sites potential evapotranspiration (ETo) were calculated using FAO 56 method whereas Dareton site used FAO 24 method (Doorenbos and Pruitt 1977). In general ETo exceeded the rainfall by 4 to 7 times confirming the importance of deep drainage to leach salts. The IRES (method 1) gave consistently higher deep drainage values than Cl tracing (method 2). Irrespective of locations and seasons drip flushed its root zone with much less water than sprinkler system.

Table 8. Irrigation, rainfall and deep drainage during 2004-2006 estimated by IRES and Cl balance

Field Site	Year	Irrigation (mm)	Rainfall (mm)	ETo (mm)	Irr Water EC (dS/m)	DD by IRES [#] (%)	DD by Cl Tracing (%)
1. Loxton Drip Vine	2004 - 05	644	332	1382	0.263	24	9
	2005 - 06	602	294	1431	0.250	23	12
2. Loxton Sprinkler Vine	2004 - 05	761	332	1382	0.263	26	20
	2005 - 06	911	294	1431	0.250	30	21
3. Dareton Sprinkler Citrus	2004 - 05	1246	197	1852	0.172	28	18
	2005 - 06	1120	288	1772	0.145	17	14
4. Irymple Drip Vine	2004 - 05	566	203	1491	0.152	7	1
	2005 - 06	512	269	1577	0.145	12	3

Method 3 estimates deep drainage from real time soil water potential using Darcy's flux equation. A soil water content - suction (θ - ψ m) relationship was developed from data generated by two sensors located just below the root zone (Biswas et al. 2006a). The logging capacitance probe is a proven tool for measuring changes in soil water content within crop root zones. Many irrigators use capacitance probes for irrigation scheduling. Capacitance probes are not intended to measure deep drainage. The multi-sensor capacitance probe is a popular field technique, which allows an automated continuous and real-time 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 (SENTEK 1997).

In this method van-Genuchten parametric model (Van Genuchten 1980) was used to smooth hourly capacitance probe's moisture data, from 80 and 110 cm depth sensors, into pressure head (matric potential) as follows:

$$|h| = \frac{1}{\alpha} \left[(S_e)^{-1/m} - 1 \right]^n \quad \therefore \quad n = 1/(1-m), m < 1 \quad S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad [8]$$

where, h is pressure head, n is a fitting parameter of soil moisture release curve and always has a value $n > 1$; α (cm^{-1}) is the inverse of the air-entry value. θ_s ($\text{cm}^3 \text{ cm}^{-3}$) is the water content at saturation, θ_r is the residual water content, θ is the measured water content from the capacitance sensors.

Using soil hydraulic gradients derived from capacitance probe by known set of water retention parameters DD can be estimated by using Darcy's law (Brown 2003) under a steady state flux condition as:

$$D = K(\theta) \left(\frac{\Delta h}{\Delta z} + 1 \right) \Delta t \quad [9]$$

Where, $k(\theta)$ (cm d^{-1}) is the unsaturated hydraulic conductivity at the water content θ ($\text{cm}^3 \text{ cm}^{-3}$) 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 was established by using van Genuchten (1980)'s analytical expression as shown in equation 9.

$$k(\theta) = k_s S_e^{1/2} \left[1 - (1 - S_e^{1/m})^m \right]^2 \quad [10]$$

where, k_s is the saturated hydraulic conductivity (cm d^{-1}).

A large network of capacitance probes exists in the Lower Murray orchards and vineyards for scheduling irrigation. There are approximately 7,500 such probes used for irrigated agriculture across Australia. Most of the probes have sensors sitting at or below the root zone depths generating data that can be used to calculate deep drainage by having knowledge of soil moisture release curve and saturated hydraulic conductivity of the site.

Using equations [8], [9] and [10] the real time DD occurring with associated rainfall, irrigation and ETo events under the Loxton drip irrigated vineyard is given in Figure 6. Simple water balance as seen in 6[a] calculated from evapo-transpiration demand (solid line) minus total irrigation and rainfall (broken line) was negative, which meant that there was less water available to plant. When high rainfall event of 50 mm occurred in mid December 2004 it resulted in a relatively high drainage flux (0.02 to 0.04 mm/day). Individual drainage events are presented in 6[b] where UD represent under the drip. Cumulative marginal drainage was calculated from a second capacitance probe installed along the drip line at 50cm away from the dripper, which was the mid point between two drippers. There were negligible differences between cumulative drainage measured at 100 cm depth and when calculated right under the drip or at the margin of hypothetical wetting zone of dripper. Overall, total DD resulted in negligible leaching of root zone (~1%) confirming the finding of Cl tracing (Method 2).

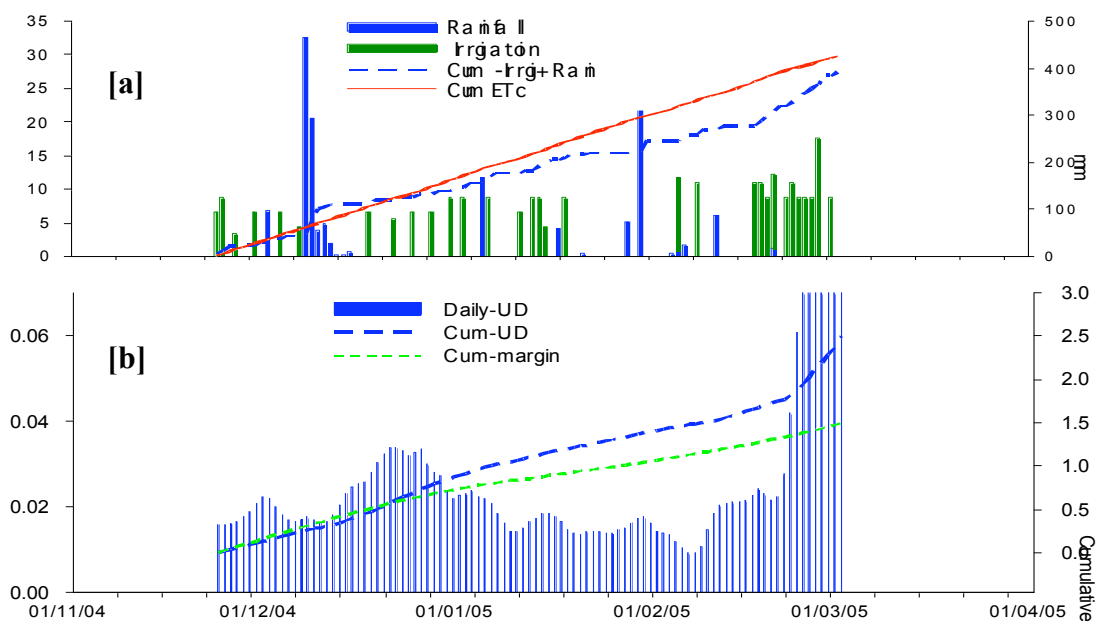


Figure 6. Daily and cumulative DD under Loxton (site 1) drip irrigated vineyard

Sprinkler irrigated Dareton citrus property recorded 250 mm of deep drainage (DD) equating to 17% of the total amount of irrigation and rainfall during year 2002-03. During this period total irrigation depth applied and rainfall were 1197 mm and 284 mm respectively. During the subsequent two years (2004-05 & 2005-06) the percent of deep drainage values were 15 and 18% respectively. The annual deep drainage estimated at the Dareton citrus site was much lower than those reported by (Rogers and Bartholic, 1976) and (Fares and Alva 2000) from citrus groves in Florida who reported nearly 50% of 18 ML applied water went past the root zone as deep drainage. However, the deep drainage at Dareton, NSW was nearly double the estimated value reported by MDBC for Riverland and Sunraysia (pers comm. Bob Newman, MDBC, 2004).

Sufficient root zone flushing (deep drainage) is critical for a sustainable irrigated horticulture. Although the results from the 3 methods vary considerably, all the direct results from Chloride trace and Darcy flux suggest that negligible leaching occurs under drip irrigation (1-12%) compared to the uniform sprinkler irrigation (14-21%), regardless of the crops grown. The general concern for precision drip irrigation in the lower Murray region is that if winter rainfall does not provide effective leaching, there is a major risk of accumulation of residual salt in the root zone.

3.5 Modelling the Processes of Root Zone Salinity

To be able to predict the quantity and distribution of salt within the root zone, a two dimensional solute transport model (LEACHM-TRANSMIT) (Hutson and Wagenet 1995) simulation was run for 278 days to estimate the salt accumulation in the root zone for irrigation salinities of 0.3 dS/m (current river water salinity at Loxton) and 0.8 dS/m (the Morgan benchmark). The scenarios are

shown in Figure 7. Under a drip irrigated vineyard with 0.3 dS/m water, about 130 kg/ha of salt would accumulate in the root zone during first irrigation season. If River salinity increases to 0.8 dS/m, 2000 kg/ha of salt would accumulate in a 1 m root zone during a normal grape growing season.

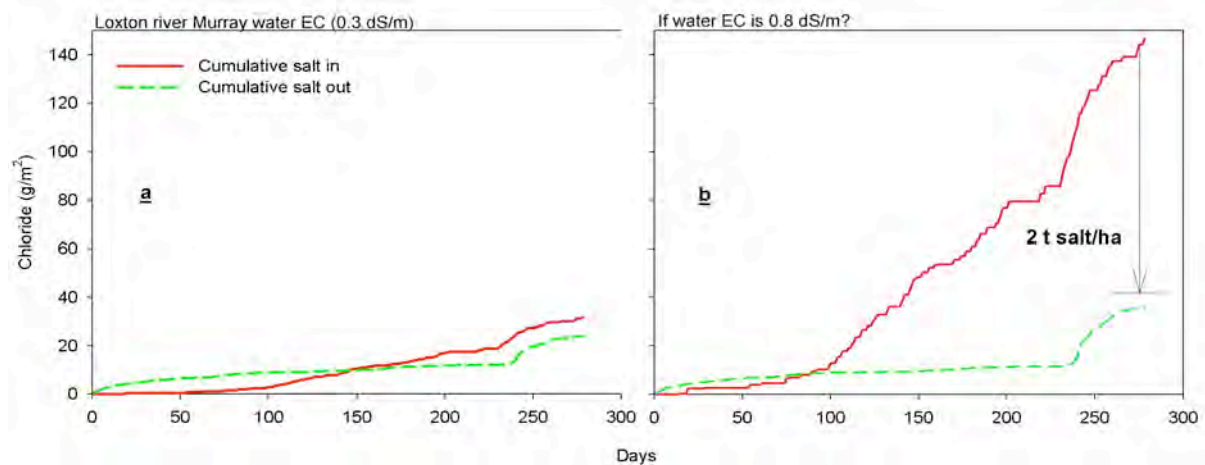


Figure 7. Results of a two dimensional salt transport model showing salt build up with different salinities of River water, the 0.3 dS/m (current level), and 0.8 dS/m the Morgan benchmark

When temporal changes of salinity in the root zone was plotted against the depths, a contour map of ECe was obtained, as shown in Figure 8, where the inside box shows the existing profile salinity (ECe) at the start of the experiment. As demonstrated in Fig 8, a drought year with high River salinity of 0.8 dS/m could increase topsoil salinity to 5 dS/m, at which up to 60% yield loss may occur when plotted in the classical soil salinity and yield loss relationship (Maas and Hoffman, 1977).

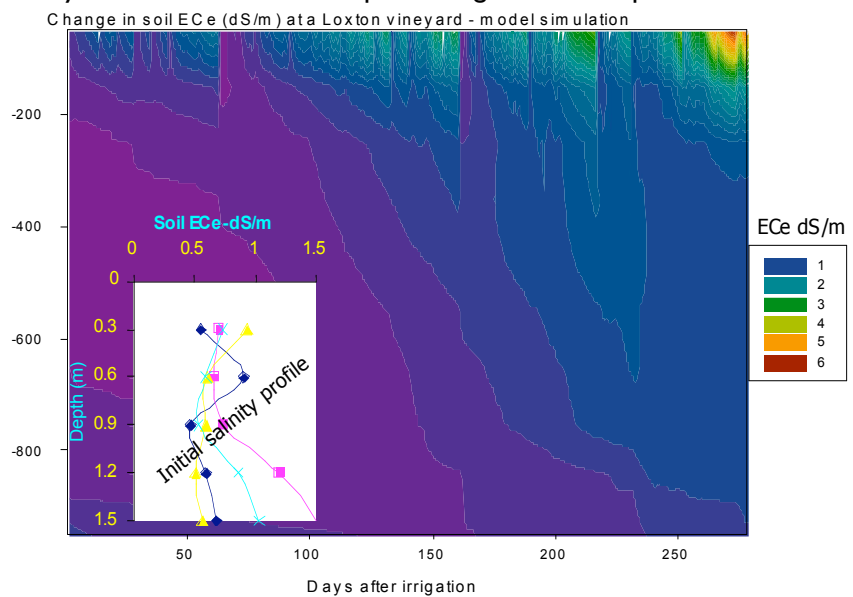


Figure 8. Soil ECe change under Loxton drip irrigated vineyard during a single season if river water reaches 800 EC (0.8 dS/m)

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 (G. Sanderson, NSW DPI Dareton, pers comm.). 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 (Table 9). The survey results in 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 9. Grape leaf petiole and berry juice sodium (Na) and Chloride (Cl) content

Plant part & Element	LRC drip, Site#1					LRC sprinkler, Site#2					Irymple drip, Site#4				
	Flowering		Harvest		Survey	Flowering		Harvest		Survey	Flowering		Harvest		Survey
	2004	2005	2005	2006	Standard ^A	2004	2005	2005	2006	Standard ^A	2004	2005	2005	2006	Standard ^A
Petiole Na (%)	0.11	0.05	0.46	0.24	0.91	0.07	0.02	0.14	0.1	0.55	0.12	0.04	1.1	2	0.91
Petiole Cl (%)	0.2	0.21	0.99	0.83	1.31	0.15	0.12	0.35	0.49	1.44	0.73	0.44	1.5	1.8	1.31
Berry Cl (mg/l)			39	11	85			*	13	61			80	127	85
Berry Na (mg/l)			38	28	56			*	29	91			78	41	56

^A Figures in bold represent the Sunraysia survey average result at harvest, whereas EU wine Cl and Na standards are 606 and 394 mg/L respectively.

When compared to the Sunraysia comparative survey result, the salt concentrations in the plants at the two Loxton sites were low, implying no immediate salinity risk. However, both petiole and berry Na & Cl contents at Irymple vine site exceeded the survey standards. This was due to the high salinity in the root zone.

The Cl and Na contents in juice for all the sites were lower than the European Union wine standards. The European Union and Australian bilateral agreement on wine requires wine to contain less than 394 mg/L of sodium. The maximum Cl concentration permitted is 606 mg/L (equivalent to 1000 mg/L, when expressed as NaCl).

The chloride and sodium levels in the citrus varied between 0.2-0.8 %, have remained very low throughout the trial period. This is a reflection of the low salinity irrigation (~0.2 dS/m) water, high water volume (13 ML/ha/yr) under-tree sprinkler application and low soil electrical conductivity (EC) in the root zone.

3.7 Loss in Production of Lower Murray Horticulture due to River salinity rise

Economic Assessment of Salinity Impact on Lower Murray Horticulture has involved a range of industries/crops included in each of 4 River sections starting from Mildura to Lake Alexandrina. Historic River salinity data for different sections of the Lower Murray for the last 25 years was also collected from the MDBC database. For each of these industries/crops, the area of production, related to the three major soil types in the four regions, was tabled. From these figures, the percentage and value of lost production was calculated under different salinity scenarios.

3.7.1 Major River sections and salinity conversion factors

The entire Lower Murray was grouped into Sunraysia and Riverland regions, Blanchetown to Wellington and the Lower Lakes. This incorporates “reaches” 9 to 22 of the Murray Darling Basin as specified in the GH&D Murray-Darling Basin Commission Salinity Impact Study of February 1999 (Gutteridge *et al.* 1999). The 14 reaches of the River Murray are grouped into *four sections*: (i) reaches” 9 to 15 are grouped as “Sunraysia” (A1); (ii) reaches” 16 to 19 are grouped as the “Riverland” (A2); (iii) reaches” 20 to 21 are grouped as “Blanchetown to Wellington” (A3) and (iv) reach 22 is the “Lower Lakes” (A4).

Current published data on the area of the twelve crops/industries has been acquired for river sections A1, A2, A3 & A4 (to varying degrees) from the Australian Bureau of Statistics, the Department of Water, Land & Biodiversity and the Phylloxera and Grape Industry Board of SA. Utilising crop salinity relationships, most recent production yield, and farm gate values per tonne for 12 major crops/industries in each of the four sections, the gross returns were determined for the selected crops in each of the four sections of the Murray River. These returns were calculated for 2 Leaching Efficiency (LE) scenarios of 100% and 70% LE. For pressurised irrigated vineyards, (Biswas *et al.* 2006c) reported that LE is less than unity and for a drip it about 70%. Irrigation water salinity to average soil salinity was calculated using the (Hoffman and van

Genuchten 1983) equation for 100% and 70 % LE respectively. A detailed report including methodology is given in Appendix I.

3.7.2 Effects of River salinity on value of loss production

The impact of water salinity on the Lower Murray crop yield is influenced mainly by the existing soil types (sand, loam and clay), irrigation water salinity, leaching fraction and crops tolerance to root zone salinity. The relative yield (Y_r) is the percentage of normal yield expected under the saline conditions existing at that time in that section of river. The geographical scope of this project comprises the Sunraysia and Riverland regions, Blanchetown to Wellington and the Lower Lakes.

Farm Gate value figures for each of the twelve crops/industries have been acquired from the 2004-05 PIRSA Food Score Card. The resultant decline in production due to increasing salinity under varying soil conditions has been translated into value of lost production for the specific crops/industries within each section of the river.

Figure 9 presents the value of lost production along the 4 major sections of the River when and if Morgan salinity reaches 1000 EC during growing season. In this model it was assumed that all growers are practicing precision irrigation with WUE of 85% or higher as many grape growers already do. Effectively the results will show us the upper range of 'value of lost production'. If the LE is 100%, the total loss for the four river sections was between \$70 & \$80 million with 1000EC (1 dS/m) at Morgan. Given that the LE is often below its full efficiency, at 70% LE, the total losses for the four river sections may be between \$110 & \$120 million when salinity at Morgan is 1 dS/m.

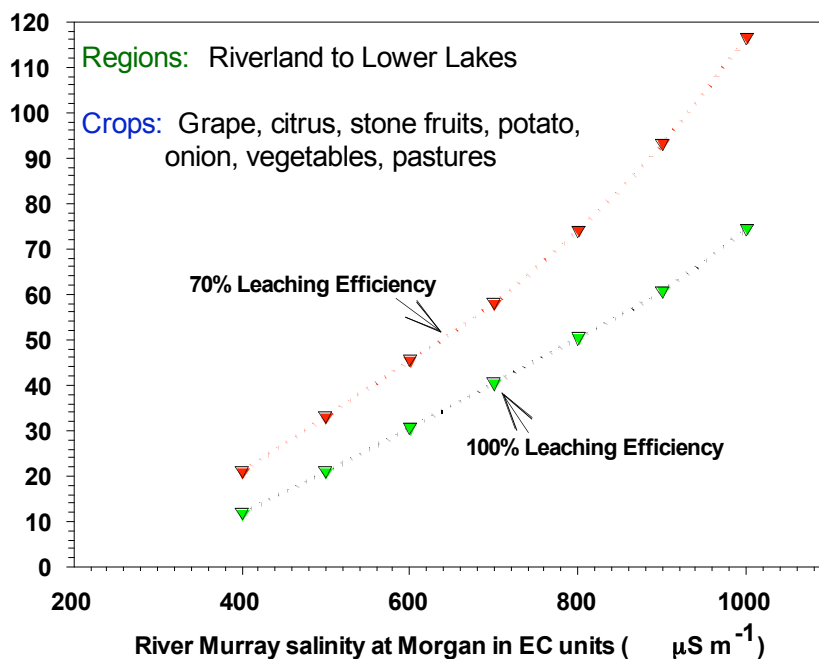


Figure 9. Value of lost production of major crops along lower Murray due to increasing River salinity.

4. Draft best management practices for root zone salinity

A draft BMP's was prepared and presented at the Root-Zone and Solute Management Workshop, in late Oct 2006, conducted by this project in association with the CRC for Irrigation futures. While the project team did not field validate the BMP's, a range of good management practices were drawn from the field investigations at the project sites. This paper was subsequently

modified to include comments from key irrigators. It is recognised that the development of any best management practices is an iterative process over time, which will include improvements suggested by irrigators. This draft publication attached as an Appendix 2 with this report is aimed to guide irrigators in starting to implement best management practices.

Experiences from the project indicate that BMP's should be developed both at the on-farm level by irrigators, and at the regional level by water managers and policy-makers. The basis of BMP's is firstly having the ability to measure the problem, i.e. root-zone salinity hazard. The development of the Soil Water Extractor has assisted in this regard. Best management practice should then include a proper monitoring schedule and some related threshold values for action. Measurement using a suite of tools is important to obtain a clear picture of trends.

A primary action in off-setting the build-up of salinity remains leaching of the root-zone. Results from this project show that the leaching efficiency of irrigations can often be low, particularly during or at the end of the irrigation season. An alternative strategy now being considered is winter irrigation of a wet profile, when the leaching efficiency is usually high. This will still require the continuation of management practices contributing to good soil structure, such as building up of organic matter and that application of gypsum to sodic soils.

5. Communication & feedback: DEPI 5 and stakeholders

A Communication Strategy was developed by the project team during the first year of the project. This strategy identified key stakeholders, some key messages to be presented at an appropriate timing, and a range of communication processes that would be addressed during the project. These processes included, communication between the project team, technical presentations and publications, a media program, and a final evaluation of the impact of the project on stakeholders. The Strategy was continually up-dated to include activities completed as part of each of the processes, and a report presented to each meeting of the Project Steering Committee.

Communication between team members was critical as the project involved sites in SA, NSW and Victoria. This was achieved not only through frequent project team meetings rotated between the three sites, but also through additional informal leadership initiated by the Principal Investigator and Project Leaders.

An extensive program of presentations and updates at major conferences and workshops was maintained throughout the project. Twelve presentations were given to annual ANCID and IAA conferences, NPSI Investors Forums, and CRC Irrigation Futures annual research conferences. A presentation was given to an international Irrigated Agriculture conference in Turkey & International Society for Horticulture Science Conference in Mildura. Local irrigator groups and water agencies were also addressed and milestone reports widely circulated to stakeholders.

Ten articles were published by rural newspapers in the Riverland and Sunraysia, the SA "Stock Journal", and "The Land" in NSW. Three radio and TV presentations were done with regional ABC and commercial media. Updates of project results have been included in national publications/newsletters by NPSI, the CRCIF and the CRC for Plant-Based Management of Dry-land Salinity.

Although not planned at the beginning of the project a key tool, for irrigators to use in measuring soil water salinity and nutrients, has been the Soil Water Extractor. This was initially developed for use at project sites, however has already been quickly taken up by irrigators and irrigation advisory people in the Riverland and elsewhere, such as the SE and also interstate in NSW and WA. This activity has provided an additional opportunity to target a wider audience with project results.

The team organised a major Root-zone and Solute Management Workshop was convened in Adelaide in October 2006, towards the end of the project, targeting stakeholders and also

including presentations from other related projects nationally. An exit survey of the 70 participants was conducted to evaluate the impact of the project in the area of root-zone salinity management. Overall the survey indicated the workshop had met a real need, and there was a growing interest in root-zone water and solute management nationally both from individuals as well as organisations. This workshop was designed for a specific audience; however it was clear that a much larger workshop is needed to give this issue wider exposure.

6. Conclusions

There has been a significant research and educational input into improving irrigator water use efficiency over the past 15-20 years. It is now time to put a similar effort into managing root-zone salinity. The DEP 15 project has initiated important research on root-zone processes that can be applied not only in the Riverland and Sunraysia, but in all irrigation areas. The project has been able to point the way to some practical Best Management Practices, which irrigators can now include in current soil salinity and nutrient monitoring programs.

Average leaching efficiency (efficiency at which drainage water mixes with the soil solution) of surface 30 cm soil in drip-irrigated fields has been found to be 65% compared to 90% for sprinkler. A 65% LE for the drip implies that at least one third of leachate is non-mixed irrigation water which is bypassed without removing salt from the soil.

Recognising the need for an inexpensive and simple tool for real time monitoring of soil water salinity that works within 40-60 kPa moisture ranges, the DEP15 team developed the SARDI soil water extractor (SARDI SWE). This is a modified porous suction cup device, that samples soil water under a suction of 60-70 kPa. Grower friendly 'Root Zone Salinity WATCH Toolkit' including SWE has supplied to NSW, VIC, SA and WA growers (including corporate wineries eg, Fosters Group). To date there are about 500 SARDI extractors installed in irrigated horticulture. Following increased demand for this device, SARDI on behalf of investors, has licensed the "soil water extractor technology" to SENTEK Sensor Technologies Pty Ltd, a local firm, for manufacture and (inter)national marketing. Simultaneously at the initiative of CRCIF, the project published a SWE instruction manual.

Sufficient root zone flushing (deep drainage) is critical for a sustainable irrigated horticulture. Using Cl tracer, it is found that current irrigation management produce negligible leaching under drip irrigation (1-12%) compared to the uniform sprinkler irrigation (14-21%), regardless of the crops grown. The general concern in the lower Murray regions is that if winter rainfall does not provide effective leaching, there is a major risk of accumulation of residual salt in the root zone.

Two-D root zone simulation modelling showed that if River salinity increases to 0.8 dS/m, 2000 kg/ha of salt would accumulate in a 1 m root zone during single irrigation season. A drought year with high River salinity (~1 dS/m) will increase topsoil salinity (EC_e) to 5 dS/m. The threshold EC_e for grape is 1.5 dS/m while for citrus the value is 1.7 dS/m.

Real time soil salinity survey showed no immediate risk of yield loss due to soil salinity except for the Victoria's Irymple site where saline water table contributed salt to the roots. While none of the measured EC_e exceeded 1.5 dS/m; during summer there was a distinct trend of salt build up at around 60 cm and half way between dripper emitters, which during winter was displaced from the profile by rain. Winter seems to be the best time when a supplementary leaching irrigation will be likely to maximise salt displacement from the root zone and results in minimum drainage. It was found that intermittent irrigation was more efficient (7% increase) than continuous application.

Plant salt concentrations of both citrus and grapes were low, implying no immediate salinity risk. Both Cl and Na contents were lower than the international (EU) wine standard (Cl = 394 mg/l and Na=606 mg/l). However, Na & Cl contents at Irymple vine site exceed the Sunraysia survey standard due to the high water table with saline water.

If Morgan benchmark salinity reaches 1000 EC (1 dS/m), the estimated value of production loss from all irrigated crops including pasture along the River Murray from Nyah in Victoria to the Lower Lakes in South Australia accounted for \$117 million at 70% LE. As expected, the low

salinity river water from Sunraysia to Riverland had a marginal impact compared to the moderately saline lake districts.

A workshop organised by DEPI5 team was attended by 74 persons comprising scientists, consultants and growers participated the workshop. The evaluation survey indicated the workshop had met a real need, and there was a growing interest in root-zone water and solute management nationally both from individuals as well as organisations. The messages and areas of future work highlighted the need to now involve growers much more actively in the development of tools and best management practices in relation to root-zone salinity in particular.

7. Recommendations

The workshop on root zone salinity management recommend an adult education approach for training of irrigators, regional planners and policy makers on risk management. It is recommended that training modules be developed to sit alongside existing irrigation training.

A further network of trial sites needs to be developed in major irrigation areas in South Australia and interstate to increase irrigator awareness for root-zone salinity management, to ensure sustainable irrigation practices.

Grape's salt tolerance needs review in the light of current growing practice whereby an optimum yield is no more a criterion.

There is a need for a three dimensional visualisation of root zone salinity model because of precision water application involving non-uniform wetting.

The deep drainage estimate from the IRES module needs field validation against most robust techniques eg., tracer, drainage meter, log Tensiometer flux techniques.

The current theory for crop yield/salinity relationships is not applicable in years of substantial winter rainfall and also when the winter rainfall carry-over plus in-season rainfall is a substantial component of the crop water balance. Secondly, the salinity impact varies with the EC during the season; probably more importantly, the impact depends on at what crop physiological stages the salinity impact occurs.

The methodology for estimating the value of crop production loss due to irrigation salinity across the Murray-Darling Basin needs further refinement before it can be used for policy decisions.

8. References

- Adams T, Sparrow D, Knowels S, Barber A (2006) Adoption of water use efficiency tools by irrigation communities in the murray darling basin of south australia. (ANCID, Darwin, NT: 15-18 Dec)
- Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: Guidelines for computing crop water requirements. pp. 78-86. (Food and Agriculture Organisation of the United Nations:
- Australian Wine and Brandy Corporation 2001, 'German limits on sodium levels', The Wine Contact, Official Newsletter of the AWBC, Adelaide, February.
- Ayars RS, Westcott DW (1985) 'Water Quality for Agriculture.' (Paper 29 (Rev 1), FAO, Rome, Italy,
- Biswas T (2006) Simple and inexpensive tools for root zone watch. *J.Australian Nutgrower* 20, 14-16.
- Biswas TK, Schrale G, Bourne J (2005a) 'Salinity Impact on Lower Murray Horticulture - DEPI5 Project Milestone 2 Report.' (Water Resources & Irrigation, SARDI, Adelaide SA 5001)
- Biswas TK, Schrale G, Sanderson G, Bourne J (2005b) 'Salinity Impact on Lower Murray Horticulture -Milestone 3 Report (DEPI5 Project).' (Water Resources & Irrigation, SARDI, Adelaide SA 5001)
- Biswas TK, Adams AC, Schrale G (2006a) Root zone drainage flux assessment by real time multi-sensor capacitance probes. pp. 141-148. (In Proc. International symposium on water and land management for sustainable irrigated agriculture. CUKUROVA UNIVERSITY, Adana-Turkey:
- Biswas TK, Schrale G, Sanderson G, Bourne J (2006b) 'Salinity Impact on Lower Murray Horticulture -Milestone 5 Report (DEPI5 Project).' (Water Resources & Irrigation, SARDI, Adelaide SA 5001)
- Biswas TK, Schrale G, Stevens R, Bourne J (2005c) 'Salinity Impact on Lower Murray Horticulture -Milestone 4 Report (DEPI5 Project).' (Water Resources & Irrigation, SARDI, Adelaide SA 5001)
- Biswas TK, Schrale G, Stirzaker R (2006c) New Tools and Methodologies for In-situ Monitoring of Root Zone Salinity and Leaching Efficiency under Precision Irrigation. (In Proc. 5th Int. Symposium on Irrigation of Horticultural Crops, Mildura, 2006, for publication by Int. Soc. Hort. Sci. in *Acta Horticulturae*:
- Bouma J, Dekker CW (1981) A field method for measuring short-circuiting in clay soils. *J Hydrol* 52, 347.
- Bouwer H (1969) Salt balance, irrigation efficiency, and drainage design. *ASCE J of Irrig & Drainage Div* 95, 153-170.
- Brown GO (2003) Henry Darcy's perfection of the Pitot tube. (Eds GO Brown, JD Garbrecht, and WH Hager) pp. 14-23. ASCE, Reston, VA)
- Clothier BE, Green SR (1994) Rootzone processes and the efficient use of irrigation water [Review]. *Agricultural Water Management* 25, 1-12.
- Clothier BE, White I (1981) Measurement of sorbtivity and soil water diffusivity in the field. *Soil Sci Soc Am J* 46, 155.
- Doorenbos J, Pruitt WO (1977) Crop water requirements. FAO Irrigation and drainage paper no.24.FAO Rome, Italy.
- Fares A, Alva AK (2000) Soil Water Components Based on Capacitance Probes in a Sandy Soil. *Soil Science Society of America Journal* 64, 311-318.
- Gutteridge, Haskins, Davey PL (1999) 'Salinity impact study.' Melbourne, Australia)
- Hoffman GJ, van Genuchten MT (1983) Soil properties and efficient water use: water management for salinity control. In 'Limitations to Efficient Water Use in Crop Production'. (Eds HM Taylor, WR Jordan, and TR Sinclair) pp. 73-85. (ASA-CSSA-SSSA: 677 South Segoe Rd, Madison, WI 53711 USA)
- Hutson JL, Wagenet RJ (1995) A multiregion model describing water flow and solute transport in heterogeneous soils. *Soil Sci Soc Am J* 59, 743-751.
- Kies S (2006) Intermittent irrigation effects on root zone solute movement in a Riverland soil. 'BSC (Honours) Flinders University, Adelaide, SA.
- Maas EV, Hoffman GJ (1977) Crop salt tolerance-current assessment. *ASCE J.Irrig & Drainage Div.* 103, 115-134.
- Rogers JS, Bartholic. JF (1976) Estimated evapotranspiration and irrigation requirements for citrus. *Proc.Soil Crop Sci.Soc.Fl.* 35, 111-117.
- Schrale GS, Biswas TK (2004) 'SALINITY IMPACT ON LOWER MURRAY HORTICULTURE -Stage 1 Report for NPSI (Land & Water Australia).' (Water Resources & Irrigation, SARDI Sustainable Systems, GPO Box 397, Adelaide SA 5001)
- SENTEK. EnviroSACN. Hardware manual ver.3.0. 1997. 77 Magill Road, Stepney, SA, 5069, Sentek Pty. Ltd. Ref Type: Catalog
- Stevens RM (2002) Interactions between irrigation, salinity, leaching efficiency, salinity tolerance and sustainability. *Australian Grapegrower and Winemaker* 466, 71-76.
- Stirzaker RJ (2003) When to turn the water off: scheduling micro-irrigation with a wetting front detector. *Irrigation Science* 22, 177-185.
- Thorburn PJ, Rose CW (1990) Interpretation of solute profile dynamics in irrigated soils. III. A simple model of bypass flow in soils. *Irrigation Science* 11, 219-225.
- Van Genuchten MT (1980) A closed form of equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci.Soc.Am.J.* 44, 92-98.
- Walker R, Stevens R (2004) Recent developments in the understanding of the effects of salinity on grapevines. In 'Salinity Impact on Lower Murray Horticulture -Milestone 1 Report (DEPI5 Project)'. (Eds G Schrale and TK Biswas) pp. 1-16. (Water Resources & Irrigation, SARDI, Adelaide 5001)

Appendix 1. Economic Assessment of Salinity Impact on Lower Murray Horticulture

Appendix 2. Managing Root-Zone Salinity In Irrigated Horticultural Crops