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

Irrigation Salinity Impact on Lower Murray Horticulture

Measuring root zone salinity and yield loss

4 Sites: Loxton (SA), Irymple (Vic) and Dareton (NSW)

Crops: Grapes (Chardonnay, Colombard) and Citrus (Mandarin)

Irrigation: Drip and under cover sprinkler (River Murray water)

Instrumentation: Capacitance probe, tensiometer, gypsum block, salinity sensor, soil solution extractor

Funding partners

FINAL REPORT

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

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DEP15 Project: Salinity Impacts on Lower Murray Horticulture
Final Report

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

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Murray-Darling Basin Commission (MDBC)
South Australia Murray-Darling Basin Natural Resource Management (previously known as RMCWMB).

CONTENTS

FIGURES

TABLES

1. 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.

Many have achieved irrigation efficiency, more commonly known as "water use efficiency (WUE)" of at least 85% (Stevens 2002). Water use efficiency (WUE) has been defined as the volume of water used "consumptively" by the crop i.e., evapotranspiration divided by the total volume applied to the field.

Irrigation water contains dissolved salts that can accumulate in the root zone as evapotranspiration (*Et*) removes irrigation water and leaves the salts behind. Even though there is still a leaching fraction, it is unclear how efficiently salt is being displaced from 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 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 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 DEP15) 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. Three previous reports submitted to the funding agencies contained the outputs of Milestone 1,2, 3 and 4 activities respectively. These reports are: (Biswas *et al.* 2005a; Biswas *et al.* 2005c; Schrale and Biswas 2004; Biswas *et al.* 2005d; 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 (ie correct amount at the right time) has been widely promoted to minimise excess drainage from the root zone of permanent horticulture. However, precision irrigation and inadequate leaching lead to salt build up in plant's root zone (Stevens 2002). Therefore it is important to maintain sufficient drainage from the root zone to maintain the root zone salinity at acceptably low levels, but – at the same time- not dramatically increase groundwater discharge into the River Murray.

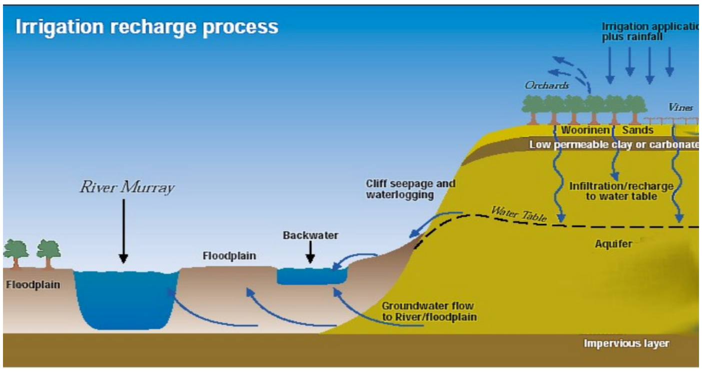


Figure 1. Regional geological profile

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 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 investigations 4 representative sites (Figure 2) across NSW, Vic and SA were fully instrumented where long-term and reliable irrigation data were available. These sites also have water table deeper than 3 m.

Besides regular soil coring and plant sampling, the main instrumentation used for data collection at these sites are listed in Table 2:

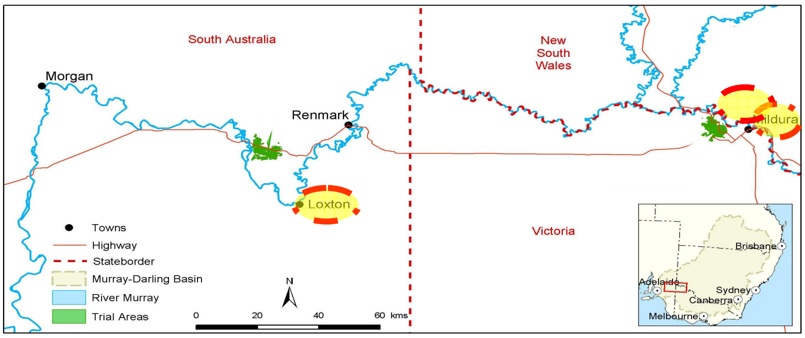
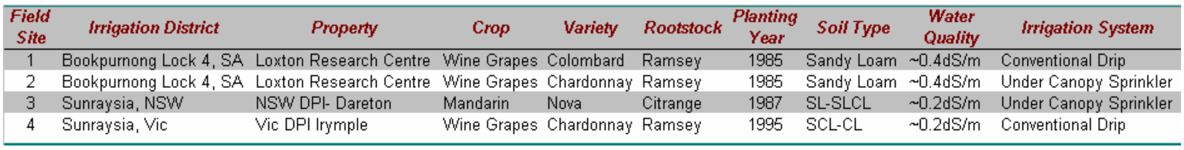


Figure 2. DEP 15 project sites (yellow circles)

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	Citrange	1987	SL-SLCL	~0.2dS/m	Under Canopy Sprinkler
4	Sunraysia, Vic	Vic DPI Irymple	Wine Grapes	Chardonnay	Ramsey	1995	SCL-CL	~0.2dS/m	Conventional Drip

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 its full quota of salt.

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 1 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 value of soil salinity (Cl_{sw}) was at least 2-fold higher than the values estimated by using a number of formulae for irrigation water to soil salinity conversion (GHD, 1999, Hoffman and van Genuchten, 1983, and Ayers and Westcot, 1985). The Stage 1 results presented in Table 1 show that the mean leaching efficiency was 63% at these sites ie 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 Fraction =1-FAE or Clw/Clswb	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. Recognising the growers' need for an inexpensive and simple method, the DEP15 researchers developed a technique during 2005-6 for measuring LE that uses the SWE (Soil Water Extractor - suction cup) and the wetting front detector. The leaching efficiency was estimated by comparing the chloride concentration in WFD water with that of the SWE water. It is assumed that the WFD is sampling both (matrix +?) preferential flow and that the SWE is sampling the matrix 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.

Leaching efficiency can be written as:

$$LE = 1 - \frac{[Cl_{SWE} - Cl_{WFD}]}{[Cl_{SWE}]} \qquad [1] \text{ where;}$$

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

Soil water EC ($ECsw$) 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} (mg/L) = 348*$ECsw$ (dS/m) -138.4; $r^2 = 0.99$ (n=55; p=0.05) [2]

Equation [1] was used to calculate a complete set of LE calculated at 0.3 and 0.6m soil depths for both drip and sprinkler, listed in Table 4. The LE values under drip varied between 48 and 85% giving an average of 65%. At the same time, the sprinkler LE estimated for the topsoil layer varied between 70 and 107% giving an average of 90%. 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 subsurface layer (0.6m) was 79% with a range from 67% to 104%.

Table 4. A comparison of leaching efficiencies for two different 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	-

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. This is particularly of concern when the leaching fraction is only 10-15% of total applied water.

Figure 3 shows that LE is a variable property of the same soil and crop type; the highest leaching efficiency was measured in winter. 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. For a sustainable irrigated horticulture, it is critical to achieve high WUE but also to maintain adequate salt leaching from the root zone.

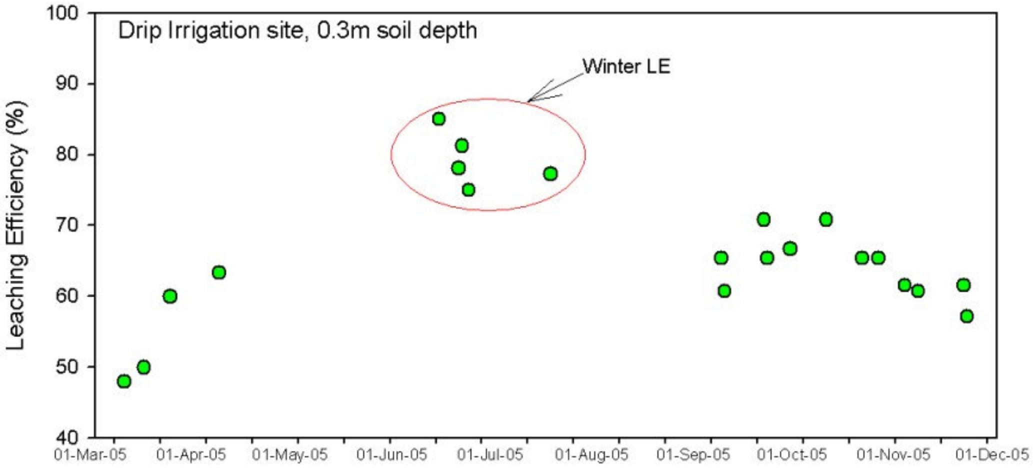


Figure 3. Leaching Efficiencies of a drip irrigated vineyard's topsoil layer (0.3m)

Winter seems to be the best time when a supplementary leaching irrigation will be likely to maximise salt displacement from the root zone and result in minimum drainage. In a laboratory bench-type study, conducted by a DEP 15 student (Kies 2006) using intact soil cores it was found that intermittent application was slightly more efficient than continuous application. Table 5 shows the comparison between two irrigation strategies. When using the same volume of water, a one-hour intermittent application removed 0.3g/L more salt than applied continuously at the same rate. The measured leaching increase of 0.3g/L is estimated to be equivalent to approximately 0.5 tonnes of extra salt leached per ha, equating 7% increase in salt leaching.

Table 5. Comparison of salt loads by applying continuous and intermittent leaching irrigations

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 (eg., resistance, capacitance, passive and suction lysimeters) available, these devices are often expensive and require specialised skills.

3.3.3 New DEP15 Salt Watch Tool

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 project 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 (Biswas *et al.* 2006c; Biswas *et al.* 2005b). Appendix D gives details on SWE and its field use.. While there are other devices available, this particular device enables growers themselves to assess the root zone salinity risk throughout the irrigation season.

SARDI SWE

Soil Water Extractors were typically installed in a same location ('station') at 0.3 m, 0.6 m and 0.9 m depth in the root zone. These devices are permanently installed and can be sampled at any time with minimal disturbance. Besides being used for the DEP15 project, about 500 SARDI SWE's have been installed by researchers, growers and consultants for tracking salt and nutrient movement in the root zone.

The soil water salinity readings from the SWE in a drip irrigated vineyard, in the middle of the root zone (0.6 m) (Figure 4), showed an increase in salt build up to 3 dS/m during the growing season, and then fell below 2dS/m at the end of winter. The above average annual rainfall of 334 mm (historical average 250 mm) in the Riverland during 2005 was sufficient to leach the irrigation-induced salinity from the root zone to a level of about 1-2 dS/m. At the sprinkler site the SWE could only be continuously sampled in the middle of root zone and rarely exceeded 1 dS/m (Figure 5). It demonstrated that the profile was properly leached due to the higher LE and also by the relatively high winter rainfall in that year.

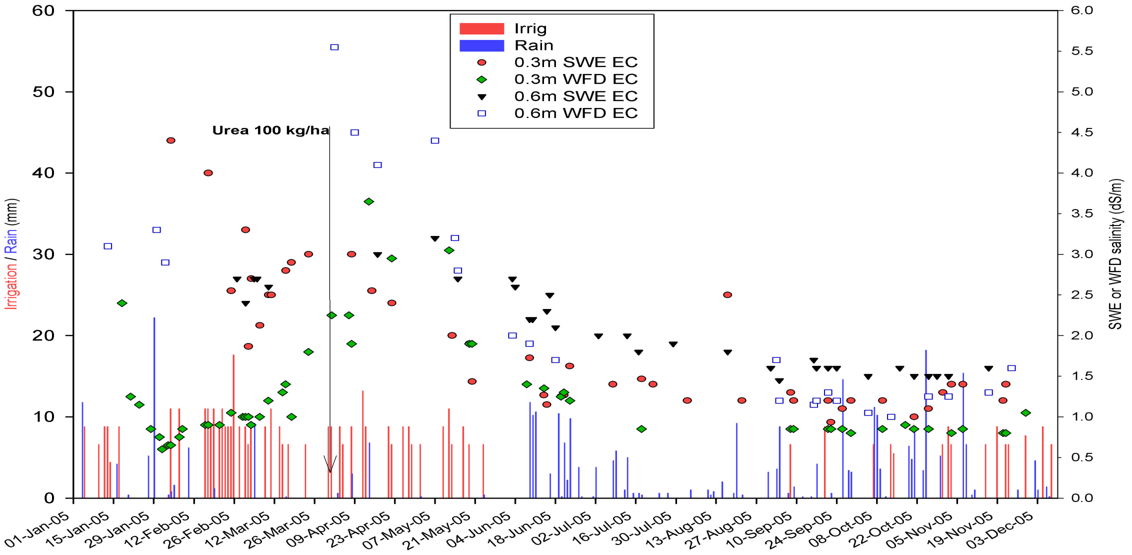


Figure 4. Salinities measured by SWE and WFD in a drip irrigated vineyard at 0.3 and 0.6 m. irrigation/rainfall (left y axis); SWE and WFD salinities (right y axis).

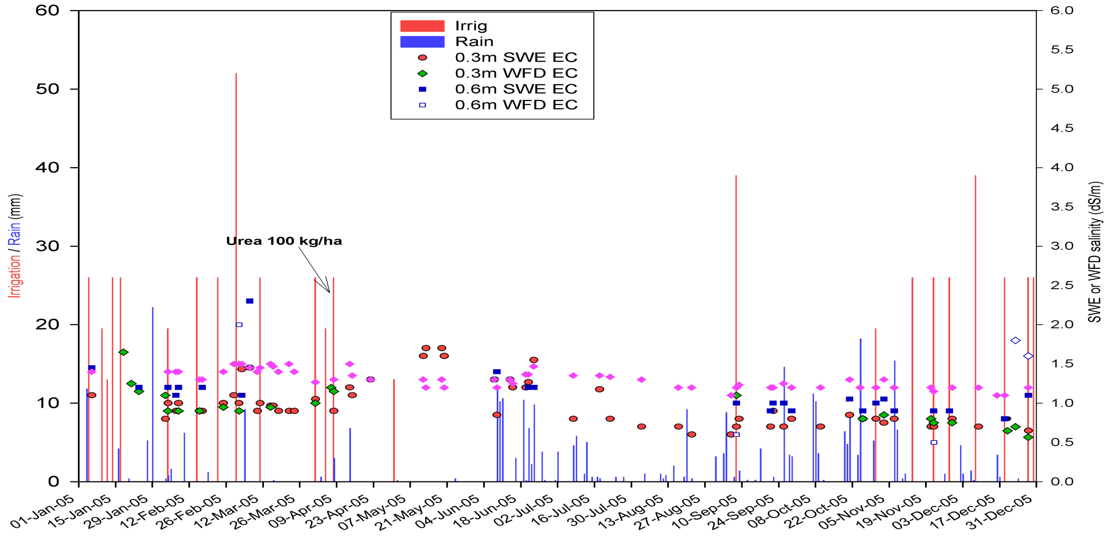


Figure 5. Salinities measured by SWE and WFD (FullStop) in an under canopy sprinkler irrigated Chardonnay vineyard. Irrigation/rainfall (left y axis) and soil water EC measured by SWE and FullStop (right y axis).

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 and contributed to the high salinity which fell to one-third due to drought and more irrigation in 2006.

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

The threshold ECe for yield reduction for grape is 1.5 dS/m while for citrus the value is 1.7 dS/m (Maas and Hoffman 1977). 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. Salinity from SWE was found to be twice the ECe. Hence threshold ECsw is 3.6 dS/m for grapes and 3.4 dS/m for citrus. Therefore, at present there is little risk of yield loss due to soil salinity except for the Irymple site. Soil water EC should be monitored for changes, especially in dry years or when the irrigation water salinity increases. During droughts river water salinity often tends to rise and in some instances it may reach 1 dS/m. High water use efficiency coupled with poor quality irrigation water and low LE will necessitate the use of SWE that allow continual soil water sampling.

The drip irrigated root zone showed a difference in the soil paste salinity (ECe) along the row when measured by taking soil cores to 90 cm deep in Dec and June. In winter (June) there was uniform displacement of salts throughout the profile while during summer (Dec) there was a distinct build up of salts at around 60 cm and half way between dripper emitters. None of the measured ECe exceeded 1.5 dS/m

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.

3.3.5 The leaching requirement

In order to maintain acceptable yields it is necessary to leach the residual salts from irrigation water. The salinity threshold for an own rooted grape is 1.8 dS/m (Walker and Stevens 2004). The threshold is the maximum ECe value that a crop can tolerate without a potential yield decline. Since electrical conductivity (EC) soil solution (ECsw) =2xECe; if ECsw is greater than 3.6 decisiemens/meter (dS/m), there is a need for additional water for leaching in order to maintain maximum yield potential. 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.

By modifying Rhoades equation (Rhoades 1972) with ECsw, we get leaching requirement:

$$LR = \frac{ECiw}{[(2.5 \times ECsw) - ECiw]} \qquad [3]$$

where $ECiw$ = irrigation water EC in dS/m and $ECsw$ is the average soil water EC in dS/m of the root zone measured by extracting water from suction cup.

For example, if ECw is 1 dS/m, then the LR equals 1/[(2.5 x 3.6)-1] which is equal to 0.125 or 12.5%. The water requirement (WR) needed to achieve this LR depends on crop evapotranspiration according to: $WR = \frac{ET}{(1-LR)}$ [4]

Assuming the annual ET of grape in the Lake district is 1200 mm, then WR equals 1200/(1-0.125), or 1371 mm. Since rainwater contributes to the overall soil EC, any measurable rain needs to be taken into account when assessing the leaching requirement.

Table 7. Average root zone salinity threshold of soil water (ECsw)[**]

Tree crops	**Varieties**	**Threshold salinity at which yield decline starts**
		ECsw
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 1 Report. SARDI, GPO Box 397, Adelaide 5001. This study relates salinity tolerance to ECe only.

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 is based upon the 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 Cl in drainage water. By monitoring these concentrations in the field, a seasonal picture of deep drainage can be built up. If a Soil Solution Extractor is used, soil water can be extracted from the root zone at a standard suction (~60 kPa) equivalent to that applied by the plant roots.

Using all methods 1 & 2, the deep drainage results from four trial sites are summarised in Table 8.

Method 3 estimates deep drainage from real time soil water potential using Darcy's flux equation. A soil water content - suction (θ-ψm) 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 designed 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).

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

Site#	Year	Irrigation (mm)	Rainfall (mm)	ETo (mm)	Irri 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

#IRES= Irrigation Recording & Evaluation System

In this method van-Genuchten parametric model was used to smooth hourly capacitance probe's moisture data, from 80 and 110 cm depth sensors, into pressure head (matric potential). Using these results and soil hydraulic functions the deep drainage was estimated by using Darcy's law (Brown 2003) under a steady state flux condition as given in equation 1.

$$D = K(\theta)(\frac{\Delta h}{\Delta z}+1)\Delta t \qquad [5]$$

Where, k(θ) (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. For example, the 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. The estimated DD compared favourably with results from chloride tracing method.

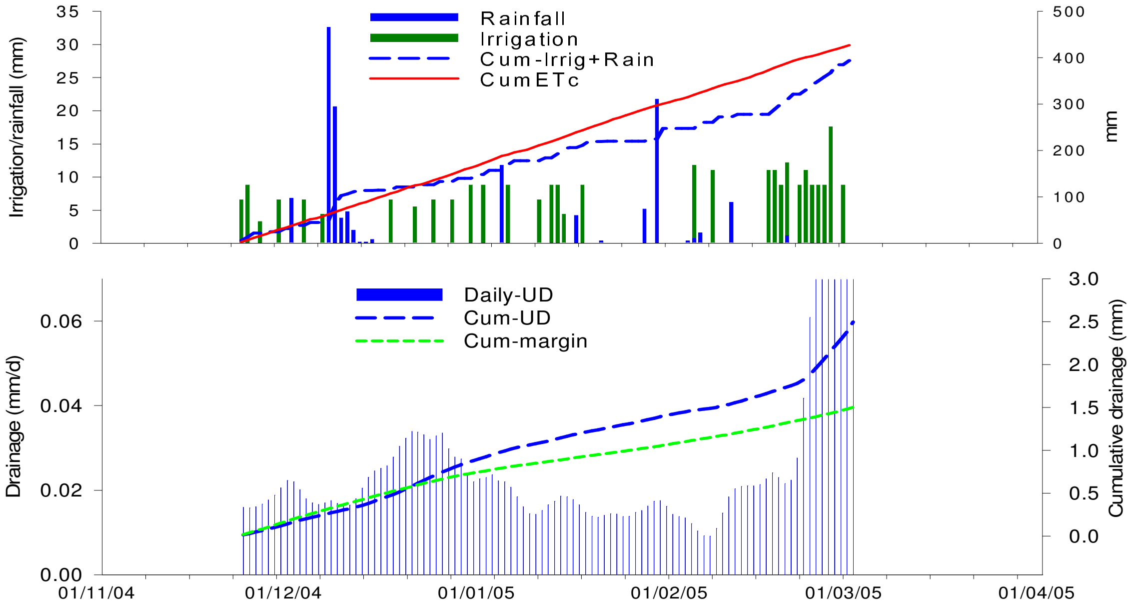


Figure 6. DD under Loxton (site 1) drip irrigated vineyard

Figure 6 depicts the real time DD occurring with associated Rainfall and Irrigation events under the Loxton drip irrigated vineyard. Relatively high rainfall events occurring in mid December 2004 of 50mm resulted in an increased drainage (0.02 to 0.04 mm/day).

Overall water balance (Fig 13) calculated from ET demand minus total irrigation and rainfall was found negative, which meant that there was less water available to plant. This resulted in negligible DD (<1%) confirming the finding of Cl tracing data by Method 2.

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 Modeling the Processes of Root Zone Salinity

To develop a strategy for root zone salinity management, 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.

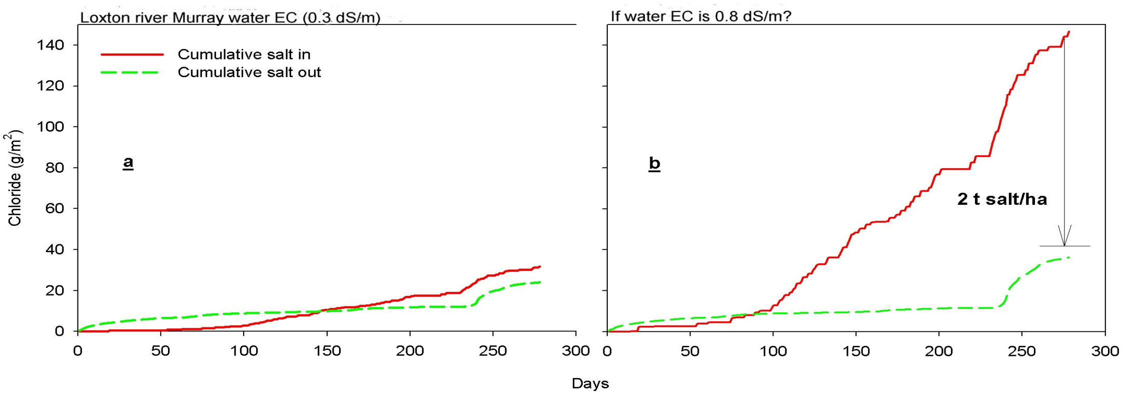


Figure 7. Results of a two dimensional salt transport model showing salt build up with different salinities of River water, the 0.3 dS/m (current level), and 0.8 dS/m the Morgan benchmark

When temporal change in soil EC was plotted against the depth, we obtained a contour map, as shown in Figure 8, where the inside box shows the existing profile EC 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).

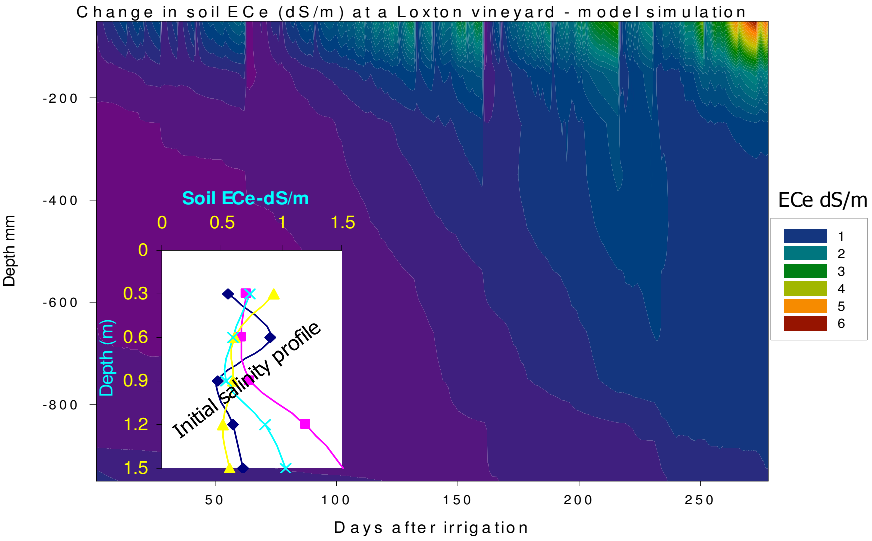


Figure 8. Soil ECe change under Loxton drip irrigated vineyard during a single season if river water reaches 800 EC (0.8 dS/m)

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, NSWDPI 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

	LRC drip, Site#1					**LRC sprinkler, Site#2**					**Irymple drip, Site#4**				
Plant part & Element	*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, whereas wine Cl standard =394 mg/l and wine Na Standard =606 mg/l

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 exceed the survey standard. This was due to the high salinity in the root zone. Berry Cl and Na contents were lower than the international wine standard.

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 Crop loss 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).*

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 are determined for the selected crops, as specified in Table 1, 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. Leaching Efficiency is the efficiency with which the leaching fraction carries the salt when it moves through the soil profile. 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. The results are presented in Tables 2 and 3.

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.

3.7.2 Effects of River salinity on value of loss production

The impact of salinity on the crop yield is influenced by the river salinity and existing soil type (sand, loam and clay). The relative yield (Yr) is the percentage of normal yield expected under the saline conditions existing at that time in that section of river.

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. A graphical presentation of total lost production from all crops/industries for sections A1, A2, A3 & A4 of the river are presented for both the 100% and 70% LE's.

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 $50 & $60 million with 1000EC (1 dS/m) at Morgan. Given that the LE is often below its full strength, at 70% LE, the total losses for the four river sections would be between $80 & $90 million with 1000EC at Morgan.

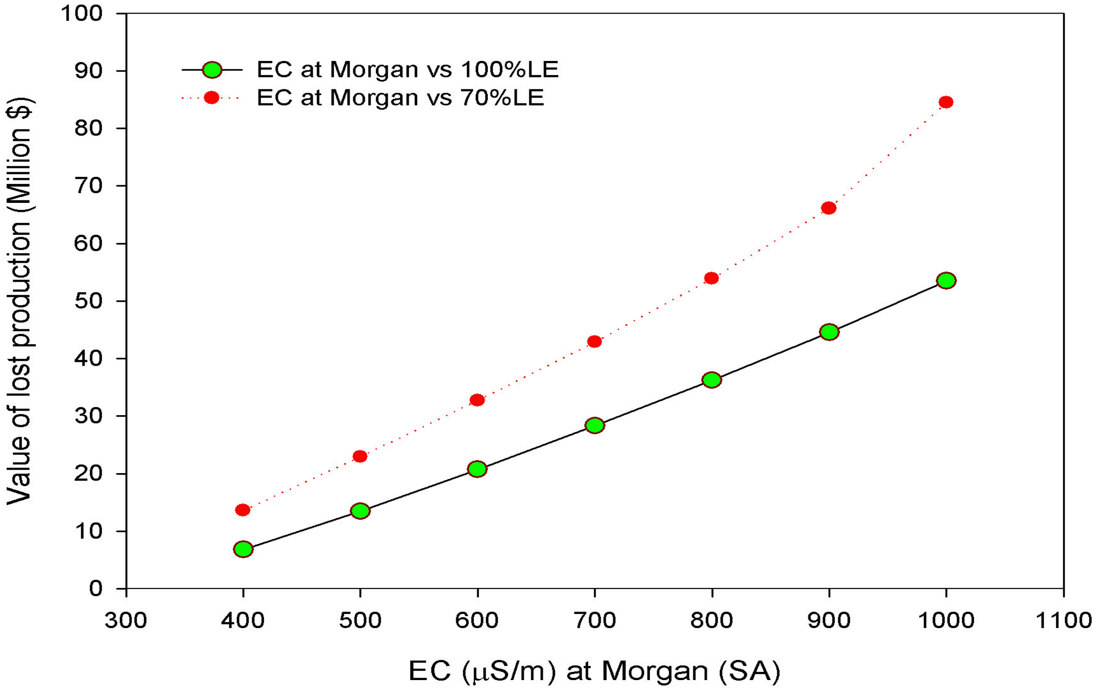


Figure 9. Value of lost production due to increasing river salinities

4. Draft best management practices for root zone salinity

A project milestone was a draft of Best Management Practices (BMP) for irrigators for controlling root-zone salinity. 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.

A paper on BMP's was prepared and presented at the Root-Zone and Solute Management Workshop. This paper has now been 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 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: DEP15 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, 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 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

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.

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 (~1dS/m) will increase topsoil salinity (ECe) to 5 dS/m. The threshold ECe for grape is 1.5 dS/m while for citrus the value is 1.7 dS/m (Maas and Hoffman 1977).

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 ECe 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 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 salinity reaches 1000 EC (1 dS/m), the estimated 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 $90 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.

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.

7. Recommendations

There is a need for a more general educational approach, with irrigators, regional planners and policy makers, to create a culture of risk management within irrigation communities, and water management agencies, especially as it relates to root-zone salinity management. It is recommended that training modules be developed to sit alongside existing irrigator training in irrigation design and layout, equipment testing and irrigation scheduling.

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

There is a need for a three dimensional visualisation of root zone salinity model.

IRES needs calibration for being able to estimate drainage component

Irrigator experiences in measuring and managing salinity need to be evaluated in order to improve the draft best management practices suggested in the project.

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 spike(s) occur.

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

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