Modelling the Cost of Irrigator Response to Lower River Murray Salinity

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ABSTRACT:

This paper reports on an analysis of irrigator water demand and profit changes across varying annual water availability, crop water requirements, and river salinity conditions for irrigation along the South Australian portion of the Lower Murray. The paper also investigates the validity of the current relationship between salinity of irrigation water and irrigated crop yield underlying MDBC salinity offset investments. The assumption implicit in the current MDBC net benefits formula may be mis-specified in that the possibility to avoid yield loss with additional leaching is not accounted for. This paper reports how that mis-specification, that irrigators would simply accept yield losses, leads to overstatement of the benefits of actions to decrease salinity.

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- CSIRO Land and Water
- Primary Industries Research Victoria (Vic DPI)
- The University of Adelaide
- SA Department of Water Land and Biodiversity Conservation (DWLBC)
- South Australian Research and Development Institute (SARDI).

In addition to research provision by LTA members, other research providers include:

- SA Department of Environment and Heritage (DEH), and
- Salient Solutions.

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Stakeholders

- SA MDB NRM Board
- Wimmera CMA
- Mallee CMA
- Murray Darling Basin Commission
- Victorian Department for Sustainability and Environment (DSE)
- Victorian Department of Primary Industries (DPI)
- SA Department of Water Land and Biodiversity Conservation (DWLBC)

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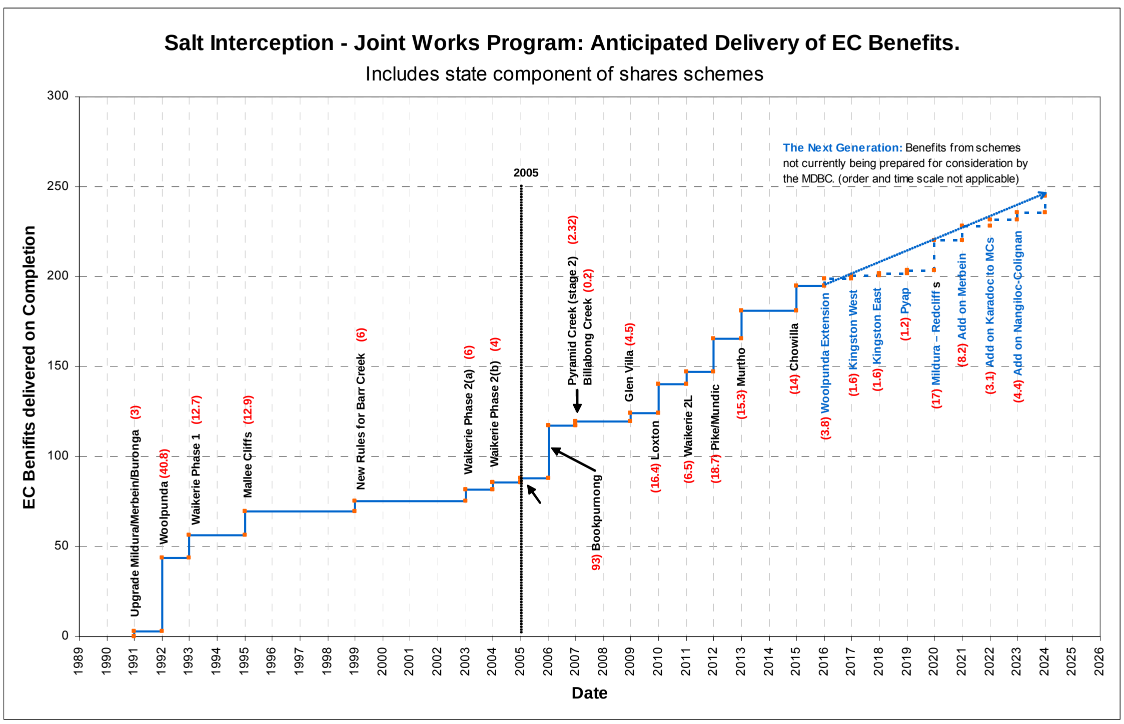
1. INTRODUCTION

Levels of saline groundwater inflow into the River Murray have been rising over the past decades and are predicted to continue rising over the next century. Potential results include damage to irrigated crops, municipal, residential and commercial water using infrastructure. Avoiding such damage has been a key justification for Murray Darling Basin Ministerial Council, Basin Salinity Management Strategy (BSMS) program of salinity offset investments that is jointly financed by the MDBC and States along the River (MDBMC, 2001). Through the program, as shown in Figure 1, there has been over $100M investment in salt interception and drainage disposal with more investment anticipated. To date, efforts have resulted in a reduction in growth of River salinity by an average annual 100 electrical conductivity (EC) units over what it otherwise would have been at the reference measurement point at Morgan, SA near the mouth of the River.

Figure 1: The salinity impact of salt interception schemes built as a result of MDBC salinity agreements



Source: Connor, 2005

The criteria for choice of level of investment in action to offset salinity under the BSMS (MDBC, 2003) can be understood as an application of the standard benefit cost analysis (BCA) framework (Mishan, 1971), with investment options compared based on:

Net Benefit = NPV[3] { - capital cost - o&m cost + irrigated agriculture salinity benefit

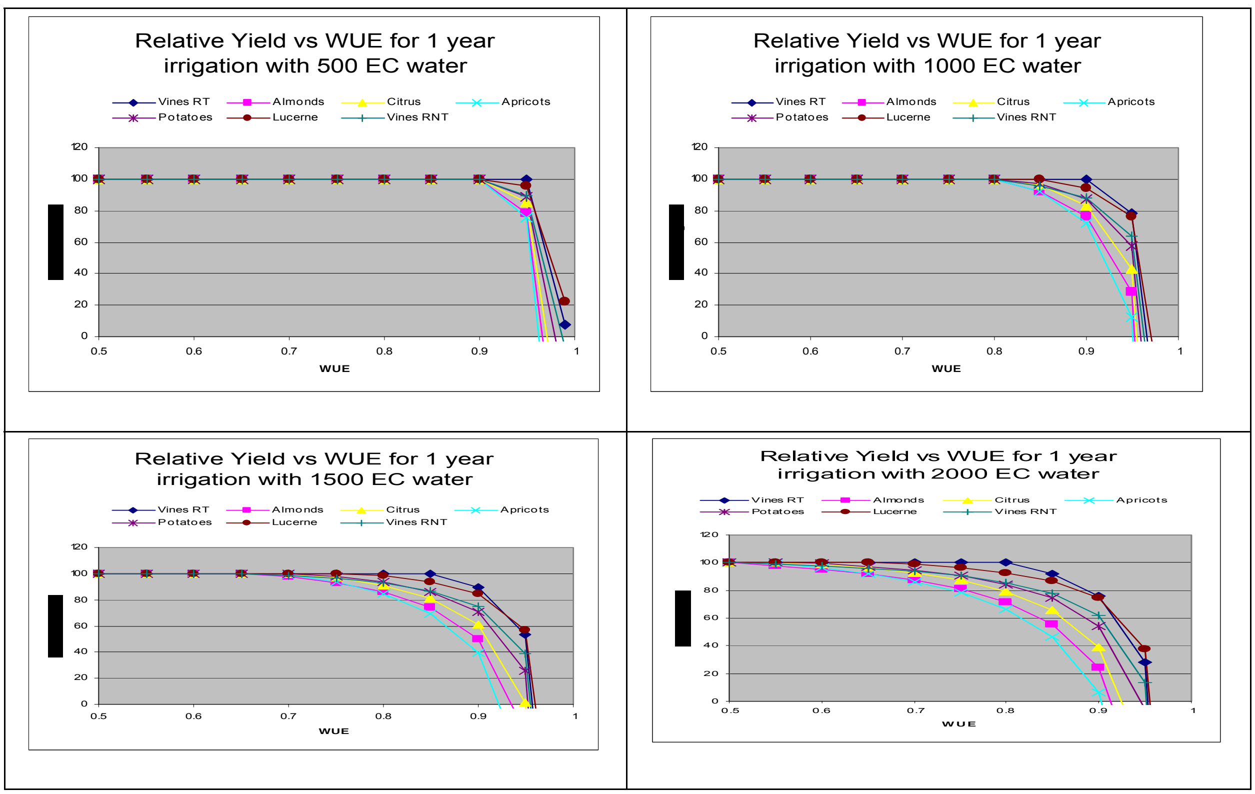
+ household commercial and industrial water infrastructure salinity benefit

} (1)

The focus of the analysis reported on here is the methodology used in the BSMS investment choice formula to assess irrigated agricultural benefits of changes in River salinity levels in the BSMS net benefits formula. Under the current specification, irrigators are assumed to face reduced yield when River salinity exceeds threshold levels that vary by crop based on “bent stick” salinity damage functions for major Murray Basin irrigated crops (GHD, 1999). With this specification, it is implicitly assumed that irrigators have no choice but to accept increased damage at higher levels of irrigation water salinity.

In fact there is an alternative to accepting yield losses, when irrigating with saline water, farmers can leach salt introduced to the soil with water applications over and above what is required to realise full potential yield with less saline irrigation water. The result, as shown in Figure 2, is that full potential yield can be maintained even when irrigating with saline water, if sufficient water is leached.

Figure 2: The relationship between irrigation water salinity and crop yield



Source: (GHD, 1999)

3 NPV is the abbreviation used for net present value

In essence, the current relationship between salinity of irrigation water and irrigated crop yield underlying MDBC salinity offset investments is mis-specified in that the possibility to avoid yield loss with additional leaching is not accounted for.

This analysis is an application of an integrated model being developed by CSIRO for the Lower Murray Landscapes Futures project known as the River Murray Corridor Systems Model (Walker, et al, 2005). The modelling goal is an integration of existing biophysical and economic models to determine the salt and biodiversity impacts of land use and management actions. The eventual intent is to enable stakeholders who are sponsoring the project including State agencies and catchment management boards in Victoria and South Australia to use the model to test natural resource management strategies and future land use scenarios against various catchment management targets, and measure the economic impacts of land management decisions.

In particular this article is an application of the irrigator response model component of the River Murray Corridor Systems Model. The objective of irrigator response modelling is to provide a modelling capacity capable of predicting irrigator responses to changes in:

- economic conditions (e.g. commodity prices, production costs);
- policy (e.g. irrigation land use zoning, or salinity charges);
- biophysical system state (e.g. salinity of irrigation water, climate influence on crop ET and water availability).

The irrigator response model will provide economic impact assessments and be integrated at a later date with water and salt biophysical process models to provide more comprehensive River Murray landscape futures modelling.

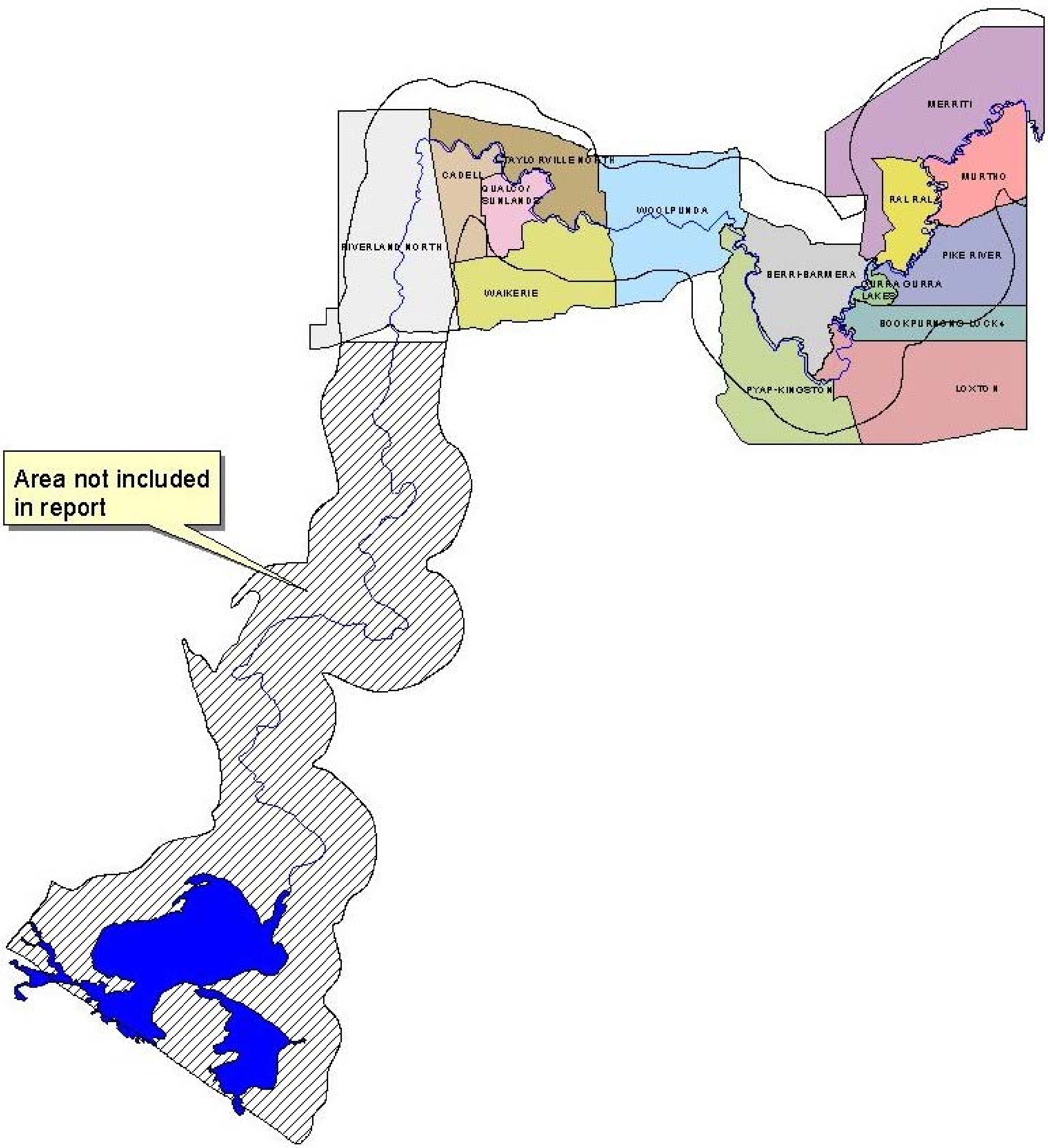
2. OBJECTIVES

The objective of this report is to assess irrigator profit, and water demand impacts of increasing River Murray salinity levels with alternative specification of possible responses. Change in irrigator's profits, water demand, and the level of drainage are estimated over a range of agro-climatic conditions and River Murray salinity levels with two model specifications. In one specification irrigators have the option to drain additional water above their minimum requirements in order to leach salt out of the root-zone, helping avoid salinity damage to their crops. In the other specification additional leaching is not an option and irrigators must simply accept the damage resulting from higher salinity irrigation water.

3. METHODOLOGY AND DATA

A non-linear mathematical program has been used to model short-run irrigator responses to changes in agro-climatic variables, such as evapotranspiration and growing season rainfall, and River Murray salinity levels (measured in EC). The modelling is at a Land and Water Management plan area level of spatial resolution for the area of the South Australian Lower Murray shown in Figure 3.

Figure 3: Study area – the South Australian Lower Murray



Source: Connor, 2003

As the model is of irrigators' short-run responses, it is assumed that the current crop mix (j) is fixed, along with the irrigation practices (h) used to irrigate them. Any fixed costs incurred by the irrigator, such as crop establishment or pumping infrastructure costs, have been assumed to be sunk, and therefore do not impact on an irrigator's decision in the short-run.

For a given irrigation district (I), salinity impact zone (z), and River Murray salinity level (e), the model maximises an irrigators (a proxy for the irrigation district) total profit given their current crop mix (j), irrigation technologies (h), crop returns (price * yield), variable costs of production, and their water allocation.

The model solves over varying states of nature (s), which reflect the differences in agro-climatic variables between years, such as evapotranspiration and growing season rainfall, and the price of water in the temporary water market. The states of nature available in the model reflect the level of the agro-climatic variables and price of temporary water for the years 1975 (s75) through to 2005 (s05).

The irrigator in the model can choose exactly how much water to irrigate, depending on the marginal benefits and marginal costs of water use. A salinity yield response is included which simulates how sufficiently high salinity levels are expected to impact on yields of the various crops depending on level of water leaching. At high salinity levels, the irrigator may choose to apply more water than the crop requirements, in order to leach the salt out of the root-zone to maintain crop production. The trade-off for maintaining the yield at high levels when irrigating with saline water is that the irrigator will need to purchase and pump additional water for their crops. If, for example, the marginal benefit from applying (leaching) another 1mm per ha of water above the crop requirements (possible increased yield due to reduced salt damage) exceeds the marginal cost ([price of water + pumping cost] * 1mm per ha), then it would be profitable for the irrigator to do so.

The next section describes the model in more detail, outlining the objective function, equations, constraints and all of the variables used within the non-linear program. The variables written in capitals are the endogenous variables, while the lower case variables are exogenous.

3.1 Objective Function

Algebraically, the objective function is as follows:

Maximise - $\sum_{j,z,h,d}$ (Yield$_j$ * Yield_Fraction$_{jed}$ * Price$_j$
– Variable_C$_j$ – Variable_IC$_{jhs}$
– Variable_PC$_{lz}$ * ED_WATER_USE$_{jzhd}$
– TempWater_C$_s$ * (ED_WATER_USE$_{jzhd}$ – Average_Water$_{ljh}$))
* ED_HA_CHOICE$_{jzhd}$ (1)

Where:

Yield$_j$ = Maximum potential yield of crop (j) (t/ha);

Yield_Fraction$_{jed}$ = Fractional value (between 0 and 1) representing percentage of maximum yield attainable for crop (j), given salinity level of irrigation water (e), and the choice of drainage rate (d);

Price$_j$ = Price received per tonne of agricultural production of crop (j) ($/t);

Variable_C$_j$ = Variable costs of production for crop (j), not related to irrigation ($/ha);

Variable_IC$_{jhs}$ = Variable irrigation costs for crop (j), using irrigation practice (h) under state of nature (s) ($/ha);

Variable_PC$_{lz}$ = Variable pumping costs (electricity and maintenance costs) to pump water to the irrigator's crops, for each region (l) and salinity impact zone (z) ($/mm/ha);

TempWater_C$_s$ = The price of temporary water rights ($/mm/ha) for state of nature (s);

Average_Water$_{ljh}$ = The average water requirements for crop (j) in region (l) using irrigation practice (h) (mm/ha);

ED_WATER_USE$_{jzhd}$ = The optimised level of water use for a hectare of crop (j) in salinity impact zone (z) using irrigation practice (h) and drainage rate (d) (mm/ha);

ED_HA_CHOICE$_{jzhd}$ = The optimised number of hectares of crop(j) in salinity impact zone (z) using irrigation practice (h) chosen to irrigate with a drainage rate (d) (ha);

The above objective function is maximised subject to the constraints listed below in section 3.2.

3.2 Key Functional Relationships and Constraints

3.2.1 Area Limitations

As the model is trying to optimise irrigator profit from the already existing crops and associated infrastructure within each region, it is necessary to constrain the optimised number of hectares chosen by the model to be less than or equal to what currently exists. This means that the choice variables in the model the level of water use and drainage (d) on each existing hectare of development, and the amount of temporary water that irrigators buy and sell given their initial allocation of permanent water and water prices that vary across years.

$$\sum_d ED\_HA\_CHOICE_{jzhd} \leq Current\_Area_{ljzh} \quad (2)$$

Where:

$ED\_HA\_CHOICE_{jzhd}$ = as defined above;

$Current\_Area_{ljzh}$ = Existing developed hectares of crop (j) using irrigation practice (h) in salinity impact zone (z), within region (l);

3.2.2 Water Limitations

<u>Temporary Water Purchases (Sales)</u>

There are two instances in the model where the profit maximising choice may be to purchase additional water entitlements from the temporary water market. The first instance is that where, ignoring the possibility of salinity damage, an irrigators annual water allocation is not sufficient to meet the annual water requirements of the crops. Given that permanent water allocation levels are assumed to equal average requirements across all states of nature, this only occurs in the relatively dry (high ET, low RAIN) years. The second instance is where even though the annual water allocation is sufficient to meet the crop requirements with non-saline water, the irrigator chooses to irrigate above the minimum requirements in order to leach salt through the root-zone to prevent salinity damaging the crops as this is economically optimal for their circumstances.

For relatively wet years (Low ET, High RAIN) where the irrigator's water allocation exceeds their requirements, the irrigator has the option of selling this excess water back into the temporary water market to make a profit. The part of the objective function representing the temporary water market is reproduced as equation 3 below.

$$- TempWater\_C_s * (ED\_WATER\_USE_{jzhd} - Average\_Water_{ljh}))$$

$* ED\_HA\_CHOICE_{jzhd}$ (3)

<u>Minimum Water Use a Function of Either System Efficiency or Leaching Requirement</u>

In this short-run model, there is fixed endowment of irrigation systems capital in each Land and Water Management Planning (LWMP) area. This is represented as a number of hectares of irrigation systems of various types in each LWMP. As shown in Figure 2 the level of irrigated crop yield attainable depends on the level of water applied in excess of the crop water requirement. No irrigation practice is 100% efficient; all result in some drainage below the root zone with the options represented in this model ranging from 70% to 95% efficient. Depending on salinity level of irrigation water and the efficiency of the system in place, realising maximum potential yield may not require any leaching (drainage) above the amount that results from system inefficiency. When, no leaching in excess of what occurs through normal the irrigation system water loss is required, water use per hectare is determined as the crop evapotranspiration requirement divided by the system efficiency as shown in equation 4

$$ED\_WATER\_USE_{jzhd} \geq Crop\_Water_{slj} / Ie_{jh} \quad (4)$$

In the cases where the River Murray salinity level is relatively high, leaching above the normal level associated with a given irrigation system is required to avoid salinity damage. In these cases, the irrigator can decide to choose a higher leaching level and avoid damage loss. The constraint in equation 5 becomes binding when this occurs. The structure of the model objective function and constraints are such that this occurs only when the marginal benefits of applying this extra water, (the marginal revenue product of increased yield), outweighs the marginal costs of the extra water purchase and pumping costs to apply additional water. The linkage between yield loss and leaching level is the hectare choice variable, $ED\_HA\_CHOICE_{jzhd}$ the subscript d indicates that hectares must be chosen by drainage rate. When salinity levels are high choosing hectares with low levels of drainage results in yield loss through the $Yield\_Fraction_{jed.}$

$$ED\_WATER\_USE_{jzhd} \geq Crop\_Water_{slj} / Leaching\_Requirement_{jed} \quad (5)$$

For constraint 4 and 5:

$Crop\_Water_{slj}$ = crop water evapotranspiration (ET) requirements (mm/ha) net of crop useable rainfall;

Ie_{jh} = Irrigation efficiency of irrigation practice (h) being used to irrigate crop (j) which is a fraction between 0 and 1 but typically in the range .7 to .95 and represents the fraction of applied water that can be assumed to meet crop ET requirement;

$Leaching\_Requirement_{jed}$ = 1- The percentage of crop ET that must be leached to achieve a drainage rate of (d).

3.3 Data Sources and Assumptions

Variable	Data Source	Assumption(s)
Yield	PIRSA (2005a)	-
Yield Fraction	GHD (1999)	-
Price	PIRSA (2005b)	-
	PIRSA (2005c)	-
Variable Costs of Production	PIRSA (2005a)	-
Variable Irrigation Costs	LIC (2006)	Based on Grape irrigation costs by irrigation practice. Costs for other crop types were determined by pro-rating the net irrigation requirements (higher water requirements means higher cost)
Variable Pumping Costs	-	Engineering formula provided by SA Water
Temporary Water Prices	BIGMOD Regression	-
Water Allocation	-	Assumed to equal the average requirements (see section 4.5.3)
Crop Evapotranspiration	Bureau of Meteorology	-
	PIRSA (2000)	-
Effective Rainfall	Bureau of Meteorology	Assumed to be equal to 65% of total crop rainfall
Irrigation Efficiencies	Skews and Meissner, 1999	-
Current Areas	RLAPA (2005)	-

4. RESULTS

Given the large number of regions and possible states of nature evaluated, reporting on all results would be infeasible. We report, instead one representative area, the Loxton LWMPA, for:

- two of the fifteen different irrigation practices modelled, an averagely managed drip irrigation system, and a poorly managed overhead irrigation system;
- two of the 30 states of nature modelled, a dry (1982) and a wet (1995) year; and
- levels of salinity varying between 500 and 2000 EC.

The differences across the two years modelled in terms of crop water requirements and expected temporary water market prices are shown in Table 1.

Table 1: Difference in Agro-Climatic Variables and Temporary Water Costs between a Relatively Dry (1982) and Wet (1995) State of Nature (year)

		Winegrapes		Citrus		Stonefruit	
		1982 (Dry)	1995 (Wet)	1982 (Dry)	1995 (Wet)	1982 (Dry)	1995 (Wet)
Evapotranspiration	(mm/ha/yr)	640.91	642.74	842.29	819.59	948.08	940.77
Growing Season Rainfall	(mm/ha/yr)	35.62	124.35	56.29	202.93	43.03	141.64
Net Irrigation Requirement	(mm/ha/yr)	605.29	518.39	786.00	616.66	905.05	799.13
Temporary Water Costs	($/ML)	$150.84	$31.03				

4.1 Profit Gains from Allowing Additional Leaching

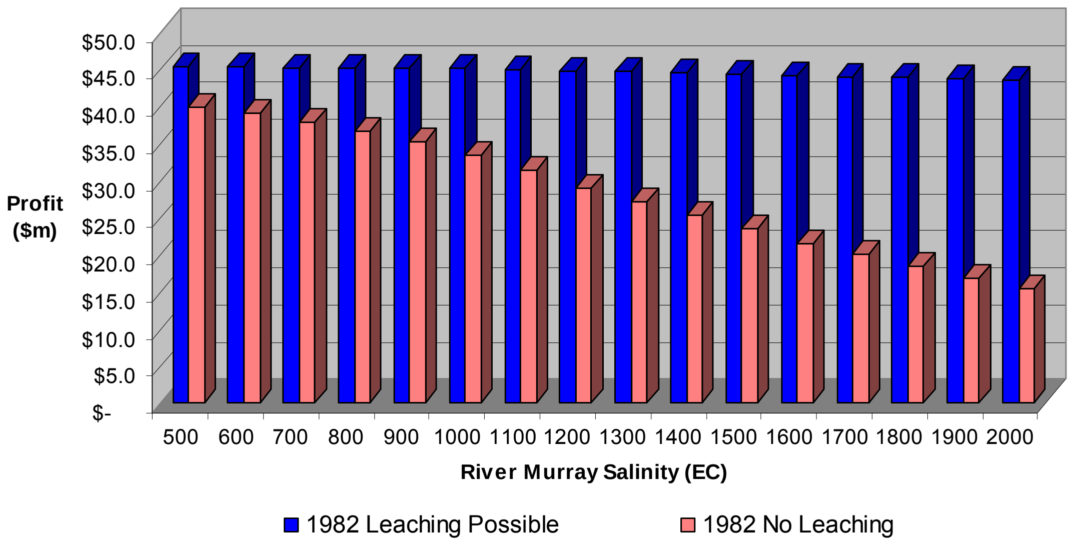
One objective of this paper is to compare estimated profit impacts of high river salinity, with and without the assumption that irrigators have the option of draining additional water above their minimum requirements at times where River Murray salinity levels were relatively high to avoid yield losses.

As shown in Figures 3 and 4, for relatively dry and wet years respectively, allowing the possibility of leaching more water than the minimum as an alternative to accepting yield loss can reduce estimates of irrigator profit losses resulting from high irrigation water salinity levels quite substantially.

For the dry year modelled (1982 conditions), when additional leaching is allowed, the reduction in profit for the Loxton LWMPA resulting from an increase in the River Murray salinity level from 500 to 2000 EC, is estimated at only $1.9m or 4%. This lost profit is due to the additional costs of water purchases in order to leach salt out of the root-zone under the highly saline conditions.

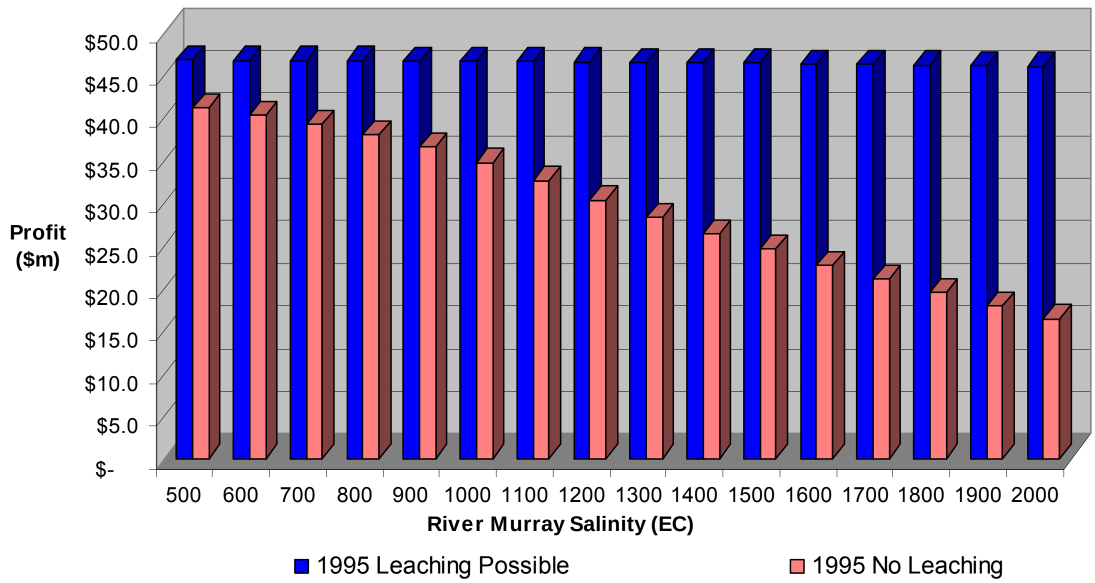
Under the scenario where leaching was not allowed to occur above the minimum requirement, the profit loss estimated as a result of salinity increasing from 500 to 2000 EC is estimated to be $24m or 61%. This is an estimate of the resulting salinity damage to crop yields, due to a build up of salt in the root-zone.

Figure 3: Total Irrigator Profit ($m) for Loxton in 1982 (Dry Year)



The estimated changes in profit for a change in River Murray salinity from 500 to 2000 EC for the wetter year scenario (1995 conditions) were very similar to estimates of the profit impact of salinity under dryer conditions. Profits only dropped by $0.8m or 2% when additional leaching was allowed, because less temporary water purchase was required to meet leaching requirements. The drop in profit was around $25m or 60% when additional leaching was prohibited. This is less than in the dry year as result of lower water requirements and water prices.

Figure 4: Total Irrigator Profit ($m) for Loxton in 1995 (Wet Year)



4.2 Optimal Drainage Rates Chosen for Winegrapes, Citrus and Stonefruit under Increasing Salinity Levels

An example of the dynamics behind the results in section 4.1 above is shown in figures 5-8 for the two irrigation practices and three crops. These figures show the increasing level of drainage chosen at increasing levels of salinity by the model when additional leaching is allowed. They also give a picture of the relative sensitivities to salt damage for each crop, depicted by the rise in optimal drainage given a certain rise in salinity.

Figures 5 and 6 below show the optimal drainage rate by crops, irrigated using either an averagely managed drip irrigation season (figure 5) or a poorly managed overhead irrigation system (figure 6) in a relatively dry year. Figures 7 and 8 below show the optimal drainage rate by crops, irrigated using either an averagely managed drip irrigation season (figure 7) or a poorly managed overhead irrigation system (figure 8), but for a relatively wet year.

All of the figures show that for all the crops considered, given the choice, a rational irrigator would choose more leaching rather than yield loss in response to rising River Murray salinity, given the current economics of irrigated crop production. In addition, the figures show that optimal leaching levels in response to increasing levels of salinity are much greater for citrus, and especially stonefruit, than for vines.

The difference between the optimal levels of drainage in figures 5 versus 7 and also figures 6 versus 8 reflect the lower basic water requirements (ET-RAIN) for a relatively wet year (as the sensitivity to salinity is the same for both cases).

Figure 5: Per Hectare Drainage by Crop for an Average Drip Irrigation System in Loxton in 1982 (Dry Year)

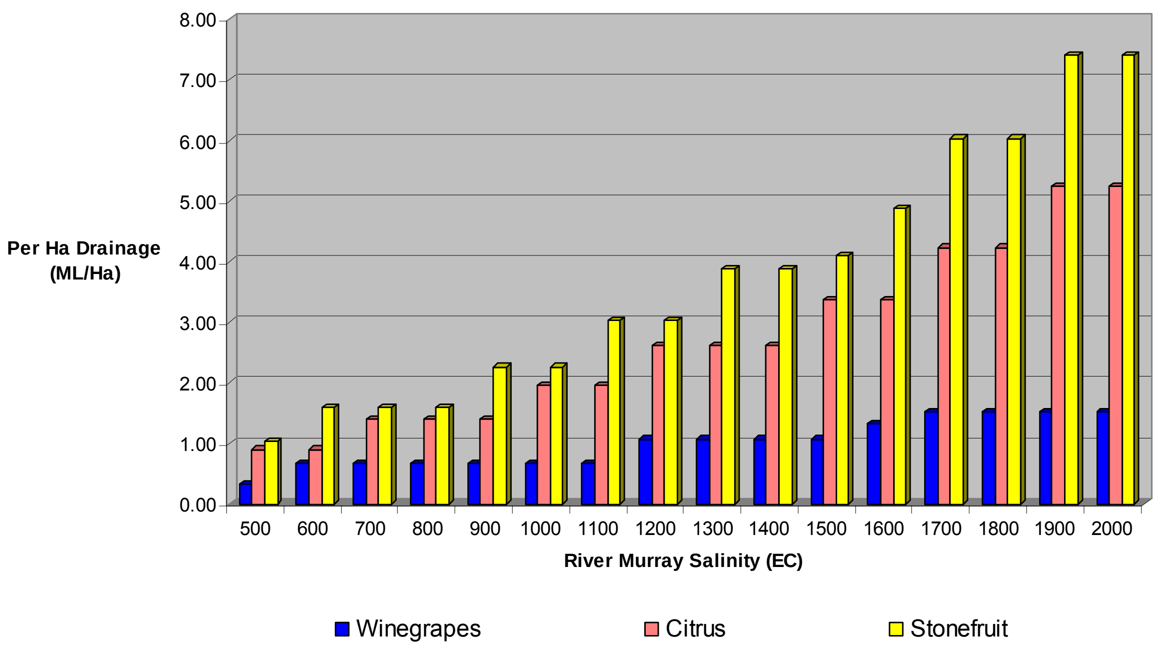


Figure 6: Per Hectare Drainage by Crop for a Poor Overhead Irrigation System in Loxton in 1982 (Dry Year)

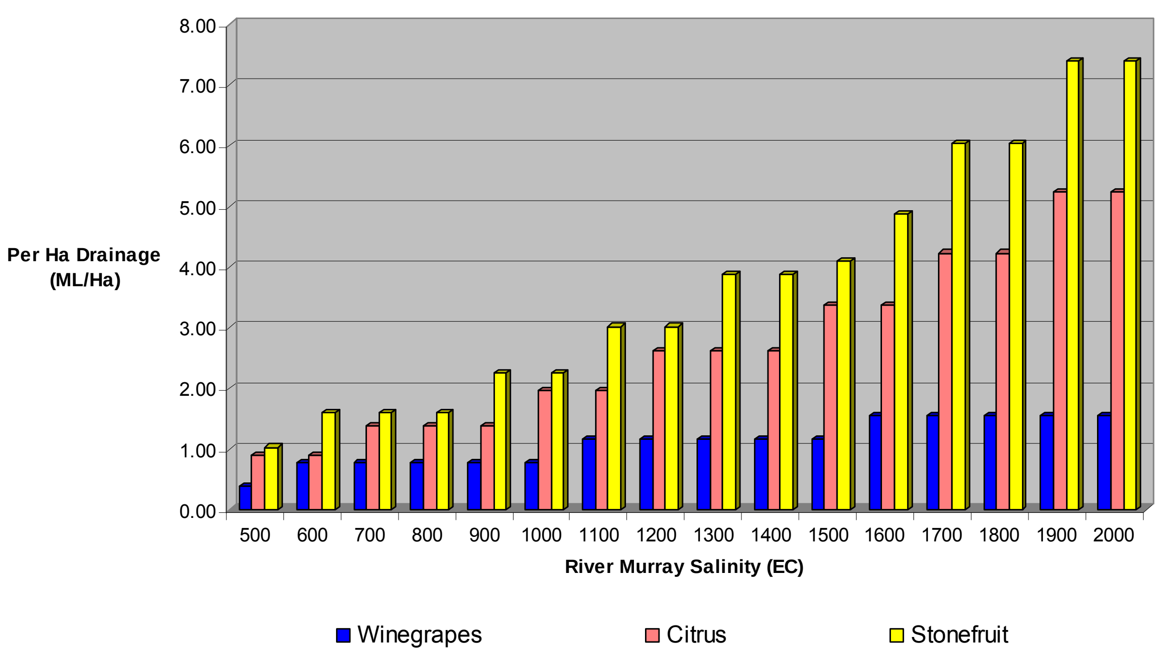


Figure 7: Per Hectare Drainage by Crop for an Average Drip Irrigation System in Loxton in 1995 (Wet Year)

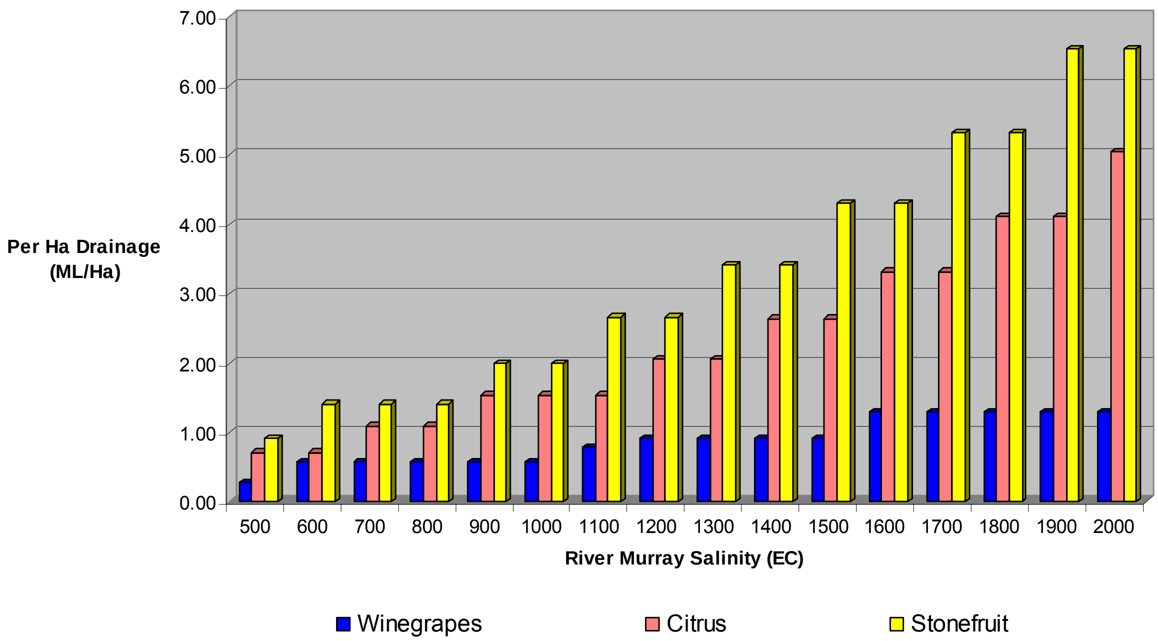
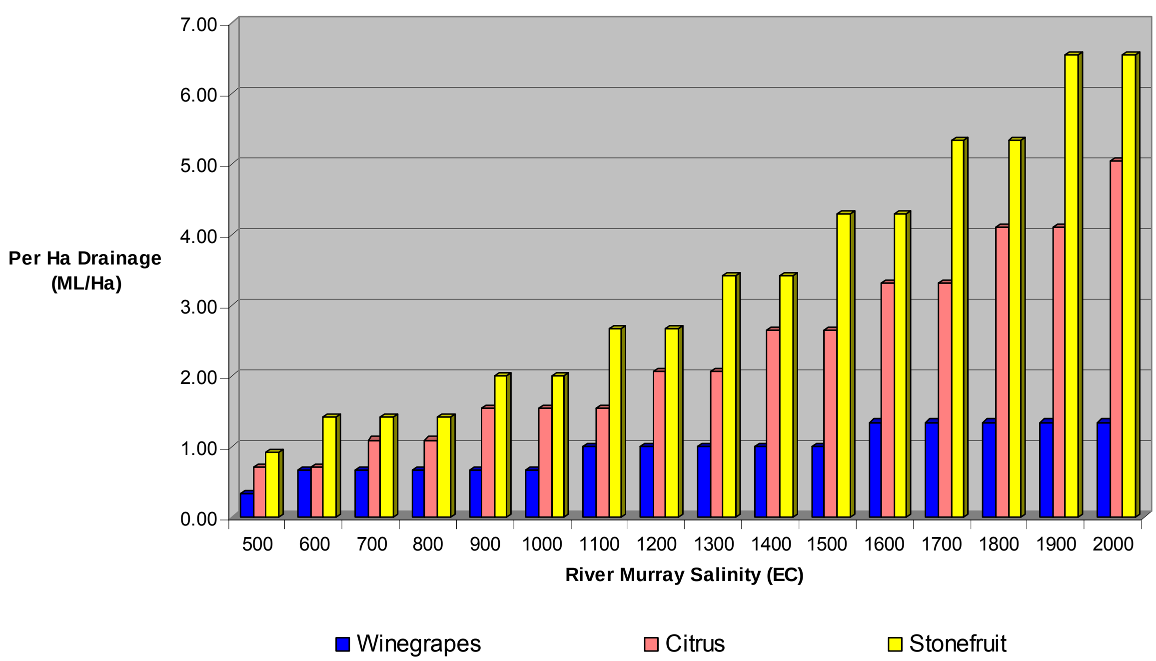


Figure 8: Per Hectare Drainage by Crop for a Poor Overhead Irrigation System in Loxton in 1995 (Wet Year)

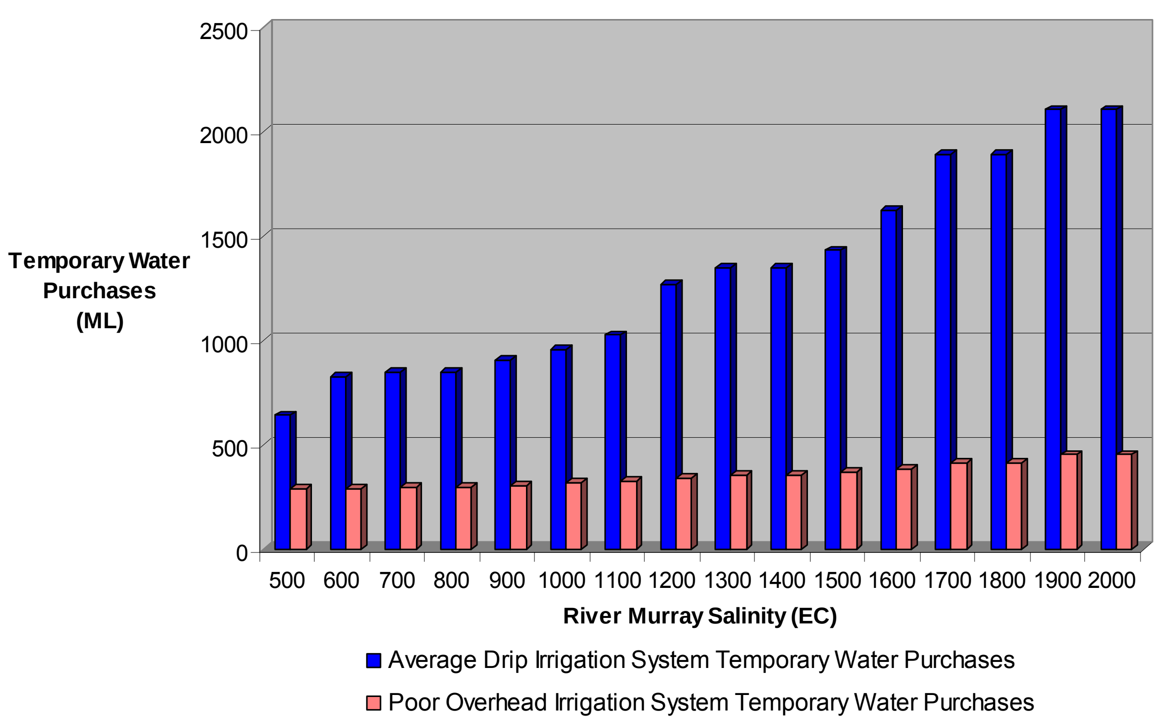


4.3 Temporary Water Purchases under Increasing Salinity Levels

When increasing leaching is a possible response to increasing irrigation water salinity, there will be greater demand for purchase of additional water entitlements from the temporary water market at higher salinity levels. The amount of water demanded estimated in the model are shown in figures 9 and 10 for a relatively dry and wet year respectively (for all crops being irrigated with the respective irrigation practice in the Loxton LWMPA). It must be noted that the difference in the magnitude of the amount of temporary water purchased by irrigators using the two different irrigation technologies is mainly due to the number of hectares being irrigated, not the efficiency differences between the two irrigation practices.

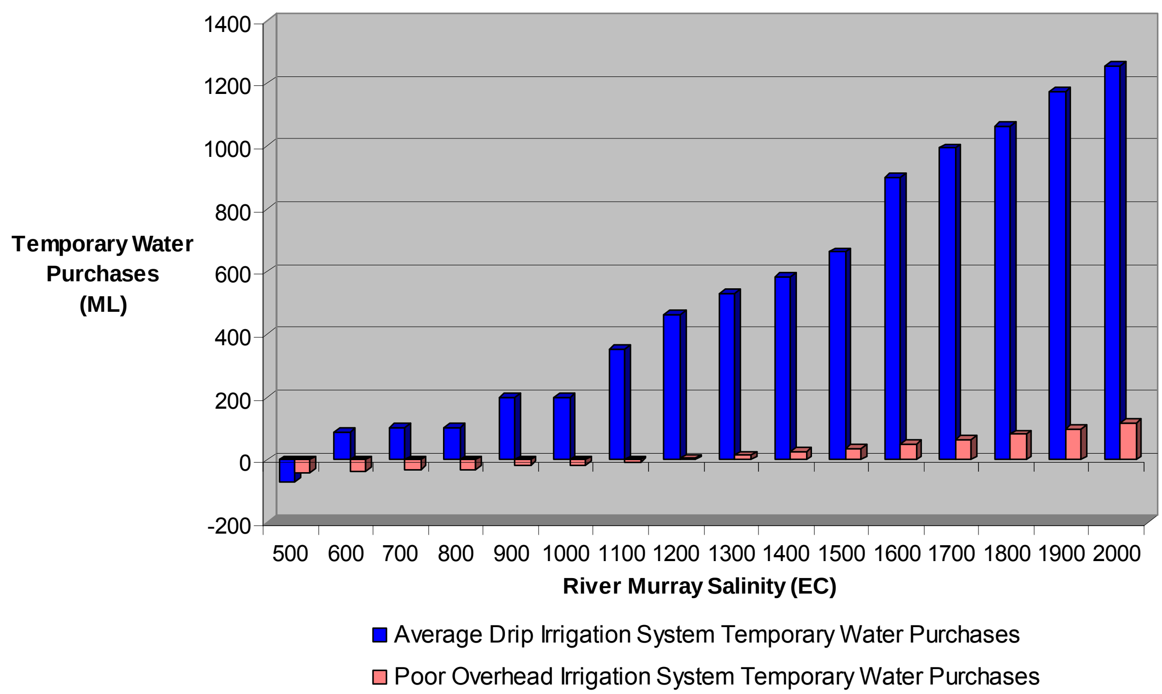
For the relatively dry year of 1982, irrigators using either an averagely managed drip or poorly managed overhead irrigation system need to purchase additional water entitlements (above their initial allocation) under all of the modelled River Murray salinity levels (500 through to 2000). Notably, the increased demand for water is much greater with more efficient irrigation technology, as with the less efficient overhead system, inherent system inefficiency provides all of the leaching that is necessary until irrigation water salinity exceeds a threshold level for each crop. In contrast for the more efficient drip system, leaching in excess of system losses are required at all levels of salinity modelled.

Figure 9: Temporary Water Purchases (or Sales) for two Irrigation Systems in Loxton in 1982 (Dry Year)



For the relatively wet year of 1995 as shown in Figure 10, irrigators using either an averagely managed drip or poorly managed overhead irrigation system are estimated to purchase additional water entitlements (above their initial allocation) for all River Murray salinity levels above 1200 EC. For the lower salinity levels, there is potentially an amount of temporary water that can be sold onto the temporary water market, above the modelled optimal requirements for irrigation with the overhead system. This is mainly due to the lower water requirements (and relatively larger initial allocations) in wet years, as shown in figure 2 above.

Figure 10: Temporary Water Purchases (or Sales) for two Irrigation Systems in Loxton in 1995 (Wet Year)



5. CONCLUSIONS

One important implication of the findings reported here is that the current method of estimating irrigated agricultural benefits of changes in salinity, overestimates the cost of salinity increases, and under estimates benefits of salinity decreases. Results reported here would tend to suggest that the response to increasing salinity is to increase irrigation drainage leaching. Thus, the assumption implicit in the current MDBC net benefits formula used in assessing salinity-offset investments, that irrigators would simply accept yield losses, leads to overstatement of the benefits of actions to decrease salinity. The level of over estimation of profit loss from increasing salinity as result of ignoring leaching response possibility is shown in Table 2 for the dry year (1982) scenario.

Table 2: Over estimation of profit loss from increasing salinity as result of ignoring leaching response possibility, for 1982 conditions

River Murray Salinity (EC)	Over Estimate of Profit Loss (%) when leaching response is ignored
500	14%
600	16%
700	19%
800	23%
900	28%
1000	35%
1100	43%
1200	54%
1300	65%
1400	76%
1500	90%
1600	105%
1700	120%
1800	139%
1900	159%
2000	183%

Another important implication of the findings is that increasing levels of salinity in the River could lead to increased leaching. This in turn would lead to further (though time delayed) increases in salinity, leading to an increased need to leach in a negative feedback spiral.

There are several limitations to the modelling to date including:

1. In modelling, it is assumed that additional leaching can occur to avoid salinity damage, with the only cost being the cost of additional water purchases. However, for winegrapes, there is the potential to lose quality in the grapes if too much water is applied. This has the implication of reducing the price received for the produce, and hence is a potential cost of leaching above the

minimum requirements. The extent to which this quality effect will play a part in an irrigator's decision to leach additional water or not is dependant on factors such as:

- Grape variety;
- Intended market; and/or
- Current contractual arrangements.

For irrigators currently receiving a low price for their grapes, an additional drop in price may not be significant enough to prevent them from leaching more water in order to maintain production levels (depending on the significance of the price drop and the level of salinity damage in question).

Given the current winegrape market conditions for the South Australian Lower Murray, the issue of additional leaching effecting grape returns may not be much of a concern as it would be more generally (WFA, 2006). Hence, this relationship has been left out of the model, even though it may be an important factor when interpreting the results for winegrapes.

2. The model currently assumes that there is an unlimited amount of temporary water available on the market, and if an irrigator needs to purchase any of this water, they can do so at the market price for any given year. This assumption may not reflect what actually occurs in the market place, as increasing demand will usually lead to an increase in price. This price may eventually reach a level where the marginal benefits of applying additional water to leach salt from the root-zone will be less than the cost associated with additional water purchases (at high temporary water prices).

3. Without access to detailed water allocation data by each LWMPA, the model currently assumes that each LWMPA is allocated enough water to meet their *average* minimum net crop requirements. That is, the LWMPA water allocation is equal to the average crop evapotranspiration requirement, minus average growing season rainfall, divided by the irrigation efficiency, multiplied by the total area of each crop and irrigation practice.

I.e.

$$\text{Water Allocation} = \sum_{j,h} [(\text{Average\_ET} - \text{Average\_RAIN}) / Ie_h] * \text{Current\_Area}_{ljzh}$$

This will mean that each LWMPA will potentially have excess water in relatively wet years, and a deficit of water in the relatively dry years.

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