Potential impact of saline irrigation water on the grape industry in the Murray Darling Basin

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Fiona Alexander and Anna Heaney

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Australian Bureau of Agricultural and Resource Economics
GPO Box 1563 Canberra 2601

Telephone +61 2 6272 2000 Facsimile +61 2 6272 2001
Internet www.abareconomics.com

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summary

Land clearing and the establishment of irrigation has facilitated the development of high value agriculture in the Murray Darling Basin, but this has also contributed to rising salinity in the basin's waterways. Salinity is expected to continue to rise, with the Murray Darling Basin salinity audit suggesting that salt mobilisation in the basin could double from 5 million tonnes a year in 1998 to 10 million tonnes in 2100 (MDBMC 1999). The grape industry is reliant on water, and the future of the Australian viticultural industry could be affected by the rising salinity of irrigation water.

ABARE was commissioned by the GWRDC to assess the long run implications of increasingly saline irrigation supplies in the Murray Darling Basin's main rivers on the viticulture industry. Specifically, the project was designed to:

- highlight the regions where research and development into managing irrigation with saline water may be a higher priority in the future;
- highlight the regions where catchment or farm level infrastructure may be needed to manage or avoid the yield losses associated with saline irrigation water; and
- provide information to help ensure appropriate consideration is given to protecting viticultural assets when developing catchment based salinity management plans in the Murray Darling Basin.

Grapes are a crop that is moderately sensitive to salinity. Saline irrigation can depress plant growth through two effects. A droughting 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 Salinity and Landuse Simulation Analysis (SALSA) model developed at ABARE was used to simulate the impact of rising stream salinity on grape yield and producer returns in the basin over a fifty year period. The model combines simulation and optimisation techniques to represent the relationship between surface and ground water processes and the relationship between these processes and dryland and instream salinity. The impact of salinity in soil and water resources on agricultural

productivity is simulated by the model. Grape production for the larger grape growing areas that draw surface water from the Murray or its tributaries were explicitly incorporated into the SALSA model. The baseline simulation of the model is one of 'business as usual' in grape production. That is, irrigation management practices and proportion of plantings that are salt tolerant are assumed unchanged, and area is assumed only to change in response to salinity.

Importantly, results from the model reveal that grape yields, and thus producer returns, are only marginally affected by rising stream salinity. Therefore, future Australian grape production is likely to be relatively unaffected by rising stream salinity trends. Some regions will, however, be affected to a greater extent than others and, although these effects remain relatively small, options exist for both the grape industry and the wider community to mitigate these future impacts.

Results from the model illustrate that stream salinity and increases in salt concentration are generally larger the further along the river system, reflecting higher underlying ground water salinities. Salt concentrations, and thus grape yield losses, are projected to be highest in the Victorian Mallee and South Australian Riverland horticultural regions where grape production is a major irrigated activity. At the end of the fifty year period yield losses are negligible in the Goulburn Valley and the New South Wales Murray catchment, while rising to almost 3 per cent at Lock 2–Morgan. The reductions in yield impose a cost of lost production revenue for modeled grape growers in the basin of $20.4 million (net present value) over the fifty year period. This represents the difference in economic returns between those received by producers if the current situation were to continue compared with those received under the scenario of rising stream salinity. This is small compared with the current annual returns from grape production of more than $1.5 billion (gross value of production) in 2000-01 (Australian Bureau of Statistics 2001). The greatest impacts are felt in the South Australian Riverland where total losses reach almost $13 million, compared with $5.9 million for Murray Sunraysia and $0.8 million for the Murrumbidgee.

These results may underestimate future salinity impacts as the model is based on average yearly stream salinity, while stream salinity can vary over time. Results from this study indicate that monthly salinity is likely to be higher in the months when vines are most susceptible to damage, which suggests that salt impacts are likely to be greater than those estimated. However, the range of observed and projected salinity levels are

still well below levels that would result in significant yield losses. Hence, the impact on grower returns is still likely to be small.

These results highlight the regions where research into and implementation of options to mitigate the impact of saline irrigation water should be of highest priority. Grape growers can take steps on farm to reduce the effects of salinity during application of saline irrigation by improving the efficiency of their irrigation system, minimising salt buildup within the rootzone and reducing the toxic salt buildup within the plant. Using salt tolerant rootstock and locating new plantings in areas where soils are more lightly textured and where irrigation water is less saline are other options. A range of measures can also be undertaken elsewhere in the basin both on- and off-farm to reduce the salinity of surface water by reducing accessions to saline ground water systems. On-farm irrigation efficiency could be improved through improved management, land forming and adoption of more efficient irrigation practices, such as a drip system. Off-farm irrigation management could be improved by replacing open channels with pipes to lower channel leakage in irrigation areas. Subsurface drains in irrigation areas and ground water pumping can also reduce accession to ground water aquifers and high water tables. Government initiatives, such as the Land and Water Management Plans, the Salinity and Drainage Strategy, the South Australian River Murray Salinity Strategy and the new National Action Plan for Salinity and Water Quality act to encourage investment in these measures.

introduction

Salinity and water quality problems are widely recognised as a priority issue for natural resource management programs and policy. The National Land and Water Resources Audit and the Murray Darling Basin Commission Salinity Audit both highlight the alarming increase in salt loads in Australia's rivers and streams over recent decades. These trends are expected to continue, with the Murray Darling Basin salinity audit (MDBMC 1999) suggesting that salt mobilisation in the basin could double from 5 million tonnes a year in 1998 to 10 million tonnes in 2100.

Production of wine, dried and table grapes in Australia was valued at more than $1.5 billion in 2000-01, with wine grapes representing most of this ($1.2 billion GVP) (Australian Bureau of Statistics 2001). Since the mid 1980s, the Australian wine industry has expanded rapidly, with the number of wine producers and the amount of wine produced more than doubling. Exports have increased eightfold in volume since 1990 to 417 million litres in 2001-02, and are valued at over $2 billion. Furthermore, wine exports are the fifth highest valued agricultural export behind wheat, beef, wool and dairy products, and the fastest growing export commodity (Spencer 2002). The viticultural industry is heavily reliant on surface river flows for irrigation water in a number of areas in the Murray Darling Basin. As salinity levels in waterways rise toward critical agronomic thresholds for grape production, the future of the Australian viticultural industry may be affected.

ABARE was commissioned by the GWRDC to assess the long run implications of increasingly saline irrigation supplies in the Murray Darling Basin's main rivers on the viticultural industry in the basin and long term industry expansion. Specifically, the project was designed to:

- highlight the regions where research and development into managing irrigation with saline water may be a higher priority in the future;
- highlight the regions where catchment or farm level infrastructure may be needed to manage or avoid the yield losses associated with saline irrigation water; and
- provide information to help ensure appropriate consideration is given to protecting viticultural assets when developing catchment based salinity management plans in the Murray Darling Basin.

In response to the salinity problem, the Commonwealth and state governments have agreed to design and implement a National Action Plan to deliver improved salinity and water quality outcomes. A feature of the plan is likely to be investment in defensive or remedial actions where high value assets, such as irrigated grape production, are threatened by salinity or deteriorating water quality. This report focuses on areas where remedial actions might work.

saline irrigation water in the basin and grape production

The historical salt load and predicted increase in salt concentration in the Murray River is the result of two main processes. First, a substantial proportion of the salt load in the Murray River comes from saline drainage water and the discharge of saline ground water flows from irrigation. The extent to which irrigation affects water quality depends on several factors. Irrigation and crop transpiration concentrate salt in the plant root zone that can re-enter the river system through drainage systems. More importantly, soils throughout most of the irrigation areas in the southern Murray Darling Basin are shallow. The deep percolation of irrigation water through the soil has led to a large increase in the rate of recharge into the ground water system. Increased ground water recharge has led to rising water tables and increased ground water discharge. Ground water discharge transports salt to the river by direct seepage or by surface discharge that eventually reaches the river system. The volume of salt transported to the river depends to a large extent on the salinity of the ground water. The salinity of ground water discharge in the Murray River and its tributaries is generally low in the upland catchments. Ground water salinity levels tend to increase moving downstream and reach levels approaching seawater in lowlying regions of South Australia. Consequently, the salt concentration of river flow generally increases as it moves downstream.

Second, the salt concentration of streams and rivers is increasing as a delayed effect of past vegetation clearing. As native vegetation was replaced with pastures and crops that use less of the available water, an increase in ground water recharge has, over time, led to an increase in ground water discharge. The length of the delay between vegetation clearance and increased ground water discharge can vary considerably — from a few years or decades to several hundred years. Consequently, the impacts of past clearing on ground water recharge are likely to continue well into the future. These impacts include the continued mobilisation of salt into the landscape and waterways and an increase in base flow (ground water discharged directly into streams and rivers). Predictions from the modeling work undertaken at ABARE indicate that while base flows in the Murray River are likely to increase by more than 10 per cent at Morgan over the next fifty years, this will be outweighed by an increase in the volume of salt mobilised leading to an increase in salt concentration of Murray River flows.

Tolerance to saline soil and water resources is crop dependent, with crop yield being adversely affected by salinity when the salinity threshold of the particular species is exceeded. Most plants respond to the salinity of the soil solution that bathes their roots rather than the salinity of the applied water — except where the foliage is irrigated directly, as occurs with overhead sprinkler irrigation. As salt is concentrated in the root zone, soil salinity levels can be

considerably higher than in applied irrigation water. In light, sandy soils, soil salinity will tend to remain near the level of the water applied. In heavy clay soils, soil salinity can be more than five times higher than the level of salt in applied irrigation water (GHD 1999).

Box 1: Salinity measurement

Salinity is measured by the amount of dissolved salts in either soil or water. The most common method of reporting salinity of water is in terms of its electrical conductivity (ECw), measured as microSiemens per centimetre (S/cm) at 25°C. The electrical conductivity of soil salinity (ECe) is also commonly expressed as deciSiemens per metre (dS/m). The weight of salt in irrigation water in milligram per litre (mg/L) is equal to approximately the ECw multiplied by 0.6 (GHD 1999).

Several studies have been undertaken in Australia and overseas investigating the yield response of grapevines to increasing salinity (see, for example, Prior, Grieve and Cullis 1992; Walker, Blackmore and Clingeleffer 1996; Cass, Walker and Fitzpatrick 1996). Grape vines are moderately sensitive to salt, and grow best when salinity of irrigation water is below 800 EC (see box 1 for a description of salinity measurement) (Elliot unpublished). Studies have indicated that there is no yield decrease for grape vines when soil salinity is below 1500 EC. Yield is reduced by 10 per cent when soil salinity is 2500 EC, 25 per cent at a soil salinity of 4100 EC and 50 per cent at a soil salinity of 6700 EC (Doorenbos and Kassam 1979; GHD 1999).

Saline water can cause considerable yield loss before symptoms of salinity damage become obvious. Saline irrigation can have two effects that depress plant growth (Stevens 1996; Stevens, R., Research Scientist, Irrigation and Salinity, SARDI/PIRSA, personal communication, March 2003):

- a droughting, or osmotic, effect, which occurs because the buildup of salts within the soil make it the harder for the grapevine to extract water for plant growth.
- a toxic effect, which is caused by the chloride and sodium ions in water entering and accumulating in the plant to concentrations which are poisonous to plant metabolism. Entry is much easier through the leaves than the roots, and yield loss from foliar injury following overhead irrigation tends to be much worse than losses following surface irrigation. Stevens (unpublished data) demonstrated that the leaf chloride concentration in vines irrigated with overhead sprinklers was twice that for vines irrigated by drip irrigation (GHD 1999).

Following the application of saline irrigation (that is, when saline irrigation is replaced by nonsaline irrigation) plant growth continues to be depressed. The reasons for this depression of growth during recovery are not understood — growth depression persists for some years after removal of soil salts and after concentration of salts within the plant fall to levels that are nontoxic (Stevens, R., personal communication, March 2003).

The impact of salinity on grape yield depends on the salt content of the irrigation water, salt tolerance of the variety/rootstock (table 1), climatic conditions, soil type and water management. Salt sensitivity also changes considerably during the development of a plant. Most crops are relatively salt sensitive to saline irrigation in the early stages of development but generally become increasingly tolerant as growth proceeds.

With grape crops there may also be a difference in sensitivity within a season at varying stages of development. The critical stage for Australian grape production is between November and January. Research has been undertaken at the Loxton Centre to investigate the effects of saline drip irrigation treatments (with a salinity of 3500 EC) over six years on yields of mature Colombard vines on Ramsey rootstock. The cumulative performance of the vines over this time period was compared with vines irrigated for the entire season with river water (440 EC). The results indicated that yield loss was greatest (7 per cent lower) when vines were irrigated with saline water between flowering and veraison, from early November to early January. When irrigated between veraison and harvest, between early January and late March, yields were only reduced by 3 per cent. There was no decline in yields when vines were irrigated with saline water between bud burst and flowering, mid-September to early November, or between harvest and leaf fall, from late March to early May (Lantzke and Calder 1999).

1 Chloride tolerance limits for some grape varieties / rootstocks by root uptake

Grape variety/ rootstock	Chloride concentration
	Mg/L
Ramsey, 1623-3 – rootstock	950
Dog Ridge – rootstock	700
Sultana	600
Cardinal	235

Source: Stevens (1996).

methodology

Model specification

The Salinity and Landuse Simulation Analysis (SALSA) modeling framework was developed at ABARE, in cooperation with the Murray Darling Basin Commission (MDBC) and CSIRO Land and Water Division. It incorporates the relationships between land use, vegetation cover, surface and ground water hydrology and agricultural returns. The basin scale model consists of a network of land management units linked through overland and ground water flows. The spatial coverage of the SALSA model includes the predominantly dryland regions of the Murray Darling Basin spanning from the Condamine–Culgoa catchment in southern Queensland clockwise around the eastern edge of the basin to the Avoca catchment in Victoria. The catchments considered in this study are labeled in map 1. Catchments within the Murray Darling Basin shown in map 1 that are shaded in grey are not considered to contribute surface or ground water flows to either the Murray or Darling Rivers and are not included in the analysis.

Irrigation areas within each of these catchments are represented. The SALSA model also includes the Victorian Mallee and South Australian Riverland irrigation areas immediately adjacent to the Murray River that extend from Nyah downstream to Morgan[1]. To allow for a range of hydrological response times, reflective of the distance of the irrigation development from the river valley, the land management units in the Victorian Mallee and South Australian Riverland irrigation areas were split into three bands — within 2.5 kilometres from the Murray River, between 2.5 and 5 kilometres from the river and between 5 and 10 kilometres from the river. A similar methodology was used in the other irrigation regions although response times were assumed to be longer in the larger regions.

Within the modeling framework, economic models of land use are integrated with a representation of hydrological processes in each land management unit. The hydrological component incorporates the relationships between irrigation, rainfall, evapotranspiration and surface water runoff, the effect of land use on ground water recharge and discharge rates, and the processes governing salt accumulation in streams and soil.

The salinity of catchment outflows reflects a combination of saline discharges from ground water and runoff into the principal river system and is calibrated against gauge data for surface water flows and salt loads (Jolly et al. 1997). Projected salt loads were obtained from

[1] All data presented for the Victorian Mallee and South Australian Riverland refer to irrigation areas within 10 kilometres of the Murray River. These areas do contain some dryland agriculture. Within the larger Mallee regions, water tables outside irrigation areas are unlikely to mobilise ground or surface water flows to the Murray River.

1 Catchments in the Murray Darling Basin covered by the SALSA model



the national salinity audit (MDBMC 1999), Barnett et al. (2000) and Queensland Department of Natural Resources (QDNR 2001). To derive the impact of saline irrigation water and soil salinity in the root zone of agricultural activities, threshold and yield reduction rates (bent stick estimates) are utilised. This is discussed further in a following section.

In the agroeconomic component of the model, land use is allocated to maximise economic return, or production revenue, from the use of agricultural land and irrigation water. Each land management unit is managed independently to maximise returns given the level of salinity of available land and water resources, subject to any land use constraints. Incorporated in this component is the relationship between salinity and yield loss for each agricultural activity.

The cost of salinity is measured as the reduction in economic returns to agricultural activities from those that are currently earned. Future growth of the industry was not incorporated into the model because of the difficulty with making assumptions about grape area fifty years into the future. For simplicity, all grape area was assumed to be bearing because nonbearing represents a relatively small proportion of total area of grapes (11 per cent in 2001-02 — Australian Bureau of Statistics 2002a). A real discount rate of 3 per cent was used for all calculations. The modeling approach is described in more detail in appendix A.

Incorporating grape production into the SALSA model

Grape production for the major grape growing regions was explicitly incorporated into the SALSA model as a horticultural land use. The regions included were those drawing surface water supplies from the Murray River, and the larger regions drawing water from tributary rivers, such as Mudgee. Grape growing areas supplied by ground water or surface water runoff were not included. For simplicity, smaller areas and those positioned in reaches where the river water was not going to reach potentially damaging levels to the grape vines were also not included. The areas modeled include:

- Mudgee
- Cowra
- Murrumbidgee
- New South Wales Murray catchment
- Goulburn Valley
- Swan Hill
- Murray–Sunraysia — New South Wales and Victorian growers from the Darling to the Murrumbidgee junction
- Along the Darling River between Menindee and the Murray junction
- South Australian Riverland.

These areas represent the majority of grape producing area in the basin. The regions that were not modeled lie principally in the Victorian section of the basin. The Pyrenees, for example, was not modeled because this area is irrigated with runoff. Most of the area in the Loddon catchment is irrigated with bore or dam water. Growers in Heathcote extract water from channel supplies but this area is relatively small in size. Salinity concerns in these areas were reported to be minimal except for some concerns with saline bore water.

Goulburn Valley is the principal region in the Goulburn–Broken catchment that extracts water from tributary rivers that are included in the SALSA model. Grape growers in other parts of this catchment, such as the Strathbogie Ranges, are supplied irrigation water from runoff. In the Ovens–Kiewa catchment grape growers in the Alpine Valley are irrigated mainly by bores and dam water, while the King Valley is irrigated with water from the King River, which is not explicitly included in the model. The other main grape growing region in the Ovens–Kiewa catchment, Rutherglen, will not be impacted by salinity, as salt loads in this part of the Murray River are not forecast to increase significantly.

In all of the nonmodeled regions in Victoria average water use was reported to be low, generally less than 1 megalitre per hectare, because of the level of rainfall in these areas and the cooler climate. Drip irrigation was the principal application method used and nonirrigated grapes were also grown in these areas. Grape areas in the Queensland component of the basin were not modeled because they represent a small proportion of national grape area and the level of salinity in these waterways are not anticipated to reach levels that will damage grape production.

Agronomic data

To construct the agroeconomic data set, digitised boundaries for the catchment and subcatchment units are utilised together with ABS census data and geo-coded ABARE farm survey data. Subcatchment areas are aligned with Statistical Local Areas (SLAs) and ABS census data are used to allocate the proportion of land in agriculture and non-farm use. It is assumed that land use outside of agriculture remains unchanged over the analysis period. Information for these regions was collected on grape area, existing salinity problems, irrigation practices and land value through communication with key industry contacts (see appendix B) and existing data sources. The economic returns to grapes are capitalised in the value of land and fixed improvements, so information was collected on the value of a hectare of established grapes with an irrigation system in place.

Data on area and irrigation application method in Sunraysia was obtained from SunRISE 21.[2] The survey data are based on aerial photography taken in February 2000 and the 2001 crop database. Where there were no records for 2001 (because there were no changes or updates notified) then the 1997 data weres used and cross referenced against the aerial photography.

The proportion of grapes on salt tolerant rootstock for this region was also based on SunRISE 21 information (SunRISE 1999), as was the area of grapes from Menindee to the Murray junction. The area of grape plantings in the Avoca catchment around Swan Hill and the irrigation application methods for this area were obtained from Australian Bureau of Statistics (2002a,b) survey data.

The area of grapes along the reaches in the South Australian Riverland was obtained from the Phylloxera and Grape Industry Board of South Australia and supplemented with data from the Australian Bureau of Statistics (2002). All growers in South Australia with vineyards of 0.5 hectares or more are required to register with the board under the *Phylloxera and Grape Industry Act 1995*, and information is collected by the board from all registered growers. Around 500 hectares of grapes in South Australia lie past Morgan and were not included in the model. The proportion of plantings on salt tolerant rootstock was obtained from GHD (1999) and the application methods for the South Australian Riverland were taken from Kaine and Bewsell (2002). Average water use in the regions was based on communication with industry representatives combined with information from the New South Wales Department of Agriculture (Wilson 1995) for the South Australian Riverland, Sunraysia and Swan Hill.

Yield response functions for grapes

The costs to irrigated agriculture and horticulture resulting from yield reductions caused by increased river salinity are modeled explicitly. The impact of saline water on the productivity of plants is assumed to occur from the plants extraction of saline water from the soil. The electroconductivity of the soil EC (ECe) reflects the concentration of salt in the soil

[2] Information on application method was not collected for a small proportion of the grape area in Sunraysia and some of the area was irrigated with more than one method. The proportion of area irrigated with each application method for this area was assumed to be the same as for Sunraysia as a whole, except for Culleraine that is predominantly drip irrigation.

water and reduces the level of output per unit of land input (land yield) and per unit of water input (water yield).

Yield losses as a result of increasing areas of high water tables are also incorporated into the SALSA model. The area of land that is affected by high water tables is determined by discharges into the root zone of the soil and the evapotranspiration from saturated soils. However, the impact of high water tables on grape production was not incorporated into the scenario presented here, as they were not reported as a significant existing problem in the regions considered (table 2).

For most crops, including grapes, the relationship between relative yield and salinity is sigmoidal in shape (Maas 1990). Maas and Hoffman proposed the response curve could be represented as two linear lines, one a tolerance plateau with a slope of zero representing the threshold ECe below which there is no yield decline, and the other a concentration dependent line in which the slope indicates the yield reduction per unit increase in soil salinity. The slope has been increased to account for the toxic effects of the cumulative uptake of salt over time. Three yield functions are considered (figures A–C). These yield response functions were tailored to each grape production area according to salt tolerance of rootstock, irrigation method and soil type as specified in GHD (1999). Soil physical properties

2 Information collected for the river reaches modeled [a]

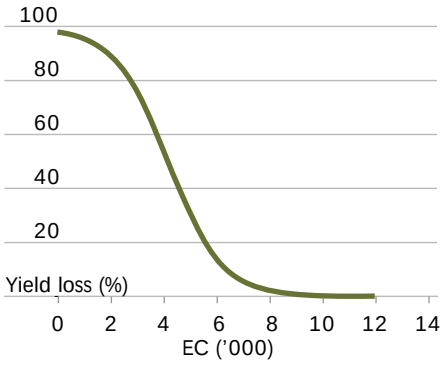
	Unit	Macquarie-Bogan	Lachlan	Murrumbidgee	NSW Murray
Area modeled		Mudgee GI	Cowra GI	Riverina MIA	Murray
Water source		60% Cudgegong River, 40% bores	78% Lachlan or Belubula rivers, 2% dams, 20% bores	Principally Murrumbidgee	River Murray, Billabong Creek, Channels
Area of grapes	ha	4 500	1 652	15 309 [c]	850
Salt tolerant proportion	%	Minimal	0	13	Minimal
Average water use	ML/ha	1.5	1	5	3.5
Irrigation application methods		100% drip	All drip [b]	42% drip, 33% furrow, 24% flood, 1% overhead	95% drip 5% flood
Affected by high water tables/ dryland salinity?		Mudgee has patches that are affected but not major problem	No	No major problems but have saline watertable so concern if watertable rises	No problems with high water tables. Water low salinity levels [d]
Average land value	$/ha	45 000–60 000	40 000	28 000	45 000

Continued ➪

determined the conversion of ECw to ECe based on leaching fractions.

Maas's yield–ECe relationship for grapes was used in the model to quantify the annual yield losses to grapes from saline irrigation water. This function provides a reasonable approximation of yield damage that has been demonstrated in Australian studies (GHD 1999). While saline irrigation during sensitive stages of growth may have an impact on plant development there are insufficient data to determine the consequences for average annual salt impacts. Use of an average annual yield impact was proposed because the model runs on a yearly timestep using average annual stream

A Yield loss function for grapes with non-tolerant rootstock

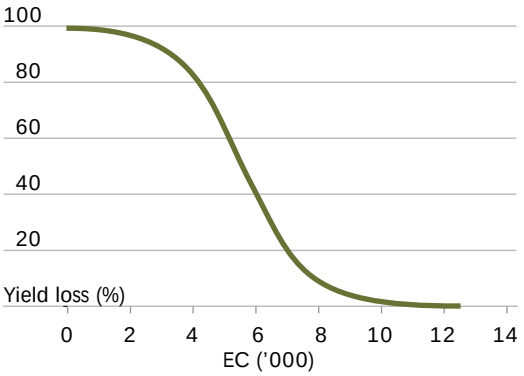


2 Information collected for the river reaches modeled a

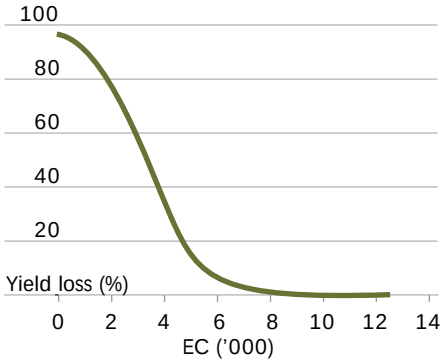
	Unit	Darling	Goulburn Broken	Avoca	Sunraysia – Victoria and NSW	
Area modeled		Menindee to Murray Junction	Goulburn GI	Swan Hill	Boundary Bend	Robinvale
Water source		Darling	Mostly Goulburn River, 5–10% Murray River	River Murray	River Murray	River Murray
Area of grapes	ha	1 500	1 200	2 894	182	4 008
Salt tolerant proportion	%	60	60	10	20-30	20-30
Average water use	ML/ha	7	0.8	8-9	8.26	9
Irrigation application methods		25% drip, 25% micro sprinkler, 50% overhead	Mostly drip	45% drip/ micro, 36% spray, 18% flood	28% drip, 7% furrow, 3% low level, 62% overhead	12% drip, 34% furrow, 7% low level, 1% micro sprinkler, 25% overhead
Affected by high water tables/ dryland salinity?		Potential of some salinity problems due to irrigation. Water supply can be saline	No problems with salinity or high water tables	South part Swan Hill fairly saline soils so flush out soil and put in tile drains	No problems with salinity or high water tables	Not major problem as grapes tend to be planted where not affected
Average land value	$/ha	30 000	40 000	25 000	28 000	30 000

a Not all this information was used in the model. **b** Mostly with moisture sensing equipment such as gypsum blocks or Enviroscans. **c** Potentially at lower end. **d** Vineyards tend to be on high locations to avoid frost. Watertable problems existed five years ago but are no longer a problem because of measures introduced to address this.

B Yield loss function for grapes with salt tolerant rootstock



C Yield loss function for grapes irrigated with overhead sprinklers



2 Information collected for the river reaches modeled [a] *Continued*

		Sunraysia–Victoria and New South Wales		
Area modeled	**Unit**	**Happy Valley**	**Colignan**	**Mildura [b]**
Water source		River Murray	River Murray	River Murray
Area of grapes	ha	280	3 773	18 059
Salt tolerant proportion	%	20–30	20–30	20–30
Average water use	ML/ha	7.9	8.2	9
Irrigation application methods		38% drip, 6% furrow, 7% low level, 49% overhead	29% drip, 10% furrow, 7% low level, 54% overhead	16% drip, 38% furrow, 16% low level, 1% micro sprinkler, 29% overhead
Effected by high water tables/ dryland salinity?		Not major problem as grapes tend to be planted where not affected	Not major problem as grapes tend to be planted where not affected	Not major problem as grapes tend to be planted where not affected
Average land value	$/ha	31 000	31 000	33 000

Continued ➪

salinity levels. The incorporation of monthly data to estimate seasonal impacts of saline irrigation on grape yield is not possible using the SALSA model. Another limitation is that variance in soil salinity is not accounted for, as the parameters assumed in the model are averages for within a river reach and over a year. As soil salinity is highly variable within a reach there may be some salinity impacts on yield that have not been picked up by the model (Stevens, R., SARDI-PIRSA, personal communication, February 2003).

2 Information collected for the river reaches modeled a *Continued*

Area modeled	Unit	South Australian Riverland				
		Border–Lock 5	**Lock 4–Lock 5**	**Lock 3–Lock 4**	**Lock 2–Lock 3**	**Morgan–Lock 2**
Water source		River Murray	River Murray	River Murray	River Murray	River Murray
Area of grapes	ha	3 445	4 849	6 690	2 862	2 646
Salt tolerant proportion	%	40	60	45	48	45
Average water use	ML/ha	8	8	8	8	8
Irrigation application methods		8% furrow, 37% overhead, 5% undervine sprinkler, 36% micro sprinkler, 14% drip	8% furrow, 37% overhead, 5% undervine sprinkler, 36% micro sprinkler, 14% drip	8% furrow, 37% overhead, 5% undervine sprinkler, 36% micro sprinkler, 14% drip	8% furrow, 37% overhead, 5% undervine sprinkler, 36% micro sprinkler, 14% drip	8% furrow, 37% overhead, 5% undervine sprinkler, 36% micro sprinkler, 14% drip
Effected by high water tables/ dryland salinity?		No	No	No. Most deep ground water, but rising ground water mounds. However protected by drainage system	Not major problem	Not major problem
Average land value	$/ha	33 000	33 000	33 000	33 000	33 000

a Not all this information was used in the model. **b** Includes 640 hectares at Culleraine.

results

Modeled impacts of saline irrigation water

The baseline simulation of the model is one of 'business as usual' in grape production. That is, irrigation management practices and proportion of plantings that are salt tolerant are assumed unchanged, and area is assumed only to change in response to salinity. In the simulation period, the impact of land cover on surface water flows, ground water flow systems and instream salinity was estimated.

Salt concentration in streams and rivers is predicted to increase over the simulation period (table 3). Increases in salt concentration are generally larger in the lower reaches of the Murray River reflecting higher underlying ground water salinities. Increases in salt concentration in Victorian tributary catchments such as the Ovens–Kiewa and Goulburn–Broken are small as these regions have relatively fresh ground water and mobilise smaller volumes of salt to the river system. Importantly, salt concentration is highest in the Victorian Mallee and South Australian Riverland horticultural regions where grape production is a major irrigated activity.

The corresponding impact of the rise in stream salinity on grape production is shown in table 4. Importantly, results from the model reveal that grape yields, and thus producer returns, are only marginally affected by rising stream salinity. This highlights that the future of the grape industry, as a whole, is likely to be relatively unaffected by rising stream salinity trends. Some regions will be affected to a greater extent than others and these results may potentially underestimate salinity impacts, as discussed below. However, even where impacts are felt

3 Salt concentrations along the Murray Darling system

Catchment	Salt concentration		
	Year 0	Year 50	Increase
	mg/L	mg/L	%
Macquarie–Bogan **a**	160	220	38
Lachlan **a**	117	151	28
Murrumbidgee **a**	111	130	17
NSW Murray	89	95	7
Ovens–Kiewa **b**	34	35	3
Goulburn–Broken **a**	76	87	15
Campaspe **b**	64	69	8
Loddon	150	156	4
Avoca **b**	164	177	8
Sunraysia c			
Boundary Bend	162	201	24
Robinvale	172	210	22
Happy Valley	178	225	26
Colignan	185	232	25
Mildura	257	301	17
Lindsay	235	280	19
South Australian Riverland c			
Border–Lock 5	242	288	19
Lock 5–Lock 4	255	309	21
Lock 4–Lock 3	277	333	20
Lock 3–Lock 2	292	353	21
Lock 2–Morgan	323	390	21

a Measured in the tributary above the grape producing areas. **b** Measured at the confluence of the Murray. **c** Measured in the Murray River below the grape producing areas.

there are options for both the grape industry and the wider community to mitigate these future impacts.

At the end of the fifty year period, yield losses are negligible in the Goulburn Valley and the New South Wales Murray catchment, rising to almost 3 per cent at Lock 2–Morgan. The reduction in grape yield becomes greater the further down the river system, reflecting higher stream salinities, and larger increases in stream salinity.

Yield loss is also influenced by the irrigation application method and proportion of the crop that is salt tolerant. The yield loss in Mildura, for instance, is lower than that for the upstream reach of Colignan because less of the area is irrigated with an overhead irrigation system. The proportion of grapes that are salt tolerant also varies across the reaches in South Australia.

The reductions in yield impose a cost on grape producers by reducing economic returns from grape production. The total estimated reduction in production revenue for grape growers in the basin is $20.4 million (in net present value [NPV] terms) over the fifty year period. This represents the difference in economic returns between those received by producers if the

4 Impacts of saline irrigation water on the grape industry in the Murray Darling Basin

	Total area a	Cost/ha	Total cost	Yield loss in 50th year
	ha	$'000 NPV	$'000 NPV	%
Macquarie–Bogan–Mudgee	2 700	0.03	74	0.1
Lachlan–Cowra	1 289	0.02	25	0.1
Murrumbidgee	15 309	0.05	833	0.1
NSW Murray	850	0	0	0
Menindee to the Murray junction	1 500	0.34	514	1.4
Goulburn Valley	1 200	0	0	0
Avoca–Swan Hill	2 894	0.01	38	0.1
Total of above	25 742		1 484	
Sunraysia				
Boundary Bend	182	0.04	7	0.1
Robinvale	4 008	0.14	572	0.5
Happy Valley	280	0.26	74	0.9
Colignan	3 773	0.40	1 518	1.2
Mildura and Culleraine	18 059	0.21	3 703	0.6
Total Sunraysia	26 302		5 873	
South Australian Riverland				
Border–Lock 5	3 445	0.55	1 881	1.6
Lock 5–Lock 4	4 849	0.32	1 552	1.1
Lock 4–Lock 3	6 690	0.70	4 698	2.0
Lock 3–Lock 2	2 862	0.82	2 343	2.2
Lock 2–Morgan	2 646	0.95	2 524	2.7
Total Riverland	20 492		12 998	
Total			20 355	

a Area irrigated using surface water.

current situation were to continue compared with those received under the scenario of rising stream salinity. This is small compared with the current annual returns from grape production of more than $1.5 billion (GVP) in 2000-01 (Australian Bureau of Statistics 2001). The greatest impacts are felt in the South Australian Riverland where total losses reach almost $13 million, compared with $5.9 million for Murray Sunraysia and $0.8 million for the Murrumbidgee. These are the largest grape producing regions in the basin, and Sunraysia and the Riverland have the highest salt concentrations in irrigation water.

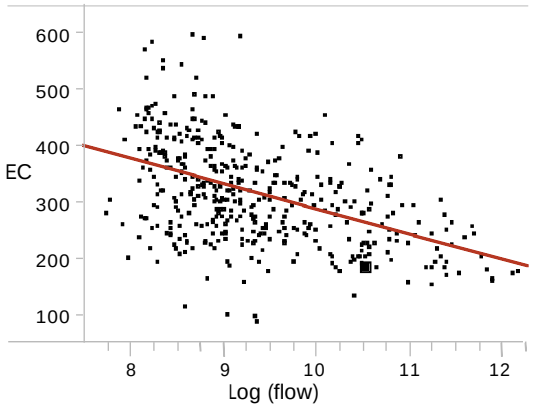
Variability in stream salinity and other factors

Impacts on yields and producer returns may be greater than estimated in the model because of the variance in the salinity of the soil and irrigation water. As discussed previously, average annual soil salinity for each reach is used in the model. Therefore, a situation may exist where it is estimated that there will be no grape yield reductions in a reach, but, in reality, some plantings in the area may be affected.

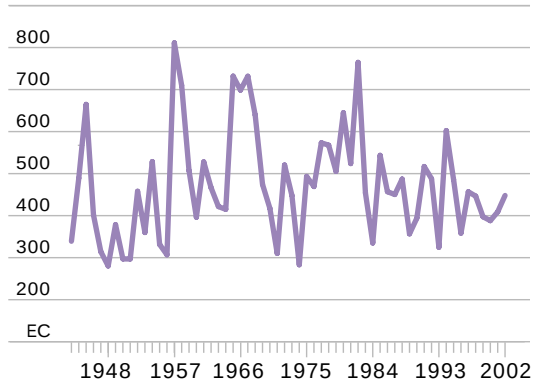
The model also estimates average yearly stream salinity over the fifty year time period. Stream salinity, however, can vary throughout the year as well as across years. As this variability may result in yield losses that are greater than would be predicted on the basis of average salinity, because the yield loss relationship is nonlinear.

Stream salinity is inversely proportional to its flow. As saline inflows are relatively constant, this implies that river salinity depends on the dilution of these inflows by tributary flows (GHD 1999). This relationship can be seen in figure D in which salinity is plotted against river flows above Mildura. The regression line, which expresses salinity as a linear function of the natural logarithm of flows, accounts for approximately 21 per cent of the variation in EC levels. Clearly, river salinity is affected by natural factors as well as changes in supply system management, irrigation management and government policies. Variability in salinity at Morgan, for example, is moderated by river operations (dilution flows), guaranteed flow entitlements to South Australia and salt interception schemes (MDBMC 1999).

D Salinity and river flows at Mildura

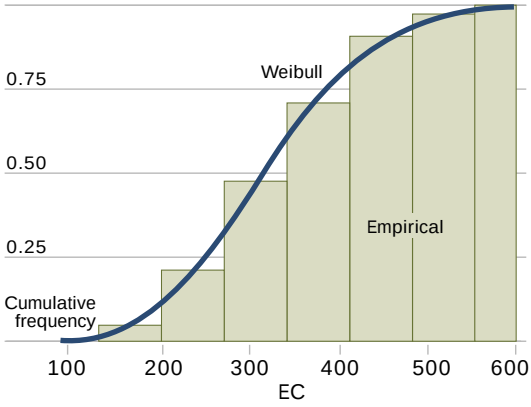


E Mean annual EC at Berri, South Australia



Data were collected on the monthly and annual variation in stream salinity (for different time periods because of the time span of the data available and their source) to illustrate the risk that this may pose to the grape industry. As is evident in figure E there is substantial variation in annual mean stream salinity (DWLBC 2003). The cumulative distributions of salinity during the peak irrigation season, November–February, are shown for Mildura and Berri in figure F and figure G respectively. While the mean of the distribution is considerably higher at Berri, the shapes of the two distributions are quite similar, with both yielding a good fit using a Weibull distribution.

F Cumulative distribution of EC at Mildura during the peak irrigation season

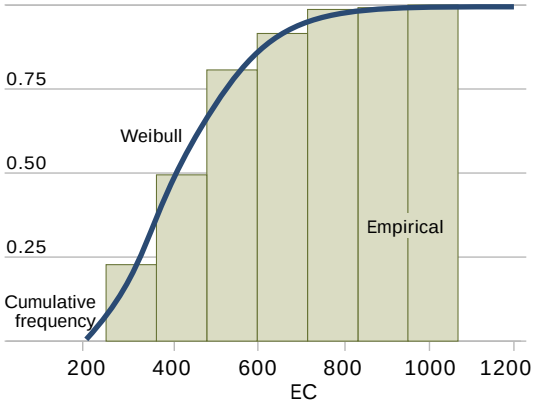


Above Mildura, there is about a 25 per cent chance that salinity levels will be in excess of 400 EC during the peak irrigation season, compared with an average of about 320 EC. There is about a 10 per cent chance that salinity levels will exceed 500 EC. Above Berri, there is about a 25 per cent chance that salinity levels will be in excess of 550 EC during the peak irrigation season, compared with an average of about 420 EC. There is about a 10 per cent chance that salinity levels will exceed 700 EC.

As yield losses due to salinity increase at an increasing rate, these higher EC levels will generate losses in excess of what would be predicted by an average salinity level. However, this impact was estimated to be small, due to the fact yield responses to salinity were small and approximately linear over the range of observed salinity levels. For example, the yield losses at Mildura based on average salinity levels was estimated to be 1.8 per cent. Based on the observed distribution of salinity levels, yield losses were estimated to average 1.9 per cent. However, this does not take into account the possibility that periodic use of more saline irrigation water could result in permanent longer term yield losses.

Producer returns may also be lowered because of the reduced marketability of the wine produced, even where producer yields are not impacted. ABARE projects that as Australia's wine industry continues to expand the reliance on demand from overseas markets will increase (Spencer 2002). The European Union views sodium content as evidence of illegal additions of sodium metabisulphite or of ion exchange processes and an EU– Australian bilateral agreement on wine requires wine to contain less than 394 ppm of sodium. Also, a limit of 60 ppm of free sodium, defined as the difference

G Cumulative distribution of EC at Berri during the peak irrigation season



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). There is the potential that Australian producers in the warmer climate regions with rapid evaporation in summer and saline soils and water could exceed 60 ppm sodium levels, especially when overhead sprinklers are used (Smith 2003). A 1997 survey of 1214 grape juices showed a mean concentration of sodium ion of 55 ppm with a peak reading of 145 ppm (735 ppm Chloride ion) in grape juice from the Padthaway region of South Australia (Smith 2003).

Impacts of climate change on water resources

The uncertainty associated with future trends in emissions and the level of global warming and other climatic changes that may occur in response to those trends mean that estimating the impacts on water resources, and hence grape production, is extremely difficult. Previous research undertaken at ABARE comparing global warming scenarios from the *Special Report on Emissions Scenarios* (SRES) suggests that precipitation is expected to decrease and evaporation to increase over much of the Murray Darling Basin in the present century (Beare and Heaney 2002). The consequent reduction in surface water flows over a relatively short time frame, coupled with the delayed effects of a reduction in ground water recharge, generates both positive and negative economic and environmental impacts. The projected impacts of the scenarios considered on river flows, water quality and economic returns in the Murray Darling Basin vary considerably. In the two scenarios considered, river flows were projected to decline by between 8 and 18 per cent over the Murray Darling Basin by 2100. At Morgan, river flows were predicted to be between 12 and 16 per cent lower by 2050, and between 20 and 30 per cent lower by 2100.

While a moderate increase in the rate of global warming was projected to result in a substantial decline in river flows and economic returns, this did not result in uniformly worse environmental outcomes. Reduced runoff was projected to lead to increased salinity in most tributary rivers. However, irrigated activity was projected to be affected significantly, as there was less surface water available. The reduction in irrigated activity did, however, lead to a reduction in recharge, resulting in an improvement in water quality in the mainstem of the Murray River. Salinity levels at Morgan were projected to rise by between 2 and 4 per cent by 2050, and projected to fall by between 6 and 10 per cent by 2100.

When the uncertainty inherent in the SRES scenarios is coupled with the unknowns associated with regional climate projections, changes in surface water yields, ground water systems and crop yields, any direct concern about the specific range of outcomes appears unwarranted. The fact that climate change can generate significant changes in both economic and environmental outcomes at a regional scale adds to the risk associated with longer term public and private investments. At the same time, it increases the value associated with the capacity to adapt to changes in the physical environment. Building the capacity to adapt may take the form of more flexible institutional arrangements to facilitate the efficient reallocation of resources, improved efficiency of water use by improving on farm and delivery infrastructure and investing in options such as increased conservation of ground water and other resources.

Measures to address rising stream salinity

Measures to mitigate the impact of saline irrigation water and rising water tables can be undertaken at the farm, local or state level. Grape growers can take steps on farm to reduce the impacts of saline irrigation water on their vines. Measures can also be undertaken both on and off farm to reduce the salinity level of the irrigation water within the basin. A range of measures have already been carried out within the context of Land and Water Management Plans, the Salinity and Drainage Strategy, South Australian River Murray Salinity Strategy and other government initiatives. Furthermore, the government has recently introduced the National Action Plan for Salinity and Water Quality to identify and fund high priority actions to address salinity and deteriorating water quality to sustain productive and profitable land and water uses as well as the natural environment.

Mitigation options for grape growers

On-farm measures that address the effects of salinity during application of saline irrigation can be summarised as (Lantzke and Calder 1999; R. Stevens, Research Scientist, Irrigation and Salinity, SARDI/PIRSA, personal communication, March 2003; Skewes unpublished, Stevens 1996):

1. operating the irrigation system so that:
    a. it is as efficient as possible
    b. it minimises salt buildup within the rootzone
    c. it avoids creating conditions which favor accumulation of toxic salts within the plant.
2. selecting grapevine rootstocks and locating new plantings on certain soils so that the accumulation of toxic salts within the plant are minimised.

The factors causing depression of growth during recovery from saline irrigation are not currently understood so on-farm measures that may address this are not known.

Improving operation of the irrigation system

1a. Operating the system efficiently

More efficient irrigation application can reduce the concentration of salt in the root zone because evaporation losses are reduced, and less water needs to be applied to the plant. More efficient water application can also help avoid temporary waterlogging. Research has indicated that temporary waterlogging reduces the ability of vines to exclude toxic salts (Stevens 1996).

The efficiency of the existing on-farm irrigation system can be improved by having good distribution uniformity — where each vine will receive the amount of water that the irrigator planned to deliver to it — as opposed to poor distribution uniformity. With poor distribution uniformity vines have to be overwatered to ensure that each vine receives at least the amount of water that an irrigator planned to deliver to it.

Irrigation scheduling and management of the system could also be improved to reduce water use. Furthermore, alternative irrigation methods can be adopted on-farm such as partial root zone drying (PRD) and regulated deficit irrigation (RDI), which may provide the additional benefit to grape growers of improved grape quality (Campbell-Clause and Fisher 1999; Dry 2000). Alternatively, a more efficient system, such as drip irrigation, could be installed. While being a more water efficient system, drip irrigation can also reduce the effects of salinity by maintaining a continuously moist soil around the plant roots and providing steady leaching of salt to the edge of the wetted zone. However, if soils are dry when it rains this salt may be washed back toward the root zone.

1b. Minimising salt buildup within the rootzone

Salt buildup within the rootzone can be minimised by the irrigator applying an amount of water that is sufficient to replace the water removed from the soil since the last irrigation by evapotranspiration plus an extra amount to leach the salts that were left behind when the water was extracted from the soil by evapotranspiration. Leaching will, however, contribute more salt to the ground water and displace the ground water toward waterways. Further, such a practice can only be successful if an irrigation system has good distribution uniformity and soil drainage rates are high enough to avoid waterlogging caused by the application of the extra water. How much leaching is required to maintain acceptable growth depends on the salt content of the irrigation water; the salt tolerance of the crop; climatic conditions; soil type; and water management (see Stevens 2002).

In the new Water Allocation Plan for the River Murray it is a requirement for irrigators in the South Australian Riverland to have an irrigation efficiency of 85 per cent as a condition of their licence. This condition applies immediately upon purchasing a licence, or by 2005 if they have an existing licence. Similar conditions may also be introduced in Victoria (Goodman, A., River Murray Catchment Water Management Board, personal communication, February 2003; Russell, O., Sunraysia Rural Water Authority, personal communication, February 2003). This requirement may limit the ability of irrigators in the South Australian Riverland, Sunraysia and Swan Hill to use leaching as a remedial action for salt impacts. Growers may also face a tradeoff between applying water for leaching and restricting water application in order to meet quality expectations of wineries (Spencer, D., Research Economist, ABARE, March 2003).

1c. Reducing toxic salt buildup within the plant

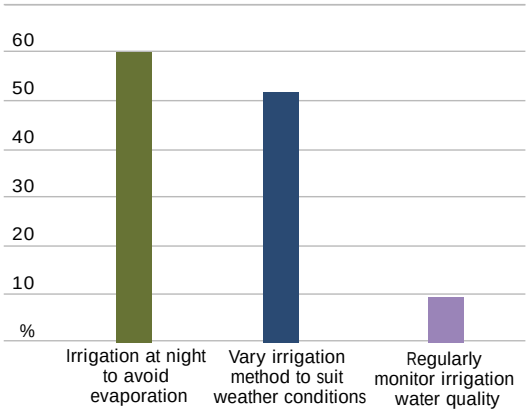
Plant root membranes are better able to keep salts out of the plant if they are well oxygenated and if soil solutions contain a reasonable amount of calcium, therefore waterlogging of the rootzone should be avoided. Further, farmers need to avoid causing soils to become sodic as this condition tends to lower soil calcium concentrations and to prevent soil drainage and favor waterlogging. Wetting of the leaves with saline water should be avoided.

Membranes of the leaves are less able to keep salts out than the root membranes so irrigation systems that wet the leaves should be avoided. Where such systems are used, it is possible to minimise any adverse impacts by irrigating at night with a sprinkler revolution rate greater than once per minute. Watering in the heat of the day and during high winds concentrates salts on the leaves through evaporation. Slow revolution sprinklers also encourage the build

up of salt due to longer drying periods. Sprinklers that produce fine droplets should also be avoided.

As illustrated in tables 5 and 6 and figure H there is potential for more efficient irrigation practices to be used on-farm in Sunraysia, Swan Hill and the South Australian Riverland. The impact of saline irrigation water on grape production could be reduced by using less overhead and more drip irrigation. Similarly greater use of recommended irrigation practices and technologies on farm, such as soil moisture monitoring and partial rootzone drying, could reduce the impacts of saline irrigation water.

H **Proportion of wine grape growers using selected irrigation management practices in the Riverland**



To reduce the salinity of available irrigation water where there are several sources of differing quality water available on a property the poorer quality water can be blended with better quality water to reduce or prevent salinity damage. This would be particularly beneficial in the months when saline irrigation water is most detrimental to grape growth, between early November and early January. Alternative water sources could include ground water and rain-

5 Proportion of surveyed grape area irrigated with selected systems

	Furrow	Sprays	Overhead sprinkler	Undervine sprinkler	Micro drip
	%	%	%	%	%
Murray–Sunraysia **a**	32	34	16	1	17
South Australian Riverland **b**	8	37	5	36	15
Murrumbidgee **c**	57	1		42	

a Data provided by SunRISE 21 Inc., New South Wales and Victorian growers Murrumbidgee to the Darling Junction.
b Kaine and Bewsell (2002) from 2001 survey. **c** Data provided by Murrumbidgee Horticulture Council Inc.

6 Proportion of grape growers using selected recommended practices / technologies

	Pressure irrigation only	PAN a	Soil moisture monitoring	Regulated deficit irrigation	Partial root zone drying	Alternate row irrigation
	%	%	%	%	%	%
Sunraysia, Vic.	45	14	34	13	5	25
Sunraysia, NSW	65	14	50	19	5	10
Robinvale	70	13	40	19	3	19
SA Riverland	85	12	42	39	5	5
Murrumbidgee	21	14	24	16	13	36

a PAN denotes using evaporation information to schedule irrigation.
Source: Kaine and Bewsell (2002) from 2001 survey.

fall runoff captured in farm dams. The ability to use ground water as a substitute for surface water depends on both the quality and quantity of ground water. Conjunctive use of surface and ground water is not applicable everywhere in the basin due to high salinity of ground water resources in some areas of the basin. In the Riverland, Sunraysia and Swan Hill irrigation areas ground water is highly saline so conjunctive water use is not an option. The feasibility of capturing water runoff in on farm dams for later use is also limited because average rainfall is low while evaporation is high and soils tend to be sandy.

Selecting rootstocks and soils for new plantings

To reduce the effects of saline irrigation water, new vines could be planted on salt tolerant rootstocks, in areas where soil types are more resistant to salt accumulation or where irrigation water is less saline. Salt tolerant rootstocks (such as Ramsey, 101-14, 1103 Paulsen and 140 Ruggeri) can also provide other benefits such as protection against nematodes and Phylloxera, and higher yields. Research undertaken at CSIRO Merbein has shown the use of salt tolerant rootstock reduced the concentration of chloride in the leaf by 60 per cent (Stevens 1996).

Yield losses to salinity can be reduced by locating new vine plantings on sites where the soils in the lower rootzone are more lightly textured. Average yield loss for mature own-rooted sultana grapevines from irrigation over five years with saline water (400–3500 EC) was shown to be 28 per cent on lighter textured soils compared with 55 per cent on heavier textured soils (Prior, Grieve and Cullis 1992; Prior et al. 1992).

Measures to reduce stream salinity and water tables in the Murray Darling Basin

The level of salinity in streams can be lowered by reducing accessions to saline ground water systems so that less saline ground water is discharged to the river. Drainage flows from irrigation areas to saline aquifers alongside rivers can be reduced through improved on- and off-farm irrigation management (Stevens 1996).

For instance, it may be possible for more water efficient practices to be adopted on-farm such as drip irrigation systems, or improved irrigation management and landforming to enable more uniform application of water. Other options include surface drainage and reuse systems, and land retirement. Improvements in water use efficiency can lead to water quality benefits by reducing ground water recharge that, in turn, reduces the discharge of saline ground water into the river system. Without some incentive to landholders, there will be suboptimal investment in water use efficiency practices. This is because many of the benefits accrue to water users who do not undertake the efficiency improvements. There is no incentive for these downstream beneficiaries to contribute to the cost of the efficiency improvements because of the free rider problem where those who do not contribute still benefit from the investment. Because downstream users capture these benefits there is no incentive for the upstream irrigator to consider them when making their investment decisions (McDonald and Heaney 2002).

Off-farm irrigation management could be improved by replacing open channels with pipes to lower channel leakage in irrigation areas. Piping of irrigation water supply systems is more of an option for Sunraysia and Swan Hill than the Riverland. Virtually all of the water supply systems in the Riverland are piped. In Sunraysia, however, irrigation trust areas supply water through open channels while private diverters have piped systems. An open channel system also supplies water to Swan Hill. Piping of open channels can be very costly but can encourage the adoption of more water use efficient practices on-farm. This is because the water is supplied pressurised (to varying levels), which reduces the cost of irrigating with more efficient application systems than flood irrigation. The use of soil moisture monitoring and irrigation scheduling is also encouraged as water can be supplied on demand.

Subsurface drains in irrigation areas and ground water pumping can also reduce accession to ground water aquifers and high water tables. Examples of these solutions are the Wakool–Tullakool subsurface drainage scheme, ground water pumping which has been introduced to protect the main horticultural areas between Mooroopna and Tatura and south of Cobram in northern Victoria, and the Waikerie and Woolpunda Salt Interception Schemes in South Australia. There are, however, constraints on their use, including the suitability of aquifers from which to pump and the need to dispose of ground water effluent from subsurface drainage (Macumber and Dyson 1988; Stevens 1996; MDBC 2003).

Dilution flows are another option that can be used to reduce the salinity of the river at critical times. Storage flows can be intentionally released to maintain surface water below target salinity levels. Grape growers would obtain the greatest benefit from dilution flows during the months that saline irrigation is most detrimental to grape growth and in those years when river flow is low. In 1987 as part of the MDBC Salinity and Drainage Strategy it was agreed that South Australia would be entitled to additional water to mitigate the impacts of saline surface water flows. This additional dilution flow is only provided when the storage volumes in the Menindee Lakes system exceed nominated trigger points and the combined storage volume of the Hume and Dartmouth Reservoirs also exceed nominated triggers (Department of Land and Water Conservation, New South Wales 2003).

In dryland areas that contribute to the discharge of saline ground water to streams, strategic planting of native trees and shrubs and replacement of annual pasture with perennial pasture can reduce the quantity of recharge entering the ground water system (Walker, Gilfedder and Williams 1999).

conclusions

Land use change since European settlement has contributed to a trend of rising salinity in surface water. This trend is expected to continue, with the Murray Darling Basin salinity audit (MDBMC 1999) suggesting that salt mobilisation in the basin could double from 5 million tonnes a year in 1998 to 10 million tonnes in 2100.

As the viticultural industry is reliant on surface water, these salinity trends may have an impact on the future of the Australian viticultural industry. Results from the SALSA model illustrate that salt concentration in streams and rivers will generally be larger in the lower reaches of the Murray River, reflecting higher underlying ground water salinities. In particular, salt concentration is highest in the Victorian Mallee and South Australian Riverland horticultural regions where most of Australia's grape plantings are situated.

Grapes are only moderately sensitive to salt, however, and results from the SALSA model suggest that impacts on grape yields and consequently grape producer returns from rising stream salinity in the basin will be minimal. Under the assumption of 'business as usual', grape yield losses at the end of the fifty year period are projected to be negligible in upstream areas like the Goulburn Valley and to rise to almost 3 per cent at Lock 2–Morgan, reflecting the higher, and faster rising stream salinities further down the river. Consequently, the impact on producer returns from yield losses is greater for regions further down the river system.

Yield losses over the fifty year period impose a total cost on producers for the modeled regions in the basin of $20.4 million (net present value) in lost production revenue. Losses are highest in the South Australian Riverland ($13 million) and Sunraysia ($5.9 million) as these are the largest grape producing areas in the basin and salt concentration is greater in these areas.

The SALSA model may potentially underestimate the impacts of rising stream salinity on yields and producer returns. For instance, analysis of monthly variation in salt loads in Sunraysia, the South Australian Riverland and Murrumbidgee revealed that stream salinity tended to be highest in those months where plant yield is most affected. However, the range of observed and projected salinity levels are still well below levels that would generate substantial yield losses. Hence, the impact on growers' returns is still likely to be small. Further, the physical relationships between vine growth and saline irrigation are not well understood. For example, the reasons for depression of vine growth during recovery after a period of saline irrigation are not understood. Periodic exposure to higher levels of saline irrigation water may generate permanent or longer term yield losses

These results highlight the regions where research into and implementation of options to mitigate the impact of saline irrigation water should be of highest priority. Grape growers can take steps on-farm to reduce the impacts of saline irrigation water on their vines by improving the efficiency of their irrigation system, minimising salt buildup within the root zone and reducing the toxic salt buildup within the plant. Other options include using salt tolerant rootstock, and locating new plantings in areas where soils are more lightly textured and where irrigation water is less saline. A range of measures can also be undertaken elsewhere in the basin both on- and off-farm to reduce the salinity of surface water, such as improving on- and off-farm irrigation efficiency and investment in ground water pumping and salt interception schemes. Government initiatives, such as the Land and Water Management Plans, the Salinity and Drainage Strategy, the South Australian River Murray Salinity Strategy and the new National Action Plan for Salinity and Water Quality act to encourage investment in these measures.

model documentation

A basin scale model for assessing salinity management options

*Rosalyn Bell and Anna Heaney**

This appendix describes the Salinity and Landuse Simulation Analysis (SALSA) modeling framework designed to evaluate salinity management options such as land use change, improvements in irrigation practices and engineering interventions in the Murray Darling Basin. The model incorporates the relationships between land and water use, vegetation cover, surface and ground water hydrology and agricultural returns. The results from simulations of the model are intended to provide order of magnitude estimates for the impact of salinity management options, highlighting the catchments in which more detailed analysis is required.

Introduction

Land clearing and the establishment of irrigation have facilitated the development of high value agricultural production in Australia's Murray Darling Basin. However, land clearing and irrigation have also imposed costs. The replacement of native vegetation with crops and agricultural systems has substantially increased the amount of water entering ground water systems and, as a result, led to rising water tables. As water tables rise, there is increased discharge of salt into streams and relocation of salt in the soil to the soil surface. Higher stream and surface soil (dryland) salinity can reduce the productive capacity of agricultural resources, adversely affect infrastructure such as roads and rural services that support agriculture, and affect the quality and variety of a range of environmental assets including wetlands, floodplains and riverine ecosystems.

Strategies have been, and continue to be, implemented to address the problem of salinity in the riverine environment. The Salinity and Drainage Strategy was introduced in 1989 to manage irrigation salinity along the Murray River in New South Wales and Victoria, and increased salt concentration in the lower Murray River in South Australia. The Draft Basin Salinity Management Strategy, released by the Murray Darling Basin Commission in September 2000, proposed a series of end of valley salinity targets for 2015 as well as fore-

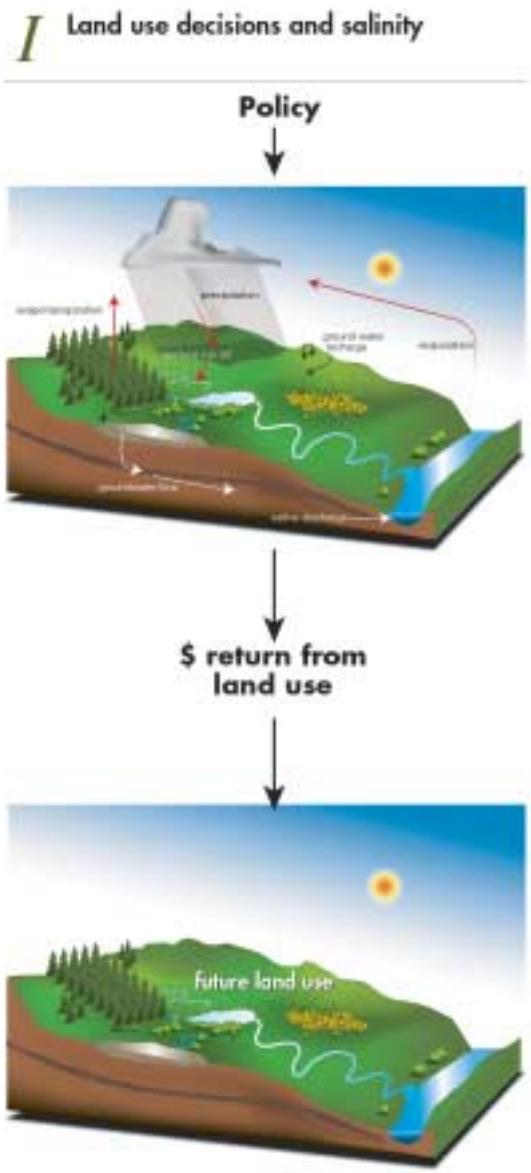
*This work was undertaken in collaboration with the MDBC, Dr Glen Walker and Warrick Dawes from CSIRO Land and Water and Dr Ray Evans from Salient Solutions Australia. The project leader was Dr Stephen Beare, Research Director, ABARE. An earlier description of the model is described in Bell and Klijn (2000), and forms the basis for this appendix.

shadowing the need to develop longer term initiatives. The Commonwealth and state governments agreed in November 2000 to fund a national salinity and water quality program.

Investing in a portfolio of initiatives requires an understanding of how different landscapes respond to alternative land and water use options at both a regional and a broader scale. To evaluate salinity management options in the Murray Darling Basin, a simulation modeling framework that incorporates the relationships between land use, vegetation cover, surface and ground water hydrology and agricultural returns was developed at ABARE, in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Overview of the model structure

In order to assess the potential level of costs and benefits associated with salinity management, the effect of current and potential land use and engineering options on salinity levels and economic returns is examined. This requires explicit consideration of the response of individual land managers to financial incentives and constraints created by alternative policies. It is important to recognise that policy instruments are likely to lead to externalities as individuals will not take into account downstream benefits and costs. These issues have a significant bearing on the model design and are discussed further in Bell and Beare (2000) and Bell, Mues and Beare (2000).



From a biophysical perspective, alternative land use options correspond to a level of ground cover that, for a given soil type and level of precipitation and irrigation in a region, determine the impact of that land use option on recharge and surface water runoff. The effect of any change in recharge on discharge and, in turn, on soil and stream salinity levels, is dictated by the characteristics of the ground water system. Increased stream salinity and dryland salinisation may reduce the productive capacity, and hence economic returns, of land in particular uses in later years. The model developed in this paper incorporates this feedback loop of land use and salinity and is represented in figure I.

2 River catchments in the Murray Darling Basin

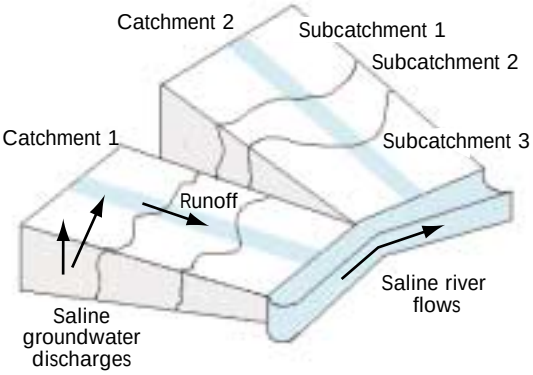


The basin scale model is composed of a series of 14 catchments and 11 irrigation areas in the Victorian Mallee and South Australian Riverland — Victoria: Goulburn-Broken, Avoca, Loddon, Campaspe, Ovens-Kiewa, and Victorian Mallee; New South Wales: Macquarie–Bogan, Gwydir, Namoi, Border Rivers, Castlereagh, Lachlan, Murray (Riverina) and Murrumbidgee; Queensland: Border Rivers and Condamine–Culgoa; South Australia: South Australian Riverland — linked through the main river channels in the Murray Darling Basin (map 2).

Surface and ground water discharges from a catchment combine to contribute to salinity levels in the rivers that connect the catchments. In turn, each of these catchments is divided, on the basis of the type of ground water system present, into subcatchments or land management units with similar hydrogeological characteristics. The land management units are linked to each other through surface flows in the form of runoff and ground water discharge into streams and rivers (figure J). It is assumed that externalities can be generated between, but not within, land management units, hence a land management unit is represented by a single land manager. The land management component of the model is presented in detail

below. The model is developed using the user interface and simulation facilities of Extend (Imagine That Inc. 1997). Simulations are undertaken with an annual time step over a time horizon of 50–250 years.

J Linkages between catchments and subcatchments



Agroeconomic component

The management problem considered in the agroeconomic component of the model is that of maximising the economic return from the use of agricultural land by choosing between alternative steady state land use activities in each year. There are seven possible land use activities: 1. irrigated crops, 2. irrigated pasture, 3. irrigated horticulture, 4. dryland crops, 5. dryland pasture, 6. alternative cropping/pasture activity with reduced recharge; and 7. plantation forestry.

Each region is assumed to allocate its available land each year between the above activities to maximise the net return from the use of the land in production, subject to constraints on the overall availability of irrigation water from rivers, *sw**, and from ground water sources, *gw**, and suitable land, *L**:

$$\max \frac{1}{r}\sum_j p_j x_j\left(L_j,\ sw_j,\ gw_j\right) - csw\sum_j sw_j - cgw\sum_j gw_i \tag{1}$$

subject to

$$\sum_j sw_j \le sw^*,\quad \sum_j gw_i \le gw^* \quad and \quad \sum_j L_j \le L^* \tag{2}$$

where x_j is output of activity j, L_j is land used in activity j, sw_j is surface water and gw_j is ground water used for irrigation of activity j, r is a discount rate, and csw is the unit cost of surface water used for irrigation and cgw is the unit cost of ground water used for irrigation. The net return to output for each activity is given by p_j and is defined as the revenue from output less the cost of inputs, other than land and water, per unit of output.

For each activity, the volume of output depends on land and water use (or on a subset of these inputs) according to a Cobb-Douglas production function:

$$x_j = \begin{cases} A_j L_j^{\alpha_{Lj}} sw_j^{\alpha_{swj}(t)} gw_j^{\alpha_{gwj}} & 0 < \alpha_{Lj} + \alpha_{swj} + \alpha_{gwj} < 1 \quad for\ j = 1,2,3 \\ A_j L_j^{\alpha_{Lj}} & 0 < \alpha_{Lj} < 1 \quad for\ j = 4,5,6 \\ A_j L_j & for\ j = 7 \end{cases} \tag{3}$$

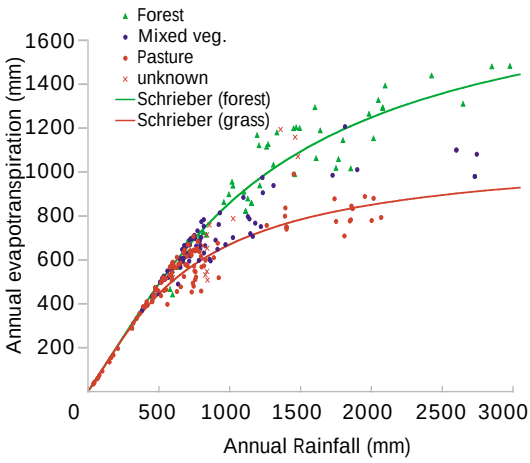
where A_j, α_{Lj}, α_{swj} and α_{gwj} are technical coefficients in the production function. Note, the technical coefficients on surface irrigation water are time dependent to capture the impact of changes in salt concentration in the source river.

Hydrology component

Surface water

The hydrology component of the model was developed in collaboration with CSIRO (Dawes, Walker and Evans 2000). There are two parts to the hydrology component of the model. The first part is the distribution of precipitation and irrigation water in each subcatchment between surface runoff, evapotranspiration and ground water recharge. Evaporation and transpiration are determined as a function of precipitation and ground cover, as well as irrigation application rates and efficiency. Evapotranspiration (*ET*) is the weighted sum of evaporation on tree covered and grass covered areas, ET_{trees} and ET_{grass} respectively (see figure 4, Zhang, Dawes and Walker 1999).

K Evapotranspiration by cover type



Each of these is a function of precipitation *PPT* and irrigation water applied in that year

$$ET(t) = \upsilon ET_{trees} PPT(t) + [1-\upsilon] ET_{grass} PPT(t) + \gamma \sum_j \left(sw_j(t) + gw_j(t) \right) \tag{4}$$

where υ is the proportion of land in the catchment unit that is covered by trees and γ is the proportional contribution of irrigation water to evapotranspiration and reflects the efficiency of irrigation techniques within the subcatchment.

The soil texture type in each catchment unit determines the extent *Rfac* to which water seeps through the land surface to the ground water table. Hence, the rate of ground water recharge *R* in a given year is given by:

$$R(t) = Rfac \left[PPT(t) + \sum_j \left(sw_j(t) + gw_j(t) \right) - ET(t) \right] \tag{5}$$

The amount of surface water runoff (ρ is then given by:

$$\rho(t) = PPT(t) + \sum_j \left(sw_j(t) + gw_j(t) \right) - ET(t) - R(t) \tag{6}$$

The excess of precipitation and irrigation water over evaporation and transpiration is spliyt between surface water runoff and ground water recharge using a constant proportion (recharge fraction). The volume of irrigation water entering the ground water system depends largely on terrain and soil structure. Irrigation areas are generally located in flat terrain leading to

reduced runoff and consequently higher recharge fractions. On heavier less permeable soils in the upland river catchments, recharge fractions are assumed to be in the range 50–60 per cent. On the sandier more permeable soils in the South Australian Riverland and Victorian Mallee, recharge fractions are 100 per cent.

Water application rates in the southern Murray Darling Basin for horticulture are around 10 megalitres per hectare a year, equivalent to 1000 mm of precipitation, whereas average application rates for pasture are between 4 and 6 megalitres per hectare a year (Gordon, Kemp and Mues 2000). Irrigation efficiency is defined as the proportion of irrigation water applied that is returned to the atmosphere through evaporation and transpiration. In horticultural areas such as western Victoria and the South Australian Riverland, irrigation efficiency can approach 75 to 80 per cent for horticulture (A. Meisner, Department of Environment, Heritage and Aboriginal Affairs, personal communication, November 2000). In areas where there is widespread use of flood irrigation on pasture, irrigation efficiency is of the order of 50 per cent.

Some soils have intervening layers of clay that impede drainage into the ground water system. Tile drainage is used in these areas to avoid waterlogging. Tile drainage is represented in the model though a combination of an increase in irrigation efficiency where drainage is reused or allowed to evaporate, or as a return flow to the river system. Saline ground water discharge can be intercepted through ground water pumping for subsequent disposal in evaporation ponds. In some irrigation areas, such as the South Australian Riverland, there is ground water discharge to the flood plains that is mobilised in flood events and does not contribute to the problem of high salt concentrations. Reductions in average saline discharge from these effects are accounted for in calculating river salt and water balances.

Ground water

The second part of the hydrology component is the determination of ground water discharge. The basic premise behind the ground water hydrology component is that when a catchment is in equilibrium, recharge and discharge are equal. When annual recharge rates are changing, there is a lag before discharge is affected. These contributions of recharge are assumed to be additive and uncorrelated over time. The approach adopted here bypasses intermediate calculations such as ground water level, which are necessary for water balance accounting, and instead seeks to determine gross discharge at a subcatchment level, with a minimum level of information required.

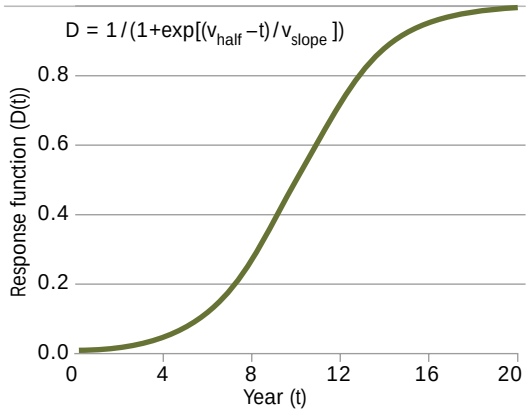
The total discharge rate D in year t is a logistic function of a moving average of recharge rates in the current and earlier years (figure L) according to:

$$D(t) = R(0) + \sum_{i=t-m}^{t} \frac{R(i) - R(i-1)}{1 + \exp\left[\left(\upsilon_{half} - i\right) / \upsilon_{slope}\right]} \tag{7}$$

where $R(0)$ is the initial equilibrium recharge rate, m is the number of terms included in the moving average calculation, and υ_{half} and υ_{slope} are the time response parameters determined on the basis of the hydrological characteristics of the subcatchment. The moving average

formulation allows the accumulated impacts of past land use change to be incorporated as well as to model prospective changes.

Weighting function for contribution of past recharge to discharge



As the distance from the river increases, the time before a change in the level of recharge is fully reflected in the level of ground water discharge increases substantially. Irrigation areas in western Victoria and the South Australian Riverland were divided into land use bands according to distance from the river. Parameters for the ground water response functions in these irrigation areas were obtained from Watkins and Waclawik (1996). Similar ground water response functions were assumed for the remaining irrigation areas based on discussions with CSIRO and other hydrologists. Response times were assumed to be longer the larger the irrigation area. However, in areas with substantial areas of high water tables, response times were reduced.

A threshold approach is used to distribute this discharge rate between discharges to a ground water aquifer D_{gw}, to a river which carries salt downstream *Dsw* and into the vegetation root zone of soil *Drz*. That is, discharge is assumed to first be released into an aquifer until a threshold D_{maxGW} is reached. Discharge is then released into streams in the subcatchment until a threshold D_{maxSW} is reached. Finally, any remaining discharge is assumed to contribute to dryland salinity and further stream salinity in the proportion *Lfrac*.

$$(8)\quad Dgw(t) = \begin{cases} D(t) & for\ D(t) < D_{\max GW} \\ D_{\max GW} & for\ D(t) > D_{\max GW} \end{cases}$$

$$Dsw(t) = \begin{cases} 0 & for\ D(t) < D_{\max GW} \\ D(t) - D_{\max GW} & for\ D_{\max GW} < D(t) < D_{\max SW} \\ (1 - Lfrac)\left(D(t) - D_{\max SW}\right) & for\ D(t) > D_{\max SW} \end{cases}$$

$$Drz(t) = Lfrac\left(D(t) - D_{\max SW}\right)$$

Impacts of salinity on productivity

To assess the benefits and costs of alternative salinity management strategies it is essential to estimate the impact of changes in ground and surface water salinity on the productivity, and hence earning capacity, of regional agricultural systems. Three sources of productivity change are considered. First is the change in the electroconductivity of surface irrigation water, which can occur with ground water discharges to streams. Second is the electroconductivity of ground water used for irrigation. Third is salinity of the soil water within the plant root zone, which is simply an accumulation of past saline discharges to land and saline irrigation applications.

The costs to irrigated agriculture and horticulture resulting from yield reductions caused by increased river salinity are modeled explicitly. The impact of saline water on the productivity of plants is assumed to occur by the extraction by plants of saline water from the soil. The electroconductivity of the soil *EC* reflects the concentration of salt in the soil water and reduces the level of output per unit of land input (land yield) and per unit of water input (water yield). This is represented by modifying the technical coefficients α_{swj} in the production function for each activity from the level of those coefficients in the absence of salinity impacts. That is:

$$\alpha_{swj}(t) = \frac{\alpha_{swj}^{\max}}{1+\exp\left(\mu_{0j}+\mu_{1j}EC\right)} \tag{9}$$

where μ_0 and μ_1 are productivity impact coefficients determined for each activity and α_{swj}^{max} is the level of the technical coefficient in the absence of salinity.

The area of land that is fully affected by high water tables $Area_{rz}$ is determined by discharges into the root zone of the soil and the evapotranspiration from saturated soils ET_{sat}:

$$Area_{rz} = \frac{D_{rz}}{ET_{sat}} \tag{10}$$

However, there is generally a lag before high water tables begin to have an impact on the productivity of land. The area of land that is affected by salinisation $Area_{salty}$ in a given year is determined as a logistic function of a moving average of the area of high water tables in the current and earlier years:

$$\begin{aligned} Area_{salty}(t) &= Area_{rz}(0) \\ &+ \sum_{i=t-m}^{t}\left[Area_{rz}(i)-Area_{rz}(i-1)\right]\left\{1+\exp\left[\left(\upsilon_0-1\right)/\upsilon_1\right]\right\}^{-1} \end{aligned} \tag{11}$$

where *m* is the number of terms included in the moving average calculation, and υ_0 and υ_1 are parameters to be determined on the basis of the soil type and hydrological characteristics of the subcatchment. The proportion of land *Sfac* that is affected by discharges of saline ground water is then determined as:

$$Sfac = \frac{Area_{salty}}{\bar{L}} \tag{12}$$

where $\bar{L}$ is the total area of land in the subcatchment. Output of each activity is then adjusted by the change in the productivity of inputs used in the production process:

$$x_j = \begin{cases} A_j\left[(1-Sfrac)L_j^{\alpha_{Lj}^{\max}} + Sfrac\, L_j^{\alpha_{Lj}}\right] sw_j^{\alpha_{swj}} gw_j^{\alpha_{gwj}} & j=1,2,3 \\ A_j\left[(1-Sfrac)L_j^{\alpha_{Lj}^{\max}} + Sfrac\, L_j^{\alpha_{Lj}}\right] & j=4,5,6,7 \end{cases} \tag{13}$$

Incorporating salinity management options

A range of policy options is available to influence land use. These include regulations on the area and location of particular activities, subsidies for desired land use options and taxation of undesirable options. The effectiveness of a given intervention will depend on a range of factors, including the costs of switching into an alternative land use, the benefits of reduced recharge rates and the costs of any reductions in usable surface runoff. The distribution of such costs and benefits is also likely to be complex, depending on factors such as climate, soil and location of the farm enterprise.

Salinity management options may be introduced into this framework in several ways. First, the area of land used for a particular activity may be constrained. For example, an upper limit $\bar{l}_j$ could be placed on the area of land used for cropping or pasture activities associated with higher ground water recharge rates:

$$l_j \geq \bar{l}_j \quad for\ j = 1-5 \tag{14}$$

Alternatively, policy imposed requirements may specify the minimum area of land $\underline{l}_j$ to be used for plantation forestry or for alternative cropping and pasture activities that are associated with lower ground water recharge rates:

$$l_j \geq \underline{l}_j \quad for\ j = 6,7 \tag{15}$$

A second approach to salinity management may be the imposition of a charge $-\tau$ or subsidy τ that alters the net returns associated with using land for a particular activity:

$$p_j^{\#} = p_j + \tau \tag{16}$$

A third direct approach to salinity management may be a levy ψ on subcatchments for any measured salinisation of streams or land through ground water discharges above some target level D_{target}, effectively reducing the net returns in (1) by an amount equivalent to:

$$\psi\left(D(t) - D_{target}\right) \tag{17}$$

While a levy on the salinity contribution may be feasible at a broad catchment level, difficulties in accurately measuring saline discharges may mean such an approach cannot be effectively imposed at the level of a catchment type unit. Such problems would also limit the applicability of discharge permit schemes (see Bell and Beare 2000 for further discussion on the feasibility of various salinity management options).

Given a choice of a policy instrument, the optimal level of intervention must also be determined. Within the context of the simulation model this can be accomplished by embedding the model in an optimisation or learning algorithm. The use of genetic algorithms to optimise policy settings in an integrated hydrological and economic simulation model is described in Bell and Beare (1999) and Beare, Bell and Fisher (1998).

Data requirements and calibration

The data requirements for specifying the model are extensive and a number of parameter values must be initially assumed and then calibrated. Two trial catchments — the Goulburn–Broken catchment in Victoria, and the Macquarie–Bogan catchment in New South Wales — were selected to validate the data collection and calibration procedures outlined below. These catchments were selected because of the availability of detailed information on land cover and ground water.

Agroeconomic data

To construct the agroeconomic data set, digitised boundaries for the catchment and subcatchment units are used together with ABS census data and geo-coded ABARE farm survey data. Subcatchment areas are aligned with Statistical Local Areas (SLAs) and then ABS census are used to allocate the proportion of land in agriculture and non-farm use. It is assumed that land use outside of agriculture remains unchanged over the analysis period. Land use and irrigation data were obtained from a wide range of sources, including ABARE farm survey data, ABS and regional water authorities such as Goulburn–Murray Water and SA Water. The volume of irrigation water used in each catchment was split between the land use alternatives using application rates for the crops grown in the region derived from ABARE farm survey data.

ABARE (1999) farm survey data are projected to a 0.2° grid using a kernal smoother (Wand and Jones 1995). The farm survey data are used to determine the proportion of land in the five nonforestry land use activities, other than horticulture, listed above. Survey data from 1996-97 were also used to determine net returns per hectare associated with each activity (ABARE 1990). The net return includes fixed costs and the cost of depreciation, allocated on a per hectare basis.

To calculate initial values for the production function parameters in (3), the total rent at full equity accruing to each activity was first calculated as the summation of rent associated with the use of land and other fixed inputs to production and surface and ground water. That is:

$$RentTotal_j = RentL_j + RentSW_j + RentGW_j + RentOther_j \tag{18}$$

where:

$$\begin{aligned} \text{Rent}L_j &= L_j(0)p_{min} \\ \text{Rent}SW_j &= sw_j(0)\, \tilde{cs}w \\ \text{Rent}GW_j &= gw_j(0)\, \tilde{cg}w \\ \text{Rent}Other_j &= L_j(0)(p_j - p_{min}) \end{aligned}$$

and p_{min} is the net return to land and other fixed capital structures in their marginal use and $\tilde{cs}w$ is the opportunity cost of surface water used for irrigation and $\tilde{cg}w$ is the opportunity cost of ground water for used irrigation in the initial period. Not all regions have ground water sources suitable for irrigation. The opportunity cost of surface and ground water used for irrigation is assumed to be $50 a megalitre for areas with predominantly pasture production and $200 a megalitre for horticultural areas.

Initial values for the production function coefficients for each activity were then determined as:

(19)
$$\alpha_{Lj}(0) = \frac{RentL_j}{RentTotal_j}$$
$$\alpha_{swj}(0) = \frac{RentSW_j}{RentTotal_j}$$
$$\alpha_{gwj}(0) = \frac{RentGW_j}{RentTotal_j}$$
$$A_j = L_j(0)^{1-\alpha_{Lj}(0)} sw_j(0)^{-\alpha_{swj}(0)} gw_j(0)^{-\alpha_{gwj}(0)}$$

Within a simulation, these coefficients are then adjusted from the initial values according to equation (9).

The Murray Darling Basin Commission has linked its hydrological modeling to estimates based on cost impacts of incremental increases in salinity. Costs downstream of Morgan are imputed as a function of EC changes in salt concentration at Morgan. The analysis considers agricultural, domestic and industrial water uses. Using the cost functions derived in this model, each unit increase in EC at Morgan is imputed to have a downstream cost of $65 000 (MDBC 1999a).

Forestry data

The methodology used in the plantation forestry analysis has been described in Burns, Walker and Hansard (1999). A discounted cash flow approach is used to calculate the net present values (NPV) associated with the development of plantation forests in a region. Potential plantation returns were calculated spatially using average milldoor prices for new mill developments and subtracting harvest costs and transport costs from mills to all potential plantation sites. These potential returns were then multiplied by the yields of timber for several plantation regimes producing pulp logs, sawlogs and/or pruned logs. The potential plantation yields were also differentiated spatially by ranking the productivity of agricultural land by rainfall isohyets. Only softwood regimes were modeled for the Victorian catchments, as hardwood capability was estimated not to extend into these areas.

The NPV of a single plantation rotation was determined by subtracting all discounted costs associated with establishing and maintaining the plantation from the discounted revenues associated with the sale of plantation timber. It is assumed that an equal area of plantation is developed each year and rotations are repeated in perpetuity to derive the potential value of land when used to grow timber plantations.

There was a number of simplifying assumptions used in the analysis, including the following:

- All prices and costs are expressed in constant 1999 values, net revenue is measured on a pretax basis and all parameters are assumed to remain constant forever.

- For each catchment, it was assumed further processing infrastructure would be developed to process timber from additional plantation resources. These assumed mill developments were located in centres currently associated with timber processing. No account was taken of the potential rents and volumes available in the region to develop this capacity.
- Investments in the timber mills used in the analysis were assumed to be completely divisible, such that they can be of any size up to a maximum for each processing type with constant per unit total processing costs. These investments are assumed to be repeated continually once mills reach shutdown age.
- Plantation establishment and management costs are independent of the size of investment, type of investor, individual site conditions, and existing infrastructure such as roads.
- Each catchment was assumed to be a small region, such that forest product prices are determined elsewhere independently of volumes of timber produced in the regions.
- The plantations are established on a continuous rotation and returns to land not yet planted are assumed to be that of dryland pasture.
- A real discount rate of 7 per cent was used for all calculations.

For more information relating to the assumptions behind the forestry modeling framework see Burns et al. (1999).

Hydrology data

The data set for the surface water hydrology is constructed with precipitation data and interpolated to subcatchment levels using spatial smoothing techniques (MDBC1999c).

The ground water hydrology data set is derived from a combination of existing estimates of the rate of ground water rise (MDBMC 1999) and simulations of ground water discharge from an existing model (Dawes, Walker and Stauffacher 1997). To enable the calculation of ground water recharge rates, a dominant soil texture is determined in each subcatchment. The soil type classification is based on work undertaken for the Soil Information Strategy project for the Murray Darling Basin (MDBC 1999b).

In order to include the impact of past land use changes on current and future ground water discharge, a recharge rate associated with native land cover is determined for each subcatchment. The length of time that land has been cleared for agriculture and the time span of the aquifer (from equation 7) is used as a basis for determining the extent to which current discharge is related to recharge under native and under current vegetation cover.

The salinity of catchment outflows reflects a combination of saline discharges from ground water and runoff into the principal river system and is calibrated against gauge data for surface water flows and salt loads (Jolly et al. 1997). Projected salt loads were obtained from the national salinity audit (MDBMC 1999), Barnett et al. (2000) and Queensland Department of Natural Resources (QDNR 2001). To derive the impact of saline irrigation water and soil

salinity in the root zone of agricultural activities, threshold and yield reduction rates (bent stick estimates) are utilised (MDBC 1999a).

Concluding remarks

The model described in this appendix provides an integrated framework in which the effect of current and potential land use and engineering options on salinity levels and economic returns can be assessed. The scale of the model to a river system basin level necessitates a relatively coarse representation of the physical and economic structure of the system, with a number of simplifying assumptions made to comply with time and computing constraints. As such, the results from simulations of the model are intended to provide initial orders of magnitude estimates for the impact of land use options on salinity and economic returns. Evident from the model simulations will be the variability in gains and costs of salinity management between catchments, including the indirect benefits or costs incurred by a catchment as a result of land use changes in upstream catchments. Such information will highlight those catchments in which more detailed analysis of the impacts of salinity and land use changes are required.

To date, the catchment model has been developed to estimate the benefits and costs of reforestation as a tool for salinity management (Heaney, Beare and Bell 2000). The results of this work suggest that broad scale reforestation as a tool for managing dryland and instream salinity may impose significant costs on agriculture and rural economies more generally. These costs are incurred as a result of reduced surface water yield and increased salt concentration of surface water flows in the near term. To demonstrate how a targeted approach to reforestation may still be cost effective, the model was used to identify the influence of different hydrological and land use characteristics on the costs and benefits of reforestation within the Macquarie–Bogan catchment. The results show reforestation targeted to regions in this catchment that have high ground water salinity levels and relatively fast responding aquifers may generate substantial net salinity benefits. Other catchments are likely to have different productive and nonproductive assets that may affect the benefit–cost profile of salinity mitigation through reforestation.

The model has also been developed to simulate the impacts of changes in return flows as a result of improvements in irrigation efficiency and those associated with trade in water allocations between irrigation regions (Heaney, Beare and Bell 2001; Beare and Heaney 2001, Heaney and Beare 2001a,b). Return flows from irrigation contribute a substantial proportion of river flows and water entitlements held by downstream users in the Murray River system. Return flows also have a significant impact on water quality as a large proportion of the salt load in the Murray River comes from the discharge of saline drainage and ground water flows from irrigation.

Improvements in irrigation efficiency and water trade between irrigation regions can alter the pattern of return flows, imposing indirect benefits and costs on downstream users and the environment. These impacts vary continuously along the river depending on the hydrological and agronomic characteristics of the catchments undertaking the action. As a consequence, it may be infeasible to fully internalise return flow impacts on others through a system of private property rights.

To date, the SALSA model has also been used to examine salinity management options in the northern Murray Darling Basin (Heaney and Levantis 2001), to analyse the potential costs and benefits of increased environmental flows in the Murray Darling River system (Heaney, Beare and Goesch 2002) and of improving water use efficiency in the southern Murray Darling Basin (McDonald and Heaney 2002). The SALSA model was also used to examine the potential impacts of climate change (Beare and Heaney 2002).

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Region/catchment	Contact and association
Macquarie–Bogan	Lucy White, Promotions Manager, Mudgee Wine Grape Growers Association Tim Hamilton, Secretary, Bathurst Vigneron Association Margot Sharpe, President, Orange Region Vignerons Association Inc. Williams Machin First National Real Estate and Stocking Agent Glenda Hoffman, Consultant, Committee member of Mudgee Wine Grape Grower's Association Inc. Frank Helwig, Winemaker, Orlando Vineyards, Mudgee Steve Hirst, Chairperson, Viticulture Sub-Committee Clarrie Beckingham, District Horticulturalist, NSW Agriculture
Lachlan	Mark Ward, President, Cowra Region Vineyard Association Jeremy Bright, District Horticulturist, NSW Agriculture
Murrumbidgee	Harry Creecy, District Horticulturist (Viticulture), NSW Agriculture Belinda Wilkes, CEO, Murrumbidgee Horticulture Council, Inc Brian Simpson, CEO, Wine Grapes Marketing Board Emma Jamieson, Industry Development Officer, Wine Grapes Marketing Board Peter Wood, Director, Peter Wood Professionals Pty Ltd Lilian Parker, Environmental Services Manager, Murrumbidgee Irrigation
Ovens–Kiewa	Guy Darling, CEO, Darling Estate Wines, King Valley Elleanor Anderson, Executive Officer, Alpine Valleys Winemakers and Grapegrowers' Association Malcolm Campbell, Viticulturist, Rutherglen Chris Pfeiffer, Chairman, North East Victorian Winegrowers Association Bert Eastoe, Director, Cosgrave and Eastoe Pty Ltd
Goulburn–Broken	John Beresford, Secretary, Goulburn Valley Wine Association Inc Paul Dahlenburg, Site Manager, North East Victoria Viticulture, Glenrowan

	Renee Boote, Secretary, Strathbogie Ranges Wine Region Inc. David Ritchie, President, Central Victorian High Country Winegrowers Association
Campaspe	John Whiting, Viticulture Officer, Department of Primary Industries, Victoria
Loddon	John Whiting, Viticulture Officer, Department of Primary Industries, Victoria Karen Sorenson, Secretary, Bendigo aand District Wine Growers' Association Andrew Mills, Secretary, Heathcote District Winegrowers Association
Avoca	John Whiting, Viticulture Officer, Department of Primary Industries Graeme Miles, Viticulturist, Mt Avoca Vineyard Heather Field, Irrigation Extension Officer for Horticulture, Department of Primary Industries
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Sunraysia	Ian Ballantyne, Manager, Natural Resources, Mallee Catchment Management Authority Chris Cleary, Director, Cleary Valuers Pty Ltd Justin Lane, Irrigation Extension Officer, Sunraysia Rural Water Authority Owen Russell, Water Development Coordinator, Sunraysia Rural Water Authority Mike Stone, Executive Officer, Victorian and Murray Valley Winegrape Growers' Council John Whiting, Viticulture Officer, Department of Primary Industries, Victoria
South Australian Riverland	Mark Skewes, Irrigation Consultant, Rural Solutions South Australia Rob Stevens, Research Scientist, Irrigation and Salinity, SARDI/PIRSA Rod Ralph, Data Manager, Central Irrigation Trust John Abbott, Project Manager, Renmark to the Border Local Action Planning Association Inc. Renee Webster, Project Officer, Riverland West Local Action Planning Association Inc. Peter Hackworth, Executive Officer, Phylloxera and Grape Industry Board of South Australia

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