Report to client

Targeting land and water use options for salinity management in the Murray Darling Basin

Targeting land and water use options for salinity management in the Murray Darling Basin

ABARE report to the
Murray Darling Basin Commission

Anna Heaney, Stephen Beare and Rosalyn Bell

October 2001

ABARE
Innovation in Economic Research

Heaney, A., Beare, S. and Bell, R. 2001, *Targeting Land and Water Use Options for Salinity Management in the Murray Darling Basin*, ABARE Report to the Murray Darling Basin Commission, Canberra, October.

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

ABARE is a professionally independent government economic research agency.

ABARE project 1704

Contents

1. Introduction 1

2. Tradeoffs and the hydrological cycle 3

3 Model specification 6

4 Baseline costs and salt projections 7

5 Model results 10

Reduced discharge 10

Recharge reductions 11

Recharge reduction in the uplands 13

Improvements in irrigation efficiency 15

6 Concluding comments 19

References 21

Figures

A Baseline costs to agriculture, by catchment, 2100 9
B Downstream salinity benefits per tonne reduction in end of valley discharge, per year, by catchment 10
C Net benefits from targeted reforestation – 50 year equilibrium response time 15
D net benefits from targeted reforestation – 100 year equilibrium response time 15
E External benefits and costs per megalitre of a 5 per cent uniform improvement in water use efficiency for all irrigated activities, by catchment 17

Tables

1 The cost of salinity, salt concentration and loads for catchments in the Murray Darling Basin, 2000 and 2100 8
2 The benefits from annual recharge reductions of 10 000 megalitres, by irrigation area 12
3 Effecits of a 5 per cent uniform improvement in water use efficiency in the major irrigation areas for all irrigated activites 16

1. Introduction

This study provides results drawn from a modeling framework developed to evaluate the costs and benefits of salinity mitigation options involving land and water use change in dryland catchments and irrigation areas to achieve salinity targets. The model covers 25 catchment areas within the basin, linking land and water management with surface water and ground water flows and economic returns. The model can be used to estimate the direct effect of land and water use changes on the regions in which production practices are changed. It also generates estimates of downstream costs and benefits to agriculture, urban and industrial users from changes in water flows and water quality. The recent audit of salinity trends in Australia's Murray Darling Basin is used in this project (MDBMC 2001).

The model is first used to establish a no intervention baseline scenario that provides estimates of the future cost of salinity in the absence of any policy intervention. The baseline simulation adopted is one of 'business as usual' in agricultural production. In a simulation period, the impact of land cover on surface flows, ground water aquifers and dryland salinity is assessed. Agricultural producers are able to alter their use of land and irrigation water in response to changes in the salinity of these resources, but there is assumed to be no policy intervention to manage salinity in this scenario. The cost of salinity in the baseline scenario is measured as the reduction in economic returns from agricultural and forestry activities from those that are currently earned. That is, the costs of salinity are measured relative to those borne today.

The results of alternative scenarios are then compared with those for the no intervention baseline to evaluate the costs and benefits of salinity mitigation options. Results are presented in this report for scenarios in which the economic and biophysical impacts of reductions in ground water discharge and recharge in both dryland and irrigated parts of a catchment are assessed. Scenarios of improvements in irrigation efficiency in the major irrigation areas in Victoria, South Australia and the New South Wales Murray were also undertaken.

The analysis allows a comparative catchment assessment of alternative land and water use options for mitigating salinity. Outputs from the model include future values of predicted salt loads, instream salt concentrations, areas of high water tables, and the benefits per tonne of salt reduced, both to the regions undertaking the action and to downstream water users.

The basin level scale of the model 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 order of magnitude estimates of the impact of land use changes and engineering options, highlighting the catchments in which more detailed analysis is required.

The underlying agronomic, economic and hydrological processes represented in the model have been documented previously. Brief descriptions of the key hydrological linkages associated with land use change and the basic structure of the model are provided in the next two sections. This is followed by the business as usual baseline, the simulation experiments and some concluding remarks drawn from the analysis.

2. Tradeoffs and the hydrological cycle

The interactions between precipitation, vegetation cover, surface water flows and ground water processes are complex. They have the potential to generate a wide range of tradeoffs when attempts are made to manage the problems of stream and dryland salinity through land use change. The types of productive activity that can be undertaken, the response of the environment to changes in salinity and the hydrological system itself affect these tradeoffs.

There are a number of variables that determine ground water flows, surface water yields and the mobilisation of salt within, and from, a catchment area. These variables include:

- precipitation,
- rates of evaporation and transpiration,
- ground water response times,
- soil types,
- ground water salinity and
- the morphology of the catchment.

Precipitation returns to the atmosphere as evapotranspiration from vegetation cover, flows over land into surface water bodies or enters the ground water system. On average, evaporation and transpiration increase with higher levels of precipitation. However, for any given increase in precipitation, evapotranspiration will not increase by the same amount; hence, the proportion of precipitation that will either flow over land or into the ground water system (ground water recharge) increases with precipitation.

Furthermore, the influence of vegetation cover on transpiration increases with higher precipitation (Zhang, Dawes and Walker 1999). In low rainfall areas (under 500 millimetres a year), different vegetation covers transpire about the same volume of water. In a high rainfall area, trees and other deep rooted plants transpire a substantially larger volume of water when compared with shallow rooted grasses. Hence, the impact of changing vegetation cover on surface water yields and ground water recharge increases with the level of precipitation.

The volume of precipitation that is not returned to the atmosphere through evapotranspiration will either flow overland or recharge the ground water. The fraction of this excess water that enters the ground water system depends on the rate of infiltration, the rate at which water can penetrate the soil surface, and percolation through the soil profile. The rate of penetration depends on several factors including the slope or gradient of the land, size and structure of the soil and the level of soil moisture. On more steeply sloped land there tend to be fewer and smaller local depressions to store water that can then infiltrate the soil. Clay soils have finer soil particles creating smaller gaps through which water can enter and move through the soil profile. Sandy and less compacted soils have larger gaps allowing water to enter and move through the soil profile more easily than in heavier soils.

The equilibrium response time of a ground water flow system is the time it takes for a change in the rate of recharge to be fully reflected in a change in the rate of discharge. One of the most important factors is the lateral distance of ground water flows, that is the distance between recharge and discharge. The greater the lateral distance the ground water flows, the slower the response time. Hence, the distance between where recharge and discharge is occurring will have a substantial impact on the timing of costs and benefits of revegetation.

There are a number of other important factors that influence the ground water response time, including the slope of the land and the permeability of the soil and deeper substrates. The equilibrium response time does not reflect the actual flow of water through the ground water system but the transmission of water pressure. The response rate increases as the slope of the land increases because of the increase in hydrological pressure. The more permeable the soil and deeper the substrates the less the resistance or friction, resulting in a faster response rate.

A catchment can contain a number of component flow systems. In a regional flow system, hydraulic gradients can be very flat, hence for a given lateral distance, a long period of time is required for the system to come to equilibrium. Over the flow system as a whole, however, the impact of changes in vegetation cover on discharge may not be seen for several hundred years.

Generally, the upper reaches of the catchment are more steeply sloped and these areas are characterised by local flow systems. In these local systems, ground water pressure pulses move through the aquifer rapidly and the delay between a change in the rate of recharge and the volume of discharge from the aquifer over a given distance may be fast in comparison to a regional flow system. Over the flow system as a whole, replanting native vegetation on cleared land may fully restore the balance between recharge and discharge within 100 to 200 years.

In both regional and local flow systems, actions can be taken that have a more immediate impact. For example, revegetating an area adjacent to a river or stream in a regional flow system may reduce discharge within 60 years. The same action in a local flow system may reduce discharge within 30 years.

The higher relief in a local flow system usually results in discharge directly into incised streams that is referred to as base flow. When the capacity for ground water to discharge into streams is exceeded, ground water is discharged to the land surface causing dryland salinisation. Saline ground water discharged into the top two metres of the soil profile can affect agricultural productivity and damage infrastructure.

Discharge from both base flow and land discharge systems may contain relatively high salt loads that will increase salinity in downstream areas of the catchment. Other things being equal, the benefits from revegetation may be greater where there are existing or emerging high water tables, as revegetation can mitigate the loss of productive land and other adverse impacts of dryland salinisation. This may be in addition to the benefits of reduced saline discharge into surface water flows.

However, as local flow systems in a catchment are not linked by a continuous aquifer, the water table of downstream areas is unaffected by changes in the upstream flow systems. Hence, revegetating a local flow system will not be an effective instrument to manage high water tables in lower reaches of the catchment. Addressing the problem of dryland salinity generally requires changes to the local landscape within the flow system in which water tables are rising.

3. Model specification

The framework is a dynamic representation of the relationship between the hydrological cycle and the economic returns to alternative land uses. In the model, economic decisions to optimise land use are integrated with a representation of hydrological processes in each catchment. The hydrological component, developed in cooperation with CSIRO hydrologists, incorporates the relationships between rainfall, evapotranspiration and surface water runoff, the effect of land use change on ground water recharge and discharge rates, and the processes governing salt accumulation in streams and soil. Each catchment is divided into subcatchment units with similar hydrological characteristics, principally the nature of the ground water flow system. The subcatchments are linked to each other via the surface network of rivers and streams. Hence, salt washoff and ground water discharge within a catchment combine to contribute to salinity levels in the rivers that connect the catchments.

In the agroeconomic component of the model, land and water use are allocated to activities each year to maximise economic return in that year given prices of outputs and other inputs in that year. Agricultural land is allocated between seven land use activities: irrigated cropping, irrigated pasture, irrigated horticulture, dryland cropping, dryland pasture, alternative crops/pasture with low recharge, and plantation forestry. Land use can shift with changes in the availability and quality of both land and water resources. Incorporated in this component is the relationship between yield loss and salinity for each agricultural activity. The modeling approach is described in more detail in Bell and Heaney (2001) and Bell and Klijn (2000).

In addition to the costs of salinity to agriculture, estimates of costs to infrastructure within the basin and to water users downstream of Morgan are included. The costs to infrastructure are based on cost estimates derived from the Ivey Report on a per household basis (Ivey ATP 2001). 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 per unit EC changes in salt concentration. The analysis considers agricultural, domestic and industrial water uses (MDBC 1999). 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. This cost is included in the analysis presented here.

4. Baseline costs and salt projections

The baseline simulation was calibrated to reflect key aspects of the national salinity audit and subsequent projections published by State Agencies (MDBMC 1999; Australian Water Environments 1999; Barnett et al. 2000; Queensland Department of Natural Resources 2001). These key aspects include salt loads, concentrations and areas subject to high water tables in dryland catchments. There is, however, considerable variation between states in the extent of available projection data.

The ABARE model is based on different hydrological assumptions from the salinity audit, which is based largely on the projection of trends in the ground water table. As noted, the hydrological framework provided by CSIRO is based on an adjustment process toward an equilibrium in which ground water discharge equates over time with ground water recharge. In addition, the ABARE model incorporates irrigation areas and large regional aquifers that were not included in the salinity audit. Hence the load and salinity projections are different from the audit.

Furthermore, an attempt was made to account for end of valley contributions to flows and salt loads on a consistent basis. For this reason, loads and concentrations were measured downstream of the confluence of a valley tributary to the main river as opposed to just within the tributary itself. This is important along the Murray River as there are irrigation areas that contribute significant salt loads directly to the river.

Baseline costs were calculated relative to benefits at current levels of river salinity and high water tables from agriculture and infrastructure. Thus, only the costs and/or benefits associated with changes in stream flows, concentrations and water tables from current levels are estimated. Infrastructure costs are limited to those associated with urban and industrial water use. A real discount rate of 5 per cent was used to express this cost in net present value terms over the 100 year simulation. The costs and selected physical estimates for each catchment are presented in table 1. Estimated baseline costs to agriculture over the 100 year simulation are shown in figure A.

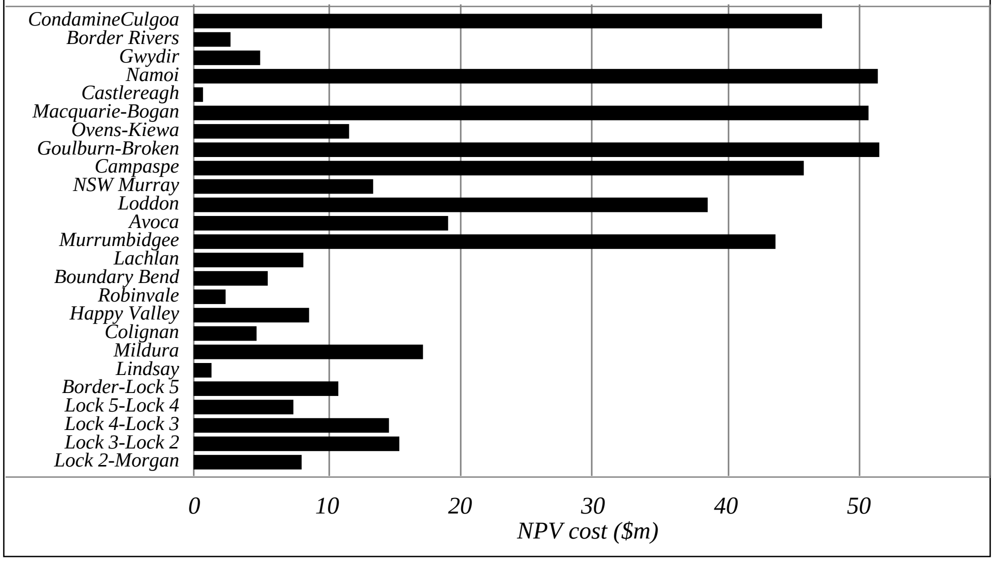
The total estimated cost is approximately $608 million, in net present value (NPV) terms. This cost does not include damage to roads and other infrastructure caused by high water tables and environmental damage. There are three main reasons for the relatively low cost. First, over the projected range of increases in salt concentrations, the loss in irrigation yields is small. Second, the principal agricultural activity in dryland areas with emerging high water tables is pasture, for which returns are relatively low. For example, in New South Wales, land values in these regions would be of the order of $300–400 per hectare. If, for example, a million hectares went out of production today, this would impose a direct cost of $300–400 million, NPV. As these changes occur gradually over a 100 year time period, the present value costs would be considerably less. Third, in areas with emerging high water tables, such as the

1 *The cost of salinity, salt concentration and loads for catchments in the Murray Darling Basin, 2000 and 2100*

	Baseline costs to agriculture, 2100	Salt concentration downstream of the confluence, 2100 [a]	Salt loads at the end of the valley	
			2000	2100
	$m, NPV	mg/L	kt/yr	kt/yr
Condamine–Culgoa	47.18	531.9	89	450
Border Rivers	2.68	220.4	54	142
Gwydir	4.91	250	68	135
Namoi	51.38	272.7	140	245
Castlereagh	0.61	353.5	10	49
Macquarie–Bogan	50.68	294.9	85	129
Ovens–Kiewa	11.60	35.65	103	114
Goulburn–Broken	51.49	64.2	267	368
Campaspe	45.81	76.59	125	133
New South Wales Murray	13.41	113.7	214	290
Loddon	38.58	185.7	424	495
Avoca	19.05	219	110	229
Murrumbidgee	43.68	214	180	312
Lachlan	8.16	na	9	68
Boundary Bend	5.48	233.3	0	150
Robinvale	2.31	242.7	68	71
Happy Valley	8.59	257.5	45	112
Colignan	4.64	265	45	53
Mildura	17.16	333.9	507	521
Lindsay	1.25	325.3	0	0
Border – Lock 5	10.79	362.6	148	335
Lock 5 – Lock 4	7.41	377.4	45	116
Lock 4 – Lock 3	14.60	400.4	60	166
Lock 3 – Lock 2	15.38	418.9	59	142
Lock 2 – Morgan	8.03	456.8	66	84
Total cost to agriculture	484.85			
Cost downstream of Morgan	77.66			
Infrastructure costs	46.04			
Total cost	608.55			

a The confluence with either the Murray or Darling River systems.

A Baseline costs to agriculture, by catchment, 2100



Goulburn–Broken catchment, ground water salinity is not sufficiently high to result in a large loss of productivity.

In the Goulburn–Broken, Macquarie–Bogan and Namoi catchments most of the costs are also caused by high water tables. However, in the Condamine–Culgoa catchment there is a substantial increase in river salinity that affects cotton yields in the second half of the simulation. Furthermore, the collective impact of increased river salinity in the Victorian and New South Wales Mallee is more than $95 million.

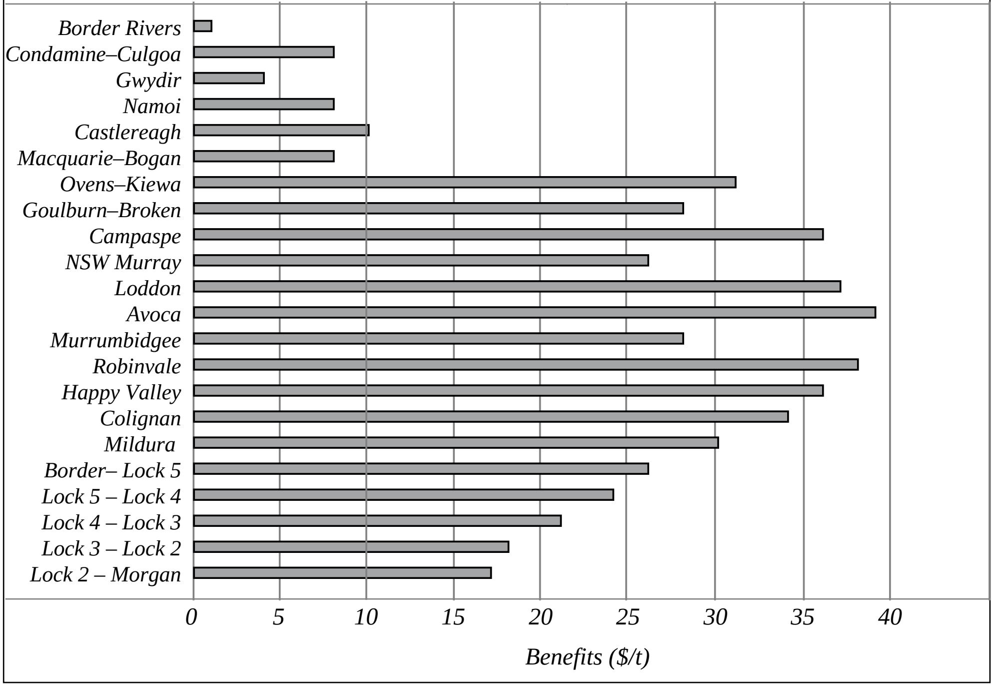
These costs should not be considered in isolation. There may be environmental aspects of land and river salinisation that impose substantial economic costs other than those measured and may not be measurable. However, it does appear that, in direct economic costs, it is possible to prioritise the catchments by the need for remedial action. At the same time, it is necessary to address the issue of whether cost effective action is possible given the technological options available at this time.

5. Model results

Reduced discharge

Simulations were undertaken in each catchment to determine the potential salinity benefits from reducing annual discharge into the main river. Reduced discharge from a catchment was simulated by enhancing or establishing ground water drainage schemes that removed between 2000 and 5000 megalitres of drainage water a year, depending on the total amount of discharge available. This would be equivalent, for example, to building a salt interception scheme in the lower reaches of a catchment. Salinity benefits from reduced discharge accrue to downstream irrigators through reduced concentration of irrigation water. There are no internal benefits from reducing discharge. Benefits are also derived for water users downstream of Morgan from improved water quality. The value of the salinity benefits to downstream catchments is shown in figure B.

B ***Downstream salinity benefits per tonne reduction in end of valley salt discharge, per year, by catchment***



There are three main drivers underlying the results.

First is the location of the catchment undertaking the action in the Murray–Darling River system. All other things being equal, the further upstream the catchment is in the system, the higher are the benefits from the action as more downstream users benefit.

Second, reducing discharge reduces the volume of both water and salt that flows into the main river. Therefore, the higher the ground water salinity in the catchment, the greater is the reduction in salt concentration for each tonne of salt removed. For regions that have high ground water salt concentrations, such as the South Australian Mallee, the salinity benefits of reduced discharge are relatively high, despite their downstream location.

Third, salt is being redeposited from rivers into the landscape in some regions. This can occur through seepage into regional aquifers and evaporation on flood plains. As the latter tends to be mobilised into the river system during floods, it has little impact on water quality. This will to some extent dissipate the downstream benefits of reduced discharge.

The results provide a measure of the downstream return to meeting an end of valley load reduction or target. Returns in the Darling system are relatively low, owing to the fact that roughly two-thirds of the salt mobilised from catchment in northern New South Wales and southern Queensland is redeposited in the landscape before it can reach the Murray River. While the upper catchments in the Murray system have relatively low ground water salinity, the returns are high given their location upstream of major horticultural areas. Returns are also high within the horticultural areas of the Mallee because of the high levels of ground water salinity. However, with fewer and fewer assets downstream, benefits decline moving downstream.

Recharge reductions

In this analysis, annual recharge was reduced in the major irrigation areas of Victoria, South Australia and the New South Wales Murray. The volume of recharge was reduced by 10 000 megalitres a year from each catchment at a time. The recharge experiments were run over a 100 year period to estimate a net present value (NPV) of the reduced costs of salinity to agriculture and to water users downstream of Morgan. The cost of the intervention is not included in this analysis. The results are listed in table 2.

Benefits from reductions in recharge are derived in two ways. Internal benefits accrue to the catchment undertaking the action if it results in a lowering

2 *The benefits from annual recharge reductions of 10 000 megalitres, by irrigation area*

Catchment	Internal benefits	External agricultural benefits	Benefits downstream of Morgan	Total benefits	End of valley salt reduction
	$’000, NPV	$’000, NPV	$’000, NPV	$’000	kt/yr
Ovens–Kiewa	895	94	30	1 082	1
Goulburn–Broken	1 980	100	30	2 110	1
Campaspe	4 607	621	190	5 418	9
New South Wales Murray	1 437	83	30	1 550	2
Loddon Barr Creek and Cohuna	1 012	1 908	960	3 880	13
Loddon Tragowel	457	223	110	790	2
Avoca **a**	na	na	na	na	na
Murrumbidgee	74	3	10	87	1
Boundary Bend	648	2 311	1 200	4 160	54
Robinvale	937	4 642	2 550	8 129	45
Happy Valley	200	500	320	1 020	
Colignan	0	2 160	1 450	3 610	33
Mildura	857	4 962	5 140	10 959	147
Border – Lock 5	0	5 040	7 370	12 410	144
Lock 5 – Lock 4	0	989	1 760	2 749	32
Lock 4 – Lock 3	0	150	470	620	9
Lock 3 – Lock 2	0	66	590	656	12
Lock 2 – Morgan	0	0	440	440	8

a Total recharge in the irrigation area in the Avoca catchment was less than 10 000 megalitres. **na** Not available.

of high water tables, reducing the cost of forgone agricultural production. The internal benefits are highest in the Campaspe catchment because of its relatively high ground water salt concentration in comparison with other Victorian catchments and high water tables in the irrigation area.

External benefits are derived from the improvement in water quality available to downstream users. As with the reduction in discharge simulations, location of the catchment undertaking the action is a major driver of the external benefits.

The main driver of the benefit profile is the response time of the aquifer underlying the irrigation areas. In irrigation areas that have aquifers with shorter response times, the benefits are derived sooner. The ground water salinity in each irrigation area is the main determinant of the volume of the reduction in salt loads with the largest reductions in the South Australian and Victorian Mallee. The combination of short response times, high ground water salinities and location upstream of high value horticultural areas means that the external benefits of recharge reductions in the Mallee are high, despite their downstream location.

Recharge reduction in the uplands

The establishment of plantation forestry can be an effective means of reducing recharge in the upland reaches of a catchment. However, the tradeoffs associated with changing land use to reduce recharge are determined by the hydrological characteristics of the flow system. Changing vegetation cover to increase the level of transpiration reduces both surface water yields and ground water recharge. The distribution of these losses depends on soil type and catchment topography. Losses of surface water yields will be greatest on sloped terrain with high clay content soils. The reduction in ground water recharge will be greatest on flat terrain with sandy soils.

The timing and extent of the salinity benefits from reduced recharge need to be weighed against any possible reduction in surface water yield. The reduction in surface water yield arising from large scale reforestation is relatively quick. In a slow responding aquifer, the reduction in saline discharge may not offset the costs to water users from the reduced availability of surface water, even in the longer term. Furthermore, the combination of a relatively quick reduction in surface water yields with a slow reduction in salt loads means there may be a short term increase in stream salt concentrations. That is, there is less fresh water to dilute the total salt load.

The impacts of widespread reforestation have been reported elsewhere and indicate it may not be a cost effective mitigation option given average characteristics of a catchment. (Heaney, Beare and Bell 2000). In general, reduced surface water yield under the cap on extraction for irrigation lead to significant costs to downstream irrigators through lower water allocations. At the same time, it can take considerable time before the reduction in runoff is offset by reduced ground water discharge. Hence, salt concentrations can increase in the short to medium term. As a consequence, upland reforestation does not tend to be a cost effective option for salinity management.

However, within the overall landscape there are likely to be smaller subsystems with a wide range of hydrological characteristics. Reforestation targeted to areas with specific hydrophysical characteristics may be cost effective. These areas may include areas of high salinity impact where the hydrological processes generate more favorable tradeoffs. The objective in the analysis presented in this section is to highlight the type of landscapes in which a targeted approach to reforestation is most likely to be more cost effective than broad scale plantation forestry.

In the analysis presented here, a small subsystem was added to the ABARE model to represent a hypothetical subcatchment of 5000 hectares located in the local flow system in the Macquarie–Bogan, Goulburn–Broken, Ovens–Kiewa and Murrumbidgee catchments. Of this, an area of 1000 hectares was planted to trees. An area of 500 hectares was assumed to be salinised in each catchment in the base year of the simulation.

In each simulation, these local flow subsystems were given hydrological profiles with different equilibrium response times and ground water salt concentrations. Each of the local subsystems was assumed to have clay–loam soils. A local flow system was chosen because other systems, with longer response times, are less likely to generate feasible reforestation options.

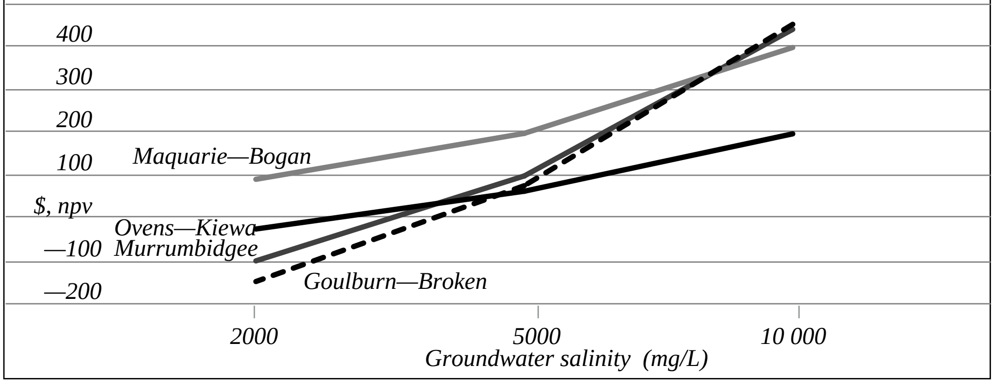
Salinity benefits in flow systems with areas of dryland salinisation are derived from two sources — improvements in water quality due to the reduction in discharge of saline water directly into streams, and the mitigation of high water tables. To the extent that the reduced salt loads translate to lower salt concentrations, this benefits downstream areas of the catchment. The reduction in high water tables is restricted to the ground water flow system where forestry is established because of the lack of connection between local ground water flow systems.

Net benefits in all the simulations were higher as ground water salinity increased. This is because the costs avoided by establishing forestry, when compared with the baseline, are higher at higher ground water concentrations.

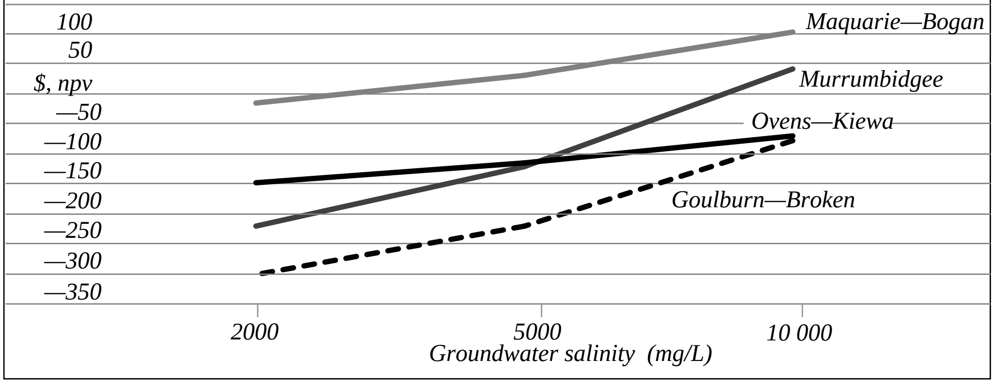
The land use change of the scale simulated leaves similar end of valley salt loads and surface water salt concentrations after the systems reach equilibrium. It is the timing of the reduction in area salinised that is the main determinant of the benefit profile. In aquifers with longer response times, there are no salinity benefits from the reduction in recharge until several decades after the land use change. In contrast, the costs associated with reforestation, such as reduced surface water yields and possibly a short term increase in stream salt concentration, are often more immediate. In aquifers with shorter response times, benefits are derived much sooner and are therefore more likely to offset these costs.

In each of the catchments, net benefits from targeted reforestation are derived at ground water salinities above 5000 milligrams per litre in aquifers with a 50 year equilibrium response time (figure C). In contrast, net benefits are derived in the Macquarie–Bogan catchment at ground water salinities above 5000 milligrams per litre when the equilibrium response time is 100 years (figure D). With the exception of the Murrumbidgee, net benefits from reforestation are negative even at higher ground water salinities.

C **Net benefits from targeted reforestation — 50 year equilibrium response time**



D **Net benefits from targeted reforestation — 100 year equilibrium response time**



Improvements in irrigation efficiency

The model has been developed to estimate the benefits of improved water use efficiency as a tool for salinity management in Victorian, South Australian and the New South Wales Murray irrigation areas. Investment in changing irrigation practices can have significant implications for salinity management in irrigation areas, as irrigation water use can affect ground water levels. Generally, irrigation causes ground water tables to rise over a much shorter time span than in dryland areas.

Water flow and water quality is affected by improvements in water use efficiency in two ways. First, internal benefits may accrue to the individuals undertaking the action as a result of more efficient agricultural production. Given that irrigators retain the right to water saved, internal benefits from improvements in water use efficiency are derived from an increase in agricultural revenue as a result of increased availability of irrigation water. There is also an associated increase in per hectare net revenue as producers incur lower water delivery costs.

Second, improved water use efficiency reduces return flows from both runoff and ground water discharge. The salinity of return flows can vary substantially depending on the relative mix of runoff versus ground water discharge. Hence, a change in water use efficiency can have either a positive or negative impact on downstream users. Further, as there is a delay between when the reduction in discharge from the improved efficiency is translated into a reduction in ground water discharge. Initially there may be costs imposed by reduced runoff which are then followed by the benefits of reduced salt load and concentrations. The extent to which a reduction in salt loads and concentration is achieved depends, among other things, on the response time of the ground water aquifer, the volume of the reduction in ground water leakage and the underlying ground water salinity.

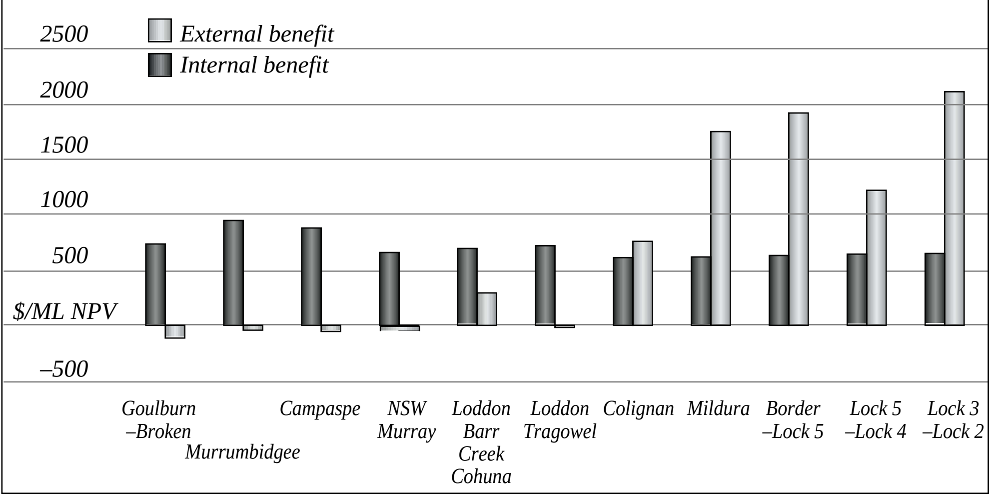
The overall net benefit from an increase in water use efficiency can be highly location specific. This is evident from the results of the water use efficiency experiments shown in figure E and in table 3. In the experiments, water use efficiency was increased by 5 per cent, leading to an equivalent percentage increase in ET and decline in return flows. Irrigators were allowed to retain

3 ***Effect of a 5 per cent uniform improvement in water use efficiency in the major irrigation areas for all irrigated activities***

Catchment	**Internal benefits**	**External agricultural benefits**	**Benefits downstream of Morgan**	**Total benefits**	**Total external benefits**
	$’000, NPV	$’000 NPV	$’000, NPV	$’000, NPV	$/ML **a** NPV
Goulburn–Broken	45 220	–4 730.56	–2 300	38 189.44	–114.17
Campaspe	12 920	–415.13	–390	12 114.87	–54.74
New South Wales Murray	80 990	–3 224.39	–2 180	75 585.61	–43.86
Loddon Barr Creek and Cohuna	15 870	4 462.66	2 240	22 572.66	293.02
Loddon Tragowel	10 460	–99.91	–170	10 190.09	–18.54
Murrumbidgee	96 740	–2 643.49	–1 790	92 306.51	–43.36
Colignan	1 804	1 316.33	920	4 040.33	1 369.23
Mildura	5 799	8 062.90	8 360	22 221.90	2 365.57
Border – Lock 5	2 702	3 351.10	4 860	10 913.10	2 546.28
Lock 4 – Lock 3	2 999	1 394.30	4 290	8 683.30	1 861.21
Lock 3 – Lock 2	2 329	756.80	6 810	9 895.80	2 756.38

a Expressed as total external benefits (agricultural benefits plus those derived downstream of Morgan) per megalitre saved through improved water use efficiency.

E External benefits and costs per megalitre of a 5 per cent uniform improvement in water use efficiency for all irrigated activities, by catchment



the water saved to expand production. Hence the overall reduction in return flows was less than 5 per cent and varied with the irrigation efficiency of the regions.

Overall, an improvement in water use efficiency in the upper catchments generates a negative external benefit. As these areas are characterised by large volumes of surface water runoff and low ground water salt concentrations, the reduction in return flows from irrigation increases salt concentration in the Murray River, reducing yields from irrigation water in downstream uses. Further, under cap conditions, the reduction in return flows reduces the quantity of irrigation water available for use in downstream irrigation areas. Positive external benefits are derived from improvements in water use efficiency in the lower reaches of the Murray River system where ground water salt concentrations are high and ground water response times are short relative to those in the upper reaches of the system.

The downstream benefits received and costs incurred from changes in water quality are not captured by the individuals taking the action but, instead, accrue to downstream users. As these external benefits and costs are nonexclusive and diffuse, institutional arrangements or public investment may be needed to get the optimal level of investment in water use efficiency.

Irrigators' rights to water saved through improved efficiency will influence their incentives to adopt or invest in water saving practices and technologies. To have an economically efficient level of investment in improving water efficiency the nature of these rights will need to be location specific. For example, in the upper catchments where there are negative externalities from reduced return flows, irrigators may be entitled to retain a proportion of the water saved. In the lower reaches of the Murray River, where there are positive externalities associated with reduced return flows, irrigators may need to receive compensation in excess of their water saving to generate an efficient level of investment.

6. Concluding comments

The results presented in this report have some general implications for the ongoing development of salinity management plans in the Murray Darling Basin. First, the direct economic costs of increased dryland and river salinity over the next 100 years are significant but are not, given the salinity audit projections, a serious threat to the viability of agriculture in the basin. Furthermore, the impacts of increasing dryland and river salinity vary substantially between river valleys and there is a strong argument for prioritising public expenditure in attempting to mitigate the problem.

However, there are two important additional considerations. One, there are environmental and perhaps other public assets that are or may be at risk that could warrant expenditure above the direct economic costs. Nevertheless, there are competing options for public expenditure to address environmental problems as well as to provide social infrastructure such as roads, schools and health care. A case may need to be made to ensure there is an adequate return to public investment in salinity management for environmental purposes. Two, there is a high level of uncertainty associated with timing and magnitude of the processes that lead to the mobilisation of salt within the landscape and waterways. New information could substantially change the implications of different management or business as usual options.

A second implication of the results presented here is that end of valley targets are not an adequate performance measure for salinity management. Taken in isolation, they may misdirect efforts toward cost effective management of salinity as they do not provide a good measure of internal catchment health nor do they provide any direct indication of the potential downstream benefits of meeting those targets. In general, the value of meeting a specific load reduction target is much greater along the Murray system than along the Darling.

A broader set of targets is required to promote cost effective investment in salinity management. For example, targeted reforestation may be a cost effective tool for mitigating emerging problems with dryland salinity. However, such a strategy is unlikely to have a significant impact on base flow ground water discharge and would therefore make little or no contribution to meeting an end of valley target.

A third implication of the results is that the potential contribution of changes in the location of irrigation areas and irrigation practices is substantial.

SALINITY MANAGEMENT

Reductions in irrigation recharge in some regions can lead to significant reduction in salinity concentrations in the River Murray in the medium term. To facilitate this, an effective water market that takes into account the salinity impacts of return flows may be required, as well as targeted private and public investment in water use efficiency.

References

Australian Water Environments 1999, *Assessment of the Trends in Salt Loads and Salinity Along the River Murray in South Australia*, Final Report, May.

Barnett, S., Yan, W., Watkins, N.L., Woods, J. A. and Hyde, J.M. 2000, *Murray Darling Basin Salinity Audit – Groundwater Modelling to Predict Future Salt Loads to the River Murray in SA*, Department for Water Resources, South Australia, Adelaide, December.

Bell, R. and Heaney, A. 2001, *A Basin Scale Model For Assessing Salinity Management Options: Model Documentation*, ABARE technical working paper 2001.A, Canberra, September (www.abareconomics.com).

Bell, R. and Klijn, N. 2000, A basin scale model for assessing salinity management options, ABARE paper presented at the Xth World Water Congress, Melbourne, 11–17 March.

Heaney, A., Beare, S. and Bell, R. 2000. 'Targeting reforestation for salinity management', *Australian Commodities*, vol. 7, no. 3, pp. 511–18.

Ivey ATP 2001, The current cost of dryland salinity to agricultural landholders in selected Victorian and New South Wales catchments, Report to the Murray Darling Basin Commission and National Dryland Salinity Program, Ivey ATP in association with Wilson Land Management Services, Wellington.

MDBC (Murray Darling Basin Commission) 1999, *Salinity Impact Study*, Report by Gutteridge Haskins and Davey Pty Ltd, Canberra, February.

MDBMC (Murray–Darling Basin Ministerial Council) 1999, *The Salinity Audit of the Murray–Darling Basin: A 100 Year Perspective*, Canberra, October.

Queensland Department of Natural Resources 2001, *Projection of ground water discharge and salt loads for the Queensland catchments of the Murray–Darling Basin – Draft report*, Resource Sciences and Knowledge, QDNR, Indooroopilly.

Zhang, L., Dawes, W.R. and Walker, G.R. 1999, *Predicting the Effect of Vegetation Changes on Catchment Average Water Balance*, CRC for Catchment Hydrology Technical Report 99/12, Canberra.