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Options for salinity mitigation in the Murray–Darling Basin

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Abstract:

The Murray–Darling Basin faces increasing pressure on water quantity and quality. In 2006-07, salt interception schemes implemented as part of the Murray–Darling Basin Salinity Management strategy removed over 470,000 tonnes of salt from the water supply, reducing the salinity of water flowing to Adelaide by about 200 EC units. However, the costs of salinity mitigation schemes are increasing. With possible continuing declines in average inflows, costs of salinity and salinity mitigation are expected to increase even further in the future. In this paper, a state-contingent model of land and water allocation is used to compare alternative options for salinity mitigation.

Key words: salinity, drought, water

The options for salinity mitigation in the Murray Darling Basin

1. Introduction

Humans have harvested water to irrigate naturally arid and semi-arid lands for thousands of years. Throughout this period, the problem of salinisation of soil and water has been a common and, in many cases, intractable, problem. The application of irrigation water not only transports new salt to an area but also raises the water table. The rising water table mobilises salt previously trapped in the soil profile, which rises to the surface and limits plant growth. Saline surface water is then concentrated by evaporation and returned to the water source through runoff. Rising salinity and loss of soil fertility is widely believed to have played a major role in the decline of some of the first large-scale civilisations based on irrigated agriculture, such as Sumeria (Jacobsen and Adams 1958).

Australian irrigation systems are particularly prone to salinisation and related problems of water quality. Many soils are saline, and flows of water are highly variable. Rising salinity threatens the function of Ramsar wetlands[1] in the Murray–Darling Basin (Australian Nature Conservation Agency 1996). Salinisation has adverse effects on crop yields, on the feasible range of production systems, and on the supply of potable water for urban use.

The gradual increase in salinity following the expansion of irrigation in the Murray–Darling Basin was among the first indications that constraints on sustainable use of water were being exceeded. By the early 1980s, the problem was already the subject of considerable research.

Policy responses have included a range of measures designed to reduce salinity, mainly by capturing and diverting saline flows before they enter the river system (Murray–Darling Basin Ministerial Council 2001). However, costs of salinity mitigation schemes are increasing, and, with possible continuing declines in average inflows, these costs are expected to increase even further in the future. It is therefore of interest to identify the most cost-effective policy options for salinity mitigation.

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[1] Ramsar wetlands are wetlands of international significance, designated under the Convention on Wetlands negotiated at Ramsar, Iran in 1971.

This paper will examine the costs and benefits of alternative approaches to salinity management, using a state-contingent model of land and water use under uncertainty (Adamson, Mallawaarachchi and Quiggin 2007). The model incorporates the relationship between water use, salt loads and salinity and the effects of salinity on potability, agricultural production and environmental services. The effects of salinity mitigation measures are modelled under current conditions and under a climate change projection in which droughts become more frequent.

The paper is organised as follows. Section 2 is a general description of irrigation, water use and salinity in the Murray–Darling Basin. The current salinity mitigation program and the implications of future changes to water flow and salinity levels are discussed. In section 3 the modelling approach of Adamson, Mallawaarachchi and Quiggin 2007) and some details of the model are presented. Section 4 contains model simulations, which are used to assess the costs and benefits of alternative salinity mitigation options. Finally, in Section 5, some concluding comments are offered.

2 Salinity and its Management in the Murray–Darling Basin

The Murray–Darling Basin

The Murray–Darling Basin covers over one million square kilometres in south-east inland Australia. Water flows through Queensland, New South Wales, Victoria, the Australian Capital Territory and down to South Australia where supplies are then drawn off to augment Adelaide's potable water for 1.1 million inhabitants (Australian Bureau of Statistics 2006).

Water from the Basin is used for urban supplies, recreational facilities, as drinking water for stock, for irrigation of agricultural crops, and to provide environmental services to the 2.7 million people living in the Basin (Murray–Darling Basin Commission 2006a), as well as to other Australians. The Murray–Darling Basin produces over 40 per cent of Australia's total gross value of agricultural production. It uses over three-quarters of the total irrigated land in Australia, and consumes 70 per cent of Australia's irrigation water (Australian Bureau of Statistics 2007).

Management of the Basin is a complex process involving collaboration between private, quasi-public and public (state and federal) organisations with different policy concerns, resources, capabilities and levels of knowledge. The Murray–Darling Basin

Agreement, between the Commonwealth and the governments of New South Wales, South Australia, Victoria, Queensland and the Australian Capital Territory, focuses on the promotion and coordination of effective planning and management to ensure reasonable, efficient and sustainable use of the Murray–Darling Basin's resources (Murray–Darling Basin Commission 2006b).

The National Water Commission established in 2004 under the National Water Initiative, is responsible for 'helping to drive national water reform and advising the Minister for Climate Change and Water and State and Territory governments on water issues'. (National Water Commission 2008).

With increased public concern over the future of the Basin, the number of policy actors and the range of potentially conflicting interests and objectives has increased further. The severe drought conditions currently prevailing have exacerbated the difficulties of managing the Basin to achieve sustainable resource use.

Salinity

Salinity has long been a focus of policy and public concern in the Murray–Darling Basin. The Basin is a naturally saline environment, and large quantities of salt have accumulated in the underlying water table. Human activities, including irrigation and land clearing, have brought salt from the water table to the surface and into runoff entering streams, with negative effects on soil and water quality. The severity of these effects depends upon the spatial characteristics of catchments, rainfall and human modification to the landscape.

Salinity has adverse effects on agricultural producers, the environment, infrastructure and urban water supplies. Effects include reductions in crop yields, damage to roads and buildings, reduced quality of drinking water and damage to appliances and urban water systems.

Flow volatility and irrigation practices influence the salinity levels recorded in the Basin. Table 1 provides a record of salinity levels at Morgan[2] since 1975, measured in electrical conductivity (EC) units[3].

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[2] Morgan in South Australia is 165 km northeast of Adelaide. It is chosen for salinity measurement because it is the source of the Morgan–Whyalla pipeline, and is upstream of the source for the Mannum–Adelaide pipeline.

As noted by the Murray–Darling Basin Commission (2007a), while the initial effect of drought conditions is to reduce inflows of salt to the Basin, sustained drought conditions raise the risk of increased salinity. The current low salt levels are, in part, also due to the implementation of new salinity mitigation schemes and to management of water releases from the Hume Dam to ensure that Adelaide's water is potable (Murray–Darling Basin Commission 2007b).

Table 1 Summary of Salinity Levels recorded at Morgan (EC Units)

	Time interval	**Average**	**Median**	**95 percentile**	**% Time > 800 EC**
1 year	July 2006 – June 2007	377	378	452	0
5 years	July 2002 – June 2007	411	386	615	0
10 years	July 1997 – June 2007	477	459	709	0
25 years	July 1982 – June 2007	553	523	937	11
25 years	Recorded 1975–2000	632	608	1,061	23

Source: Murray–Darling Basin Commission 2007a

Salinity management

The Murray–Darling Basin Agreement lists a series of goals for salinity levels in the Basin. The central goal is to ensure that, 95 per cent of the time, the salinity of Adelaide's water supply is less than 800 EC units. Further targets include: maintaining water quality for the shared water resources of the Murray and Darling Rivers; controlling the rise in salt loads in all tributary rivers in the Basin; controlling land degradation; protecting important terrestrial ecosystems, productive farm land, cultural heritage and built infrastructure; and maximising the net benefits from salinity control across the Basin (Murray–Darling Basin Ministerial Council 2001).

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[3] The electrical conductivity (EC) of soil or water is determined by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. EC is measured in microsiemens/cm (for a specified measurement cell at 25 degrees C).

Some of these goals were partly achieved by introducing a Cap on diversions of water from the Basin in 1994. The Cap was designed as interim measure to prevent overuse of water supplies until a sustainable system of property rights could be introduced. However, it remains an important element of the management system for the Basin, in large measure because property rights systems have not functioned as well as expected, and have been subject to a range of restrictions (Bell and Quiggin 2008).

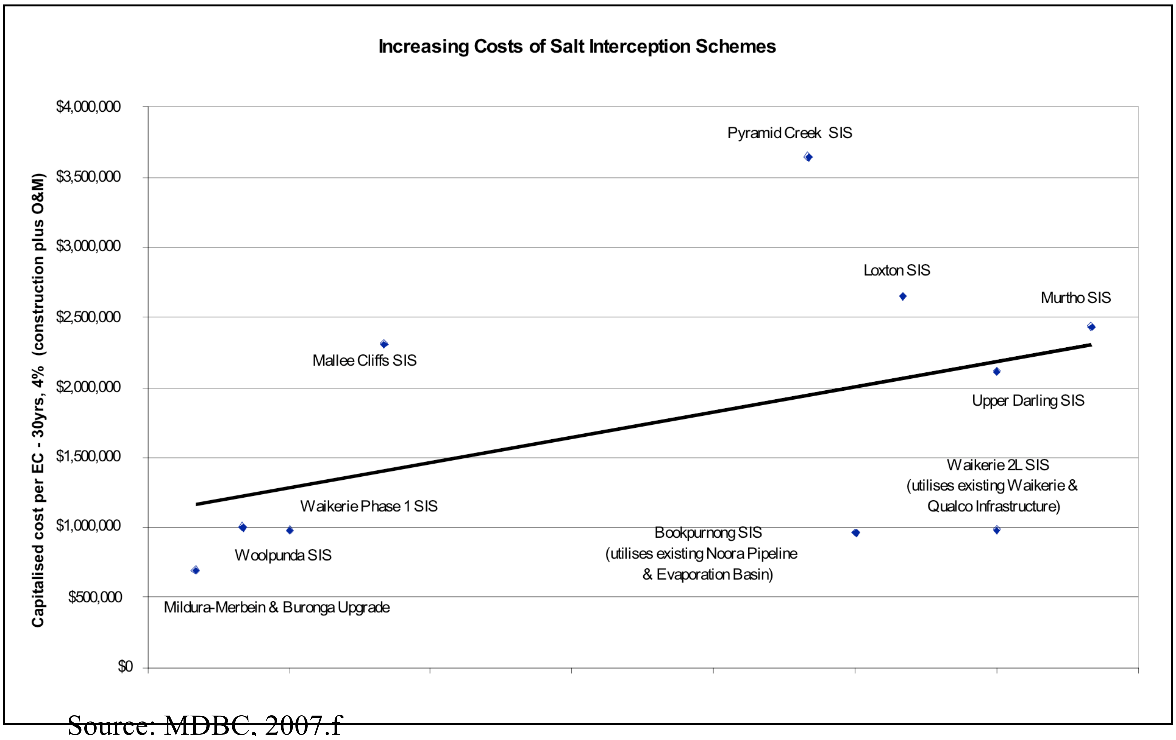
Table 2: Salinity Mitigation Schemes in operation 2006-07

Location	**State**	**Operation started**	**Construction Cost ($m)**	**Salt diverted (tonnes) ****
Barr Creek	Victoria	1968**	n/a	30,084
Mildura–Merbein	Victoria	1981**	<20*	39,844
Rufus River	Victoria	1984*	3.3 *	22,577
Woolpunda	SA	1990*	25 *	101,800
Waikerie	SA	1992*	3.4 *	58,300
Mallee Cliffs	Victoria	1994**	n/a	62,550
Buronga	Victoria	2004/05*	3.96	87,930
Bookpurnong	SA	2005*	11.2 *	39,569
Pyramid Creek	Victoria	2006	>10*	28,475
Total				**471,129**

Sources:
 * SA Water 2007
** Murray–Darling Basin Commission 2007a 2007d

In addition to measures to promote more sustainable water use, a number of schemes have been introduced to mitigate salinity by intercepting and diverting saline flows. The Basin's first salinity mitigation scheme started in 1968. Table 2 provides a list of existing schemes, their location, the year their operation commenced, construction costs and quantity of salt (tonnes) diverted in 2006-07.

The cumulative effect of these schemes has been to remove 470,000 tonnes of salt from the Basin each year. It is estimated that the schemes have reduced the salinity level recorded at Morgan by between 80 and 265 EC units (Murray–Darling Basin Commission 2007a).



Source: MDBC, 2007.f

Figure 1 Capitalised cost per EC over time

As is shown in Figure 1, the cost of salinity schemes has risen over time. Early schemes such as Mildura–Merbein cost as little as $0.5 million for each EC unit reduction in salinity levels. More recent schemes such as Pyramid Creek have costs approaching $4 million for each EC unit reduction.

Drought, climate change and salinity

The severity of this drought was highlighted in 2006-07 when runoff into the Murray River was the lowest on record at 1,040 Gigalitres (GL)[4], some 10,000 GL less than the annual average inflow of (11,100 GL). The previous recorded lowest was 2,000 GL in 1914-15 (Murray–Darling Basin Commission 2007a), at a time when total annual diversions were also around 2,000 GL (Murray–Darling Basin Ministerial

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[4] A Gigalitre (GL) is equal to a thousand Megalitres or a billion litres.

Council 2000). By 2005-06 extractions were over 9,000 GL (Murray–Darling Basin Ministerial Council 2007) from 6,530 GL of inflow.

The ability to supply irrigators with significant volumes of water in periods of very low inflows has been due to the building of water storages and to transfers of approximately 1,100 GL annually from the Snowy River (Murray–Darling Basin Commission 2006a). The Dartmouth Reservoir, Hume Reservoir, Lake Victoria and Menindee Lakes are the main storages in the Basin. They have a total storage volume of 9,352 GL. However, as a result of prolonged drought, these storages fell below 20 per cent of capacity (1,896 GL) by late 2007 (Murray–Darling Basin Commission 2007c), implying that the capacity for further releases is limited.

Scientific evidence suggests that we are facing anthropogenic global warming, which is likely to alter climate conditions for the Basin. Projected outcomes include more frequent droughts, along with higher temperatures and evaporation, leading to lower inflows into the Basin.

Although the initial impact of the drought was to reduce salinity, the South Australian section of the Basin is likely to face higher salinity levels as a longer term impact of changing conditions (Murray–Darling Basin Commission 2007c). Therefore it is important to evaluate alternative options for further salinity mitigation in the Basin.

3 Model specification and mitigation options

This analysis is based on an application of the state contingent Murray–Darling Basin model documented in Adamson, Mallawaarachchi and Quiggin (2007). Responses to changes in average inflows and in the pattern of inflows, arising from climate change have been simulated by Adamson, Mallawaarachchi and Quiggin (2008) and Mallawaarachchi et al. (2007).

The model can be solved using two different solution concepts. The sequential solution is the allocation of land and water that maximises the return to a representative farmer in each catchment subject to a series of constraints on the use of water, land and labour. The model is solved sequentially, with the allocation of water in upstream catchments determining, along with natural inflows, the quality and quantity of water available in downstream catchments.

The global solution is the allocation of land and water that maximises returns for the Basin as a whole, including returns from irrigated and non-irrigated agriculture, returns from urban water use in Adelaide, and the estimated social value of environmental flows. Results from the global solution are considered as a benchmark against which alternative institutional arrangements can be compared.

The model uses linear programming to maximise the economic return for the Basin at a Catchment Management Authority scale for 20 regions (k= 1…20): 18 catchments, Adelaide, and a measure of flows at the end of the river system. The last two regions allow for the representation of water quality arriving at Adelaide and a proxy value for environmental flows.

The model includes 15 commodity production activities (M) producing state-contingent outputs in three states of nature (S=3, Wet, Drought and Normal). Model solutions are derived by allocating land and water between the production systems subject to constraints on the availability of land, labour, capital and water. Returns to activities are affected by the salinity of water flows, which in turn is affected by upstream water use and by variation in natural inflows.

The state contingent approach chosen in this model is based on the recognition that individuals adapt to changing conditions as the season changes. Therefore, the model describes three state-contingent forms (Wet, Drought and Normal) of each commodity under the possible states of nature (M*S).

The model is a description of farming activities producing one or more state-contingent commodities. For example, the 'Rice' activity produces wheat and vegetables as well as rice, as part of a crop rotation. The same commodity may be produced by different methods, with different water requirements. For example the 'fixed' cotton production system models a crop rotation that produces an irrigated crop in all states of nature. By contrast, the 'flexible' cotton production system assumes that a dryland crop is planted in the drought state of nature.

Flows of water and salt are represented by a directed water flow network that incorporates state contingent water flows and salt loads, using data provided by the Murray Darling Basin Commission.[5] The model defines salinity as:

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[5] Thanks to Andy Close and Cris Diaconcu from MDBC for the water and salinity dataset.

$$\sigma^k{}_s = s^k{}_s / f^k{}_s$$

where:

$\sigma^k{}_s$ is the salinity in region *k,* state *s*;

$s^k{}_s$ is the salt load in region *k,* state *s*; and

$f^k{}_s$ is the water flow in region *k,* state *s.*

Salinity can be reduced either by increasing water flow or by reducing salt load.

Salinity mitigation options and climate change

We begin by modelling three reference cases:

- Current climate conditions[6] with mitigation of 430,000 tonnes of salt each year through salinity interception schemes;
- Current climate conditions without salinity interception schemes; and
- Increased probability of Drought states with mitigation of 430,000 tonnes of salt each year through salinity interception schemes.

The analysis of these reference cases shows that increasingly frequent droughts may, in the long run, offset the benefits of existing salinity mitigation schemes in whole or part. To analyse possible responses we take the reference case with increased probability of Drought states as a baseline and simulate alternative engineering and water management regimes that might be adopted in response climate change. We will examine the following options:

- Increased salinity mitigation through investment in more salinity interception schemes;
- A reduction in the Cap on aggregate water use for irrigation in each catchment;
- An optimised trading system yielding the global solution in which returns for the Basin as a whole are maximised.

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[6] Current climate conditions are defined as a probability distribution over inflows which approximately matches the mean and standard deviation of historical data for the period 1900-2000

4 Results and Discussion

The results of the three reference case scenarios, the alternative engineering and management options for salinity mitigation and the theoretical optimum are presented and discussed in this section.

Detailed specifications of the scenarios are presented in Table 3. The first column lists the six scenarios modeled.

The next three columns of Table 3 show the probabilities for each of the three states of nature (Wet, Drought and Normal). In the 'Baseline' and 'No mitigation' scenarios, the probabilities are 0.3 for Wet, 0.2 for Drought and 0.5 for Normal. In all other scenarios, the probability of Wet decreases to 0.2 and the probability of Drought increases to 0.3.

The fifth column of Table 3 shows the amount of salt removed from the Basin through mitigation works. The current level of 430 000 tonnes is assumed for all scenarios except 'No mitigation' (no salt removed) and 'Increased mitigation' (530 000 tonnes removed).

The sixth column of Table 3 shows the assumed Cap on extractions from each catchment, expressed as a percentage of the existing Cap. This value is 100 per cent for all scenarios except the 'Reduced Cap' scenario (90 per cent) and the optimal allocation, where no Cap is imposed.

The final column shows the solution concept used. The global solution concept is used for the optimal allocation, and the sequential solution concept for all other scenarios.

Results

The results are summarised in Table 4. Each row of Table 4 presents simulated values for variables of interest (water use, environmental flows, salinity and economic value) for a given scenario. These variables are as follows.

Water use is total water consumed in agricultural and urban use (in GL). Since drought is of particular concern, water use for the Drought state is reported along with average water use (the probability-weighted mean water use across all three states of nature).

Environmental flows are measured by the volume of water flowing to the mouth of the Murray River and into the sea along with average environmental flows and flows in the Drought state.

Drought state and average salinity levels are reported, measured as the salinity in EC units of water supplied to Adelaide. This measure corresponds closely to the level of salinity at Morgan, the main target variable for the Murray Darling Basin Commission's salinity strategy.

The average economic value of water in the Basin is divided into two components. Use value is the value derived from water use in agriculture and urban use in Adelaide. Environmental value is the value imputed to environmental flows, calculated at a rate of $100/ML.

Baseline

The results of a 'Baseline' simulation are presented in the first row of Table 4. The Baseline simulation includes the effects of existing salinity mitigation schemes, estimated to reduce salt load by 430 000 tonnes each year.

The economic value derived from the Basin as a whole, including urban use in Adelaide and the value of environmental flows is estimated at $5,533 million.

Under the baseline simulation, the salinity of water supply to Adelaide is maintained at levels below 600 EC in all states of nature.

No mitigation

To assess the impact of existing mitigation activities, which extract 430,000 tonnes of salt from the system each year, the model can be solved in the absence of mitigation. The results for the 'No mitigation' simulation are shown in the second row of Table 4. Comparing the 'No mitigation' results to those for the Baseline simulation, the reduction in salinity from existing salinity mitigation works is estimated at and 215 EC in the Drought state and 114 EC on average. This is consistent with the Murray–Darling Basin Commission (2007a) estimate of salinity benefits of between 80 and 265 EC from the Salinity and Drainage Strategy.

The reduction in salinity is estimated to increase average economic value by $137 million, from $5396 million to $5,533 million. On these estimates, each reduction of 1 EC unit increases annual economic value by approximately $1.2 million.

As noted above, the capital costs of existing salinity mitigation schemes have generally ranged from $0.5 million to $2 million per EC removed, implying annual costs of less than $0.2 million per EC removed. Since operating costs are modest, the results derived here suggest that previous interventions have yielded substantially positive net benefits.

Increased Drought

The third row of Table 4 shows the estimated results of a decline in average inflows, modeled as an increase in the probability of the Drought state from 0.2 to 0.3 with a corresponding decline in the probability of the Wet state from 0.3 to 0.2 As a result of this change in the probability distribution, average inflows decline by 1280 ML.

In this simulation, average salinity levels rise to 608 EC. More importantly, estimated salinity levels in the Drought state rise to 948 EC. This result implies that the target level of 800 EC would be exceeded in around 30 per cent of years.

In the absence of changes in the Cap and other water allocation policies, water use in irrigation declines by 365 GL and average environmental flows decline by 916 GL. After taking account of adaptation measures such as reduced water intensity, the increased frequency of drought lowers the economic return on average from $5,533 million to $4,954 million per annum: a decrease of $579 million.

The increased frequency of drought causes significant shifts in land allocation as producers adapt to the increased probability of poor water availability. Detailed results on the allocation of land are presented in an Appendix, available from the authors. In general, as would be expected, farmers switch to technologies that use less water. The shift to less water intensive production technologies is particularly evident in the dairy industry, where 300,000 Ha transfers from high water technologies to less water-intensive technologies.

Increased Drought with increased mitigation

The fourth row of Table 4 shows the results of simulations in which intervention measures remove an additional 100 000 tonnes of salt per year. After removal of an additional 100 000 tonnes of salt, salinity in the drought state is estimated to reach 873 EC, above the desirable threshold of 800 EC.

The simulated land allocation (available as an Appendix) is similar to that for the 'increased Drought' scenario. This reflects the fact that the availability of water and the policy framework are similar in the two scenarios. Although lower salinity levels produce higher crop yields for the SA MDB region, these changes are not sufficient to induce a change in land use. Hence, the benefits of salinity mitigation are reflected in higher yields for existing land uses in the SA MDB and in improved water quality in Adelaide, but not in changed land allocations either in this region or upstream.

The model results imply that removing an additional 100,000 tonnes of salt from the lower Murray Darling Basin improves the salinity of Adelaide's supplied water quality by about 75 EC units and increases economic return by $32 million. The cost of currently available options for salinity mitigation is estimated to range from $2 million to $4 million for each EC removed (see Fig 1), implying a capital cost of $150 million to $300 million. The estimated rate of return is therefore between 11 per cent (32/300) and 21 per cent (32/150).

Further simulations, not reported in the table, modelled the removal of 200 000 and 300 000 tonnes of salt per year. Because the relationship between salinity and crop yield is nonlinear, salinity mitigation yields diminishing marginal returns over the range modelled here. Increasing the mitigation effect from 100 000 to 200 000 tonnes per year increases economic return by a further $32 million. Increasing from 200 000 to 300 000 tonnes per year adds an extra $24 million to economic return.

Moreover, as the cheapest options for salinity mitigation have already been adopted it is expected that each additional tonne of salt removed would become more expensive through time. Thus, the critical discount rate for the final 100 000 tonnes would be below 10 per cent.

Increased Drought with reduced Cap

Changes in water allocation represent a potential alternative to increased mitigation as a response to an increased frequency of Drought states. Within the existing policy framework, the simplest response is to reduce the Cap on aggregate water allocations

In the fifth row of Table 4, we report the results of a simulation in which the Cap on average extractions is reduced by 10 per cent, broadly in line with the reduction in inflows projected to take place under the increased frequency of Drought states considered here.

Such a reduction in water use could be met in a number of ways: by reducing all allocations proportionally, by reducing the security of supply associated with some water rights, or by purchasing water rights and allocating them to environmental flows

In this simulation, the average salinity of Adelaide's water supply is reduced to 516 EC and to 763 EC in the Drought state is reduced, compared to 607 and 948 EC in the absence of changes to the Cap. Salinity in all states is projected to be below 800 EC in all years. However, it is likely that seasonal variation and other sources of uncertainty would cause the target level to be exceeded at some periods.

Estimated economic returns from the Basin decline from $4954 milliom to $4916 million in this projection. However, possible uncounted or under-accounted benefits from improved water security, relative to the case when the Cap is not adjusted in response to higher drought frequency, need to be considered.

Increased Drought with optimized water allocation

The final row of Table 4 presents results for the globally optimal allocation of land and water, assuming an increase in the frequency of Drought states and the continuation of existing salinity mitigation schemes. The global solution is that which would be expected to arise as a long run equilibrium under conditions of an optimally designed system of water rights, taking account of salinity impacts, with free trade of water between catchments and between agricultural, urban and environmental uses.

The globally optimal allocation yields higher economic value, and lower salinity than the alternative responses to an increase in the frequency of Drought. The outcomes are fairly similar to those for the baseline simulation, implying that, in the long run, improvements in water allocation could offset the adverse effects of an increase in the frequency of Drought.

Detailed analysis of the allocation of land between regions and crops (available as an Appendix from the authors) shows that the optimal allocation involves a reduction in the use of water (particularly for irrigated pasture for dairying) in upstream catchments and an increase in the use of water for horticultural crops in downstream catchments. This is consistent with the results derived by Adamson, Mallaawaarachchi and Quiggin (2007) under the assumption that historical patterns of climate variability are maintained.

The solution derived here reflects the assumption of a relatively modest increase in the frequency of drought. With a further increase in drought frequency, most horticultural crops become uneconomic, as does irrigated pasture, because of the high cost of ensuring a stable supply of water in all states of nature. The optimal solution then favours opportunity cropping, with a focus on annual crops such as wheat and cotton, which can be planted after the availability of water is known.

Concluding comments

Salinity and other water quality problems are likely to be exacerbated by climate change. Some combination of engineering measures to intercept and divert highly saline flows and policy measures designed to ensure sustainable levels of water use is required as a response.

The simulations reported here suggest that further interventions to mitigate salinity could be cost-effective. However, as the marginal cost of mitigation increases, it will be necessary to adjust the existing allocation of water rights. An improved allocation of water rights could offset most or all of the economic loss associated with an increase in the frequency of drought arising from climate change.

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