

Modelling the Economic Benefit of Cap and Trade for Irrigation Salinity Management

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Abstract

Irrigated agriculture often leads to recharge to the regional groundwater systems greater than what the systems can absorb, resulting in the development of shallow watertables causing salinity and waterlogging. A cap and trade based policy could be a method to control net recharge in an irrigation district. An allocation of net recharge contracts to irrigation farms will internalise the costs associated with the management of net recharge to the groundwater. Irrigators may reduce their costs of meeting net recharge contracts via creating or purchasing credits that reduce recharge through perennial vegetation, engineering solutions or crop rotation options. Key outcomes are anticipated to be reduced cost of meeting groundwater management targets and increased agricultural and environmental production into the future in the region. This paper will outline the nature of the economic impacts of adopting such a policy in the Coleambally Irrigation Area.

Keywords: salinity, irrigation, recharge, tradeable credits, cap and trade, hydrologic-economic modelling

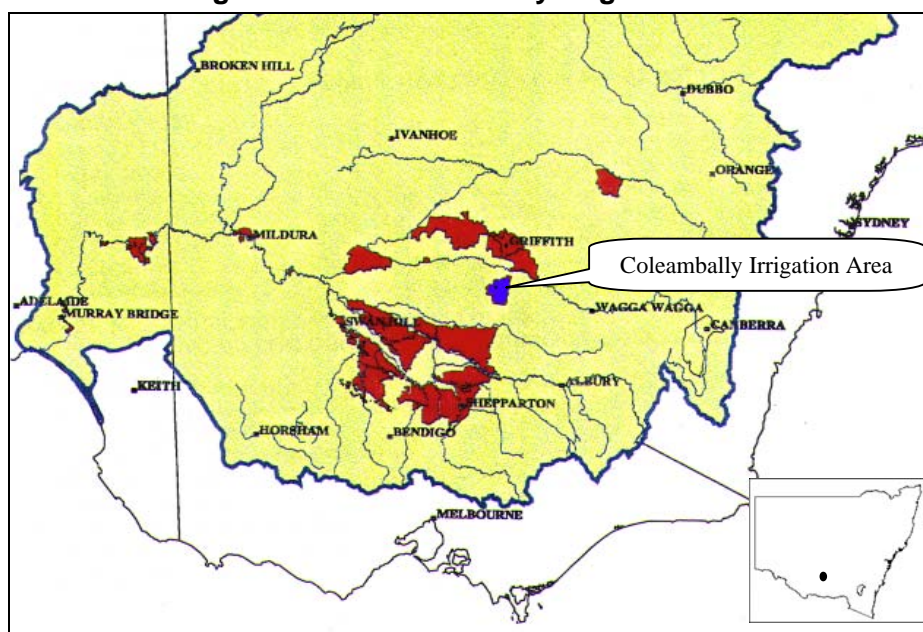
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1. Introduction

Irrigation induced salinity is a well known problem in mature irrigation areas across Australia. Irrigated agriculture often leads to recharge to the regional groundwater systems greater than that which the systems can absorb, resulting in the development of shallow watertables causing salinity and waterlogging. The consequences of salinity in irrigation areas include production losses, increased production costs and damage to environmental and infrastructure assets in the region.

The Coleambally Irrigation Area (CIA) in south-west New South Wales (Figure 1) is a region not immune to irrigation induced salinity. The CIA was developed in the 1960's following the completion of Blowering Dam on the Tumut River. The CIA encompasses approximately 79,000 ha of which approximately 97% is developed for irrigation. The CIA has a bulk water entitlement of approximately 629 ML which is diverted from the Murrumbidgee River. The main crops grown in the area include rice, maize, soybean, winter cereals, canola, and pastures for livestock. Prior to irrigation, the watertables in the CIA were around 20 metres (Khan et al., 2002). However, due to recharge to the groundwater from inefficient irrigation practices, leaky channels and recharge from rainfall, a significant proportion of the CIA now has watertables within 2 metres of the soil surface (Coleambally Irrigation Co-operative Limited, 2003). Shallow watertables induce waterlogging and soil salinisation, both of which have a negative effect on crop production, infrastructure and the environment.

Figure 1: The Coleambally Irrigation Area



A number of instruments have been adopted to address the threat that irrigation induced salinity poses to the CIA and other communities. These have included regulatory approaches limiting rice crop areas and water use, identification and sealing of leaky channels, deep groundwater pumping, education and training directed towards improving on-farm water use efficiency and net recharge management, and direct incentives via the Land and Water Management Plan (LWMP) to improve on-farm water management. Each of these actions has had some success in reducing recharge and the incidence of irrigation-induced salinity. However, no strategy to date has been wholly successful in achieving community management. As a consequence there is a significant risk that the area and severity of waterlogging and salinity will increase in the CIA if further action is not taken.

This paper is the result of research into the exploration and development of tradeable recharge rights as a tool to manage irrigation induced salinity in the CIA. The project is a pilot under the National Market Based Instruments Pilots Program. The focus of the research is to determine the efficiency gains to the CIA of a cap and trade policy compared to other policies for recharge management and to develop practical solutions on how to implement a cap and trade framework as a potential policy solution to the waterlogging and salinity problem. A tradeable recharge scheme is being investigated because it offers potential efficiency, equity, effectiveness and flexibility advantages over current and historical recharge management policies. The cap within the framework allocates responsibility for individual recharge contributions to the shared groundwater aquifer. A trading framework facilitates flexible adjustment by allowing a differential reduction in recharge between farms within the overall cap. Further flexibility is offered by the potential for non-irrigation actions to offset the impacts of irrigated agriculture. The additional flexibility within a cap and trade network facilitates potential efficiency gains compared to other policy instruments as trade can take advantage of the different marginal costs of recharge abatement between irrigators and time periods.

The imposition of an irrigation recharge cap and trade framework would also create a number of costs and benefits to irrigators through changes to agricultural production, and also to the local and wider community through protection of infrastructure, biodiversity and reduction in potential negative downstream impacts. The hypothesis explored in this paper is whether the gains from trade accessed by a cap and trade mechanisms are sufficient to outweigh the costs of changing management? Also, to determine whether the efficiency gains from cap and trade are greater than other mechanisms to meet specific recharge abatement targets? The primary focus in this paper is on the costs and benefits to irrigation farmers. This is effectively a threshold value analysis because almost all costs of changing management are imposed on irrigation farmers, while benefits accrue to both irrigation farmers and the wider community. If a cap and trade policy generates a net benefit to irrigation farmers then the policy would be worthwhile adopting because the additional benefits to the wider community that are not estimated in this report are likely to enhance the net benefits of adoption.

The applied economic modelling presented in this report is dependent on identifying and defining an appropriate biophysical context and the impacts of changing management on the biophysical outcomes generated through time. The biophysical context is the basis for defining the future stream of costs and benefits if ‘business as usual’ was continued and, therefore, the comparative impacts of changing management. Defining an appropriate context is complicated where there are potential environmental thresholds or discontinuities in the biophysical responses to either natural events or management actions that then impact on the economic values generated from the system. In the Coleambally region there remains considerable uncertainty as to the nature of potential thresholds and their potential interaction with potential management actions or climatic events. Therefore, particular attention is paid to defining the nature and implications of assumptions that underpin the biophysical context for the conclusions drawn in this paper. Because of the uncertainty the conclusions in this report should be regarded as preliminary and subject to review when additional information becomes available.

The paper is structured as follows. A broad overview of the important biophysical issues and methodological framework underpinning the incorporation of biophysical impacts into an economic analysis is described in the next section. Section 3 gives an outline of the methodology and assumptions used for the economic analysis. The resultant cost and benefit estimates for the alternative recharge abatement policies are presented in Section 4 along with some interpretation where necessary. A discussion of the conclusions from the economic modeling, along with the next research steps, completes the paper.

2. Concepts and methodological framework

Irrigated agriculture often leads to recharge to the regional groundwater systems greater than what the natural systems can absorb without increasing the risk of inducing salinity and waterlogging problems. Net recharge to the groundwater system occurs because the aggregate water supplied to the soil profile exceeds the evapotranspiration of crops, leaching requirements of soils, and water movement within underlying groundwater systems.¹ With continued net recharge watertables eventually rise to a point where they cause waterlogging and subsequent soil salinisation. In turn salinity and waterlogging reduce agricultural productivity and thus reduce the potential monetary returns from agriculture.

Further action is required in the CIA to achieve sustainable levels of recharge. A cap and trade based policy could be a method to control net recharge in an irrigation district. An allocation of net recharge contracts to irrigation farms will internalise the costs associated with the management of net recharge to the groundwater. Irrigators may reduce their costs of meeting net recharge contracts via creating or purchasing credits that reduce recharge through perennial vegetation, engineering solutions, or crop rotation options. Key outcomes are anticipated to be reduced cost of meeting groundwater management targets and increased agricultural and environmental production into the future in the region. Various recharge abatement policies are assessed to determine which policy has the potential to create the greatest net benefit to the CIA.

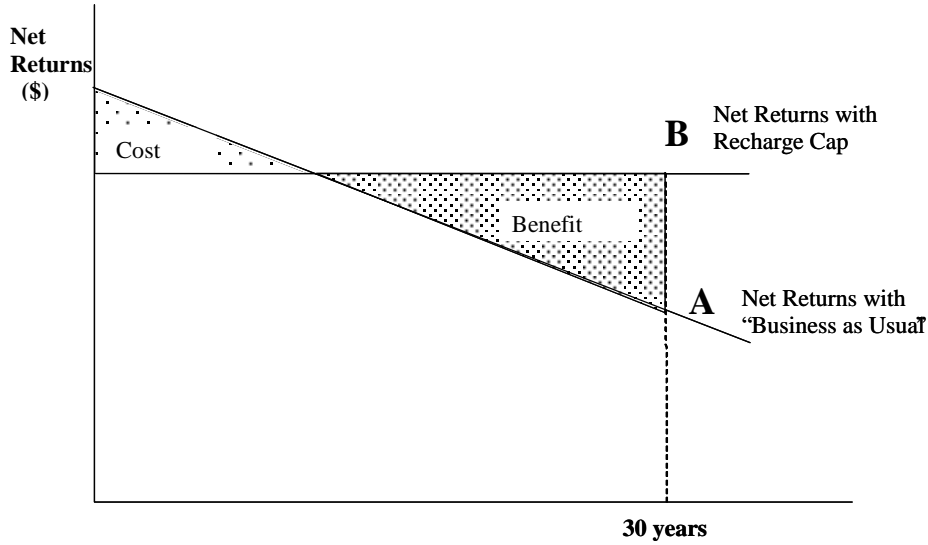
2.1. *The economic analysis framework*

There are a number of potential policy options available to assist in managing net recharge including market-based and regulation based approaches. Policy selection is generally based on selecting the policy that is estimated to generate the greatest net benefit to the community. Effective policy selection is therefore predicated on accurate estimation of the relative benefits of alternative courses of action. The alternative courses are normally compared against continuing current management, termed the ‘do nothing’ or ‘business as usual’ (BAU) outcome. BAU is defined as the set of biophysical outcomes and commensurate economic outcomes that would occur with no change to policy.

It is important to note that BAU does not mean a static outcome. As an example of the alternative courses of action consider Figure 2. Continuing BAU is likely to lead to declining yields and net annual returns to irrigators as waterlogging and salinity increasingly impact on production – represented by line ‘A’. BAU is contrasted against potential policies intended to avoid future waterlogging and salinity. These policy alternatives effectively impose a sustainable recharge limit that is estimated to control watertables at a required depth to minimise salinity impacts. Line ‘B’ depicts the impacts of one potential alternative policy. Initially, the policy decreases the net annual returns to irrigators due to changed management practices. However, returns are maintained into the future by removing future waterlogging and salinity damage that would otherwise occur. These future returns eventually exceed the declining BAU returns. The relative merits of the alternative policies are compared via a net benefit test that subtracts the BAU discounted stream of net annual returns from that generated by the alternative policy. This test is equivalent to asking whether the discounted ‘benefit’ triangle in Figure 1 exceeds the initial ‘cost’ triangle. A positive net benefit indicates that adoption of the policy alternative would be profitable when compared to business as usual and should be further considered.

¹ See for example the article by Shahbaz Khan and Tanya Ginns “Sustainable Irrigation Tools” in the Large Area Edition of the Farmers Newsletter (2003) No. 164, on pages 30 and 31 or CSIRO’s Research Project Sheet No. 11: Irrigation: Getting the balance right by Shahbaz Khan that can be downloaded from: <http://www.clw.csiro.au/staff/khans/index.html>.

Figure 2: Net benefit of controlling recharge

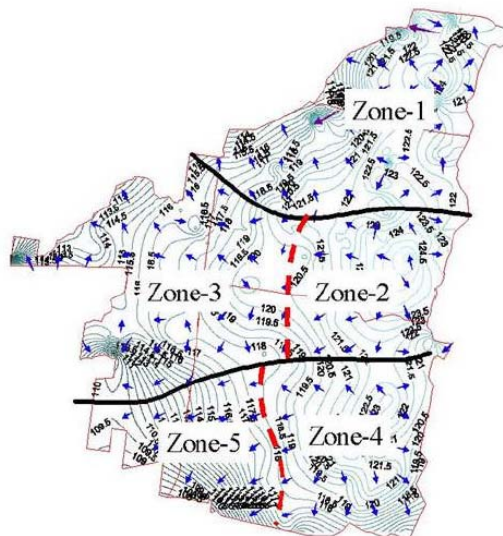


2.2. Estimating the impacts of ‘business as usual’

BAU is the baseline with which each policy alternative is compared. Hence, correctly estimating the relative merits of each alternative policy is dependent on accurately defining and estimating the biophysical and consequent economic outcomes under BAU. The complication in estimating the appropriate BAU scenario in CIA is the damage path that would result from continued net recharge, in particular, estimating the area and degree to which land within the CIA is subject to waterlogging or salinity in future time periods.

Khan, Paydar and Rana (2004) describe and quantify the vertical and lateral groundwater flows in the CIA on a regional and sub-regional basis (Figure 3). Current CIA recharge is estimated to average approximately 55,000 ML of which the net recharge is approximately 25,000 ML (Khan et al., 2004). Therefore, to minimise the impacts of salinity from rising watertables, irrigators within the CIA need to reduce net recharge by 25,000 ML per year on average. Their work is a basis for setting a ‘cap’ on the total net recharge that the system can absorb and therefore underpins any attempt to set individual recharge management objectives with a tradable net recharge credit framework.

Figure 3: CIA groundwater management zones



Similarly, work by Shahbaz Khan and colleagues to develop the SWAGMAN Farm[®] model provides the basis for estimation of net recharge at the farm scale and the basis for estimation of individual net recharge contributions. SWAGMAN Farm[®] is a lumped water and salt balance model which integrates agronomic, climatic, irrigation, hydrogeological and economic aspects of irrigated agriculture under shallow watertable conditions at a farm scale. This model has been used to develop management options such as net recharge management for control of shallow watertables in the CIA and other irrigation regions. This model can simulate the effects of growing a certain crop mix on shallow watertable and soil salinity or it can compute an optimum mix of crops to maximise farm net returns for which the watertable rise (or farm net recharge) and soil salinity remain within the allowable constraints for given hydro-climatic conditions (Khan et al., 2002).

Taken together, these two pieces of research provide the overall basis for setting targets and managing recharge in the CIA. The complicating factor in estimating the costs of BAU is a clear picture of the impacts of future net recharge on the current groundwater surface. Researchers have gathered significant data about the current groundwater surface but have yet to complete research that will estimate the impacts of future recharge under a BAU scenario on groundwater surfaces and consequent production impacts. Hence, the time-path and extent of future reductions in agricultural production in the region due to waterlogging and salinity cannot be estimated with certainty. Specifically, the area of land subject to waterlogging and salinity and the consequent economic costs may not be linearly related to past changes or future estimates. It should also be noted that any estimation of future agricultural production impacts is further complicated by the fact that land managers will actively respond to salinity and waterlogging impacts by modifying management practices (e.g. by changing crop types, varieties, rotations) to minimise production losses.

2.3. The threshold impacts

Where environmental thresholds are present within systems, past responses to similar events do not necessarily provide guidance to the behaviour of the system under future events of a similar magnitude. The main threshold of importance in the CIA arises from the impact of watertables and soil salinisation on crop production. The damage from rising watertables is not uniform but rather increases as groundwater rises within two metres of the soil surface and salt gradually builds up in the plant root zone through time. Therefore, the costs of rising watertables on any particular unit of land will not be uniform but rather they will be dependent on the depth to water and the degree to which soil salinisation has occurred.

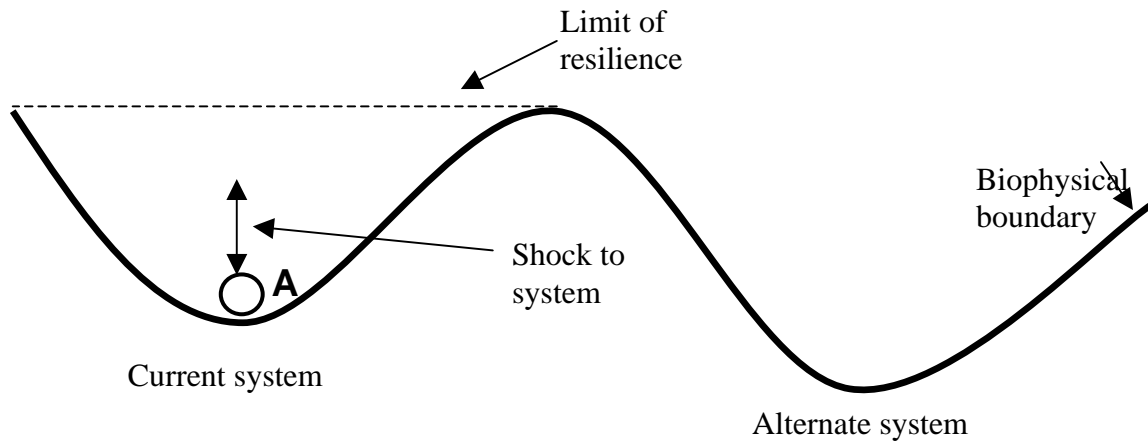
2.4. Climate driven episodic events and thresholds

A key influence on net recharge is the impact of rainfall. Natural rainfall events are not uniformly distributed through time. Instead rainfall is distributed as a series of events, some of which are much larger than others inducing local or widespread flooding. Larger events are more likely to be significant in determining net recharge because rainfall exceeds evapotranspiration. Because these events occur only periodically they are often termed episodic events. These episodic events have the potential to alter the stream of costs and benefits from changing management in the CIA through sudden shifts in the damage function (from a rapid rise in groundwater levels). The impact of episodic events will be more severe if they cause thresholds to be breached.

It is useful to discuss the nature of environmental thresholds in a resilience context. Episodic events can push environmental systems beyond thresholds. Consider for example the diagrams shown in Figures 4 and 5. The initial position of the system is represented by 'A' which lies in a basin of attraction. A shock to the system as such as that shown in Figure 4 is insufficient to

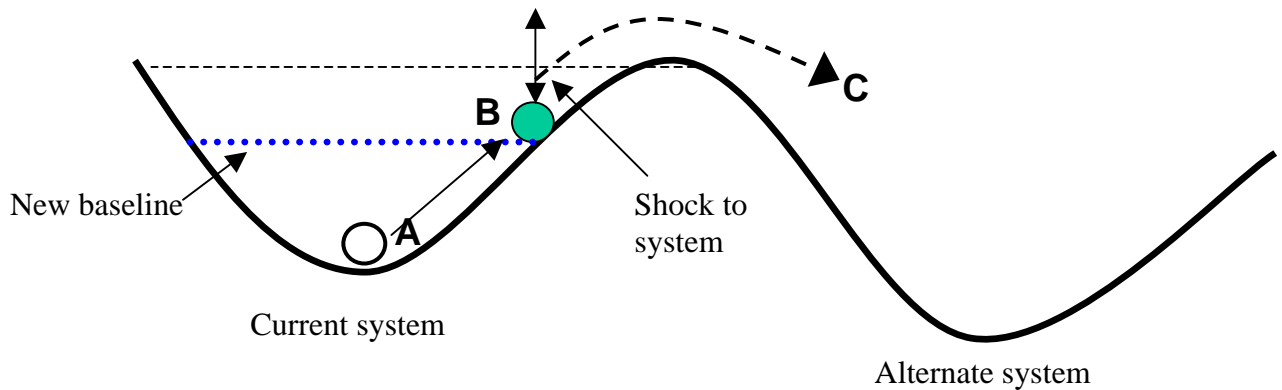
breach the limit of resilience and move into an alternate system from which it may be difficult, impossible, or simply take a very long period of time to return to the current system.

Figure 4: System response to a shock



In Figure 5, a new baseline has emerged in the current system, perhaps due to landuse impacts such as long-term irrigation causing net recharge and rising watertables. Under this new condition the system configuration has moved from 'A' to 'B'. A similar shock to the system to that in Figure 4 is now more than sufficient to push the system towards 'C' within an alternate system. The shock to the system that is sufficient to push the system over a threshold in Figure 5 could not do so in Figure 4.

Figure 5: Changed system response due to landuse impacts

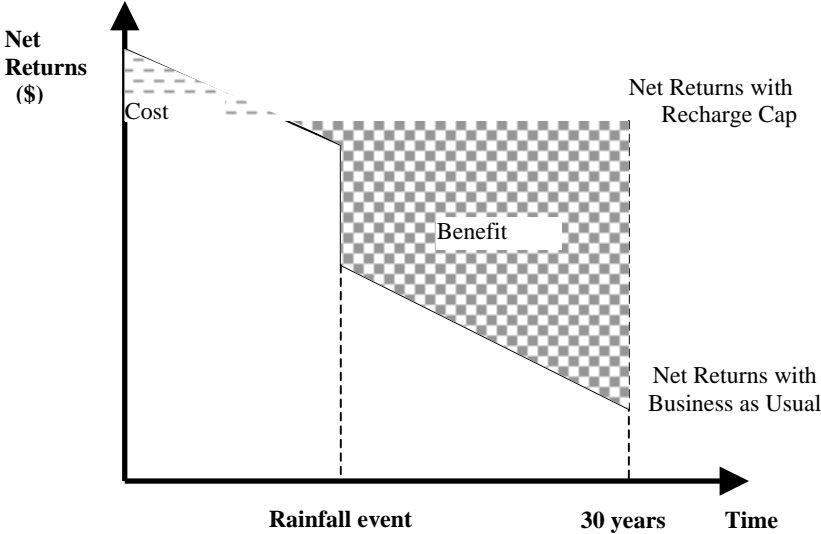


The impact of normal variations in climate complicates estimation of the costs of waterlogging and soil salinity because they can effectively act as shocks to the groundwater system. Prolonged dry periods can slow or halt rising watertables. Alternatively, prolonged wet periods can dramatically shift watertables upwards. The sudden upward shift can potentially have similar consequences to the shock shown in Figure 5 in altered systems such as irrigation areas.

As an example consider Wang, Khan and O'Connell's (2004) analysis of the impact of major episodic rainfall and flood events in the Wakool Irrigation District (WID) in southern NSW between 1973-1975. Floods during this period are attributed to causing an average watertable rise of 1.73m across the region. Less severe flooding in 1981 was estimated to cause an average 0.64m rise. Wang, Khan and O'Connell also note that the impact of these events was driven at

least in part by local rainfall with a large part of the WID exhibiting a watertable rise after rainfall, rather than a concentration along waterways and low-lying areas directly subject to floods. Furthermore, the impact of these upward shocks on the groundwater system was long term, with groundwater levels in 2001 remaining, on average, 0.82m higher than prior to the 1973 floods in the WID (Wang, Khan and O’Connell, 2004). If these shifts are sufficient to push watertables into the root zone of crops then a discontinuity will occur in the damage function. In this case the rainfall event would increase the cost of BAU via a shock to the damage function underlying the estimation of BAU such as that shown in Figure 6. The impact of the shock is to increase the net benefits from controlling net recharge².

Figure 6: Net benefit of controlling recharge with system shock



Significant rainfall events may alter the net returns arising under an otherwise effective recharge control policy. Such a policy is designed to prevent increases in waterlogging and salinity in the root-zone of crops and consequent reductions in agricultural productivity. Essentially, such policies should be designed to avoid system impacts reaching the point where expected climatic variations could cause the system to reach damage thresholds. That is, to avoid situations where the baseline reaches the situation shown in Figure 5, where climatic variations may induce increased salinity and waterlogging regardless of the policy regime in place.

If the system baseline has already reached a point where climatic variations may achieve damage thresholds (such as shown in Figure 5) the question arises as to the effectiveness of alternative policy options in lowering the baseline and increasing system resilience. This may be the case in the CIA. In this case an effective recharge policy option in the CIA would need to create additional recharge capacity, through groundwater pumping or drainage for example. This is because changing land-use management to minimise recharge in the region will only lower the baseline extremely slowly and will not increase the system resilience for many years. Targeted offset activities (such as groundwater pumping) do however have the potential to lower the baseline sufficiently to increase system resilience. Offsets are also very expensive and would need to be very well targeted in order to achieve these objectives.

Shahbaz Khan and colleagues are currently pursuing a number of research projects that are intended to determine the potential impacts of climatic variation on the Coleambally

² If the recharge abatement policy is insufficiently effective to prevent the system from exceeding an environmental threshold as a result of a shock, the ‘net returns with recharge cap’ curve may also be kinked downwards.

groundwater system. At present we do not know whether the system is closer to that shown in Figure 4 or that shown in Figure 5. Hence, it is difficult to determine with certainty the appropriate damage function or the likely long-term effectiveness of recharge trading as a policy option. As a result we have taken a pragmatic approach of making a number of assumptions about the state of the Coleambally system and its future trajectory. These assumptions are summarised in Section 2.6.

2.5. What are the alternative policy options?

A number of potential policy options are available that would reduce recharge within the irrigation district to sustainable levels in order to minimise the negative impacts of salinity. We define four recharge management policy scenarios that would cap recharge to a sustainable level as follows:

1. Impose a quota that caps the area of rice grown;
2. Impose a uniform reduction on total farm water allocations;
3. Impose a farm recharge cap with no trade; and
4. Impose a farm recharge cap with trade.

Each of the four alternative net recharge management policies is compared to the fifth option of continuing business as usual (BAU). The policy options are designed to reflect the differences between command and control policies compared to incentive based policies. Hence, options 1 and 2 are designed to represent command and control input caps and do not incorporate any flexibility in the way in which farmers can respond. Alternatively, options 3 and 4 are output-based policies with on-farm flexibility to change cropping mixes and practices allowed under option 3, and across farm flexibility allowed under option 4. These scenarios are described in more detail in Section 3.

2.6. A summary of the key biophysical assumptions

In order to make an initial assessment of the likely scale of the costs and benefits of changing irrigation management in the CIA to manage future net recharge impacts a number of assumptions are required relating to the relationship between irrigation and the underpinning biophysical systems. A number of more detailed assumptions related to the economic modeling are described in Section 3.

2.6.1. Weather

Average rainfall and evapotranspiration were used based on Griffith weather data for the years 1962 – 2002.

2.6.2. Irrigation water supply

Water supply is based on 86% general security allocation. This is the average of allocations for the years 1996/97 to 2001/02. This was a period when the weather was relatively 'average' and allocation levels were not affected from low runoff in the catchment due to lower than average rainfall. Due to the relatively high allocation, it is assumed that there are no water purchases on the water market, however, surplus can be sold for \$30/ML. It is assumed that all farms have recycling and do not have any groundwater pumping.

2.6.3. Recharge cap

Biophysical modelling of local and regional aquifers was used to divide the CIA into 5 groundwater management zones, each of which has different levels of sustainable recharge (Khan et al., 2004) (Figure 3). For the economic analysis, the zones have been reduced to 3 i.e. North (Zone1), Central (Zone 2 & 3) and South (Zone 3 & 4). The recharge cap is effectively the level of sustainable recharge, estimated to be approximately 30,000 ML. Current levels of

recharge for the CIA is approximately 55,000 ML. Therefore on average 25,000 ML of net recharge needs to be abated per year. The average levels of recharge abatement for each zone was derived by Khan et al (2004) and is summarised in Table 1. Overall, the average recharge abatement is 0.28 ML/ha. However due to the different groundwater conditions in each of the zones, the recharge abatement required in the north zone is low (0.06 ML/ha) whereas it is high in the south zone (0.49 ML/ha).

Table 1: Estimation of net recharge (ML) for CIA (1999/00 to 2001/02)

Period	Net Recharge	North Zone	Central Zone	South Zone	Total CIA
Mar 99 – Feb 00	Total	-9	13,641	10,914	24,546
Mar 00 – Feb 01	Total	-709	8,238	16,314	23,843
Mar 01 -Feb 02	Total	5,364	8,713	11,150	25,227
1999/00 -2001/02	Average (ML)	1,549	10,197	12,793	24,539
	Average (ML/ha)	0.06	0.28	0.49	0.28

2.6.4. Salinity damage function under BAU

Current biophysical models employing the best available information have been used to estimate that current policies to manage recharge to already high watertables in the CIA will not be effective in minimising the future impacts of salinity on agricultural production and the environment (Khan et al 2004). These estimates indicate that the area and concentration of soil salinity of agricultural lands in the CIA is likely to increase in the next 20 to 30 years resulting in declining net returns from agricultural production due to declining yields

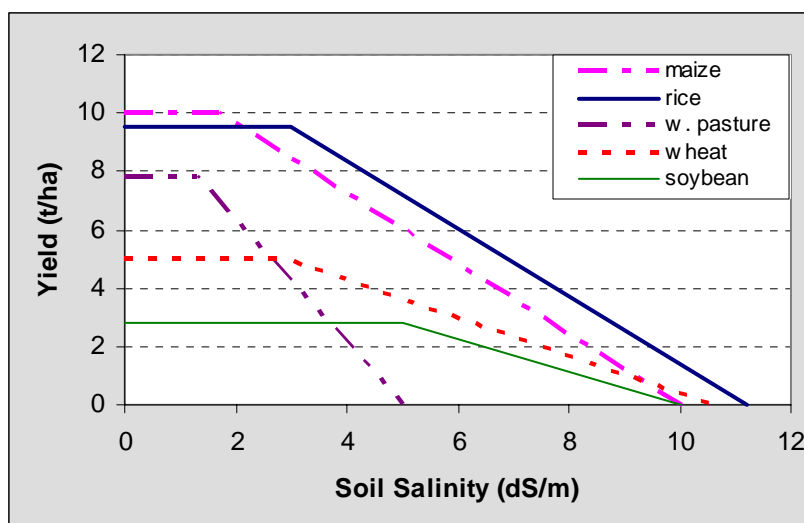
An estimate of the areas in CIA affected by various salinity levels is summarised in Table 2. The soil salinity forecast is based on two sources of data. First, today’s percentage area of each soil salinity class is based on the soil survey data obtained in 2000 (Coleambally Environment Report, 2000). For subsequent years, the initial soil conditions have been linearly extrapolated at the same rate as reported in Marshall et al., (1994) between the years 2004 to 2024. Detailed hydraulic modelling that is currently not available would be required for a more accurate estimate.

Table 2: Predicted distributions of soil salinity (% of area)

Soil Salinity Range (dS/m)	2004	2014	2024
0-2	85.4	75.0	64.5
2-4	7.8	14.8	21.8
4-8	4.5	6.1	7.8
>8	2.3	4.1	6.0

The SWAGMAN Farm[®] model does not incorporate estimates of salinity impacts on crop yield. The yields, and consequently the aggregate net annual return generated by the optimal crop mix, are adjusted for the changing salinity impacts over time using crop salinity thresholds (see Figure 7 and Appendix 1) in a spreadsheet model. It is assumed that each crop has the same percentage area attributed to the four soil salinity classes in Table 2. This means that the net annual return will decline in each future year as the impacts of salinity on crop production increases. However, this assumption does not allow for the tactical response of farmers choosing the optimal crop mix that will maximise returns with the prevailing soil salinity conditions (i.e. the growing of salt tolerant crops on the saline areas). Therefore, the economic impact of salination is possibly over-estimated in this study.

Figure 7: Yield response of crops to rising soil salinity



Source: rice, maize, soybean– ANZECC (2000); wheat and winter pasture – Grieve et al. (1986)

2.6.5. Waterlogging damage function

Waterlogging occurs when there is inadequate oxygen in the air and water of the soil pores. Prolonged waterlogging decreases crop yields from processes of reduced root density and depth as well as increased denitrification which reduces available nitrogen to the crop (Grieve et al., 1986). Waterlogging can also lower yields as a result of reducing timeliness and efficacy of field operations such as sowing and harvesting. Areas most susceptible to waterlogging are on irrigation layouts with poor surface drainage and soil types with high clay content. Areas with high watertables can increase the incidence and prolong waterlogging events due to the lack of internal drainage. Based on the research by Grieve et al., (1986), it was estimated that waterlogging in the CIA occurs approximately one year in three for winter crops and every year for summer crops, with average annual yield losses ranging from 1.3% to 13.7% (Marshall et al., 1994). Waterlogging is primarily a function of surface drainage and soil type. The additional yield losses associated prolonged waterlogging as a result of shallow watertables has not been quantified by research therefore these losses have not been included in this study. Consequently the benefits of a recharge abatement scheme will have been underestimated.

2.6.6. Episodic events

Research into the impacts of climatic variation on watertables and therefore the potential effectiveness of recharge management policies is ongoing as discussed in Section 2.3. In the absence of more detailed information we have assumed that the system is not yet within the range in which a significant event, such as a wet period comparable to the 1973-1975 period, would have a threshold impact on either the BAU or alternative recharge management options.

3. Economic analysis methodology

3.1. Defining the business as usual scenario

The first step in the economic analysis is to define the biophysical parameters for the BAU scenario. These have been discussed in the previous section. The BAU scenario is characterised by the resource allocations and biophysical outcomes that result. Within irrigation areas there are commonly a number of local and regional recharge and discharge zones. The area of influence for these zones are related to the soil types, irrigation activity and hydraulic properties of shared shallow groundwater aquifers. The implications of regional variation are two-fold. First, the impacts of BAU are not uniform across the CIA but vary according to

regional responses. Second, a region wide cap may reduce the total volume of recharge but fail to reduce the impacts in discharge zones. Worse, an inappropriate system wide cap may negatively impact on deeper aquifers and reduce potential future groundwater reserves.

The next step in the modelling was to define a basis for estimating the stream of net annual returns across the CIA given the differential future impacts of continuing BAU in each zone. The approach taken was to define ten representative farms for each zone. The representative farms were selected from a data set of actual farms within the region. They were selected to reflect the variation in soil types and cropping decisions across each zone. Soil types on one or two representative farms have been adjusted so that the total area of each soil type for the 10 representative farms for each zone are in the same proportion as the soil areas for the whole zone. This was required for extrapolation purposes as soil type plays a significant role on crop mix and recharge amounts. The average physical characteristics of the representative farms for each zone are summarised in Table 4.

Table 4: Representative farms physical attributes

	Area (ha)	Allocation @ 86% (ML)	Soil Area*					Groundwater [#]		
			NSMC	SMC	RBE	TRBE	SANDS	Depth (m)	Salinity (dS/m)	Leakage (ML/ha)
North Zone										
Avg farm	229	1,212		30%	7%	44%	19%	4	3	0.63
Zone total	24,000	113,400								
Central Zone										
Avg Farm	238	1,177	1%	22%	11%	56%	11%	2	5.6	0.29
Zone total	39,995	170,080								
South Zone										
Avg Farm	281	1,191	2%	11%	36%	45%	6%	2	6.6	0.24
Zone total	26,200	123,800								

* NSMC: Non self mulching clay, SMC: Self mulching clay, RBE: Red brown earth, TRBE: Transitional red brown earth, SANDS: Sandy loams)

[#] The average watertable depth was based on year 2000 levels (Figure 10.3, Coleambally Environment Report, 2003) and groundwater salinity values were based year 2001 levels (Figure 11.1, Coleambally Environment Report, 2003). Deep leakage from the watertable was based on Figure 27 in the report by Khan et al., 2004.

For the business as usual scenario, the economic component of the SWAGMAN Farm[®] model³ will be used to optimise agricultural production by maximising the total gross margin (TGM) for each representative farm with specified crop rotational constraints (see Appendix 1). The volume of net recharge for each farm was unconstrained. The total gross margin and recharge for the 10 representative farms for each groundwater management zone are then aggregated and extrapolated to derive a value for the groundwater management zone.

For simplicity, average conditions (weather, crop gross margins, allocation etc) are assumed for each year in the analysis period of 20 years. Therefore the optimal crop mix and associated recharge for each representative farm are the same for each year in the analysis period.

An underlying assumption within the business as usual scenario is that the area of soil salinity will increase over time which will affect crop yields and consequently farm net returns. An estimate of the areas in CIA affected by various salinity levels and its potential impact on crop production is calculated under the assumptions outlined in Section 2.6.4.

³ All modeling carried out using SWAGMAN Farm version 3.1, 2000, © CSIRO Land and Water.

3.2. Defining the alternative policy scenarios

Crop mix is the key determinate of recharge rates on farm. The recharge abatement policies investigated in this study are based on abating on-farm recharge by changing crop mix. This is because each crop has varying levels of recharge to the groundwater, which is influenced mainly by soil type, volume of irrigation water applied, and depth to watertable. Some crops, particularly rice, are generally recharging crops, whereas winter crops and perennial pastures are generally discharging crops. Engineering options such as groundwater pumping are not considered. This is due to the relatively high cost of drainage disposal since the shallow groundwater is too saline for it to be used for irrigation purposes.

3.2.1. Impose a quota on rice area (input cap)

Paddy rice is the main crop generating recharge in the CIA. Therefore, limiting the area of rice grown will reduce recharge for the region. Imposing a non-tradable rice area quota would be an extension of existing rice policy that already restricts the area of rice that can be grown in the CIA. The rice area quota is calculated in two steps. First, the aggregate area of rice that would meet recharge targets is estimated by zone. The farm quota is then allocated by a uniform proportionate reduction in rice area, based on the zone with the highest percentage reduction in rice area to meet the recharge target as the quota is the same for all farms in the CIA. The total gross margin is then estimated by allowing re-optimisation of farm crop mixes with the rice quota constraint in place using SWAGMAN Farm[®] for each representative farm. It is assumed that the water not used for rice can be used for other crops or sold on the temporary trade water market at a representative price for recent years.

The total gross margin and recharge for the 10 representative farms for each groundwater zone are then aggregated and extrapolated to derive a value for the groundwater zone. It is assumed that if the cap is achieved, salinity impacts are negligible therefore the derived total gross margin is the same over time.

3.2.2. Impose a restriction on total farm water use (input cap)

A “water cap” is similar to the rice area cap but has the flexibility of no restrictions on any particular crop. The cap is calculated using a similar two-step process to the rice cap.

3.2.3. Impose a farm recharge cap with no trade (output cap)

Under this scenario the SWAGMAN Farm[®] model is used to estimate the optimal agricultural production subject to the additional constraint that farm recharge not to exceed the farm recharge cap. The farm cap is calculated in two steps. First, the ‘sustainable’ recharge level is calculated as a proportion of current recharge by zone. Each farm is then allocated a number of credits that are “grandfathered” as the sustainable proportion of existing recharge. That is, the recharge cap for each representative farm will be a proportional decrease equivalent to the reduction required to meet zone targets. This recharge ‘cap’ must then be met through on-farm recharge abatement such as the changing of crop mix or the sale of surplus water through temporary trade.

SWAGMAN Farm[®] is used to estimate the total gross margin from the optimal crop mix and subject to the recharge cap for the 10 representative farms for each groundwater zone. These individual results are then aggregated and extrapolated across the zones to derive a value for the groundwater zone. Meeting the cap eliminates future increases in salinity impacts and therefore the aggregate total gross margin is the same over time.

3.2.4. Impose a farm recharge cap with trade (output cap)

A recharge cap and trade, in theory, should be the most efficient recharge policy of reducing regional recharge for the least cost in forgone agricultural production (ignoring transaction costs of trades). To determine the optimal crop mix under a recharge cap and with trade permitted between farms, the 10 representative farms for each zone are treated as one farm. That is, the inputs of the 10 farms are aggregated and resources put to the best use across the farms. This reallocation of resource use across farms subject to the recharge cap reflects the optimal allocation of resources following trade under a tradable recharge cap.

The aggregate cap is calculated as for a recharge cap with no trade in section 3.2.3. SWAGMAN Farm[®] is used to estimate the optimal total gross margin so that recharge does not exceed the recharge cap of the aggregated farm. Meeting the cap eliminates future increases in salinity impacts and therefore the aggregate total gross margin is the same over time.

4. Results

4.1. Validation of the model

The estimated crop mix and total gross margin for the “business as usual” scenario are compared to those reported for the CIA. The business as usual scenario yields a total gross margin of \$37.4 million from 51,000 ha of irrigated crop (of which rice account for 45% of the total irrigated crop area) and 26,600 ha of dryland cropping. This result is not too dissimilar to average cropping areas and estimated total gross margin for the years 1998/99 to 2001/02.

For the business as unusual scenario, the net recharge estimated by the SWAGMAN model was 23,355 ML. Compared to the average net recharge estimates in Khan et al (2004) for the period 1999/00 to 2001/02, the SWAGMAN model over-estimates net recharge for the north and central zone and under-estimates net recharge in the south zone. However, the total net recharge derived by the SWAGMAN model is within 5% of the average of the net recharge estimates in Khan et al. (2004).

As the cropping areas for the two main crops in the CIA (rice and wheat) the total gross margin and the net recharge from the SWAGMAN model are similar to alternative data sources, the outputs from the SWAGMAN model output appear to be relatively robust. This means that the outputs from the recharge policy scenarios can be utilised with some confidence.

4.2. Comparison of recharge abatement policies

The economic impact of continuing business as usual is summarised in Table 5. The impact of waterlogging and salinity on agricultural production are projected to reduce the annual total gross margin from nearly \$35 million per year to less than \$32 million per year in 20 years time.

Table 5: Cropping areas and potential total gross margin for the business as usual scenario⁴

Crop	Business as usual (YR 1)		Business as usual (YR 20)	
	Area (ha)	TGM	Area (ha)	TGM
rice	22,962	\$22,331,796	22,962	\$20,963,969
maize	8,610	\$6,288,075	8,610	\$5,321,358
soybean	252	\$126,775	252	\$119,392

⁴ The TGM values in Table 5 and Table 6 incorporate salinity impact losses

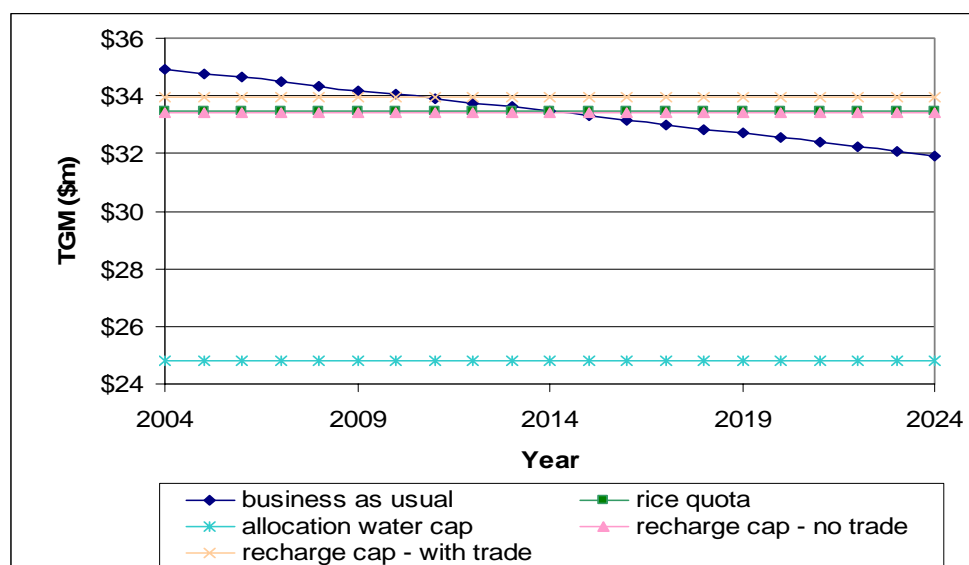
lucerne	539	\$402,987	539	\$374,177
wheat	17,887	\$3,744,294	17,887	\$3,338,334
canola	736	\$175,039	736	\$162,075
pasture	0	\$0	0	\$0
dry pasture	16,931	\$1,272,663	16,931	\$1,080,526
dry wheat	9,689	\$578,038	9,689	\$573,455
fallow	8,589		8,589	
TOTAL		\$34,919,667		\$31,933,285

The projected economic outcome under each of the recharge abatement policies considered is summarised in Table 6. The constraints imposed through these policies were designed to successfully manage recharge within sustainable levels thus avoiding future increases to waterlogging and salinity and the resultant production impacts. Therefore the total gross margin is expected to continue at the estimated level throughout the 20 year period. The annual TGM for the various recharge abatement policies is illustrated in Figure 8.

Table 6: Cropping areas and potential total gross margin for each recharge policy scenario

Crop	Rice Quota		Allocation Water Cap		Recharge Cap – No Trade		Recharge Cap – With Trade	
	Area (ha)	TGM	Area (ha)	TGM	Area (ha)	TGM	Area (ha)	TGM
rice	16,318	\$15,870,489	15,249	\$14,830,842	18,902	\$18,383,856	18,031	\$17,536,368
maize	8,534	\$6,232,740	8,604	\$6,284,095	6,906	\$5,043,611	8,615	\$6,291,753
soybean	252	\$126,775	0	\$0	336	\$169,031	0	\$0
lucerne	5,711	\$4,266,931	75	\$55,713	4,315	\$3,224,089	6,665	\$4,979,751
wheat	24,902	\$5,212,764	1,035	\$216,570	18,155	\$3,800,387	15,080	\$3,156,642
canola	1,324	\$314,627	0	\$0	4,933	\$1,172,568	0	\$0
pasture	0	\$0	0	\$0	0	\$0	0	\$0
dry pasture	15,120	\$1,136,489	17,287	\$1,299,377	12,812	\$963,036	17,279	\$1,298,764
dry wheat	5,423	\$323,542	35,356	\$2,109,255	11,248	\$670,995	11,911	\$710,602
fallow	8,612	\$0	8,589	\$0	8,589	\$0	8,615	\$0
TOTAL		\$33,484,357		\$24,795,853		\$33,427,573		\$33,973,879

Figure 8: Annual total gross margin for the recharge abatement policies



The summary results of the economic modelling are reported in Table 7. Each of the policy options without trade is estimated to yield a negative net present value to irrigators. The economic modelling indicates that these policies should not be considered for adoption unless there are significant non-production net benefits that have not been included within this model. Implementing a rice quota is estimated to reduce the annual total gross margin from agricultural production to \$33.5 million per year. Discounting this stream of future benefits at 5% per annum, the net present value (NPV) generated is negative \$2.8 million. Similarly, implementation of a water input cap is estimated to reduce the annual total gross margin to \$25m per year yielding a discounted NPV of \$182 million. Implementing a policy of a zero net recharge cap per farm is estimated to generate an annual total gross margin of \$33.4 million per year and a discounted NPV of negative \$3.6 million.

In contrast the implementation of a zero net recharge cap per farm in combination with trading of recharge credits is estimated to generate an annual total gross margin of \$34 million per year. Adoption of the cap and trade policy is estimated to generate a NPV of \$3.4 million. Hence, initial evidence suggests that this policy should be adopted because it will generate a net benefit.

Table 7: Economic impact of recharge abatement policies

	Rice quota	Allocation water cap	Recharge cap - no trade	Recharge cap - with trade
TGM/year	\$33,484,357	\$24,795,853	\$33,427,573	\$33,973,879
Total net benefit	\$844,622	-\$181,613,973	-\$347,853	\$11,124,586
NPV	-\$2,845,326	-\$114,241,969	-\$3,573,369	\$3,430,911

4.3. Discussion

Intuitively, one would have expected that imposing a rice quota would have resulted in a lower annual net return than imposing a zero net recharge cap per farm. This is because it is expected that a rice quota would be less flexible than a recharge cap in terms of the crop mix options available to irrigators. However, this is not the case in the modelled estimates. In fact, the recharge cap was more restrictive for farms that had a high proportion of the more permeable soil types. The abatement cost for these farms was significantly greater under the recharge cap than under the rice quota. Approximately 20% of the representative farms had a large proportion of the farm with the more permeable soil types. The significant increase in abatement cost of the recharge cap compared to the rice quota for these farms neutralised the marginal benefit of decreased abatement costs on the remaining representative farms.

The water cap proved to have the greatest impact on farm profitability. This is a reflection of the influence of water as a key limiting resource in agricultural production in the region. It is also an indicator of the relative inefficiency of a broad-based input cap relative to a targeted input cap, such as a rice quota, where low impact alternative water uses are available. Model estimates also show that a well-targeted input cap can perform similarly to an output cap without trade where alternative, low opportunity cost abatement options are available. This is a particularly important conclusion for MBIs because it indicates that where trades are not available, or cannot be facilitated, a well-targeted input cap may outperform a cap and trade instrument.

The additional benefits captured by the cap and trade model reflect the fact that not all profitable resource reallocations that result from a capping recharge can be captured on-farm due to the differential opportunity costs between farmers. In the case of the economic modelling presented in this report, these differential opportunity costs are driven by differences in resource allocation. However, based on experience in other markets we can anticipate that there will also

be differences in opportunity costs that are driven by variation in the direct costs of production as well as factors including farming and social preferences. Hence, the potential benefits generated under a cap and trade policy are likely to be underestimated.

Finally, a cap and trade model that incorporates banking and borrowing is likely to generate additional benefits under real life variations in climate compared to the constant climate modelled in this report. It should be kept in mind that the benefit estimates for each of the alternative policy options modelled are an underestimate of the total benefits that would be derived from reducing recharge. This is because they do not include estimates of the public and private good benefits to the wider community from recharge abatement. These benefits include those generated by reduced damage to native vegetation and wetlands in the region, reduced damage to infrastructure such as roads, drains and supply channels, and avoided downstream impacts.

Finally, there are two types of likely costs that are not included within the modelling. First, estimates do not include any once-off costs associated with changing management. That is, it is implicitly assumed that the only costs of changing management are the opportunity costs from foregone production. This is clearly not the case where some irrigators may need to purchase specialist equipment or learn specialist management techniques in order to change their farm management. Second, the cost estimates do not include any policy costs. These include the costs of designing and implementing the policy and the ongoing costs under the policy. For the cap and trade model these costs also include transaction costs associated with trading recharge credits. Taking a threshold value approach, these transaction costs would have to be less than \$268,000 per year for the cap and trade policy to be economically viable within the relatively static model reported above.

5. Conclusions

5.1. Summary of findings

The focus in this report has been an initial estimation of the economic impacts of alternative policy options for managing recharge in the CIA. The imposition of these policy options would create a number of costs and benefits to irrigators, through changes to agricultural production, and to the local and wider community, through protection of infrastructure, biodiversity, and reduction in potential downstream impacts. The focus in this report has been on the direct costs and benefits to irrigation farmers.

We find that a cap and trade policy has the potential to generate a net benefit to the CIA of approximately \$3.5m. Alternative policies based on input caps such as limiting the area of rice grown or the quantity of water available generate a negative net present value. Less flexible output policies without inter-farm trading also do not generate a positive net present value. However, we note that the findings are subject to a number of factors that are likely to lead to over or under estimation of net benefits. In particular we note that the increased complexity of a cap and trade model introduces additional transaction costs associated with trades and would only generate a positive net present value if policy management and transaction costs are less than \$268,000 per annum.

The findings in this report have been made based in part on a number of assumptions about the biophysical system in the CIA and about future economic conditions. The implications about varying some of these assumptions are noted in Section 5.2. However, it is important to note that the findings in this report should be regarded as a best estimate based on the available information that should be revised as further information comes to light. In particular it is

emphasised that the benefits from changing irrigation management should be regarded as a lower bound to the potential benefits from changing wetland management. The implications of the assumptions on the opportunity costs of changing management are more complex, but should the system be close to damage thresholds, these costs may also be substantially higher.

5.2. Next steps and future research options

A number of further research steps are suggested with the findings in this report. These can be divided between direct extensions of the modelling and wider research opportunities.

Two key direct extensions from the modelling presented in this report are yet to be undertaken. First, an extension of the economic model to incorporate the dynamic impacts generated by weather variation. Weather plays a major role in farm management decisions in the CIA and the consequent impacts on recharge and the costs and benefits derived by alternative policy options. In this report each of the recharge policy scenarios was based on average weather conditions and resultant water allocations. The assumption of average weather conditions aids in making the economic analysis relatively tractable and eases the examination of differences between policies. The disadvantage is that, in reality, there will be significant year to year variation in water availability. This variation means that banking and borrowing provisions within a cap and trade model may generate a major component of the gains from flexibility within a cap and trade instrument.

As an extension of the model we trialed a preliminary model of the cap and trade policy scenario using a historical sequence of weather events that have been classified as dry, average, or wet years. A dry year is one that has an annual rainfall less than the 25 percentile (in which banking can be expected to occur), a wet year in one that has annual rainfall greater than the 75 percentile (in which borrowing can be expected to occur), and an average year will be all the remaining years (with no prior expectation about banking or borrowing). Allocation levels will be variable over this time frame based on predicted average supply levels for these categories of years. We found insufficient variation in year to year returns to drive banking and borrowing of credits and thus additional gains from trade.

The second direct extension of the model is to undertake a sensitivity analysis of the results to identify key factors driving the net present values from alternative policies and to identify whether more information is required about key assumptions in the modelling.

Wider research opportunities are generated by the costs and benefits for which estimates were not included in the model. These include public good values beyond the farm and transaction costs associated with policy implementation and management.

One aspect of these wider opportunities that is being progressed within this project is use of experimental economics as a tool in designing cap and trade programs. Cap and trade models are not usually able to capture all possible cost-effective trades as is assumed in the modelling in this report. One hypothesis involves identifying the efficiency of different trading formats compared to the perfect cap and trade efficiency modelled in this report. It would then be possible to incorporate the efficiency estimates from the economics experiments into the sensitivity analysis to re-estimate the likely net present values generated under cap and trade models. The findings from the economics experiments will be reported in a future background report from the project team.

Finally, and most importantly, there are a number of outstanding biophysical parameters for which restrictive assumptions have been made in the modelling in this paper. For example, we

do not yet know the potential impact of climatic variation on watertables and consequently agricultural production in the region. A number of these issues are being progressed by Shahbaz Khan and colleagues at CSIRO Land and Water in Griffith, however further issues of importance are expected to remain outstanding at the conclusion of this work along with potentially new issues being uncovered.

6. References

ANZECC and ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Volume 3, Primary Industries - Rationale and Background Information (Chapter 9), National Water Quality Management Strategy, Paper No. 4.

Coleambally Irrigation Co-operative Limited (2003) *Annual Environment Report 2003*, Coleambally Irrigation, Coleambally.

Evans, L (1998) Interim Quality Guidelines for the use of Groundwater for Irrigation, Workshop for Irrigators, NSW Agriculture

Grieve, A., Dunford, E., Marston, D., Martin, R.E. and Slavich, P. (1986) Effects of Waterlogging and Soil Salinity on Irrigated Agriculture in the Murray Valley: a review. *Aust. J. Exp. Agric.* 26(6) 761-77.

Hanson B., Gratton S. and Fulton, A (1993), Agriculture Salinity and Drainage, Water Management Series 93-01, Department of Land, Air and Water Resources, University of California, Davis.

Khan, S., O'Connell, N., Wang, Z., Robinson, D. and Xevi, E. (2002) 'Environmental Concepts and Models for Participative Management of Irrigation Areas - Applications in the Murray Darling Basin', In: Irrigation Advisory Services and Participatory Extension in Irrigation Management Workshop organized by FAO, Montreal, Canada.

Khan, S., Paydar, Z. and Rana, T. (2004) *Net Recharge Targets to Meet Regional Environmental Goals*, Technical Report No. 12/04, CSIRO Land and Water, Griffith.

Madden, J. C. and Prathapar, S. A. (1999) *Net Recharge Management SWAGMAN Farm[®] - Concepts and Application to the Coleambally Irrigation Area*, Consultancy Report for Coleambally Irrigation. Consultancy Report 99-11, CSIRO Land and Water, Griffith.

Marshall, G., McGrath, S. and Jones, R. (1994) *Agricultural Effects of Land Salinisation and Waterlogging in the Coleambally Irrigation Area Economic Evaluation of the Current Trends Scenario*, A report to the Community Working Group of the Coleambally Land and Water Management Plan, NSW Agriculture.

Slavich, P. G. and Read, B. J. (1984) 'Assessment of electromagnetic induction measurements of soil salinity for indication of crop response', In: Muirhead, W.A. and Humphreys, E., (Eds.) Root Zone Limitations to Crop Production on Clay Soils, Symposium of the Australian Society of Soil Science Inc. Riverina Branch, Griffith, 25-27 September.

Wang, B., Khan, S. and O'Connell, N. (2004) *A GIS Approach to Quantify Impact of Flooding on Shallow Groundwater Levels in the Wakool Irrigation District*, CSIRO Land and Water Technical Report No. 22/04, CSIRO Land and Water, Griffith.