Tradeable recharge credits in Coleambally Irrigation Area: Report 2

Economic impact of tradeable recharge credits and other net recharge abatement policies for the Coleambally Irrigation Area

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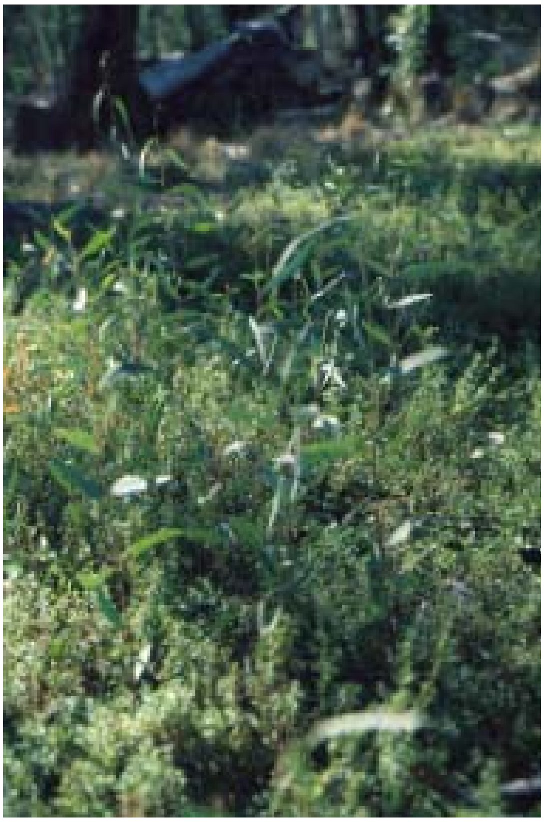

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This paper is the second in a series from a two-year research program. The focus in this paper is on laboratory tests of alternative institutional frameworks using experimental economics techniques. Papers in this series are:

- *What are the issues?*
- *Economic impact of tradeable recharge credits and other net recharge abatement policies for the Coleambally Irrigation Area*
- *Designing Experiments to test tradeable recharge credits in the Coleambally Irrigation Area*
- *Laboratory Tests of Alternative Institutional Frameworks*
- *Field Trial and Farm Case Studies*
- *Biophysical Modelling for Linking Farms with Regional Net Recharge Targets*
- *Experiences, lessons and findings*

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Executive Summary

This is the second report in a series detailing the outcomes of research exploring the potential for a cap and trade market based instrument to manage irrigation induced salinity and water logging in the Coleambally Irrigation Area (CIA) in western New South Wales (NSW).

Consideration of the cap and trade approach to managing waterlogging and salinity is predicated on the hypothesis that this approach offers efficiency gains over alternative policy options. A key aspect of this research is to test this hypothesis with respect to recharge management in the CIA.

In this report the focus is on the economic modelling of the costs and benefits of alternative net recharge management options including the cap and trade approach. Selection of a cap and trade approach requires that:

1. The gains to irrigation farmers from increased future yields outweigh the costs of changing management practices. This can also be specified as the gains from changing management generate a net benefit over continuing 'business as usual'; and
2. The gains under a cap and trade approach are larger than those under alternative recharge management approaches.

Assessing the scale of the potential gains from a cap and trade approach are the focus of analysis in this report. The analysis is partial as it does not consider the transition and community costs and benefits of changing irrigation management such as infrastructure protection and biodiversity conservation. Nevertheless, it provides important information for policy makers. For example, if the present value of identified farm benefits outweighs costs, consideration can then turn to the question of whether these net benefits would be greater than likely scheme administration and irrigator transaction costs.

If identified farm benefits do not outweigh costs, a threshold value can be estimated to assist consideration of the broader merits of the instrument. That is, the threshold value of estimated net benefit to irrigators can be considered against the non-monetary benefits of reducing recharge that would be accrued by both irrigation farmers and the wider community and the costs of implementing the instrument. For example, if farmers faced a net cost of $5m then non-monetary net benefits to farmers and the wider community would need to be greater than $5m for the community to experience a net benefit as a whole.

The results from the applied economic modelling approach summarised in this section are highly dependent on the identification and definition of an appropriate biophysical context and measurement of the biophysical outcomes generated over time. The biophysical context forms the basis for defining the future stream of costs and benefits.

The farm scale costs and benefits of five options were analysed in this project. These five options are described in brief in Table A. The options include continuation of current management, termed the 'do nothing' (or BAU) outcome and four alternatives. The alternative options are designed to represent potential input and output based policies with various levels of flexibility in the way in which farmers can respond.

The constraints imposed through each of the alternative recharge management options considered were designed to successfully manage recharge within sustainable levels thus avoiding future increases to waterlogging and salinity and the resultant production impacts. Projected income under alternative policies will be lower in the early years than under the BAU scenario, but through reducing the rate of groundwater rise and reducing yield losses, income will be higher in later years. Clearly the merits of the policy will rest on these later gains being greater than the reductions in income in the early years.

Each of the policy options without trade is estimated to yield a negative net present value (NPV) 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 the analysis.

In contrast the implementation of a zero net recharge cap per farm in combination with trading of recharge credits is estimated to generate a discounted stream of benefits from this policy compared to the BAU policy over the 20 year period of $3.4 million (assuming a five percent discount rate). Hence, the analysis suggests that this policy would generate a net farm level benefit.

There are a number of factors and assumptions within the modelling at the farm production scale and at the community scale that may impact on the validity of the initial conclusions drawn from the modelling. Additional analysis was undertaken to determine the likely impact of five potential factors at the farm scale:

- Opportunity cost of water and farm management decisions;
- Production costs or losses from soil salinity;
- The impact of waterlogging in addition to salinity impacts;
- The impact of requiring additional recharge mitigation in order to reduce the potential impact of episodic climatic events; and
- The scope for additional gains from trade resulting from banking and borrowing of recharge credits.

Table A: Policy options for which economic modelling was undertaken

Scenario	**Economic theory / policy**	**Estimation methodology**	**Impact salinity and damage path**
1. Business as usual	Open access (current rice area quota continues)	Estimate a farm model for 10 representative farms in each zone. Yield declines due to increasing soil salinisation.	Linear damage path
2. Rice cap	Input cap on most damaging process – rice production	As for 1. but reduce rice area proportionately until target recharge achieved. Water can be shifted to alternative crops or sold out of area.	No further yield decline.
3. Water cap	Input cap on most damaging input – irrigation water inputs	As for 1. but water inputs proportionately reduced until target recharge achieved. No compensation for lost water (no water sales).	No further yield decline.
4. Cap and no trade	Cap on net recharge at the farm scale but no trading allowed – regulation.	As for 1. but regional targets proportionately applied to recharge at the farm scale. Water can be sold out of area at average historic prices (no water purchases).	No further yield decline.
5. Cap and trade	Cap on net recharge with trade allowed.	Model treats the 10 representative farms as one farm and optimises. Water can be sold as per 4.	No further yield decline.

Other farm scale factors that were not estimated but which may impact on the scale of benefits from a implementing a cap and trade policy include:

- once-off costs associated with changing management; and
- differences in opportunity costs that are driven by variation in factors outside of the direct costs of production such as farm goals and social preferences.

Two important issues emerge at the community scale referring to the benefits and costs of designing and implementing a cap and trade mechanism respectively. First, 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. Second, the cost estimates do not include any policy costs. These include the costs of designing, implementing and enforcing the policy and the ongoing ‘administrative’ costs to participants under the policy.

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1. Introduction

This report comprises part of a series detailing the outcomes of research into the exploration and development of tradeable recharge rights as a tool to manage irrigation induced salinity and water logging in the Coleambally Irrigation Area (CIA) in western New South Wales (NSW). This project is a pilot under the National Market Based Instruments Pilots Program. The pilot is based on developing (cost-effective) incentives to individual irrigators that reflect their impact on a shared groundwater aquifer. The shared resource means that one individual's actions may affect other irrigators and the wider community and effective incentives to manage these issues must reflect these interrelationships.

Prior to irrigation, the watertables in the CIA were around 20 metres (Khan et al., 2002). However, due to recharge from inefficient irrigation practices, leaky channels and recharge from rainfall in fallow paddocks, an increasing proportion of the CIA will have watertables within 2 metres of the soil surface (Coleambally Irrigation Co-operative Limited, 2003). Shallow watertables induce waterlogging and salinity, both of which have a negative effect on crop production, infrastructure and the environment. Current recharge management policies have not been sufficient in abating net recharge. 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.

The focus of the project is on the practical concerns involved in implementing a cap and trade framework as a potential policy solution to waterlogging and salinity. These were explored in our first background report titled 'Tradeable recharge credits in Coleambally: What are the issues?' 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 access to potential 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 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 report is whether the gains from trade accessed by a cap and trade mechanisms are sufficient to outweigh the costs of changing management? The primary focus in this report 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 additional net benefits to the wider community that are not estimated in this report would enhance the total 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 assessing 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. In the Coleambally region there remains considerable uncertainty as to the nature of potential thresholds and their potential interaction with 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 report. Because of the uncertainty, the conclusions in this report should be regarded as preliminary and subject to review when additional information becomes available.

The report is structured as follows. In the next section the methodological framework is set out and linked to the biophysical context in which it is set. The description of the biophysical context includes defining the underpinning assumptions employed in this analysis. The five alternative policy options that are compared are defined in the third section. Resultant cost and benefit estimates are presented in section four along with discussion of their implications given the underpinning assumptions. A discussion of the conclusions from the economic modelling along with the next research steps completes the report.

2. Concepts and methodological framework

Irrigated agriculture often results in recharge to regional groundwater systems above what the natural systems can absorb without increasing the risk of 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. The methodology employed to assess these costs and benefits is described in this section.

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

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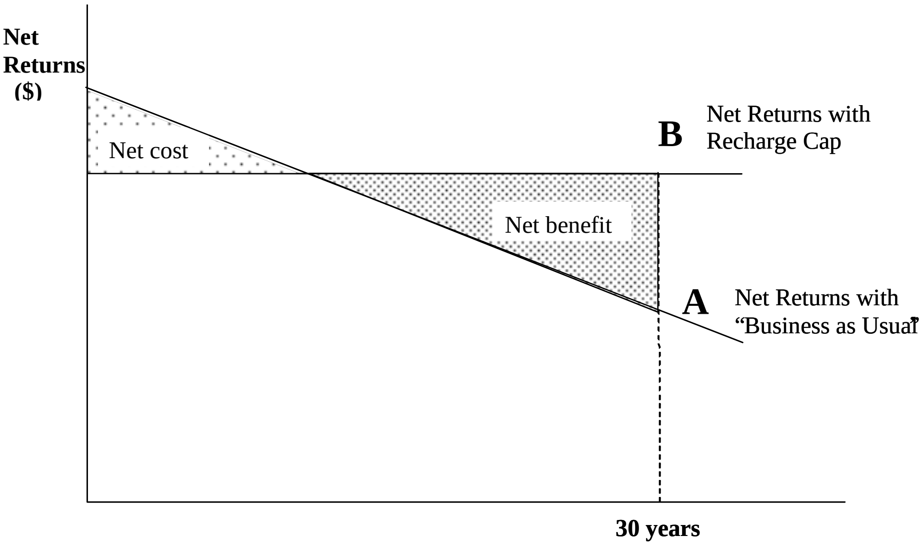
[1] See for example the article by Shahbaz Khan and Tanya Ginns "Sustainable Irrigation Tools" in the Large Area Edition of the Farmers Newsletter (2003) No. 164, on pages 30 and 31 or CSIRO's Research Project Sheet No. 11: Irrigation: Getting the balance right by Shahbaz Khan that can be downloaded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

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 alternative courses of action consider Figure 1. Continuing BAU is likely to yield declining 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 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. The policy's net returns is initially lower than the BAU's net returns, though by removing future waterlogging and salinity damage that would otherwise occur these returns are maintained into the future and eventually exceed the declining BAU returns.[2] 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 'net benefit' triangle in Figure 1 exceeds the initial 'net 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.

Figure 1: Net benefit of controlling recharge



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[2] Net returns are the profits to irrigators.

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.

Particular difficulties arise in accurately estimating the area and degree to which land within the CIA is subject to waterlogging or salinity in future time periods. Groundwater, unlike surface water, does not have a level surface. Instead the surface of groundwater has peaks and depressions. These peaks and depressions result from the permeability associated with different geological features and between aquifers, and the impact of management actions on recharge. For example, there is a significant depression in groundwater levels around the deep groundwater bore in north central Coleambally. This variability means that the area of land subject to waterlogging and salinity across the CIA will not simply be the area of land below a certain altitude but rather will be related to a set of specific geological parameters and the impact of land management actions on these. Some of these parameters are now reasonably well defined. Khan, Paydar and Rana (2004) describe and quantify the vertical and lateral groundwater flows in the CIA on a regional and sub-regional basis. 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 tradeable net recharge credit framework.

Similarly, work by Khan and colleagues to develop the SWAGMAN Farm® model provide the basis for estimation of net recharge at the farm scale, and thus 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 farm scale crop choice and management options for control of shallow watertables in the CIA and other irrigation regions. This model can be used to simulate the effects of growing a certain crop mix on shallow watertable and soil salinity or to 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 is unlikely to be linearly related to past changes or future estimates. At this point we do not know whether the likelihood that the system is close to thresholds that would significantly alter future management options. 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.[3] 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 groundwater system. In this paper we have taken a pragmatic approach of making a number of assumptions about the state of the Coleambally system and its future trajectory.

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 (for example changing crop types, varieties, rotations, locations) to minimise production losses.

2.3 Summary of 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, 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 modelling are described in Section 3, where the alternative policy options are defined.

2.3.1 Weather and irrigation water supply

Average rainfall and evapotranspiration were used based on Griffith weather data for the years 1962 – 2002. 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 by recent low rainfall and consequent runoff in the upstream. Due to the relatively high allocation to Coleambally irrigators, 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.

2.3.2 Basis for a 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, as shown in Figure 2 (Khan et al., 2004). For the economic analysis, the zones have been reduced to 3 i.e. North (Zone1), Central (Zones 2 and 3) and South (Zones 4 and 5). The reduction to three zones for analysis represents a pragmatic trade-off between the differential impacts within zones and the number of potential market participants. The recharge cap is effectively the level of sustainable recharge, estimated to be approximately 30,000 ML/per year (Khan et al., 2004). Current levels of recharge for the CIA are approximately 55,000 ML/per year. Therefore on average, 25,000 ML of net recharge needs to be abated per year. The average levels of recharge abatement for each zone are summarised in Table 1 (derived from Khan et al. 2004). Overall, the average recharge abatement required to meet the target is 0.28 ML/ha. However due to the different groundwater conditions in each of the zones, the

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[3] For further discussion of potential threshold issues see appendix 1.

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).

Figure 2: CIA groundwater management zones

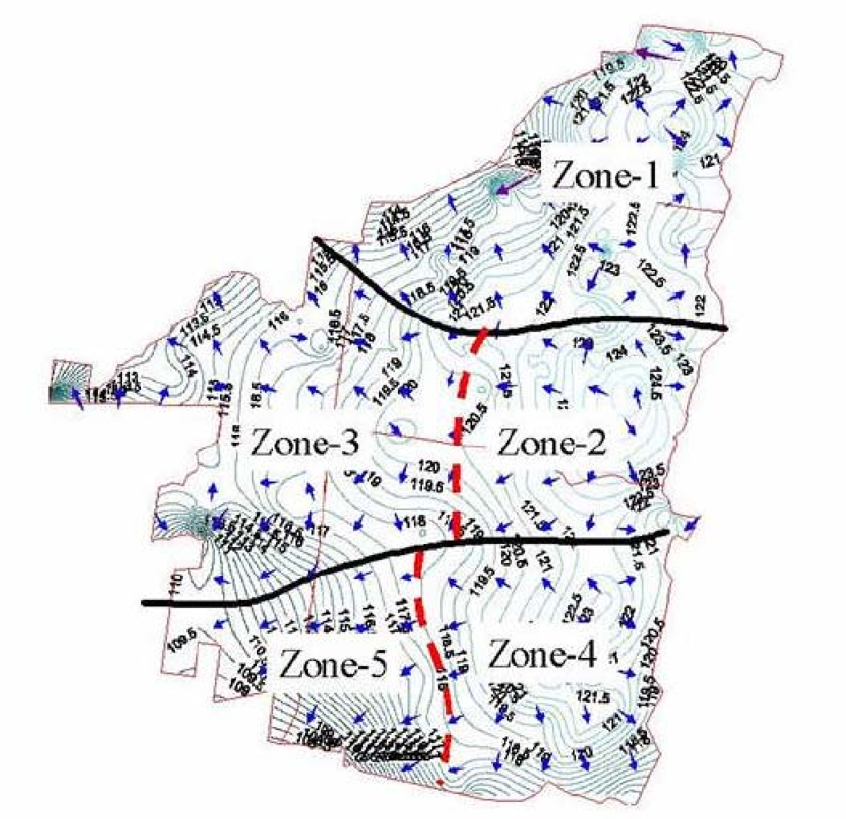


Table 1: Estimation of net recharge (ML) for CIA (1999/00 to 2001/02)

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**

Note: Net recharge is the amount that would need to be above to achieve a zero water table rise.

2.3.3 Soil salinity

Current biophysical models employing the best available information have been used to estimate that existing rice area quotas and maximum water application rates 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 agricultural production and consequent impacts on farm returns.

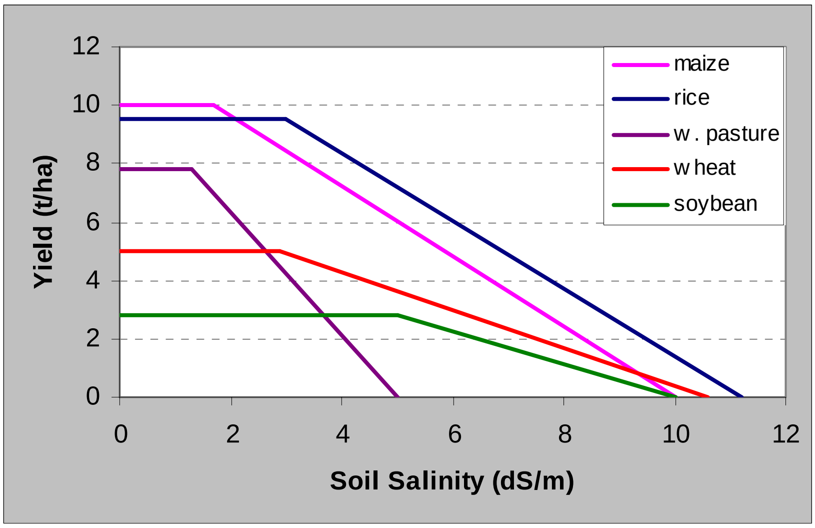
An estimate of the areas in CIA affected by a range of salinity levels is summarised in Table 2. The estimate of future soil salinity is based on two sources of data. First, today's percentage area of each soil salinity class is based on the soil survey data obtained in 2000 (Coleambally Environment Report, 2000). For subsequent years, the initial soil conditions have been linearly extrapolated using Marshall et al., (1994) over a twenty year period. It is assumed that no additional soil salinisation has taken place between 2000 and 2004 due to the recent low rainfall and irrigation period. Detailed hydraulic modelling that is currently not available would be required for a more accurate forecast.

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 the 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 3 and Appendix 2) in a spreadsheet model. It is conservatively 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 impact 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 (that is, the growing of salt tolerant crops on the saline areas). The implications of this assumption are discussed in section 4.4.

Figure 3: Yield response of crops to rising soil salinity



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

2.3.4 Waterlogging

Waterlogging occurs when there is inadequate oxygen in the air and water of the soil pores. Prolonged waterlogging decreases crop yields by causing reduced root density and depth as well as reducing the available nitrogen to the crop (Grieve et al., 1986). Some crops are more susceptible to waterlogging (for example vegetables, vines, cotton, trees) than other crops (for example grasses, cereals). Waterlogging can also lower yields as a result of reducing the 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.

Assessing yield losses caused by waterlogging is difficult due to the many biophysical and management factors that contribute to the process of waterlogging. Waterlogging is primarily a function of surface drainage and soil type.[4] Large variations in yield losses can occur due to the length of the waterlogging period and the stage of plant development when the waterlogging occurs. Past research by Grieve et.al (1986) and Marshall et.al. (1994) has provided some estimates of yield losses attributed to water logging that were used to drive assumptions about waterlogging for sensitivity testing.[5] Waterlogging was estimated to occur one year in three for winter crops and every year for summer crops. In addition, waterlogging losses due to reduced timeliness of cropping operations was estimated to be 25% of crop yield in 1 in 5 years. Winter crop yield loss figures and timeliness yield loss figures were reduced by 25% where farms have access to district drainage, and an additional 50% where farms are land-formed.[6]

2.4 Farm biophysical variation – the source of gains from trade

Irrigation farms within the CIA are not identical. They vary in basic resource characteristics such as size of landholding, mix of soil types, depth to watertable (that is current impact of salinity and waterlogging), rice quota held (related to property size and soil type). There will also be variation between farms based on individual landholder preferences, farming technologies and other factors. The focus in this

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[4] Note also that in heavy clay soils alternative management actions including surface drainage (for example laser levelling, permanent beds), improved irrigation scheduling to crop water requirements, and the incorporation of soil management practices that increase soil porosity (for example deep ripping, gypsum application) e more effective than lowering water tables (Christen and Ayres, 2001).

[5] Grieve at al. (1986) estimated that annual yield losses attributed to waterlogging in the Murray Valley were 12.5% for winter pastures, 25% for summer pastures and 20% for wheat. Marshall et al. (1994) estimated that waterlogging causes an average annual yield losses ranging from 1.3% to 15% for various crops in the CIA. Christen et al. (1985) estimated the loss for wheat to be 8% on a landformed paddock in the MIA. A review article by Tregaskis and Prathapar (1994), reported yield losses of 25%for perennial ryegrass, 50% for white clover, 8.7% for white clover/ryegrass, nil for soybean, 25-46% for wheat and 16% dry matter yield loss for maize.

[6] Mike Ridley, Coleambally Irrigation, pers. comm. 2005. Improved drainage and land-forming are key activities to reduce the potential waterlogging in crops. It is estimated that 60% of the irrigable area in the CIA has been land-formed. The yield loss figures for summer crops have already incorporated these reductions.

report is on identifying the gains from trade that arise from variation in the basic resource characteristics across farms.

In order to capture the impacts of variation in resource characteristics a pragmatic trade-off was made between the complexity and difficulty in assembling information across more than 300 farm units in the CIA area and adequately estimating the scale of gains from trade. Resource characteristics vary across the five zones shown in Figure 2. It is likely that zones 2 and 3 will be combined in the initial phases of any recharge trading scheme as will zones 4 and 5. This leaves three separate areas for which the gains from trade need to be estimated.

In order to capture variation in resource allocation across the three zones ten farms were selected from a data set of actual farms within the region (for a total of 30 representative farms). They were selected to reflect the variation in soil types and cropping decisions across each zone. Small adjustments were made to individual farms in order to reflect the mix of different soils across these zones. This was required for extrapolation purposes as soil type plays a significant role on crop mix and recharge amounts. The physical characteristics for each representative farm are summarised in Appendix 2.

Selection of a mix of farms that accurately reflects cropping decisions in the CIA is important 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 lucerne are generally discharging crops. The mix of crop is therefore a key determinant in recharge rates, and via feedback to groundwater levels, future economic returns in the region.

For each of the policy alternatives discussed in the Section 3, the impact on the representative farms was estimated and extrapolated across the three zones before aggregation to the CIA level.

3. Defining policy alternatives

3.1 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. Strengthen the existing rice quota by reducing the cap on the area of rice;
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 base-line 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. A detailed description of the scenarios is given in the next sections. 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. Options 3 and 4 are output-based policies requiring adherence to specified level of recharge. Option 3 allows on-farm flexibility to change cropping mixes while option 4 allows flexibility to be extended across farms via trading of recharge management responsibilities and practices allowed under option 3 and across farm flexibility allowed under option 4.

3.2 Defining the business as usual scenario

The first step in the economic analysis is to define the biophysical parameters for the BAU scenario. The BAU scenario is defined by the baseline assumptions described in section 2.4 and 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 is 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 three regions for which estimates are calculated were shown in figure 5.

For the business as usual scenario, the economic component of the SWAGMAN Farm® model[7] will be used to optimise agricultural production by maximising the total gross margin[8] (TGM) for each representative farm with specified crop rotational constraints (see Appendix 1.2). 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 (such as weather, crop gross margins, and water allocation) are assumed for each year in the analysis period of 20 years. Therefore the optimal crop mix and associated recharge and total gross margin 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. An estimate of the areas in CIA affected by various salinity levels and its potential impact on crop production was outlined in Section 2.5.4.

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

[8] TGM is used as a proxy for the profits or net returns to landholders. It represents the net return to the landholder for an activity (crop) before the fixed costs of managing a farm are taken into account.

3.3 Defining the alternative policy scenarios

3.3.1 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-tradeable 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 ($30/ML).

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 would be negligible therefore the derived total gross margin is the same over time.

3.3.2 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. Firstly, the water “cap” is derived by estimating the water allocation that would result in zero net recharge for each zone for an optimal crop mix that meets the cropping rotational constraints in Table A2. The cap is then allocated via a uniform proportionate reduction in water to each farm, based on the zone with the lowest water allocation required to meet the recharge cap. SWAGMAN Farm® is then used to maximise farm total gross margin constrained by the derived water cap for each representative farm.

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 achieving the water cap would lead to no additional salinity impacts in the future therefore the derived total gross margin is the same over time.

3.3.3 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 is not to exceed the farm recharge cap. The farm cap is calculated in two steps. First, the target 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 and the sale of surplus water outside of the region 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 is assumed to eliminate future increases in salinity impacts and therefore the aggregate total gross margin is the same over time.

3.3.4 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). 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 tradeable recharge cap.

The aggregate cap is calculated as for a recharge cap with no trade in section 3.3.3. 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 in Table 1 and Figure 7.[9] The business as usual scenario yields a total gross margin of $37.4 million from 51,000 ha of irrigated crop (of which rice accounts for 45% of the total irrigated crop area) and 26,600 ha of dryland cropping. This result is similar to actual cropping areas and estimated total gross margin for the CIA. The two main crops, rice and wheat have roughly the same areas. However, there is a significant difference in the area of irrigated pasture. This is not a significant concern as irrigation management of pastures in the CIA is usually on an opportunistic basis. That is, pastures are generally only irrigated when the farm has surplus water from other cropping requirements. As a result, the pastures may only get one watering during the growing season, and consequently the production from irrigated pasture would not be significantly greater than the production from dryland pasture. When comparing the total pasture areas between the model and actual areas, they are approximately the same. Also the total gross margin for the crop mix derived by the SWAGMAN model is similar to the calculated total gross margin for the actual cropping areas.

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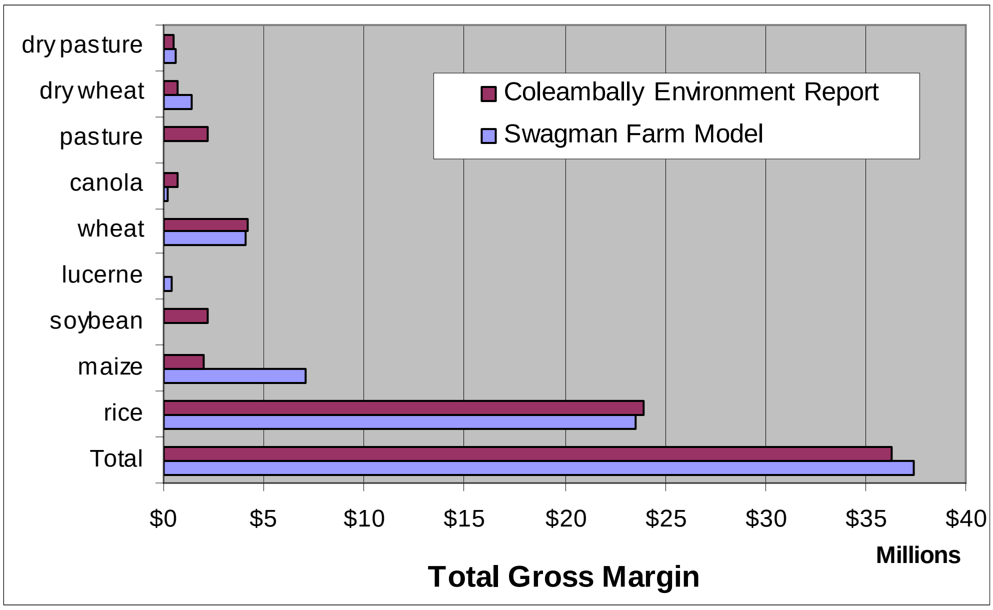
[9] For all scenarios except the water cap it is assumed that the average water allocation is 86% of full entitlements. Additional discussion on the assumptions is provided in Appendix 1.

Table 3: Comparison of model derived cropping areas and total gross margin to the average cropping areas and total gross margin for the period 1998/99 to 2001/02

Crop	SWAGMAN Farm® Model		Coleambally Environment Report[^]	
	Area (ha)	TGM ($)[#]	Area (ha)	TGM ($)[#]
Rice	22,962	23,535,723	23,374	23,958,094
Maize	8,610	7,051,429	2,411	1,974,404
Soybean	252	132,622	4,116	2,169,264
Lucerne	539	425,539		
Wheat	17,887	4,096,093	18,207	4,169,460
Canola	736	186,289	2,592	655,713
Pasture	0	0	10,238	2,170,509
dry pasture	16,931	1,439,166	8,600	516,000
dry wheat	9,689	581,362	8,057	684,845
Fallow	8,589	0	8,600	0
	86,195	**37,448,222**	**86,195**	**36,298,289**

[^] average CIA cropping areas 1998/99 to 2001/02 as reported in the Coleambally Environment Report.
[#] calculated using gross margins in Appendix 1.

Figure 4: Comparison of total gross margins for model validation



For the business as unusual scenario, the net recharge estimated by the SWAGMAN model was 23,355 ML (Table 4). 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).

Table 4: Comparison of net recharge for the CIA between SWAGMAN model and Khan et al, (2004) average estimate for the period 1999/00 to 2001/02

Zone	Zone Area (ha)	Estimated Net Recharge by SWAGMAN Model		Estimated Average Net Recharge – 1999/00 to 2001/02 by Khan et al. (2004)		Difference (ML)
		(ML/ha)	(ML)	(ML/ha)	(ML)	
North	24,000	0.112	2,684	0.06	1,549	1,135
Central	35,995	0.345	12,417	0.28	10,197	2,220
South	26,200	0.315	8,253	0.49	12,793	-4,539
TOTAL	86,195	0.271	23,355	0.28	24,539	-1,184

As the cropping areas for the two main crops in the CIA (rice and wheat) the total gross margin and 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. For the business as usual scenario, the data in Table 5 reflects the change in net returns due to the impacts of increasing soil salinity over a 20 year period. The impact of salinity on agricultural production is projected to reduce the annual total gross margin from nearly $35 million per year in 2003/04 to less than $32 million per year in 2023/24 (20 years time).

Table 5: Cropping areas and potential total gross margin for the business as usual scenario[10]

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
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 at a level that would avoid future increases to waterlogging and salinity and the resultant production impacts. Therefore

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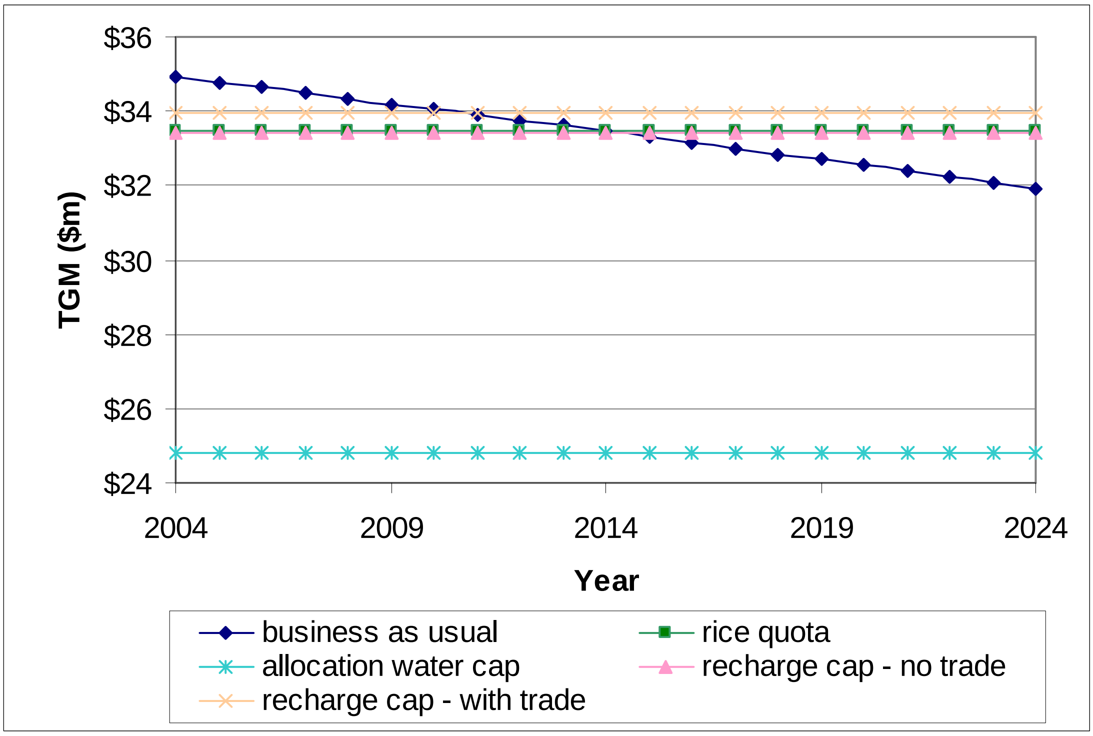
[10] The TGM values in Table 6 and Table 7 incorporate salinity impact losses.

the total gross margin is expected to continue at the modelled level throughout the 20 year modelled period. The annual TGM for the various recharge abatement policies is illustrated in Figure 5.

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 5: Annual total gross margin for the various recharge abatement policies



The summary results of the economic modelling are reported in Table 7. Implementing a rice quota (equivalent to 30% reduction from maximum allowable area) is estimated to reduce the annual total gross margin from agricultural production to $33.5 million per year. If this stream of future benefits is discounted at 5% per annum, the net present value (NPV) generated is negative $2.8 million.[11] Similarly, implementation of a water input cap (equivalent to 55% water allocation) is estimated to reduce the annual total gross margin to $25m per year yielding an undiscounted sum of benefits of negative $182 million and a discounted NPV of negative$114 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. The undiscounted sum of benefits generated by this policy compared to the business as usual policy over a 20 year period is negative $348,000, with a consequent discounted NPV of negative $3.6 million.

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.

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. At a five percent discount rate 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 to the community.

Table 7: Economic impact of recharge abatement policies

	BAU	Rice quota	Allocation water cap	Recharge cap - no trade	Recharge cap - with trade
TGM/year	$34,919,667 to $31,933,285	$33,484,357	$24,795,853	$33,427,573	$33,973,879
Total NPV	$432,153,382	$429,308,056	$317,911,413	$428,580,013	$435,584,293
Difference from BAU	--	-$2,845,326	-$114,241,969	-$3,573,369	$3,430,911

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[11] Net present values are the sum of future benefits discounted to an equivalent amount now. A discount rate of five percent was selected as being broadly similar to the real interest rate faced by landholders on borrowings for capital investment. Net benefits are estimated over a 20 year period because net benefits rapidly tail-off beyond 20 years unless gross benefits are very large. For more information see for example Turner, Pearce and Bateman 1994.

4.3 Sensitivity tests of key assumptions

4.3.1 Opportunity cost of water and the costs of managing recharge

The opportunity cost of water could have a bearing on the level of net recharge in the region. In the past three irrigation seasons (2002/03 to 2004/05) when the general security water allocations have been lowest on record (37% to 41%), the market value for water has ranged from $40/ML to $200/ML and the average price in each year from $55/ML to $115/ML (www.murrumbidgeewater.com.au). If the value of water in the water market exceeded the opportunity cost of most cropping alternatives in an irrigation region, water sales would result in water leaving the irrigation region. A threshold analysis of water prices revealed that if there were no restrictions on the volume of water leaving the CIA, a water price of around $78/ML would result in enough sales to limit agricultural production to meet the net recharge target. That is, for the assumptions on water allocation, crop returns and cropping area constraints used in this analysis a water price of $78/ML would result in sufficient water sales to reduce net recharge below target levels. The opportunity cost of water to Coleambally irrigators will vary from year to year depending on water availability, crop returns and the sustainable level of net recharge. In years when water availability is high and crop returns are below average, the opportunity cost of water is likely to be less than $78/ML. When water availability is low and crop returns are above average, the opportunity cost of water is likely to be much higher than $78/ML.

4.3.2 Area of CIA subject to soil salinisation

The viability of any net recharge policy is largely dependent on the assumptions of production losses in the BAU scenario. In this case, the viability of the tradeable recharge credits policy is quite sensitive to the estimated soil salinity conditions summarised in Table 2. The soil salinity estimates only have to decrease by 10% to return a negative NPV for the tradeable recharge credits policy.

4.3.3 Incorporating waterlogging losses in the BAU scenario.

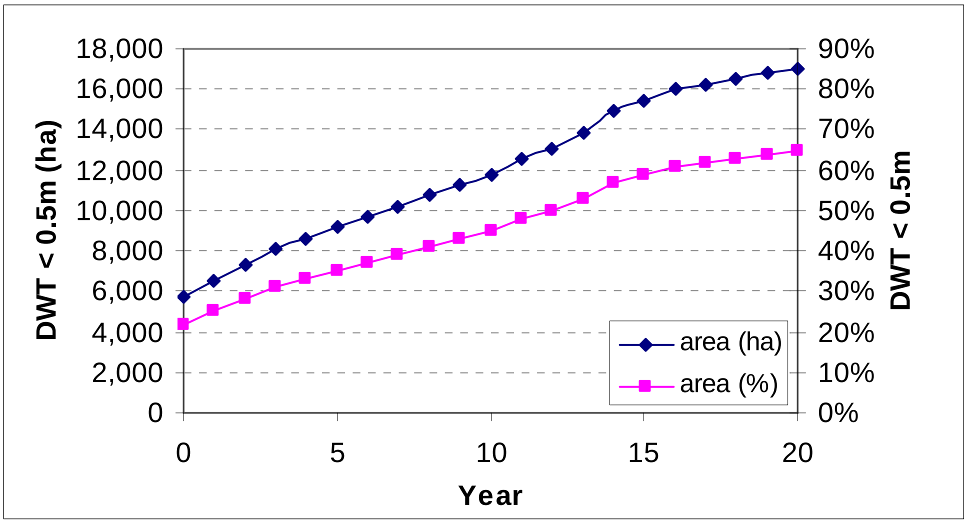
In the previous analysis, only salinity losses into the future were estimated for the BAU scenario. The incorporation of waterlogging losses is in addition to the production losses attributed to high watertables thus making the benefits of any net recharge abatement policy more attractive. A sensitivity test of the impact of including waterlogging losses to the BAU scenario and the resultant impact on the tradeable net recharge policy was conducted for southern region of CIA.

The southern region of CIA covers an area of approximately 26,200 ha. The soil salinity for this region is much higher than the average for the CIA due to the prolonged period of high watertables as shown in Table 8. High watertables also increase the incidence of waterlogging. The area prone to waterlogging is likely to increase over time if high watertables persist. From groundwater modelling, the predicted area of watertables less than 0.5 metres and therefore the area at most risk of waterlogging, could increase from 22% of the area to 65% of the CIA over the next 20 years (Figure 6). Agricultural losses attributed to waterlogging were estimated by applying the waterlogging yield loss functions in Table 3. The total crop area prone to waterlogging estimated in Figure 6 was adjusted to avoid double counting of losses attributed to salinity. The soil salinity area greater than 4 dS/m were deducted from the total area prone to waterlogging to estimate the additional crop area that will experience losses attributed to waterlogging alone. This avoids any incidence of double counting salinity and waterlogging for the same unit of land.

Table 8: Predicted distributions of soil salinity (% of area)

Soil Salinity Range (dS/m)	2004		2014		2024	
	CIA	South	CIA	South	CIA	South
0-2	85.4	79.0	75.0	68.2	64.5	57.5
2-4	7.8	4.0	14.8	11.1	21.8	18.2
4-8	4.5	10.0	6.1	11.7	7.8	13.5
>8	2.3	7.0	4.1	8.9	6.0	10.8

Figure 6 Predicted area of Southern CIA with watertables less than 0.5 metres



The annual TGM for the tradeable recharge abatement policy compared to BAU is illustrated in Figure 7. 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 $8.3 million per year for the southern region of CIA.[12] That is in Table 7, an average soil salinity value for all CIA was used compared to an average value for the south only[13]. At a five percent discount rate, adoption of the cap and trade policy is estimated to generate a NPV of $8.7 million for the southern region alone[14]. Therefore when the additional costs of waterlogging are considered, the tradeable net recharge credit policy has the potential to generate significant agricultural benefits, particularity for the southern region of the CIA.

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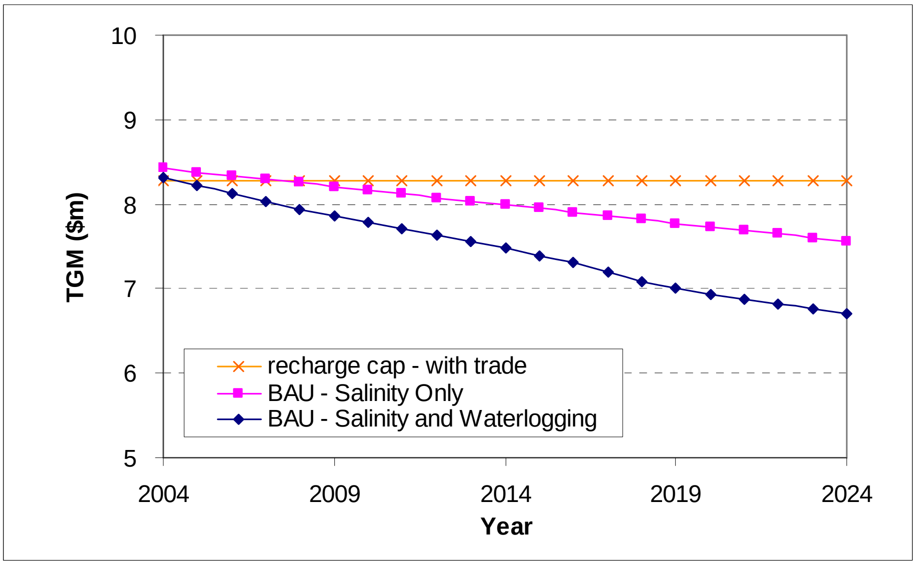
[12] For comparison, the breakdown of TGM calculated in Table 7 was: North $10.2m, Central $14.6m, South $9.2m. The difference in the south value by $0.9m is due to different soil salinity assumptions (Table 8).

[13] The undiscounted stream of benefits from this policy compared to the business as usual policy over a 20 year period are estimated at $17.3 million.

[14] Comprising $2.8m salinity reduction benefits and $5.9m waterlogging reduction benefits.

Figure 7: Southern CIA total gross margin



4.3.4 The creation of additional groundwater capacity

As discussed in Section 2 and Appendix 1, episodic events such as a run of very wet years could make the tradeable recharge scheme ineffective if there is no capacity within the groundwater system to absorb the above average levels of recharge. It has been estimated from preliminary groundwater modelling that if all farms in the CIA abated an additional 0.22 ML/ha, an additional 19,000 ML of groundwater storage would be created which would have the capacity to nullify an episodic event of consecutive very wet years.[15] However, to create the additional groundwater capacity, farmers will need to abate more recharge by incorporating a greater proportion of discharging crops into their crop mix. This is most likely to come as an additional cost to the farmers as the marginal return of discharging crops is usually less than the marginal return of recharging crops such as rice and maize.

A sensitivity test of the impact on the tradeable net recharge policy of restricting the recharge cap by 0.22 ML/ha to create groundwater capacity was conducted for the southern region of the CIA. The additional recharge cap reduced the annual total gross margin by 5% to $7.9 million. The relatively small change in TGM was due to rice and dryland pastures areas being substituted for irrigated wheat. That is, the additional returns from wheat in the forgone dryland pasture area almost compensated for the lost returns from the forgone rice area. The analysis shows that the policy has the potential to generate a stream of net benefits to Southern CIA over the 20 year period, resulting in a NPV of $3.4 million. Therefore, imposing an additional recharge cap to create groundwater capacity for episodic events still results in the tradeable net recharge credit policy having the potential to generate significant benefits to the CIA.[16]

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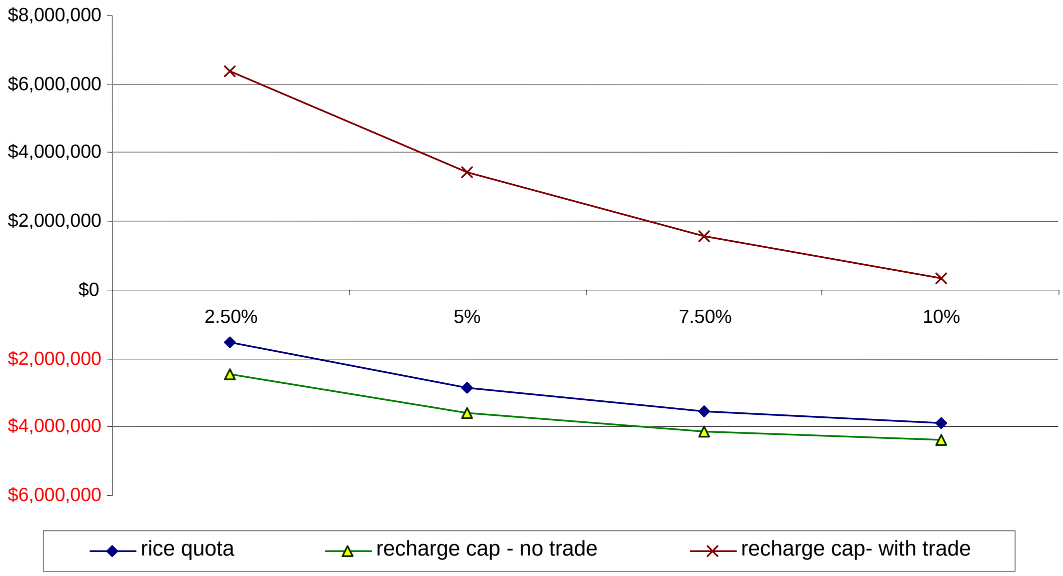
[15] Pers comm., Shahbaz Khan, CSIRO Land and Water, 2005.

[16] As noted by a reviewer the estimated benefits of this policy should also be higher since the potential threshold impacts caused by episodic events are avoided. Unfortunately the likelihood of an episodic event is unknown so the additional benefits cannot be estimated.

4.3.5 Sensitivity to discount rates

Sensitivity analysis to discount rates was conducted at 2.5%, 7.5% and 10% in addition to the 5% rate used in the initial model. The conclusions did not change with the different rates however the higher the discount rate, the less attractive is the cap and trade scenario. The results are summarised in Figure 8.

Figure 8: Sensitivity analysis of discount rates



4.4 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 more permeable soil types. The increase in the 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 an output oriented 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 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. Furthermore, a cap and trade model that incorporates banking and borrowing could generate additional benefits under real life variations in climate compared to the constant climate modelled in this report.

As an extension of the model we trialled 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.[17]

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. Furthermore the SWAGMAN Farm® model does not take into account on-farm adjustments towards more salt tolerant crops and avoidance of saline areas thus contributing to underestimation of aggregate benefits.

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 farm 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. Policy costs include the costs of designing and implementing the policy and the ongoing administrative and other costs under the policy. For the cap and trade model these costs also include transaction

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[17] We did not vary water prices within this analysis because of the variations in average annual water prices during recent dry years were not uniformly higher than average. However, with water price variations our conclusions may change.

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 direct costs and benefits to irrigators, through changes to agricultural production, and indirect costs and benefits to the local and wider community, through protection of infrastructure and 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. Sensitivity tests were reported in section 4.3 and the implications about varying some of these assumptions are noted in section 5.2. The sensitivity tests show that the modelling is largely robust to changes in the key assumptions. Inclusion of more detailed salinity or waterlogging data may significantly change the net benefits but these are likely to remain small when compared to total farm gross margins. Despite the apparent robustness of the modelling, it is important to note that, because of the underpinning assumptions the findings in this report should be regarded as a first 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 because non-farm benefits are excluded from the analysis.

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.

The economic model employed does not 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. However our preliminary analysis indicated interyear trades were unlikely to be profitable but a more detailed model may alter these conclusions.

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. Amongst other elements, the experiments involve identifying 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, although sensitivity analysis of one scenario was undertaken. A number of these issues are being progressed by Shahbaz Khan and colleagues at CSIRO Land and Water in Griffith. Further issues of importance are expected to remain outstanding at the conclusion of this work along with potentially new issues being uncovered.

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.

Christen, E. W. and Ayars, J. E. (2001) Subsurface *Drainage System Design and Management in Irrigated Agriculture: Best Management Practices for Reducing Drainage Volume and Salt Load*, CSIRO Land and Water Technical Report 38/01, CSIRO Land and Water, Griffith.

Christen, E.W., Muirhead, W., Spoor, G. and Moll, J. (1985) First patented in 1797 available now in the MIA, 1995!! *Farmers' Newsletter*, No. 145 p15-17.

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

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.

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.

Tregaskis, K. L. and Prathapar S A (1994) *Selected Papers Researching the Effects of Salinity and Waterlogging on Crops within the Murray Basin*, Technical Memorandum 94/11, Division of Water Resources.

Turner, R.K., Pearce, D., and Bateman, I., 1994. *Environmental Economics, An elementary Introduction.* Harvester Wheatsheaf, Hemel Hempstead, Hertfordshire.

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.

Appendix 1 The potential for 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 (see box 1 for an example).

Box 1: Environmental thresholds

A large number of environmental thresholds have been identified and documented by the Resilience Alliance including those involving eutrophication of lakes and other water bodies, dryland salinity and rangelands. A database of these can be viewed at: www.resalliance.org.

One documented example involves dryland salinity in Western Australia. Initially the system was able to absorb and store salt deposited by rainfall in the region. However, as native vegetation was removed a threshold was reached, particularly in upper catchment areas, where the reduced transpiration and increased recharge of groundwater aquifers leads to stored salt becoming mobilised into the root-zone of plants causing reduced agricultural production and surface salt scalding. The threshold varies with soil type.

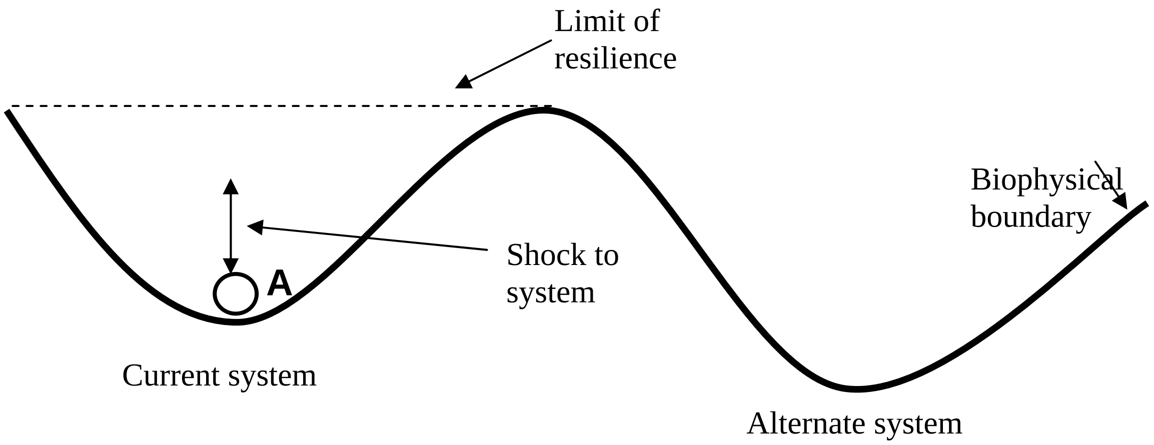
The main potential threshold of importance in the CIA arises from the impact of watertables and soil salinisation on crop production. The damage from rising watertables is not uniform but rather increases as groundwater rises within two metres of the soil surface and salt gradually builds up in the plant root zone through time. Therefore, the costs of rising watertables on any particular unit of land will not be uniform, but rather will be dependent on the depth to water and the degree to which soil salinisation has occurred. However, the cost to agricultural production for any particular unit of land that becomes subject to a rising watertable through time is often assumed to move along a linear damage function as the damage becomes progressively more severe.

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.

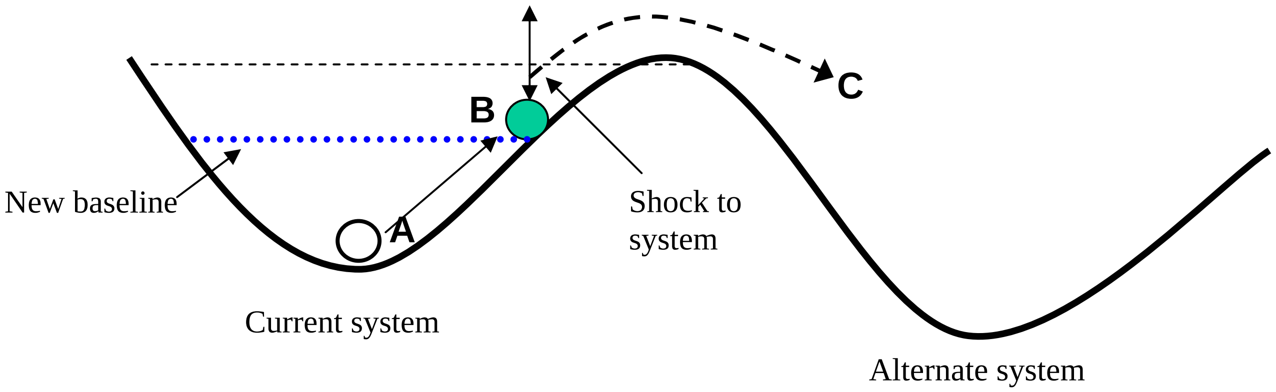
It is useful to discuss the nature of environmental thresholds in a resilience context. Episodic events can push environmental systems beyond thresholds. Consider for example the diagrams shown in Figures 9 and 10. The initial position of the system is represented by ‘A’ which lies in a basin of attraction. A shock to a system, such as that shown in Figure 9, 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 9: System response to a shock



In Figure 10, 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 9 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 10 could not do so in Figure 9.

Figure 10: Changed system response due to landuse impacts

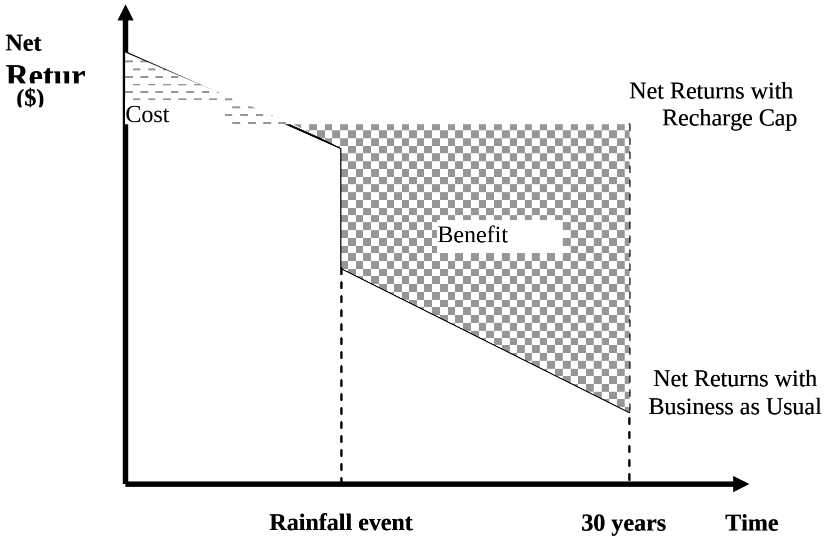


The impact of normal variations in climate complicates estimation of the costs of waterlogging and soil salinity because they can effectively act as shocks to the groundwater system. Prolonged dry periods can slow or halt rising watertables. Alternatively, prolonged wet periods can dramatically shift watertables upwards.

The sudden upward shift can potentially have similar consequences to the shock shown in Figure 10 in systems subject to ongoing landuse impacts.

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 11. The impact of the shock is to increase the net benefits from controlling net recharge[18].

Figure 11: Net benefit of controlling recharge with system shock



Significant rainfall events may be able to 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 climatic variations could cause the system to reach damage thresholds. That is, to avoid situations where the baseline

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[18] 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.

reaches the situation shown in Figure 10 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 10) the question arises as to the effectiveness of alternative policy options in lowering the baseline and increasing system resilience. This is maybe the case in the CIA. In this case, an effective recharge policy would need to create additional recharge capacity, through groundwater pumping or drainage for example. 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 often 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 groundwater system. At this point we do not know whether the system is closer to that shown in Figure 9 or that shown in Figure 10. 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 2.5.

Appendix 2 Swagman Model Assumptions

Model Farms

Data from the farms used as the basis for each zone are shown in Table A1.

Table A1: Representative farms physical attributes

Farm No.	**Area (ha)**	**Allocation @ 86% (ML)**	**Soil Area**					**Groundwater#**		
			NSMC	**SMC**	**RBE**	**TRBE**	**SANDS**	**Depth (m)**	**Salinity (dS/m)**	**Leakage (ML/ha)**
North Zone										
1	218	1195		201			17	4	1	1
2*	214	1190				95	119	4	1	0.37
3	214	1192		214				4	3.5	0.63
4*	351	1378		9	160	72	110	4	3.5	0.63
5	208	1180		14		194		4	3.5	1
6	208	1185		109		99		4	3.5	0.75
7	209	1189		47		150	12	4	3.5	0.25
8*	224	1194				103	121	4	3.5	0.37
9	212	1197		68		131	13	4	3.5	0.5
10	231	1218		21		170	40	4	3.5	0.75
Total	2,289	12,118		683	160	1014	432			
%				30%	7%	44%	19%			
Zone	24,000	113,400								
Central Zone										
11	218	1197				115	103	2	7.5	0.25
12	200	1189		200				2	10	0.25
13	224	1197		102		78	44	2	3.5	0.25
14	218	1189		140		78		2	3.5	0.25
15	209	1197		8	73	114	14	2	3.5	0.37
16*	223	1199				211	12	2	5	0.5
17	218	1190			79	139		2	5	0.25
18*	335	1261	11			324		2	7.5	0.25
19	214	1166		46	72	96		2	7.5	0.25
20	318	980	17	17	27	170	87	2	3.5	0.25
Total	2,377	11,765	28	513	251	1325	260			
%			1%	22%	11%	56%	11%			
Zone	39,995	170,080								
South Zone										
21	266	1177		6	146	6	108	2	7.7	0.25
22	229	1207		54	95	80		2	7.5	0.25
23	320	1366		20	212	39	49	2	1	0.2
24*	221	1207		4	107	110		2	3.5	0.25
25	219	1197	5	48	24	142		2	5	0.2
26	211	1192	11	28	32	127	13	2	15	0.25
27	219	1194			144	75		2	7.5	0.25
28*	233	1198	21	34	100	78		2	7.5	0.25
29	214	1187	32	85	27	70		2	3.5	0.25
30*	679	980		31	124	524		2	7.5	0.25
Total	2,811	11,906	69	310	1011	1251	170			
%			2%	11%	36%	45%	6%			
Zone	26,200	123,800								

* soil areas have been adjusted to regional proportions (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.

1.2 Further detail on modelling assumptions.

Water
Water supply is based on 86% general security allocation. This is the average of allocations for the years 1996/97 to 2001/02. 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. Irrigation water salinity is assumed to be 0.15 dS/m and rainfall salinity to be 0.01dS/m. It is assumed that all farms have recycling and do not have any groundwater pumping. Rainfall and evapotranspiration are based on average Griffith values.

Crop gross margins
Crop gross margin and irrigation application are summarised in Table A2. It was assumed that irrigation application for each crop was the same on all soil types except SANDS which required 15% more. Water cost was assumed to be $16.86/ML. This incorporates both fixed and variable water costs, assuming an allocation of 86%.

Crop rotations
There are limits on individual crop areas in any one year due to crop rotations for disease and weed management, market constraints and environmental policy (i.e. for rice). Also, there is a minimum area of fallow to allow for crop transition and irrigation maintenance. The assumed crop area constraints are summarised in Table A3.

Table A2: Crop Gross Margin and Irrigation Application

	Price[1] ($/t)	Yield[1] (t/ha)	Variable Costs (LESS water costs) ($/ha)	Gross Margin (LESS water costs) (/ha)	Irrigation Applied (ML/ha)	Water Costs @ $16.86/ML ($/ha)	Total Variable Costs ($/ha)	Gross Margin ($/ha)	Gross margin per ML ($/ML)
Rice	207	9.5	730	1237	12.5	211	941	1026	82.1
Maize	180	10	838	962	8.5	143	981	819	96.3
Soybean	389	2.8	427	662	8	135	562	527	65.9
lucerne hay	150	15	1259	991	12	202	1461	789	65.7
wheat	130	5	379	271	2.5	42	421	229	91.5
barley - malt	140	4	335	225	2.2	37	372	188	85.4
canola	318	2.7	555	304	3	51	606	253	84.3
fababean	220	4	625	255	3.5	59	684	196	56.0
lucerne pasture	30	26	191	589	10	169	360	420	42.0
summer pasture	30	30	223	677	12	202	425	475	39.6
winter pasture	30	12	89	271	3.5	59	148	212	60.6
dryland pasture	30	2	0	60	0	0	0	60	-
dryland wheat	130	2.5	240	85	0	0	240	85	-

[1] price and yield units for pastures is DSE/ha and $/DSE respectively

Table A3: Crop area constraints

Maximum area		
rice	69	ha
maize, soybean, hay lucerne	10%	of farm area
dry wheat	20%	of farm area
canola, fababean, summer pasture, lucerne	30%	of farm area
wheat, barley, winter pasture	50%	of farm area
dry pasture	100%	of farm area
Minimum area		
fallow	10%	of farm area

Initial soil water conditions

For farms with watertables greater than 2m, initial soil water content is assumed to be "average" which is equivalent to 85% of field capacity and when watertables is less than 2m, initial soil water content is assumed to be "wet" which is equivalent to 90% of field capacity (Table A4).

Table A4: Soil water parameters

					Initial Soil Water Content	
Soil Type	Leaching Fraction	Wilting Point	Field Capacity	Saturated Content	Average (i.e. WT>2m)	Wet (i.e. WT<=2m)
SMC	0.02	0.25	0.38	0.48	0.32	0.34
NSMC	0.03	0.23	0.38	0.46	0.32	0.34
TRBE	0.04	0.3	0.42	0.47	0.36	0.38
RBE	0.05	0.22	0.35	0.45	0.3	0.32
SAND	0.05	0.2	0.28	0.4	0.24	0.25

Crop soil salinity threshold

Crop yields need to be adjusted to allow for changing soil salinity conditions over time. The Relative yield is the declined crop yield from potential yield as a result of the change in soil salinity. Potential yield is the maximum achievable yield in a non-saline soil. The relationship between relative yield and soil salinity can be described by the following equation:

$$Yr = Yp\ (1-B\ (ECe-A))$$

Where Yr = relative yield (t/ha)
Yp = potential yield (t/ha)
A = crop salinity threshold value (dS/m)
B = % reduction in relative yield per increase in soil salinity (dS/m)
ECe = average root zone soil salinity (dS/m)

The crop salinity threshold values and the percentage reduction in relative yield per unit increase in soil salinity for the main crops grown in the CIA is summarised in Table A5.

Table A5: Crop soil salinity thresholds

Crops	Soil Salinity Threshold (dS/m)	Percentage yield decline per unit increase in soil salinity	Reference
rice	3.0	12.0	1
maize	1.7	12.0	2
sorghum	0.7	30.0	3
soybean	1.6	25.0	3
sunflower	5.5	25.0	2
wheat	2.9	13.0	4
barley	3.5	9.0	5
oats	5.0	20.0	2
canola	3.5	3.3	3
fababean	0.8	7.9	2 (phasey bean)
lucerne	1.5	6.9	2
grape	1.5	9.5	2
winter pasture	1.3	27.0	4
summer pasture	1.6	9.0	4
sub clover	0.0	8.1	3
white clover	0.0	8.1	3
p. ryegrass	5.6	7.6	1

References
1. 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.
2. ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Vol 3, Chapter 9.
3. Evans, L (1998) Interim Quality Guidelines for the use of Groundwater for Irrigation, Workshop for Irrigators, NSW Agriculture
4. 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., vol. 26(6), pp.761-77.
5. 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.