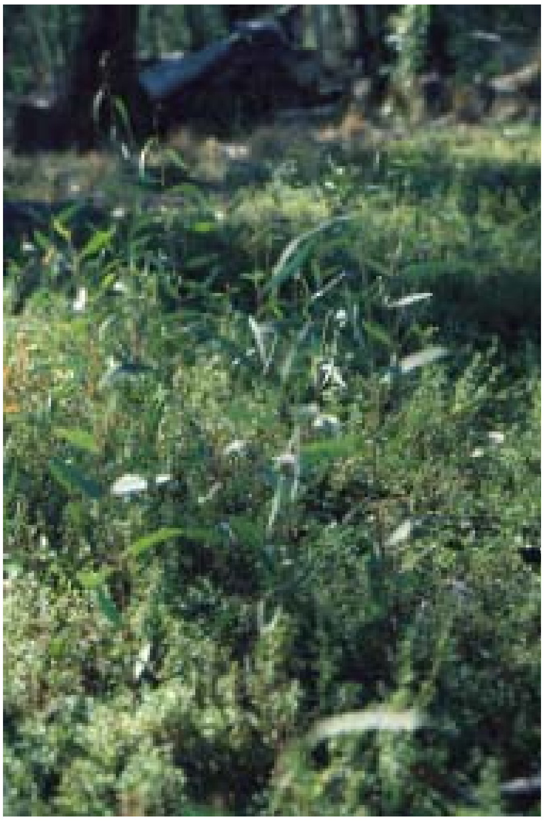
Tradeable recharge credits in Coleambally Irrigation Area: Report 7

Experiences, lessons and findings

July 2005

CSIRO & BDA Group

Stuart M Whitten, Shahbaz Khan, Drew Collins, David Robinson, John Ward and Tariq Rana



For more information on the issues discussed in this document please contact the following people:

For information on biophysical modelling of recharge and recharge management in the Coleambally region (including the SWAGMAN® series of models):

Dr Shahbaz Khan
CSIRO Land and Water
Griffith, NSW 2680
(02) 6960 1500 (ph)
(02) 6960 1600 (fax)
shahbaz.khan@csiro.au
www.clw.csiro.au/division/griffith/

For information on recharge rights and potential market options:

Stuart Whitten
CSIRO Sustainable Ecosystems
GPO Box 284
Canberra, ACT 2601
(02) 6242 1683 (ph)
(02) 6242 1705 (fax)
stuart.whitten@csiro.au

Or:

Drew Collins
BDA Group
GPO Box 4022
Manuka, ACT 2603
(02) 6282 1443 (ph)
(02) 6161 9310
drewcollins@netspeed.com.au

For information on the experimental economics:
John Ward
CSIRO Land and Water
Urrbrae, SA.
(08) 8303 8685
(08) 8303 8590 (fax)
j.ward@csiro.au

Whitten, Stuart M, Shahbaz Khan, Drew Collins, David Robinson, John Ward and Tariq Rana (2005) Tradeable recharge credits in Coleambally Irrigation Area: Report 7, Experiences, lessons and findings. CSIRO & BDA Group

ISBN: 0975178377

This paper is an overview of a two-year research program. It synthesises the results presented in a series of reports investigating a market-based approach to manage the threat of salinity and waterlogging in the Coleambally Irrigation Area. 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*

Acknowledgements:
Coleambally Irrigation Cooperative provided important assistance and support in undertaking the project. The research presented in this project has been funded by the National Market Based Instruments Pilots Program under the National Action Plan for Salinity and Water Quality and by CSIRO. All errors and omissions are entirely the responsibility of the authors.

Executive Summary

Across Australia, a range of complex natural resource management problems are challenging traditional policy approaches to management. In many instances, the loss in resource yield or quality is impacting resource-using industries while the costs of changing management to ensure the future sustainability of land, water and biodiversity resources appears substantial.

This has prompted governments, industries and communities to investigate alternative strategies and policy instruments that could promote sustainable resource use at low cost. One initiative under the National Action Plan for Salinity and Water Quality is the *National Market Based Instruments Pilots Program*. Market Based Instruments (MBIs) are policy tools that encourage changes in management practices through market signals, rather than through explicit directives such as regulation. Instruments generally work through the modification of prices faced by resource users (such as through taxes or subsidies) or through the creation of tradeable rights (sometimes referred to as environmental markets).

Irrigated agriculture often leads to groundwater recharge greater than regional aquifers can absorb. This in turn leads to rising watertables that can cause waterlogging and salinity impacts. The management challenge is to limit the net recharge to sustainable levels. That is, to prevent water application beyond the evapotranspiration of crops, leaching requirements of soils, and water movement within underlying groundwater systems.

MBIs are being investigated to find out if they can assist in the management of irrigation-induced salinity in irrigation areas such as Coleambally in NSW.

Salinity in the Coleambally Irrigation Area is leading to losses in production, increases in management costs, and damage to environmental amenity and infrastructure. While a number of policy instruments have been adopted to address the threat of irrigation-induced salinity, no strategy to date has been wholly successful in achieving Coleambally community management targets. This prompted interest by the Coleambally Irrigation Cooperative Ltd (CICL) in investigating the potential use of a tradeable-rights instrument and the subsequent development of a MBI Pilot in collaboration with CSIRO and the BDA Group.

The tradeable rights instrument investigated is a ‘cap-and-trade’ scheme. Under this type of policy instrument a limit on the overall level of an activity or pollution associated with the environmental damage is established, and ‘rights’ to the agreed individual level of activity are allocated among users. Through the trading of these rights, greater efficiency, effectiveness and flexibility can often be achieved relative to other policy instruments.

The overarching goal of this study has been to explore the potential application of a cap-and-trade approach to manage net recharge in the Coleambally Irrigation Area. This has involved the conceptual development of the instrument, the development of the necessary biophysical information base, economic assessment of alternative policy approaches, experimental testing of institutional frameworks, and ground-proofing of our research findings (within the Coleambally region).

This report provides an overview of this study and the lessons it provides for the broader application of this type of policy instrument. Earlier reports have focused on individual components of the research. This has included the identification of what's needed in the institutional design, modelling the economic costs and benefits of alternative options, exploring the biophysical research methods and conclusions, designing and conducting economic experiments, and testing institutions with Coleambally landholders.

Management of net recharge has a number of similarities with other environmental markets, where the actions of a group of individuals or businesses are degrading a common property resource such as an airshed or waterway. Cap-and-trade schemes have proved both workable and efficient where the impactors have been of a point source nature. That is, the source and nature of impacts are readily observable and measurable, such as pollution discharges from a chimney or drain.

Net recharge is a diffuse source problem to which cap-and-trade approaches have had limited application. Critical to the use of tradeable rights instruments is a robust scientific knowledge base and a regulatory platform from which to establish the new rights. For many diffuse source problems it is difficult to attribute impacts to sources. The diffuse nature of impacts results in spatial and temporal variation in the ultimate impact of recharge associated with alternative activities. Furthermore, there is often limited regulation of diffuse source pollutants in place that could provide the basis for establishing new rights.

However, the circumstances of irrigation management and research support in the Coleambally Irrigation Area suggested that it was possible to accurately and cost-effectively estimate paddock-scale recharge, and to establish and enforce a tradeable net recharge rights scheme.

Over recent years, the CSIRO Division of Land & Water in Griffith has developed several modelling techniques to inform and aid recharge management in the region, including a series of multi-layer groundwater flow and salt transport models called 'SWAGMAN'. The SWAGMAN Farm model has been calibrated to provide an accurate and repeatable framework for estimating paddock-scale recharge and thus a suitable metric for recharge property rights.

In addition, the rights of irrigators to contribute net recharge could be defined via changes to water supply contracts that all irrigators must hold with CICL. This would require irrigator agreement to the creation of the new property rights (because CICL is a cooperative owned and managed by CIA irrigators). An agreement was considered probable as the CIA irrigators would be the main beneficiaries of the scheme.

In our investigation of the merits of a cap-and-trade scheme to the management of irrigation water and salinity in the CIA we have addressed a number of specific gaps in our knowledge. These include:

- Measuring diffuse source net recharge to shared irrigation aquifers;
- Identifying the net recharge impact boundaries (extent of the commons) and setting targets for net recharge;

- Determining the definition and allocation of rights to a new environmental service - ‘net recharge’;
- Identifying mechanisms for facilitating a market for net recharge including management flexibility, exchange mechanisms, administrative frameworks, monitoring rule violations, and nature and imposition of penalties;
- Estimating the efficiency of a cap-and-trade instrument compared to other policy instruments;
- Estimating the likely effectiveness of a cap-and-trade instrument given the characteristics of market participants;
- Developing tests of institutional frameworks directly with stakeholders to improve the robustness of institutional design; and
- Identifying ways to successfully engage with the community to achieve adoption and change in management.

The findings from our investigations support enthusiasm for MBIs as a means to promote cost-effective management, but also caution that these instruments will not always be the best policy tool when all factors are considered.

Drawing on the modelling capacity developed at CSIRO Land and Water we were able to develop an aggregate recharge target and the means to allocate and monitor net recharge at the farm level cost-effectively. An institutional framework to support the new recharge market was postulated. The framework would leverage off existing water supply obligations. This framework would be workable from an administrative and enforcement perspective and transactions costs could be kept low if done through an internet trading platform.

Nevertheless, the costs of developing and implementing a cap-and-trade scheme and the ongoing transaction costs incurred by irrigators in trading recharge rights are likely to be greater than the costs incurred in administering current policies. Therefore, the merits of a cap-and-trade scheme rest on it achieving greater recharge management benefits net of scheme costs.

Accordingly our investigations focussed on identifying the likely extent of cap-and-trade benefits. Economic modelling indicated that salinity is currently imposing relatively small costs on CIA irrigators, and that under a ‘business-as-usual’ scenario these costs would only serve to reduce annual agricultural income by some 8.5% after 20 years.

By reducing recharge to a sustainable level under a cap-and-trade scheme, income is initially reduced from that which would have prevailed under business as usual, but is greater in later years. The higher net income achieved under the cap-and-trade scheme when accounting for the lower incomes initially, and with the effect of discounting, was found to be small, less than 1% of estimated farm income over the 20 year period.

Such small benefits do not support the adoption of tradeable recharge rights in the CIA. Modelling by its very nature involves estimations and simplifications, and the estimated level of benefits is not statistically significant. In addition, benefits would need to net out transaction costs and a premium reflecting the risks in introducing a new policy regime. Furthermore, experimental tests indicate that it is unlikely the full gains from a cap-and-trade scheme could be accessed by irrigators, thus further reducing the net benefits available over current recharge management policies.

Despite these empirical findings, our investigations have raised a number of issues for recharge management in the CIA and for the use of tradeable rights instruments more broadly.

In relation to recharge management in the CIA, there are a number of aspects to both the science and the institutional development that may improve the prospects of tradeable recharge rights in the future. For example, we were unable to explore fully the impact of stochastic climatic variability and extreme events on the potential benefits of alternative policies, nor the impact of water rights reforms. Also, the off-farm benefits from adopting improved recharge management were not included. Hence, we suggest that CICL revisit tradeable net recharge credits in the future, particularly when broader policy reforms provide the means to incorporate environmental and downstream benefits into a recharge market.

The research does indicate that a focus on net recharge can provide an effective management tool to guide policy instruments otherwise based on inputs or activity levels.

The biophysical research undertaken to support recharge management within this project, and more generally in the CIA, provides the means to more accurately target the current policy regime with recharge goals. That is, the current limits on rice cropping could be more closely targeted towards achieving recharge targets using the biophysical research from this and related projects.

Finally, the experiments conducted with irrigators indicate that the provision of recharge information and opportunity for communication between irrigators may in itself achieve a significant proportion of the desired recharge outcomes. It will also assist in engendering irrigator support for CICL in maintaining and refining its rice policy instrument.

Our research has a number of implications for the broader application of tradeable rights instruments. First, through the application of a sophisticated biophysical information base, it has been possible to design tradeable rights for a diffuse source of pollution. Importantly the metric used, net recharge, has a direct and measurable relationship with the environmental impact being managed and performance against this metric can be cost-effectively assessed.

Second, the analysis highlighted the importance of robust economic analysis in both policy design and the evaluation of alternative policies. Despite the enthusiasm for MBIs, they will not always offer the best policy response. And this may be compounded where property rights cannot be fully defined. In these instances a market instrument cannot guarantee an improvement in social welfare.

In this study, the available biophysical information indicated a high level of complexity in developing a robust property right, as in previous applications of tradeable rights to atmospheric pollutants and nutrient management in the US. We also anticipated that climate driven stochastic variability would be an issue. However, despite the significant knowledge about spatial and stochastic factors, the interaction between stochastic rainfall events, biophysical outcomes and thresholds could not be fully developed in the time available. Until this can be done, the robustness of any recharge rights created will be uncertain.

Finally, the experimental economics component demonstrated the value of this relatively new area of economic investigation to the development of MBIs. The experimental investigations confirmed that traditional economic analysis will overstate potential benefits as real world market participants rarely conform to the myopic profit maximising agents typically assumed in economic analysis. Moreover, while the experimental economics can be used to help develop and test market design prior to implementation, the findings on the value of information and communication underlie the potential of these alternative policy instruments to provide some of the gains offered through market constructs.

In concluding, the study has brought together a diverse set of resource managers, policy makers, scientists and economists who have collaborated in investigating the potential for tradeable recharge rights in the CIA. While the study results do not support such a policy approach at this time, the analysis has estimated the significance of the environmental problem and confirmed the value of biophysical investigations. It has also provided insights on the appropriateness of the current policy regime and the possibility of the broader use of these instruments. For these reasons the MBI pilot has proved successful, and the research partners are appreciative of the support provided by the *National Market Based Instruments Pilots Program.*

We note also the impacts of the major drought that overlapped the project with consequent prevention of an implementation trial. While this limited the practical application of the MBI pilot the team was able to make a number of significant conclusions for the ongoing development and implementation of MBIs.

Table of Contents

Executive Summary ……………………………………………………………iii

1. Overview of the pilot……………………………………………………1

1.1 Biophysical issue……………………………………………………..2

1.2 Approach to recharge management…………………………………..3

1.2.1 Policy approaches…………………………………………………….3

1.3 Research goals………………………………………………………5

1.3.1 Identifying the knowledge gaps…………………………………….. 5

1.4 Report structure……………………………………………………6

2 Designing an environmental market for net recharge management?..7

2.1 Previous applications of similar MBI instruments………………………7

2.2 Designing new institutions – a cap-and-trade model for net recharge 9

2.2.1 What are net recharge rights and who will use them?......................9

2.2.2 What is the cap?...9

2.2.3 Application of the cap at the individual scale……………………….. 11

2.2.4 Underpinning institutions……………………………………………. 12

2.2.5 What would a market for recharge look like?................................. 13

2.2.6 Increasing market potential through offsets…………………………..13

2.3 Outstanding design issues……………………………………………13

3. Biophysical modelling…………………………………………………14

3.1 Net recharge methodology and analysis………………………………14

3.2 Results of the net recharge analysis of CIA………………………….. 15

3.3 Water Balance of the CIA (Methodology)…………………………….. 17

3.3.1 Supply system…………………………………………………………17

3.3.2 Rainfall contribution…………………………………………………. 18

3.3.3 Groundwater balance…………………………………………………18

3.4 Area wide net recharge targets………………………………………21

3.5 Measuring paddock scale recharge……………………………………22

3.6 Exploring the likely impacts of extreme events………………………23

4. Economic modelling: Farm scale costs and benefits of net recharge management………………………………………………24

4.1 Alternative policies…………………………………………………25

4.2 Summary results of economic analysis………………………………..27

4.3 Sensitivity analysis and caveats……………………………………..30

4.4 Define hypothetical demand and supply curves for credits…………32

5. Institutional design 2: Exploring market potential using experiments……………………………………………………………...33

5.1 Prioritise impediments for experimental tests…………………………..33

5.2 Treatments and hypotheses…………………………………………...37

5.3 Simulated catchment……………………………………………………38

5.4 Pre-tests – Yanco field trial…………………………………………….. 40

5.5 Experimental setting…………………………………………………..40

5.6 Results…………………………………………………………………41

5.7 Conclusions for field trial……………………………………………...43

6. Testing results in the Coleambally context………………………..44

6.1 Simulation trial…………………………………………………………44

6.1.1 Context and setting……………………………………………………...44

6.1.2 Yanco demonstration outcomes………………………………………45

6.2 Farm case studies……………………………………………………..46

6.2.1 Context and setting……………………………………………………...46

6.2.2 Case study results……………………………………………………… 47

6.3 Conclusions…………………………………………………………….48

7. Lessons for MBI design and implementation……………………... 49

7.1 Policy advice in Coleambally Irrigation Area………………………… 49

7.1.1 Potential for tradeable net recharge credits in Coleambally Irrigation Area………………………………………………………………………49

7.1.2 Policy advice to the Coleambally community……………………… 51

7.2 Advice for MBI research and development……………………………52

7.2.1 Addressing cap-and-trade knowledge gaps………………………… 52

7.2.2 Factors underpinning the successful investigation of the cap-and-trade approach to recharge management…………………………………… 54

7.2.3 Conclusions for future cap-and-trade applications…………………..54

7.2.4 Broader conclusions for MBI development and implementation…...55

8. Discussion and conclusions……………………………………… 56

8.1 Project conclusions……………………………………………………56

8.2 Opportunities for further research……………………………………57

8.2.1 Specific to Coleambally policy development………………………… 57

8.2.2 Wider MBI research issues…………………………………………58

References…………………………………………………………………59

Appendix……………………………………………………………………...62

List of Figures

Figure 1: The net recharge concept 2
Figure 2: Linkages between regional targets, net recharge property rights and farm management decisions 10
Figure 3: Location of Coleambally Irrigation Area 10
Figure 4: Possible zones in the Coleambally Irrigation Area 11
Figure 5: Temporal variations in net recharge in the CIA 16
Figure 6: Summer net recharge as a function of winter net recharge (discharge) 16
Figure 8: Net water requirements (ML) in the CIA for 2000/2001 crops 21
Figure 9: Interface of SWAGMAN Farm – a tool for aiding net recharge management 23
Figure 10: Predicted/Modelled Scenario for Water table depth rise in Western Coleambally 24
Figure 11: Sample zero net recharge supply and demand curves 32
Figure 12: Total recharge by treatment. 41
Figure 13: Quantity of recharge units traded by treatment. 42
Figure 13: Total recharge comparing the control and communication treatments of 45
the laboratory and field experiments 45
Figure 14: Average penalty by treatment (experiments and simulation trials) 46

List of Tables

Table 1: Potential Net Water Requirements (ML) in the CIA for 2000/2001 Crops under Average Climate Conditions 20
Table 2: Net recharge targets for 5 zones in the CIA 22
Table 3: Policy options for economic modelling was undertaken 26
Table 4: Cropping areas and potential total gross margin for BAU scenario .. 28
Table 5: Cropping areas and potential total gross margin for alternative policies. 29
Table 6: Economic impact of recharge abatement policies 30
Table 7: Market impediments assessed for potential experimental analysis .. 35
Table 8: Summary of the experiment selection process 36
Table 9: Experimental design 39

Abbreviations

CIA	Coleambally Irrigation Area
CICL	Coleambally irrigation Cooperative Ltd
LWMP	Land and Water Management Plan
MBI	Market based instrument
NMBIPP	National Market Based Instruments Pilots Program
SWAGMAN	**S**alt **W**ater **A**nd **G**round **W**ater **MAN**agement Model

1. Overview of the pilot

Irrigation induced salinity is a well known problem in mature irrigation areas across Australia and the Coleambally Irrigation Area (CIA) is no exception. The consequences of salinity include production losses, increased production costs and damage to environmental amenities and infrastructure assets in the region.

A number of policy instruments have been adopted to address the threat that irrigation induced salinity poses to Coleambally and other communities. These have included:

- Regulations limiting crop areas or water use, for example through restrictions on the area of rice that can be grown by individual landholders;
- Development of an on-farm net recharge management tool (by Shahbaz Khan and colleagues at CSIRO Griffith); and
- Direct incentives for landholder management changes, for example through Land and Water Management Plan (LWMP) incentive programs.

Each of these actions has had some success in reducing the incidence of irrigation-induced salinity. However, no strategy to date has been wholly successful in achieving community management targets and protecting future livelihoods.

Within this context Coleambally Irrigation Cooperative Ltd (CICL) has recently reviewed the regulatory and other approaches applied to manage irrigation salinity and waterlogging issues. The review was initiated partly in response to community pressures for enhanced flexibility and was in part due to a planned review of the current LWMP. At the same time CICL and the project team have been exploring the potential for a cap-and-trade MBI approach to deliver efficiency gains over alternative approaches. In particular, use of a market-based approach may offer efficiency, effectiveness and flexibility advantages over current and historical instruments. This research has been funded under the National Market Based Instruments Pilots Program (NMBIPP).

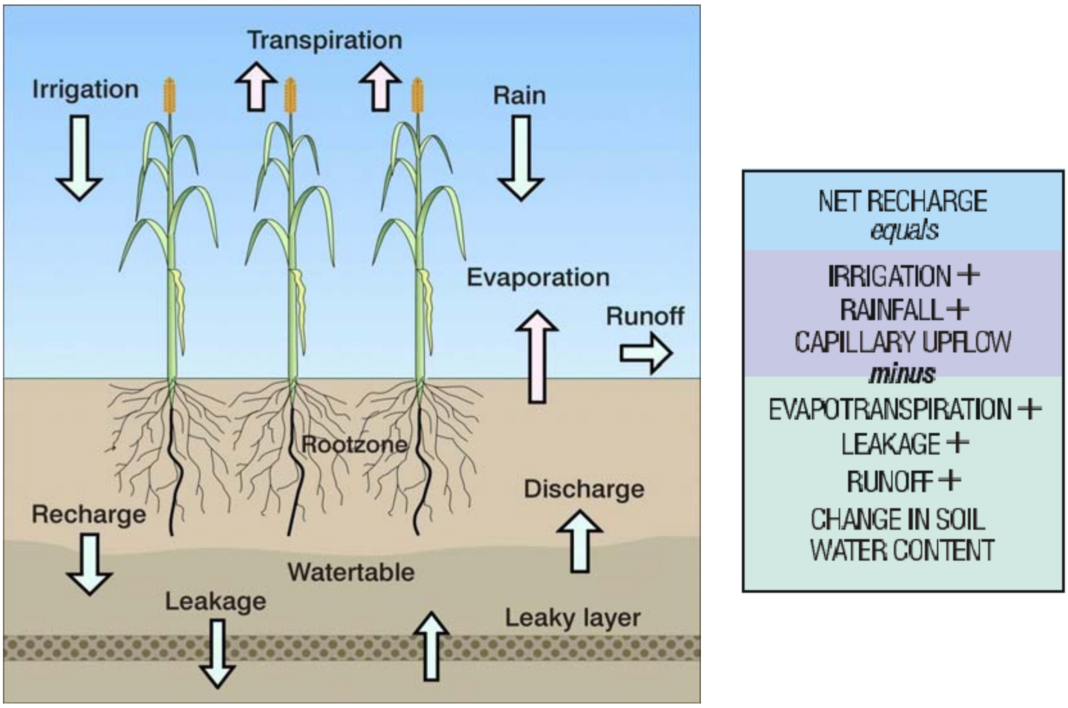
This is the final report from the project. It is designed to provide an overview of the research, the context of that research, and the policy conclusions for the Coleambally community and for broader MBI development. These conclusions result from the research undertaken and should not necessarily be taken as the opinion of all the contributing researchers. As in all good research, the intellectual debate about the implications of the research amongst team members has been robust and some differences will remain. Nor should the policy conclusions be taken as the opinion of CICL who, while they are partners in the research, obviously will make any final decisions about the applicability of the research in their local context.

1.1 Biophysical issue

Irrigated agriculture often leads to net recharge greater than regional groundwater systems can absorb. Net recharge occurs because the aggregate water supplied exceeds the evapotranspiration of crops, leaching requirements of soils, and water movement within underlying groundwater systems.[1] The net recharge concept is illustrated in Figure 1.

The impacts of net recharge beyond the absorbance capacity of natural systems include waterlogging, soil salinity, and saline groundwater interception by natural and irrigation channels and drains. In turn these impacts cause reduced agricultural production, damage to remnant vegetation, and damage to local and down-stream infrastructure. Many of these costs occur off-farm or away from the recharge site thereby imposing a range of costs on individual landowners, and their neighbours and the wider community. Off-farm costs are external and are not normally included in farm-based irrigation management decisions.[2]

Figure 1: The net recharge concept



Source: More on net recharge can be found in CSIRO's Research Project Sheet No. 11: Irrigation: Getting the balance right by Shahbaz Khan.

The CSIRO Land & Water division in Griffith has developed several modelling techniques in the region to inform and aid recharge management including a series of

---

[1] See for example the article by Shahbaz Khan and Tanya Ginns, 2003.

[2] They may also not be fully in landholder's decisions because landholders are not fully informed about the future regional impacts of their actions.

multi-layer groundwater flow and salt transport models called 'SWAGMAN'®.[3] These are supported by regional MODFLOWS and APSIM models. These models are further described in later sections of this report and are the basis for estimating the impact of irrigation on salt and water movement in the landscape.

1.2 Approach to recharge management

1.2.1 Policy approaches

Three broad policy approaches are normally suggested when seeking to achieve environmental outcomes:

- Facilitative: provision of information or property rights without direct incentives to change landholder management. For example, extension programs providing information about how to manage land to improve biodiversity conservation;
- Changes to prices faced by land managers, often referred to as incentives, directly through taxes or subsidies or through the establishment or modification of property rights. For example, riparian buffer strip fencing grants (through either materials or monetary payments); and
- Coercive: Non-voluntary measures designed to compel change in landholder management. Regulations designed to protect native vegetation are an example.

Practical policy applications usually involve a mix of these measures. For example, facilitative measures are often instrumental in the success of primarily incentive-based policies. Historically, recharge management in the CIA has been addressed using a combination of coercive regulation (for example the Rice Environmental Policy and Water Licence Conditions)[4], subsidies (for example under the CIA Land and Water Management Plan), and facilitative measures (such as voluntary application of net recharge management mechanisms using soil survey results and SWAGMAN® modelling of whole farm planning).

Market-based instruments (MBIs) are a relatively new approach to environmental and agricultural management that are currently fashionable. MBIs are policy tools that encourage certain behaviours through market signals, rather than through explicit directives such as regulation. While MBIs are commonly included within the "incentives" category of interventions, they typically require regulatory (coercive) and information (facilitative) underpinnings.

There are three broad groupings of MBI instruments:

- Price based instruments that act to modify prices to reflect environmental damage or generate an incentive for beneficial actions. Examples include

---

[3] Shahbaz Khan and others at CSIRO Land and Water in Griffith have developed the SWAGMAN® series of models. More information about these models can be found at: http://www.clw.csiro.au/publications/projects/projects22.pdf.

[4] For example, the rice regulations impose conditions on the soil types, maximum area on which rice can be grown and the maximum water usage allowable. Other regulations impose standards on maximum water use per hectare for other crops.

auctions for biodiversity and subsidies for fencing remnant vegetation or riparian buffer strips. Price based instruments offer budget certainty and are particularly useful where the non-excludability of consumers and the lack of property rights may prevent other instruments from being effective;

- Quantity based instruments (sometimes referred to as market creation or trading instruments) which set limits on resource use or rights to pollutant thus creating scarcity. Examples include the water market in Australia, the international carbon market, and offsets for vegetation clearance in several Australian States.[5] These offer certainty for a targeted biophysical outcome, but not for the cost to achieve that outcome; and
- Market friction instruments that are intended to reduce or remove obstacles to existing or self-generating markets. Examples include revolving funds for conservation purchase, environmentally friendly labelling, and sustainable investment funds. Market friction outcomes are reliant on existing property rights and tend to be less certain and longer term compared to alternative instruments.

There are three likely advantages of a market-based net recharge mechanism over existing systems in the CIA:

1. Enhanced individual flexibility in adjusting irrigation management to meet CIA community targets;
2. Improved targeting of incentives towards reducing net recharge. These are likely to drive innovation in net recharge management and reduce future costs in meeting recharge targets. This advantage is important because substantial innovation benefits have been proven in many other market-based mechanisms; and
3. Avoidance of the costs and inefficiencies involved in collecting and redistributing levies or other charges into a common pool to pay for recharge management.

Some benefits of recharge management extend beyond the CIA (for example, reduced salt exports to rivers). This implies a justification for government assistance for improved landholder management. However, these payments can just as easily be made through a market-based mechanism as through grants, tax relief, public ‘buy-back’ of entitlements under trading schemes or other methods.

In the following six chapters the experiences and findings from the project are summarised. These include application of the cap-and-trade approach to a new issue and region, the development of the necessary biophysical information base, economic assessment of alternative policy approaches, experiment testing of institutional frameworks, and ground-proofing of the research finals within the Coleambally region.

---

[5] These have a long history of opportunistic use in development consent processes in several states and at LG level.

1.3 Research goals

The overarching research issue throughout this pilot is the identification and design of the necessary steps to design a quantity based MBI for the management of net recharge.[6] The trading instrument approach explored is based on a cap-and-trade framework designed to limit contributors to a common property aquifer. We also examined the possibility of incorporating an offsets framework into the broad cap-and-trade framework. We did so in order to include the recharge benefits generated by abatement activities by voluntary parties.[7] There are a number of subsidiary questions that must also be addressed. I a cap-and-trade model the most economically efficient option? Do we know enough about the biophysical issues to design an effective instrument? Is the community willing and able to effectively engage in a quantity based framework, including trading of responsibilities within the instrument, to manage their common property net recharge?

1.3.1 Identifying the knowledge gaps

Management of net recharge has a number of similarities with other environmental markets including: the actions of irrigators impacting on a common property aquifer; a well-defined group of impactors; and some historic regulation of impacts via rice quotas and maximum water application rates. However, net recharge is typically considered a diffuse source problem for which cap-and-trade models have had limited application. There are also a number of issues that will need to be overcome that are common to previous applications. These include: defining the extent of the commons and the appropriate 'cap' to be applied; method of allocation of rights; how best to facilitate an ongoing market in recharge credits; what administrative framework is required; and an appropriate monitoring and enforcement strategy.

In examining the application of a cap-and-trade model to management of irrigation water logging and salinity the pilot has addressed a number of specific knowledge gaps including:

- Measurement of diffuse net recharge to shared irrigation aquifers;
- Identifying the net recharge impact boundaries (extent of the commons) and setting targets for net recharge;
- Definition and allocation of rights to a new environmental service 'net recharge';
- Mechanisms for facilitating a market for net recharge including management flexibility, exchange mechanisms, administrative frameworks, monitoring rule violations, and nature and imposition of penalties;
- Estimation of efficiency of MBI compared to other policy instruments;
- Estimation of the gains from trade under a cap-and-trade approach;

---

[6] For more information on the selection of a cap-and-trade approach see the first research report from the project.

[7] A distinction is drawn between mitigation activities that directly reduce the impact of a potentially damaging action such as irrigation, and abatement activities that indirectly avoid or reduce damage via other actions such as establishment of deep-rooted perennials such as tree crops. This distinction is not always practical because tree crops and other deep-rooted perennials that abate damaging actions may require irrigation for establishment or persistence.

- Development of pre-tests of institutional frameworks directly with stakeholders to improve the robustness of institutional design; and,
- Identifying ways to engage successfully with the community to achieve adoption and management change.

The knowledge gaps include biophysical issues (measurement, target setting, potential impact of extreme events), and institutional issues (allocation, markets, administration, monitoring, and enforcement). There are also economic trade-offs associated with the biophysical issues including the incentives generated to landowners from alternative measures versus the cost of measurement, and the reduction in the potential gains from trade from setting targets at smaller scales and thus including fewer potential market participants. Although the institutional design is discussed prior to the biophysical issues, the process of institutional design is not linear and solutions must often be found to biophysical issues known in advance or which emerge as the pilot progresses.

1.4 Report structure

The overarching goal of the ‘Tradeable Recharge Credits in the CIA’ project was to explore the potential application of a cap-and-trade approach to improve net recharge management in the Coleambally Irrigation Area. The key outcome in Coleambally is to manage the threat of waterlogging and salinity caused by net recharge to shared aquifers. The remainder of this report is divided into seven sections.

The focus in section 2 is a review of the necessary conditions and design parameters for applying an appropriate quantity based instrument for net recharge management. Previous applications of similar instruments are described briefly in order to detail the problems that may need to be overcome in this pilot. The response to the institutional design questions is broadly summarised in Section 2.2 before a summary of our overarching economic design recommendations for a cap-and-trade application are provided in Section 2.2. More detail about the institutional design questions can be found in the first research report from this pilot: “*Tradeable recharge credits in Coleambally Irrigation Area: what are the issues?*”

The biophysical research that underpins the economic and institutional analysis is described in section 3. This includes the modelling platforms and biophysical parameters that provide a basis for setting aggregate targets and individual recharge responsibilities. More details about the underlying biophysical research can be found in a forthcoming research report from the project “*Biophysical modelling for linking farms with regional net recharge targets*”.

The economic analysis of policy options is the focus in section 4. Five recharge management options based on regulation of inputs, outputs and a cap-and-trade approach are defined along with the base case of business as usual. The net present value (NPV) of these approaches is estimated along with a sensitivity analysis and discussion of the ensuing results. The section concludes with the definition of aggregate supply and demand curves that summarise the output from the economic modelling for the experimental analysis that follows. More detail about the economic modelling can be found in “*Economic impact of tradeable recharge credits and other net recharge abatement policies for the Coleambally Irrigation Area*”.

The focus in section 5 is on the experimental analysis of alternative institutional structures. The basis for the analysis is the impediments to the development and implementation of a market-based approach that arise from the institutional analysis in section 2. Several potential impediments are prioritised for testing and clear hypotheses about participant behaviour defined. The experimental process to test these is summarised. This includes a field trial and laboratory tests. The experimental process concluded with a summary of conclusions that were used to design the field simulation. Two research reports provided additional details about the design and results from the experimental models:

1. *Designing experiments to test tradeable recharge credits in the Coleambally Irrigation Area.*
2. *Tradeable recharge credits in Coleambally Irrigation Area: laboratory tests of alternative institutional frameworks*

The final research stage involved undertaking a simulation trial with Coleambally irrigators followed by a set of farm case studies. These were designed to ground proof the research outcomes in the absence of a more extensive trial precluded by the ongoing drought conditions in the region and changing CICL priorities. The simulation trial and case studies are briefly summarised in Section 6. The results of these aspects of the research are reported and can be found in "*Field trial and farm case studies*".

The seventh section of the paper draws together the lessons for MBI design and implementation, firstly focusing on policy advice for CICL and more broadly for future MBIs.

The report is concluded with a summary of the main conclusions from the research and a brief discussion of potential future research.

2 Designing an environmental market for net recharge management?

2.1 Previous applications of similar MBI instruments

The primary focus in this project was a cap-and-trade MBI, which is supported to a lesser extent by the potential for incorporating offsets. The concept of a cap-and-trade model is perhaps deceptively simple. A common pool resource is being impacted adversely by the aggregate impacts of those either withdrawing or contributing to the resource. A cap is therefore applied to a specific action or output with the objective of limiting the outcome to some specified target. The actual source of the action or output is not regarded as important, so any combination of contributors is acceptable so long as the aggregate impact remains below the cap. Unused individual shares of the cap can be traded to other potential or actual contributors. The resultant gains from trade provide an ongoing incentive for those able to reduce their impact on the commons most cheaply to do so. The cap-and-trade market thus provides built-in incentives to achieve outcomes at lowest cost.

Different forms of a cap-and-trade model have been applied successfully to a number of issues in Australia and internationally. These include:

- Hunter River Salinity trading project (ABARE, 2001a);
- Water markets in Australia and internationally (Easter, Rosegrant, and Dinar);
- Fisheries quotas (Newell, Sanchirico and Kerr 2004); and
- Nitrogen oxide (NO_x) and Regional Clean Air Market (RECLAIM) markets in the United States (NCEE, 2001).

These applications share relatively well-identified point sources of contribution or withdrawal. The point source makes for relatively simple and exact measurement of the action or pollutant in question compared to diffuse source actions or pollutants. The spatial commons to which these applications are applied is also well defined. The commons addressed by these applications are also largely one dimensional in the sense that the overall goal is a single issue such as overall water extraction in water markets, sustainable fish harvests, and Hunter River salt damage. An exception is the local health impacts of NO_x emissions, which are protected through local hotspot restrictions within the overall cap-and-trade scheme (NCEE, 2001). Finally, these applications were subject to stringent command and control regulations prior to the introduction of the cap-and-trade model. Hence, there was familiarity with the concept of limiting impacts and an incentive for resource users to trade.

An arguably less successful application has been nutrient trading among point and diffuse sources in the US. To date, only point sources have been directly included in these schemes through the imposition of statutory discharge limits. Diffuse sources have been brought into these schemes as voluntary offsets.[8] Mitigation activities undertaken by diffuse sources effectively act as abatement actions when compared to the capped point source emitters.

Measurement of diffuse source contributions is complex and the results uncertain. Identifying and monitoring diffuse sources is also much more difficult and potentially expensive when compared to point sources. However, if the gains from trade are sufficiently large, significant efficiencies can be achieved by their inclusion through offsets.

As diffuse sources are often now the dominant origin of nutrients, interest has turned to including these sources within nutrient caps. That is, to place statutory nutrient management requirements on the diffuse sources. While the US EPA’s legislative powers to do this have been tested and upheld, States are yet to bring diffuse sources under nutrient trading caps.

---

[8] The concept of voluntary offsets means that point source emitters can purchase offsets from diffuse source emitters but the diffuse source emitters voluntarily decide whether or not to participate.

2.2 Designing new institutions – a cap-and-trade model for net recharge

The previous discussion shows that application of the cap-and-trade concept to net recharge management will involve a number of important differences from previous applications. In this section the institutional design issues that must be overcome in applying the cap-and-trade concept to net recharge management are set out using the CIA as the case study. Application involves answering six questions:

1. What are net recharge rights and who will use them?
2. What is the cap?
3. What form of net recharge target is appropriate (variable from year-to-year or fixed)?
4. How should the initial net recharge ownership be allocated?
5. What administration and trading rules are needed, including who can trade with whom, and whether banking and borrowing are allowed?
6. How should monitoring be undertaken and what type of penalties should be imposed for rule violation?

2.2.1 What are net recharge rights and who will use them?

Quantity based MBIs require a clear means to establish and enforce ownership of net recharge from different sources – termed 'net recharge property rights'. These property rights define whether and how much each irrigator can contribute to net recharge in the CIA. In the CIA the rights of irrigators to contribute net recharge could be defined via changes to water supply contracts that all irrigators must hold with CICL. This would require irrigator agreement to the creation of new property rights because CICL is a cooperative that is owned and managed by CIA irrigators. It is possible to design a scheme with 'opt-in' and 'opt-out' provisions but this will make for a more complicated structure with additional potential for gaming the system.

Ideally, a cap-and-trade scheme would apply to all sources of net recharge within the region who can limit their net recharge and who can be included within the scheme cost-effectively. It is unlikely that urban households could be included cost effectively because of their very small individual contributions.[9] Sources included could comprise irrigators and other sources such as sewage treatment plants. Other potential future users, such as third parties representing downstream beneficiaries of improved recharge management, should also be considered valid rights holders unless there is strong reason to believe they may adversely distort the market.

2.2.2 What is the cap?

Setting a cap for net recharge involves both the practical difficulty of measuring diffuse contributions to a common property source and the conceptual basis for setting a cap and assigning contributions as individual property rights. The focus in this

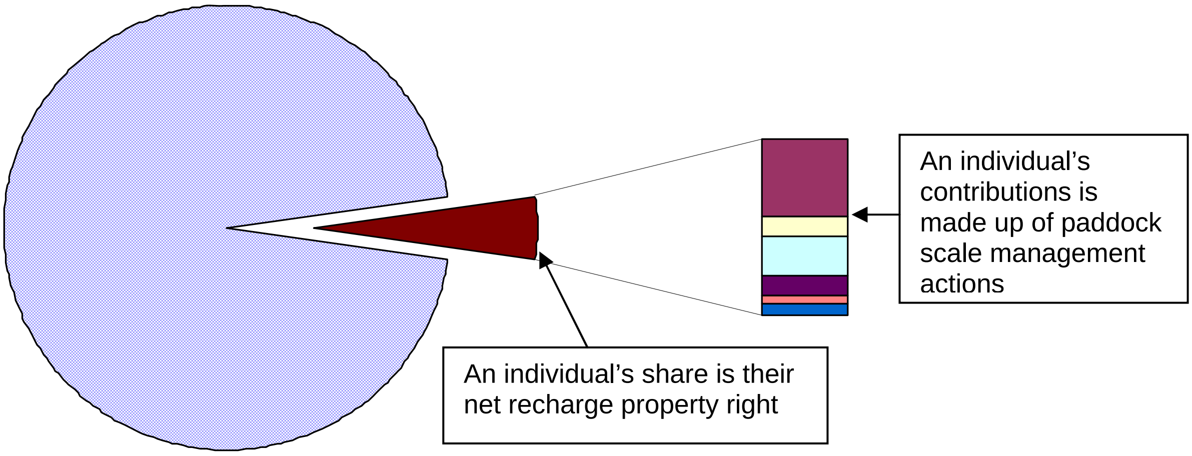
---

[9] Although households may make small contributions individually, in aggregate their contribution may be significant. In this case it is important to identify whether there are ways to cost-effectively encourage improved management compared to other contributors.

section is on the conceptual basis. A more detailed assessment of the biophysical science is provided in the next section.

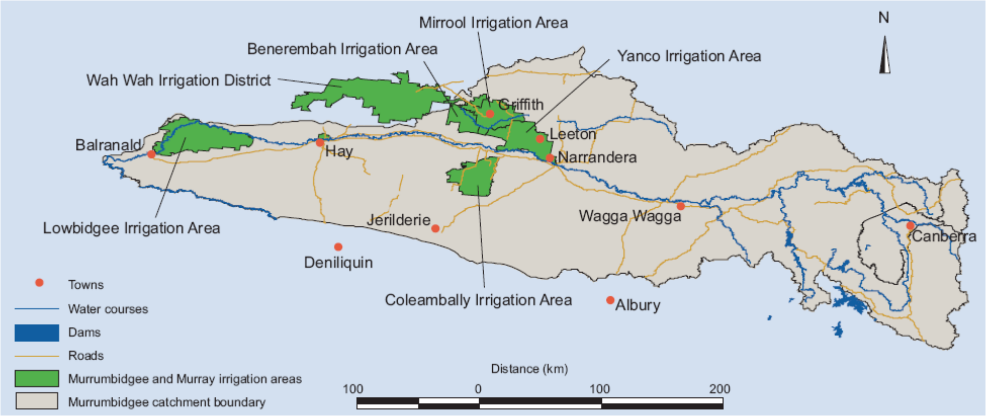
The overall goal of a cap-and-trade policy is to limit net recharge to a common property resource. This means that a cap must be set at an overall level and applied at the individual level as shown in Figure 2.

Figure 2: Linkages between regional targets, net recharge property rights and farm management decisions



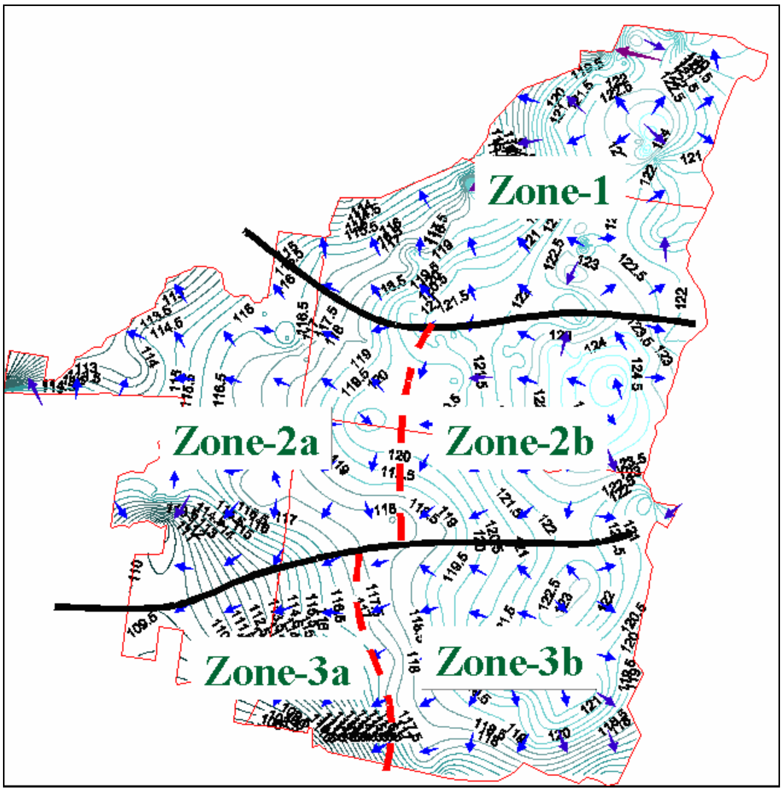
The cap must be set to reflect the extent and impact of irrigator contributions to the aquifer commons. The cap may be ineffective if potential contributors are excluded, covers several unlinked or partially linked commons, or fails to reflect differential impacts. In the case of the CIA (shown in Figure 3), the scientific information (summarised in more detail in section 2.2) indicates that there are several commons, some of which are partially linked as shown in Figure 4. In this situation a CIA region wide cap may reduce the total volume of net recharge but fail to reduce the impacts in discharge zones. Worse, a system wide cap may reduce some better quality net recharge that is beneficial to deeper aquifers and hence reduce potential future groundwater reserves.

Figure 3: Location of Coleambally Irrigation Area



Source: CSIRO (2005) Off- and on-farm savings of irrigation water.

Figure 4: Possible zones in the Coleambally Irrigation Area



Target setting within the cap-and-trade model is a complex issue. Ideally targets should be set such that the marginal cost of recharge abatement (as indicated by the equilibrium price in the recharge market) reflects the marginal benefit of an additional unit of recharge abatement to the wider community (including irrigators, local and downstream communities). However, the presence of groundwater level thresholds together with non-monetary benefits from recharge abatement complicates the estimation of an appropriate target on this basis. An alternative basis for target setting is via biophysical sustainability constraints, in this case maintenance of water tables at a level that maintain current production areas.

2.2.3 Application of the cap at the individual scale

A measure for applying the regional cap to individual farms needs to be developed. The measure differs substantially from end of pipe sample and inference based measures typically used for point source cap-and-trade solutions. Instead recharge measures are reliant on estimation techniques – specifically the SWAGMAN model, which is designed to estimate, recharge contributions based on biophysical relationships. It is described in more detail in Section 3. This is a major innovation in the approach to management of the diffuse source common property aquifer problem in irrigation salinity and waterlogging management.

Decisions about the application of the cap in a stochastic climatic environment must also be made. Allocation of fixed volume recharge provides certainty to irrigators but a fixed aggregate cap will be a blunt instrument in response to climatic variation. It is also important to retain some flexibility in application due to scientific uncertainty, unforeseen consequences, and application errors. Farm level flexibility in the form of banking and borrowing will also need to be considered in this context.[10]

Actual allocation of the cap among individuals represents a further challenge. If the resulting markets are to be competitive and will incur small transaction costs, then from an economic perspective the basis for the allocation of rights is of little importance. This is because subsequent trade will deliver an optimal allocation and use of the rights. However, where competition is constrained or transaction costs significant, then trading may not deliver an optimal allocation of rights. In these instances, competitive allocation procedures such as auctions may provide a more efficient outcome. In practice, equity considerations have usually led to ‘grandfathering’ or gifting of allocations based on historic actions.

Finally, questions of when the cap will be met must be addressed. Many cap-and-trade mechanisms elsewhere have been phased in to ensure adequate time for stakeholders to adjust future investments to the new regime such as was the case with the RECLAIM in the US (NCEE, 2001). Delaying application may be problematic if additional reductions are required in the future to compensate for the impact of current actions on the common property aquifer.

2.2.4 Underpinning institutions

The major benefit from implementing a market-based instrument when compared to alternative approaches is access to gains from trade between irrigators. Access to the gains requires a market structure that facilitates exchange underpinned by an institutional structure that adequately protects the recharge rights allocated to irrigators.

The main institutional structures are designed to ensure the integrity of the rights that result under the cap. Creation of a new property right to recharge can be underpinned by existing water supply contracting arrangements between CICL and State Water and between individual irrigators and CICL. Basic information about who holds property rights needs to be maintained on a register that will need to include owner details, quantity of recharge rights, third party interests, and restrictions on use and trade.

A comprehensive and current register is critical to an effective monitoring regime. Actual monitoring in the CIA is relatively simple via annual satellite sensing of key crops (rice) and farm water use.[11] Penalty strategies will need to be carefully considered because robust penalties will be required for longer-term compliance. Initial mistakes or market failures should not be penalised severely.

An important consideration in creating a new market for recharge is to identify ways of achieving irrigator support, such as through the use of voluntary trials. Experience developed through such trials will enhance confidence and skills among market

---

[10] Banking and borrowing can equally be considered as trading recharge between years.

[11] Satellite photos capture rice areas only. The image is too hard to distinguish types of winter crops. Water use determined by water ordering system to crop type. However, both sets of info still do not monitor net recharge but can be estimated using model.

participants and reduce transaction costs. Exposure of trial participants to penalty regimes required for subsequent cap-and-trade instruments is likely to discourage trial participation.

One way to garner support for a voluntary trial is to offer incentives such as concessionary water prices. Incentives could be a feature of more permanent instrument applications where for example, the concession effectively represents the externality cost of the recharge to scheme non-participants.

2.2.5 What would a market for recharge look like?

Transaction costs reduce the gains from trade that are available to irrigators. Such costs are often higher in new markets such as recharge markets. In such cases it is especially important to identify ways of reducing the costs of transacting and the risks associated with markets with few participants (termed ‘thin’ markets). Existing experience with water markets may reduce irrigator’s transaction costs, particularly if trading platforms and processes are similar to existing water markets. Trade approval processes that are needed to maintain the integrity of the registry and cap should also take into account transaction costs.

In many cap-and-trade applications market power is a potential problem but it is only likely to emerge in the recharge credit markets in the CIA if the number of participants was restricted or if a small number of participants dominated total recharge volumes.

2.2.6 Increasing market potential through offsets

The traditional cap-and-trade model is limited to mitigating damaging actions rather than alternative abatement activities that offset the net recharge from irrigation sources. For example, non-irrigated tree planting may capture recharge under other cropping systems before it reaches saline aquifers. Introducing offsets brings in a number of complications such as time lags between undertaking abatement actions and recharge offsets, and the importance of spatial relationships between the offset activity and the recharging activity. The property rights issued to offsetting activities will need to reflect these issues to ensure the integrity of the overall cap is maintained. While offsets may be an important consideration in some instances, the current cost of implementing known offsets in the CIA reduces the benefits of incorporating such activities within the framework, at least initially.

2.3 Outstanding design issues

A number of issues emerged from the investigation of a cap-and-trade model. These issues were the major focus during the remainder of the project. They can be divided between biophysical issues and institutional design issues, and included:

- Setting appropriate biophysical targets for net recharge at the aggregate and sub-aggregate level;
- Refinement of measures of paddock scale net recharge in isolation and in combination;
- The potential implications of groundwater level thresholds for target setting and policy selection;

- Response to allocation of rights at the individual level;
- Estimating the scale of potential gains from trade;
- The impact of potential market impediments such as relatively thin markets, socialised verses individual penalties and performance of markets; and
- Community acceptance and adoption of proposed market mechanisms and structures.

A preliminary set of guidelines addressing the major design issues was drawn up to help guide the research processes during the project and to serve as a basis for guidelines should a recharge trading scheme be implemented. As these were not progressed to a field test they remain preliminary (Appendix 1).

3. Biophysical modelling

A brief background to net recharge methodology and analysis is provided. Discussion then focuses on target setting and refinement of paddock scale net recharge. An outline of the implications of extreme events on targets is provided before setting out the basis for estimating damage functions for the economic modelling.

3.1 Net recharge methodology and analysis

To estimate the net yearly recharge to groundwater a simple spatial method was used where for each of the monitoring times (that is March and September) a groundwater surface for the entire CIA (approx. 80,000ha) was developed using the contouring software ‘SURFER’. Data from piezometers were used from the time period 1994 to 2004. Net recharge between the following periods was determined by establishing the volume change between the two surfaces using SURFER. The result is the soil volume which is then multiplied by the effective porosity, assumed to be 0.05, to calculate the change in the volume of groundwater.

The data was gridded to the following dimensions:

Easting	378590m – 420875m
Northing	6120000m – 6162175m

Kriging was used with a linear variogram model to derive shallow groundwater level surfaces. Once gridding was performed the resultant mesh was blanked out using a digitised boundary map of the CIA. The blanking operation warrants that data outside the boundary of the CIA is ignored in any calculations.[12] Piezometric data gridded and blanked thus formed each piezometric surface and these surfaces were determined for March and September of each year. When a groundwater surface of a succeeding period is deducted from the surface of the previous period this gives the net volume change between the two periods. If the volume change is positive then net recharge has occurred and if the volume change is negative then net discharge has occurred. It is assumed that the piezometric levels and readings represent the underlying watertable and the calculations are based upon these and the following assumptions:

---

[12] That is areas outside the CIA are assumed to make no contribution to net recharge.

- The piezometers less than 15m deep accurately reflect watertable level. This is likely to be the case but some areas where aquifer confinement occurs may impact to a greater or lesser degree on the validity of this assumption;

- The effective porosity value used (5 percent) will affect the magnitude of the values estimated here but will not affect whether the result is net recharge or discharge and it will not affect the trend over time as this methodology is based upon differences. As this analysis uses a uniform effective porosity for the whole area, errors will be created as the piezometric rise/fall in a clayey soil and sandy soil will be assessed to be the result of the same volume of net recharge, which is not the case; and

- The results obtained from the area wide analysis are representative averages of the irrigation area, and can therefore be strongly influenced by distinct fluctuations in particular subregions of the CIA.

Four analyses of net recharge were determined using the above method. These included:

1. Net annual recharge (September): the volumetric watertable difference between September of a given year and September of previous year;

2. Net annual recharge (March): same method as above;

3. Net Seasonal Recharge (summer): the volumetric addition during irrigation season, calculated by the volumetric watertable difference between March of a given year and September of the preceding year; and

4. Net Seasonal Discharge (winter): the volume of water dissipated during the winter months (the non-irrigation period) determined by the volumetric watertable difference between March and September of any given year.

3.2 Results of the net recharge analysis of CIA

Figure 5 shows seasonal net recharge, winter rainfall and irrigation allocation for different years (March 1994 and March 2004). In the CIA, recharge mainly occurs in summer and discharge the following winter. According to this analysis the total net recharge exceeded 40 GL/season only during the 1997/1998 irrigation period. For all other irrigation periods the total net recharge is less than 40 GL/season.

Figure 5: Temporal variations in net recharge in the CIA

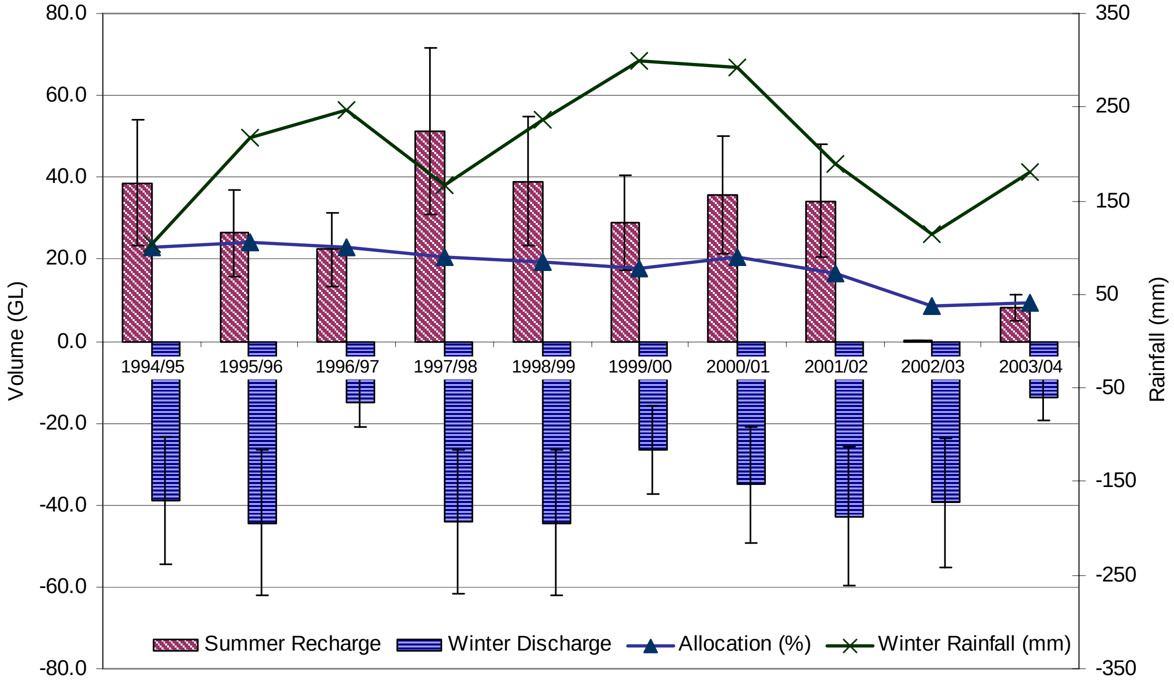


Figure 6 shows overall recharge and discharge periods. The net recharge values lying below the 45 degree line show an overall net discharge whereas the values lying above this line show net accessions to the groundwater. The large winter discharge in 2002 was due to dry conditions in that year with a record deficit of evapotranspiration minus rainfall. The relationship in Figure 6 is useful in determining what levels not to exceed for net recharge management and what subsequent summer recharge values can be absorbed by the system.

Figure 6: Summer net recharge as a function of winter net recharge (discharge)

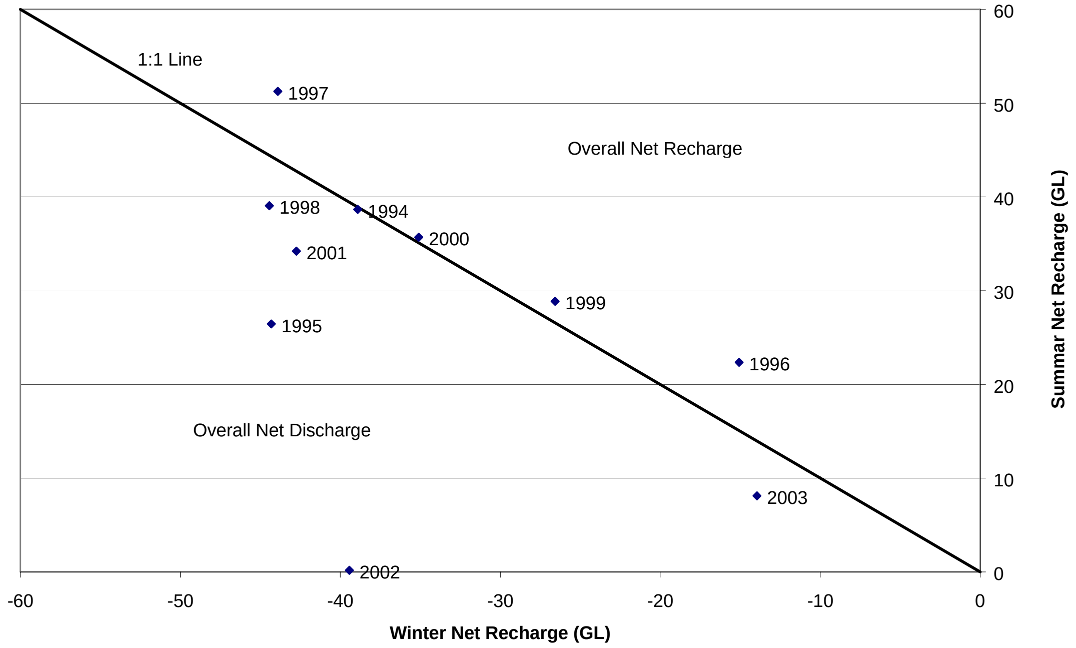
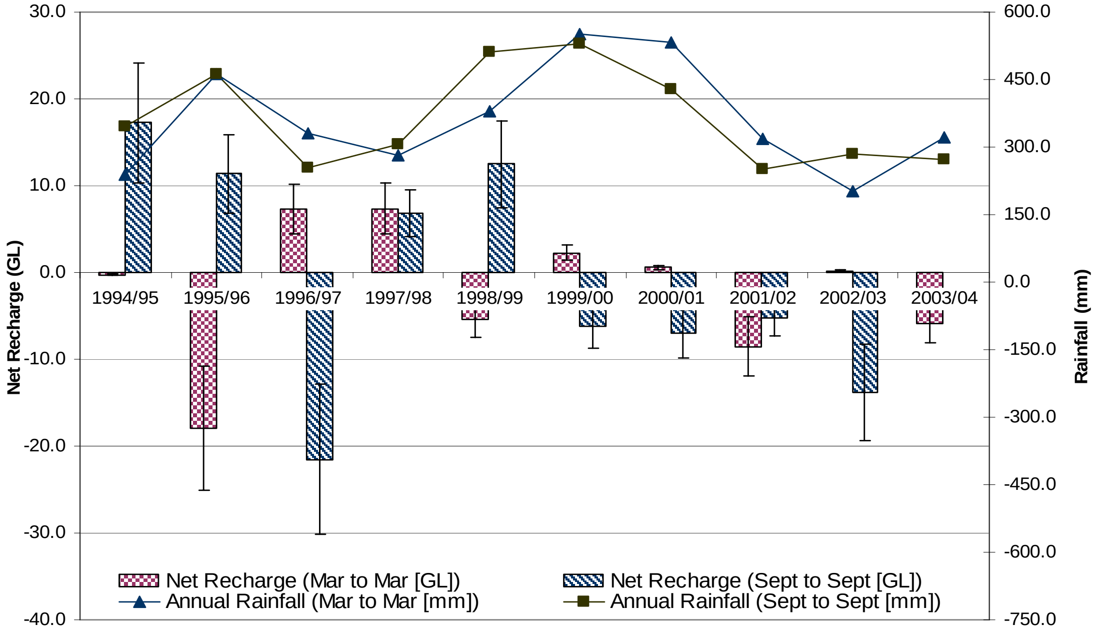


Figure 7 shows the annual net recharge estimated over longer time frame (including summer and winter seasons) and therefore provides alternative analysis on recharge trends. The March to March period analysis shows lesser fluctuation than the September to September period analysis. This might be because March to March analysis is dominated by the recent irrigation activities and not complicated by the winter conditions that follow.

Figure 7: Net annual recharge (and discharge) for Coleambally



3.3 Water balance of the CIA (methodology)

A water balance of the CIA was carried out by the project team. It included: the supply system; rainfall; and groundwater.
The methodology used to estimate and calculate these components is described in the following sections.

3.3.1 Supply system

The water balance of the supply system included: diversions; rain on supply; channel seepage; channel evaporation; escapes; deliveries; and channel filling.
Water balance of the supply system is calculated by the mass balance equation described as:

> *Diversions + Rain on Supply = Deliveries + Channel Seepage + Channel Evaporation + Channel Filling + Escapes + unaccounted losses due to underestimation of flows by Dethridge wheels*

Data for diversions from the river to the supply system and the deliveries at the farm boundaries were collected from the CICL. The volume of rainfall on the supply channels was estimated from rain data and surface area of the channels. The volume of water required to fill the empty supply system was estimated by the channel geometry.

The true losses in the irrigation system from the point of withdrawal from the river to the delivery at farm boundaries are evaporation and seepage. Evaporation from the supply channels is estimated from evaporation data and surface area of the channels. The range for seepage losses from the channels were derived from previous studies.

The balances (which can be up to 14% of delivery) are attributed to unaccounted losses due to underestimation of flows by Dethridge wheels which meter the delivery to the farm.

3.3.2 Rainfall contribution

The rainfall component of water balance includes: Rainfall; Rain on supply; Rain on drains and Rainfall runoff. The rainfall data are collected from meteorological stations in the region. The volume of rainfall on the supply channels and drains is estimated from rain data and surface area of the channels.
Rainfall runoff is estimated by using USDA/SCS curve numbers (USDA, 1986). The curve numbers are selected from tabulated values for fallow or appropriate land use, treatment, and hydrologic conditions (crop condition) plus an antecedent soil moisture adjustment.

Effective rainfall is the part of rainfall that is stored in the root zone and can be used by the plants.

3.3.3 Groundwater balance

The net recharge was estimated by using simple method where a groundwater surface for the entire CIA (approx. 80,000ha) was developed for March and September using the contouring software ‘SURFER’. Khan *et al* (2004) estimated the regional vertical leakage capacity between the shallow and deeper aquifers at around 30,000 ML/year and the lateral outflow from the shallow aquifers at 15,000 ML/year. These estimates were used in this water balance to calculate the total recharge.

Total Recharge = vertical leakage + lateral outflow + net recharge

A whole of the CIA water balance was produced and the results are given in Appendix 2. We concluded that:

- There is a positive component of unexplained/escape losses for system for all study years except for 1997/98. This positive component ranges from 31 to 64 GL;
- Use of the USDA method shows significant rainfall-runoff (over 78 GL for 1999/2000); and
- The total recharge to the shallow aquifer varies between 56 GL-85 GL with annual net recharge of 11 to 40 GL during the irrigation period.

To cross-validate estimates of on-farm delivery and recharge, a theoretical net crop water requirement balance for the year 2000-2001 was carried out. Table 1 and Figure 8 show the net monthly crop water requirements (*Crop Water Requirement - Rainfall*) for the crops grown in the CIA during the 2000/2001 period for dry, average and wet climate conditions. The crop water requirements are dominated by summer crops, in particular rice. Under the average climate conditions the total crop water requirements should be around 417 GL, whereas computed on-farm deliveries are around 375 GL. Possible explanations include:

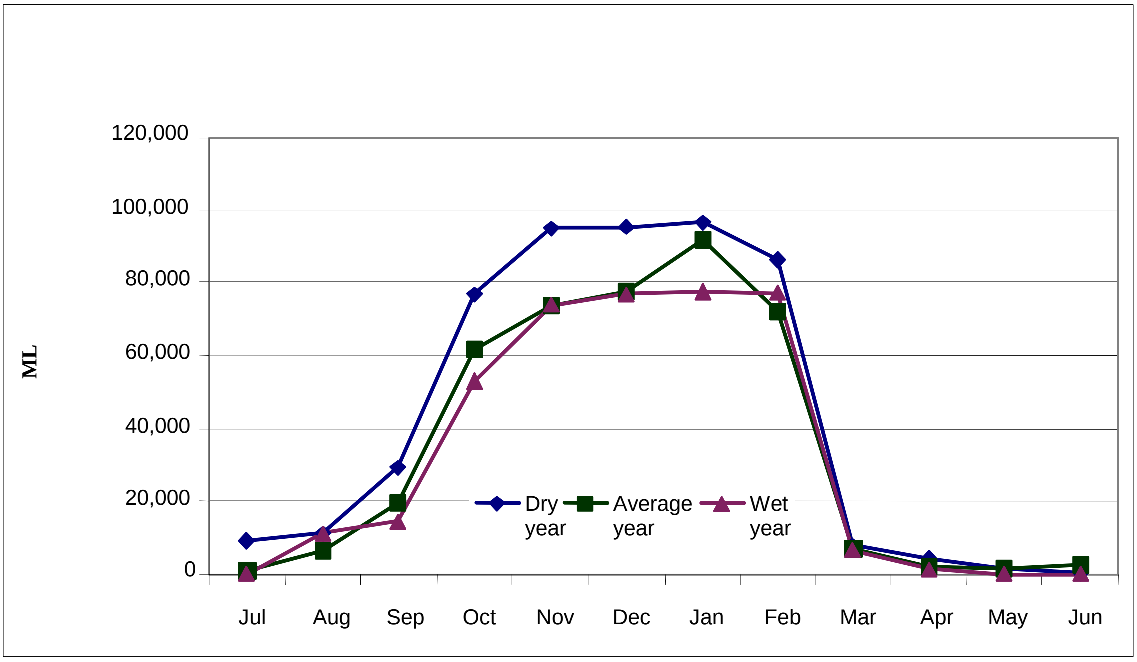
- Crops are stressed by water logging and salinity and not transpiring at a healthy rate;
- Water wheels are under recoding water deliveries by around 11 percent; or
- Alternative source of water supply, for example, carry over and groundwater may be available.

These explanations are not mutually exclusive. In order to resolve these issues a more rigorous water measurement and GIS recording of crop areas and corresponding water use is recommended.

Table 1: Potential Net Water Requirements (ML) in the CIA for 2000/2001 Crops under Average Climate Conditions

Crop	**Area (ha)**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
Rice	26,820	0	0	0	36,207	56,751	68,606	76,222	56,793	0	0	0	0	294,579
Wheat	12,388	595	3,902	10,102	12,462	7,449	0	0	0	0	0	0	818	35,329
Oats	1,290	129	406	1,052	1,076	367	0	0	0	0	28	84	204	3,346
Barley	2,689	0	753	2,044	3,168	1,617	0	0	0	0	0	0	54	7,635
Maize	2,888	0	0	0	0	1,579	4,407	6,244	4,783	1,569	0	0	0	18,581
Canola	1,951	0	205	941	1,627	471	0	0	0	0	0	0	129	3,373
Soybean	4,551	0	0	0	0	1,766	4,009	8,601	9,994	4,668	0	0	0	29,039
Winter Pasture	9,880	0	1,383	5,315	6,541	3,183	0	0	0	0	1,759	1,304	1,107	20,591
Stone Fruit	112	0	0	23	84	152	200	227	173	136	70	22	0	1,088
Lucerne (Cut)	200	0	77	178	378	518	619	653	518	411	246	121	51	3,771
TOTAL	62,769	724	6,727	19,655	61,543	73,854	77,841	91,947	72,262	6,785	2,104	1,531	2,361	417,333

Figure 8: Net water requirements (ML) in the CIA for 2000/2001 crops



3.4 Area wide net recharge targets

Based on studies by Khan *et al* (2004) net recharge targets for 5 zones (Figure 4) were derived using MODFLOW and APSIM models for the period 1999-2000 (Table 2). On the basis of these calculations the total vertical leakage from shallow to deeper aquifers is estimated to be 31 GL. This estimate is twice the previously estimated vertical outflow capacity of the aquifers in the CIA. This is mainly due to decline in deeper aquifer pressures due to continued groundwater pumping. The net lateral flow from the upper Shepparton formation is small due to the smaller transmissivity of this aquifer. If the total transmissivity of the Shepparton formation is considered the total lateral outflow will be around 15 GL as estimated by the previous studies. The total estimated recharge for 1999/2000 is 55.70 GL. The total recharge reduction requirement is 9.7 GL (0.12 ML/ha on the average) taking into account the lateral and the vertical outflow capacities (15+31 GL).

If the total recharge to the Shepparton formation can be managed according to the vertical leakage between aquifers the watertable will remain static or decline over a period of time. The upper limits of net recharge for the different zones are computed by adding the vertical leakage with the net local outflow and are given in the last row of Table 2.

Table 2: Net recharge targets for 5 zones in the CIA

Period	Water Balance Component	Zone1	Zone2	Zone3	Zone4	Zone5
Mar99-Aug99	Horizontal Inflow (ML)	133	39	155	46	72
	Horizontal outflow (ML)	296	147	202	151	99
	Net Recharge(+)/Discharge (-) (ML/ha)	0.11	-0.16	-0.1	-0.02	0.12
	Leakage(ML/ha)	0.19	0.17	0.15	0.12	0.13
	Total Recharge(ML)	2613	-2075	-2656	-375	1556
	Leakage (ML)	4513	2205	3984	2250	1686
	Net recharge (ML)	-1900	-4280	-6640	-2625	-130
Sep99-Feb00	Horizontal Inflow (ML)	147	27	160	49	81
	Horizontal outflow (ML)	304	179	246	167	119
	Net Recharge(+)/Discharge (-) (ML/ha)	0.27	0.69	0.85	0.47	0.69
	Leakage(ML/ha)	0.17	0.27	0.16	0.14	0.14
	Total Recharge(ML)	6413	8948	22578	8813	8948
	Leakage (ML)	4038	3502	4250	2625	1816
	Net recharge(ML)	2375	5446	18328	6188	7132
Yearly Total	Horizontal Inflow (ML)	280	66	315	95	153
	Horizontal outflow (ML)	600	326	448	318	218
	Total Recharge(ML)	9026	6873	19922	8438	10504
	Leakage (ML)	8551	5707	8234	4875	3502
	Net Recharge (ML)	475	1166	11688	3563	7002
	Upper Limit of Total Recharge	8871	5967	8367	5098	3567

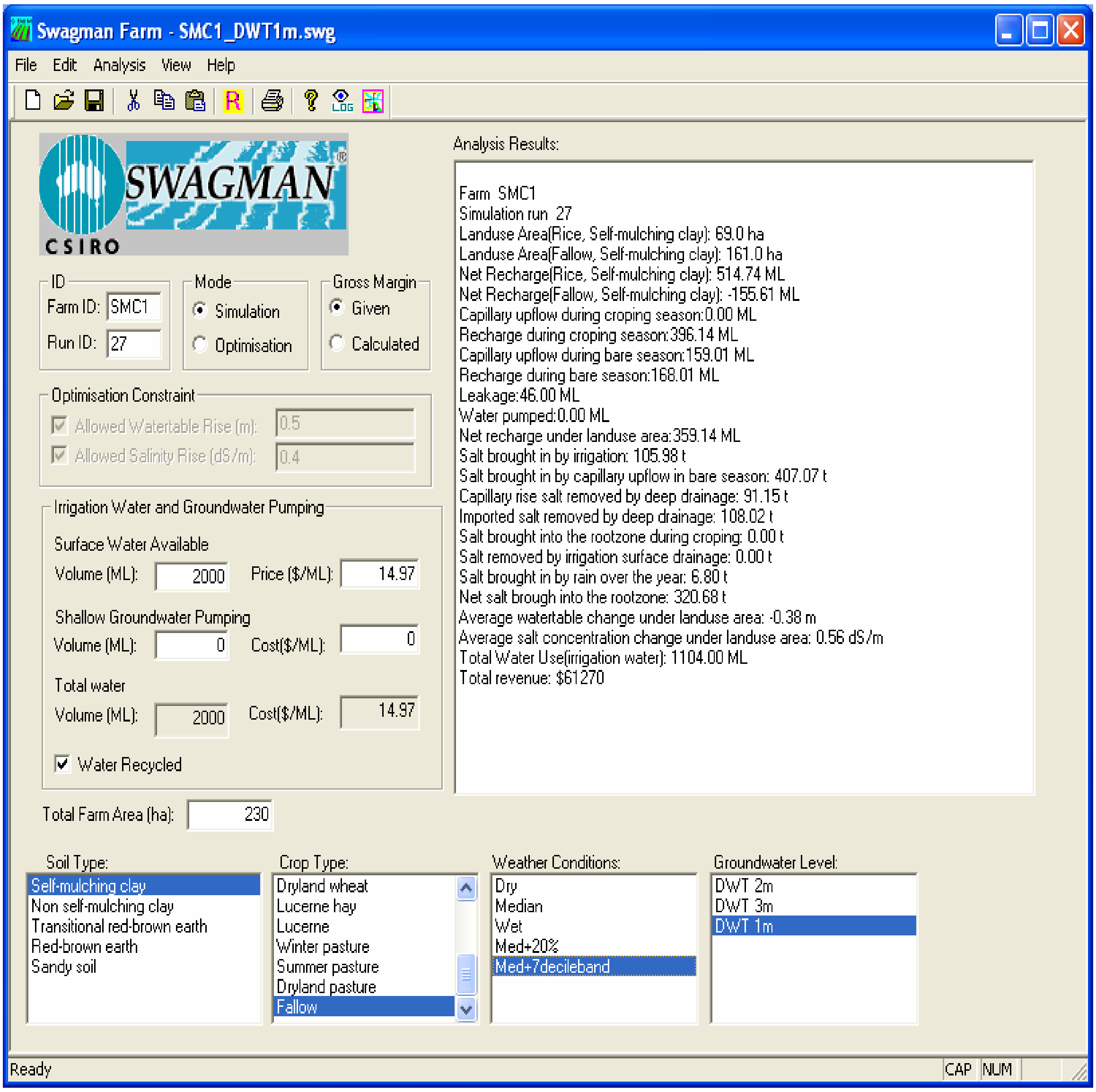
3.5 Measuring paddock scale recharge

The net recharge management implementation process builds on strong research partnerships between CICL, CSIRO and the CRC for Sustainable Rice Production over the past seven years.

New software tools have helped promote rational land and water management options and provide a means to monitor change in water use efficiency and environmental conditions. One of the innovative tools is a state of the art farm level hydrological economic model, SWAGMAN Farm (Salt Water And Groundwater MANagement). SWAGMAN Farm can clearly show economic and environmental tradeoffs in adopting different land and water management options and help to decide sustainable irrigation intensities. Regional groundwater investigations, surface-groundwater interaction models of the irrigation regions and the SWAGMAN Farm model can be used to develop strategies such as improving water use efficiency, reducing net recharge to groundwater and monitoring changes in environmental conditions on a spatial basis.

In addition to referencing to the regional piezometer data it is recommended to validate SWAGMAN Farm watertable change by installing two shallow test wells (to be cited according to the low and high electromagnetic response) on each farm. This will help confirm the watertable fluctuations under each of the farm at the start and the end of a given year.

Figure 9: Interface of SWAGMAN Farm – a tool for aiding net recharge management



ID
Farm ID: SMC1
Run ID: 27

Mode
● Simulation
○ Optimisation

Gross Margin
● Given
○ Calculated

Optimisation Constraint
☑ Allowed Watertable Rise (m): 0.5
☑ Allowed Salinity Rise (dS/m): 0.4

Irrigation Water and Groundwater Pumping

Surface Water Available
Volume (ML): 2000
Price ($/ML): 14.97

Shallow Groundwater Pumping
Volume (ML): 0
Cost($/ML): 0

Total water
Volume (ML): 2000
Cost($/ML): 14.97

☑ Water Recycled

Total Farm Area (ha): 230

Soil Type: Self-mulching clay
Non self-mulching clay
Transitional red-brown earth
Red-brown earth
Sandy soil

Crop Type: Fallow
Dryland wheat
Lucerne hay
Lucerne
Winter pasture
Summer pasture
Dryland pasture

Weather Conditions: Med+7decileband
Dry
Median
Wet
Med+20%

Groundwater Level: DWT 1m
DWT 2m
DWT 3m

Analysis Results:

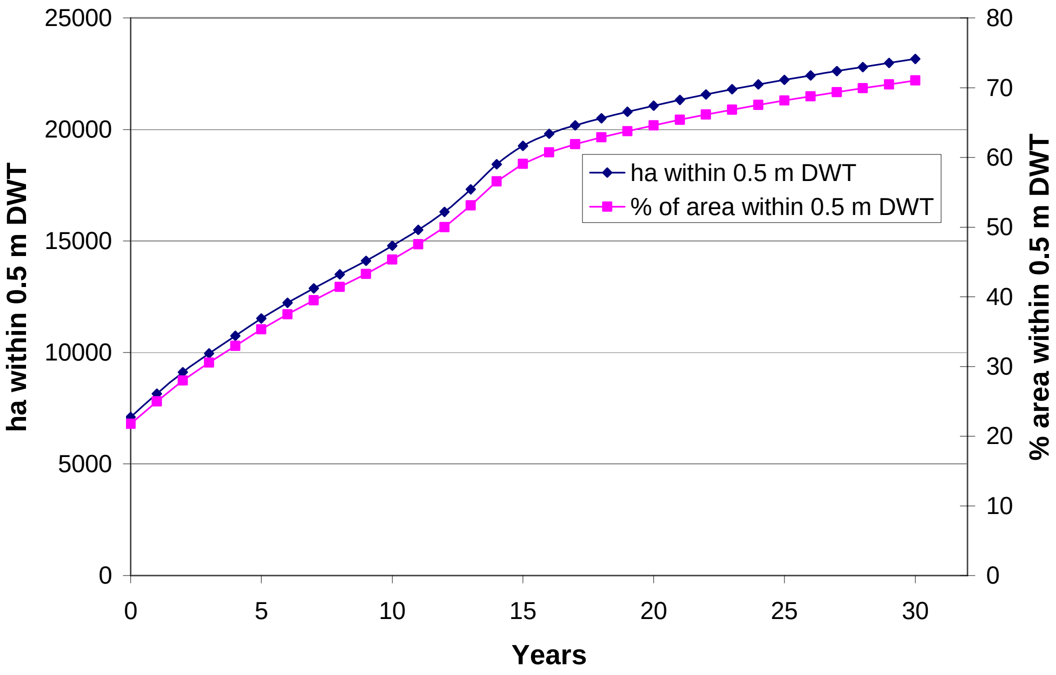
```
Farm  SMC1
Simulation run  27
Landuse Area(Rice, Self-mulching clay): 69.0 ha
Landuse Area(Fallow, Self-mulching clay): 161.0 ha
Net Recharge(Rice, Self-mulching clay): 514.74 ML
Net Recharge(Fallow, Self-mulching clay): -155.61 ML
Capillary upflow during croping season:0.00 ML
Recharge during croping season:396.14 ML
Capillary upflow during bare season:159.01 ML
Recharge during bare season:168.01 ML
Leakage:46.00 ML
Water pumped:0.00 ML
Net recharge under landuse area:359.14 ML
Salt brought in by irrigation: 105.98 t
Salt brought in by capillary upflow in bare season: 407.07 t
Capillary rise salt removed by deep drainage: 91.15 t
Imported salt removed by deep drainage: 108.02 t
Salt brought into the rootzone during croping: 0.00 t
Salt removed by irrigation surface drainage: 0.00 t
Salt brought in by rain over the year: 6.80 t
Net salt brough into the rootzone: 320.68 t
Average watertable change under landuse area: -0.38 m
Average salt concentration change under landuse area: 0.56 dS/m
Total Water Use(irrigation water): 1104.00 ML
Total revenue: $61270
```

3.6 Exploring the likely impacts of extreme events

In the net recharge section we have explained the net recharge analysis for the last 10 years for non irrigation and irrigation seasons. The results show that the net recharge for the year/season 1997/98 is the highest in the ten year period and therefore it has been considered as the extreme event for the study area.

By using this recharge in the calibrated MODFLOW model of the CIA (Khan *et al*, 2004) the simulation was run for the next 30 years to analyse the impact of extreme rainfall upon the water-table in western Coleambally. Figure 10 shows the time dependent increase in the western CIA under 0-0.5 m depth to watertable under the assumption of repeated high rainfall events. For more information see the fifth research report from this series '*Biophysical modelling for linking farms with regional net recharge targets*'.

Figure 10: Predicted/modelled scenario for water table depth rise in western Coleambally



Note: DWT = depth to water table

4. Economic modelling: Farm scale costs and benefits of net recharge management

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 policies. This research tests this hypothesis with respect to recharge management in the CIA. To this end economic modelling of the costs and benefits of net recharge management were undertaken. A second aim of the economic modelling was to develop hypothetical demand and supply curves for recharge mitigation based on real farms in the CIA. This allows prediction of a market-clearing price for recharge credits in the absence of transaction costs, and facilitates a context specific experimental design in Section 5.

A number of alternative policy instruments could be used to promote recharge reduction. Even if each led to the same level of net recharge, there would be different costs and benefits attributable to them. First, at the farm level, different instruments would lead to the adoption of differing farm management practices, with different spatial and temporal characteristics. Second, each policy instrument will generate a different set of costs at the community scale. These include the costs of developing, implementing and enforcing the instruments, and the costs to the participants in identifying beneficial actions or means to comply with various directives. Also at the community scale, each instrument and attendant changes in farm management practices and recharge may lead to different impacts to third parties, such as to downstream water users or the environment.

The immediate policy question is in relation to the first group of farm level costs and benefits. That is, whether the gains to irrigation farmers from lower salinity and yield impacts from the imposition of a net recharge cap are sufficient to outweigh the costs of changing management practices in accordance with a net recharge cap-and-trade framework.

This question is the focus of analysis in this section. The analysis is partial as it does not consider the community costs identified above. Nevertheless, it provides important information for policy makers. For example, if identified farm benefits outweigh 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 costs 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.

The results from the applied economic modelling 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 if ‘business as usual’ (BAU) was continued. Definition of BAU is complicated by the potential for environmental thresholds or discontinuities in the biophysical responses to natural events and management actions. For example, a series of wet years may cause unexpectedly large areas to become waterlogged.

In the Coleambally region there remains considerable uncertainty about the nature of environmental thresholds and the system’s response to different management actions or climatic events. Therefore, in the second research report from the project, particular attention is paid to outlining the nature and implications of the assumptions that underpin the biophysical analysis.[13]

4.1 Alternative policies

There are a number of policy options available to assist in managing net recharge, including market-based and regulation based approaches. Policy selection is founded on generating the greatest net benefit to the community. Effective policy selection is therefore predicated on the accurate estimation of relative benefits arising from alternative courses of action. The farm scale costs and benefits of five options were analysed in this project (Table 3).

---

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

Table 3: Policy options for 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. Aggregate and extrapolate to total.	Yield declines to? level 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 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.

The options include continuation of current management, termed the ‘do nothing’ or (BAU) outcome and four alternatives. The alternatives are designed to represent potential input and output based policies with various levels of flexibility in the way in which farmers can respond. That is, the policies are designed to represent a suite of approaches to net recharge management that are available to government and which are likely to be considered. Other alternatives are not analysed because they were considered unlikely to achieve net recharge targets (moral suasion and communication alone). Hence, analysis is focused on mechanisms that require greater regulatory oversight of net recharge activities than current approaches.

4.2 Summary results of economic analysis

The economic gains from changing recharge management are assessed by comparing the economic outcome from continuing BAU against each of the alternatives. In order to capture variation in resource allocation across the zones ten farms were selected from a data set of actual farms within the three broad zones (for a total of 30 representative farms). They were selected to reflect the variation in soil types and cropping decisions across each zone. 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. Estimation was undertaken using the economic component of the SWAGMAN Farm® model[14] to optimise agricultural production by maximising the total gross margin[15] (TGM). The detailed assumptions and validation of the economic model underpinning the economics are described in detail in the second project report (*Economic impact of tradeable recharge credits and other net recharge abatement policies for the CIA).*

The results of continuing BAU are summarised in Table 4. The area of saline land was linearly extrapolated between 2004 and 2024 using Marshall *et.al.* (1994). Salinity and waterlogging damage functions were estimated using ANZECC (2000) and Grieve *et.al.* (1986). The results indicate that increasing salinity is projected to reduce the TGM generated by agriculture within the CIA by $3m annually from nearly $35m to nearly $32m over the next twenty years.

---

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

[15] 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.

Table 4: Cropping areas and potential total gross margin for BAU scenario

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**

Note: Salinity is predicted to impact on margins rather than area planted (see report 2).

The projected economic outcome under each of the recharge management options is summarised in Table 5. 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 estimated TGM under each policy scenario is expected to be maintained each year throughout the 20 year modelled period. For example, imposing a recharge cap without trade is estimated to generate a TGM of $33.4m each year.

A summary of results of the economic modelling is shown in Table 6. Implementing a rice quota (equivalent to a 30% reduction from maximum allowable area) is estimated to reduce the current annual TGM from agricultural production to $33.5 million per year. At this level, TGM under this policy will be lower in the early years than under the BAU scenario, but through reducing the rate of groundwater rise and reducing yield losses, TGM 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 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. For example, the ‘Rice Quota’ policy generates a negative net present value (NPV) of $2.8 million (at a 5% discount rate).

In contrast the implementation of a zero net recharge cap per farm in combination with trading of recharge credits is estimated to a NPV of $3.4 million (over 20 years at 5%). Hence, the analysis suggests that this policy would generate a net farm level benefit to the community.

Sensitivity analysis of the discount rate between 2.5 and 10 percent does not alter the sign of these conclusions.

Table 5: Cropping areas and potential total gross margin for alternative policies.

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**

Table 6: 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 (20 years)	$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 Sensitivity analysis and caveats

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. In several cases additional analysis was undertaken to determine the likely impact of these factors.

Farm production scale

There are five potential factors at the farm scale for which additional analysis was conducted:

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

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 (including costs of shifting resources away from farming or outside of the region); 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.

Alternative assumptions as to the opportunity cost of water would alter the financial attractiveness of alternative crop and irrigation mixes and consequent cost of achieving a net recharge cap within the CIA. Hence, threshold analysis was undertaken to identify that at a price of $78/ML sufficient water would be sold beyond the CIA (in the absence of restrictions on water trade) to meet net recharge targets.

The viability of any net recharge policy is largely dependant on the assumptions of production losses in the BAU scenario due to soil salinisation. The viability of the tradeable recharge credits policy was found to be sensitive to the baseline soil salinity estimates assumed. Threshold analysis indicated that if actual soil salinity impacts were 10% lower than assumed, then the tradeable recharge credits policy would return a negative NPV.

Soil salinisation is often, but not always, preceded by periods of waterlogging. Management changes that lead to reduced salinity also reduce the likelihood of prolonged periods of water logging and consequent production losses. Additional analysis was undertaken in the southern part of the CIA, which is the most affected by salinity. The analysis focused on the impact of including the additional costs of waterlogging along with the soil salinisation estimates within the cap-and-trade scenario. Findings indicate that the additional benefits of reduced waterlogging are substantial and may be sufficient to more than double the total net benefits across the region to $8.7m in the southern CIA (compared to $2.8m for the cap-and-trade strategy).[16]

Episodic rainfall events may be sufficient to cause a substantial impact on waterlogging and soil salinity if there is insufficient capacity within the groundwater system to absorb the above average levels of recharge. Additional analysis in this case was focused on the cost of further reducing net recharge in order to create sufficient additional aquifer space to manage episodic events. This case was modelled in combination with the waterlogging sensitivity analysis and found to generate NPV of $3.4m to the southern CIA or a reduction of $4.3m over the combined salinity and waterlogging analysis.[17]

The final area of sensitivity analysis was the additional gains from trade that could be sourced from allowing the equivalent of inter-year trading through on-farm banking and borrowing. This was achieved by assessing the impact of dryer years at the 25th percentile and wet years at the 75th percentile of rainfall. 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.

Community scale

Two important issues emerge at the community scale referring to the benefits and costs of designing and implementing a cap-and-trade mechanism. First, the benefit estimates for each of the 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 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.

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. For the cap-and-trade model these latter costs include transaction costs associated with trading recharge credits. The significance of policy costs was considered through a threshold value approach. It was estimated that

---

[16] Note that the proportionate difference in the central and northern regions would be much smaller due to the deeper initial water table.

[17] The proportionate difference in the central and northern regions would be much smaller due to the smaller reduction required.

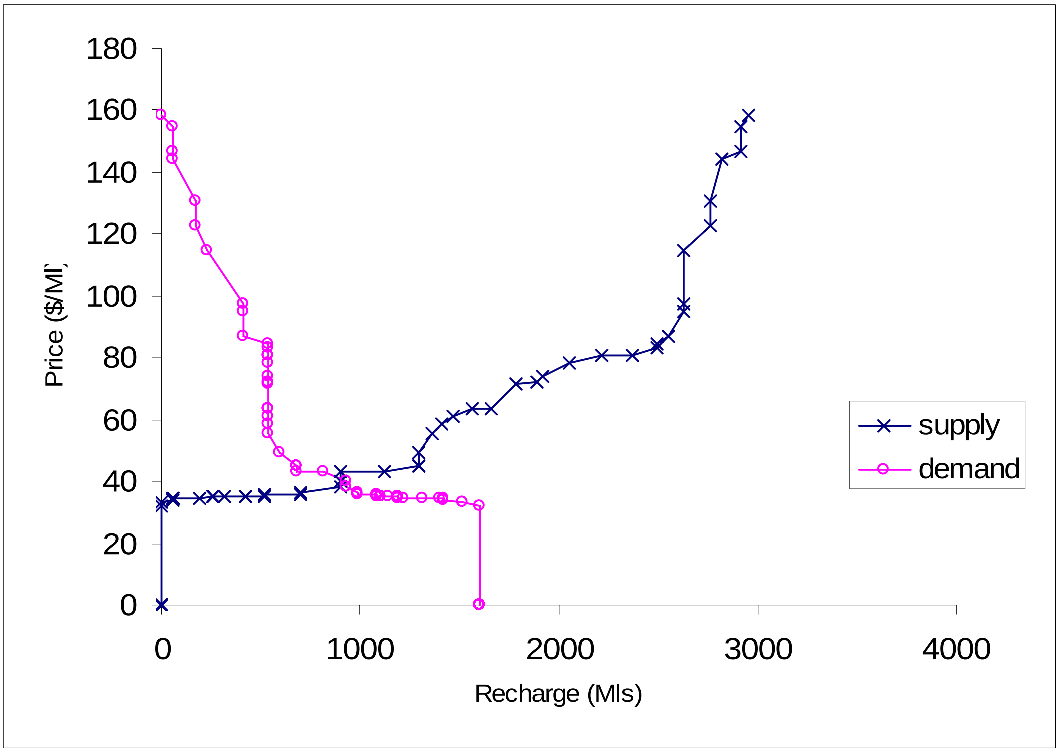
policy costs would have to average less than $268,000 per year for the cap-and-trade policy to be yield a net benefit using the baseline economic analysis.

4.4 Define hypothetical demand and supply curves for credits

A second goal of the economic modelling is to define supply and demand curves for net recharge credits. These curves are constructed from the costs of reducing (or benefits from increasing) net recharge for the model farms on which the economic analysis was undertaken. That is, the supply curve represents the aggregation of opportunity cost of reducing recharge for each model farm. These curves are hypothetical in the sense that they are defined under the assumption of zero transaction costs of trade. The aggregated curves allow for the estimation of gains from trade in a hypothetical market as a basis for comparison in an experimental setting.

Supply and demand curves for the ten model farms used to represent the range of enterprises in the south region of the CIA are shown in Figure 11. Under a zero net recharge target scenario, the equilibrium price of recharge is $38 per ML.

Figure 11: Sample zero net recharge supply and demand curves



An important factor that emerged from the analysis of the aggregate costs and benefits of a cap-and-trade model and the estimation of supply and demand curves is the small size of gains from trade and consequent farm scale benefits as a proportion of total farm income. The implications of the relatively small gains from trade are explored further in Section 5.

5. Institutional design 2: exploring market potential using experiments

A number of outstanding issues relating to the design and implementation of a cap-and-trade policy approach were identified through the initial cap-and-trade institution exploration described in Section 2. The implications for market efficiency and the relative effectiveness of design options were poorly known for many of these outstanding issues. Hence, experimental economics techniques were employed to design a computer based simulation game based on modelled farms in the CIA that were used to assess the effectiveness of treatments.

Experimental economics involves creating a calibrated environment where various incentives and rule combinations can be tested and evaluated. In the case of the CIA the environment is context specific, in that the environment is calibrated against model farm data from the region, as are the experimental treatments. Specifically, experimental economics was used to:

1. Test the significance of market impediments in a setting calibrated to represent important economic and biophysical features of the actual CIA;
2. Test behavioural responses to longer term policy options that may require changes to current institutional structures; and
3. Inform and pre-test on-ground solutions to support policy implementation.

The experimental research progressed through a number of stages in order to achieve these aims. First, the major market impediments identified were prioritised for inclusion in experimental treatments. Second, a simulated context based on model farms from the Coleambally region was created as a basis for experimental treatments. The simulation model was then subjected to a field trial to test that the important aspects of context had been captured. Next, laboratory experiments to test treatments of market impediments were undertaken. These experiments were used to inform a simulation trial with Coleambally landholders as discussed in section 6.[18]

5.1 Prioritise impediments for experimental tests

Eleven market impediments were identified as important to market design. These are defined in Table 7, along with a summary of likely consequences and potential solutions. The impediments were prioritised for further investigation as resources allowed. Prioritisation was via qualitative ranking based on:

- Likely significance of the impediment in the CIA;
- Potential of the solution to improve efficiency;
- Potential administrative and political feasibility; and
- Ease of designing and implementing an experimental treatment.

---

[18] Further information about the experimental design and results are available in two background reports: '*Designing Experiments to test tradeable recharge credits in the Coleambally Irrigation Area*'; and '*Laboratory Tests of Alternative Institutional Frameworks*'.

A summary of these rankings is shown in Table 8. The impediments for which treatments are tested are also shown in Table 8. Solutions to a number of the most important potential impediments were embedded into the experimental design rather than tested as treatments. This was because they were viewed as critical to any proposed outcome and therefore a necessary base for testing the effectiveness of solutions to other measures. For example, some form of property rights is essential to any market or non-market solution. Other factors were designed into the experiment via the use of a context specific parameterisation of the experiments. For example, existing farm data was used as the basis for the ensuing experiments, in part to identify the importance of thin markets in reducing market efficacy.

Table 7: Market impediments assessed for potential experimental analysis

Market impediment	**Definition**	**Potential solutions**
Common Pool Resource	Property rights to shared aquifers are not defined leading to: • decisions confounded by a social dilemma; and • free riding behaviour.	• Allocate property rights obligations to farmers. • Social contracts formalising non-market agreements.
Property rights	The absence of defined rights makes market exchange unlikely due to • Uncertainty/unreliability in market outcomes; • low market participation; and • high transaction costs in defining and defending contractual property rights.	• Allocate property rights obligation to farmers. • Property rights assigned to beneficiaries.
Thin markets	Insufficient buyers and sellers implies a lower probability of finding trading partners thus higher transaction costs. Can lead to market power and hoarding behaviour.	• Do nothing – numbers may be sufficient to avoid issue per Smith (1982). • Centralised trading point. • Introduce external trader.
Mismatched annual supply and demand	Stochastic rainfall events can lead to systemic under or overachievement of recharge reduction, leading to most participants incurring either excess credits or debits, regardless of land management practices.	• Normalise performance leading to constant recharge credit allocations. • Allow credit banking and borrowing with specified end point for clearing.
Entitlement distribution	Irrigators hold *de facto* rights at present. Auction of rights is theoretically most efficient mechanism but procedural fairness makes grandfathering of any rights much more likely.	• Grandfather property rights obligations to farmers. • Community determined distribution of entitlements.
Risk assignment	Three risks could be faced by irrigators under a performance based system: a) stochastic events such as rainfall variability; b) effectiveness of management options in achieving recharge reduction; and c) free riding by other farmers	• Normalised performance reduces stochastic risk. • Other risk factors not proposed for experimental tests.
Performance incentive failure	Performance based approaches based on estimating recharge outcomes provide stronger ongoing incentives for recharge management than input incentives. All approaches reliant on penalty for non-compliance.	Two tiers of penalty for non-compliance: a. An individual penalty; and, b. Socialised and equally imposed penalty equivalent to production costs on all.
Insufficient variability in recharge reduction costs	Little difference in participant's costs of recharge reduction generates little incentive to trade, with a potential for thin markets.	Non market social contracts
Capital constraint	Capital constraints may limit adoption of recharge reducing management options.	Alternate finance arrangements
Information constraint	Information constraints may limit adoption of recharge management options.	Farmer participation in trials could improve information.
External market preferences	Non-market or external market preferences may limit adoption of recharge management options	No specific treatment

Table 8: Summary of the experiment selection process

Market impediment	**Solutions**	*Significance*	*Administrative alignment*	*Political feasibility*	*Efficiency gain*	*Field test and simulated trial*	*Experimental treatment*
Common Pool Resource	Develop coordination mechanism:						
	Allocate recharge property rights to enable market exchange	High	High	High	Low to medium	✓ FT, D	✓ D
	Develop non-market social contracts		Medium	High	High	✓ ST	✓
Property rights	Allocate temporary recharge property rights	High	High	High	High	✓ FT, D	✓ D
Thin markets	Rely on existing farm data	High	High	High	Medium	✓ D	✓ D
	Introduce agency trader		Medium	Medium	High		
Mismatched supply and demand	Normalised performance	High	High	High	High	✓ D	✓ D
	Credit banking / borrowing		Medium	High	Low to medium		
Entitlement distribution	Allocate property rights to farmers	Medium	High	High	Low	✓ FT, D	✓ D
	Community determined		Medium	Medium	High		
Risk assignment	Normalised performance	High	High	High	Low	✓ D	✓ D
Performance incentive failure	Rely on improved recharge information (via SWAGMAN)	Medium	Low	High	Low		✓
	Socialised production based penalty		Medium	Medium	High	✓ D	✓
	Individual non-compliance penalty		Medium	Medium to high	High	✓ FT	✓
Insufficient gains from trade	Develop non-market social contracts	High	Low to medium	Medium to high	High	✓ ST	✓
Capital constraint	Alternate finance arrangements	Uncertain	High	Low	Low to medium		
Information constraint	Field trial participation	Uncertain	High	High	Medium to high		
External preferences	No specific treatment	Uncertain	Uncertain				

Notes: ✓ indicates market impediment tested using either field trial (FT), simulated trial (ST) or embedded in design (D).

5.2 Treatments and hypotheses

The baseline treatment (treatment one) was designed to represent the status quo; farmers make decisions with little information about their impact on recharge, there are no binding recharge allocations or opportunities to trade allocations, losses due to rising water tables are shared among all farmers in the catchment and are not known in the short run. In this scenario, there is little incentive for individuals to limit their contribution to recharge, as the benefits in the form of increased income are private while the subsequent crop losses are shared. The problem of excess recharge cannot be solved by a single farmer acting alone.

A number of authors (eg Ostrom 1998) have suggested that such problems may be effectively managed if those involved can coordinate their decisions, using either formal or informal institutions. The provision of information about the problem is necessary to achieve effective management, but is unlikely to be sufficient in itself (Smith 1987, 2002; Tisdell *et al.* 2004). If simply providing information is sufficient to manage the problem, then there would be no need to develop more complex institutions.

Hypothesis one: Providing information on individual contributions to recharge and periodic crop damage will reduce recharge levels.

Treatments two and three provide the participants with increased information. In treatment two they are informed how their decisions impact on total recharge, based on data from the SWAGMAN Farm model, while in treatment three they get this information plus they learn how much income they stand to lose due to excessive recharge at the end of each period rather than at the end of the experiment. By examining the effect of information alone, it is also possible to distinguish the effects of the institutions used in subsequent treatments from the information that must be provided with them.

In many natural resource dilemmas, effective management can be achieved through voluntary social contracts. If participants are allowed to communicate, there is potential for such contracts to be formed. There is considerable experimental and field data indicating that in certain cases communication can be very effective in improving the outcome of resource dilemmas.

Hypothesis two: providing a forum for discussion, allowing the formation of a voluntary social contract to coordinate management decisions, will reduce recharge levels.

In treatment four, participants were provided with the same information as in treatment three, and before each period they were brought together and allowed to discuss coordinating their decisions.

Communication is sometimes very effective in such situations, but other times not. It tends to be less effective where those involved face different costs and benefits from cooperation. A recharge trading mechanism can provide an alternative means of coordinating individual decisions to ensure that overall recharge targets are not exceeded. If there is heterogeneity among farms in their costs of reducing recharge, as in the CIA, then there are potentially gains from trade among farms to determine who should contribute to reducing recharge. Under a market institution, farmers have an incentive to reveal their costs of avoiding recharge, which they do not have under communication and voluntary social contracts.

Hypothesis three: providing a market mechanism to trade voluntary recharge entitlements will reduce recharge levels.

Treatment five consisted of information plus a single call market for trading recharge allocations each period. Treatment six combined the market with the communication treatments, providing a discussion forum before each period.

Under all these institutions, any costs resulting from non-compliance are still shared among all farms. Therefore individual farmers may still be tempted to free ride. An alternative would be to create an individual incentive for compliance with recharge targets.

Hypothesis four: imposing recharge target non-compliance penalties on individuals will lead to lower levels of recharge than when the excess recharge penalty is imposed equally on all players.

Treatment seven combined the information and market treatments, but with the individual rather than the group being penalised for failing to meet their recharge target. Treatments are summarised in Table 9.

5.3 Simulated catchment

A simulated catchment was constructed comprising twelve model farms based on a representative sample of farms from the CIA, with sizes ranging from 200 to 335 hectares. The SWAGMAN Farm model was used to estimate levels of income and recharge for each model farm under alternative management options. For each model farm there were five management options, representing different mixes of crops. SWAGMAN Farm was used to calculate the threshold level of recharge below which the water table would not rise – this was the policy target in this simulation.

To provide context, experimental participants were told they were playing the role of a farmer, and the nature of the recharge problem was explained. Participants were randomly assigned to a model farm, and in each period of the experiment were asked to choose one of five management options. In the baseline treatment they were given a table showing the income produced by each option. In subsequent treatments they were provided with more information about the amount of recharge produced by each option and a recharge allocation (the threshold for a zero contribution to a rise in the water table). In the market treatments, they were also informed of the increase in income for each additional unit of recharge.

Table 9: Experimental design

Treatment		Individual recharge information	Institution		Penalty			Replicates
			Communication	Market	Socialised	Individual	Timing	
1	**Control**	✗	✗	✗	✓	✗	End of session	2
2	**Recharge info**	✓	✗	✗	✓	✗	End of session	2
3	**Info + crop loss**	✓	✗	✗	✓	✗	Each round	2
4	**Communication**	✓	✗	✓	✓	✗	Each round	2
5	**Market**	✓	✓	✗	✓	✗	Each round	2
6	**Market + communication**	✓	✓	✓	✓	✗	Each round	2
7	**Market + individual non-compliance**	✓	✗	✓	✗	✓	Each round	2

5.4 Pre-tests – Yanco field trial

The experimental simulation and recharge credit trading environment was field demonstrated at Yanco Agricultural College. Seventeen irrigators and seven CIA staff participated. The demonstration was relatively informal, precluding use of the data for subsequent analysis. Rather the field demonstrations were intended as an extension process, to familiarise irrigators with the inter-dependent nature of excess groundwater recharge, to promote acceptance of the SWAGMAN model, and enable irrigators to explore and experiment with recharge market structures. It also provided an opportunity for participants to provide feedback on the proposed experimental simulations.

The irrigators enthusiastically participated in the recharge trading demonstration, recognising the immediate need for remedial, shared recharge management. Importantly, the cohort of irrigators represented those affected by increasing catchment recharge and rising groundwater, and those from high recharge areas of the catchment. The demonstration provided a forum for constructive and vigorous discussion of the shared nature of catchment recharge and highlighted the social dilemma facing constituents.

In the experimental simulations, market prices generally reflected modelled outcomes, although the level of trade was limited. The incentive to trade was small. That is, the proportion of trading income relative to farm income was very low. The data for the simulated catchment were refined and re-framed for the laboratory sessions in accord with irrigator comments. Specifically, suggestions were made for a larger penalty for non-compliance with recharge targets.

There was widespread consensus for a combined two day SWAGMAN / market trading workshop. The reliability of the SWAGMAN Farm model was generally not well recognised by participating irrigators. Improved recognition and adoption of the model would be enhanced by the combined workshop. In order to coordinate with farm management schedules, the majority of participants agreed the best time for the workshop was early 2005.

5.5 Experimental setting

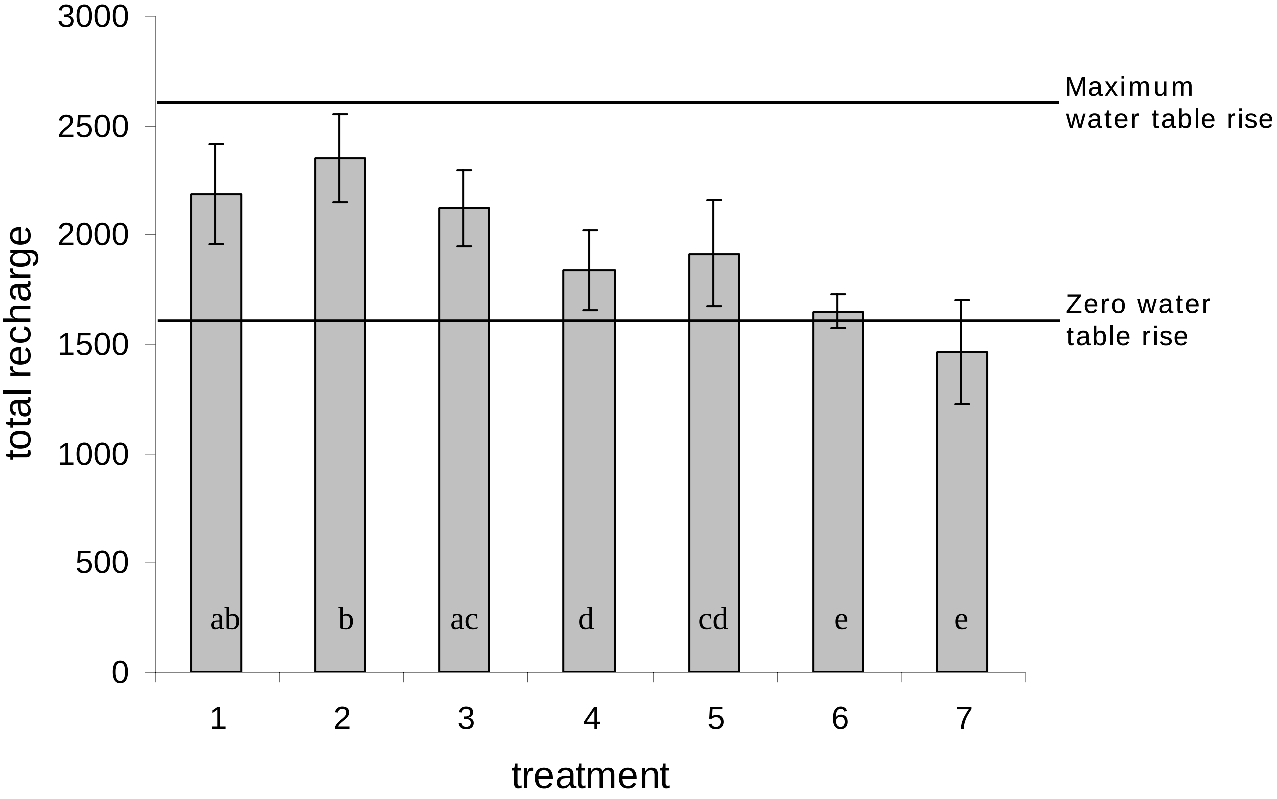
Experiments were carried out at the Griffith University experimental economics laboratory in Brisbane, using the MWATER experimental software platform developed and administered by Dr. John Tisdell. The software provides a standardised decision-making environment. Participants were drawn from a pool of approximately 200 Griffith students who had taken part in a number of previous experiments.

Each session involved approximately ten periods (the exact number was randomly varied so the participants could not be sure when the experiment would end). Participants were paid based on the income earned by their model farm. In each period they received a payment based on their performance relative to the optimum for that particular farm. If total recharge across the 12 farm catchment exceeded the threshold level, some crop damage was considered to have occurred, and all players paid a penalty. The penalty was up to 75% of optimum farm income, depending on the extent to which total recharge exceeded the threshold. In the individual penalty treatment, participants who exceeded their recharge allocation had their income reduced to that of the nearest option which did meet their allocation.

5.6 Results

Overall levels of recharge were highest in the baseline and information only treatments (Figure 12, treatments 1-3). The coordinating institutions, communication and market (treatments 4-5), were associated with a significant decrease in overall recharge. Combining the market and communication treatments reduced recharge still further (treatment 6), and introducing individual penalties for non-compliance (treatment 7) was associated with the lowest level of recharge, in this case below the target threshold of zero water table rise. In all treatments the rise in water table was below the maximum possible.

Figure 12: Total recharge by treatment.



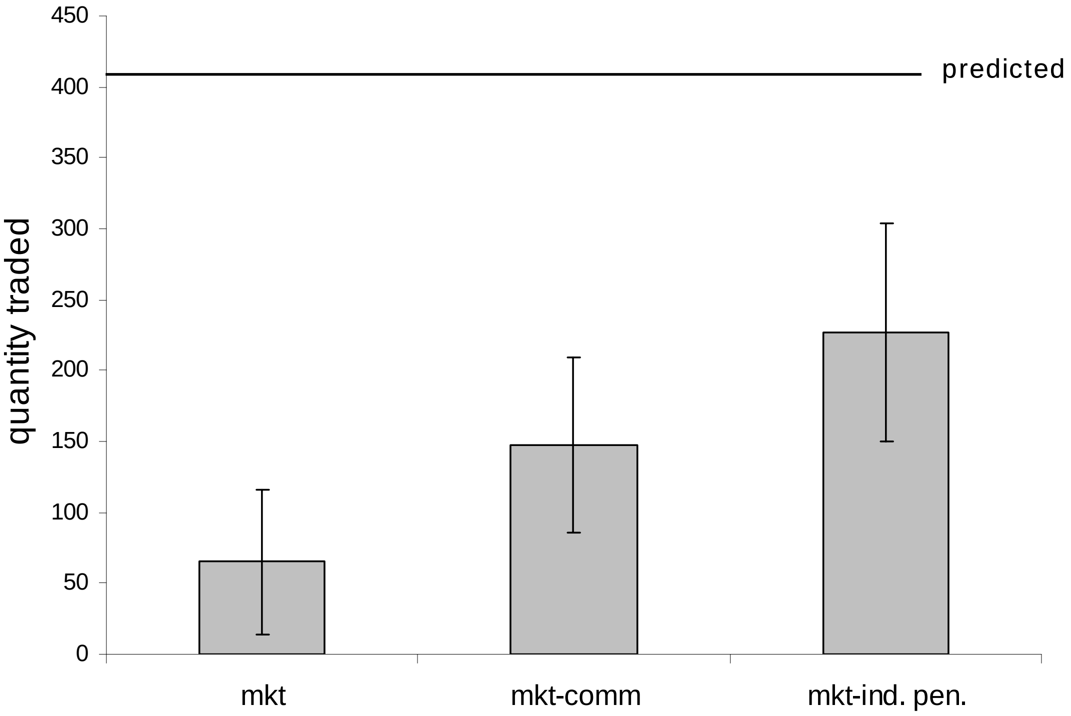
Notes: Error bars show standard deviation.
Bars with the same letter are not significantly different at the 5% level.

Crop loss was zero with the individual non-compliance penalty, and was very low in the market-communication treatment. Crop loss was significantly higher in the market only and communication only treatments, and higher still in the information only treatments. Among the information treatments, crop loss was significantly lower when experimental subjects were provided with crop loss information after each period rather than at the end of the session.

Player income was highest in the market-communication and market-individual non compliance treatments. Income in the market only treatment was significantly higher than in the communication only treatment. The lowest incomes were in the information only treatments. Treatment three, which provided the most SWAGMAN information to participants, had significantly higher incomes than treatments one and two.

In the market treatments, the overall quantity traded was significantly below the levels predicted by the model (Figure 13). Volumes were significantly higher in the market and communication treatment than with the market only. The market and individual penalty treatment resulted in another significant increase in trade quantity. Gains from trade followed the same pattern, increasing from treatment five to six to seven, but still falling well short of the level predicted by the model. Overall gains from trade were tiny compared to overall income. Even in the treatment with the most active market (treatment 7), gains from trade still made up only around 1% of total farm income.

Figure 13: Quantity of recharge units traded by treatment.



Notes: Error bars show standard deviation.

5.7 Conclusions for field trial

In the baseline treatment, in which experimental subjects were provided with no information about recharge, overall recharge levels were relatively high, resulting in significant crop loss. However, it should be noted that recharge levels were some way below the maximum, suggesting that some participants may be voluntarily limiting their income in order to keep recharge down. Introducing additional information about individual contributions to recharge did not result in a reduction in total recharge when crop loss was not known until the end of the experiment. Crop loss remained high in both these treatments. However providing crop loss data at the end of each period did result in an overall decrease in crop loss and an increase in income. Therefore these experiments give only very limited support for hypothesis one, that providing information about recharge and crop loss will reduce recharge levels. As previous studies have found, information may be necessary for successful management, but it is seldom sufficient.

Providing the communication forum resulted in significant decreases in total recharge and crop loss, and increased incomes. Hypothesis two is therefore strongly supported by the experimental data. This suggests that face to face communication is allowing the formation of social capital and informal social norms. Such institutions are attractive because they are entirely voluntary, and involve very low transaction costs. This form of institution should be investigated further in the field trial to test whether the result holds among groups of irrigators. Developing effective social norms is likely to be far more challenging among a large group of irrigators than among a dozen students.

The market mechanism also delivered reduced crop loss and increased incomes. Even in the absence of an enforceable cap on individual contributions to recharge, the ability to trade appeared to provide a reasonably effective coordination mechanism. Combining the market with a communication forum further improved performance. This suggests that people can use the market mechanism to achieve voluntary abatement targets. Hypothesis three, that markets can facilitate a reduction in recharge, is therefore also supported.

The most dramatic reduction in recharge occurred when the crop loss penalty for non-compliance was converted to an individual rather than a group penalty, supporting hypothesis four. This is to be expected, as there is no longer any incentive to free ride. Combined with the market institution, this treatment delivered the highest gains from trade. However, as in all the market treatments, gains from trade were still significantly lower than predicted by the economic model. Participants traded less than predicted, reducing the already slight potential trade gains.

These experiments have demonstrated that communication, trading, and individual non-compliance penalties are all effective institutions for reducing recharge in the simulated catchment when combined with recharge information based on the SWAGMAN Farm model. There is a case for investigating all three institutions further in trials with stakeholders from the CIA.

6. Testing results in the Coleambally context

A major element of the pilot is to test the cap-and-trade approach at the regional level. Despite the ongoing impacts of a severe drought combined with ongoing water reforms we were able to undertake a simulation trial involving Coleambally irrigators. Additional information on the impact of recharge credit trading on individual farm management strategies was gathered via several farm case studies. More detailed results from the simulation trial and farm level case studies are available in the fifth report from the project titled: '*Simulation trial and farm case studies'*.

6.1 Simulation trial

6.1.1 Context and setting

The simulation trial was designed as both an extension process to aid in familiarising irrigators with net recharge trading concepts and frameworks, and to test the reality of the structure to their farming enterprises. The main goal of the simulation trial was for landholders to experience the concepts of net recharge trading in a structured setting that they were able to relate to their own farm management decision-making processes.

The informal nature of the simulation trial is not compatible with the controlled setting experimental design requirements. That is, the treatment environments of the field and laboratory experiments are not consistent. This precludes formal statistical comparison and analysis of the data collected in the different settings. Performance criteria of the Coleambally MBI field workshop is therefore restricted to graphic comparison of recharge and crop loss values, qualitative appraisals of the level and willingness of participation, acceptance of recharge markets as a potential recharge solution, and suggested strategies and instruments for future recharge management.

A SWAGMAN Farm demonstration[19] and tutorial preceded the experimental sessions, a response to recommendations from the August 2004 field demonstration and collaborative workshop.

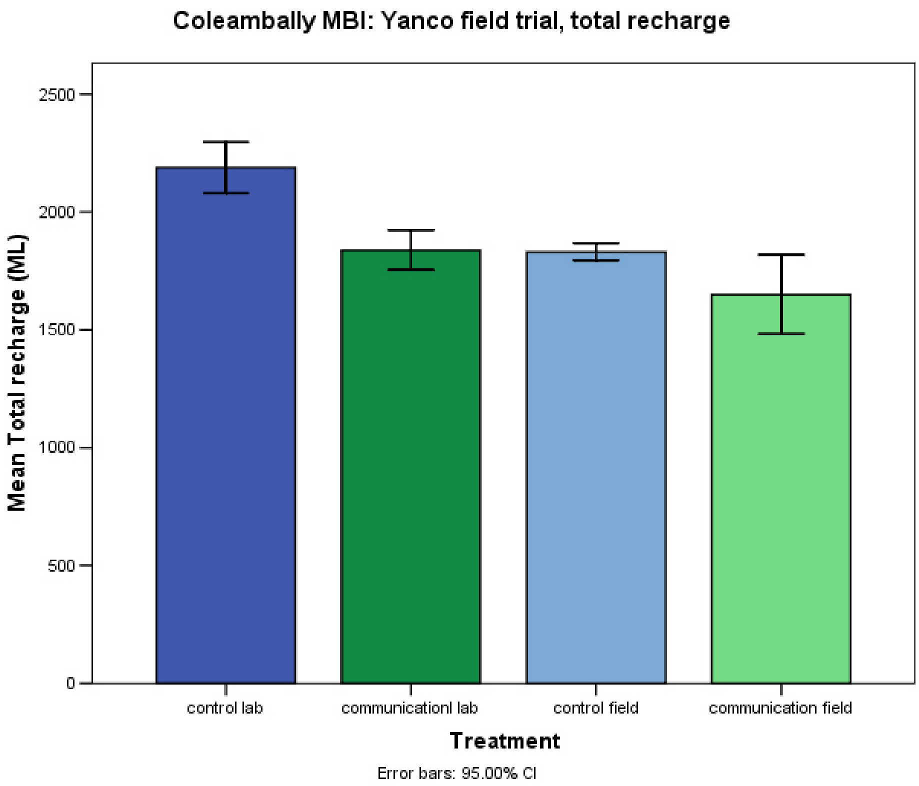
The simulation trial was conducted in a computer laboratory at Yanco Agricultural College at Leeton and involved thirteen participants.[20] Twelve computers at Yanco were employed as terminals and re-routed to the Griffith University experimental economics server via the Internet. Each terminal screen represented a discrete model farm in the central sub-catchment of the CIA, with specific farm income, cropping management and recharge characteristics. The data and farm decision variables are identical to those employed for the student experiments conducted at Griffith University (reported in section 5).

---

[19] From the third report from the project: Recommendations from the field demonstration of August, 2004:"Widespread consensus for a combined two day SWAGMAN/ Market trading workshop. The reliability of the SWAGMAN model was generally not perceived nor recognised by participating irrigators. Improved recognition and adoption of the model would be enhanced by the combined workshop."

[20] All participants were irrigators of which three also worked for CICL.

Figure 13: Total recharge comparing the control and communication treatments of the laboratory and field experiments



6.1.2 Yanco demonstration outcomes

During the workshop a single 10 period control and a 10 period communication treatment were conducted.[21] The total recharge and crop loss results of the control and communication treatments observed at the MBI workshop are compared graphically with the laboratory experiments in Figures 14 and 15. Formal statistical comparison of the data collected in the different settings was precluded because the treatment environments of the field and laboratory experiments are not consistent.

The results from the laboratory trial and the simulation trial are broadly consistent although the simulation trial appears to outperform the laboratory setting. This is consistent with expectations as Coleambally irrigators are familiar in broad terms with recharge issues and can be expected to have a greater degree of social acceptance of the need to change management, as well as a commitment to change management through acceptance of existing land and water management plans.

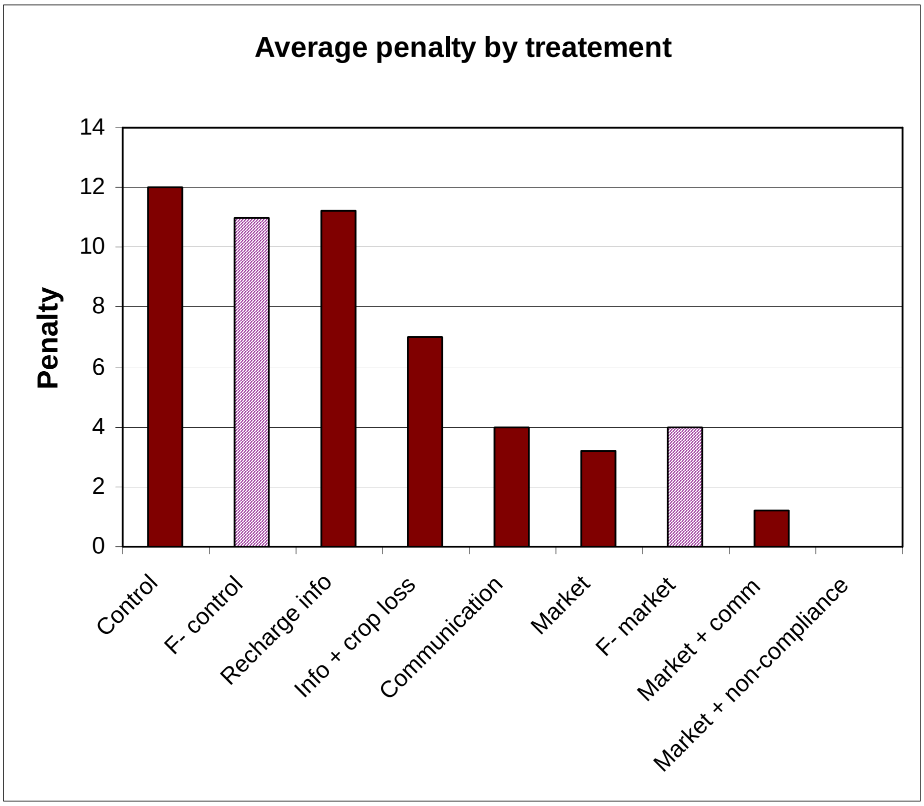
In contrast to the field trial, irrigator attitudes at the simulation trial revealed high levels of scepticism towards market exchange of recharge units and the reliability of data interpretation contingent on the simplified decision making environment. A dominant theme expressed by several farmer participants was the need for an increasingly interactive farm management process, offering a contextually richer and expanded decision set, inclusive of water trading, irrigation decisions and more

---

[21] CICL did not support initial plans for a longer workshop or multiple workshops due to other pressing farmer consultations relating to upcoming Land and Water Management Plan revisions.

precise crop management. Whilst an aspiration of the experimental research, the provision of participant determined and interactive experimental decision sets is beyond the scope of the simulated trial setting and would require substantial commitment to an on-ground pilot as initially envisaged in the project.

Figure 14: Average penalty by treatment (experiments and simulation trials)



6.2 Farm case studies

6.2.1 Context and setting

The aim of the farm case studies was to conduct a detailed assessment of the impacts of a net recharge cap-and-trade framework on actual farm management decisions. A series of structured questions were posed to farmers to elicit the changes they would make to their management in order to meet specific recharge abatement targets. Using the information about crop management changes, the opportunity cost of abatement was calculated and the farmers were asked at what prices the recharge credit would have to be for them to either buy or sell credits. The farm case studies also provided an opportunity for feedback on the use of the SWAGMAN Farm model in the context of a cap-and-trade environment.

Three farm level case studies were conducted. In each case the farmer had attended either the experimental field trial or simulation trial and was familiar with the project and the concepts of both net recharge management and tradeable recharge credits. All farms were located in the southern half of the CIA where high watertables and associated problems are most prevalent. Diversity between the farms was also an important criterion in selection.

Case study structure followed the following series of scenarios:

1. *Base Scenario*: identify current farm management and consequent net recharge;
2. *Recharge Abatement Scenario 1*: identify changes to meet a net recharge target that is 40% less than base scenario net recharge and whether the farmer would participate in a recharge market if the clearing price was $30/ML;
3. *Recharge Abatement Scenario 2*: identify changes to meet a net recharge target that is 70% less than base scenario net recharge and at what recharge credit prices the farmer would consider participating in a recharge market;
4. *Recharge Abatement Scenario 3*: repeat scenario 2 for a 100% recharge reduction; and
5. Identify critical factors in deciding on the crop mix to meet recharge targets (such as marketability of certain crops, expertise in growing certain crops and stock management desires and skills) and in participation in recharge markets.

6.2.2 Case study results

All of the case study participants were knowledgeable on the concepts on net recharge management and tradeable recharge contracts as a policy tool to achieve sustainable recharge in an irrigation region. Prior to the case study interviews, the three farmers had attended at least one of the experimental economics workshops in which the concepts on net recharge management and tradeable recharge contract were explained, in addition to providing them with the opportunity to participate in the trading recharge simulation exercises. The farmers found the workshop informative and felt that it increased their understanding of net recharge management and tradeable net recharge contracts. Also, the three case study farmers have traded in the water market, thus endowing them with practical experience in trading a resource. Given this experience, all farmers said they would be comfortable in trading net recharge credits. However, one case study participant felt that the concept of tradeable recharge credits as a net recharge management tool probably raises more questions than it answers and indicated some concerns with the measurement and tradability of net recharge.

General conclusions from the three case study farms were:

- The main recharge abatement strategy was to replace recharging summer crops (rice, maize) with discharging crops (lucerne, winter cereals), particularly following rice as this offers the greatest recharge abatement potential;
- All participants would consider crop management strategies to create recharge credits if the market value of credits was greater than the cost of abatement;
- The SWAGMAN Farm model is a useful education tool in determining land use options to manage net recharge for the farm; and
- Net recharge trading offers advantages and disadvantages and it is not yet clear that the advantages outweigh the disadvantages.

It is important to note that although all three farms opted to substitute rice or maize with lucerne to abate recharge, this may not be the case on other farms. Many farms may be reluctant to grow lucerne because it is labour intensive, the farm lacks infrastructure for stock grazing (many farms have removed fencing). Some farmers are not interested in running stock and lack the necessary machinery or access to contractors. Finally, the hay market is considered volatile due to the seasonality of feed supply for stock within the region.

The main advantages of recharge trading that were identified by case study participants is the potential for more flexibility in crop choices to achieve recharge targets and thus reduce net recharge at a reasonable cost to farmers. It was observed that net recharge trading has the potential to create a significant positive impact for the CIA if the policy framework is kept simple and can be monitored accurately. Potential disadvantages identified include insufficient credits being available for sale and complex measurement and auditing requirements for each farm with consequent difficulty in achieving community consensus. Participants also made suggestions for non-compliance penalties that included monetary and water supply options. Carryover and shortfalls were also suggested to incorporate flexibility into any compliance regime.

6.3 Conclusions

The conclusions from the simulation trial and the farm case studies support the institutional, economic, biophysical and experimental analysis undertaken during the course of this study. Landholders are aware of the net recharge issue and their impact as a group on the problem. They are also aware of the SWAGMAN series of models and generally supportive of the concept of individual measurement of contributions to net recharge. Discussion during the field and simulation trials indicated that landholders retain some scepticism about the paddock scale measurement. That is, farmers are not yet sufficiently confident about the SWAGMAN Farm model to undertake net recharge trading, although they recognise and support the value of the tool as a farm management aid in reducing net recharge.

The farm management changes offered in response to the recharge management scenarios described in the farm level case studies were consistent with those hypothesised using the SWAGMAN Farm model. Departures from profit maximising strategies are relatively minor and due to the costs of changing management and individual farm management goals. This is consistent with our conclusions from the economic modelling which note that the once-off costs of changing management are not included within the economic analysis and may be significant. The farm level case studies indicate that, in at least some circumstances, these will lead to the adoption of minor differences in applied strategies to manage net recharge.

Finally, the concerns by irrigators in both the simulation trial and case studies indicate a healthy scepticism of net recharge trading including the complexity in setting up mechanisms and achieving community adoption of the new tool. This scepticism needs to be taken into account when considering whether the adoption of such a scheme is worthwhile in Coleambally.

7. Lessons for MBI design and implementation

7.1 Policy advice in Coleambally Irrigation Area

7.1.1 Potential for tradeable net recharge credits in Coleambally Irrigation Area

The primary focus in this project was the investigation of the suitability of a cap-and-trade model for managing salinity and waterlogging in the CIA. Thus, the initial focus was on investigating the issues involved in applying the cap-and-trade approach to the management of irrigation salinity and waterlogging. The concept of the cap-and-trade approach is sound but a number of important issues needed to be overcome in order for the application to be both practical and efficient. These were:

- The effective conversion of diffuse irrigation recharge to a point source for which a cap can be identified and administered via measurement of farm scale recharge;
- Assessment of the efficiency of the cap-and-trade approach compared to alternative policy approaches;
- Effective design of instruments to overcome remaining institutional design issues such as allocation of property rights and design of institutions that allow the gains from trade to be accessed; and
- The community must understand, at least in a broad sense, the issues being faced and the potential solutions available in order to make informed decisions about the costs and benefits that they will incur in managing the issue.

Conversion of recharge from a diffuse source problem to a point source issue comprises two elements: an aggregate recharge target; and a measurable individual application of the target. The overall cap or aggregate recharge target in the CIA is linked to the vertical and lateral movement of water between aquifers because limiting total recharge to an equivalent value will lead to no further rise in groundwater levels and consequently no production damage. Groundwater movements on this scale were modelled by Khan *et al* (2004) using MODFLOW and APSIM. Groundwater movements are not uniform across the landscape and sub-caps will need to be applied across a number of zones to avoid the problem of overall targets being achieved while some areas experience ongoing and perhaps worsening damage.

Application of the aggregate target at the individual level is reliant on mechanisms that allow paddock scale recharge to be accurately and cost-effectively estimated. In the CIA, the SWAGMAN Farm model has been calibrated to provide an accurate and repeatable framework for estimating paddock scale recharge. The SWAGMAN Farm model thus provides a suitable metric to act as the basis for recharge property rights, and therefore the allocation and measurement of recharge credits. The model is available as an on-line computer model (with secure access to individual data) and can be applied by individual landholders once basic farm parameters such as soil types have been entered for individual management units. Farmers can then explore different ways of meeting a recharge cap applied to their farm. While the SWAGMAN Farm model is not currently linked to an Internet trading platform this would be relatively easy using the M-water platform that the experiments are based on.

In contrast to the development of an appropriate set of biophysical measures on which to base a cap-and-trade policy, the estimates of the relative efficiency of a cap-and-trade approach when compared to alternative policies provides less encouragement. The total benefits of a cap-and-trade approach compared to BAU indicate that the total NPV is approximately ten percent of current annual income (at a five percent discount rate). That is, the annual benefits are less than one percent of annual income. While these estimates are limited to the on-farm costs and benefits of recharge management in a restricted setting, they proved robust to a number of sensitivity tests as discussed in Section 4. The most important restriction to the model results appears to be the lack of an external buyer representing benefits to infrastructure, and non-monetary benefits within and beyond the Coleambally community. On the other hand, transaction costs associated with designing, implementing and running a cap-and-trade model were not incorporated into the economic analysis. Finally, it should also be noted that while major advances have been made in the biophysical modelling that underpins the economic analysis, research is ongoing in a number of areas such as the costs of waterlogging and implications of episodic climatic events.

The NPV of the alternative policies are largely made up of the potential gains from trade that a cap-and-trade model allows access to in comparison with alternative recharge management options. Experimental economics was employed to assess the relative efficiency of alternative institutional structures in accessing these gains. The experiments indicate that the most efficient model for accessing the gains from trade is a standard cap-and-trade approach with individual penalties. However, the gains from trade are a very small proportion of farm gross margins and less than half of the available gains from trade were accessed in the experimental setting. This was also the experience with the U.S Acid Rain scheme and indicates caution with the new instrument (possible caused by risk aversion). Given that the experiments are expected to out-perform actual applications this means that the gains from trade under a cap-and-trade approach will be fairly small.

The experimental setting did indicate the potential for recharge markets to function and to capture at least some of the available gains from trade. Should the potential gains from trade be found to be much larger than originally estimated, or if ways are found to incorporate other non-irrigator beneficiaries, a cap-and-trade approach may provide greater net benefits over other options.

Finally, a simulated trial and farm case studies were undertaken to test the cap-and-trade concept in a more applied setting. Results from the simulated trial were comparable to the laboratory experiments and indicate that the conclusions for market design are likely to be robust in the field. Farm case studies indicated that the SWAGMAN Farm model is viewed as a useful tool at the farm scale. The farm case studies also indicated concerns about the practicality of a recharge credit trading scheme including the anticipated complexity and functionality of the scheme. Despite concerns, case study participants noted the need for recharge management. Concerns about the suitability of a cap-and-trade approach are important because community acceptance of the approach is needed to support adoption, especially if a voluntary trial and adoption is envisioned. Some of these concerns may have been caused or exacerbated by the impact of the drought on irrigation water supplies and consequently on farm income, as well as the continuing water reform processes at the state and national level.

7.1.2 Policy advice to the Coleambally community

Three kinds of policy advice to the Coleambally community arise from our research:

1. Immediate advice relating to adoption of a cap-and-trade policy for recharge management as described in section 2.1;
2. Advice flowing directly from our conclusions; and
3. Advice for future policy investigation and consideration.

Our research does not support the adoption of the form of cap-and-trade policy described in section 2.1. This is because the farm scale economic costs and benefits are considered insufficient to drive adoption and participation in a net recharge market. The transaction costs that would be incurred in the fine-tuning the design, implementation and administration of a cap-and-trade policy are likely to outweigh the net benefits estimated. Furthermore, experimental tests indicate that it is unlikely the full gains from trade could be accessed by irrigators, thus further reducing the net benefit. The conclusion that benefits are unlikely to outweigh the transaction costs is due to the small farm level benefits relative to total income.

The research does indicate that a focus on outputs and flexibility will be important whatever the policy employed. First, an output-oriented approach to managing salinity and waterlogging issues is critical to establishing a linkage between management change and the desired objective as well as in setting and measuring achievement of aggregate recharge objectives. The biophysical research undertaken to support recharge management within this project and more generally in the CIA is essential at both the regional and farm scale to support output-oriented approaches and to evaluate the relative cost-effectiveness of different policy options. The economic analysis of policy options also indicates that targeting outputs and incorporating flexibility at the farm scale are critical in reducing the costs of policy and in delivering efficient outcomes. For example, without water trading restrictions, a temporary trading water price greater than $78 per ML is likely to achieve recharge management goals within the CIA. Finally, the experiments indicate that focusing on recharge and providing information and opportunity for communication may achieve a significant proportion of the desired recharge outcomes.

While the conclusions do not support adoption of recharge trading as a management tool, they do indicate that this is the most efficient policy option at the farm level. However, given the nature of production, salinity impacts, and costs of introducing alternative tools, extension of the existing rice quota is likely to be the best interim policy. This does not conflict with the strong arguments presented for outcome-based management. Rather the input tool (rice quota) needs to be aligned with outcome goals.

Finally, there are a number of areas of both underpinning science and institutional development that may improve the prospects of adoption in the future. For example, we were unable to fully explore the impact of stochastic variability and extreme events for policy design. Neither were the wider community benefits from adopting improved recharge management incorporated into the cap-and-trade framework (that would require an external buyer and source of finance). Hence, we suggest that CICL revisit tradeable net recharge credits in the future when the policy environment and water supply conditions are more favourable to broader policy reform.

7.2 Advice for MBI research and development

An important goal of the National Market Based Instruments Pilot Program is distillation of the findings from this project for broader MBI research, development and implementation. Hence, the focus in this section is on identifying key outcomes and advice for future MBI investigations and applications.

7.2.1 Addressing cap-and-trade knowledge gaps

A number of specific knowledge gaps were addressed during the project, including:

- Measurement of 'diffuse' net recharge to shared irrigation aquifers;
- Identifying the extent of the commons and setting targets for net recharge;
- Definition and allocation of rights to a new environmental service 'net recharge';
- Mechanisms for facilitating a market for net recharge including management flexibility, exchange mechanisms, administrative frameworks, monitoring rule violations, and the nature and imposition of penalties;
- Estimation of efficiency of MBI compared to other policy instruments;
- Estimation of the gains from trade under a cap-and-trade approach;
- Development of pre-tests of institutional frameworks directly with stakeholders to improve the robustness of institutional design; and
- Identifying ways to engage successfully with the community to achieve adoption and management change.

A significant contribution has been made towards removing each of the knowledge gaps targeted in the project as well as further issues that were uncovered in the course of the research, such as the impact of episodic events on policy effectiveness and efficiency. The achievements in addressing knowledge gaps can be broadly divided between biophysical research, linking biophysical processes and governance institutions, economic analysis, and institutional investigation.

Prior to the project commencing a number of recharge management tools had been developed by Shahbaz Khan and colleagues. These included the SWAGMAN Farm model that was developed as a farm management tool to aid in the management of recharge to shared aquifers at the local scale and larger scale tools such as MODFLOW and APSIM. Prior to this project these tools had not been linked to derive regional volumetric groundwater targets that could then be linked to farm scale targets. A major achievement during the project was to identify aggregate targets and zonal targets (see Khan & Zirell, 2005a). The SWAGMAN Farm model was also further developed during the course of the project to improve the representation of synergistic responses that occur, for example where Lucerne and rice are grown next to each other (Khan & Zirill, 2005b).

The second major area of achievement was the explicit linkage of the increasingly sophisticated biophysical information into the design of economic instruments. In particular, the information about recharge at the farm scale and the shared common property aquifer scale were linked through the investigation and definition of a cap-and-trade approach that could create individually defined property rights to recharge. This approach uses the biophysical information and models developed to convert diffuse source recharge to common property shared aquifers into individually owned shares that are estimated at the paddock scale as a proxy for a point source. The proposed property rights define recharge management as an environmental service. These structures were further refined into a framework for recharge trading described in Appendix 1.

An important objective in policy selection is to identify which policies are likely to be more effective or efficient than the available alternatives. Effectiveness in targeting recharge outcomes is achieved by targeting the incentives as closely as possible to the cause, in this case recharge. Efficiency requires achieving the desired outcome at lower cost than the alternatives. The economic modelling indicated that a cap-and-trade model is the most efficient amongst those tested. However, the cap-and-trade model does not deliver a large benefit over and above doing nothing and accepting the costs of salinity and waterlogging. The economic analysis excluded non-monetary benefits and the transaction costs of implementing and administering a cap-and-trade policy. Furthermore, uncertainty remains about some of the biophysical parameters. However, the economic analysis proved robust to a number of sensitivity tests.

The economic analysis also provided estimates of the gains from trade in a cap-and-trade market and predicted market clearing prices. That is, the economic analysis provided indicative prices for recharge credits assuming full compliance and optimal trading under the scheme. Both prices and gains from trade were further explored in experiments designed to test assumptions about how markets would function including the extent to which the gains from trade would be realised and the market clearing price. The experimental outcomes supported the estimated market clearing price but, as expected, found that less than half of the available gains from trade were realised. The expectation that the market mechanism tested would not realise the full gains from trade was based on previous experience and because the market structure employed did not allow repeat offers within individual trading periods.

The experimental tests provided a robust framework for testing recharge markets directly with stakeholders, in this case with Coleambally Irrigators. The results from field tests and simulation trials are comparable with the experimental results and would allow broader education and pre-testing of markets prior to implementation. Unfortunately social and political considerations within the region caused by the drought and water reform process restricted the amount of testing that could be undertaken directly with stakeholders. This is the only area that the pilot did not achieve the full objective of identifying ways to engage successfully with stakeholders to achieve management change. Despite this weakness the project has delivered extensive information to the Coleambally community about the management options available and the development of appropriate policy options to move recharge management forward in an effective and efficient fashion.

7.2.2 Factors underpinning the successful investigation of the cap-and-trade approach to recharge management

The critical factor underpinning consideration of a cap-and-trade approach is definition of an appropriate property right on which to base individual responsibilities. This applies not just to the legal authority to issue and monitor a property right, but especially to the definition of a cost-effective metric. In the case of recharge management the metric facilitates conversion of diffuse source recharge to point source recharge at the paddock scale, for which responsibility can be allocated to the land manager. SWAGMAN Farm provided the necessary measurement framework. Application of the SWAGMAN Farm based metric as a concept is robust but does require validation at the farm scale.

Our research emphasises the importance of undertaking a robust and comprehensive analysis of the design features that would need to be incorporated into the cap-and-trade policy. This comprised the initial exploration of a cap-and-trade approach to recharge management and the experiments conducted on alternative institutional frameworks. The initial analysis highlighted a number of design issues of importance including the definition and measurement of property rights, linking market features to biophysical constraints, and parameters such as setting targets, allocation of rights, impact of stochastic climatic variation, setting up robust administrative frameworks, and the impact of potential market impediments such as thin markets and penalty regimes. A key finding also relates to the apparent feasibility of introducing a cap-and-trade scheme for what is essentially a diffuse source pollutant. The apparent feasibility in this case rests on recent developments in science and a pre-existing platform to leverage off (that is, water supply contracts).

Finally, the analysis highlighted the role of a robust economic analysis in policy selection. MBIs may not always be better than other options or doing nothing, and in this case the conclusions from the economic analysis do not support the adoption of a cap-and-trade approach in the form originally envisaged. The economic analysis also gives additional insight into the reasons for this conclusion, therefore facilitating informed policy development.

7.2.3 Conclusions for future cap-and-trade applications

The conclusions for future cap-and-trade applications are split between those applying to recharge management and cap-and-trade applications more generally. As indicated the potential gains from trade that were modelled in this project are lower than initially expected and sufficiently small to warrant caution in adopting a cap-and-trade approach in the CIA. The gains from trade are determined by both the aquifer dynamics which determine the biophysical payoffs from alternative management actions, and the differences in economic returns amongst management options. The CIA is unusual in the southern Murray Darling Basin in that nearly all water is used on annual crops. Furthermore, the CIA is relatively distant from rivers with relatively little salt export downstream through either surface or sub-surface flows compared to most irrigation areas. The gains from trade may be larger and therefore a cap-and-trade approach more desirable for systems closer to rivers or with greater variation in water use.

Two conclusions were drawn relating to cap-and-trade applications more generally. First, a cap-and-trade market is fundamentally different to price-based approaches, or even many other quantity-based approaches such as offsets. A cap-and-trade market is designed to be a new, stand alone market. The market results from the allocation of property rights and the commensurate responsibilities attached to property rights. In this case, the property rights relate to recharge and the responsibilities relate to managing irrigation within the recharge rights held. The allocation of property rights may impose both costs and benefits on irrigators. This is in contrast to auctions and positive price-based approaches which effectively assume that property rights are already held by landholders. Thus cap-and-trade approaches are perceived to be, in part, a contest about who holds the property rights! That is, price-based mechanisms generally recognise de-facto property rights while cap-and-trade may restrict rights. Furthermore, the metric will be subject to a greater level of debate because it may impose penalties for continuing business as usual rather than allocating rewards for changing management. Therefore, it is likely that cap-and-trade approaches will take longer to implement than auctions and similar approaches because confidence must be built in the metric and supporting institutional frameworks.

Second, biophysical information is critical. The irrigation recharge issue is well known and a number of models had already been developed to aid in recharge management that could be adapted to the cap-and-trade framework. The available biophysical information indicated the high level of complexity in developing an appropriate cap-and-trade framework. However, designing effective institutions to manage recharge remained an issue. For example, we expected spatial complexity based on previous applications of the cap-and-trade approach to atmospheric pollutants and nutrient management in the US. We also anticipated that climate driven stochastic variability would be an issue that may drive gains from trade through banking and borrowing arrangements. Despite the knowledge about spatial and stochastic factors, the interaction between stochastic rainfall events, biophysical outcomes, and thresholds proved difficult to deal with in the project.

7.2.4 Broader conclusions for MBI development and implementation

We drew a number of broader conclusions for MBIs. These relate to metric development, designing institutions to cope with stochastic climatic events in NRM, developing outcome based environmental policy, the potential for evolution towards MBIs, and the availability of experimental economics skills.

Metric development and incorporation of stochastic climatic events were discussed in the sections 7.2.2 and 7.2.3. The conclusions drawn in those sections can be extrapolated here. In brief, metrics are often hard to construct, and communities may be reluctant to accept them. Furthermore, coping with stochastic variability can be critical to designing and delivering effective instruments. Nevertheless metrics are critical to the overall process of designing effective MBIs that provide outcome-based incentives for improved environmental management. Our conclusions reinforce the importance of biophysical scientists working with economists and other professionals to design and deliver effective instruments.

Two broad conclusions can be drawn from our research for developing outcome based environmental policy. First, focusing on outcomes may drive most of the benefits from policy rather than an explicit focus on the gains from trade. By focusing on outcomes we mean that incentives should be designed to focus on achieving the desired outcome which will deliver many of the benefits from innovation in achieving outcomes more efficiently through time. The experimental findings clearly show that a large proportion of the gains from trade accessed during the experiments resulted from the outcome focus through information and communication treatments.

Second, while adoption of a MBI may not be immediately possible due to political, social or other constraints, the focus on an outcome oriented policy may facilitate evolution of institutions towards more efficient structures through time. This has been the case for example with pollution taxes in NSW that introduced load rather than concentration based regulatory limits. With the establishment of load limits across regulated point sources, the ‘currency’ for trading pollution abatement effort has been established, and a number of pilot trading schemes have subsequently been launched. This could also be the case if outcome based rice quotas were adopted in the CIA.

The final broad conclusion for MBI development and implementation relates to the skills and expertise required. While a number of skills critical to MBI development are in short supply in Australia, perhaps the most critical is the small pool of applied experimental economists. A shortage of these skills proved to be the most critical faced during the project and caused significant delays in achieving milestones in this area. While the project team has now largely overcome these shortages these skills remain scarce across Australia and are likely to severely constrain experimental pre-tests supporting future MBI development and implementation.

8. Discussion and conclusions

8.1 Project conclusions

Project conclusions relate to Coleambally specifically and more broadly to development of cap-and-trade approaches and MBI development.

A cap-and-trade approach is a technically feasible and sound approach to recharge management in the CIA. Appropriate institutions can be defined that convert diffuse aquifer recharge to individual point sources. Appropriate targets can be set for recharge management and these are backed up by defendable metrics at the region (target setting) and individual (property right measurement) scales. The development of a cap-and-trade approach to recharge management is permitted by the advances made in the underpinning biophysical science and careful application of theory to the CIA context as well as a pre-existing platform that could be leveraged off (water supply contracts)..

Economic analysis of the cap-and-trade approach indicates that while it would promote the most efficient suite of management practices for achieving recharge management outcomes, the benefits over doing nothing may be relatively small.

Finally, experimental economics proved to be an extremely useful tool for informing and pre-testing institutional design. These pre-tests confirmed the findings from the economic analysis and reiterated the importance of information and property right structures in managing net recharge within the CIA.

8.2 Opportunities for further research

8.2.1 Specific to Coleambally policy development

A number of specific opportunities for further research with respect to CIA policy development were identified during the project. These included: the scale of costs and benefits from changing management; the importance of heterogeneity amongst individuals in driving the gains from trade; developing appropriate institutional support to encourage improved recharge management; and dynamic economic modelling to support policy choice.

The economic modelling within the project was restricted to the on-farm costs and benefits from implementing a cap-and-trade approach. Hence, off-farm costs to ecosystem services and infrastructure were not included, nor were the downstream impacts of continuing BAU. These costs are likely to be significant because important local biodiversity areas contained in wetlands and surrounds are often the first threatened by rising water tables while roads and bridges are major community infrastructure that are likely to be impacted.

The economic modelling was based on the biophysical differences between farms including water allocations, soil types and the impact of the rice area restrictions (rice quota). There are likely to be additional sources of variation between irrigators driven by individual preferences including knowledge about alternative cropping systems, skill base and farm management goals. For example, the farm case studies provided evidence that some irrigators would be reluctant to alter their system to include animal production due to the additional labour requirements and different skills needed. Previous studies, such as evaluations of the SO_2 markets in the US have found that the individual variation is significantly larger than anticipated and substantially enhances the available and actualised gains from trade (NCEE, 2001).

A major issue in the voluntary adoption of a cap-and-trade framework as initially envisaged in the CIA is community acceptance of both the need for change and the vehicle for change. Little is known about designing mechanisms for facilitating acceptance of change processes of about how to design institutions that may evolve towards more efficient structures through time.

Finally, the analysis of a cap-and-trade approach in Coleambally was undertaken in isolation of what is occurring in other irrigation communities. Imposing a cap-and-trade framework on Coleambally would increase the costs of production and, although protecting future production, would increase costs and reduce competitiveness relative to other irrigation areas. A more dynamic approach would link water rights, water price, and recharge management thus integrating issues beyond the CIA. However, the costs of such an approach may outweigh the benefits, particularly if the costs of managing recharge are envisaged to be similar in other regions.

8.2.2 Wider MBI research issues

Three broader issues were identified as important areas for future research from the project, not all of which are restricted to MBI development and implementation.

First, the impacts of biophysical thresholds are poorly defined in both a biophysical and institutional design setting. In a biophysical setting it is important to identify and quantify the impacts of thresholds in order to determine their impacts on the desired outcome. The biophysical quantification feeds into any economic analysis of the costs and benefits of alternative policy approaches. Ideally, probabilities can be attached to the quantified magnitudes of change caused by breaching biophysical thresholds. The economic analysis can then be used to guide instrument design in order to avoid thresholds or any modifications to institutions in response to the potential presence of thresholds.

The second area of research relates to the transaction costs associated with alternative policy approaches. The scale of transaction costs can be important to the recommended policy conclusions. For example, it was considered likely that the transaction costs would outweigh the net benefits generated by a cap-and-trade approach compared to doing nothing within this project. However, relatively little is known about the scale of transaction costs under alternative policies. A related issue is identifying ways that allow greater proportion of the potential gains from trade to be realised. As demonstrated in this project, the realised gains from trade are likely to be substantially smaller than the potential gains from trade. Alternative institutional designs may provide improved ways of realising the gains from trade.

Finally, many communities may not yet be willing to adopt MBIs but may be willing to consider outcome focused instruments with the potential to evolve into MBI forms in the future. As an example, consider the path of evolution of the Hunter River cap-and-trade program to manage mining and power plant saline discharges. Investigation into potential metrics for a trading scheme led to an output based regulatory approach, that has provided greater benefits than trade activity in the early years of the scheme. There may be mechanisms that can be set in train at a low cost that will lead towards a cap-and-trade approach in the future.

References

ABARE (Australian Bureau of Agricultural and Resource Economics) (2001a) *Alternative policy approaches to natural resource management*, ABARE, Canberra.
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.
Khan, S. (2000) Irrigation: Getting the balance right. CSIRO's Research Project Sheet No. 11 (http://www.clw.csiro.au/staff/khans/index.html).

CSIRO (2005) Off- and on-farm savings of irrigation water: Murrumbidgee valley water efficiency feasibility project, Commonwealth of Australia.

Easter, K. W.; Dinar, A., and Rosegrant, M.W. (1998) 'Water Markets: Transaction Costs and Institutional Options'. Easter, K. W.; Rosegrant, M. W., and Dinar, A. Markets for Water: Potential and Performance. Boston: Kluwer Academic Publishers; pp. 1-33.

Edraki, M, Smith D, Humphreys E, Khan S, O'Connell N, and Xevi E (2003) Validation of the SWAGMAN® Farm and SWAGMAN® Destiny models. CSIRO Land and Water Technical Report 44/03.

Faeth, P., (2000) Fertile Ground: Nutrient Trading's Potential to Cost-effectively Improve Water Quality. World Resources Institute, Washington, DC (pubs.wri.org/pubs_alpha.cfm).

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), pp. 761-777.

Hockenstein, J.B., Stavins, R.N., and Whitehead, B.W., (1997) 'Crafting the Next Generation of Market-Based Environmental Tools.' Environment, pp. 39:13-20 & 30-33 (ksghome.harvard.edu/~.rstavins.academic.ksg/cvweb.html).

Khan S. and Zirell J. (2005b) Cropping Options to Maintain Watertable and Salinity Levels for Spatially Variable Regional Groundwater Flow Capacities, Charles Stuart University Consultancy Report.

Khan S., Connell N. O' , Wang Z., Robinson D. and Xevi E. (2002) Environmental Concepts and Models for Participative Management of Irrigation Areas – Applications in the Murray Darling Basin. Irrigation Advisory Services and Participatory Extension in Irrigation Management Workshop organized by FAO – ICID. Montreal, Canada. Paper No. 2.

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

Khan S., Xevi E., and Meyer W. S. (2003) ‘Salt, Water and Groundwater Management Models to Determine Sustainable Cropping Patterns in Shallow Saline Groundwater Regions.’ Journal of Crop Production, pp. 325-340.

Khan S. (2000) SWAGMAN® Series, Research Project Information from CSIRO land and Water, Sheet No.22 October 2000.

Khan S. and Ginns T. (2003) Sustainable Irrigation Tools. Farmers Newsletter, Large Area Edition, No. 164, pp. 30-31.

Khan S. and Zirell J. (2005a) Water and Salt balance of the Coleambally Irrigation Area, Charles Stuart University Consultancy Report.

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.

Murtough, G., Aretino, B., and Matysek, A., (2002) Creating Markets for Ecosystem Services. Productivity Commission Staff Research Paper, Ausinfo, Canberra (www.pc.gov.au/research/staffres/cmfes/index.html).

NCEE (2001). The United States Experience with Economic Incentives for Protecting the Environment. National Center for Environmental Economics, office of Policy, Economics, and innovation, Office of the Administrator, U.S. Environmental Protection Agency, Washington, DC 20460.

National Wildlife Federation (1999) A New Tool for Water Quality: Making Watershed-Based Trading Work for You *(* www.nwf.org/watersheds/)

Newell, Richard G., James N. Sanchirico, and Suzi Kerr (2004) "Fishing Quota Markets" Journal of Environmental Economics and Management. Resources for the Future, Discussion paper 02-20.

Organisation for Economic Co-operation and Development (2001). Domestic Transferable Permits for Environmental Management: Design and Implementation. Paris, OECD (oecdpublications.gfi-nb.com/cgi-bin/OECDBookShop.storefront/EN/product/972001071P1)

Ostrom, E. (1998). ‘A behavioural approach to the rational choice theory of collective action.’ American Political Science Review, vol. 92, No 1, pp. 1-22.

Soil Conservation Service (1986), Urban Hydrology for Small Watersheds, U.S. Dept. of Agriculture, Soil Conservation Service, Engineering Division, Technical Release 55, Washington, DC.

Smith V., (1982) ‘Markets as economizers of information: experimental examination of the hayek Hypothesis.’ Economic Inquiry; 20 (2), pp. 165-179

Smith V. L. (1987) Auctions. In The new Palgrave; Eatwell, J., Milgate, M. and Newman, P. (eds), vol 2 pp 39-53. London; Macmillan.

Smith V. L. (2002) ‘Method in experiment: rhetoric and reality.’ Experimental economics, 5, pp. 91- 110.

Stavins, R.N., (2000) Experience with Market-Based Environmental Policy Instruments. Resources for the Future Discussion Paper 00-09 (ksghome.harvard.edu/~.rstavins.academic.ksg/cvweb.html)

Tisdell, J., Ward, J and Capon, T. (2004) ‘Impact of communication and information on a heterogeneous closed water catchment environment.’ Water Resources Research, 40, (9) W09S03.

United States Soil Conservation Service. (1986) Technical Release 55: Urban Hydrology for Small Watersheds. U.S. Department of Agriculture.

Whitten, S.M., Salzman, J., Proctor, W. and Shelton D. (2003) Markets for Ecosystem Services: Applying the concepts, RIRDC.

SWAGMAN Farm (online version): www.colyirr.com.au/swagmanfarm/Default.aspx

Appendix

Appendix 1 – A Framework for net recharge trading

Quick reference glossary

Liable party	An individual in a scheme *zone* receiving irrigation water from CICL who nominates to participate in the scheme.
Entitlements	0.1 ML volumetric units of net recharge allocated to liable parties according to the allocation rules. They will be allocated annually, have a life of seven years and be tradeable.
Credits	Accredited 0.1 ML volumetric units of net recharge reduction that would not otherwise be counted towards the net recharge performance of the liable party. They have a life of seven years and are tradeable.
Zones and sub-zones	Unique geographic sub-areas of the CIA relating to unique aquifers and net recharge management goals.
Register	Official record of ownership of entitlements and credits held by CICL or their representative.

Definitions of participants

Liable Parties	In any given year, an individual holding a water supply licence for a property in a scheme *zone*, and where the individual nominates to participate in the scheme. While there would be no minimum irrigation water volume for inclusion in scheme, expect very small irrigators to ignore '*concessional water charges'* rather than bear costs of scheme participation. Additional revenue received could be applied by the irrigation company to buy-back *entitlements* or purchase *credits* and therefore achieve net recharge abatement on behalf of the smaller non-participants.
Regulator	The irrigation company or their representative is the scheme administrator and will regulate compliance through licence activities. Participation in the scheme is voluntary, but it is anticipated that the incentive of concessional water prices will encourage a high level of participation.

Definition of recharge rights

Recorded net recharge	This is the net recharge to groundwater in a given year for a given property as estimated via agreed SWAGMAN model and as described in a separate paper describing the modelling framework, assumptions and data, including the source of property level data, verification procedures and so on, this is what drives asset values so needs to be tight and a secure system. The estimation of recorded net recharge may be adjusted using pre-determined weights to reflect differential impacts associated with net recharge in sub-zones.
Zones	Geographic areas relating to unique aquifers and net recharge management goals. Separate liabilities and sustainable net recharge targets will apply in different *zones*.
Sub-zones	Geographic areas within zones with differential impacts on aquifers. These zones will have different weightings applied to the recorded net recharge reflecting the target (externality impact) for that sub-zone. For example, if the externality impact is double within a sub-zone then individuals will have to abate twice as much net recharge as other properties to achieve the same outcome and the weighting would be 0.5.

Setting the cap

Zone sustainable net recharge	Based on groundwater modelling, the sustainable volume of net recharge (ML) per zone will be estimated. Its derivation will be linked to irrigation area net recharge management goals, which in turn are linked to its bulk water supply licence, catchment targets, and, local management goals.

Application of the cap at the individual scale

Individual liability	Where a liable party nominates to participate in the scheme, and on an annual basis, *recorded net recharge* on the specified property must be less than or equal to 110% of the net recharge *entitlements* and *credits* surrendered for that property in that year if they wish to pay concessional charges for irrigation water supplied to that property.
Non-compliance carry over	Where in any year the recorded net recharge is greater than the net recharge entitlements or credits surrendered, the difference is subtracted from the individual's entitlement allocation in the following year. Where a liable party participating in the scheme fails to provide the necessary property-level information to allow calculation of recorded net recharge or access to the property to allow auditing of the information, all entitlements held by that party will be cancelled and the net recharge volume of any entitlements sold will be recorded as carryover. Where a liable party 'opts-out' of the scheme in any year, no recorded net recharge is determined, and any carry-over is carried forward indefinitely until the liable party opts-in. 'Opt-outs' must pay non-concession prices.
Net recharge entitlements	Individual tradeable net recharge entitlements will be created in units of 0.1 ML and allocated to liable parties on an annual basis according to the entitlement allocation

	rules below. Separate entitlements will be created for each zone and will not be transferable between zones. Liable parties may surrender net recharge entitlements to CICL or their representative to offset actual net recharge and assist compliance with their liability under the scheme. Entitlements not surrendered within 7 years of issue will expire and cannot be used to offset compliance.
Number of net recharge entitlements	For each zone = the zone's *sustainable net recharge* (in ML) x 10. Each of these entitlements will have a unique identifier. This identifier will allow tracking of ownership and facilitate trades. That is, there will be a fixed recharge target (subject to review after 5 years) and number of annual entitlements issued, with the following exception: According to pre-determined benchmarks, the number of net recharge entitlements issued in any year may be adjusted to reflect very wet or dry years. This will prevent an irrigation drought in very wet years and ratchet back some net recharge in very dry years where allowable net recharge would otherwise be easily met – these should be designed to largely offset each other over the long-term. The rules for these exceptional circumstances will be clearly specified.
Allocation of net recharge entitlements	To be determined. Some considerations include: 1. Whether 'rights' to a stream of annual entitlements (either fixed number or proportional share) are allocated or whether entitlements are allocated on a yearly basis according to scheme rules – the latter may be complicated by ownership changes. 2. Allocations could be grandfathered under yet to be determined rules. 3. The irrigation company will hold an entitlement reserve with the intention to sell at market prices and hence to provide liquidity. Revenue from reserve sales could be dedicated toward credit generation to help ensure future market liquidity. 4. No entitlements will be allocated after year 1. This means new entrants must buy-in to the scheme in order to receive concession prices. This will prevents rorting via ownership transfer but the irrigation company reserve will maintain liquidity for buy-in. 5. Any phase in of entitlements will need to be considered here. 6. No entitlements will be issued, nor landholder participation in the scheme and access to concessional water charges be allowed, where the non-compliance carry-over exceeds 10%. A landholder may reduce the carryover at any time through surrendering *net recharge entitlements or credits*.
Banking and borrowing of entitlements and credits	Banking will be allowed but not borrowing. This is because the 10% carry-over without affecting compliance is essentially borrowing. The seven-year entitlement and credit life will limit the effective maximum that can be banked.

Underpinning institutions

Register	Ownership and trade of entitlements and credits to be recorded on register held by the irrigation company or their representative and publicly accessible. The irrigation company or their representative may impose a small administration charge on a cost recovery basis for recording ownership changes.
Concessional water charges	A new regime of charges for irrigation water delivered by the irrigation company will be introduced concurrently with the commencement of the scheme. General charges will increase to incorporate an externality charge reflective of the groundwater / salinity damages associated with unsustainable water use. Concessional water charges will be available for irrigators in any year where they nominate to participate in the Scheme and where they comply with their liability in that year. The premium between general charges and concessional water charges will be used to either conduct abatement activities on behalf of non-participating individuals or purchase net recharge entitlements or credits on their behalf in the market (Any entitlements or credits bought or generated for this purpose must be retired and cannot be resold).
Monitoring and auditing	Liable parties will need to provide the necessary property-level information to allow calculation of recorded net recharge. This data will be defined consistent with the SWAGMAN model to estimate net recharge. The irrigation company or their representative will conduct a monitoring scheme that will involve a combination of remote sensing and on-farm compliance audits to verify this data where necessary. This will include a requirement for the irrigation company or their representative to have access to the property to allow auditing of the information. Access may require reasonable suspicion or something similar and will certainly require reasonable notice. The costs associated with monitoring and auditing should be paid from water charges, as management of net recharge is a condition of the irrigation company water supply licence.
Five yearly review	The five year review will include coverage of the following issues: 1. Scheme performance (compliance and effectiveness in achieving regional targets, level of participation, level of individual compliance, extent of trades, extend of net recharge credit generation, efficacy of monitoring and auditing); 2. Hydrological relationships within and between zones as well as overall zone and sub-zone targets; and 3. Options for refining the scheme.

Provisions for trade

Trading of net recharge entitlements and credits	Net recharge entitlements may be freely traded between liable parties and between liable parties and CICL. Both parties will need to notify CICL or their representative of the unique identifier of the net recharge entitlements or credits traded. Ownership changes come into force once recorded on the *Register.* All trades will be subject to restrictions on individual recharge entitlements.

Provision for offsets

Net recharge credits	Where actions bring about reductions in net recharge in a zone included in the scheme, and where that net recharge would otherwise not be counted towards the net recharge performance of a liable party, the party responsible for that action may seek accreditation of the net recharge reduction. Net recharge credits, expressed in ML and rounded down to the nearest 0.1 ML, will be transferable to liable parties and the irrigation company, and liable parties may surrender credits to the irrigation company to offset recorded net recharge and assist compliance with liabilities under the scheme. Credits will have a lifespan 7 years (for consistency).
Accreditation of Credits	The irrigation company or its representative will be responsible for accrediting credits; they will have total discretion as to when and which nominated activities they may investigate however information on these should be publicly available. Credits will only be granted where net recharge reductions have been realised; credits will be entered onto the entitlement register. The irrigation company or their representative may impose a small charge for accreditation on a cost recovery basis.

Appendix 2 - Whole of the System Water Balance for CIA (All values are in GLs)

	2003/04		2002/03		2001/02		2000/01		1999/00		1998/99	
	IN	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
SUPPLY												
Diversions (river)	362.1		472.1		603.7		599.1		466		561	
Rain on supply	0.7		0.3		0.5		0.7		0.9		0.7	
Groundwater	33.1		45.6		35.4		22.6		31.7		28.7	
Channel seepage		15		15		15		15		15		15
Channel evaporation		14.8		16.8		15.4		14.3		13.7		14
SW Deliveries (CIA farms)		231		293.3		375.6		375.6		295		355
GW Deliveries		33.1		45.6		35.4		22.6		31.7		28.7
Channel filling		11		11		11		11		11		11
Esc/unexplained		44.6		60.7		62.4		45.9		31.1		64.3
RAINFALL												
Rainfall	399.3		158.2		314.6		400.2		521.6		449	
Rain on supply		0.7		0.3		0.5		0.7		0.9		0.7
Rain on drains		0.9		0.3		0.7		0.9		1.1		1
Rainfall runoff		36.8		0.2		15.8		37.1		78.1		52.2
DRAINAGE												
Rain on drains	0.9		0.3		0.7		0.9		1.1		1	
Irrigation Runoff	11.6		14.7		18.8		18.8		14.8		17.8	
Esc/unexplained	44.6		60.7		62.4		45.9		31.1		64.3	
Channel empty	11		11		11		11		11		11	
Rainfall runoff	36.8		0.2		15.8		37.1		78.1		52.2	
ET drains		4		4		4		4		4		4
Drainage in Creeks		99.8		81.8		103.6		108.6		131.1		141.2

Seepage in Drains		1		1		1		1		1		1
SHALLOW GW												
Channel seepage	15		15		15		15		15		15	
Recharge	34.4		32.2		52.8		52.6		54.8		52.9	
Seepage from Drains	1		1		1		1		1		1	
Deep Leakage		30		30		30		30		30		30
Lateral Outflow		15		15		15		15		15		15
Capillary Rise		11.2		3.0		32.3		23.0		23.5		29.3
Watertable Change		-5.8	0.2			-8.5	0.6		2.3			-5.4
DEEP GW												
Deep leakage	30		30		30		30		30		30	
Lateral outflow		20		20		20		20		20		20
Deep pumping		33.1		45.6		35.4		22.6		31.7		28.7