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Technical Report No. 03/07

Optimised Irrigation Productivity and River Health through Pick & Mix Strategies

Catchment Water Cycle Management, Alternative Cropping Systems, Real Water Savings and Aquifer Storage and Recovery

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CRC for Irrigation Futures

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Acknowledgements

The authors wish to acknowledge inputs from the Pratt Water Study in the Murrumbidgee Valley.

Executive Summary

This report summarises the findings of an irrigation-river system analysis aimed at investigating the ramifications of introducing water demand management strategies to modify river flows, so that they more adequately replicate natural flows in the river while enhancing the overall productivity of the irrigation systems.

To achieve this aim, the project focused on the following specific objectives:

- To identify opportunities to modify irrigation system demand and supply parameters through improved on- and off-farm infrastructure management, changed cropping mixes, potential ground water substitution and trading options;
- To assess the wider economic, environmental and social impacts of these change management strategies;
- To obtain community feedback on the value of these options in meeting the economic and environmental issues arising from the implementation of water reform in irrigated catchments;
- To achieve consensus between catchment stakeholders and scientists on future catchment scenarios and knowledge gaps; and
- To identify opportunities for joint CRC-industry research investments in future.

Project components

The project was divided into five main components: (i) system analysis (demand management & economics); (ii) harmonising the distribution system (iii) framework for assessing social acceptability of management options; (iv) social Benefit-Cost assessment; and (v) linking improved seasonality of flows with system harmonization

(i) *System analysis (demand management & economics)*

The main aim of this project component was to investigate the hydrological and economic consequences of introducing demand management measures for improving the seasonality of flows. In particular, to estimate the trade-off between replication of natural flows in the river and agricultural income under different irrigation demand management options.

(ii) *Harmonising the distribution system*

The main aim of this project component was to examine the current technological position of irrigation distribution in Australia with a view to determine opportunities for improving system harmonisation. As such, it was intended to scope three key knowledge areas: (1) Identification of flow control technologies in Australia, (2) review of state-the-art modelling in canal operation modelling; and (3) identification of opportunities for adoption of canal automation technology to improve harmonisation of the on-off farm interface

(iii) *Framework for assessing social acceptability of management options*

The main aim of this project component is to explore 'community' involvement in setting irrigation research agendas and evaluating water management options in the Murrumbidgee Valley. Particularly, to involve stakeholder in identification of possible demand management options from a range of options and gauge their acceptability.

(iv) *A social Benefit Cost method for assessing improved seasonality of flows through demand management*

The purpose in this study was to assess whether it was possible to estimate the social costs and benefits of irrigation. Such an assessment relied on completeness of the available information. In other words, the study focused on whether it was possible to specify all the costs and benefits of irrigation, or as many as possible, that would result in a reasonable estimate of the net present value of implementing a range of demand management strategies.

(v) *Linking improved seasonality of flows with system harmonization*

The main aim of this project component was understand how improved irrigation demand management can result in a harmonised (balanced) irrigation and environment catchment system.

Study area

This study was conducted in the Murrumbidgee valley of New South Wales. The Murrumbidgee River has a catchment area of approximately 84,000 km^2 and a length of 1600 km from its source in the Snowy Mountains to its junction with the Murray River. The main irrigation areas in the catchment are the Murrumbidgee Irrigation Area (MIA), Coleambally Irrigation Area (CIA) and the Lower Bidgee Irrigation Area. The study was confined to two irrigation areas, MIA and CIA. Major irrigated crops in both districts include grapes, citrus, rice, wheat, barley, oats, canola, soybeans, maize and sunflowers. Lucerne and pastures for sheep and cattle are also irrigated.

Stakeholders interaction for identification of demand management options

A range of irrigation demand management options were identified through the rigorous discussions with the key stakeholder groups in the region. Two key stakeholders' workshops were organised during the course of the project – one in Leeton in April 2004 and the other in Griffith in March 2005 - to discuss possible irrigation demand management options and their perceived benefits. The options include (i) market based reduction in surface water demand; (ii) conjunctive water use augmented by aquifer storage and recovery; (iii) spreading of water demand with improved cropping mix; (iv) increase conveyance efficiency (canal lining); (v) increase on-farm water use efficiency through water-saving irrigation technologies; and (vi) en-route storages.

On the basis of discussions with the stakeholders the most attractive options for managing peak summer water demand were conjunctive water use, en-route storages and improved cropping mix. The key criteria for success of the irrigation demand management options were demonstrable water savings and clear reduction in peak summer water demand.

Main findings and recommendations of the project components

System analysis (demand management & economics)

(i) Main findings at the farm level

- A hypothetical farm with total area of 440 hectares with 2695 ML of water, without any cropping restrictions, was considered for the farm level analysis of different irrigation demand management options.
- *Market based reduction in surface water demand:* The analysis of farm level impacts of market based reduction in water demand shows that compared to farm baseline profit for the year 2000/2001; a 10% decrease in water demand would reduce farm profit by almost 5% or $33,458 when compared with a baseline year. However, when surface water demand was reduced by 20%, farm income decreased by almost 12% or $78,973 when compared with a baseline year. Overall, with market based reduction of 10% and 20%

of surface water demand, a typical farm has an additional 222 ML and 443 ML of water respectively that can either be traded to improve the seasonality of flows or to grow alternative “higher value” crops.

- *Conjunctive water use (groundwater abstraction only):* Farm level impact of a decrease in peak water demand by 10% or 222 ML and increase in supplemental supply from groundwater shows a decrease in farm profit of almost 0.4% or $2,531 compared to baseline year. However, when surface water demand was reduced by 20% or 443 ML and the same amount of water was substituted from groundwater; the drop in farm income was only 1% or $6,498.
- *Conjunctive water use (injection/infiltration + extraction)*: A reduction in peak water demand by 10% and increase in supplemental supply of groundwater through Aquifer Storage and Recovery (ASR) shows a decrease in the farm profit of almost 1.4% or $8,828. Alternatively, farm income decreased by almost 2.7% or $17,716 when surface water demand was reduced by 20% and supplemental groundwater supply increased.
- *Spreading water demand with an alternate cropping mix:* The optimization result shows that with a 10% reduction in surface water demand the total farm income increases by about 1.7% or $10,794 with water saving of 222 ML/year. This translates into a reduction in peak summer water demand of 8.25%. However, 20% reduction in supply causes a reduction in farm income of 2.44% or $15,890. Importantly, the resulting water saving of around 443 ML per year can reduce the peak summer water demand by 16.5%.
- *Increased end use efficiency (Water saving irrigation technologies):* Two on-farm water-saving irrigation technologies -drip and sprinkler irrigation -, were selected for increasing on-farm water use efficiency. The farm-level analysis shows that due to reductions of surface water demand and adoption of on-farm water saving irrigation technologies, farm income dropped by 4.15% or $27,105. This, however, will save 416 ML of water which may used to reduce the peak demand by 15% and can effectively be traded.

(ii) Main findings at the system-level

- The regional impact was assessed by evaluating the impact of each demand management option on major crops and aggregating them for the MIA and CIA irrigation systems.
- The estimates show that the capital investment to line canals with bentonite is about $133,733/km which translate to $1,713/ML. An investment of $33 million/year is required for 20 years to save about 200 GL of water per year and improve conveyance efficiency to 85%.
- The estimated capital investment for three 50 GL storages and one 250 GL storage is approximately $75 million and $115 million, respectively, with an annual operating cost of about $2 million. This could reduce the peak demand by 119 GL (8.5%) and 203 GL (14.5 %) of water, respectively.
- The comparison among different possible demand management options shows that spreading water demand through improved cropping mix which matches with soil and climatic conditions is the best irrigation demand management option. The new crop mix shows a positive gain in agricultural returns of $5.49 million after the reduction of 10% demand of surface water while a loss of $4.79 million is incurred for 20% reduction in water demand.

- Conjunctive water use through more groundwater extraction or infiltration and extraction is also a realistic option capable of securing over 215 GL of water compared to 2000/2001 of water use with minimum cost to agriculture return. To secure 215 GL of water through groundwater extraction it would cost only $3.23 million in terms of reduced return from agriculture. While, it would cost around $8.96 million to agricultural for same 215 GL of water through the ASR development program.
- The most expensive option to recover additional water for environmental purposes is through canal lining because of high labour and material costs. However, this option is still feasible and capable of providing over 215 GL of water to satisfy the long term environmental demand.

(iii) Recommendations

- Improved cropping mixes should be encouraged while matching proper soil and climatic conditions. However, this may need structural adjustment and incentives to transform to alternative farm enterprises. Additionally, this needs to be supported by market development for alternative crops.
- A well coordinated and integrated management of the surface and groundwater resources would help to maximise conjunctive water uses.
- Canal lining and water-saving irrigation technology is also a viable option. However, it requires considerable private-public investment both off-farm and on-farm level. An accurate accounting system is needed to measure benefits and provide confidence in private investment decisions.
- Leasing water and preferential access rights may help remove barriers to the adoption of irrigation technologies, move farmers and irrigation area to next step of the irrigation efficiency ladder, reduce local and regional environmental impacts and secure water for better ecological futures.

Harmonising the Distribution System

(i) Main findings

- The analysis of various canal technologies shows that channel distribution systems in Australia still rely largely on traditional technologies for water control; and despite that new technologies developed both in Australia and overseas have become readily available in past decades, the level of adoption still remains low.
- The study reveals that the vast majority of Australian systems (78%) rely on open channels or a combination of open channels and pipelines for distribution of water to farmers. Only 22% of systems rely only on pipelines for water distribution. In terms of system capacity, open channels account for 94% of the systems surveyed. A similar picture emerges regarding the use of canal lining. A small proportion of main canal systems (2%) are lined. Concrete remains the main lining material despite new membrane materials becoming more available in recent years.
- Canal regulation is achieved mainly by a combination of overshot cross regulators on the main canal and undershot structures in lateral and spurs outlets.
- A large proportion (60%) of these main canal regulators is still manually operated. This figure is higher (64%) in secondary canal structures. 46% of the systems surveyed have equipped the main canal regulators with remote

control mechanised structures. This figures drops to 33% for secondary canals the incorporate some kind of remote control operation.

- There is increasing diversification in technology used for flow metering. Thirty nine percent of systems surveyed rely only on Dethridge meters. Magflow meters are used in 37% of systems surveyed in conjunction with an array of other metering devices. The adoption of new metering technology is driven by more accurate flow measurement and ability to use SCADA technology.
- A large proportion of irrigation providers (52%) surveyed have undertaken some form of infrastructure upgrade in the last 5 years which often includes some form of infrastructure refurbishment combined with channel automation. This figure increases to 60% of irrigation providers which plan to undertake system upgrades in the next 5 years.
- There is little evidence that sufficient monitoring and evaluation of system upgrades is carried out to determine whether these objectives are achieved. There is no evidence that actual on-farm and catchment impacts arising from canal automation are either identified or evaluated.
- A comprehensive review of canal operation models was also undertaken which reveals a wide array of computer models available to simulate the operation of canal systems. However, the use of these models still remains largely in the research domain.

(ii) Recommendations

- Canal automation together with modern control and communications technology represents the best and most obvious opportunity for advancing harmonisation of the three system domains: River, distribution and farm systems. Based on this, it is therefore recommended that various forms of canal automation technology available should be adopted.
- The future efforts in canal automation should emphasise the integration of the farm, distribution system and river system to maximise the benefits to agricultural production and provision of environmental in-stream requirements.
- As a matter of urgency, systematic research is necessary to evaluate the impacts of canal automation technology at farm, system and catchment levels of current pilot projects. Learned lessons from existing case studies can contribute to maximise the benefits and avoid mistakes in future canal automation projects.

Framework for assessing social acceptability of management options

(i) Main findings

- Social acceptability research, combined with hydrological and economic models, was found to be an effective way to evaluate the scope of different irrigation demand management options to improve seasonality of flows.
- Two key stakeholders' workshops were organised during the course of the project – one in Leeton in April 2004 and the other in Griffith in March 2005 - to discuss possible irrigation demand management options and their perceived benefits.
- The first meeting demonstrated the value of articulating assessment criteria when dealing with new and potentially disruptive options for management of irrigation demand in a catchment context.

- The assessment criteria developed at the first meeting were only approximations. As a consequence, a refinement of those criteria through meetings with different community members would be necessary for them to become a truly useful tool.
- It was evident from the two meetings that some options for improving seasonality of flows in rivers through irrigation demand management and harmonising irrigation systems with the environment were more acceptable to this group of community participants than other options
- Further, it could be concluded that this acceptability influenced what participants considered as worthwhile research to pursue. The most acceptable options for this group were those that involved changes to the delivery of water to the irrigation district and/or individual properties.
- The development and co-ordination of en-route storages and various processes for achieving conjunctive use of ground and surface water were seen to have the potential to produce some environmental enhancement with minimal disruption to the irrigation community.
- Options which had more direct and potentially negative impacts on individual farmers, such as spreading water demand with improved cropping mix, were not as acceptable to the meeting participants.
- However, even as a rough tool the areas of the different options that requires further work to make them more acceptable to the irrigation community are clearly articulated.

(ii) Recommendations

- Social acceptability theory emphasises the importance of understanding how judgements about whether to accept and adopt are made. To effectively gauge social judgement of different ideas it is recommended to follow a systematic and transparent process to move beyond immediate reflex reactions to new and risky ideas. Under the current project, only two meetings were possible, and only a few participants were able to be involved in the meetings. However, to effectively gain the trust of the key stakeholder there should be frequency meeting with the key stakeholders. So as a technique for future development of projects that communities may not first seems hostile to it and shows some promise.

A social Benefit Cost method for assessing improved seasonality of flows through demand management

(i) Main findings

- It would appear that obtaining reasonable estimates of the private benefits of distributing water through an irrigation scheme is possible. However, even crude estimates of the environmental returns would not appear to be possible at this stage.
- It was found that in MIA and CIA agriculture contributed $1,475 million and recreation contributed $21 million.
- Obtaining reasonable estimates of the private costs of supplying irrigation water would seem possible. However, estimating the public costs would appear to be more difficult than obtaining the public benefits of irrigation. While some costs could be determined using the amounts spent on containing it, such estimates are quite limited.

- The salvage value and that of hydro-electric power generation were not considered. The cost of supplying water was estimated to be $21.4 million, while foregone production accounted for $86.5 million and the opportunity cost of water was calculated to be $23 million. This results in net private benefits from irrigation of $1,365.4 million.
- The net private benefits do not include the costs of constructing the schemes (as they are sunk), or the public costs and benefits of irrigation. It was found that reasonable estimates of the public benefits and costs would be difficult, if not impossible, to obtain.
- The large net private benefits derived from irrigation provide some scope to implement a range of demand management strategies. The strategies reviewed in this study range from increasing water efficiency through to changing water demand. The problem arises in the sense that those who lose from implementing a measure are not those who gain. In other words, it is more likely that a potential Pareto improvement could be possible.

(ii) Recommendations

- Initially, the study proposed a social Benefit Cost analysis for evaluating irrigation demand management options. However, given the difficulties in valuing ecosystem services to some extend measuring environmental costs, Cost Effective Analysis (CEA) maybe best suited for this study. The CEA is best suited for the studies where ecosystem services can not be determined accurately.
- To value ecosystem services, a residual method in the valuing process could be employed. However, it should be noted that such an approach is inadequate as all unaccounted for activities would be considered to be an ecosystem service. Despite this, it may provide a good proxy for valuing said services. The need for finding a proxy valuation technique arose because the existence of ecosystem services defies normal valuation techniques. In particular, no markets exist for them.

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Glossary of Acronyms

ANCID	Australian National Committee on Irrigation and Drainage
ASR	Aquifer Storage and Recovery
CEA	Cost effective analysis
CIA	Coleambally Irrigation Area
CRC IF	Cooperative Research Centre for Irrigation Futures
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Crop water requirement
GL	Giga litre
MAR	Managed Aquifer Recharge
MIA	Murrumbidgee Irrigation Area
ML	Mega litre
RIBP	Regional Irrigation Business Partnerships
SHARP	System Harmonisation for Applied Regional Planning

1. Overview of Project

1.1 Introduction

In Australia, rivers are regulated to principally provide water for agriculture. This act of moving water in time and space has had both favourable and unfavourable environmental impacts. Most obviously, the impact has been favourably seen in agriculture where a variety of activities that were impossible in the absence of water are now possible. Less favourable impacts have been felt on river health. The very act of regulating rivers has resulted in the hydrograph of the river becoming inverted. The highest flows now occur in the summer period, to meet the needs of irrigators while the lowest flows occur in the winter and spring, when the storages refill (Figure 1). In the southern Murray Darling basin rivers once flooded naturally in spring and were dry in summer. Now, due to regulation, they are dry in spring and flooded in summer. What has been favourable for agriculture has led to unfavourable conditions for the natural environment. Maintaining a healthy river environment in terms of rate, temporal variability, volume over season − seasonality of flow through the allocation and management of water resources has become a big challenge for policy makers, one in which they must balance with the competing demands of the irrigation industry.

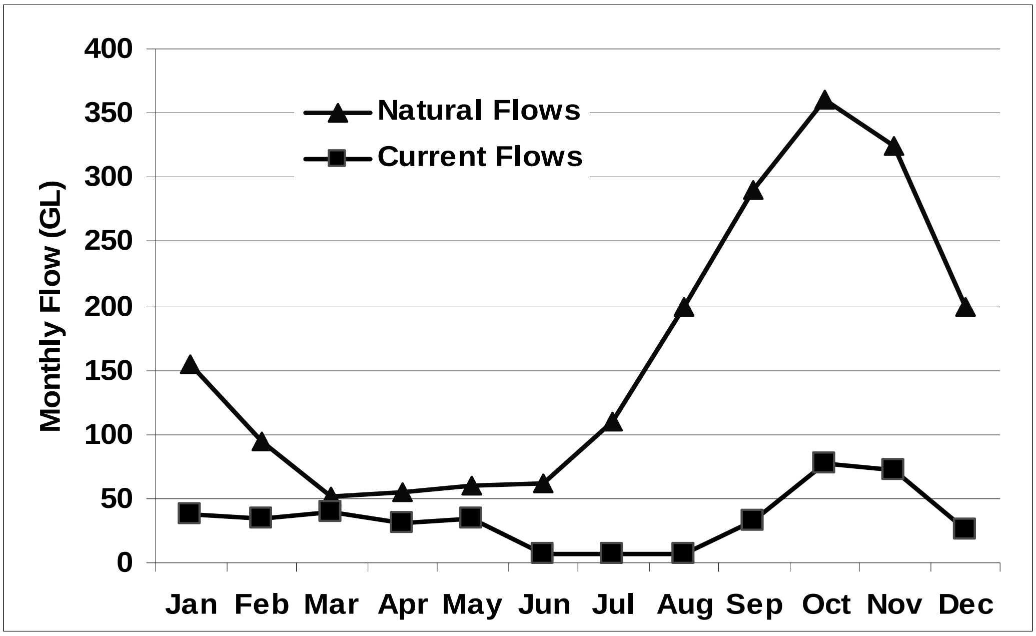

Figure 1. 100 years monthly average of current and natural flows at Balranald Murrumbidgee River

The fundamental question is how this seasonality of flow − rate, temporal variability, seasonal volume − can be partially restored to mimic natural flow regimes? The traditional approaches for securing environmental flows aimed to recover volumes of water include; (i) reducing allocations to irrigators without compensation; (ii) buy water, by providing compensation or purchase on the open market; or (iii) save water, by improving infrastructure to reduce losses from supply systems. These approaches involve high social and political costs for managing environmental flows, and do not address the seasonality of flow challenge.

An alternative to the above approaches for achieving better environmental outcomes, options which replicate the river's more natural hydrograph, maybe to improve the seasonality of flows using different irrigation demand management options to reduce peak summer demand for irrigation water by spreading demand over summer and winter periods. Reintroducing natural flow sequences through irrigation water demand management will reduce the ecological impacts that have resulted from too high and too less flows in rivers. In economic phraseology this case would result in a Pareto Improvement, which makes environment better off, without making agricultural worse off (Osborne and Rubenstein, 1994). However, it may take a truly integrated and cooperative approach at a range of stakeholders' level through water reform and demand management to contribute environmental, social and economic benefits.

The purpose in this report is to document the findings of a preliminary project on what could be done to improve the health of rivers by returning them to a more natural flow. While it is assumed herein that the environmental benefits of more natural flows are positive and desired, they are not quantified. Rather, the aim in this report is to assess the hydrological, social, on-farm and broader resource economic issues that arise from returning more natural flows to a regulated river system. In undertaking this task a number of techniques that could be employed to manage the demand are explored. It is concluded that 10% to 15% of peak water demand during summer can be reduced from the average total annual water demand of 1400 MCM. However, this may result in reduced agricultural return or require private and public investments in the form of on-farm water saving technologies, canal lining or construction of en-route storage. However, if we value the saved water at current market prices then benefits are expected to be higher than the costs involved.

1.2 Project goal and objectives

This project is a part of the "Smart System and System Harmonization" project. The main aim of this project is to investigate the ramifications of introducing demand management measures to modify river flows so that they more adequately replicate natural flows in the river.

To achieve this aim, the project focuses on the following specific objectives:

- To identify opportunities to modify irrigation system demand and supply parameters through improved on- and off-farm infrastructure management such as canal automation, changed cropping mixes, potential ground water substitution and trading options;
- To assess the wider economic, environmental and social impacts of these change management practices;
- To obtain community feedback on the value of these options in meeting the economic and environmental issues arising from the implementation of water reform in irrigated catchments;
- To achieve consensus between catchment stakeholders and scientists on future catchment scenarios and knowledge gaps; and
- To identify opportunities for joint CRC-industry research investments in future.

1.3 Project components

The project was divided into five main components: (i) system analysis (demand management & economics); (ii) harmonising the distribution system (iii) framework for assessing social acceptability of management options; (iv) social Benefit Cost assessment; and (v) linking improved seasonality of flows with system harmonization *(i) System analysis (demand management & economics)*

The main aim of this project component was to investigate the hydrological and economic consequence of introducing demand management measures for improving the seasonality of flows. Particularly, to estimate the trade-off between replication of natural flows in the river and agricultural income under different irrigation demand management options.

(ii) Harmonising the distribution system

The main aim of this project component was to examine the current technological position of irrigation distribution in Australia with a view to determine opportunities for improving system harmonisation. As such, it is intended to scope three key knowledge areas: (1) Identification of flow control technologies in Australia, (2) review of state-the-art modelling in canal operation modelling; and (3) identification of opportunities for adoption of canal automation technology to improve harmonisation of the on-off farm interface

(iii) Framework for assessing social acceptability of management options

The main aim of this project component is to explore ‘community’ involvement in setting irrigation research agendas and evaluating water management options in the Murrumbidgee Valley. Particularly, to involve stakeholders in identification of possible demand management options from a range of options and gauge their acceptability.

(iv) A social Benefit Cost method for assessing improved seasonality of flows through demand management

The purpose in this study was to assess whether it was possible to estimate the social costs and benefits of irrigation. Such an assessment relied on completeness. In other words, was it possible to specify all the costs and benefits of irrigation, or as many as possible, that would result in a reasonable estimate of the net present value of implementing a range of demand management strategies.

(v) Linking improved seasonality of flows with system harmonization

The main aim of this project component was understand how improved irrigation demand management can result in a harmonised (balanced) irrigation and environment catchment system.

1.4 Study area

This study was conducted in the Murrumbidgee valley of New South Wales (see Figure 2). The Murrumbidgee River has a catchment area of approximately 84,000 km2 and a length of 1600 km from its source in the Snowy Mountains to its junction with the Murray River. The geographic boundaries of the Murrumbidgee catchment include the Great Dividing Range in the east, the Lachlan River Valley to the north and the Murray River Valley to the south. The Murrumbidgee River originates in the Fiery Range of the Snowy Mountains approximately 50 km north of Kiandra. It flows in a south-easterly direction towards Cooma and then turns north through the Australian Capital and then west until it joins the Murray (Khan et al., 2004 a).

1.5 Stakeholders interaction for identification of demand management options

A range of irrigation demand management options were identified through the rigorous discussions with the key stakeholder groups in the region. Two key stakeholders’ workshops were organised – one in Leeton in April 2004 and the other in Griffith in March 2005; to discuss the possible irrigation demand management options and their perceived benefits. The options include (i) market based reduction in surface water demand; (ii) conjunctive water use augmented by aquifer storage and recovery; (iii) spreading of water demand with improved cropping mix; (iv) increase conveyance efficiency (canal lining); (v) increase on-farm water use efficiency through water-saving irrigation technologies; and (vi) en-route storages - substitute water use period by storing water along the river.

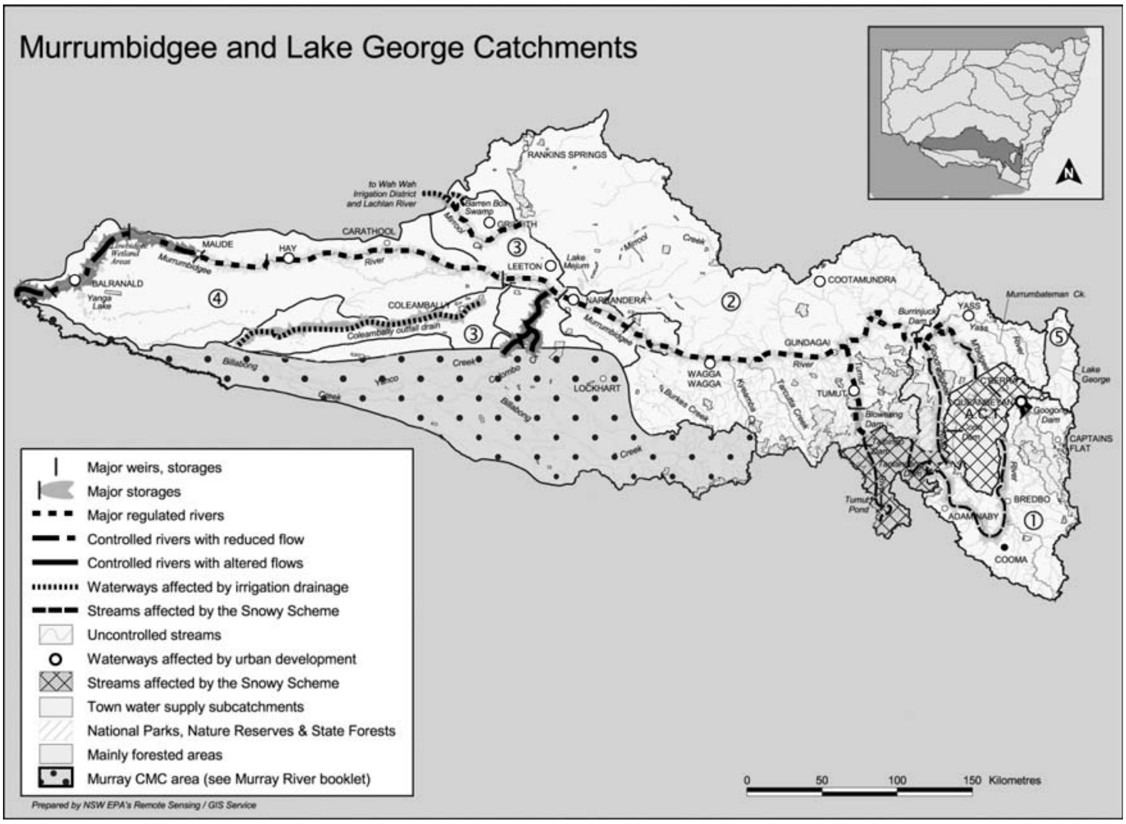

Figure 2. Location of the Murrumbidgee River Valley. Source: Khan et al., 2004a

On the basis of discussion with the stakeholders the most attractive options for managing peak summer water demand were conjunctive water use, en-route storages and improved cropping mix. The key criteria for success of the irrigation demand management options were demonstrated by anticipated water saving and reduction in peak summer water demand.

(i) Market based reduction in surface water demand

Market based reduction in water demand are often promoted as a cost-effective way of attaining environmental objectives. This is also considered to promote technological advances as market forces ensure the most economically efficient route to achieve the target. Water to improve seasonality of flows can be purchased through an open market mechanism. The environmental managers can buy water for environment requirements at market price and provide it back to the rivers on a seasonal flow improvement basis. Targeted buying of water access entitlements will not only results in greater production from the same (or less) amount of water but also accrues greater environmental benefits where water is traded from degraded areas and/or low value low efficiency production (Ouyahia et al., 2005).

(ii) Conjunctive use of surface and groundwater through aquifer storage and recovery

Current groundwater storages can be augmented using aquifer storage and recovery (ASR), also called managed aquifer recharge (MAR). This stored water can be used to meet part of the peak flow demand. However, substitution of surface water with groundwater can only be feasible if the cost of using surface water is greater than the cost of using groundwater and on-farm irrigation infrastructure is capable of using water from the two sources.

(iii) Spreading water demand with improved cropping mix

Since agriculture is the largest water user, reallocation of crops both temporally and spatially will likely result in reduced demand for water. Improving crop mix by focusing on both winter and summer crops can help improve environmental outcomes and optimise the water demand according to environmental requirement. For example, the alternative cropping pattern may require replacing rice, which is major water user, with less water intensive crops in the summer and spreading the water demand to the winter months.

(iv) Increasing conveyance efficiency (canal lining)

System level improvement in efficiency can be achieved by reducing conveyance losses such as seepage, leakage and evaporation. High investments are required to contribute to increase system level efficiency by improving the structures. By saving the water loss through infrastructure improvement, there will be no change in actual resource use at the farm level. However, saved conveyance losses can be used to improve the seasonality of flow in the rivers.

(v) Increasing on-farm use efficiency (Water-saving irrigation technologies)

By improving the on-farm water use efficiency, less water will be required by the farmers to maintain same level of production. This can be achieved by introducing various water saving irrigation practices such as drip irrigation and sprinkler irrigation system. This may help provide saved water to augment flows in the rivers.

(vi) En-route storages

Changing dam release pattern by providing en-route storages of water; this can be achieved by arranging small water storage facilities closer to farmer's field that are capable to supply water in peak demand. The en-route storages can help augmenting irrigation supplies from the rivers during peak demand, and also achieve improved seasonality of flows. En-route storages with different inlet and outlet capacities provide a multi-purpose option in addressing issues of limited flow, channel damage, rainfall rejection, system response times and strategic environmental watering (Pratt Water, 2004).

1.6 Aim and organisation of the report

The aim of this document is to present the summary of various project components. The second section of the report deals with the summary of the investigation of hydrological and economic consequences of introducing demand management options. Section 3 deals with canal automation and examines current technological position of irrigation distribution in Australia with a view to determine opportunities for improving system harmonisation. The section 4 explores the 'community' involvement in setting irrigation research agendas and evaluating water management while section 5 presents of the economic aspects of this project with emphasis of social cost benefit analysis. The final section 6 integrates the findings of all four components of the projects into system harmonisation proposal as part of the next stage of CRC Irrigation Futures Research Program.

2. System Analysis (Demand Management & Economics)

The main aim of this project component was to investigate the hydrological and economic consequence of introducing demand management measures for improving the seasonality of flows. Particularly, to estimate the trade-off between replication of natural flows in the river and agricultural income under different irrigation demand management options.

2.1 Methodology

The impact of preserving the seasonality of flows by reducing the peak flow variations through surface water supplies reductions on agricultural income and water use requires analysis both at farm and catchment-level. Changes in water availability directly impact on the area of irrigated enterprise and resulting returns along the rivers, and subsequently on environment quality. Therefore, both farm and system levels perspective of the agricultural system attempt to elucidate properties that emerge from interactions among components – agricultural productivity, economic opportunities and environmental quality. The analysis considered both (1) direct production and economic effects of reduced water supply on agriculture (crop acreage, water use, irrigation system costs and farm-level revenue) and (2) indirect effects of the agricultural adjustments on system-level.

2.2 Modelling framework

To quantify the impact of improving the seasonality of flows on agricultural income and water use, hydrologic and economic analysis both at farm and catchment-levels are required. A three-stage modelling procedure was developed to analyse a variety of hydrologically improved and economically viable irrigation demand management options. The hydrological sub-models determined the optimal water use pattern for a specific demand management option and economic modelling determined the optimal on-farm response in terms of farm income. The conceptual framework for the irrigation demand management options that integrates hydrological and economic aspects is shown in Figure 3. The detail of the methodology is available at improved seasonality of flows through irrigation demand management and system harmonisation main report.

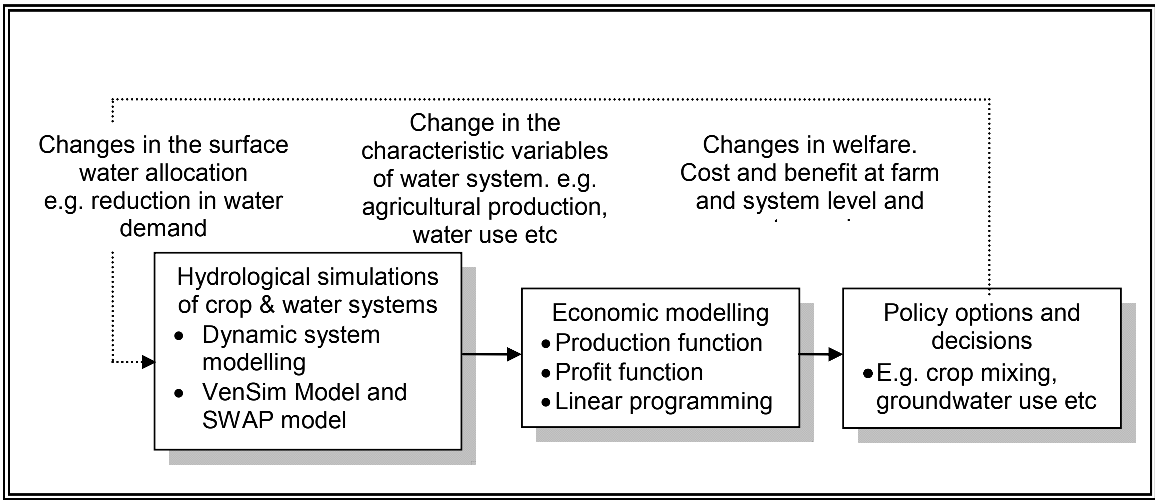

Figure 3. Conceptual framework for analysis of demand management options

At the farm level this study used a hypothetical farm with total area of 440 hectares in the Murrumbidgee Catchment to evaluate the farm-level impacts of reducing water demand. Representative farm models were developed to capture the nature of agricultural system in the study area. A standard farm budgeting framework was adopted to consider changes in water availability and associated farm adjustment responses. The economic models were solved on the basis of annual allocation availability under different demand management scenarios. Effects on whole farm gross margin and net farm income essentially measure the impacts on the income generation capacity of the representative farms. This study had a short-term focus and was undertaken under the assumption of relevant price range and relatively inelastic demand for water. It is assumed that farmers respond to reductions in water availability by changing their crops mix to make the best use of the available water or by adopting various on-farm water-saving irrigation technologies. In the absence of sufficient water, crops can be grown with deficit irrigation or replaced with a dryland enterprise to offset some of the income loss and if water is in excess it will be traded.

2.3 Water Saving Scenarios

Both the farm level and system level analyses of demand management options presented in Section 1.5 were carried out under the following two scenarios:

- 10% reduction in surface water use
- 20% reduction in surface water use

2.4 Results and discussions

2.4.1 Farm-level analysis

(i) Market based reduction in surface water demand

Market based reduction in surface water demand assumes that farmers will reduce the demand of water, approximately by 10% and 20%, that can be available for environmental allocation through the open market or increased production area. Farmers can trade this available water either to an environmental manager or to other farmers.

Farm level impact of market based reduction in water demand showed that, compared to 2000/2001 year farm baseline profit; a 10% decrease in water demand will reduce the farm profit by almost 5% or $33,458 (Table 1). However, when the surface water demand was reduced by 20%, the farm income was decreased by almost 12% or $78,973 (Table 2). Overall, with the market based reduction of 10% and 20% of surface water demand, the farm has additional 222ML and 443ML of water that can be traded to improve the seasonality of flows or to grow “higher value crops”.

The water can be traded temporarily or permanently depending on the water prices and requirements. The temporary water trading prices ranged between $45/ML to $200/ML during 2005, depending upon the seasonal allocation, quantity and time of water trading (CICL, 2005). The permanent water trading prices ranged between $800/ML to $1,600/ML (MIA, 2005; CICL, 2005). If the farmer saves 443ML of water (Table 2) and mutually trades it in temporary water market at $200/ML, than he can receive $88,525 of additional income. On the other hand, if traded in permanent market, the price per ML can be as high as $664,500.

Table 1. Comparison of change in area, income and water use of possible demand management options at farm level after a reduction of surface water demand by 10%

Irrigation demand management options	Water demand (ML)			Farm income ($)	Change in income ($)
	Surface	Ground water	Available water		
Baseline	2,700	00	00	651,656	
Market based reduction	2,473	00	222	618,198	-33,458
Conjunctive water use (groundwater abstraction)	2,473	222	222	649,125	-2,531
Conjunctive water use (ASR)	2,473	222	222	642,828	-8,825
Spreading water demand with new cropping mix	2,473	00	222	662,450	10,794
Water saving irrigation technologies	2,257	00	461	624,551	-27,105

(ii) Conjunctive water use including aquifer storage and recovery

The calculation of pumping and recovery costs was based on specifications of the most commonly used groundwater bores in the area. The cost of pumping and recovery depends on groundwater depth and the type of aquifer recharge methods. Depending on the preferred option for ASR development program, the cost estimates show considerable variations; ranging from $35/ML to $333/ML. The current pumping cost, without aquifer storage, is about $35.29/ML. However, with 10% and 20% increase in groundwater use without the aquifer recharge, the estimated increase in pumping cost is $2.5/ML and $5.75/ML, respectively. The estimated cost of aquifer storage and recovery using infiltration basin ranges between $57/ML to $126/ML, depending on the location; while the cost of aquifer storage and recovery using injection well is ranging between $111/ML to $333/ML. Infiltration basins are a more economically feasible option compared to injection wells.

(a) Conjunctive water use (groundwater abstraction only): The impact at farm level of a decrease in peak water demand by 10% or 222 ML and increase in supplemental ground water supply shows a decrease in farm profit of almost 0.4% or $2,531 compared with the base year 2000/01 (Table 1). However, when surface water demand is reduced by 20% or 443 ML and supplemental groundwater increases by the same amount, the farm income decreases by 1% or $6,498 (Table 2).

(b) Conjunctive water use (injection/infiltration + extraction): This case is based on the assumption that during the winter season the excess water will be recharged to the aquifer via infiltration basins, and that water will be extracted during the summer to compensate for reduction in peak diversions from the river. The estimated average cost of infiltration and extraction through infiltration basins is about $67.5/ML. A reduction in peak water diversion of 10% and a corresponding increase in supplemental groundwater supply from ASR show a decrease in the farm profit of 1.4% or $8,828 (Table 1). On the other hand, when the surface diversions are reduced by 20% with a corresponding increase in supplemental groundwater supply, farm income decreases by 2.7% or $17,716 (Table 2)

Table 2. Comparison of change in area, income and water use with possible demand management options at farm level after a reduction of surface water demand by 20%

Irrigation demand management options	Water demand (ML)			Farm income ($)	Change in income ($)
	Surface	Groundwater	Available water		
Baseline	2,700	00	00	651,656	
Market based reduction	2,252	00	443	572,683	-78,973
Conjunctive water use (groundwater abstraction)	2252	443	443	645,158	-6,498
Conjunctive water use (ASR)	2252	443	443	633,940	-17,716
Spreading water demand with new cropping mix	2252	00	443	635,766	-15,890
Water saving irrigation technologies	2,257	00	461	624,551	-27,105

(iii) Spreading water demand with alternate improved cropping mix

The objective of optimization under this option was to find an alternative mix of summer-winter crops that uses 10% or 20% lesser water. The optimization results indicates that with a 10% reduction in surface water diversions, farm income can be successfully compensated with an alternative cropping mix that relies on high value and less water intensive crops e.g. maize, wheat, canola, soybean etc . Results show that the total farm income increases by about 1.7% or $10,794, while the water saving is about 222 ML/year, with a reduction in peak summer diversions of 8.25% (Table 1).

When we restrict the demand of irrigation water by 20%, the model shows a reduction in farm income of 2.44% or $15,890. This is due to high transaction costs of shifting from one crop to another and considerable amount of water reduction at the farm-level. The total water saving is around 443 ML per year, which may reduce the peak summer water diversions by 16.5% (Table 2).

(iv) Increased end use efficiency (Water saving irrigation technologies)

Two on-farm water-saving irrigation technologies -drip and sprinkler irrigation - to increase on-farm water use efficiency. Drip irrigation was selected for horticultural crops, vines and citrus, while sprinkler irrigation was selected for major summer, winter and vegetable crops. The farm-level analysis shows that farm income would reduce by 4.15% or $27,105 with a reduction of surface water demand and adoption of on-farm water saving irrigation technologies. This income reduction is caused by the investment in water-saving irrigation technologies. However, water-saving from improved irrigation technologies will make an additional 416 ML of water available to the farm which will reduce the peak demand by 15%. This amount can either be traded or used on additional cropland (Table 1).

2.4.2 System level analysis

The system level analysis was carried out to analyse both on-farm and off-farm impact, as a whole, of each irrigation demand option implemented in MIA and CIA irrigation system collectively.

For canal lining, bentonite was selected as lining material based on previous research on its efficiency and cost effectiveness (Pratt Water and Khan et al., 2004b). The model estimates show that the required capital investment is about $133,733/km; which translates into the capital investment of water saved is about $1,713/ML with a present value of $165/ML. Therefore, to save about 200 GL of water per year by improving the conveyance efficiency to 85%, an investment of about $33 million/year is required over 20 years.

For en-route storages, the model estimate shows that construction of three 50 GL storage facilities or one 250 GL storage facility could be a feasible option. After accounting for seepage and evaporation losses, three 50 GL of above-ground storage reservoirs would help reduce the peak diversions by 119 GL (8.5%); whereas the 250 GL en-route storage would enable a reduction in peak diversions of 203 GL (14.5%) after accounting for seepage and evaporation losses.

The estimated capital investment for three 50 GL storages and one 250 GL storage is approximately $75 million and $115 million, respectively, with an annual operating cost of about $2.0 million. The annualised capital investment for three 50 GL storage is about $4.58 million, whereas the annualised capital investment for 250 GL storage is about $7.02 million over a period of 35 years.

To effectively compare various proposed demand management options, all costs and benefits were annualised. Table 3 and Table 4 show the comparison of agricultural return and water use of baseline conditions with the possible demand management options, after reducing the surface irrigation water demand of the system by about 10% and 20%.

The results show a trade-off between water saving and agricultural returns. It is possible to save over 200 GL of water from a total of 1,400 GL of total diversions in 2000/2001. However, the implementation of these measures will require an appropriate private-public investment to implement water saving technologies, canal lining or construction of en-route storage.

The comparison between management options shows that spreading water diversions through improved cropping mix in harmony with appropriate soil and climatic conditions is the best irrigation demand management option. The new crop mix shows a positive gain in agriculture returns of $5.49 million after the reduction of 10% demand of surface water (Table 3) while a loss of $4.79 million is incurred if irrigation diversions are reduced by 20% (Table 4). These results also show that alternative cropping mix requires 216 GL less water when compared to 2000/2001 water use (1400GL). Figure 4 compares monthly demand for water with baseline conditions and new crop mixes for the MIA. Conjunctive water use through more groundwater extraction or infiltration and extraction is also a realistic option capable of securing over 215 GL of water compared to the 2000/2001 water year with a minimum cost to agriculture. To secure 215 GL of water through groundwater extraction it would cost only $3.23 million in terms of reduced return from agriculture; but it would cost around $8.96 million to save the same volume of water through the ASR development program (Table 4).

Canal lining is the most expensive option to recover additional water for environmental purposes because of high labour and material costs. However, this option is still feasible and capable of providing over 215 GL of water to satisfy the long term environmental demand.

Table 3. Comparison of water use and income of baseline conditions with proposed demand management options at system level after reduction of surface water demand by 10%

Scenarios	Gross return	Benefit or loss to agriculture	Constru -ction costs	Surface water use	Ground water use	Total water use	Available water
	($M)	($M)	($M)	(GL)	(GL)	(GL)	(GL)
Baseline	292	0	0	1399	0	1399	0
Voluntarily reduction in surface water supply	276	-16.14	0	1285	0	1285	114
Groundwater extraction only	291	-1.26	0	1285	114	1399	114
Groundwater infiltration + extraction (ASR development)	288	-4.49	0	1285	114	1399	114
Spreading water demand with improved cropping mix	297	5.49	0	1282	0	1282	116
Increase system efficiency	292	0.00	19	1399	0	1399	114
Increase end use efficiency	284	-7.89	0	1217	0	1217	183
Substitute water use (En-route storages)	292	0.00	5	1399	0	1399	119

Table 4. Comparison of water use and income of baseline conditions with proposed demand options at system level after a reduction of surface water demand by 20%

Scenarios	Gross return	Benefit or loss to agriculture	Construction costs	Surface water use	Groundwater use	Total water use	Available water
Baseline	292	0	0	1399	0	1399	0
Voluntarily reduction in surface water supply	255	-36.82	0	1183	0	1183	216
Groundwater extraction only	289	-3.23	0	1183	216	1399	216
Groundwater infiltration+ extraction (ASR development)	283	-8.96	0	1183	216	1399	216
Spreading water demand with improved cropping mix	287	-4.79	0	1182	0	1182	216
Increase system efficiency	292	0.00	36	1399	0	1399	216
Increase end use efficiency	281	-11.61	0	1156	0	1156	243
Substitute water use (En-route storages)	292	0.00	7	1399	0	1399	203

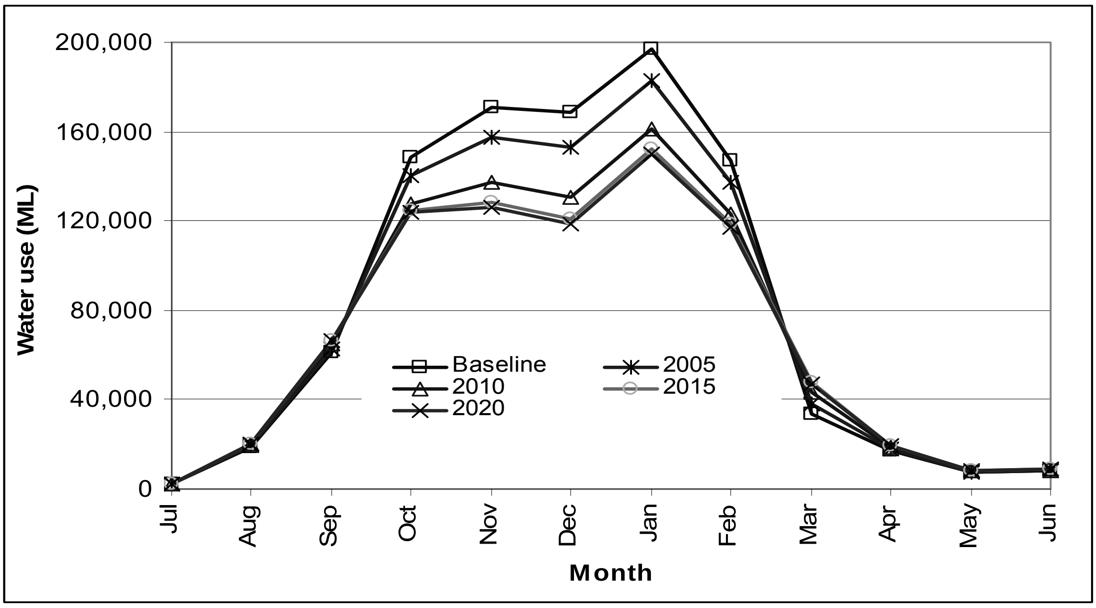

Figure 4. Comparison of monthly demand for water between baseline conditions and new crop mix achieved over 20 years for MIA

2.4.3 Sensitivity analysis

Sensitivity analysis of total monthly crop water requirement (CWR) and net economic returns was conducted separately by varying two variables; area under rice crop and the area under vine crop and keeping all other crop areas constant. A random uniform distribution of both variables was assumed and minimum and maximum limits were specified. The two variables are randomly varied about their distributions drawn between minimum and maximum values. The sensitivity analysis indicates that CWR is understandably more sensitive to area under rice than that of vines while net economic returns behave conversely (Figures 5 and 6). For example, there is 95 percent reliability (95% confidence bound) that change in the rice area by ±15 (i.e. current percent area ± 15) results in possible change in peak (in January) of CWR between 196.5 GL and 382.5GL as compared to the peak CWR of 289 GL of the current cropping pattern.

Similarly the corresponding change in net system level return remains between $255 million and $335 million. Hence it can be envisaged that reduction in the rice area by 15% will reduce the peak summer water demand for the month of January by maximum 32% and an overall demand reduction by maximum 26% which is equivalent to 362 GL. This water can be made available for trading or local increased production.

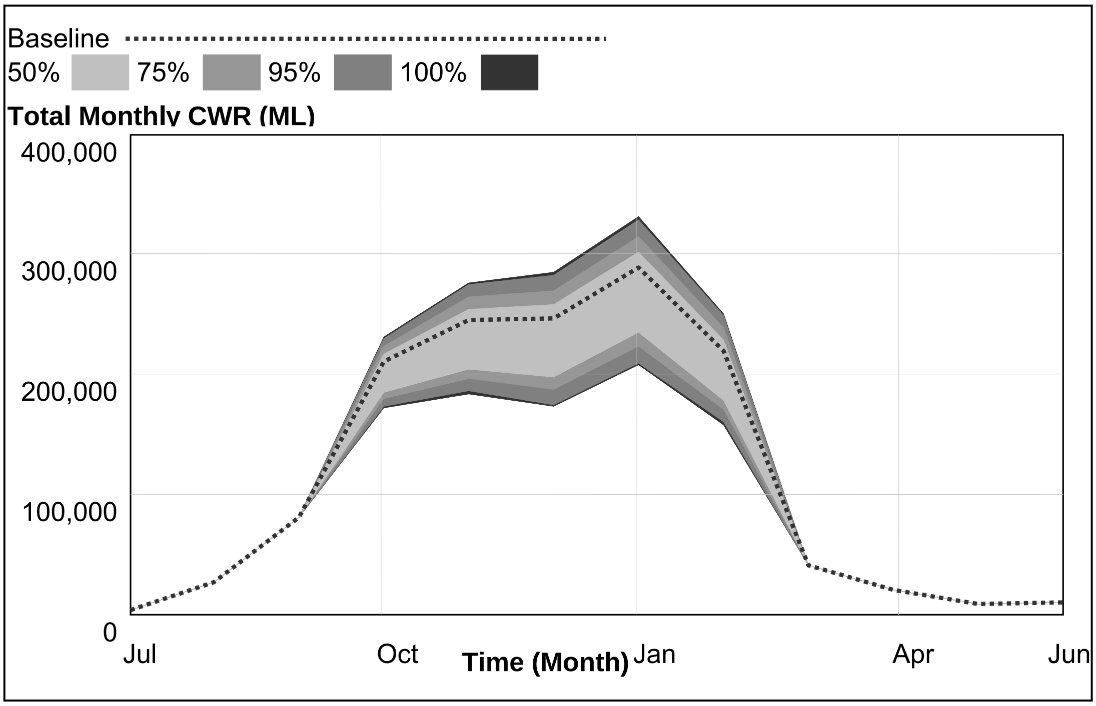

Figure 5. Sensitivity of monthly CWR of the MIA and CIA to 15 percent change in area of vines within 50%, 75%, 95% and 100% confidence bounds

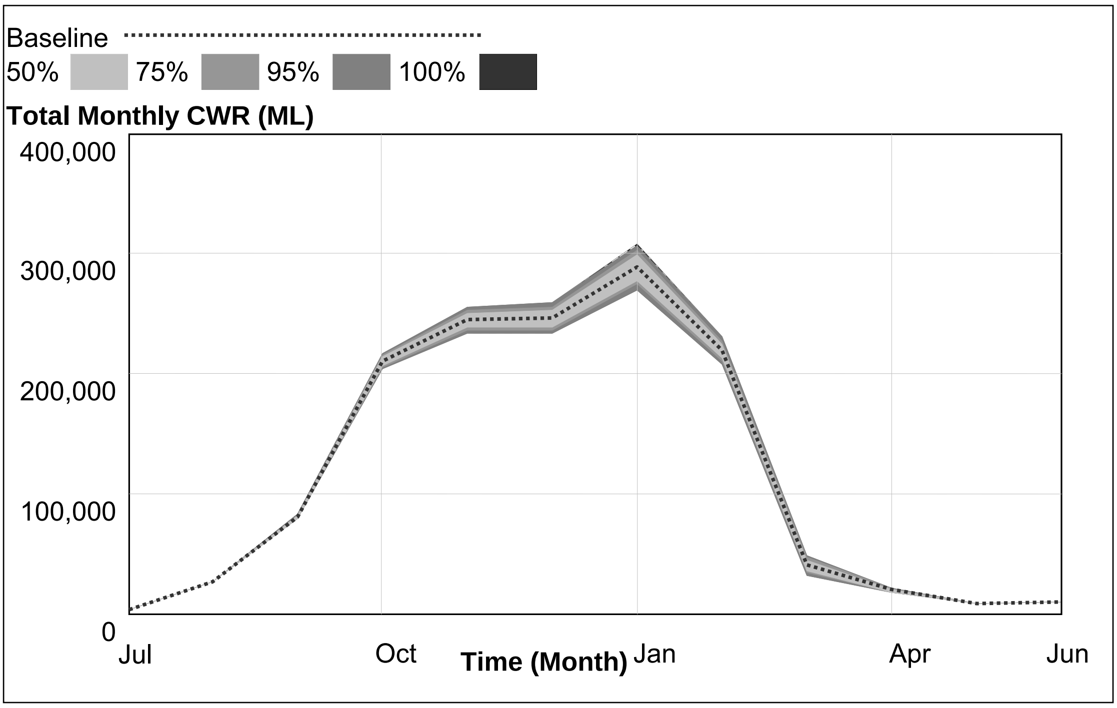

Figure 6. Sensitivity of monthly CWR of the MIA and CIA to 10 percent change in area of vines within 50%, 75%, 95% and 100% confidence bounds

2.5 Conclusions and recommendation

2.5.1 Conclusions

An integrated hydrologic-economic modelling approach is used to determine the economic costs, associated water saving and possible reduction in river diversions under possible irrigation demand management options. The results show that there is a trade-off between peak demand reduction and agricultural income. However, the extent of trade-off depends upon the type of demand management option. For example, securing 215 GL of water for environmental purposes through alternative cropping mix incurs a cost of $4.79 million/year from agricultural return compared with canal lining which costs $35.68 million/year in investment to save the same amount of water. Spreading water demand through new crop mixes are the most cost-effective irrigation demand management option for improving the seasonality of flows. Conjunctive surface–groundwater use is another attractive option to make additional surface water available for the environment during the peak demand months. Although increasing on-farm water use efficiency is in the farmer's own self-interest, it would also help increase stream flows. This option would require farmers to invest $303/ML for drip irrigation and $83/ML for sprinkler irrigation.

2.5.2 Recommendations

On the basis of above findings, it is recommended that improved cropping mix should be encouraged considering appropriate soil and climatic conditions. The alternative crop mix must entail less water intensive crops in summer and emphasise winter crops. However, this option may need structural adjustment and incentives to assist in the transformational process and appropriate market development for alternative crops.

Conjunctive water use by either additional extraction or infiltration and extraction is a feasible demand management option. A well coordinated and integrated management of surface and groundwater would help optimise the use of rain, river and groundwater resources. Market based reduction in water demand also provides an alternative for improving seasonality of flow in the river. However, it needs to be supported by a very well established water market.

As the existing infrastructure becomes increasingly old and obsolete, opportunities for infrastructure modernisation will arise to adopt new technology in canal automation, lining and related water saving technology. The associated water saving can be used to improve the seasonality of flow in the rivers. Infrastructure modernisation will entail considerable investment which can be raised through both private and public sources. This however will require innovative investment models involving private and public sectors which will also ensure adequate return and equity.

Both off and on farm level capital investments are possible either by utilising the saved water on higher value crops or by including saving costs to the overall water supply charges with a proportionate cost sharing arrangement. There is a need to reduce the break-even period by considering “leasing of water” by the government from farmers for the environment at around $300/ML for a fixed period of 5 to 10 years. Such an arrangement will require sophisticated market models to ensure adequate return to farmers while avoiding market distortions. Unless water saving cost and benefits are shared by all beneficiaries the “real water savings” are not possible.

Another possible incentive for achieving water savings may be through unbundling of water entitlements to allow for differential levels of security to provide “preferential access rights” to saved water to those investing in water saving technologies. This will help remove barriers to the adoption of irrigation technologies, move farmers and irrigation area to next level of the irrigation efficiency ladder, reduce local and regional environmental impacts and secure water for better ecological outcomes.

3. Harmonising the Distribution System

The main aim of this project component is to examine the current technological position of irrigation distribution in Australia with a view to determining opportunities for improving system harmonisation. As such, it is intended to scope three key knowledge areas: (1) Identification of flow control technologies in Australia, (2) review of state-the-art modelling in canal operation modelling; and (3) identification of opportunities for adoption of canal automation technology to improve harmonisation of the on-off farm interface.

3.1 Methodology

The state-of-the-art analysis is based on a survey of irrigation providers across Australia designed to gain a better understanding of the predominant technology used in hydraulic infrastructure for irrigation and their future plans for infrastructure upgrades.

A questionnaire was sent to all participants in the ANCID (2005) benchmarking assessment as this represents the most comprehensive list of irrigation providers across the country. The questionnaire was designed to complement the ANCID’s survey in the area of canal automation, and as such, it only included specific questions about the type of hydraulic infrastructure and hydraulic control used in their systems. Sixty four irrigation providers received the questionnaire of which 46 answers (72%)

were returned. This represents a total of 1.65 million ha out of a total area of 2.5 million ha of irrigation quoted by the ABS survey (ABS, 2005) with a total intake volume of 5,400 GL.

The review of canal operation modelling is a desk-top study based on a comprehensive literature review of the models published in the scientific literature and unpublished reports, with a specific focus on Australian systems. This review focuses on a description of the main features of existing models and their capability to simulate canal operation responses. The review places less emphasis on the detailed numerical techniques and schemes employed in the model to deal with the solution of the governing equations and other mathematical process.

3.2 Results and discussions

3.2.1 Irrigation infrastructure

Most of the water used in irrigation is supplied by open channel systems or a combination of open channel and pipe systems. Twenty three percent of the systems surveyed rely entirely on open channels for water supply while 55% rely on a combination of open channels and pipes and the remaining 22% are pipeline systems. These figures, however, do not reflect the relative capacity in these systems. The aggregate intake capacity of the channel systems accounts for 94% of the 62,224 ML/day included in the systems surveyed. By and large, pipeline systems are used in systems under 8,000 ha in area. Mixed systems often have most of the conveyance infrastructure in open channels with small sections or lower sections of the system in pipelines.

(i) Conveyance:

The type of conveyance – open channels or pipelines – determines to a large extent the flexibility of service provision. In general, pipe systems are hydraulically more efficient than open channels and are capable of faster reaction to changes in demand. In contrast, closed systems incur higher costs of installation than open system, in particular unlined channel systems of a similar capacity.

Most of the water used for irrigation in Australia is supplied by open channel systems or a combination of open channel and pipe systems. Twenty three percent of the systems surveyed rely entirely on open channels for water supply while 55% rely on a combination of open channels and pipes and the remaining 22% are pipeline systems. These figures, however, do not reflect the relative capacity in these systems. Open channel systems account for 4,300 GL (80%) of the 5,300 GL and 94% of the 62,224 ML/day of intake capacity of the channel systems accounts included in the survey. Most of the pipeline systems are used in systems under 8,000 ha in area. Mixed systems often have most of the conveyance infrastructure in open channels with small sections or lower sections of the system in pipelines. Furthermore, the vast majority of pipeline systems operate under low pressure.

(ii) Canal lining

A small proportion of canals are lined. Concrete is the main lining material used in Australian irrigation systems although clay and plastic compounds (PE) are used in a few cases. The proportion of lined canals differs widely between main and secondary canals although the aggregate length of lined main canals only represents 2% in the participating systems, while for secondary canals this figure is only 0.5%.

(iii) Hydraulic control

The ability to provide a flexible irrigation service is critically dependant on the hydraulic infrastructure to control water in open channels. The appropriate selection and combination of regulating structures in the main canal and offtake structures determines the controllability of the canal system, that is, how the system responds to fluctuations in demand and supply. These create transient conditions in canal system which can limit the ability to provide flexible and accurate water supply.

Two important hydraulic concepts are useful in understanding the implications of selecting the appropriate type of structures: Sensitivity (S) and Hydraulic flexibility (F). Sensitivity is used to express the change in discharge caused by a unit rise in upstream head while flexibility describes the distribution of flows resulting at canal bifurcations according to the hydraulic properties of the flow control structures. A description of the predominant type of structures in Australian irrigation systems and their flexibility is discussed below

(a) Method of canal regulation: Canal distribution systems in Australia use mainly overshot regulators to control water level. Eighty percent of the systems surveyed use either overshot regulators or a combination of overshot and undershot regulators. Those using a combination of both types of structures account for nearly 60% of the systems. It was not possible to obtain a breakdown from the survey how the structures are combined.

Most secondary and spur channel systems (70%) are equipped with undershot inlet structures. When combination of structures between main canal and corresponding lateral or spur inlets are considered, 50% of the combinations include main canal overshot regulators with undershot secondary or spur inlets. This combination favours a more stable operation of the channel system under conditions of discharge fluctuations often present in systems operated on the basis of farmers' orders. Twenty five percent of participating providers indicated the opposite combination which has a greater Flexibility Factor (F >1) and greater tendency to magnify the propagation of fluctuations in the downstream direction.

Sixty percent of the systems surveyed indicated that operation of the main canal structures is done manually while the rest are operated either mechanically or by a combination of manual and mechanical devices. For secondary canals the proportion of manually operated structures is slightly higher (64%). This trend is consistent with the fact that main canal structures are normally modernised before lower rank canals. Nearly all mechanically operated systems are by motorised actuators, except for an instance of hydraulic automatic AVIO[1] gates.

(b) Methods of structure control: This section discusses the predominant type of hydraulic control used in main, secondary and spur channels. Channel systems and closed (pipeline) systems are classified as locally or remotely operated. Locally operated structures are controlled on-site. Remotely controlled systems are operated from a control centre and are usually termed Supervisory Control. Remote operation provides operators with a number of advantages including real-time operation of the system structures to maintain canal levels at a specified optimum and other organisational management opportunities.

In recent years, several irrigation systems in Australia have incorporated remote operation through SCADA systems. As expected, adoption of SCADA systems has become more common in main canal regulators than in secondaries and spurs. Forty six percent of the irrigation providers surveyed have equipped the main channel regulators with remote control mechanised structures with a further 34% having partially converted to remote control systems. A similar analysis of the same systems for secondary and spur channels shows that 67% of structures are manually controlled with only 33% having some degree of automation.

[1] Automatic hydraulic gates designed to maintain constant downstream water level.

(iv) *Canal flow monitoring*

The ability to evaluate the operational performance of distribution systems is critically dependent on the quality of operations monitoring. Canal flow is monitored manually in the majority of the irrigation systems surveyed. Twenty five out of the 27 canal systems carry out their flow monitoring manually whilst the remaining two systems that are equipped with SCADA control are able to monitor canal flow remotely and more frequently.

Seventy percent of the irrigation providers reported monitoring daily flow monitoring and the remaining 30% monitor canal flows twice-daily. The high percentage of single daily observations correlates well with the predominance of manual monitoring systems which limits the ability to monitor flows more frequently.

Improved harmonisation of the interface between distribution and farm systems entails rapid responses to on-farm demand which can cause greater fluctuations in channel systems. The ability to monitor and correct these fluctuations in real-time are critical to control these system responses to satisfy service delivery objectives; a task very difficult to carry out in systems monitored and operated manually.

(v) Flow metering

Most irrigation providers (90%) meter their water delivery from canal and pipeline systems. A variety of flow meters are used for this purpose including Dethridge meters, magnetic flow meters and other mechanical devices. Several irrigation providers, in particular those who are in the process of upgrading from the traditional meter wheel to other devices, use a combination of devices, Dethridge meters are used in 18 systems surveyed (39%) and Magflow meters are used in 17 systems (37%) usually in combination with other systems. Use of a single type of meter such as Dethridge meters was reported by only 2 irrigation providers while only 4 irrigation providers use Magflow meters exclusively. Arrays of other devices or methods were reported by 9 irrigation providers (20%). Several providers have indicated they are progressively replacing Dethridge meters by other more modern meters including Magflow and Mace meters as part of their upgrade plans. Channel escapes and other structures are being progressively equipped with metering devices to account for drainage and residual flows.

(vi) Pipeline control

Combined mechanical and remote control of distribution systems is more prevalent in pipeline systems than in canal systems. Eight of the 20 pipeline systems surveyed are both mechanically and remotely controlled at the same time. The remaining 12 systems are manually and locally controlled.

Farm outlets in pipeline systems are predominantly manually operated by irrigators. Seventeen out of the 19 pipeline systems surveyed exhibit outlets locally controlled by irrigators. This is consistent with the fact that pipeline systems are better suited to provide water on-demand or under short notice (near on-demand).

3.2.2 Infrastructure upgrades and system harmonisation

(i) Recent upgrades

Adoption of canal automation technology in Australia is still limited. Canal automation offers one of the best options for achieving harmonisation of the interface between distribution and farm systems.

Table 5 shows the respondents' perception of the main achievements from past upgrades. A large proportion of irrigation providers (52%) have undertaken some form of infrastructure upgrade in the last five years. The main types of upgrade include conversion from open channels to pipelines, rehabilitation of decayed infrastructure often combined with some form of channel automation or a combination of minor works.

Table 5. Irrigation provider's assessment of upgrade benefits

Achievements	Percent (%)	
	Recent Upgrades	Future Upgrades
Improved level of service	43	43
Service cost reduction	28	43
Improved canal pool control	35	30
Improved water management	41	43
Improved Customer communication	26	26
Reduced OH&S risks	41	41
Reduced outfalls	30	30
Water saving	46	50
Alteration of current environmental impacts	30	35
Environmental sustainability	26	28

The median cost of upgrade per hectare was $72.0/ha ranging widely from as low as $10.0/ha up to $2600/ha. Twenty eight irrigation providers (60%) plan to execute some form of upgrade in the next five years, of which 64% are designed to upgrade the entire system while the rest are intended to upgrade part of the system. Twenty planned upgrades in the next five years form part of continuing process of upgrade which has started in the past five years. The planned upgrades include a wide range of infrastructure works such as channel remodelling, replacement and conversion from canal to pipeline systems, improved metering and conversion from local to remote monitoring and control.

It is also important to observe that a large number of irrigation providers intend to carry out infrastructure investments in the next few years. This provides important opportunities for planning these interventions in the context of improved system harmonisation. As observed above, improved level of service together with water saving and improved water management are the key drivers for infrastructure investment.

Better integration between the distribution system and the on-farm system can improve efforts to achieve system harmonisation by bridging the interface between canal operation and on-farm operation. Large irrigation distribution systems like those the predominate in South-East Australia present clear and more significant opportunities for achieving better harmonisation through this type of interventions given their longer travel time between dam releases to farms.

3.2.3 Canal operation modelling

Hydraulic modelling can play an important role in the design of new channel systems or an upgrade of existing ones. Hydraulic models are also useful for training operation personnel to better understand channel system responses to various operational interventions. Hydraulic models are used to simulate the effects of various design and operational scenarios in canal systems and to “virtually” establish comparisons between alternative strategies.

There are two main modelling approaches to canal operation:

- Hydrodynamic modelling (or traditional hydraulic modelling)
- System identification modelling

There is no evidence that hydraulic models have been used in planning recent upgrade projects either as design and planning tools or as evaluation tools. The full details of the modelling review are available in the main report of improved seasonality of flows through irrigation demand management and system harmonisation.

3.2.4 Innovations in canal automation in Australia

Real time monitoring and control technology offers the best prospect for achieving full controllability of the canal system. This technology involves the use of intelligent control logic to respond to changes in water level in the canal pools that result from changing flow rate and depth. Rubicon Systems™ has developed and tested this technology which can achieve near-on-demand channel control and deliveries. The control logic is based on a System Identification approach which models the behaviour of the system based on system observed data and can adjust it to maintain near constant water levels despite fluctuations in demand and supply (Weyer, 2001). This technology allows service providers to retrofit existing canals designed for upstream control to deliver a higher level of service. An alternative approach to achieve a similar level of service would be to redesign the canal system to operation in downstream control mode. Such a conversion is very expensive since it requires dead-level canal pools.

There are two main companies providing these products with slightly different features: Rubicon Systems have designed and tested a hardware-software system based on integrated control of cross regulators and farm off takes using a purpose designed control logic based on system identification. AWMA™ supplies hardware for control of cross regulators and farm off takes which can be fitted with SCADA remote control.

3.2.5 System upgrade and system harmonisation opportunities: A vision

Most irrigation distribution systems in Australia require significant upgrade to achieve system harmonisation objectives either by implementing channel automation or pipeline technology together with appropriate intelligent monitoring and control systems. These technologies, however, have not been widely adopted to date. The high cost involved with any of the technologies often can only be justified if significant productive and environmental benefits accrue in addition to improved level of service by the irrigation provider.

(i) On-off farm interface

Canal automation in its various forms can make a significant contribution to harmonising the on-off farm interface. Nevertheless, canal automation systems have developed to operate largely in isolation of the on-farm system. There are critical synergies that can benefit from the integration of the distribution and on-farm system to harmonise the interface between service provision and on-farm irrigation. This can only be achieved by improving the integration between the on-farm and off-farm water control systems through the use of extensive on-farm monitoring and communication systems. Figure 7 shows the main element of a whole-of-system approach to on-off farm system harmonisation.

An ideally harmonised system would integrate the demand and dispatch of water from the source to the consumption point to satisfy high level of service to users in the most cost-effective manner. Users in this context include agriculture and other non-consumptive uses and environmental demand. This aim can only be attained by fully integrating demand and supply schedules across all the segments of the system: Farm, distribution and source (surface water and groundwater).

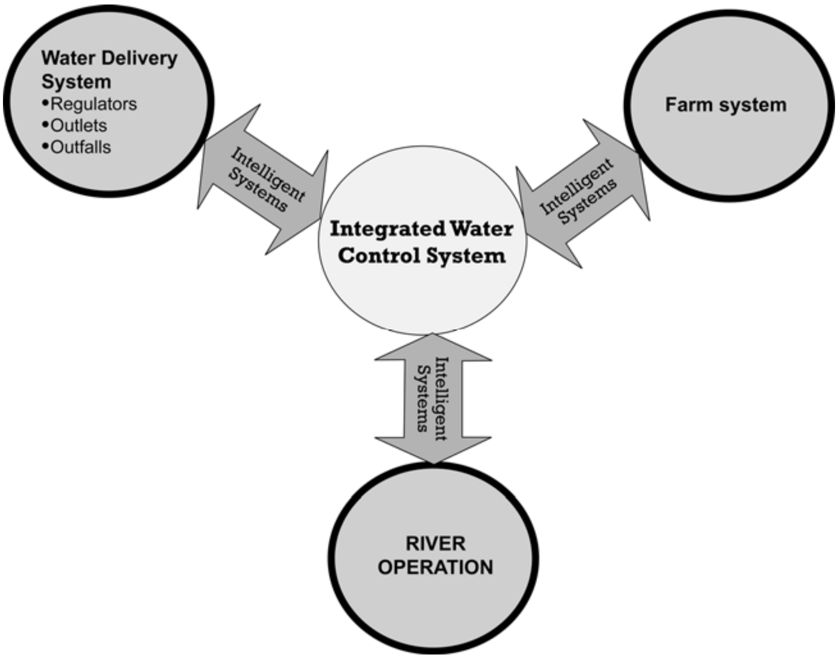

Figure 7. Main elements of a whole-of-system approach to on-off farm system harmonisation

(ii) Planning and evaluation of canal automation

A review of the literature on canal automation in Australia reveals a paucity of research into the development of clear planning and evaluation criteria for adoption of canal automation or systems upgrade in general. Two research gaps become evident: Technological assessment of systems available in the market, and criteria for assessment of costs and benefits associated with canal automation. Equipment manufacturers carry out routine reliability and functionality tests as part of their normal development process. There is however a paucity of field performance data under a range of field operational conditions.

Benefits from canal automation are a key factor in determining the adoption of this technology. It is obvious that benefits from canal automation may accrue at different levels in the system. The primary focus of canal automation is the ability to control the operation of the canal system. This constitutes the main direct benefit to the irrigation authority. There are, however, a number of other benefits which flow at different scales in the system. Improved and faster response to water delivery can bring benefits at the farm level by improving crop productivity and reduced environmental impacts. At a catchment level, improved operation control can provide important benefits in two areas: (a) more accurate water accounting; (b) improved control of environmental in-stream services, and (c) reduced volumes of outfalls. At present, a framework for evaluation of benefits and costs at various scales across the catchment is lacking.

3.3 Conclusions and recommendations

The main aim of this study is to examine the current technological position of irrigation distribution in Australia with a view to determine opportunities for improving system harmonisation. As such, it was intended to scope three key knowledge areas: (1) Identification of flow control technologies in Australia, (2) review of state-the-art modelling in canal operation modelling; and (3) identification of opportunities for adoption of canal automation technology to improve harmonisation of the on-off farm interface.

The analysis of various canal technologies shows that channel distribution systems rely largely on traditional technologies for water control; and despite that new technologies developed both in Australia and overseas have become readily available in past decades, the level of adoption still remains low.

The study reveals that the vast majority of Australian systems (78%) rely on open channels or a combination of open channels and pipelines for distribution of water to farmers. Only 22% of systems rely only on pipelines for water distribution. In terms of system capacity, open channels account for 94% of the systems surveyed. A similar picture emerges regarding the use of canal lining. A small proportion of main canal systems (2%) are lined. Concrete remains the main lining material despite new membrane materials becoming available in recent years.

Canal regulation is achieved mainly by a combination of overshot cross regulators on the main canal and undershot structures in lateral and spur outlets.

A large proportion (60%) of these main canal regulators are still manually operated, while this figures is higher (64%) in secondary canal structures. 46% of the systems surveyed have equipped the main canal regulators with remote control mechanised structures. This figures drops to 33% for secondary canals the incorporate some kind of remote control operation.

There is increasing diversification in technology used for flow metering. Thirty nine percent of systems surveyed rely only Dethridge meters. Magflow meters are used in 37% of systems surveyed in conjunction with an array of other metering devices. The adoption of new metering technology is driven by more accurate flow measurement and ability to use SCADA technology.

A large proportion of irrigation providers (52%) surveyed have undertaken some form of infrastructure upgrade in the last 5 years which often includes some form of infrastructure refurbishment combined with channel automation. This figure increases to 60% of irrigation providers which plan to undertake system upgrades in the next 5 years. In both cases, they named improved water management and water saving as high priority objectives. There is little evidence that there is sufficient monitoring and evaluation of system upgrades to determine whether these objectives are achieved. Furthermore, these objectives are exclusively focused on benefits to irrigation providers. There is no evidence that actual on-farm and catchment impacts arising from canal automation are either identified or evaluated.

A comprehensive review of canal operation models was also undertaken which reveals a wide array of computer models available to simulate the operation of canal systems. However, the use of these models still remains largely in the research domain.

3.4 Recommendations

The various forms of available canal control and automation technology can make a significant contribution to the harmonisation of the on-off farm interface. However, all efforts to date have focused primarily on the canal distribution system in isolation of the on-farm system and the river operation system. There are critical opportunities provided by modern control and communications technology to harmonise the operation of the three system domains: River-distribution-farm systems.

- Canal automation together with modern control and communications technology represents the best and most obvious opportunity for advancing harmonisation of the three system domains: River, distribution and farm systems. Based on this, it is therefore recommended that the various forms of canal automation technology that are available should be adopted at all levels of river, canal and farm water control.
- The future efforts in canal automation should emphasise the integration of the farm, distribution system and river system to maximise the benefits to agricultural production and provision of environmental in-stream requirements.
- As a matter of urgency, systematic research is necessary to evaluate the impacts of canal automation technology at farm, system and catchment levels of current pilot projects. Learned lessons from existing case studies can contribute to maximise the benefits and avoid mistakes in future canal automation projects.

4. Framework for Assessing Social Acceptability of Management Options

The main aim of this project component is to explore ‘community’ involvement in setting irrigation research agendas and evaluating water management options in the Murrumbidgee Valley. Particularly, to involve stakeholder in identification of possible demand management options from a range of options and gauge their acceptability.

4.1 Methodology

(i) Stakeholders involvement

Key stakeholder groups in the region were involved in the identification of possible irrigation demand management options. Two key stakeholders’ workshops were organised to discuss the possible irrigation demand management options and their perceived benefits.

The first meeting was held in Leeton in April. Invited participants included local water distribution company managerial staff, state agency employees, representatives from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Murray-Darling Basin Commission (MDBC), university irrigation researchers, plus two irrigators. The workshop participants mostly represented those with a dominant interest in irrigated farming productivity and profitability, although it is recognised that people may hold many values. The specific aims of the first meeting were to:

- Develop draft criteria for assessing water demand management projects/ideas’

- Share project ideas between the research team and other (i.e. community) experts, and
- Assess the proposed ideas against the draft criteria developed in item 1

A second meeting was held in Griffith in March 2005, with the same invitation list. The options under consideration at the second meeting were similar; however this time were to discuss the irrigation demand management options and their perceived benefits. The options include (i) market based reduction in surface water demand; (ii) conjunctive water use augmented by aquifer storage and recovery; (iii) spreading of water demand with improved cropping mix; (iv) increase conveyance efficiency (canal lining); (v) increase on-farm water use efficiency through water-saving irrigation technologies; and (vi) en-route storages, substitute water use period by storing water along the river.

(ii) Social acceptability, a theoretical framework

The dissemination of agricultural research outcomes in Australia has been strongly influenced by the 'diffusion' model. Diffusion is defined as the process by which an innovation or new idea is tried and adopted within a target practitioner community (Surry 1997). In the diffusion model both the features of the innovation, and the individual traits of members of the community within which the transference of ideas is occurring, are important (Rogers 1995). The diffusion model works particularly well for new or improved technology developed specifically to improve short term farm profitability or productivity. Because the transference of ideas in this model is anticipated as coming from scientific or technical experts to practitioners the main role for other stakeholders, such as farmers, is that of passive receivers. The assumption underpinning the diffusion model is that the innovation is good for the recipient stakeholders, so if diffusion (uptake) is slow it is a result of 'barriers' to adoption. In the diffusion model much effort is placed on identifying and addressing these barriers to the uptake of the innovation. In other words, the innovation remains constant, while stakeholder concerns are 'managed' to encourage uptake. While the diffusion of innovations approach is a well established model for agricultural extension, there are alternative approaches for undertaking and discussing innovative research, including the consideration of social acceptability of the proposed change(s). Assessing social acceptability requires a less narrow understanding of information and knowledge transfer processes because the nature of the innovation is considered to be negotiable in response to societal opinions. Further, it may be a more suitable model for understanding how to introduce difficult and or disruptive 'innovations' into communities that rely on production from natural resources.

4.2 Results and discussions

4.2.1 Gauging the social acceptability of different options-phase1

The process used at the first meeting was to develop criteria against which different irrigation demand management options could be evaluated, before attempting to assess the project proposals. A workshop approach as described by Spencer (1989) was used to develop these (draft) assessment criteria. This involved unstructured and uncritical generation of ideas from all participants ('brainstorming') in response to the question 'What criteria would you use to judge the effectiveness of a water management project?' All the participants then assisted in collecting the responses into categories or sets and labelling those sets with a heading that reflected all of the individual responses within it. This resulted in 11 criteria by which participants felt they could compare and judge options for improved seasonality of flows in the Murrumbidgee River (Table 6).

Table 6. Assessment criteria for evaluating improved seasonality of flows project based on the key stakeholder preference

No.	Criteria	No.	Criteria	No.	Criteria
1	Improved water use efficiency	5	Significance	9	Economic benefits
2	Demonstrated impacts on water availability	6	Risk reduction	10	Social benefits
3	Sound stakeholder processes	7	Equity/fairness	11	Environmental benefits
4	Feasibility	8	Identify costs/ cost minimisation		

Once these draft criteria were developed the participants were asked to share possible approaches (options) for harmonising irrigation demand with rivers flow regimes. A total of 7 options were selected by the key stakeholders.

A blank matrix was formed with the seven options on one axis, and the previously developed criteria on the other axis. Five groups were then formed from within the workshop participants to assess the options. Each group was asked to assign up to five points to each box in the matrix, with five points being totally acceptable, and 0 points being totally unacceptable. Adding the criteria scores provides a ranking of the projects (one group chose to rank the projects only). The ranking from highest score to lowest by each group is shown in Table 7.

Each group had a different option at the top of their list; however, there were some trends worth noting. The conjunctive use of water was ranked 1 or 2 by four of the groups. Thus, it could be concluded that it had reasonably comprehensive support or at least participants had some interest in the approach. The Barrage, various forms of en-route storage and managing evaporation scored either very high or very low, while the cropping mix and water trading ideas were in the median range for most groups. Selling water as a service was ranked either last, or not considered, by all groups.

The process of articulating assessment criteria not only allowed considered judgements about the acceptability of proposals, it also indicated specific areas where project ideas may need to change to become more socially acceptable. The conjunctive use of water option scored less well against the criteria of stakeholder processes, cost minimisation, social benefits and equity than the other criteria, suggesting that this project could become more acceptable by addressing these issues.

Table 7. The seven options for enhancing seasonality of flow and system harmonisation ranked by the 5 groups of irrigation community members

Group 1		Group 2		Group 3		Group 4		Group 5	
Rank	Option	Rank	Option	Rank	Option	Rank	Option	Rank	Option
1	Barrage	1	Conjunctive use	1	Water trading	1	Manage evaporation	1	Cropping mix
2	Conjunctive use	2	Barrage	2	Conjunctive use	2	En-route storage	2	Conjunctive use
3	Cropping mix	3	En-route storage	3	En-route storage	3	Barrage	3	Manage evaporation
4	En-route storage	4	Manage evaporation	4	Cropping mix	4	Water trading	4	Water trading
5	-	5	Cropping mix	5	Manage evaporation	5	Conjunctive use	5	En-route storage
6	-	6	Water trading	6	Barrage	6	Cropping mix	6	Barrage
7	-	7	Water as service	7	Water as service	7	Water as service	7	Water as service

Financial incentives or a greater emphasis on involving stakeholders and developing equitable sharing arrangements, or compensation may be required to make this option more acceptable. On the other hand the Barrage project idea scored poorly against efficiency, flexibility, significance, suggesting a niche role rather than a large scale option for system harmonisation. The cropping mix project idea scored poorly in many areas, but particularly against the criteria of risk reduction, equity, water use efficiency and stakeholder processes. If the cropping mix option is to be pursued much more work with individual and community water users is required to manage risk, ensure equity and to ensure that there are some water use benefits. Possibly financial or other incentives would be required to make it score higher in these areas.

4.2.2 Gauging the social acceptability of different options-phase2

By March 2006 some of the options discussed at the initial meeting had been developed into options that were sufficiently detailed to present to the community participants again. The options were presented with information about the impacts of each option under a 10% and a 20% reduction in water demand.

Again the approach used to discuss the options involved a facilitated workshop, this time based on whether the each, if any, option was worth pursuing, and what issues were important for each option.

Each of the options was considered as worth pursuing, although it was noted that the increased system and end use efficiency options were already being explored well in other projects. The option of spreading water demand with improved cropping mixes again received a mixed reception by community participants; some stated that this option was not worth pursuing, while others thought that, while it had some potential, it was a lower priority for research than the other options.

4.3 Conclusion and recommendations

It was evident from the two meetings that some options for improving seasonality of flows in rivers through irrigation demand management and harmonising irrigation systems with the environment were more acceptable to this group of community participants than other options. Further, it could be concluded that this acceptability influenced what participants considered as worthwhile research to pursue. The most acceptable options for this group were those that involved changes to the delivery of water to the irrigation district and/or individual properties. The development and co-ordination of en-route storages and various processes for achieving conjunctive use of ground and surface water were seen to have the potential to produce some environmental enhancement with minimal disruption to the irrigation community. Options which had more direct and potentially negative impacts on individual farmers, such as spreading water demand with improved cropping mix, were not as acceptable to the meeting participants. Any future work in this area would need to consider these findings as a foundation for developing and introducing improved seasonality of flows and system harmonisation.

The first meeting demonstrated the value of articulating assessment criteria when dealing with new and potentially disruptive options for management of irrigation demand in a catchment context. The process of articulating water management assessment criteria provided a space for people to share their expertise, experience and anxieties, as well as to contribute in a structured way to the development of a research project in their area. The assessment criteria developed at the first meeting were only approximations. As a consequence, a refinement of those criteria through meetings with different community members would be necessary for them to become a truly useful tool. However, even as a rough tool the areas of the different options that requires further work to make them more acceptable to the irrigation community are clearly articulated.

5. A Social Benefit Cost Method for Assessing Improved Seasonality of Flows through Demand Management

The purpose in this project component was to present the economic aspects of the project. Particularly, to assess whether it was possible to estimate the social costs and benefits of irrigation? Such an assessment relied on completeness. In other words, was it possible to specify all the costs and benefits of irrigation, or as many as possible, that would result in a reasonable estimate of the net present value of implementing a range of demand management strategies.

5.1 Methodology

5.1.1 Social Benefit Cost Analysis (BCA)

Social Cost Benefit analysis of a proposed public project is undertaken to help answer the important question: "Will the project be of net benefit to society?" It is designed to promote the maximisation of social net benefits, in an economy-wide context (as opposed to, say, investment analysis conducted by a private firm, which examines purely the private profitability of some new project). An attempt is made to put all costs and benefits arising from a project into monetary terms, to enable sensible comparisons between alternatives. Benefit Cost analysis is usually carried out on a national level.

Essential characteristics of costs and benefits in economics are that:

- Costs and benefits belong to particular actions and each decision implies at least two alternative courses of action (do or not do).
- Costs and benefits are particular to persons or groups. The same action can involve different costs and benefits for different people.
- Costs and benefits involve the future consequences of current decisions, not what happened in the past and can not be undone.
- Benefit Cost analysis attempts, as far as possible, to put all costs and benefits arising from a project into monetary terms, to enable sensible comparisons between alternatives

In undertaking a benefit cost analysis one usually attempts to gain a complete picture of all the costs and benefits that arise from a project. Included in that picture are not only the marketable commodities (valued in a free market) and those marketed in a corrupted market (where the value is corrected for by using shadow prices), but also for the non-marketable commodities as well. Non-marketable commodities can be valued using a variety of tools, such as recreation values being determined by the travel cost method. However, many others, including the value of ecosystem services, are difficult to value accurately.

5.1.2 Conceptual issues

Young (2005) argues that the benefits from water can be segregated into: (i) commodity; (ii) public and private aesthetic; (iii) waste assimilation; and (iv) damages (a dis-benefit).

Each of these is an economic benefit as they are characterised by increasing scarcity and allocation issues among competing uses. There may be consumptive uses, such as those that require extraction from the system, and non-consumptive uses, those in-stream uses such as hydropower generation and environmental uses. Further, it could be argued that the aesthetic uses are not part of a social evaluation, as they are considered non essential and non-rivalrous, and thus do not have a market. It should be noted that this view is not held by many, but was prevalent during the development phase of irrigation schemes. It is recognised that rivers act as conduits for depleting and distributing waste products. This act of waste assimilation not only adds an externality and public good component to the analysis, but also introduces quality aspects to the debate (Davidson and Malano, 2005). With damages, it is recognised that adding something as a waste can be of benefit for others. For instance, farmers who use waste water from a city may desire the nutrients available in the water. Flood waters carrying silt is another example. However, the accepted wisdom is that damage to a river is a cost and thus is a dis-benefit.

Overall, it could be argued that water should be valued first and foremost by what can be produced from it. In broad terms this means the returns obtained from the output of commodities produced from it, principally agricultural output. In addition, some valuation could be derived from the public and private aesthetic uses, such as recreational use. Both these items should account for both consumptive and non-consumptive use. Given the nature of Australian rivers, the benefits of waste assimilation and damage are likely to be negative. As a consequence they can be considered to be a cost.

5.2 Results and discussions

5.2.1 The Benefits of Irrigation

(i) The value from agricultural output

To calculate the net economic returns from agricultural output would seem to be an easy task. All that is required is to multiply the total production from the region by the price received and then take away the costs of production. In order to calculate the gross value per crop it is necessary to know the areas and yields of each crop. The costs of production are best recorded on a per hectare basis; therefore gross margins can be effectively calculated on per hectare basis.

All data and the results of calculating the net value of agricultural output in the MIA and the CIA along the Murrumbidgee are presented in improved seasonality of flows through irrigation demand management and system harmonisation main report. It was found that in 2003-04 the net value of agricultural production in the MIA was approximately $1,475.4 million. In the CIA the value of output was calculated to be approximately $198.6 million.

(ii) The value from tourism and recreation

Society values irrigation not only for its productive capacity, but also for its recreational use. Economists find it difficult to value recreational use, as a market value does not exist. In the absence of a known price, the travel cost method has been employed to obtain a proxy variable.

To use the travel cost method it is necessary to have some idea of the number of visitors to a region and how long they spent in the region and how much they spent on accommodation. It was found that in 1993-94 there were 2048 visitor nights spent in the Riverina region. It was found that the takings from all forms of lodgings during the year were approximately $23.4 million. Adjusting for inflation, it was found that if similar patterns of visits existed in 2003 and 2004, visitors would have spent approximately $29.8 million and $30.5 million, respectively. Finally, if it is assumed that only 70 per cent of visitors actually visit the Riverina to make use of the recreational facilities provided by the irrigation infrastructure, then the value of recreation in 2003 was found to be $20.8 million and $21.4 million in 2004.

(iii) The aesthetic value of the environment and valuing ecosystem services

If it is possible to "value ecosystem services", then a value can be put on the environment. However, due to number of factors such as the assigning values of water to various stakeholders, identifying and quantifying the ecosystem services and lack of markets for ecosystem services it is difficult to value ecosystem services.

Although attempts have been made to put values to the ecosystem services they remains doubtful because of the fact that without really knowing what constitutes an ecosystem service, it is impossible to know what it is worth.

What is being suggested is that ecosystem services should be treated as a residual in the valuing process. It should be noted that such an approach is inadequate as all unaccounted for activities would be considered to be an ecosystem service. Despite this, it may provide a good proxy for valuing said services. The need for finding a proxy valuation technique arose because the existence of ecosystem services defies normal valuation techniques. In particular, no markets exist for them.

(iv) Salvage values

There is little doubt that salvage values need to be incorporated into a Benefit Cost analysis. If an asset is purchased for a project, then at the end of the planning horizon, the asset may be worth something. What it is worth at the end of the project is a benefit that needs to appropriated and valued. Of course, if it is a dedicated asset that can not be mobilised, or appropriated, then its salvage value is zero. This would appear to be the case in irrigation schemes.

5.2.2 The costs of Irrigation

In this study the aim is to assess the effects irrigation has on the welfare of society in a specific region. While the valuation of benefits was complex, in many respects the conceptualisations of the costs of irrigation are far harder to achieve. For instance, the costs to be assessed are those that affect only those in the region in question. In addition, any costs incurred prior to today should be considered as sunk cost, and thus are excluded from the analysis.

(i) The costs of operating irrigation schemes

Data on the private costs of providing water to irrigators can be obtained from the annual financial reports of water supply companies. The details of operation irrigation schemes are presented in improved seasonality of flows through irrigation demand management and system harmonisation main report.

In the case of the MIL, in 2003 over $4 million was spent on business and administration costs. Water distribution costs account for approximately $6.5 million, while system maintenance accounts for nearly $5.4 million. Another important cost is that for bulk water, at just under $3.9 million in 2003. More intriguing is what is meant by engineering and environmental costs. These would appear to be legitimate costs and amount to over $1.5 million in 2003.

The costs of running irrigation companies would appear to be $21.4 million in 2003 and $21.6 million in 2004. Given that in the MIA metered diversions can account for up to 852,000 ML, the cost per ML is $25.12. Given that only 659,000 ML were used, the average cost per ML was $32.47. This figure is not that different to the price currently selling on the water exchange of between $35 and $40 per ML. However, the cost of running an irrigation scheme do not account for all the social costs of regulating rivers.

(ii) Forgone production

There is an opportunity cost associated with the fact that irrigation is undertaken. This cost is what the alternative use of the resource could be put. To explain this in its simplest terms, an irrigation scheme takes up land which normally would be used for some other purpose. The net forgone value of production in the MIA was estimated to be $85.6 million, almost six percent of what is earned from irrigation. For each ML of water used (659,000 ML) the cost of foregone production is equivalent to $129.89. Interestingly, in the CIA it was found that on the prices received in 2003-04, dryland production would have resulted in a loss of only $1.4 million.

(iii) The opportunity cost of water

As in the previous section, the water itself has an opportunity cost. The argument is that if the water were not used in agriculture what would it be used for? To calculate the opportunity cost of water it is necessary to multiply the quantity in question by the market value of the input. From the *Watermove Exchange*, the value of traded water in 2003 was $35/ ML. In the MIA entitlements total 852,000 Ml of water. In 2002-03 only 659,000 ML were supplied. This means that the opportunity cost of water is equivalent to $23.1 million in the MIA.

(iv) Environmental costs

The environmental costs of irrigation are difficult to quantify from a social perspective. Within irrigation schemes and the rivers that carry irrigation water, it would appear that the environmental costs are embodied in land (mainly through salinity), water (through turbidity) or a combination of the two (such as disruptions to flooding, pollution transfer, etc.). Despite the difficulties specified above, some information exists of the environmental effects and costs of irrigation.

(a) Salinity: NSW Agriculture (1996) has estimated an annual cost to agriculture from water logging and salinisation of around $3 million for the Murrumbidgee Irrigation Area. According to Murray-Darling Basin Salinity Audit (2005), the total annual costs (including agricultural) amount to approximately $1 million for every 5,000 ha of visibly affected land. In Wagga Wagga, current salinity costs are estimated to be approximately $500,000 per year and potential costs have been estimated at $183 million over the next 30 years if no action is taken.

(b) Nutrient and pesticide transfer: The nutrient monitoring program in the MIA is aimed at determining solutions for reducing nitrogen and phosphorus levels. Trigger levels for moderately disturbed ecosystems are 0.05mg/L total phosphorus and 0.5mg/L total nitrogen. It received $1.4 million in July 2003 for implementing land and water management programs until December 2003. A further $1.4 million has also been approved and is likely to be released in December 2003 and January 2004.

(c) Turbidity: The turbidity monitoring programs are aimed at identifying activities to reduce overall turbidity levels. The turbidity of the supply water was measured within this range. All other monitoring sites were above the trigger value. There appears to be no particular trend within each site. The conversion of flood irrigation to high tech irrigation systems and the implementation of on-farm drainage recycling and storage should decrease sediment loads and improve turbidity levels in the drainage system.

5.2.3 Determining which alternative to choose

Young (2005) put together a number set of alternatives for water resources that could be evaluated. These relate in some sense to his classification that either structural or non-structural proposals. To put these in perspective the following rules should be followed in order to get a potential Parato Improvement:

- Evaluating private investments in additional water supplies, would require that DBp >DCp, where p denotes a private perspective, DB is direct benefit and DC is direct cost. In layman's terms, a new investment is economically feasible.
- Evaluating additional water supplies from a social perspective would require that Is(DBp + IB + SB) > (DCp + IC + SC), where IB is the indirect (external) benefits, SB are the secondary benefits, IC are the indirect (external) costs, SC are the secondary costs and all other variables are as defined above. It should be noted that possibly the secondary benefits and costs cancel one another out, if a wide analysis is conducted.
- Evaluating the reallocation of water amongst sectors from a social perspective is equal to DBS + IBS > FDB +FIB + TC + CC, where DBS is the direct benefits to the receiving sector, IBS are the indirect benefits to the receiving sector, FDB are the forgone direct benefits to the source sector, FIB are the forgone indirect benefits to the source sector, TC are the transaction costs associated with the change and CC are the conveyance and storage costs.
- Given that agriculture is usually the least cost source of water, then in reallocation assessment, then it could be asserted that the costs of reallocation (i.e. that FDB +FIB + TC + CC) should be less than the next best alternative source of water, i.e. that (FDB +FIB + TC + CC) < AC, where AC is cost of employing water in the least cost source (agriculture).

In order to determine which demand management techniques are the most worthwhile, economically, it is necessary to have more information on the costs of implementing each measure and the likely effects. However, these problems are minor when compared to the lack of information on the public benefits and costs of irrigation. Further, it would seem that the opportunity of obtaining information on demand management strategies would be more likely.

5.3 Concluding remarks and recommendations

The purpose in this study was to assess whether it was possible to estimate the social costs and benefits of irrigation. Such an assessment relied on completeness. In other words, was it possible to specify all the costs and benefits of irrigation, or as many as possible, that would result in a reasonable estimate of the net present value of implementing a range of demand management strategies.

It was found that the private benefits and costs of irrigation schemes could be derived. In summary, it was found that agriculture contributed $1,475 million and recreation contributed $21 million. The salvage value and that of hydroelectric power generation were not considered. The cost of supplying water was estimated to be $21.4 million, while foregone production accounted for $86.5 million and the opportunity cost of water was calculated to be $23 million. This results in net private benefits from irrigation of $1,365.4 million.

The net private benefits do not include the costs of constructing the schemes (as they are sunk), or the public costs and benefits of irrigation. It was found that reasonable estimates of the public benefits and costs would be difficult, if not impossible, to obtain. What is needed is a technique that can overcome the data deficiencies that exist in this area. However, what is apparent is that any technique that overcomes the problems without finding a value for the environment detracts from a social Benefit Cost analysis. The problems in this field are such, that only real solution lies in taking a Cost Effectiveness analysis.

The large net private benefits derived from irrigation provide some scope to implement a range of demand management strategies. The strategies reviewed in this study range from increasing water efficiency through to changing water demand. The problem arises in the sense that those who lose from implementing a measure are not those who gain. In other words, it is more likely that a potential Pareto improvement could be possible.

6. Improved Seasonality of Flows as part of System Harmonisation

Using the concepts developed in the sections 2 to 5 the system harmonisation framework was developed. The system harmonisation is defined as "a strategy to improve cross-organisational communication and system-wide management and improve production and environmental outcomes."

Using a conceptual-operational analysis a five way System Harmonisation for Applied Regional Planning (SHARP) feasibility template (Figures 8 and 9) were developed to generate new science and knowledge for harmonising rice based irrigation system with their operating environments through agronomic, economic, technological and institutional improvements in water management.

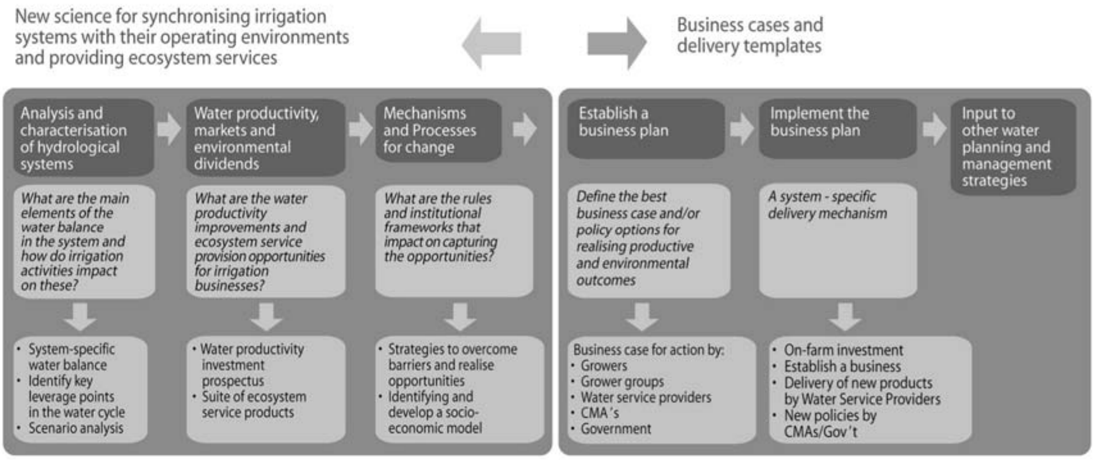

Figure 8. Five way feasibility leading to SHARP implementation

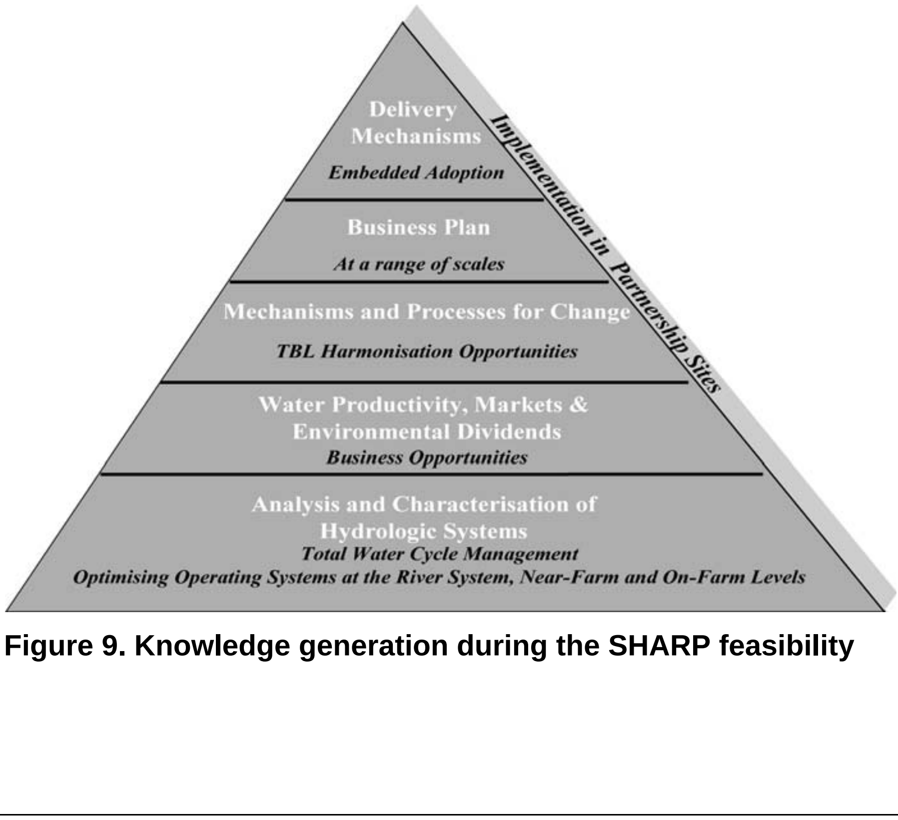

Figure 9. Knowledge generation during the SHARP feasibility

Each feasibility step involves a Conceptual-Operational-Monitoring (COM) cycle (Figure 10) to determine the "business opportunities" and "key pressure points" as listed below:

- *Conceptual Assessment*: This will involve selection/development of conceptual assessment framework and a wide ranging biophysical, environmental, economic, social, cultural and institutional assessment to identify "*business opportunities*" and "*most relevant variables*".
- *Operational Analysis*: This means focussing at an operational level on the "*most relevant variables*" that represent the key pressure points which can be adjusted to achieve selected "*system harmonisation opportunities*".
- *Monitoring and Evaluation*: This will involve designing smart monitoring systems for monitoring key variables that can capture progress towards "harmonised irrigation systems".

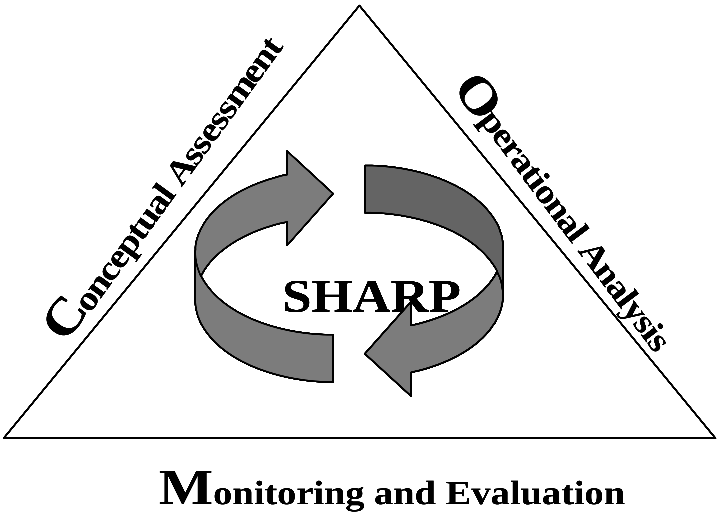

Figure 10. The COM research cycle for SHARP feasibility

Summaries of key research hypothesis, questions and methodologies for each of the feasibility steps are presented in the following sections.

This approach builds on the triple bottom line (social, economic and biophysical) integration approach presented by Khan et al. (2004a and 2004b). Key challenges and opportunities of water savings and sustainability of rice based irrigated agriculture are given by Khan (2005) and Khan (2006). This paper describes a five way feasibility to achieve real water savings and better environmental outcomes in rice based systems.

6.1 Analysis and Characterisation of Hydrologic Systems

This feasibility step will involve hydrological characteristics of the region and seeks to build an interactive "Water Balance and Residual Waste Statement of the Water Cycle" as shown in Figure 11. In addition to establishing the base position of the region this feasibility stage will also identify some of the key pressure points in the system (shown as hexagons) – in particular the capacity to optimise on farm and near farm irrigation system performance and water demand patterns to deliver productive and environmental dividends.

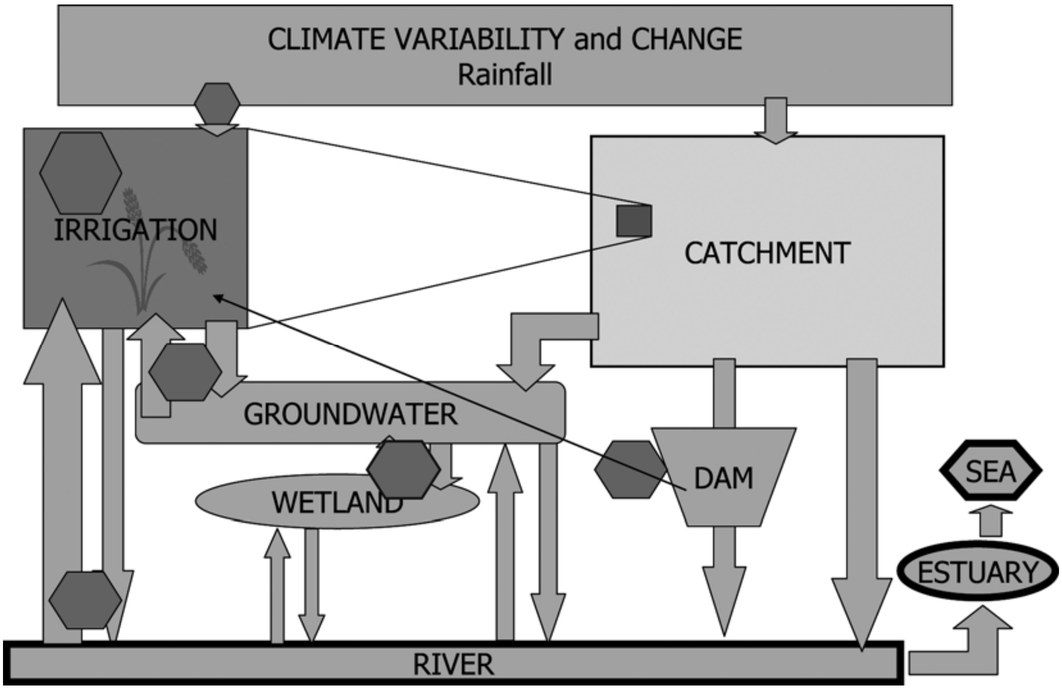

Figure 11. Identification of key pressure points in the irrigated catchment water cycle

An example of "Harmonisation" opportunities to be identified during this stage includes: "Optimising interface between river operation and irrigation system operation by the hydrologic and hydraulic efficiency of irrigation system through better synchronisation of demand-supply."

Key research questions asked during this feasibility step are:

- What is the most appropriate and comprehensive framework for assessing system harmonisation across a range of irrigation system typology?
- What are the tools needed to asses the impact of internal and external interventions on system harmonisation performance at a range of scales and irrigation systems settings?
- How to design intelligent monitoring systems that require least effort and provide information rich data, enabling the on-going assessment of system harmonisation performance at a range of scales and irrigation systems settings?

6.2 Water productivity, markets and environmental dividends

Establish the production and non-production related product and/or services most in demand within the region, and identify which ones can be delivered by the irrigation industry acting either independently or in partnership with others.

From an environmental perspective these can be identified by reviewing the associated ecosystems and their products and services. The delivery of identified ecosystem products and services will be examined in two ways. Firstly, possible adjustments to the current water supply and hydrologic patterns will be examined to assess how modified irrigation business practices can lead to better ecosystem services. Secondly, the knowledge of ecosystem requirements can be used to build a hydrologic regime for regulated river system which can deliver improved ecosystem services. The means to achieve this altered hydrologic regime will be assessed in conjunction with feasibility steps 1 and 3.

From an economic perspective this stage will help assess costs involved in improved environmental management (lost opportunity, infrastructure investment, structural and pricing reforms etc.) and how transaction costs can be minimised by attributing these costs to local, regional and national stakeholders.

The end point of this process is a list of defined products and/or services with realistic economic assessments undertaken of the key market variables of demand and price in place.

Key research questions relevant to this feasibility step is "*how do we best understand and define the economic, social and environmental systems which constitute irrigation in Australia*?

Sub questions to address this include:

- What are the most appropriate approaches for understanding who and what are dealt within irrigation schemes?
- What are the most appropriate methods of establishing the importance of irrigation and water resources within a region with respect to the economic, environmental and social performance of the region?
- What outcomes, (environmental, economic and social) are acceptable/sought following any change in hydrological flows?
- What is the current status of water productivity, the environmental systems, and the social values of the region under study?
- What are the transaction cost issues, how might they impact on the cost/benefit (triple bottom line version) of investments and what are the best ways of reducing these and dealing with any transaction cost impact issues?
- What environmental outcomes or regional values are primarily affected by irrigation practice?
- What is the value of individual ecosystem services that can be affected by irrigation management
- What are the risks and uncertainties that govern water use in the sector? What options are available to minimise risks?
- By changing practices what could the irrigation operators do to improve environmental, social and economic outcomes (individually and collectively)?
- Is there a 'critical mass' or minimum level (e.g. number of irrigators) of practice change among individuals that is necessary to bring about these outcomes?

6.3 Mechanisms and processes for change

An understanding of the most appropriate change management strategies and institutional and policy settings is needed to facilitate movement towards a more productive and sustainable irrigation environment. This process involves a comprehensive scan of the business environment to identify the social, cultural, legislative and institutional barriers and opportunities. At the operation level the provision of "harmonisation services" within a market context is new and as such it will be necessary to identify and/or establish mechanisms and processes to enter new markets and trading facilities. Triple bottom line monitoring and evaluation of "progress" towards "system harmonisation" will be developed as part of the implementation process.

- What are the regulatory issues (spanning government, industry or other code and self-regulation) involved in irrigation investments/systems, how might these impact on irrigation investments and outcomes, and how can the cost-effectiveness of these be optimised for a given situation or project.
- What are the risks to social, economic, environmental or commercial outcomes, and what mechanisms (financial, managerial, political, and economic) are best suited to minimise these?
- What are the system resilience issues (social, economic, environmental and commercial) of importance in irrigation systems and communities, what are the relevant contingencies that might impact, and how can the resilience values be optimised through business plans developed in Box 4?
- What are the issues of divergence of perspective, or different visions that are relevant to irrigation systems and communities? How might this impact on outcomes? How can they be best addressed? How can a shared vision and commitment be achieved?
- What political issues and processes are most relevant to irrigation systems and communities, and what impacts might these have? How can irrigation systems be designed (in terms of inputs, processes and outputs) to best harness and maintain political support? What political strategies are needed? How can they/should they be implemented?

6.4 Developing a business model

The research outputs associated with the above three main areas run the risk of delivering only dry academic tomes if not utilised in a meaningful fashion – hence the strict relationship between the System Harmonisation Research Program and the development of a business plan for improved water management within a particular area and its subsequent implementation by our partners or others within the region. The research will involve key stakeholder as partners to help define region specific issues and deliver relevant solutions ready for adoption.

Having identified the market, defined the product and established a legislatively and institutionally acceptable route to market the feasibility process begins in earnest.

During this phase detailed biophysical and socio/cultural analysis of the feasibility of providing the products and/or services required at the market defined price/volume relationships previously identified will be undertaken in conjunction with feasibility stages 1, 2 and 3. The questions addressed during this stage include:

- Is it possible to develop generic investment models for system harmonisation opportunities?
- How can we integrate Value Chain Management/Value Management and System Harmonisation?
- How can we generate a template for Harmonised Irrigation Businesses and Environments?

The CRC IF is aware of various business feasibility models used in both the public and private sectors, which continue to evolve in economic, financial, social and environmental terms. From a business and investment perspective such models include 'public-private partnerships'; those commonly used and measured in private enterprise; economic modelling and others established in government legislation. These models will be assessed with the RIBPs.

6.5 Implementation challenges

Like any scientific study successful execution occurs when a business entity has been established to meet the market demand in a profitable and sustainable fashion. Ultimately the success of the project is best evaluated by the liquidity of this entity and the growth in shareholder value.

A key feature of this market place will be the need to create a business model which manages to convert the largely public good nature of individually positive actions into a collective output which can be privately implemented and traded. This will require not only a sound understanding and demonstration of the biophysical realities of the region but the establishment of robust cooperative business structures and regional investment partnerships.

The CRC IF is keen to implement system harmonisation sites by developing “Regional Irrigation Business Partnerships” (RIBP) with groups of irrigators wishing to explore an alternative approach to securing their long term future.

The first and most important characteristic of an RIBP site is that it is fully and enthusiastically endorsed by our industry partners. The CRC IF’s mandate is to deliver improved productivity, profitability and sustainability to irrigation Australia wide, but in this instance we wish to focus our activities very strongly around specific industry partner needs.

Other vital characteristics for an RIBP would include:

- There is enough surface and ground water data to enable a clear understanding of key water management issues;
- There is a demonstrated need to change or recognisable opportunity for improved productive and/or environmental outcomes through improved water management;
- There are clearly identified biophysical, social, economic and institutional issues which are likely to respond to the coordinated alignment which is suggested within the System Harmonisation program;
- An existing organisation or individual represents a potential champion for the process;
- Clear business opportunities have are likely to be identified with potential funding partners available;
- The scale of the overall project is commensurate with the combined CRC IF and RIBP resources; and
- The time scale for change is in line with CRC IF objectives to deliver real change within a 4 year time frame.

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