Northern Basin Program

On-farm water use efficiency in the Northern Murray-Darling Basin

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Foreword

Water resources in the northern Murray-Darling Basin are limited and variable meaning that irrigation industries dependent on these resources have had to continually address the pressures for improved efficiency measures. While there have been extensive investigations into on-farm Water Use Efficiencies (WUE) across the Basin, much of the reporting has concentrated on southern districts.

This study has aimed to bring together current knowledge of WUE in the northern part of the Basin where most of the irrigation is applied to broad acre annual crops, mainly cotton. The study provides an indication of where the greatest potential WUE gains may be achieved and identifies priority areas for further research. Further investigations will be required to develop more detailed economic analysis of the costs involved in achieving these WUE gains.

This study represents a work in progress and points to the need for on-going collaboration between research organisations and irrigation industries in the northern Basin. Further studies of this kind will provide more accurate assessments for planned future investments in WUE that will assist in informing governments and the irrigation community.
Acknowledgements

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In particular this report would like to make special mention of those farmers that participated in the case studies. The case studies provide an insight into irrigation innovation across the Northern Murray Darling Basin at the enterprise level while identifying the drivers for private irrigation investment.
Executive Summary

This report has identified significant opportunities for improved on-farm water use efficiency (WUE) in the Northern Murray Darling Basin. Valley characteristics in terms of crops grown and irrigation systems, drivers for private investment in water use efficiency and the economics of investments in irrigation improvements have been investigated. This information has informed a number of recommendations identifying future research needs and knowledge gaps in the Northern Murray Darling Basin. Options for the accelerated uptake and adoption of technologies and practices to deliver improved on-farm WUE have been discussed.

Irrigation Enterprises in the Northern Murray Darling Basin

Approximately ¾ of the area irrigated within the Northern Murray Darling Basin is used for growing cotton. Significant irrigated areas are also used for producing pasture and Lucerne, other broadacre crops (eg. cereals, coarse grains and oils seeds) and horticulture (grapes, vegetables, fruit trees and nut trees).

![Proportion of irrigated area by crop type in 2000/1](image)

The area irrigated within the study area varies significantly year to year, largely dependant on water availability. For example, in 1996/7 approximately 390 000 Ha of land was irrigated. This increased to 510 000 Ha in 2000/1.

Significant irrigated areas occur in all valleys within the study area. However, water sources vary significantly across the study area from valleys that depend heavily on water supplied from regulated rivers (eg. Macquarie Valley) to valleys with a mix of water sources such as groundwater, regulated river supplies, supplemented flows and unregulated rivers (eg. Namoi Valley) and valleys that rely entirely on capturing and storing infrequent large river flow events (eg. Barwon-Darling Valley).
Significant differences also exist within individual valleys with many horticulture enterprises across the study area represented by smaller enterprises (in areal extent and total water use) located in the headwaters of valley (eg. Granite Belt in Border Rivers Valley); pasture and broadacre cropping enterprises dominating the river flats in the middle sections of many of the valleys and large cotton enterprises, typically with significant on-farm infrastructure for storing and distributing water, dominating the extensive floodplains at the lower ends of the valleys.

A wide range of irrigation systems are used. More than 90% of cotton is irrigated using surface (furrow) irrigation with some areas already converted to drip irrigation and an increasing proportion of cotton being irrigated by centre pivots / lateral moves. A wide variety of systems are used for irrigating other broadacre crops including surface irrigation (furrow), centre pivots / lateral moves, hand shift, side roll, travelling gun and travelling boom. High pressure overhead traveling winches and hand shift and side roll are the most prevalent systems in the pasture and Lucerne sector. Microirrigation systems (drip and micro sprays) are common in the horticulture industry except for in the vegetable sector where spray systems such as fixed and hand shift sprays are the commonly used.

Deliveries from river headworks (dams and weirs) provide approximately one third of the water used for irrigation in the Northern Murray Darling Basin. As a result, many irrigation enterprises have had to make significant private investment in systems for storage and distribution of water on-farm. An estimated 4500 GL of on-farm storage has been developed throughout the Northern Murray Darling Basin.

The performance of on-farm storages and distribution systems has a major impact on on-farm water use efficiency. For enterprises that are entirely dependent on unregulated water supplies and/or floodplain harvesting, the inefficiencies associated with on-farm storage and
distribution can exceed efficiencies associated with in-field application systems. This contrasts significantly with the Southern Murray Darling Basin where on-farm WUE is largely driven by the efficiency of in-field application systems.

Potential Gains in WUE in the Northern Murray Darling Basin

Potential gains in on-farm water use efficiency in the Northern Murray-Darling Basin have been estimated to identify key areas for further investment. A volumetric approach has been taken with consideration given to the three main components of whole-farm irrigation systems:

- on-farm storage systems (farm dams, ring tanks);
- on-farm distribution systems (channels and/or pipes); and
- in-field application systems (e.g. furrow, spray, micro-spray or drip systems).

Potential volumetric losses (or inefficiencies) within each of these sub-systems has been estimated on a valley by valley basis.

A total of 1480 GL of potential WUE gains have been identified throughout the study area. This estimate involves 100% adoption from all irrigators and represents the upper limit that could be achieved with significant capital investment required for all elements of an irrigation enterprise (on-farm storages, on-farm distribution systems and in-field application systems).

The greatest gains to be made are in the mitigation of losses from farm dams (48%), primarily through the mitigation of evaporation losses. Significant gains (45%) can be realized through improvements to the infield performance of irrigation enterprises across the Northern Murray Darling Basin.

### Opportunities for WUE gains by farm sub-system

| Improved infield irrigation systems (661 GL), 45% |
| Mitigating losses from distribution systems - high investment (104 GL), 7% |
| Mitigating losses from farm dams (713 GL), 48% |

While the largest potential WUE gains across the study area can potentially be made through mitigating evaporation losses from farm dams, this is influenced by the volume of on-farm
storages within highly unregulated valleys eg. the Condamine-Balonne valley. When examining the potential gains on a valley by valley basis, the largest WUE gains in most valleys would be achieved through addressing infield application efficiency. This is particularly the case in valleys with a higher proportion of river regulation (eg. Macquarie, Gwydir, Namoi and Border Rivers Valleys).

In determining the potential WUE gains, consideration has been given to both proven practice and technology and emerging technologies. The inclusion of emerging technologies in the estimate of WUE gains allows for priorities for Research and Development to be identified that will greatly assist in improving WUE in the Northern Murray Darling Basin.

As a result, a significant proportion of these gains cannot yet be realized and further research and development of commercially applicable technologies is required (eg. in mitigating evaporation losses from large on-farm storages) or further research is required in associated management practices to support existing technologies (eg. optimal agronomic practices for cotton irrigated by centre pivots).

**Key drivers for private investment in on-farm WUE improvements**

There are many drivers for investment in on farm irrigation and WUE. Key drivers for improving on-farm WUE in the Northern Murray Darling Basin include reduced or lower
reliability water supply, need for labour savings and the need for improved yield to maintain profitability.

**Economics of improvements in WUE in the Northern Murray Darling Basin**

To establish the economics of low and high investment strategies for improved on-farm water use efficiency, the break even cost of potential water savings ($/ML) was compared to the gross margin per megalitre (GM / ML) of different crops encountered across the Northern Murray Darling Basin.

Low investment strategies (improved management of existing irrigation systems) have focused on two key areas including: water use gains through the adoption / facilitation of improved management practices; and consulting services for surface irrigation (Irrimate™) evaluations. The experience from the Rural Water Use Efficiency project in Queensland indicates that the breakeven cost for WUE gains is approximately $96 / ML of water savings to fund extension and support services. In comparison the break even cost of water savings for an Irrimate™ surface irrigation evaluation was determined as $71 / ML.

High investment strategies (significant capital investment in alternative technologies) has assessed the economics of mitigating losses from farm dams, improving infield performance by converting to alternative irrigation systems and redevelopment of existing surface irrigation systems.

Whilst the development of evaporation mitigation technologies (EMTs) for on-farm storages is still occurring, break even costs for medium evaporation reduction varied from $300 to 400 / ML saved. Considering the average GM / ML water used of many crops ($185/ML - $1000/ML), it is likely that investment in these products will be viable in many situations.

Options for system conversions primarily considered a change to centre pivots, lateral moves and drip irrigation. A change to traveling booms (pasture) and the redevelopment of existing surface irrigation systems (cotton) was also considered. Conversion to centre pivots and lateral moves was economical at relatively minor increases in volumetric efficiency when converting from other pressurized irrigation systems. This was due to a reduction in operating, maintenance and labour costs. When converting from surface irrigation systems which have inherently low operating costs a higher volumetric efficiency was required to reduce the break even cost of water saved. Minor improvements in the volumetric efficiency were still economical however; a higher GM / ML would be required for the cost of water savings to be less than the average of the crops considered.

Opportunities to improve surface irrigation systems in cotton also included redevelopment of the existing surface system. Providing a water saving could be achieved through these changes then this was the most economical option. For drip irrigation systems typically a higher water saving would be required to justify the investment. The notable exception was horticulture where the GM / ML of water applied was significantly more than other crops.
Recommendations

Key recommendations relating to improving on-farm WUE in the Northern Murray Darling Basin have been identified. Recommendations reflect key findings, research and knowledge gaps and options to facilitate accelerated uptake and adoption of alternative technologies and practices.

Adopt a Whole Farm Approach to Irrigation Efficiency

Any projects addressing on-farm water use efficiency in the Northern Murray Darling Basin need to adopt a ‘whole farm’ approach incorporating all aspects of the on-farm irrigation systems including on-farm storages, distribution systems and in-field application systems.

Further work be undertaken to quantify potential WUE gains at both a farm and whole basin scale

Further work is to be undertaken to quantify potential WUE gains at both a farm and whole basin scale. In particular:

• Good data is required on the number, capacity, surface area and usage of farm dams across the Northern Murray Darling Basin.
• Technologies need to be further developed to cheaply and accurately measure evaporation and seepage losses from on-farm storages and distribution systems and to survey on-farm storages to accurately estimate storage volumes.
• Further benchmarking is required on the current performance of on-farm storages, distribution systems and in-field application systems covering the full range of systems, crops, soil types and climatic conditions.

Significant investment is required in R&D to enable continued improvements in on-farm WUE

Significant investment is required in R&D to enable continued improvements in on-farm WUE, in particular:

1. Cost effective evaporation solutions – exploring polymer and other technologies as a cost effective option for reducing evaporation from storages. Ongoing cash investment is required in the existing partnership between Polymer CRC, CRC Irrigation Futures and Cotton CRC with increasing investment over time, including investment in extension.
2. Cost effective seepage solutions for storages and channels – trials to quantify seepage losses and define the extent of this as an issue; trial existing technologies and seek alternatives.
3. Alternative irrigation systems – further R&D is required to identify appropriate agronomic strategies and crop responses for alternative irrigation systems (centre pivots / lateral moves and drip) in cotton. A focused R&D effort is also required in other industries, in particular the vegetable, pasture and grains to identify the opportunities for alternative irrigation systems and provide technical information (setup, crop water requirements etc) to accelerate the adoption of alternative systems.
4. Precision irrigation – investment is required in ‘future irrigation technologies’ (including real time adaptive control systems, plant monitoring sensors etc and associated
management issues eg. soil water and solute movement) to facilitate the next leap forward in improved WUE.

**Explore opportunities for immediate gains in on-farm WUE**

Opportunities to implement immediate gains in on-farm WUE including:

- Encourage the adoption of practices that minimize evaporation losses from on-farm storages (eg. preferentially using storages);
- Optimize surface irrigation systems commonly used by the cotton industry by altering cutoff times (eg. use of Irrimate™ services);
- Improving distribution systems of spray systems used in the pasture industry (eg. adopting appropriate nozzle sizes and pressures);
- Increasing the use of scheduling tools (soil water monitoring, ET based methods) to more closely match irrigation volumes to soil-water deficits.

These opportunities should be further explored and programs with appropriate extension, training and technical support to facilitate these gains should be established / extended.

**Develop integrated programs to assist in accelerated uptake and adoption**

The accelerated uptake and adoption of current practices and technology and emerging technologies to achieve WUE improvements will only occur with integrated programs that support irrigators by addressing knowledge gaps, resolving implementation issues, provide an appropriate level of ongoing management support and addressing on-farm drivers and barriers to change.

An integrated program of research and development; extension and high level technical support programs; training for irrigation professionals and irrigators; benchmarking and financial incentives is needed to deliver significant improvements in on-farm WUE.
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1 Introduction

1.1 Background

The Northern section of the Murray-Darling Basin differs markedly from the Southern section of the basin both in physical and economic characteristics. Broadly, climatic conditions vary from a summer rainfall environment to the north to a winter rainfall environment in the south. Approximately 10,000 gigalitres (GL) of water is diverted annually in the Basin for irrigation, of which 36% is diverted within the Northern section of the Basin. Irrigation in the north is dominated in areal terms by cotton, while rice and pasture are the largest users of irrigation water in the south of the Basin. Additionally, independent policy development across the four Basin states and the ACT has resulted in differing institutions, policies and programs.

The Murray-Darling Basin Commission (MDBC) is expanding its work program in the Darling Basin as part of the development of future strategies to address water resource issues in the western regions of NSW and south west Queensland. Irrigation development is now an important feature of the local economies in a number of river valleys throughout the Northern section of the Basin including the Border Rivers, Condamine-Balonne, Moonie, Gwydir, Namoi/Peel, Macquarie / Castlereagh, Warrego and Barwon/Darling Valleys.

The MDBC recognises that Water Use Efficiency (WUE) measures are a potential response to a changing irrigation environment, including reduced water availability. The application of WUE measures in the Northern section of the Basin will be in response to the specific challenges of this region relating to on farm characteristics such as scale of irrigation developments, water storages, potential evaporation and conveyance losses, crops grown, existing infrastructure and water availability.

This report has been developed to advise the MDBC and its Northern Working Group of the irrigations systems and opportunities for improved WUE and the drivers for private investment into WUE leading to a better understanding of future research needs and knowledge gaps in the Northern section of the Basin.

1.2 Project Objectives

Specifically this project aims to:

1. Highlight the differences and specifics of the valleys of the northern Murray-Darling Basin. These valleys include Border Rivers, Condamine-Balonne, Moonie, Gwydir, Namoi/Peel, Macquarie / Castlereagh, Warrego and Barwon/Darling and Lower Darling Valleys.
2. Summarise local characteristics in terms of crops grown, irrigation systems and technologies used, delivery and storage systems, water allocations, sources and management strategies across the valleys and highlight significant regional differences.

3. Identify drivers for private investment into WUE including investment in alternative irrigation systems, technologies, conveyance and storage infrastructure. Preference for use of consultants and other advisors for WUE will also be identified and options for accelerated uptake of improved WUE technologies and services will be identified. The current economics of investment in irrigation improvements will be explored including review of cost-benefit in system change and improvements (eg. changing from surface to pressurized systems, implementation of evaporation saving technologies).

4. Prepare case studies of both successful and unsuccessful adoption of WUE measures to illustrate opportunities for WUE investments with a focus on the main cropping systems in the study area.

5. Summarise future research needs and gaps in current knowledge for this part of the Murray-Darling Basin.

The report contains the following deliverables:

- An overview of irrigation in each of the valleys in the study area incorporating a discussion of crops grown and areas irrigated, irrigation systems used and associated on-farm infrastructure and water sources.
- Possible gains in WUE have been identified for each valley. Gains have been defined in terms of the sub-systems within an irrigated farm (ie. of-farm storage, on-farm distribution systems and in-field application systems).
- Key on-farm strategies to realize WUE gains have been identified and a review has been provided of current activities (research, development, extension and service provision activities) that will assist in achieving these WUE gains.
- Case Studies are included of irrigated farms that have made progress in achieving improved WUE. The Case Studies reflect the diversity of crop types and irrigation infrastructure throughout the Northern Murray Darling Basin.
- Economics for investment strategies including system conversion (field); system redesign (field) and mitigation of losses from farm dams.
- Gaps in current Research, Development, Extension and Service Provision activities have been identified and strategies for investment to maximize WUE gains are identified.

1.3 Understanding Water Use Efficiency

1.3.1 Water Use Efficiency definitions and measures

Water use efficiency (WUE) is a concept that has historically caused much confusion for scientists, water suppliers and end users alike. Much of this confusion has stemmed from the range of terms available to describe water use efficiency and a lack of understanding of what
WUE represents. A nationally accepted framework and terms and definitions for water use efficiency in irrigation have been developed in the project “Determining a Framework, Terms and Definitions for Water Use Efficiency in Irrigation” through the National Program for Sustainable Irrigation (Purcell and Currey 2003).

Water Use Efficiency as used in this report is used as a generic label for any performance indicators used to study water use in crop production. WUE can be considered as a toolbox containing many specific performance indicators referred to as water use indices and irrigation system efficiencies.

Water Use Efficiency can be considered at a number of spatial scales from a whole-of-system scale down to the individual element of an irrigated system at the farm level.

At the whole-of-system scale, the assessment of water use efficiency can be defined in very broad terms as a ratio of the accounted for water (water used for irrigation and measured end of system flows) to the total water flowing into the system (dam releases + gauged tributary inflows) (Fairweather 2005). Assessment at the whole-of-system scale can assist in the prioritisation of opportunities for increased water use efficiency on a valley basis.

In comparison, Water Use Efficiency at the farm scale can be assessed on individual elements of the irrigation system or an aggregation of all of these elements (eg. a whole farm). The time scales for a WUE assessment at the farm scale can vary from an event basis through to a seasonal or annual assessment for each or all of the elements.

The range of spatial and time scales used to assess Water Use Efficiency are summarized in Table 1.

Table 1 Classification of water losses in irrigation

<table>
<thead>
<tr>
<th>ViewPoint</th>
<th>Types of measure</th>
<th>Spatial scale</th>
<th>Time scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water supply &amp; distribution system</td>
<td>Volumetric efficiencies</td>
<td>Whole system and its components</td>
<td>Year or season</td>
</tr>
<tr>
<td>Irrigation application method</td>
<td>Volumetric efficiency, uniformity and adequacy</td>
<td>Sub-elements of field</td>
<td>Individual irrigation</td>
</tr>
<tr>
<td>Irrigation enterprise</td>
<td>Water use efficiencies</td>
<td>Whole farm</td>
<td>Year or season</td>
</tr>
</tbody>
</table>

Source: NCEA (2006)

The following water management sub-systems exist on most irrigated farms (Raine 1999):
- supply systems (e.g. harvesting or lifting from river and captured overland flows; pumping groundwater from bores; and/or supply from irrigation scheme dams, channels and/or pipes);
- on-farm storage systems (e.g. ring tank storage cells; buffer holding dams; or catchment dams);
• on-farm distribution systems (e.g. earthen channels; gated pipes; or pressurised enclosed systems);
• application systems (e.g. surface, spray, micro-systems); and
• recycling systems (e.g. tail drains and tail water recycling channels and utilising supply harvesting pumps; or catch drains feeding into holding dams).

The efficiency of water use can be defined for each of these sub-systems based on the volumetric water inputs and outputs, or uses and losses. Potential volumetric losses (or inefficiencies) within each of these sub-systems must be measured or estimated accurately to quantify whole farm water use efficiency. Irrigation system efficiencies compare a water output to a water input at different points of the farm or irrigation system. Hence, efficiencies have the same units for both input and output, and are described as ‘dimensionless’ and expressed as a percentage.

A major concern with the sole use of volumetric efficiency terms (irrigation system indices) for irrigation evaluation is that they do not provide any assessment of the overall irrigation performance in relation to crop production and economic returns. Water use indices typically compare a production output (yield, return, gross margin) to a water input (such as irrigation water, total water, or evapotranspiration) at some level in the farm or production system. As such, they have defined units: kg/mm, bales/ML, $/ML. Water use indices must be explicitly defined in terms of both the inputs used and the measurement units, but they are flexible and can be tailormade to suit a particular use.

1.3.2 Strategies for improving on farm water use efficiency

The strategies to improve water use efficiency (WUE) and productivity revolve around the central themes of reducing losses out of the system (i.e. evaporation, deep drainage, run-off) and employing appropriate agronomic strategies. The most effective strategy will be dependent on the individual farm, crop and management constraints.

Strategies for improving water use efficiency can be broadly categorized in terms of planning, design, management and monitoring. Specific examples of each are included below (but not limited to):

Planning / Investigations
• Determination of seepage / evaporation losses
• Assessment of efficiency of irrigation system (surface irrigation evaluation, evaluation of uniformity and application for centre pivot/lateral move and drip irrigation)
• EM Surveys (storages – identify potential seepage areas, fields – appropriateness of soils for irrigation system)
• Land and Water Management Plans

Design Changes
Use of evaporation mitigation measures (covers, shadecloth, monolayers, modular cover systems
• Use of seepage mitigation measures (chemical or physical)
• Storage redesign (use of cells, deeper storages, improve embankment integrity, ‘eco-friendly’ ring tank)
• Redesign of distribution systems (minimising channel lengths, pipe delivery)
• Efficient field design (slope, length)
• Alternative irrigation systems (centre pivot/lateral move, trickle, drip)
• Improvements to alternative irrigation systems
• Tailwater return systems (surface irrigation)

**Operational / Management Changes**

Objective irrigation scheduling (accurate measurement of soil water deficit, consideration of weather forecasts)
• Minimising water surface area (emptying unused channels, sumps, tail drains)
• Preferentially storing water in more efficient storages
• Use of inefficiently stored water first
• Applying efficient surface irrigation principles (times to cut-off, syphon flow rates)

**Monitoring Changes**

Storage volume monitoring
• Flow metering
• Whole farm water balance modelling

### 1.3.3 Mechanisms for increasing on farm water use efficiency

There are three main mechanisms to facilitate improvements in on-farm WUE (Marsden Jacob Associates 2003):

1. to narrow the range of WUE performance in each sector within the current technology by moving average practice toward the ‘best practice’, sometimes referred to as ‘pulling up the tail’;
2. to promote improved practices and technologies to establish a new level of best practice; and
3. to encourage the movement of water to sectors that use water more efficiently.

This project has focussed on the first two mechanisms: to narrow the range of WUE performance within each sector and improve WUE through innovation. Consideration has not been given to the potential savings in water consumption that could be generated through the transfer of water to a higher value sector with a greater WUE.

### 1.4 Methodology

This project has focused on reviewing existing studies and data. This review has focused on, but was not limited to, previous work in the Northern section of the Murray Darling Basin. Consultation has been undertaken with relevant agencies and research institutions, however this has been limited to collating relevant information. Consultation has occurred via meeting with the Northern Murray darling Basin Working Group and individuals from key...
organisations. To compliment synthesized material from previous work, case studies were developed to identify drivers for private investment in WUE and innovative on farm measures.
2 Overview of Valleys

2.1 Study Area

The Northern Murray Darling Basin is shown in Map 1. The downstream limit of the Darling Basin is at the confluence of the Darling River Basin with the Murray River in the south. However, the area of interest for this project extends only as far as the last significant irrigation enterprises just south of Menindee lakes at the upper end of the Lower Darling section.

The Darling Basin covers an area of 699,000 square kilometres, and makes up 70% of the total area of the Murray-Darling Basin. Approximately one third is in Queensland and two thirds in New South Wales. East-west, the Basin extends 1250 km, from the most easterly point near Warwick to north-west of Goolwa, the most westerly. The distance from its northern most point to its most southern is approximately 1,100 kilometres.

The Darling system receives most of its water from runoff from the relatively high rainfall, low evaporation Great Dividing Range, along its eastern edge (Webb McKeown & Associates Pty Ltd 2007). This runoff feeds the Macintyre and a series of major tributary streams, the Gwydir, Namoi, and Macquarie/Bogan systems. These travel in a mostly north-westerly direction and enter the south west flowing main stem of the Upper Darling between Mungindi and Bourke. Another series of rivers, the Warrego, Paroo, Nebine and Condamine-Balonne drain the northern section of the basin and also intersect the Darling upstream of Bourke. They generally drain a lower rainfall, higher evaporation area of the Basin. The Condamine-Balonne is the only one of these northern tributaries that contributes substantial flows to the Darling.

The Darling Basin is flatter and much less mountainous than the neighbouring Murray Basin (Webb McKeown & Associates Pty Ltd 2007). Some 60% of the Darling Basin is less than 300 metres above sea level. Even its eastern Great Dividing Range edge is often less than 1000 metres above sea level.

The low land slopes that characterise most of the Basin mean that the Darling and its major tributaries are very low energy rivers over the majority of their length. This, coupled with very variable rainfall and runoff, has meant that most of the Darlings tributaries have formed “inland deltas” in their lower reaches. The downstream portions of the Condamine-Balonne, Gwydir, Namoi, Macquarie, and Paroo are all classified as “distributary”, ie. they become a series of branching channels that distribute their flows across large areas especially during flood times.
Map 1 Darling River Basin - Study Area
For the purposes of this report, the study area has been divided into a number of river valleys:

- Border Rivers (NSW) Valley;
- Border Rivers (QLD) Valley (including the Moonie River);
- Condamine-Balonne Valley;
- Gwydir Valley;
- Namoi Valley;
- Macquarie Valley (including the Bogan and Castlereagh Rivers);
- Warrego Valley (including the Nebine and Paroo Rivers);
- Barwon-Darling Valley; and
- Lower Darling Valley.

The valley boundaries are based on a combination of river catchment boundaries, administration boundaries (e.g., NSW and QLD state border) and catchment characteristics (e.g., grouping of Warrego, Nebine and Paroo Rivers).

### 2.1.1 Climate

Much of the Darling Basin can be classified as arid with average annual rainfall exceeding 1000 mm in just a few small areas along the Basin’s eastern boundary. Rainfall over most of the Basin is less than 650 mm and drops to just 250 mm along the Basin’s western boundary (see Map 2).

Rainfall in the Basin also shows some seasonal variability (Webb McKeown & Associates Pty Ltd 2007). In the upper section of the Basin, the area that produces most of the runoff, rainfall is summer dominated. For example, the ratio of average rainfall between November and April to rainfall between May and October for Toowoomba is 1.9, Mungindi 1.6 and Tamworth 1.3. The middle section of the basin shows no significant seasonal variation. The ratio for Mudgee is 1.1 and Menindee 1.0. This means that Toowoomba has approximately twice as much rainfall in summer as in winter, whereas Menindee has approximately the same rainfall in both seasons. Only in the south-western corner of the Basin is rainfall winter dominated, with Wentworth’s rainfall being approximately 43% more in winter than in summer (summer/winter ratio 0.7). This is in marked contrast to the Murray system, which is dominated by winter rainfalls.

Evaporation rates are high right across the Basin, and everywhere average annual evaporation rates exceed average annual rainfalls. For all but a very thin strip in the east of the Basin, annual evaporation averages exceeds 1700 mm rising to greater than 2300 mm at Bourke and St George in the west.

### 2.1.2 Crops Grown

A study by Bryan & Marvenak (2004) provided a broad scale assessment of the distribution of agricultural land use from 1996/97 to 2000/01 in the Murray-Darling Basin (MDB). This baseline data has been used as the basis for assessing the distribution of crops grown in the
study area. The areas irrigated in each valley are provided in Table 2 for 2000/01 and Table 3 for 1996/97.
Northern Basin Program: On-farm water use efficiency in the Northern Murray-Darling Basin

Map 2 Average Annual Rainfall
Map 3 Point potential evapotranspiration
The area irrigated within the study area varies significantly year to year depending on water availability. For example, in 1996/7 approximately 390 000 Ha of land was irrigated. This increased to 510 000 Ha in 2000/1. Cotton is the dominant crop in terms of area grown (77% of irrigated area). Other broadacre crops including cereals, coarse grains, legumes and oil seeds account for 10% of the irrigated area. Pasture and lucerne is grown on a further 10% of the irrigated area. The remaining 3% is used for horticulture including vegetables, fruit trees, grapes and tree nuts (Figure 1). Significant irrigated areas occur in all valleys within the study area (Figure 2).

**Figure 1** Proportion of irrigated area by crop type in 2000/1

**Figure 2** Proportion of irrigated area by valley in 2000/1
### Table 2 Irrigated Area (ha) by Valley 2000/1

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Warrego</th>
<th>Condamine</th>
<th>Maranoa Balonne</th>
<th>Border Rivers (QLD)</th>
<th>Border Rivers (NSW)</th>
<th>Gwydir</th>
<th>Namoi</th>
<th>Macquarie</th>
<th>Barwon Darling</th>
<th>Total commodity</th>
<th>% of total Northern MDBC</th>
</tr>
</thead>
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<tr>
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<td>87%</td>
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<td>70%</td>
<td>91%</td>
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<td>5.3%</td>
<td>1.9%</td>
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<td>&lt;0.1%</td>
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<td></td>
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Source: Bryan and Marvenak (2004)
### Table 3: Irrigated Area (ha) by Valley 1996/7

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<th>Warrego</th>
<th>Condamine</th>
<th>Maranoa Balonne</th>
<th>Border Rivers (QLD)</th>
<th>Border Rivers (NSW)</th>
<th>Gwydir</th>
<th>Namoi</th>
<th>Macquarie</th>
<th>Barwon Darling</th>
<th>Total commodity</th>
<th>% of total Northern MDPC</th>
</tr>
</thead>
<tbody>
<tr>
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<td>20366</td>
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<td>37844</td>
<td>7600</td>
<td>5963</td>
<td>32754</td>
<td>17514</td>
<td>244041</td>
<td>76.9%</td>
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<td>% of valley</td>
<td>100%</td>
<td>63%</td>
<td>87%</td>
<td>74%</td>
<td>90%</td>
<td>94%</td>
<td>72%</td>
<td>56%</td>
<td>67%</td>
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<td>11.1%</td>
<td>29.6%</td>
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<td>954</td>
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<tr>
<td>% of valley</td>
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<td>&lt;0.1%</td>
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<td>0.1%</td>
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</table>

Source: Bryan and Marvenak (2004)
More recent information (post 2001 Agricultural Census) is available on the Irrigated Cotton areas within the Northern Murray Darling Basin (Table 4). Cotton irrigated areas have varied significantly with the area irrigated ranging from 135,400 ha to 385,100 ha in the period 2000/01 to 2005/06. During this period, the greatest driver impacting on the area of irrigated cotton has been water availability.

Table 4  Irrigated Cotton areas by Valley, 1999/2000 to 2005/06

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Source: Australian Cottongrower (2001, to 2006)
2.1.3 River Flows and Water Supply Infrastructure

Runoff into rivers in the Darling Basin is just 30% of total runoff in the Murray-Darling Basin, despite the Darling Basin accounting for 70% of the Murray-Darling’s total area. The Darling runoff figure equates to an average of just 11 mm across the Basin (Webb McKeown & Associates Pty Ltd 2007).

The rivers of the Darling Basin are highly variable. The minimum annual discharges recorded in the 3 major sources of water for the Darling system, the Namoi, Culgoa and Border Rivers were all well below 10% of their average discharge and their maximum annual flows between 400% and 800% of their average annual flow.

The first weirs were constructed across the Darling River in the late 19th Century, but it was not until the late 1950’s that construction of large-scale water supply infrastructure commenced in the Basin. Keepit Dam was the first major water supply dam constructed. It was completed in 1960. Over the next 30 years, another 10 large dams were constructed on the Darling’s major tributaries, primarily to supply water for irrigation.

The total volume of major dams on the Darling’s tributaries is 5,129 Gigalitres, equivalent to about 70% of the average annual runoff in the Basin. However, because the storages are constructed in the upper reaches of each system, only about 2,000 Gigalitres, or about 30% of runoff in the Basin, actually passes through a major dam. (Webb McKeown & Associates Pty Ltd 2007).

In the Darling Basin above Menindee, the augmentation of natural river flows by release of water from major dams (river regulation) is restricted to the main channels and a few effluents of the Macintyre, Gwydir, Namoi and Macquarie, and to short sections of the Condamine-Balonne system. No regulated supply is provided to the Barwon-Darling Valley. River regulated sections are shown in Map 4.

The ratio of major dam size to total runoff and the proportion of flows regulated by dams in the Darling Basin above Menindee are both much lower than in the Murray system. This means that a relatively high proportion of the flows in the Darling River above Menindee, and even in most of its regulated tributaries, are the direct result of runoff from rainfall and groundwater inflows rather than releases from dams (Webb McKeown & Associates Pty Ltd 2007).
Map 4 Major instream storages and River regulation
2.1.4 Irrigation Water Sources

Surface water used for irrigation in the Northern Murray Darling Basin is accessed from a number of sources, including:

Regulated Streams

Regulated water supplies are where water is released from a headworks (dam or weir in the river) and delivered to the irrigator either by river and/or an off-farm channel system. Schemes within the Northern Murray Darling Basin providing regulated water supplies are shown in Map 4.

Water users in regulated streams are issued with volumetric entitlements in both QLD and NSW. These entitlements specify a base volume of water that can be diverted each year and come in two main categories:

- High security entitlements which are available every year; and
- Normal security entitlements, which are subject to allocation announcements, made at intervals throughout the season.

For most regulated schemes within the Northern Murray Darling Basin, continuous accounting is in operation. Under this system, water users have individual accounts, which may build up to a specified percentage of the entitlement. The account increases when allocations are made and decreases as water is used. The usage in any season is limited to a specified percentage of the entitlement.

In all major irrigation valleys in New South Wales, other than the Barwon-Darling, most river extractions come from “regulated flows”. This means that they come from flows that are, at least in part, supplemented by water releases from headwaters dams. The dam releases, and extraction from “regulated flows”, occur when water is needed for crops or other purposes.

Regulated flow extractions in Queensland are only significant in the Border Rivers and a small section of the Condamine system.

Many irrigators on regulated streams are also able to extract water from natural flow events / access waterharvesting (termed ‘Supplementary Access’ in NSW and ‘Unsupplemented’ in QLD). Water is made available to irrigators in regulated streams during periods when storages are spilling or there are unregulated flows by declarations of period’s off-allocation. Water diverted in these periods does not count against an irrigator’s regulated allocation for the rest of the season. Extraction of flow events / waterharvesting is a significant source of supply in all regulated rivers in the Northern Murray Darling Basin, except for the Macquarie valley.

Unregulated Streams

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On-Farm Water Use Efficiency in the Northern Murray-Darling Basin
Unregulated streams are streams that are not controlled or regulated by releases from instream storages (dams and weirs). Entitlements on unregulated stream are defined in a number of ways including:

- Area based licences;
- Volumetric entitlements; and
- Waterharvesting licences that specify a minimum flow threshold in the stream before an irrigator can start pumping water.

Water is extracted from most unregulated rivers in the Basin. The largest volumes are taken from the Condamine in Queensland and from the Barwon Darling in New South Wales. Most of the unregulated water taken in these two systems is taken via large pumps or diversion channels at any time of the year that flows occur, and stored in ring tanks for later use on crops. Significant volumes of unregulated water are also taken for this purpose from Cox’s Creek and the Mooki River in the Namoi Valley.

In most other unregulated rivers, water is generally taken from rivers and applied direct to crops or into small hillside dams. The volumes taken in this manner are minor compared to the volumes extracted from the regulated rivers and the Condamine and Barwon-Darling systems. While these extractions may be minor in terms of volume extracted, they play a major role in supporting horticulture, particularly in areas such as the Granite Belt (Border Rivers QLD) and Bathurst Plains (Macquarie).

**Floodplain Harvesting (Overland flow take)**

Floodplain harvesting involves the capture of water on the farm via floodplain flows. Significant floodplain harvesting developments have occurred within the Condamine-Balonne valley.

**Groundwater**

Groundwater is a significant source of irrigation water supply in the Northern Murray Darling Basin. Most groundwater is extracted from alluvial sediment deposits within the Namoi, Gwydir, Macquarie, Border and Condamine Balonne Valleys. Fractured rock aquifers also provide a minor but locally important source of water particularly in the Upper Macquarie valley. The Queensland Basalts provide a major source of groundwater to irrigators in the eastern half of the Condamine-Balonne valley.

Estimates of water extractions from all water sources are provided by State agencies to the Murray darling Basin Commission and published annually in the MDBC Water Audit Monitoring Reports on the Cap on Diversions. The water diverted in each valley from 2000/01 to 2005/06 is included in Table 5. Average annual extractions of 1653 GL of surface water and 613 GL of groundwater have been recorded for the Northern Murray Darling Basin for 2000/01 to 2005/06.
### Table 5 Recorded Water Use by source and valley

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### Northern Basin Program: On-farm water use efficiency in the Northern Murray-Darling Basin

#### Annual water extractions (GL)

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Source: MDBC Water Audit Monitoring Reports on the Cap on Diversions.
Long term modeled data of surface water use was collated by Webb McKeown & Associates Pty Ltd (2007) and includes estimates of floodplain harvesting and onfarm rainfall capture not included in recorded water use in the MDBC Water Audit Monitoring Reports on the Cap on Diversions. The estimated long term modeled surface water extractions of 3195 GL is significantly higher than the 1653 GL of recorded extractions.

### Table 6 Average annual on-farm surface water use in the Darling Basin

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<td>Rainfall harvesting</td>
<td>Total Other</td>
<td>Total river system extractions</td>
<td>Extractions from hillside dams</td>
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<td>4</td>
<td>d</td>
<td>0</td>
<td>e</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Gwydir</td>
<td>318</td>
<td>82</td>
<td>d</td>
<td>15</td>
<td>e</td>
<td>415</td>
<td>429</td>
</tr>
<tr>
<td>Namoi/Peel</td>
<td>346</td>
<td>14</td>
<td>d</td>
<td>74</td>
<td>e</td>
<td>434</td>
<td>447</td>
</tr>
<tr>
<td>Macquarie</td>
<td>412</td>
<td>a</td>
<td></td>
<td>a</td>
<td>412</td>
<td>457</td>
<td>53</td>
</tr>
<tr>
<td>Condamine Balonne</td>
<td>533</td>
<td>144</td>
<td>d</td>
<td>a</td>
<td>677</td>
<td>693</td>
<td>67</td>
</tr>
<tr>
<td>Nebine</td>
<td>5</td>
<td>0.8</td>
<td>d</td>
<td>0</td>
<td>e</td>
<td>5.8</td>
<td>6</td>
</tr>
<tr>
<td>Warrego</td>
<td>49</td>
<td>0</td>
<td>d</td>
<td>0</td>
<td>e</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Paroo</td>
<td>0</td>
<td>0</td>
<td>d</td>
<td>0</td>
<td>e</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>198</td>
<td>13</td>
<td>d</td>
<td>29</td>
<td>e</td>
<td>240</td>
<td>258</td>
</tr>
<tr>
<td>Total Darling</td>
<td>2291</td>
<td>271</td>
<td>d</td>
<td>118</td>
<td>e</td>
<td>2680</td>
<td>2792</td>
</tr>
<tr>
<td>above Menindee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Darling</td>
<td>122</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>122</td>
<td>133</td>
<td>b</td>
</tr>
<tr>
<td>Total Darling</td>
<td>2413</td>
<td>271</td>
<td>d</td>
<td>118</td>
<td>e</td>
<td>2802</td>
<td>2925</td>
</tr>
<tr>
<td>Basin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

* a Not calculated by computer models for these valleys.
* b No data but probably very small.
* c The accuracy of estimates of water use from hillside dams is likely to be poor.
* d The accuracy of estimates of floodplain harvesting may be poor (see section 2.7.2.1).
* e The accuracy of estimates of rainfall harvesting may be poor (see section 2.7.2.4).

**Source:** Webb McKeown & Associates Pty Ltd (2007)
While significant irrigated areas occur in all valleys within the study area, the water sources that characterize these valleys vary markedly (Table 7), for example:

- The Macquarie catchment is a highly regulated catchment with almost all surface water extractions provided by releases from dams.
- Significant development of on-farm storage has occurred to allow access to supplementary water and floodplain harvesting opportunities.
- Unregulated flows provide all of the water used in the Moonie and Barwon-Darling Valleys.

Table 7 Water sources by valley

<table>
<thead>
<tr>
<th></th>
<th>Water diversions (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warrego</td>
</tr>
<tr>
<td>Regulated</td>
<td>1.9</td>
</tr>
<tr>
<td>Unregulated</td>
<td>0.9</td>
</tr>
<tr>
<td>Supplementary</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0.9</td>
</tr>
<tr>
<td>Supplementary</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>6</td>
</tr>
<tr>
<td>Waterharvesting</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>144</td>
</tr>
<tr>
<td>Floodplain</td>
<td>194.8</td>
</tr>
<tr>
<td>Groundwater</td>
<td>8.7</td>
</tr>
<tr>
<td>Total</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Water use based on MDB Commission audit reports for 2000/01 to 2005/06

a Supplementary (NSW) is water diverted during ‘off allocation’/unregulated flow events from regulated streams

b Waterharvesting (QLD) is water diverted from large flow events in both regulated and unregulated streams

c Estimates of floodplain harvesting based on long term modeled estimates from Webb McKeown & Associates Pty Ltd (2007)
**Farm dams**

The volume of on-farm storages for the Northern Murray Darling Basin has been estimated by Webb McKeown & Associates Pty Ltd (2007) and is shown in Table 8.

**Table 8 Volumes of major dams, weirs and farm storages**

<table>
<thead>
<tr>
<th>Valley</th>
<th>Major Dams</th>
<th>Weirs</th>
<th>Ring Tanks</th>
<th>Hillside Dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Border Rivers</td>
<td>641</td>
<td>15</td>
<td>459</td>
<td>119</td>
</tr>
<tr>
<td>Moonie</td>
<td>0</td>
<td></td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>Gwydir</td>
<td>1362</td>
<td>16</td>
<td>351</td>
<td>84</td>
</tr>
<tr>
<td>Namoi</td>
<td>882</td>
<td>23</td>
<td>190</td>
<td>402</td>
</tr>
<tr>
<td>Macquarie</td>
<td>2056</td>
<td>21</td>
<td>110</td>
<td>264</td>
</tr>
<tr>
<td>Condamine Balonne</td>
<td>188</td>
<td>51</td>
<td>1582</td>
<td>334</td>
</tr>
<tr>
<td>Warrego</td>
<td>0</td>
<td>10</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>0</td>
<td>35</td>
<td>298</td>
<td></td>
</tr>
<tr>
<td><strong>Total above Menindee Lakes</strong></td>
<td><strong>5129</strong></td>
<td></td>
<td><strong>2990</strong></td>
<td><strong>1347</strong></td>
</tr>
<tr>
<td>Lower Darling</td>
<td>2050</td>
<td></td>
<td>160</td>
<td></td>
</tr>
<tr>
<td><strong>Total Darling Basin</strong></td>
<td><strong>7179</strong></td>
<td></td>
<td><strong>3150</strong></td>
<td><strong>1347</strong></td>
</tr>
</tbody>
</table>

**Notes**

- a Estimate only, but believed to be within 10 Gigalitres of actual.
- b The estimated volume of on farm storages in the Lower Darling is only for Tandou Limited's farm. Other on farm storages are believed to exist, however it is understood that their volume is relatively small.
- c There is some doubt about the reliability of hillside storage data. Volumes are based on projections from small sample areas.
- d No estimate available but believed to be a relatively small volume.
- e No estimate available.


The reliability of the hillside storage data was identified and seem to be an overestimate. NSW Department of Water and Environment have estimated on-farm storage volumes of 524 GL in the Gwydir Valley; 100 GL in the Macquarie Valley; 204 GL in the Namoi Valley and 160 GL in the Border Rivers (NSW) Valley (Peter Christmas, DWE. 2007, pers. comm., 12 September). In particular, these estimates are significantly lower for the Namoi and Macquarie valleys.

While harvesting river flows into on-farm storages (ring tanks) is a significant source of supply for all valleys, a much greater reliance is placed on waterharvesting in valleys without significant regulated supplies and the proportion of on-farm storage to irrigated area is
greater as a result. This is particularly evident in the Condamine-Balonne and Barwon-Darling Valleys (Figure 3).

![Figure 4 Volume of on-farm storages by valley](source: Webb McKeown & Associates Pty Ltd (2007))

Webb McKeown & Associates Pty Ltd (2007) estimated the following annual net evaporation losses from storages:
- 225 GL from major river dams; and
- 1377 GL from on-farm storages (consisting of 727 GL from hillside storages and 650 GL from ring tanks).

Evaporation losses from major headwaters dams in the study area are small relative to evaporation losses from on farm water storages (i.e. ring tanks and hillside dams). Also, in terms of the area irrigated, net evaporation losses from storages in the Darling Basin are large. Evaporation is a much more significant contributor to water use 'inefficiencies' in the Darling than in the Murray system, because of the much greater use of ring tanks to store water.
2.2 Warrego/Paroo/Nebine

The Warrego Valley consists of three independent river systems, the Warrego, Nebine and Paroo catchments located in the north western corner of the Darling Basin. The Warrego valley covers an area of 192,500 km².

For the purposes of this study, the Warrego Valley has been defined as the Queensland portions of the Warrego, Nebine and Paroo catchments. Irrigation enterprises at the downstream sections of the Paroo and Warrego Rivers have been included in the Barwon-Darling Valley.

**Warrego Catchment**

The Warrego River has its source in the Carnarvon Range at the most northerly point of the Murray-Darling Basin and meets with the Darling River upstream of Louth in New South Wales. The catchment covers a total area of some 78 400 square kilometres of which 84% lies in Queensland.

The Warrego catchment is in an area extremely variable rainfall. Annual average rainfall is in the range of 250 millimetres in the lower reaches to more than 650 millimetres in the more elevated sections.

Regulated water supply is provided from the Alan Tannock Weir in the Cunnammulla Water Supply Scheme on the Warrego River. The Allan Tannock Weir was completed in 1991 as a source of water for the surrounding landholders and to provide water for the irrigation of park land in and around the township of Cunnamulla. The scheme provides irrigation water to landholders along the ponded area of Allan Tannock Weir. 2.6 GL of irrigation allocations are provided from the scheme.

A further 40GL of allocations for harvesting unregulated river flows are included in the Warrego, Paroo, Bulloo and Nebine Resource Operations Plan 2006 (Department of Natural Resources and Mines (Queensland) 2006). River flows are highly variable in the Warrego River and as a result waterharvesting opportunity is limited. From 2000/01 to 2005/06, an average of 6 GL per year has been extracted from unregulated flows (out of a possible 40 GL of allocation). On-farm storages are essential to facilitate irrigation for landholders accessing unregulated river flows. The volume of on-farm storages within the Warrego valley has been estimated at 19 GL (Webb McKeown & Associates Pty Ltd 2007).

The key crops grown in the valley are pasture (for beef cattle), cotton and grapes. There is a single large irrigation development in the Warrego catchment extracting water for cotton production (Natural Resources and Mines 2002). Regulated water supplies are used for pasture, cotton and grapes. Unregulated water supplies are used for irrigating cotton and pasture.
Table 9 includes previous estimates of irrigated areas by commodity in the Warrego catchment.

Eight irrigators in the Warrego Valley were surveyed by Potter (1999) to identify the systems used for irrigation in the Queensland Murray Darling Basin. 50% reported using spray irrigation, 25% used furrow and 25% used drip.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1996/97 a</th>
<th>2000/01 b</th>
<th>1997 c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1201 ha (100%)</td>
<td>293 ha (5%)</td>
<td></td>
</tr>
<tr>
<td>Pasture (beef)</td>
<td>5290 ha (90.1%)</td>
<td>93.2%</td>
<td></td>
</tr>
<tr>
<td>Fruit (grapes)</td>
<td>286 ha (4.9%)</td>
<td>2.3%</td>
<td></td>
</tr>
<tr>
<td>Cereals</td>
<td></td>
<td>2.3%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1 ha</td>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1201 ha</td>
<td>5870 ha</td>
<td></td>
</tr>
</tbody>
</table>

a & b Sourced from Bryan and Marvenak (2004)

Nebine Catchment

The Nebine catchment incorporates the catchments of Nebine, Mungallala and Wallam Creeks. The catchment covers a total area of some 38 100 square kilometres of which only 1% lies in New South Wales. The Nebine catchment is in an area with extremely variable rainfall. Annual average rainfall is in the range of 300 millimetres in the lower reaches to approximately 550 millimetres in the more elevated sections in the northern part of the catchment.

Irrigated crops are almost non-existent. The Warrego, Paroo, Bulloo and Nebine Resource Operations Plan 2006 (Department of Natural Resources and Mines (Queensland) 2006) identifies a total allocation of 2 GL for irrigation in the Nebine catchment. All of this allocation is from harvesting unregulated river flows.

Paroo Catchment

The Paroo catchment covers more than 76 000 square kilometres of inland Australia. Approximately half of the Paroo catchment is contained in Queensland. The Paroo River flows from its source in the Warrego Range and discharges onto a floodplain south of Wanaaring as it approaches the Darling River between Tilpa and Wilcannia.

Irrigation crop production in the Paroo catchment is small scale and restricted to a date and fig farm at Eulo and providing supplementary feed for stock (Natural Resources and Mines 2002).

The Paroo catchment is in an area of low rainfall and high evaporation. Annual average rainfall is in the range of 200 to 400 millimetres with almost 70% of the area receiving on average less than 300 millimetres per annum.
Water Availability

The Queensland Government has identified additional irrigation allocations of 8GL in the Warrego catchment and 1 GL in the Nebine catchment as part of the Water Resource Planning process (Department of Natural Resources and Mines (Queensland) 2006). As yet these allocations have not been made available for purchase by irrigators.
2.3 Condamine-Balonne

The Condamine-Balonne valley forms the north-eastern boundary of the Darling Basin, rising in the east at the Great Dividing Range and eventually entering the Barwon River via various effluent streams near Brewarrina. The Condamine-Balonne Valley covers an area of approximately 109,000 km² of which 85% lies in Queensland.

For this report, the Condamine-Balonne valley will include only the Queensland portion of the Condamine-Balonne catchment.

2.3.1 Condamine Catchment

The Condamine catchment covers an area of approximately 29,000 km². Major towns in this catchment include Warwick, Toowoomba, Dalby and Chinchilla. The Great Dividing Range bounds the area in the east, rising to almost 1,400m in places. The southern boundary is formed by the Herries Ranges, presenting a much lower (to 800 m) border than in the east. Tributaries of the Condamine River flow through relatively narrow valleys at the headwaters, with a gradual broadening to wide alluvial plains near the Condamine River.

The Condamine catchment has a highly variable subtropical climate. Annual average rainfall varies from 955 mm at Toowoomba to 682 mm at Chinchilla and is summer dominant. A strong rain shadow exists on the eastern Downs, in the lee of the Great Dividing Range. Low-lying areas are subject to frequent and severe frosts in winter.

The most common soils are the black, brown, grey, or red Vertosols (cracking clays), which are renowned for high fertility. The climate and fertile soils allow for the growth of crops in both winter (wheat, barley, oats, chick peas) and summer (sorghum, sunflower, maize, cotton and mung beans).

Groundwater is a major source of reliable supply, with approximately 200 GL accessed by irrigators.

Regulated water supplies are provided by Leslie Dam (constructed 1961) and Chinchilla Weir (constructed 1973). Approximately 30 GL of irrigation allocation is supplied to the Upper Condamine Water Supply Scheme (Leslie Dam) and a further 3 GL of irrigation allocation from Chinchilla Weir Water Supply Scheme.

Access to unregulated surface water flows is integral to many irrigation operations with irrigators supplementing their regulated river supplies or basing their entire operations on water harvested during floods, which is then held in on-farm storages. Surface water access is of an opportunistic nature.
2.3.2 Irrigation Enterprises – Condamine

A wide variety of broadacre crops are grown in the Condamine catchment. Cotton is the most significant in terms of areal extent, however significant areas of pasture, cereals, coarse grains and broadacre horticulture are also grown.

Cotton

The Darling Downs is the major cotton production area of Queensland. The region is centred around Dalby with 350 cotton growers (185 irrigated, 165 dryland) and a seasonal area of 80,000 to 85,000 hectares. It extends east to Toowoomba, south to Pittsworth and Cecil Plains, and west to Condamine and Chinchilla. Both the grains and cotton industry are well supported by regional centres with grain terminals, milling facilities and well established support services (Goyne, McIntyre et al. 2000).

Over the last few years, with the growth of the irrigated cotton industry, there has been a large increase in the number of on farm storage systems. These systems (mainly ring tanks) are regulated with allocated licenses that permit the harvesting of water when the river is above a certain flow level. They are designed to store the fluctuating seasonal flows from rivers to be used at more suitable times. By far the largest increase has been in the number of unregulated overland flow storage systems and a large number of growers are dependent on these systems for their irrigation water.

Satellite imagery of the Darling Downs in 1998 (following a wet winter) indicated that there are 310 storages (mostly ring tanks) in the Darling Downs region (John Porter, Sinclair Knights Merz 2000, pers commun.). It is estimated that these cover an area of about 3567 ha with an average depth of 4.5m. The volume of water which therefore can be potentially contained is approximately 161 GL. These figures compare well with DNR 1997 estimates of 293 tanks holding 160 GL.

Some irrigated growers on the Darling Downs also rely on underground water supplies to supplement their allocations. In some cases the allocations are restricted where extraction rates exceed the replenishment rates. In other areas in the region the quality of the water is low and it is often mixed with surface water to reduce the effects of dissolved minerals.

The areas of the irrigated cotton and grains are heavily dependent on available water in storage and the predominant seasonal conditions. If the security of the water is low then the grower is most likely to select a crop with a lower water requirement or choose to fallow. Figure 4 shows the variation in area planted to cotton from 1994/5 to 2004/5.

In 1998/99 high soil moisture and good storage levels contributed to a record cotton planting of 86,000 hectares, with 50% of this area irrigated. The 1999/00 season saw similar water storage levels and soil moisture, but lower prices resulted in a reduced area planted (43,000 ha irrigated; 30,000 ha dryland) (Goyne, McIntyre et al. 2000).
On the Downs the principal method of cotton irrigation is furrow as cotton is normally grown on the heavier black cracking clays soils. These soils are regarded as well suited to furrow irrigation and the relatively low cost of establishment has led to its wide adoption. A few growers have adopted a number of precision applicators in the form of pivots, laterals and drip. These growers have adopted these systems for a number of reasons, such as low water security or unsuitable soil types for furrow irrigation. Adoption has been slow due to the higher initial capital cost and the lack of suitably proven systems.

**Other Broadacre**

Most irrigated grains are only supplementary irrigated on a basis of water availability. In the Condamine catchment, wheat and sorghum accounted for 50% of the crops being used in rotation with cotton.

Potter (1999) in his survey of irrigation systems being used, found 33% of the irrigation is conducted from open supply drains down furrows in grains compared with 86% in cotton.

**Dairy**

As part of a benchmarking exercise for the Rural Water Use Efficiency Initiative, 441 dairy farmers were identified irrigating pasture on the Darling Downs (Barraclough & Co 2000). The area of pasture irrigated included 8,006 ha of winter pasture and 6,817 ha of summer pasture. The average application rate was 6.3 ML/ha in winter and 6.8 ML/ha in summer.
Approximately 97 GL of water were used annually for irrigating pasture for dairy. 55% of the water used was sourced from groundwater. 75% of irrigation was undertaken with high pressure systems (hand shift, winch) with 19% using centre pivots / lateral moves and a further 6% using traveling booms. Only 6% of dairy farmers used irrigation scheduling.

**Lucerne**

As part of a benchmarking exercise for the Rural Water Use Efficiency Initiative, 206 lucerne irrigators were identified on the Darling Downs (Barraclough & Co 2000). 2,002 ha of Lucerne was irrigated with an average application rate of 9.4 Ml/ha. Approximately 19 GL of water were used annually for irrigating lucerne. 60% of the water used was sourced from groundwater. 87% of irrigation was undertaken with high pressure systems (hand shift, winch) with 13% using lateral moves. 100% of farmers did not undertake irrigation scheduling.

**Horticulture**

A large proportion of horticultural production on the Darling Downs is focused in the Upper Condamine around Toowoomba and Warwick. Chinchilla is known for producing melons. Water is sourced from both underground and onfarm catchment dams with growers using drip, hand shift, solid set furrow and traveling guns for small crops and surface drip irrigation for tree crops. There are approximately 153 horticultural farming enterprises in this region (Queensland Fruit and Vegetable Growers 2000).

The Eastern Downs has significant volumes of summer lettuce and celery, and some potatoes and onions, whilst the Western Darling Downs grows large areas of rockmelons, honeydews and watermelons (Henderson 2007). The Eastern Darling Downs produces broad acre horticulture and consequently has a higher proportion of furrow irrigation.

The Chinchilla district is a small region producing mainly grapes and melons. The area is water constrained. A survey of 10 watermelon and rockmelon growers from the Chinchilla district in 2000 identified that trickle was used to irrigate 100% of the cropped area but only 30% of growers used soil monitoring equipment with the remainder scheduling irrigations by experience or assessing soil moisture by feel. The proportion of irrigators using soil monitoring equipment is likely to have increased in response to the subsequent QLD Rural Water Use Efficiency Initiative.

### 2.3.3 Maranoa-Balonne Catchment

The Maranoa-Balonne Catchment covers an area of approximately 63 670 km$^2$ from the Carnarvon Ranges in the north to the New South Wales border in the south. Major towns in this catchment include Roma, St George, Mitchell, Miles and Dirranbandi.

This system covers the Balonne-Culgoa Rivers and their associated floodplains downstream of Chinchilla. Below St George, the Balonne splits into a number of channels along the
floodplains (effluent streams) that continue downstream to NSW to the Barwon River upstream of Bourke.

Annual average rainfall is lower than the upstream Condamine catchment in the east. Annual average rainfall varies from 600mm at Roma to 517 mm at St George. Rainfall occurs mainly in the summer months.

Streamflows are highly variable in the Balonne catchment with recorded annual discharges ranging from 800% of the recorded mean to less than 5% of the recorded mean (Centre for Water Policy Research 1999).

The Lower Balonne catchment has experienced a major expansion of irrigated cotton over the past 15 years. The ability to take water varies among irrigators. A small portion of irrigators take water from a channel system fed from Beardmore Dam on the Lower Balonne. A number of others rely on surface water harvesting to offstream storages from the Lower Balonne river and tributaries, regulated by releases from Beardmore Dam; and yet another segment of irrigators rely on storing overland flow through bunds built to retain natural out-of-river. flows or overflow of water from the River (overland flows). Some irrigators have access to more than one of these sources.

In 1997/98 the water diversions in the Balonne-Culgoa system totaled 420 GL of which 350 GL was from water harvesting (unsupplemented water) (Varley 2001). Opportunities to divert water (from overland flow and unsupplemented water) have been significantly reduced in recent years (2000/1 to 2005/6) with unsupplemented diversions averaging 130 GL and being as low as 11 GL (in 2001/2). These estimates do not include water extracted as overland flow.

The Lower Balonne Water Supply Scheme supplies regulated water to a number of irrigators in the St George area. The scheme dates from the mid 1950s when the construction of the Jack Taylor Weir provided a water supply for St George and made possible the irrigation of some 2,700 hectares. In 1972, construction of the Beardmore Dam allowed for the expansion of the irrigation scheme into what now spans 9,470 hectares of irrigable land. A network of channels and drains serves land on the left bank of the Balonne River extending 32 kilometres south-east of St George. Irrigation allocations have also been granted to riparian landholders on a regulated section downstream of the Beardmore Dam. Water is supplied for the irrigation of cotton, wheat, grapes, melons, peanuts and small crops.

### 2.3.4 Irrigation Enterprises – Maranoa Balonne

**Cotton**

62 cotton growers are located within the two main cotton growing areas (St George and Dirranbandi areas) in the Maranoa-Balonne catchment.

The area under cotton is generally grown surrounding St George through the area serviced by the Lower Balonne Water Supply Scheme and then along Culgoa and Ballandoo Rivers.
from St George through Dirranbandi and close to Hebel. This latter area, the Dirranbandi irrigated cotton growing area, is approximately 120km long by about 20km wide.

Irrigated cotton is the major crop in the St George with a few irrigated peanut and wheat crops throughout the district. In total, there are approximately 44 cotton growers, 3 irrigated peanut growers and 2 irrigated wheat growers. The irrigated cotton crop is sown over some 18 500 hectares, producing approximately 138 750 bales and netting $55.5 million per year (Goyne, McIntyre et al. 2000).

Irrigated Cotton and Grain growers in the St George district source the majority of their water from the Maranoa/Balonne rivers through Beardmore Dam. In most years, growers receive 100% of their allocation which amasses some 75 000 ML. Growers in the irrigation area can also water harvest at certain times through a water harvesting agreement with State Water. On the whole the farms supplied by the Lower Balonne Water Supply Scheme are small in size and have smaller or in some cases no capacity to store water.

Dirranbandi is 100 kilometres south-west of St George. The Dirranbandi irrigated cropping economy has experienced considerable growth and development in the recent years. The Dirranbandi area was traditionally a predominantly wool, cattle area. It now produces over 165 000 bales of cotton per year (Goyne, McIntyre et al. 2000).

Dirranbandi irrigated cotton farms are typically large, well-developed enterprises which retain several water harvesting licenses. For example, 44 growers farm 18 500 hectares of irrigated cotton in St George. In comparison, only 18 growers farm 22 000 hectares in Dirranbandi. These farms are situated on a grey, cracking clay floodplain and have considerable storage infrastructure. The irrigation systems carry large flows of water and as such have appropriate infrastructure to handle this.

The area of land developed for irrigation is significantly greater than the area planted in recent years due to water shortages. Approximately 32,000 Ha (St George) and 34,000 Ha (Dirranbandi) have been developed primarily for irrigating cotton (Australian Cottongrower 2006).

**Horticulture**

A number of horticulture enterprises are located in the St George district with crops grown including table grapes, melons and onions. Most water is sourced from regulated supplies from the Lower Balonne Water Supply Scheme. Crops are irrigated predominantly using micro irrigation systems.
2.4 Border Rivers

2.4.1 Valley Overview

The Border Rivers and Moonie River Catchments are located west of the Great Dividing Range along the New South Wales-Queensland border. The total area of the catchment is 64,000 km² of which 60% is in Queensland. The Border Rivers Catchment drains the New England Tablelands of northern NSW and southern QLD. Further down the catchment are open areas of the slopes and riverine plains of the Weir-Macintyre-Dumaresq and upper Barwon River systems.

The Border Rivers (QLD) Valley occupies an area of approximately 23,900 km² and consists of creeks and rivers that drain into the Dumaresq–Macintyre–Upper Barwon River system of NSW. The principal Queensland tributaries are the Severn River, Pike Creek, Macintyre Brook, the Weir River and Moonie River.

The Moonie River catchment covers 16,000 km², almost all of which lies within Queensland. The Moonie River joins the Barwon River downstream of Mungindi in northwest NSW. For the purposes of this report, the Border Rivers (QLD) Valley includes the Moonie River catchment.

The Border Rivers (NSW) Valley occupies an area of approximately 24,000 km². The principal rivers that drain the inland slopes of the eastern highlands are the Dumaresq, Severn and Macintyre. The Border Rivers (NSW) Valley is bounded by the Great Dividing Range in the east and the Gwydir Catchment in the south and the Queensland border in the north and west.

The Queensland-New South Wales border consists mainly of the Dumaresq, Macintyre and Barwon Rivers.

Rainfall in the Border Rivers is summer dominant with annual average rainfall ranging from approximately 800mm along the Great Dividing Range (Glen Innes 858 mm; Stanthorpe 770 mm), decreasing to approximately 600mm at the centre of the region near Goondiwindi and down to 500mm at the western edge of the region (Mungindi).

Regulated watercourses in the Border Rivers (NSW) Valley include the Dumaresq, Severn and Macintyre rivers. Regulated watercourses in the Border Rivers (QLD) Valley include the Dumaresq and Macintyre Rivers and Macintyre Brook. The Moonie River catchment is entirely unregulated.

Regulated rivers are controlled by storages and weirs at the top of the catchment that capture and release water for irrigation downstream. Pindari Dam regulates the Severn and Macintyre rivers. Glenlyon Dam regulates a short section of Pike Creek in Queensland, the Dumaresq River and the Macintyre River. The major river regulating works that control the flow of water to the NSW and QLD are shown in Table 10. A series of regulating weirs control the flow of water downstream of the major storages.
Table 10 Major structures for river regulation in the Border Rivers catchment

<table>
<thead>
<tr>
<th>Structure</th>
<th>Completed</th>
<th>Capacity (ML)</th>
<th>Location</th>
<th>Sharing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenyon Dam</td>
<td>1976</td>
<td>254,000&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pike Ck</td>
<td>QLD &amp; NSW</td>
</tr>
<tr>
<td>Pindari Dam</td>
<td>1969</td>
<td>312,000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Severn R</td>
<td>NSW only</td>
</tr>
<tr>
<td>(enlarged 1994)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coolmunda Dam</td>
<td></td>
<td>69,000&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Macintyre Brook, Qld</td>
<td>QLD only</td>
</tr>
</tbody>
</table>

Sources: <sup>a</sup> Natural Resources and Water (2007); <sup>b</sup> Hope and Bennett (2003).

Water extraction in the Border Rivers has been controlled to some extent by interstate water-sharing agreements. The Dumaresq-Barwon Border Rivers Commission was formed in 1946 to oversee sharing between NSW and Queensland users. The Border Rivers NSW and Queensland Valleys differ from other valleys in the Northern Murray-Darling Basin due to their common river boundary. This characteristic intensifies the issues associated with cross-jurisdiction water sharing arrangements and the development of administrative arrangements to enable interstate trading of permanent water entitlements.

### 2.4.2 Irrigation Enterprises - Moonie River catchment

The Moonie River catchment is entirely unregulated. With no regulated water supply schemes in the Moonie and no sustained base flow, water harvesting diversions account for almost 100% of diversions in the system. There is currently a low level of overland flow development in the Moonie River catchment (Natural Resources and Mines 2002).

Irrigation is mostly associated with isolated pockets of cotton and to a lesser extent wheat, in the southern portion of the catchment (Natural Resources and Mines 2002).

32 unsupplemented (waterharvesting) licences are held by irrigators in the Moonie catchment totaling a nominal allocation of 29 GL. Average diversions in the period 2000/1 to 2005/6 have averaged 16 GL/year with diversions ranging from 3 GL (2005/6) to 31 GL (2000/1) depending on river flows and waterharvesting opportunity.

The Queensland Government has identified additional irrigation allocations of 1100 ML of unallocated water available in the Moonie catchment as part of the Water Resource Planning process (Office of the Queensland Parliamentary Counsel 2006).

### 2.4.3 Irrigation Enterprises - Border Rivers (QLD)

Irrigated cotton occurs on the floodplains and is worth approximately $300m p.a. Horticulture is worth approximately $90m p.a. and additional crops include peanuts, corn, olives, lucerne, soybeans, grapes, stonefruit and potatoes (Murray Darling Basin Commission 2004).
The average farm size in the Border Rivers–Moonie catchment is 2600 ha, and the average horticultural farm size (Stanthorpe region) is 385 ha (Murray Darling Basin Commission 2004).

**Cotton**

In addition Queensland produced, from the Border River region of south west Queensland (Macintyre Valley), together with that area of the valley which is in NSW, 374000 bales of irrigated cotton from 55,000 ha with an average yield of 6.8 bales per ha in 1998/99.

The Macintyre Valley is situated in southern Queensland. The main centre is Goondiwindi. The Macintyre river forms the state border between New South Wales and Queensland and roughly divides the valley in half.

There are 46 cotton growers in the Queensland section of the MacIntyre valley, extending as far west as Mungindi (29 in Goondiwindi area, 17 closer to Mungindi). A total of 22482 hectares of irrigated cotton was grown in the area in the 98/99 season (Goyne, McIntyre et al. 2000).

DNR annual statistics for the region indicates that a total of 74115 ML of water was harvested by Queensland Growers for irrigation of all crops from the Dumaresq River junction to the Mungindi Weir. All of the irrigated cropping in the valley is limited to the Macintyre and Weir Rivers and associated watering schemes such as the Yambocully Scheme. The Yambocully scheme sees water diverted out of the Macintyre into a channel that feeds the Yambocully Creek. Very little water is harvested from overland flows in this area.

The majority of irrigation along the floodplain area is furrow, a small amount of subsurface drip exists, and the use of overhead systems is on a slight increase. On the upper alluvium plains a combination of furrow, lateral move, centre pivot and hand move systems exist. Approximately 70% of the regions cotton irrigators have been using soil moisture measuring devices (Goyne 2002).

**Other Broadacre**

Cotton is the main irrigated crop in this valley, winter cereals and beans are watered if water is left over after the summer crop. Other summer crops grown under irrigation on the cotton farms include beans and corn. To the east of Goondiwindi, in the upper reaches of the valley, peanuts are grown under layflat and spray irrigation methods.

**Horticulture**

Horticulture in the Border Rivers (QLD) valley is concentrated in the Granite Belt at the eastern edge of the Border Rivers (QLD) valley, near the QLD/NSW border. The principal town is Stanthorpe. This is a traditional horticultural area primarily producing vegetables, deciduous fruit production, with a burgeoning wine industry, and some nursery and cut flower production. The Granite Belt is a major warm season production area for both leafy and
heading vegetables (lettuce, brassicas, celery), as well as tomatoes and capsicums. There are approximately 240 horticultural farming enterprises in this region.

Growers in the Granite Belt derive their water from on-farm catchment and storage. There is very little underground water supply and no regulated supply.

The last few years have seen a major evaluation and installation of drip irrigation in the Granite Belt region with most fruit trees, vines, and many vegetables (tomatoes, capsicums and cucurbits) are grown under trickle irrigation. Many of these growers have retained their solid-set systems to assist with crop establishment or to provide cooling irrigations in pre-harvest periods and to prevent late frost damage on some crops.

The system changes to drip irrigation have been supported by trials and demonstrations by drip suppliers, the Water for Profit program, and the DPI. Many producers would simply not have been able to produce viable areas of vegetable crops without switching to drip irrigation in the past 2 years (Henderson 2007).

**Lucerne**

As part of a benchmarking exercise for the Rural Water Use Efficiency Initiative, 277 lucerne irrigators were identified in the Inglewood district within the Border Rivers (QLD) valley (Barraclough & Co 2000). 3,886 ha of Lucerne was irrigated with an average application rate of 9.4 Ml/ha. Approximately 37 GL of water were used annually for irrigating lucerne. 73% of the water used was sourced from regulated supplies (Macintyre Brook Water Supply Scheme). Irrigation scheduling is not commonly practiced amongst Lucerne growers in this district.

A large percentage of the Lucerne and feed stocks (grown under irrigation) is supplied to two large cattle feedlots in Inglewood shire. The feedlots are the major employer in the shire and are dependent on a continual flow of feedstock to the feedlots (Natural Resources and Mines 2002).

### 2.4.4 Irrigation Enterprises - Border Rivers (NSW)

Hope & Bennett (2003) identified three distinct zones within the Border Rivers (NSW) Valley: tablelands, slopes and plains regions.

- The tablelands region lies east of Texas and Ashford and is characterised by granite and basalt tablelands.
- The slopes region lies west of Ashford and Texas and is characterised by undulating country with numerous permanent and semi-permanent billabongs. This zone extends to about 20 km downstream of Boggabilla.
- The plains region is downstream of Boggabilla where the terrain is undulating to flat. Floodplains stretch west towards Mungindi.
Plains region

Cotton occupies the greatest proportion of irrigated land within the catchment but its range is limited to the lower, flatter, western portion of the valley. On the Macintyre floodplains, past Boggabilla, the soil type most suitable to irrigated agriculture is the deep, grey cracking clay.

In 1996/7 80% of the irrigated area within the Border Rivers (NSW) valley was downstream of Boggabilla in the plains region. The average size of irrigation enterprises in this region was greater than 800 ha (Source: ABS 1998, cited in Hope & Bennett 2003).

On the floodplains, most broadacre crops (cotton, cereals, legumes and oilseeds) are irrigated by surface irrigation (furrow). Drip irrigation and centre pivots have also been installed for irrigating cotton. Vegetable crops are irrigated using centre pivots, spray systems or drip. Pasture is irrigated by spray systems (Hope and Bennett 2003).

Tablelands region

In the east of the catchment, irrigation occurs mostly on small river flats. The narrow floodplains of the upper catchment mainly consist of highly fertile alluvial deposits of loamy black soils. Lucerne is the major irrigated crop of the upper catchment but horticulture and viticulture are emerging as new enterprises. Pasture is also irrigated for fattening cattle.

Irrigation enterprises in the upstream sections of the valley are typically less than 50 ha in size (Source: ABS 1998, cited in Hope & Bennett 2003).

In the tablelands, fixed spray or bike shift systems are used for Lucerne. Much of the berry fruits, wine grapes, pome and stone fruits and some vegetables are irrigated using drip systems. Vegetables are also irrigated with sprinkler systems (Hope and Bennett 2003).
2.5 Gwydir Valley

2.5.1 Valley Overview

The Gwydir River Catchment covers an area of approximately 26,500 km². The Gwydir River rises in the New England tablelands near Uralla and travels approximately 700 km to the junction with the Barwon River north of Collarenbri. Major towns within the Gwydir catchment include Uralla, Guyra, Bingara, Warralda, Moree and Collarenebri.

The catchment contains three main landscapes – the tablelands, the slopes and the western alluvial plains. The majority of irrigation occurs in the western alluvial plains.

The western alluvial plains begin just west of Gravesend. In the lower reaches of the catchment, where the Gwydir joins the Barwon River, elevations are approximately 200 m. Just east of Moree, the landscape becomes flat and blacksoil plains extend west to the junction of the Gwydir and Barwon rivers. Near Moree, the first and largest effluent of the river, the Mehi River, begins. West of Moree, the waterway spreads into a series of channels that could be described as an inland delta. Numerous wetlands and anabranches cut through blacksoil plains and spread the discharges of the Gwydir River.

Soils vary throughout the catchment, reflecting complex topographic and geological characteristics. In the tablelands and slopes area, the steep landscape and poor fertility of soils adjacent to waterways seriously hamper irrigation development. On the slopes below Copeton Dam down to Biniguy, and along the Horton River, irrigation is restricted to alluvial soils on very narrow floodplains. The availability of good irrigation sites is limited.

West of Biniguy, self-mulching grey clays fan out into the plains of the Lower Gwydir catchment. This fan is around 5 km wide at Biniguy and extends to around 75 km wide at Boomi. It is in this area that most irrigation occurs. The area comprise undulating low hills and level plains of grey cracking clays.

The valley has a summer-dominant rainfall pattern with annual falls decreasing from nearly 900 mm in the east to less than 600 mm in the west. The Gwydir catchment receives about 60% of its mean annual rainfall from October to March.

**Crops grown**

Approximately 94% of the area irrigated in the Gwydir valley is used to grow cotton. The main irrigated crops in order of areal extent are cotton, cereals, oilseed, pasture fodder and Lucerne (Varley 2001). Nuts and stone fruit are also grown in smaller areas (348 ha and 143 ha respectively) in the Gwydir Valley (Bryan and Marvanek 2004). The total value of irrigated agriculture in 1996–97 was $245 million. Of that, $221 million was attributable to irrigated cotton (Hope and Bennett 2003).

The majority of irrigation occurs on properties on the Darling Riverine Plains downstream of Moree, with cotton being the dominant crop.
Between Biniguy to Moree, cereals, oil seeds and some irrigated cotton are produced. A large irrigated pecan nut plantation is located near Pallamallawa. Initial development of this nut farm occurred between 1968 and 1973 and the operation has a high security water entitlement of around 13,000 ML/year.

Due to the undulating landscape of the tablelands region, irrigation was not considered feasible. Very little irrigation occurs between the tableland and Biniguy as a result. Lucerne and pasture are grown in the upper catchment along the small alluvial floodplains close to the Gwydir River and its tributaries.

In 1998-99 the Gwydir Valley planted approximately 85,000 ha to irrigated cotton and a further 20,000 ha to dryland cotton. These areas were well up on areas attempted in the mid-90s due to vastly improved seasonal conditions (in the 1994-95 season the area planted to cotton fell below 20,000 ha). Total production in 1998-99 was about 674,000 bales. Although this was slightly less than for the previous season, it was worth over $300 million, much of it in export income (Centre for Water Policy Research 2000).

Cotton and cereal crops in the lower catchment are generally watered using surface methods. In the upper catchment, where lucerne and pasture crops dominate, pressure systems are used.

**Water Sources**

Irrigation water is mostly sourced from regulated surface supplies provided by Copeton Dam on the Gwydir River and a further 6 regulating weirs. Approximately 405 GL of regulated supply is used for irrigation (Hope and Bennett 2003).

On farm water storages play a significant role in water harvesting in the Gwydir Valley. Approximately one quarter of surface water extractions permitted under the Water Sharing Plan for the Gwydir Regulated River Water Source are for supplementary water access licences (‘off-allocation’ water) (Department of Infrastructure 2004).

Most irrigators in the Gwydir Valley have built farm dams for the purpose of capturing high flows generated by in-stream events below Copeton Dam. Presently there are about 115 ‘large’ farm dams in the lower Gwydir Valley, ranging in size from 500 to 15,000 ML (Centre for Water Policy Research 2000). Assessment of on-farm storage capacity in the Gwydir Valley include:

- a total volume of 430 GL in 2001/02 (Cox and Baxter 2003);
- 351 GL of ring tanks and 84 GL of hillside dams (Webb McKeown & Associates Pty Ltd 2007); and

Estimates of groundwater use for irrigation in the valley range from 15 GL (Varley 2001) to 35 GL (Hope and Bennett 2003). Much higher estimates of groundwater use have been included in Audit reports for Cap on Diversions for the MDB with groundwater diversions ranging from 61 GL to 101 GL in the period 2000/1 to 20005/6.
2.6 Namoi Valley

2.6.1 Valley Overview

The Namoi catchment region covers 42,000 square kilometres and supports a population of 94,000 people across 14 local government areas. The main towns include Barraba, Gunnedah, Manilla, Narrabri, Nundle, Quirindi, Tamworth, Walgett and Werris Creek.

The dominant watercourse is the Namoi River. Its tributaries arise from the Liverpool Ranges in the south, the Great Dividing Range in the east and the Nandewar Range to the north. Major tributaries of the Namoi River include Coxs Creek and the Mooki, Peel, Cockburn, Manilla, and McDonald Rivers, all of which join the Namoi upstream of Boggabri. The Namoi River joins the Barwon River at Walgett.

Split Rock Dam on the Manilla River and Keepit Dam on the Namoi River are the two main water storages in the valley. These structures allow the delivery of flows to meet the needs of water users downstream. Additional supply is provided by Chaffey Dam to irrigators on the Peel River near Tamworth.

The region contains three distinct landform types - tablelands, slopes and plains, each with distinctive patterns of drainage, soils, native vegetation, settlement and land use. The plains have been extensively developed for both grazing and dryland and irrigated agriculture. The main irrigation concentrations, including from groundwater supplies, occur as mainly individual property diversions, between Gunnedah to Boggabri, and Boggabri to Narrabri.

Regulated water is sourced from:
- the Upper Namoi Regulated River Water Source. This includes the regulated river sections between Split Rock Dam and Keepit Dam.
- the Lower Namoi Regulated River Water Source. This includes the regulated river sections downstream of Keepit Dam to the Barwon River, including the regulated sections of the Gunidgera/Pian system.
- the Peel River. This includes the regulated river sections downstream of Chaffey Dam to the junction with the Namoi River.

Groundwater is a significant resource in the Namoi catchment and has been extensively developed for irrigation and stock and domestic purposes, with the highest rate of groundwater use in New South Wales (Natural Resource Management 2007). Groundwater extraction is a significant when compared with the total volume of water sourced for irrigation in the valley. 46% of water used for irrigation between 2000/1 to 2005/6 was extracted from groundwater sources.

Deep drainage has been identified as an issue in the Liverpool plains (Ringrose-Voase, Young et al. 2003). The Liverpool Plains catchment occurs to the south of Boggabri and is bounded to the south by the Liverpool Ranges, to the east by the Melville Ranges and to the
west by the Warrumbungle Range and Pilliga Scrub. The Mooki River and Cox’s Creek drain the area northwards into the Namoi River. Parts of the Liverpool Plains incorporate irrigators in the Lower Namoi Regulated River, irrigators using unregulated and groundwater sources in the Mooki River and Cox Creek catchments and dryland cropping.

2.6.2 Irrigation Enterprises

The average annual irrigated area is approximately 75,000 ha with the main irrigated crops, in order of areal extent, being cotton, cereal/wheat, fodder/pasture and lucerne (Varley 2001). The Namoi catchment is a significant growing region in Australia, with an average of 68 800 hectares of cotton grown annually. Significant areas of cereals, coarse grains and oilseeds are irrigated within the Namoi Valley.

There are two main cotton growing areas in the Namoi Valley. The lower cotton growing area extends along the Namoi River from Narrabri to Walgett. Cotton is also grown extensively in the Liverpool plains including along the Namoi River from Gunnedah to Boggabri; along Mooki River and Cox Creek.

Lucerne in the Peel Valley

Unlike lower sections of the Namoi Valley that are dominated by cotton, lucerne hay grown under spray irrigation is the main irrigated crop in the Peel Valley. Crean, Scott et al (2000) identified approximately 3,500 ha of irrigated crops and pasture in the Peel Valley with lucerne accounting for as much as 76% of the irrigated area (Table 11).

Table 11 Agricultural production in the Peel Valley for 1996 to 1999

<table>
<thead>
<tr>
<th>Crop</th>
<th>1996/97 (ha)</th>
<th>% of irrigated area</th>
<th>1997/98 (ha)</th>
<th>% of irrigated area</th>
<th>1998/99 (ha)</th>
<th>% of irrigated area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucerne</td>
<td>1,069</td>
<td>65%</td>
<td>1,234</td>
<td>64%</td>
<td>970</td>
<td>76%</td>
</tr>
<tr>
<td>Pasture</td>
<td>177</td>
<td>11%</td>
<td>303</td>
<td>16%</td>
<td>145</td>
<td>11%</td>
</tr>
<tr>
<td>Oats</td>
<td>198</td>
<td>12%</td>
<td>131</td>
<td>7%</td>
<td>65</td>
<td>5%</td>
</tr>
<tr>
<td>Sudax (forage sorghum)</td>
<td>37</td>
<td>2%</td>
<td>91</td>
<td>5%</td>
<td>60</td>
<td>5%</td>
</tr>
<tr>
<td>Summer cereal</td>
<td>105</td>
<td>6%</td>
<td>134</td>
<td>7%</td>
<td>20</td>
<td>2%</td>
</tr>
<tr>
<td>Wheat</td>
<td>38</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cow peas</td>
<td></td>
<td></td>
<td>16</td>
<td>1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td></td>
<td></td>
<td>20</td>
<td>1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Navy beans</td>
<td>18</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>10</td>
<td>1%</td>
<td></td>
<td></td>
<td>20</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>1,652</td>
<td>1%</td>
<td>1,929</td>
<td>2%</td>
<td>1,280</td>
<td></td>
</tr>
</tbody>
</table>
The majority of lucerne producers in the Peel Valley utilise spray irrigation systems. A small number of irrigators use flood systems and there has been more recently some uptake of subsurface drip irrigation systems.

The Peel Valley is relatively underdeveloped compared to many other valleys, with surface water usage commonly below half of total entitlement. This is strongly climatically related, with usage ranging from 8 to 67 per cent over the 1987-88 to 1998-99 period.

Many irrigators in the Peel Valley also have access to groundwater reserves contained within the alluvium of the river’s flats. The greatest development in groundwater use is in the central part of the Valley near Tamworth downstream to Attunga. It is here that flats are at their widest, and fairly intensive irrigation is undertaken.

**Unregulated catchments**

Irrigated agriculture is an important contributor to the Namoi Valley economy, with annual irrigated production valued at $2,072 million. Around 21% of this income is derived from unregulated rivers and streams, including the Mooki River and Cox Creek catchments. In the Mooki Catchment, irrigated crops are dominated by cotton during summer and wheat during winter. Maize, sorghum, vegetables and summer oilseeds are also grown, but on a smaller scale.

Aluwihare, Crean et al (2001) undertook a study of the on-farm financial impacts of the flow-sharing options for the Mooki catchment. A single representative farm was used in the analysis to reflect a cotton-dominated farming system with access to surface water in the Mooki catchment below Breeza. Key features of the representative farm included:

<table>
<thead>
<tr>
<th>Key physical characteristics</th>
<th>Irrigated crop mix (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total farm size (ha) 442</td>
<td>Irrigated wheat 25%</td>
</tr>
<tr>
<td>Irrigated area (ha) 162</td>
<td>Irrigated cotton 61%</td>
</tr>
<tr>
<td>Dryland area (ha) 280</td>
<td>Irrigated maize 14%</td>
</tr>
<tr>
<td>On-farm storage size (ML) 729</td>
<td></td>
</tr>
<tr>
<td>Pump capacity (ML/d) 125</td>
<td></td>
</tr>
<tr>
<td>Surface water entitlement (ML) 1,294</td>
<td></td>
</tr>
</tbody>
</table>
2.7 Macquarie Valley

The Macquarie Valley is located in central NSW and covers an area of approximately 92,000 km² from the central tablelands around Oberon, Bathurst and Rylstone to the western plains around Nyngan, Brewarrina and Coonamble. The Macquarie Valley is home to 240,000 people. Major townships include Orange, Bathurst, Dubbo, Mudgee and Nyngan.

The catchment comprises three smaller catchments: from north to south, the Castlereagh, the Macquarie and Bogan catchments. The Bogan River feeds directly into the Barwon River upstream of Bourke, however for water management purposes, the Bogan catchment is usually grouped with the Macquarie catchment.

The Castlereagh Valley

The Castlereagh River rises in rugged broken country in the Warrumbungle Range at an elevation of about 850 metres and flows eastwards to the town of Coonabarabran. The river then enters hilly country and flows in a southerly direction to the town of Binnaway. Downstream of Binnaway the river begins a sweeping change in direction to the northwest. In the extreme northern section of the valley the floodplain between the Barwon and Castlereagh Rivers is intersected by Womat and Wanourie Creeks, which carry flows from the Barwon to the Castlereagh River during major floods.

The Macquarie and Bogan Valleys

The Macquarie River is formed by the joining of the Campbells and Fish Rivers, which drain a high plateau area centred near Oberon with a general elevation above sea level of 900 to 1000 metres. The river flows northward through steep gorge areas in the Hill End area and is impounded by Burrendong Dam upstream of Wellington. The Cudgegong River also flows into Burrendong Dam from the northeast.

Downstream of the dam the river continues to flow in a northwest direction through Wellington and Dubbo and is joined by several major tributaries from the east and western parts of the catchment. At Narromine the river takes a dramatic turn to the north and a complex system of anabranches and effluent creeks, connecting the Macquarie, Darling and Bogan Rivers commences. The Macquarie Marshes are located toward the end of the catchment, although the Macquarie River does emerge from the wetlands before being joined by the Castlereagh River and then flowing into the Barwon River near Brewarrina.

The Bogan River rises in the Harvey Ranges between Parkes and Peak Hill and flows northwest through a broad, flat landscape through Nyngan to join the Darling River near Bourke.

The landscape of the Macquarie varies markedly from east to west, and can be split into three general divisions: the headwaters or tablelands, the slopes and the plains. The tablelands are characterised by fast to moderately flowing streams with sandy and pebbly
beds, steep, densely vegetated ranges to extensively cleared grazing lands. The slopes are characterised by undulating to hilly cleared lands, graduating to flatter areas, with some pockets of remnant vegetation. The plain areas are characterised by broad flat landscapes and the occasional rocky range outcrop. The land flattens to the west, with wetlands and rich alluvial river flats associated with braided channels and effluent streams becoming increasingly evident. The velocity of flow is low and there are extensive silt deposits.

Agriculturally, the region is highly diverse, which adds to the complexity of natural resource management issues. Grazing industries dominate the eastern highlands and western plains, and there is extensive winter cropping on the central west slopes and inner plains; intensive viticulture and horticulture around Mudgee, Orange and on the Bell River floodplain; and irrigated cotton and other summer crops on the Macquarie River floodplain.

The Macquarie Valley has a semi-arid climate and a summer-dominant rainfall pattern in the north, tending to a winter-dominant rainfall pattern in the south. Rainfall ranges from about 1,200 mm pa in the upper catchment to <400 mm pa in the lower catchment. Potential evapotranspiration follows an inverse spatial pattern to rainfall, ranging from about 1,200 mm pa in the upper catchment to 2,200 mm pa in the lower catchment (Jones, Whetton et al. 2002).

Flows in the Macquarie and Cudgegong rivers are controlled by Burrendong and Windamere dams respectively. These dams have a combined capacity of up to 2 048 000 ML of water.

- Of the total storage capacity in Burrendong Dam (1 680 000 ML), 490 000 ML is retained for flood mitigation. The general security19 and high security20 allocations for all purposes from the Macquarie River are 610 346 ML and 34 960 ML respectively.
- Windamere Dam (368 000 ML) is located at the top of the Cudgegong River, and water is mostly used to supplement Burrendong Dam during drought years (EPA 1997). The general security and high security entitlements for all purposes from the Cudgegong River are 22 082 ML and 5489 ML respectively.

Downstream of Dubbo, several large irrigation schemes pump water from the river to supply major channel schemes (Table 12). Off-allocation flows are utilised by schemes when available.

It should be noted that in addition to the off-river schemes, there are riparian irrigators in the Macquarie catchment and the number of members is estimated to be approximately 600 with an entitlement of about 394,400 ML (Hope 2003).

General security and high flow licences are used to water annual crops such as cotton, corn, lucerne and pasture. High security licences are used to supply water to horticulture crops. Around half the water from the dams is allocated to irrigators operating along the river outside the schemes. The remainder of the entitlement is for irrigation within the schemes.

In 1996, the Macquarie Marshes were granted a high security entitlement of 50 000 ML (available at greater than 10% allocation announcement) and a general security entitlement of 75 000 ML with a carryover provision. Existing irrigation licences allow extraction of up to 58 000 ML/year from unregulated streams in and downstream of the Marshes, but not all of these are fully developed (Hope 2003).
### Table 12 Irrigation schemes and riparian irrigators in the Macquarie catchment

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Year commenced</th>
<th>Entitlement (ML)</th>
<th>Scheme area</th>
<th>Number of members</th>
<th>Length of channel (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riparian irrigators</td>
<td>394,400</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narromine irrigation scheme</td>
<td>1970</td>
<td>60,100</td>
<td>120,000 ha</td>
<td>90</td>
<td>350</td>
</tr>
<tr>
<td>Trangie–Nevertire irrigation scheme</td>
<td>1970</td>
<td>63,500</td>
<td>102,000 ha</td>
<td>66</td>
<td>250</td>
</tr>
<tr>
<td>Tenandra irrigation scheme</td>
<td>1969</td>
<td>34,800</td>
<td>32</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Buddah lakes irrigation scheme</td>
<td>1969</td>
<td>32,500</td>
<td>17,000 ha</td>
<td>19</td>
<td>58</td>
</tr>
<tr>
<td>Marthaguy irrigation scheme</td>
<td>1988</td>
<td>16,600</td>
<td>3,500 ha</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Nevertire irrigation scheme</td>
<td>1966</td>
<td>32,000</td>
<td></td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Greenhide irrigation scheme</td>
<td>1969</td>
<td>7,800</td>
<td>835 ha</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>641,700</td>
<td>848</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: Hope (2003); Fairweather (2005)

The level of dependence on farm dams in the Macquarie valley is limited. Enterprises dependent on farm dams are generally located within the Orange and Bathurst districts.

#### 2.7.1 Irrigation Enterprises

The average annual irrigated area is in the order of 69,000 ha. The main irrigated crops, in order of areal extent, being cotton, cereal/wheat, fodder/pasture, lucerne, oilseeds and vegetables (Varley 2001). Grapes, apples, citrus, cherries and stone fruit are also grown in the Macquarie valley (2321 ha, 602 ha, 265 ha, 230 ha and 191 ha respectively) (Bryan and Marvanek 2004). Vegetables are grown in the Bathurst plains region.

91% of crops are irrigated using surface methods (furrow and border check) in the Macquarie valley. Other systems used include (Hope 2003):
Northern Basin Program: On-farm water use efficiency in the Northern Murray-Darling Basin

- Overhead sprays and micro-sprinklers are generally used to irrigate orchards around the Orange area.
- Around the Mudgee area, vines are irrigated with surface drip and sprinklers. Few growers in this area use subsurface drip systems.
- Centre pivots are found just downstream of Burrendong Dam.
- Between Coonabarabran and Gilgandra there are small pockets of spray irrigation.
- Below Gilgandra, there are about six centre pivots.
- Pressurised systems are used to water crops upstream of Dubbo.
- Pressurised and surface systems are used to water crops (grains and Lucerne) between Dubbo and Narromine.
- Downstream of Narromine, systems are predominantly surface. Most cotton is typically irrigated using furrow, although some is irrigated using subsurface drip or centre pivot.

**Cotton**

Cotton is the dominant irrigated crop and is almost exclusively grown along the Macquarie River downstream of Narromine (Hope 2003). Cotton is highly dependent on irrigation and is the most valuable irrigated crop in the region. Of the total value of irrigated agriculture ($263 million), just under half ($110 million) was generated from cotton in 1996–97.

**Grapes**

ABARE undertook a survey of wine grape producers in the Mudgee region in 2002-02 (Spencer and Ashton 2003). Rainfall is the primary water source for wine grape production in the region but is supplemented by irrigation on all farms surveyed. Water for irrigation is primarily drawn from regulated supplies from the Cudgegong River or from ground water bores. Wine grape yield averaged 8.2 t/ha with an irrigation water application rate of 1.2 ML/ha. The total area of vines in 2002 was 2,936 hectares.

Although wine grape producers in the Mudgee region use less irrigation water per hectare than do producers in other regions, irrigation is nevertheless a critical input, with all surveyed farmers indicating that they irrigated 100 per cent of their wine grape area in 2001-02. All of the producers surveyed in the Mudgee region used drip/trickle irrigation systems.

A high proportion of irrigators had adopted using scheduling tools (capacitance probes 20%, gypsum blocks 20%, time domain reflectometer 3% and soil profile sampler 33%). A range of irrigation practices had been adopted including:

- 54% of producers using regulated deficit irrigation;
- 18% of producers adopting partial rootzone drying; and
- 72% irrigated at night.

**Vegetables**

The Bathurst Plains are situated around the city of Bathurst. The Macquarie River flows across the area, where it has deposited a flood plain of black, clay loam soils. Most vegetable
production occurs on the flood plain, using water from the Macquarie River for irrigation (Wade 2005).

The Oberon Plateau and the Orange Plateau overlook the Bathurst Plains. Oberon, Blayney and Orange are the main centres on the plateaus. Vegetable production is concentrated on the red, clay loam soils scattered across these districts. Farm bores and dams supply the irrigation water required for vegetable growing on the plateaus.

A wide variety of vegetable crops are grown including asparagus, beans, beetroot, broccoli, Brussels sprouts, cabbages, cauliflowers, cucumbers, lettuce, peas, potatoes, pumpkins, rockmelons, silver beet, sweet corn, tomatoes, turnips, watermelons and zucchinis.

During the growing season, the crops are watered by drip irrigation, sprinklers, travelling guns, centre pivots or linear move irrigators.
2.8 Barwon-Darling Valley

The Barwon-Darling valley includes the Barwon River and the Darling River down to the Menindee Lakes, as well as the downstream sections of the Culgoa, Paroo, Warrego, Narran, Bokhara and Birrie River catchments. Major towns include Bourke, Brewarrina, Walgett, Louth and Wilcannia. Many of the rivers within this valley are ephemeral.

Predominant agricultural land uses in this semi-arid zone are grazing, dryland cropping, irrigated cotton production. Irrigation is limited to within and upstream of the Bourke district.

The area irrigated has varied from 26000 ha in 1996/7 to 22000 ha in 2000/1 with the main irrigated crops being cotton and fodder/pasture (Bryan and Marvanek 2004). Horticulture crops, in particular citrus and grapes are also grown. Two seasons of essentially no cotton production occurred in 2002-3 and 2003-4 due to water shortages.

The Barwon-Darling River system does not receive a formal allocation of resources, and only unregulated access is available. Irrigated cotton production at Bourke is sustained with water from the Darling River. The Darling River system near Bourke does not have a major impoundment supplying allocation water. Hence water can generally only be obtained through overland flow or flood harvesting opportunities.

The infrequent nature of these flooding events combined with high evaporation rates requires that storages are quite large to store adequate water for irrigation purposes until the next overland flow or flood harvest event. The volume of ring tanks in the Barwon-Darling valley has been estimated to be 298 GL (Webb McKeown & Associates Pty Ltd 2007).

Since June 2001, the Barwon-Darling system has been experiencing the worst drought and flow sequence recorded in the past 150 years. The river at Wilcannia ceased to flow for long periods during the past few years, only broken by occasional flow events. During 2003/04, 2004/05 and 2005/06 there has been some relief with rainfall events in the north of the Murray-Darling Basin that have contributed to flows in the Barwon-Darling river system (Murray Darling Basin Commission 2007). Total annual diversions during this period have ranged from 19 GL to 268 GL.
2.9 Lower Darling

The Lower Murray Darling catchment region lies in the southwest corner of New South Wales and covers an area of 63,000 square kilometres. The Murray River forms the southern border of the catchment, which is also intersected by the lower reaches of the Darling River and the Great Darling Anabranch. The region is dominated by a semi-arid climate and highly variable rainfall.

Because much of the Lower Murray Darling region is rangelands, sustainable rangeland management is an important aspect of natural resource management (NRM) in the region.

The Menindee lakes are a significant water storage of approximately 2,000 GL, however this water is used primarily to supply the Murray system. The Lakes system is located on the Darling River, about 200 km upstream of the junction of the Darling River and River Murray, at Wentworth in south-western NSW. There are four main lakes in the system: Lake Menindee, Lake Cawndilla, Lake Pamamaroo, and Lake Wetherell. The Lakes were originally a series of natural depressions that filled during floods. As the flow receded the floodwaters in the natural depressions drained back into the Darling River.

In 1949 the Menindee Water Conservation Act was passed in the NSW parliament. Works started in 1949, with major works being completed in 1960 and completion in 1968. In 1963, the New South Wales Government agreed to lease the storage in perpetuity to the Commission to be managed in harmony with the River Murray.

The NSW and Federal Governments are jointly funding a feasibility study to identify substantial water savings in the Darling River System, including the Menindee Lakes. The outcome of the study is to be a 20 year Strategic Plan for water savings based on an integrated approach of structural works, river and storage operating strategies and water market activities.

Irrigation Enterprises

The Lower Darling system, below Menindee Lakes, has a small entitlement of 48 GL.

Irrigation in the Lower Darling valley is dominated by Tandou Limited, a public company farming operation growing cotton, wine grapes and fruit tree crops. Water for Tandou Limited operations is sourced from releases from Menindee lakes.

14,000 hectares has been fully developed for irrigation at Tandou Farm where cotton and cereal crops are grown in rotation. Tandou Farm is irrigated mainly by a gravity-fed flood/furrow system. Sub-surface drip irrigation is also extensively utilised. Tandou Limited have identified that their drip irrigation requires 15% less water than flood/furrow irrigation to produce even higher yields, and is constantly being expanded.

Tandou Orchard and Vineyard is a 5,000-hectare property near Menindee producing wine grapes, apricots and apples. The property is irrigated and fertigated by drip irrigation.
level sprays is used to minimise temperature extremes by providing evaporative cooling. More than 1,000 hectares at Tandou Orchard & Vineyard are suitable for wine grape cropping.

After a year of no cotton in 2003/4, Tandou Limited planted 710 hectares of cotton on sub-surface drip in 2004/5. In 2005/6, Tandou Limited planted 1860 hectares of cotton, consisting of 1110 hectares furrow irrigated and 740 hectares on sub-surface drip (Australian Cottongrower 2006).

Onfarm storage volume of 160 GL have been estimated within the Lower Darling Valley (Webb McKeown & Associates Pty Ltd 2007). This estimate is only for Tandou Limited’s farm. Other on farm storages are believed to exist, however it is understood that their volume is relatively small.
3 Key Drivers for Improvements in WUE

3.1 Drivers for Irrigation Investment and Management

The key drivers for on-farm irrigation change are profitability, lifestyle (e.g. is there a quicker or easier way) and asset maintenance/protection benefits. Irrigation design and management decisions are the result of a complex interaction of many variables which are rarely consistent between individuals. For example, irrigation management is often expected to maximize efficiencies and minimise the labour and capital requirements of the particular irrigation system without adversely affecting the growing environment for the plant.

There are a number of resource management and market issues which are driving future irrigation investment and management in the Northern Murray-Darling Basin including:

- reduced water resource access both in terms of the volumes available for agricultural production and the reliability of supply;
- reduced skilled labour availability and increased labour costs;
- increasing energy costs;
- increased market demand on quality and traceability of produce;
- increased competitiveness for commodity crops; and
- increased regulatory and community requirements to demonstrate resource stewardship.

Current and future industry responses to these drivers will include an increased focus on, and use of (Raine 2006):

- water trading and range of water products offered within the water market;
- routine monitoring, reporting and control (including automation) at a range of scales;
- strategies to reduce volumetric losses at a range of scales;
- alternative water sources with marginal/variable quality;
- on-farm storages to improve water capture, recycling and system buffering;
- improving application systems to provide flexibility in crop management and water control;
- supplementary irrigation strategies in commodity crops; and
- agronomic quality indicators to optimise economic water use productivity.

It should also be noted that there are a range of obstacles to the adoption of many common irrigation technologies (Stirzaker, 2005) including:

- irrigators do not see the importance of the technology. They commonly have limited data on the water they actually use, or should use, and there are few accessible champions that they can learn from;
- the entrenched culture is resistant to change, and inherited knowledge or the status quo is often seen as adequate;
- little confidence that investing in new technologies actually pays off;
Case Study: Drivers for Improving On-farm Water Use Efficiency

The drivers for water use efficiency were examined for individual farming enterprises in the Northern Murray Darling Basin (see Case Studies in Appendices). Common themes were identified as the drivers for improvements to Water Use Efficiencies: reduced or lower reliability water supply; need for labour savings and the need for improved yield to maintain profitability.

‘We wanted to reduce water use (per hectare) and increase yields. Essentially we wanted to make our water go further.’

‘we only have two full time staff so the labour saving afforded by the lateral was also a consideration.’

‘Initially we have implemented the systems so that we can accurately manage water supplies from the scheme. Under the new system we will lose water if we are inaccurate with our predictions of water requirements. With the current labour shortage we required better information and management to enable less skilled operators to become good irrigators. With the cost of water from the scheme rising from $6-$8 per ML to now around $40 per ML over the last 10 years and the rise in fuel costs the economic factors are more important than water use efficiency. Hence we haven’t implemented these systems to save water but more so to save money.’

‘The cost of water to us is insignificant however its supply is critical so we needed to be more efficient with our water use.’

‘We are facing a 50% reduction in our bore allocation over the next few years. Hence this has forced us to consider our next steps in improving WUE just so that we can maintain our current levels of production from a reduced water supply.’

‘Installing a center pivot was first considered for benefits in labor requirements, management, and WUE. It was installed primarily for our lucern hay production where it offers a improved irrigation and crop uniformity, the ability to apply small volumes of irrigation, and an increase in the amount of ‘cuts’ per season.’

‘Water is our most limiting factor. It is everything.’

‘The initial driver to investment in WUE was simply that we were faced with a situation of diminished water availability. With a need to support the cost of capital, infrastructure, staff etc we really had to maximize our production with the limited volume of water that was available. For the first time we had to focus on WUE.’

‘Our infrastructure was worn out and this forced us to rethink our current practices. On a hot windy day the evaporation losses from the big gun traveler are clearly visible.’

‘To increase productivity. It represents a win-win. Not only can we save water but we are growing more yield with less costs.’
• the presence of structural barriers make it hard to change (e.g. schemes where water is not available on demand, limitations to farm layout, poor distribution uniformities and labour shortages); and
• concern over the complexity of the technology and the uncertainty over which technologies are best suited to which applications.

3.2 Drivers for Improved WUE in Cotton

A recent study on the driving forces for positive actions to improve water efficiency in the cotton and grains industry (Callan, Christiansen et al. 2004) identified the following drivers:
• evidence of the benefits of a new practice, technology or strategy based on the findings or facts from in house and outside trials and experimentation on their farm or other farms;
• cut backs in water availability;
• the introduction of soil water monitoring devices;
• the long term sustainability of the farm and the soil;
• the need to save labour costs associated with irrigation;
• the drive to continue to gain the best financial return for a farm, and now that pest management was under control, the focus was upon maximising returns through reducing the costs per mega litre of water; and
• access to knowledgeable and supportive consultants and agronomists.

Recent studies undertaken by the cotton industry have also identified the drivers for cotton growers to convert to Centre Pivots/Lateral Moves (Foley and Raine 2001) and Drip Irrigation (Raine, Foley et al. 2000). As with most management decisions, the decision to convert to either centre pivots / lateral moves or drip irrigation is often a result of a combination of factors.

There are a wide range of reasons why growers used centre pivots / lateral moves for irrigation of cotton. The main reasons cited were the potential for water savings (93%), labour savings (85%) and reduced crop waterlogging (73%). Approximately two-thirds of growers indicated that improved uniformity of water application and the ability to automate the system was also important while approximately half the growers were interested in increased yield and either fertigation or chemigation opportunities. Other issues such as the elimination of the requirement for extensive surface irrigation earthworks was also found appealing. An experienced cotton grower reported that “return on investment” was a significant factor when he installed a lateral move machine. He commented that his lateral move had cost $1800/ha compared to a surface irrigation system costing $1300/ha and added that the lateral move could be “financed over a term” compared to the up-front capital cost of the earthworks required for surface irrigation. The ability to more readily grow a wide variety of crops other than cotton was also seen as a benefit over furrow irrigation.

Similarly, there are a wide range of reasons why the existing drip irrigation systems have been installed in the cotton industry. All growers surveyed indicated that the potential to increase crop yield was a factor influencing on their decision while approximately 70% of growers also indicated that water and labour efficiencies were also important. The cost of
labour and the relatively simple automation capability of drip systems was a major driver in the adoption of drip by smaller growers.

Thirty-eight percent of the systems have been installed in an effort to reduce water applications either because the farms are already short of water or the growers intend to use the water savings in irrigating additional area. Twenty-four percent of growers were motivated by the potential of SDI to increase yields in specific fields, particularly on marginal country (usually with hardsetting red soils) that had not responded well to the destructive wetting and drying cycles associated with both furrow and spray irrigation. Some growers have installed drip systems into environmentally sensitive areas, such as river zones, so that they could maintain dry spray paths and use ground rigs for pest control. However, it should also be noted that a small number of drip systems have been installed principally as show pieces for the various drip installers and drip manufacturing companies while others appear to have been installed principally for political and/or social reasons (ie. in an attempt to be seen to be doing the right thing).

Table 13  Issues driving adoption of alternative irrigation systems within the cotton industry

<table>
<thead>
<tr>
<th>Issues</th>
<th>Responses (%)</th>
<th>Conversion to centre pivots / lateral moves</th>
<th>Conversion to drip irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water saving</td>
<td>93</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>Labour saving</td>
<td>85</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>Reduce waterlogging</td>
<td>73</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Improved water application uniformity</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved water distribution down field</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automation</td>
<td>58</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Increase yield</td>
<td>46</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Fertigation &amp; chemigation</td>
<td>46</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Improved cotton quality</td>
<td>12</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Water limited – major issue</td>
<td></td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Soil type/field shape/slope</td>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Land limited – major issue</td>
<td></td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

Source: Raine, Foley et al. (2000); Foley and Raine (2001)

3.3 Drivers for Improved WUE in Horticulture

Most vegetable farms have limited water supplies due to reduced general security allocations or shortages due to drought. Therefore, vegetable growers are being encouraged to replace their current, less efficient irrigation systems with more efficient ‘high tech’ irrigation systems to help improve productivity, profitability, water use efficiency and labour savings (Hickey, Hoogers et al. 2006).

From previous research and experience in extending new irrigation technologies with vegetable producers in southern Queensland, Henderson (2003) identified that simply
advocating practice change on the basis of saving water and associated water changes was unlikely to be successful. Practice change was more likely when new systems made producers’ lives easier (less time at work, fewer problems, less pesticide use, easier decision making, more control of outcomes), their production more consistent (fewer pest or disease incursions, higher and predictable yields), and their produce more marketable (higher quality, less variable, fewer defects, closer to retailer and consumer specifications).

The rate of irrigation technology improvements in the vegetable industry since the mid-1990s has been significant, and has come at a time of increased publicly funded incentive programs (such as WaterWise on the Farm in NSW and Water for Profit in Queensland) for improving irrigation efficiency on-farm. Extension and incentive programs have proven to be a key driver for improving water use efficiency in the vegetable industries in the Northern Murray-Darling Basin.

The recurrent droughts in the past decade have hit southern Queensland vegetable producers (Granite Belt, Darling Downs) particularly hard. The ongoing crisis has seen investment in practice change, irrigation system improvement, and major shifts in the physical and social farmscape as vegetable growers seek to cope with scarce water supplies. The last few years have seen an evaluation and installation of drip irrigation in the Granite Belt regions. These system changes have been supported by trials and demonstrations by drip suppliers, the Water for Profit program, and the DPI. Many producers would simply not have been able to produce viable areas of vegetable crops without switching to drip irrigation in the past 2 years (Henderson 2007).
4 Current Performance of Existing Systems

A number of studies have been conducted in the last 10 years to assess on-farm water use efficiency in the Northern Murray-Darling Basin. These studies have been conducted at a range of scales including:

- Field scale - single irrigation event;
- Whole farm scale – single irrigation event and whole season; and
- Whole of system scale.

Most studies have been conducted within the Australian cotton industry however some limited information has been collected on water use efficiencies for other commodity groups within the study area.

4.1 Performance of On-Farm Water Storage and Distribution Systems

A project undertaken by the Dalton, Raine et al. (2001) physically measured the performance of each component of the whole farm water system under commercial operating conditions for the Cotton industry for 7 farms in the Border Rivers valley.

Storage system performance ranged from 50-85% with evaporation ranging from 14-39% and seepage from 1-11% of the water stored. The results of storage efficiency measurements on four storages during the 1998/99 and 1999/00 seasons are presented in Table 14. The efficiencies are principally determined by the period of storage (and therefore opportunity time for evaporation and seepage) and the surface area to volume ratio of the total volume stored.

Table 14 Storage volume balance, efficiency and losses by volume (ML) and (percentage)

<table>
<thead>
<tr>
<th>Storage Description</th>
<th>Storage Period</th>
<th>Stored Water</th>
<th>Water Used</th>
<th>Seepage</th>
<th>Evaporation</th>
<th>Storage Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm A 4m max depth 1800 ML</td>
<td>27/11/98 to 28/12/98</td>
<td>1272 ML</td>
<td>1082 ML (85%)</td>
<td>14 ML (1.1%)</td>
<td>177 ML (13.9%)</td>
<td>85%</td>
</tr>
<tr>
<td>Farm A 4m max depth 2500 ML</td>
<td>27/11/98 to 5/7/99</td>
<td>2388 ML</td>
<td>1203 ML (50.4%)</td>
<td>255 ML (10.7%)</td>
<td>930 ML (38.9%)</td>
<td>50%</td>
</tr>
<tr>
<td>Farm B 3m max depth 500 ML</td>
<td>2/12/99 to 5/5/99</td>
<td>729 ML</td>
<td>581 ML (79.7%)</td>
<td>34 ML (4.7%)</td>
<td>121 ML (16.6%)</td>
<td>80%</td>
</tr>
<tr>
<td>Farm E 4m max depth 1800 ML</td>
<td>13/8/99 to 16/2/2000</td>
<td>3649 ML</td>
<td>2776 ML (76.1%)</td>
<td>180 ML (4.9%)</td>
<td>701 ML (19.2%)</td>
<td>76%</td>
</tr>
</tbody>
</table>

Source: Dalton, Raine et al. (2001)
For example, the first storage listed had a high storage efficiency (85%) since it was effectively emptied in one month. Similarly, the third and fourth storages listed were emptied and filled several times during the storage period such that the ratio of water used to water stored was high. Conversely, the second storage listed had a poor efficiency (50%) since it operated in a static mode for a long period allowing a significant percentage to be lost as evaporation.

Distribution system efficiency was found to range from 87 to 96% with seepage representing between 2 and 8% of the distributed volume. The results of distribution efficiency estimates are presented in Table 15.

<table>
<thead>
<tr>
<th>Site</th>
<th>Distributed</th>
<th>Evaporation</th>
<th>Seepage</th>
<th>Distribution efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm A^a</td>
<td>5000 ML</td>
<td>130 ML</td>
<td>270 ML</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3%)</td>
<td>(6%)</td>
<td></td>
</tr>
<tr>
<td>Farm B^b</td>
<td>1300 ML</td>
<td>68 ML</td>
<td>109 ML</td>
<td>86%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5%)</td>
<td>(8.4%)</td>
<td></td>
</tr>
<tr>
<td>Farm E</td>
<td>4800 ML</td>
<td>94 ML</td>
<td>90 ML</td>
<td>96%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2%)</td>
<td>(1.8%)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Dalton, Raine et al. (2001)

^a For Farm A, seepage and evaporation losses were calculated for over 10km of main supply channel, 5km of tailwater return channel and 6km of head ditches.

^b For Farm B seepage and evaporation losses were calculated for over 12 km of combined main supply/head ditches and 10 km of tailwater return channel.

4.2 Performance of In-Field Application Systems

4.2.1 Cotton – Surface Irrigated

There is limited published information on the in-field performance of surface irrigation systems in cotton. It is often claimed that application efficiency of well designed and managed surface irrigated cotton is over 80 per cent, but there is increasing evidence that on many farms surface irrigation performance is highly variable.

In-field measurements on over 180 irrigation events under commercial conditions have found application efficiencies of single irrigations ranging from 35–100 per cent with seasonal efficiencies commonly between 60–85 per cent (Raine and Foley 2002).

A previous project conducted in the Macquarie valley “Measure Water to Manage Water” measured efficiencies and distribution uniformities on furrow irrigated cotton crops on an event basis over a range of soil types. This project found that the majority of application...
efficiencies were below 50%, with the majority of distribution uniformities around 60-80% (Fairweather 2005).

A project undertaken by the Dalton, Raine et al. (2001) physically measured the performance of each component of the whole farm water system under commercial operating conditions for the Cotton industry for 7 farms in the Border Rivers valley. A total of seventy individual irrigation events were monitored over two seasons on seven farms and eleven fields. Individual irrigation application efficiencies ranged from 37 to 100%. The efficiency of the infield surface irrigation application ranged from 38-84% with tailwater volumes representing an additional 4 and 32% of the inflow water in these particular cases. Deep drainage in these cases ranged from 10 to 26% of the applied volume while surface evaporation represented only 2-4%.

4.2.2 Cotton – Drip Irrigation

Raine, Foley et al. (2000) recently undertook a review of the performance of drip irrigation systems in cotton. The surveys were conducted over a six week period (May-June, 2000) and involved a total of 26 interviews with irrigators and six interviews with the major drip irrigation supply companies. The surveys encompassed more than 80% of drip irrigation users within the cotton industry including twelve growers from Queensland and fourteen from NSW.

All cotton growers using SDI reported a decrease in water use compared to traditional furrow irrigated systems. The average reduction in irrigation water use (MLirrig) associated with the operation of SDI systems compared to furrow systems was 2.56 MLirrig/ha. This represents an average 38% reduction in water application when compared with traditional nonoptimised surface irrigation systems. However, it should be noted that the water saving differential may be much smaller where optimisation of the surface irrigation is undertaken.

Yield achieved on SDI blocks is strongly related to the water management strategy. Where growers focus on maximising SDI block yields, improvements of up to 2.7 bales/ha above surface irrigated fields are achieved. However, where growers focused on maximising SDI water savings to enable increased production area on other fields using the saved water, the yields of the SDI blocks were not greatly different to surface irrigated blocks. In all cases, growers reported an increase in crop water use efficiency with an average increase of 1.29 bales/ MLirrig.

4.2.3 Cotton – Centre Pivot / Lateral Move

Foley and Raine (2001) recently undertook a review of the performance of centre pivots / lateral moves that have been installed within the cotton industry.

All growers reported an increase in the crop water use efficiency (CWUE) compared to traditional surface irrigation systems with CWUE ranging from 1.35 to 2.6 b/MLirrig. The average CWUE under centre pivots / lateral moves (CP/LM) was found to be 1.9 bales/MLirrig.
which was 72% (or 0.8 b/ML_{irrig}) higher than the average CWUE achieved using traditional surface irrigation.

The average CWUE was not as high as reported by growers using subsurface drip irrigation systems (Raine, Foley et al. 2000), which averaged 2.4 bales/ML_{irrig}. However, the CP/LM results may have been influenced by the high number of CP/LM growers who were inexperienced in cotton production (27% have grown <2 crops) and the large proportion of machines (27%) with both a designed and managed system capacity significantly less than the capacity required to meet the peak crop water use rate. This may also have impacted on the yields when reported per unit area, which were slightly lower (0.5 b/ha or 6.4%) on average under CP/LM’s when compared to traditional surface systems.

All of the growers surveyed applied less water per unit area with their CP/LM than they applied using a surface irrigation system. Growers reported applying on average 3.1 ML_{irrig}/ha less than fully irrigated surface systems, however the survey results were strongly influenced by the large proportion of growers who were short of water. Only a small proportion (4%) of the growers reported applying 0-2 ML_{irrig}/ha less water while almost a third of the growers reported applying 4-6 ML_{irrig}/ha less water than their fully irrigated surface systems. The reduction in water applied is similar to the reduction in water applications (average = 2.56 ML_{irrig}/ha) reported by growers using drip systems (Raine et al., 2000). However, it should be noted that these water savings may well be smaller when optimisation of the surface irrigation has been undertaken.

\subsection{4.2.4 Other Broadacre}

No published information is available on irrigation performance in broadacre crops (other than cotton) for the Northern Murray Darling Basin.

\subsection{4.2.5 Pasture & Lucerne}

Limited information is available on irrigation performance for pasture and lucerne in the Northern Murray Darling Basin. As part of the QLD Rural Water Use Efficiency (RWUE) Initiative, desktop studies were undertaken by Barraclough & Co (2000) of irrigation use efficiencies in the Dairy and Lucerne industries in the Border Rivers (QLD) and Condamine-Balonne valleys. Efficiency measures calculated included economic water use index (gross revenue / irrigation water input) and agronomic water use index (yield / irrigation water input). The calculated efficiency indices give individual irrigators an opportunity to benchmark their performance but do not present sufficient detail to allow opportunities for improvements in irrigation performance to be identified.

Irrigation performance was assessed at a number of trial sites as part of the QLD RWUE project with a focus on soils moisture monitoring and an assessment of spray irrigation systems. Insufficient information is available to quantify the performance of Lucerne and Dairy irrigators. However areas for possible improvement can be identified including:
• Refining the depth of irrigation applications to minimize waterlogging and maximize plant growth rates;
• Upgrading sprinklers and nozzles to improve distribution uniformity; and
• Changing irrigation practices, such as irrigating at night / low wind conditions to minimize water losses due to spray drift and evaporation.
4.2.6 Horticulture

Limited information is available on irrigation performance for irrigated horticulture in the Northern Murray Darling Basin.

As part of the QLD Rural Water Use Efficiency (RWUE) Initiative, desktop studies were undertaken by Barraclough & Co (1999) of irrigation use efficiencies in the horticulture industries in the Border Rivers (QLD) and Condamine-Balonne valleys. Efficiency measures calculated included economic water use index (gross revenue / irrigation water input) and agronomic water use index (yield / irrigation water input). The calculated efficiency indices give individual irrigators an opportunity to benchmark their performance but do not present sufficient detail to allow opportunities for improvements in irrigation performance to be identified.

Part of the difficulties associated with benchmarking the horticulture industry relate to the large number of crops grown, each with different crop water requirements. However, some aspects of system performance of irrigation systems (uniformity etc) are independent of crop type. Recent studies, particularly in the vegetable industry, have assessed system performance (Barber and Raine 2001) or included case study examples (Hickey and Hoogers 2006), (Henderson 2003), (Henderson 2007) however the number of systems for which assessments have been undertaken is insufficient for quantifying ‘typical’ system performance.

4.3 Farm Scale Water Use Efficiencies

A number of studies have been undertaken to assess the water use efficiency of the Australian cotton industry. Table 16 provides a summary of key studies undertaken and measured whole farm irrigation efficiencies (WFIE).

The average whole farm efficiency calculated from these studies of the Australian cotton industry is around 59 per cent. This means that, on average, 41 per cent of the water diverted for cotton production is lost as evaporation or seepage while it is being stored in dams, transported around the farm or applied to field.

The wide variation in WFIE suggests that there is significant scope for producers at the lower end of the ranges to increase the efficiency with which they use water. Collecting water management data at the field and farm level provides important information for the diagnostic analysis of water use efficiency.
### Table 16 Whole farm WUE Studies in the Australian cotton industry

<table>
<thead>
<tr>
<th>Project</th>
<th>Season</th>
<th>Region</th>
<th>No. of farms</th>
<th>Data collected</th>
<th>WFIE range (%)</th>
<th>WFIE Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameron &amp; Hearn (1997)</td>
<td>1988/89 to 1994/95</td>
<td>Macquarie, Namoi, Gwydir &amp; Macintyre</td>
<td>11</td>
<td>Farm level and field level data were collected. In estimating WFIE, only the water input to the farm from irrigation and rainfall, and not the soil moisture reserves used by the crop, were considered.</td>
<td>49 - 78</td>
<td>63</td>
</tr>
<tr>
<td>Tennakoon &amp; Milroy (2003)</td>
<td>1996/97 to 1998/99</td>
<td>NSW &amp; QLD</td>
<td>25</td>
<td>WFIE was calculated as the percentage of irrigation water used in crop evapotranspiration, including soil moisture reserves, relative to the total irrigation water input at the farm level.</td>
<td>20 - 85</td>
<td>57</td>
</tr>
<tr>
<td>QLD RWUE (2003)</td>
<td>2000/01 to 2002/03</td>
<td>QLD</td>
<td>29</td>
<td>The key focus of the RWUE program was monitoring water use, on-farm storage and distribution, as well as considering application methods and infield management. Demonstration (benchmarking) sites were established each season, with water use efficiency indices calculated.</td>
<td>50 - 74</td>
<td>58</td>
</tr>
<tr>
<td>Dalton et al (2001)</td>
<td>Border Rivers</td>
<td></td>
<td>7</td>
<td>The performance of each component of the whole farm water system under commercial operating conditions for the Cotton industry was measured.</td>
<td>28 - 68</td>
<td></td>
</tr>
<tr>
<td>Industry Average</td>
<td></td>
<td></td>
<td>20 - 85</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>---</td>
<td>---</td>
<td>---------</td>
<td>----</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: Dugdale, Harris et al. (2004), Goyne (2003), Dalton, Raine et al. (2001)
A number of the studies assessing whole farm irrigation efficiencies (WFIE) also calculated a range of water use indices comparing production output to water input. The results from the WUE studies are presented in Table 17.

Table 17 Water Use Indices in the Australian cotton industry

<table>
<thead>
<tr>
<th>Project</th>
<th>IWUI a (bales/ML)</th>
<th>GPWUI b (bales/ML)</th>
<th>CWUI c (kg/mm/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameron &amp; Hearn (1997)</td>
<td>1.48</td>
<td>0.82</td>
<td>3.05</td>
</tr>
<tr>
<td>Tennakoon &amp; Milroy (2003)</td>
<td>1.32</td>
<td>0.79</td>
<td>2.52</td>
</tr>
<tr>
<td>QLD RWUE (2003)</td>
<td>1.16</td>
<td>0.93</td>
<td>2.79</td>
</tr>
<tr>
<td>Industry Average</td>
<td>1.32</td>
<td>0.85</td>
<td>2.79</td>
</tr>
</tbody>
</table>

Source: Dugdale, Harris et al. (2004)

- **IWUI a** (Irrigation water use index (farm level – applied water only))
  \[
  \text{IWUI}_\text{farm}(\text{bales/ML}) = \frac{\text{lint yield}}{\text{irrigation water input}}
  \]

- **GPWUI b** (Gross production water use index (total water at farm level – pumped + rain))
  \[
  \text{GPWUI}_\text{farm}(\text{bales/ML}) = \frac{\text{lint yield}}{\text{total water input}}
  \]

- **CWUI c** (Crop water use index)
  \[
  \text{CWUI}(\text{kg/mm/ha}) = \frac{\text{yield}}{\text{ET}}
  \]

where seasonal ET was estimated using neutron probe data and simulated values

The variation in water use indices (comparing production data to water input) is not as great as the variation seen in the volumetric whole farm irrigation efficiencies (WFIE) from Table 16. The greater range found in WFIE on a farm basis, compared with CWUI, suggests that this variable has the greatest scope for improvement (Dugdale, Harris et al. 2004).

The study by Dalton (2001) physically measured the performance of each component of the whole farm water system under commercial operating conditions for the Cotton industry. This project was initiated by the cotton industry to put real numbers on the whole farm water balance of surface irrigated cotton systems such that irrigation efficiencies could be confidently stated. The project was also required to develop a process of whole farm irrigation efficiency benchmarking to enable the identification of opportunities for water use efficiency improvement.

The whole farm irrigation efficiency of seven cotton farms in the McIntyre Valley (Border Rivers) were monitored over the three years of the project. Whole farm irrigation efficiency was quantified on a volumetric basis which included both the use and loss water balance.
components of water storages, distribution channels and in-field furrow application systems (i.e. flows, soil moisture, drainage, seepage, evaporation tailwater and crop water use).

The best and worst case whole farm water balances measured during the field trials are presented in Figure 6. The proportion of the whole farm water which was used by the crop in an individual irrigation event ranged from 21-65% (or 28-68% assuming complete recycling). Significant sources of volumetric water loss in both cases included storage evaporation (14% and 39%) and infield deep drainage (11 & 13%).

![Figure 6 Components of the volume balance for (a) best and (b) worst case measured whole farm efficiencies](image)

The performance of the storage, distribution, and in-field application system components was individually measured as part of this study. In each case, the efficiency is reported as a percent of the water volume entering each component of the system. Storage system performance ranged from 50-85% with evaporation ranging from 14-39% and seepage from 1-11% of the water stored. Distribution system efficiency was found to range from 87 to 96% with seepage representing between 2 and 8% of the distributed volume. The efficiency of the infield surface irrigation application ranged from 38-84% with tailwater volumes representing an additional 4 and 32% of the inflow water in these particular cases. Deep drainage in these cases ranged from 10 to 26% of the applied volume while surface evaporation represented only 2-4%.

From this study, indicative losses in cotton irrigation systems were developed (Table 18). An expected range of losses and a ‘typical’ efficiency were identified for each of the components of the irrigation system.

<table>
<thead>
<tr>
<th>Table 18 Estimated losses in cotton irrigation systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storage (farm dams)</strong></td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Distribution</strong></td>
</tr>
</tbody>
</table>
### 4.4 Whole-of-System Water Use Efficiency

A whole-of-system water balance enables the size and location of losses across a landscape to be estimated. An inefficiency or loss at one scale may not necessarily be a loss to the entire system for example, a farm-scale water balance will correctly represent any deep drainage as a loss but cannot represent how these losses may become gains at the catchment scale (e.g. groundwater recharge). Similarly, seepage from a delivery channel may be a loss to the water authority but a bonus to the adjoining farmer, or the catchment as a whole.

Work commissioned by the National Program for Sustainable Irrigation has developed a method to assess the water balance at a range of scales for a particular valley. The method can use data from various sources and qualities (e.g. dam releases, rainfall, groundwater bores, crop yields) to provide insight into how irrigation can affect the water balance at different scales. Probabilities are used when making estimates of the various components of the water balance, and in this way the variability of the water balance elements is recognised.

The emphasis in this project has been on the development of a methodology to assess Whole-of-System Water Use Efficiency. The project also aims to recommend the tools that can be used to assess where real water savings can be found by collating all available data sources and outlining a methodology to analyse these data in a water balance framework. Potential water savings are considered at a farm, sub-catchment and valley-wide scale. The results from this approach are preliminary in nature and more work is required to increase the degree of confidence in the output (eg. further sensitivity analyses).

As part of this project, whole-of-system and delivery-scheme water use efficiencies for the Macquarie valley. Whole-of-system efficiencies were calculated which range from 57% to 94%. The year in which the high efficiency of 94% was calculated coincided with a relatively high rainfall year and the lowest evapotranspiration (ET0) and evaporation. The next highest whole-of-system efficiency occurs in a year when the dam releases and gauged tributary inflows were the lowest in the eight years of record. The climate data averaged over the catchment for the entire record suggest this was an average year.
5 Possible Gains in Water Use Efficiency

5.1 Methodology for estimating potential gains in Water Use Efficiency for the Northern Murray-Darling Basin

Possible gains in on-farm water use efficiency in the Northern Murray-Darling Basin have been estimated to identify key areas for further investment. It is important to note that these gains would not necessarily translate into reduced water use and any improvements in on-farm water use efficiency are likely to be used beneficially on-farm to increase production.

Information on irrigation enterprises within the study area has been integrated with available information on the current performance of irrigation systems and the efficiency of water use efficiency (WUE) technologies and practices to estimate potential gains in WUE.

A volumetric approach has been taken to identify WUE gains. Consideration has been given to the three main components of whole-farm irrigation systems:
- on-farm storage systems (farm dams, ring tanks);
- on-farm distribution systems (channels and/or pipes); and
- in-field application systems (e.g. furrow, spray, micro-spray or drip systems).

Potential volumetric losses (or inefficiencies) within each of these sub-systems has been estimated on a valley by valley basis.

Adopting a volumetric basis for calculating potential gains provides a clear indication of the areas where the largest gains are likely to be made in improved WUE. However the use of a volumetric basis for estimating WUE efficiency does not provide any assessment of the overall irrigation performance in relation to crop production and economic returns and will underestimate some of the agronomic gains that are possible through improved management of in-field application systems (eg. yield improvement in cotton and pasture due to reduction in waterlogging; improved quality of vegetables through more uniform irrigation application).

When determining the potential WUE gains, consideration has been given to both proven practice and technology and emerging technologies. The inclusion of emerging technologies in the estimate of WUE gains allows for priorities for Research and Development to be identified that will greatly assist in improving WUE in the Northern Murray Darling Basin.

5.1.1 Potential WUE Gains from On-farm Storages

On-farm storages represent a major source in on-farm water use efficiency in the Northern Murray Darling Basin. The major losses are seepage and evaporation. An estimate has been made of the total losses that could be occurring from on-farm storages in the Northern Murray Darling Basin and an estimate of the likely reduction in losses (potential WUE gains) that could be achieved. Table 19 presents a summary of the losses and potential gains calculated for on-farm storages for each valley in the study area.
### Table 19 Estimated potential WUE gains from on-farm storages

<table>
<thead>
<tr>
<th>Valley</th>
<th>Storage volumes (GL)</th>
<th>Evaporation loss (GL)</th>
<th>Seepage loss (GL)</th>
<th>Total loss (GL)</th>
<th>Potential WUE gain (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Large</td>
<td>Total</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Warrego</td>
<td>3</td>
<td>16</td>
<td>19</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Condamine-Balonne</td>
<td>255</td>
<td>1661</td>
<td>1916</td>
<td>76</td>
<td>498</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>93</td>
<td>610</td>
<td>703</td>
<td>28</td>
<td>183</td>
</tr>
<tr>
<td>Gwydir</td>
<td>58</td>
<td>377</td>
<td>435</td>
<td>17</td>
<td>113</td>
</tr>
<tr>
<td>Namoi</td>
<td>79</td>
<td>513</td>
<td>592</td>
<td>24</td>
<td>154</td>
</tr>
<tr>
<td>Macquarie</td>
<td>50</td>
<td>324</td>
<td>374</td>
<td>15</td>
<td>97</td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>61</td>
<td>397</td>
<td>458</td>
<td>18</td>
<td>119</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>598</td>
<td>3899</td>
<td>4497</td>
<td>179</td>
<td>1170</td>
</tr>
</tbody>
</table>
A number of assumptions were made in calculating these losses and are detailed below.

**Volume of farm dams**
An estimate of the total volume of on-farm storages was undertaken as part of a recent review of the hydrology of the Darling Basin (Webb McKeown & Associates Pty Ltd 2007) and has been adopted here (Table 8).

**Evaporation loss**
An average annual evaporative loss of 30% of the storage volumes was adopted as per Dalton, Raine et al. (2001). A discussion of typical storage efficiencies is included in Section 4.3.

**Evaporation Mitigation Technologies**
An overview of the on-farm strategies that could be employed and emerging technologies to reduce losses from on-farm storages is provided in Section 6.2. Evaporation reduction from evaporation mitigation technologies (EMTs) was assumed to be 40% reduction from monolayers, 70% reduction from shade cloth and 90% reduction from floating covers.

The choice of EMT is dictated to a large degree by the size of the storage. For small storages less than 2ha, it was assumed EMT adoption would be evenly split between floating covers, shade covers and monolayers for storages. For small storages between 2-5 ha in size, it was assumed 50% would adopt monolayers and 50% would adopt shade cloth. For large storages (>5ha), monolayers were assumed to be the only viable option.

**Storage sizes**
Storage size classes assumed to be as per Table 20 based on information collated by Baillie (2007). Storage size classes used are based on broadacre enterprises in Queensland. Similar data is not available for NSW.

### Table 20  Storage size classes from Baillie (2007)

<table>
<thead>
<tr>
<th>Storage surface area (ha)</th>
<th>% by volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>7.2%</td>
</tr>
<tr>
<td>2-5</td>
<td>6.1%</td>
</tr>
<tr>
<td>5-10</td>
<td>10.2%</td>
</tr>
<tr>
<td>10-25</td>
<td>22.5%</td>
</tr>
<tr>
<td>25-100</td>
<td>54%</td>
</tr>
</tbody>
</table>

**Seepage Losses**
An average annual seepage loss of 5% of the storage volumes was adopted as per Dalton, Raine et al. (2001). A discussion of typical storage efficiencies is included in Section 4.3.
Seepage Mitigation
It was assumed seepage mitigation technologies would achieved the best practice measured by Dalton, Raine et al. (2001), ie seepage losses would be reduced to 2% of the storage volume.

5.1.2 Calculating Potential WUE Gains from On-farm Distribution Systems

An estimate has been made of the total losses that could be occurring from on-farm distribution systems in the Northern Murray Darling Basin and an estimate of the likely reduction in losses (potential WUE gains) that could be achieved. Table 21 presents a summary of the losses and potential gains calculated for on-farm distribution systems for each valley in the study area.

A number of assumptions were made in calculating these losses and are detailed below.

Volume of water delivered on-farm
Water delivered on-farm was based on average water diversions (surface and groundwater) as identified in MDBC Water Audit Monitoring Reports on the Cap on Diversions for 2000/1 to 2005/6 (Table 4). Estimates of floodplain harvesting were obtained from Webb McKeown & Associates Pty Ltd (2007) and included in the total water delivered on farm.

Seepage and evaporation losses
Average annual seepage losses of 3% and evaporation losses of 3% of the water distributed on-farm was adopted as per Dalton, Raine et al. (2001). A discussion of typical distribution system efficiencies is included in Section 4.3.

Seepage and evaporation mitigation
It was assumed seepage and evaporation mitigation technologies would achieve the best practice measured by Dalton, Raine et al. (2001), ie seepage losses and evaporation losses would both be reduced to 1% of the water delivered on farm, ie. a total of 2% of the water delivered on farm is unrecoverable and lost to distribution system losses.
Table 21  Estimated potential WUE gains from on-farm distribution systems

<table>
<thead>
<tr>
<th>Valley</th>
<th>Volume of water diverted (GL)</th>
<th>Losses (GL)</th>
<th>Gains (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Seepage</td>
<td>Evap</td>
</tr>
<tr>
<td>Warrego</td>
<td>9.5</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Condamine-Balonne</td>
<td>590.8</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>427.1</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Gwydir</td>
<td>443.4</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Namoi</td>
<td>498</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Macquarie</td>
<td>433.4</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>169</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>2591</td>
<td>78</td>
<td>78</td>
</tr>
</tbody>
</table>

5.1.3 Calculating Potential WUE Gains from In-field Application Systems

An estimate has been made of the total volume of water applied with in-field application systems for the total irrigated area in the Northern Murray Darling Basin and an estimate of the likely efficiency gains that could be achieved.

Improving WUE for in-field application systems involves a combination of engineering (volumetric) and agronomic measures in contrast to on-farm storages and distribution systems where all of the gains are achieved through engineering (volumetric) strategies.

As a means of linking potential WUE gains and typical on-farm strategies that might be employed to achieve these WUE gains, two scenarios have been considered:

1. Low investment scenario involves using existing irrigation systems but with improved management (eg. irrigation scheduling, optimisation of surface irrigation application rates and cutoff times, improved distribution uniformity of spray systems etc). The low investment scenario involves adopting improved management practices without requiring a significant capital on-farm investment.
2. High investment scenario involves adopting new technology and associated management regimes (eg. changing from surface to pressurized systems, major redesign of existing irrigation systems). The high investment scenario typically involves a major on-farm capital investment.

A discussion of some of the key strategies that could be employed on-farm to maximize WUE for in-field application systems are outlined in Section 8.
The on-farm strategies associated the high investment scenario have the potential to deliver the greatest WUE gains. Theoretically, there is the potential for all irrigation enterprises across the Northern Murray Darling Basin to achieve the level of water use efficiency defined by the high investment scenario. The efficiency gains that can be realized through the high investment scenario represent the maximum potential gains that the irrigation industry should aspire to. However, a range of factors (biological, engineering and economic) need to be considered when identifying the best strategies for improving WUE for an individual irrigation enterprise. In some cases, adopting low cost improvements to the management of an existing irrigation system (low investment strategy) will achieve WUE gains with the greatest economic return. In other cases, the physical constraints of the irrigation enterprise or the high level of performance already realised for an existing system may dictate that WUE gains can only be achieved through the adoption of alternative technologies (high investment scenario). Other considerations (eg. labour shortages) may drive whether the low or high investment scenario is most suitable for a particular irrigation enterprise.

Table 23 presents a summary of the volumes of water applied in-field and potential gains from infield application systems for each valley in the study area.

A number of assumptions were made in calculating the potential gains from infield application systems and these are detailed below.

Volume of water applied in-field
Average irrigation application rates (Table 22) were applied to an estimated area irrigated for each valley to calculate the total volume of water applied in-field across the Northern Murray Darling Basin.

<table>
<thead>
<tr>
<th>Application rate (ML/ha)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton 6</td>
<td>Dugdale, Harris et al. (2004)</td>
</tr>
<tr>
<td>Broadacre – cereals 3</td>
<td>Capital Agricultural Consultants Pty Ltd (2002)</td>
</tr>
<tr>
<td>Pasture 7</td>
<td>Capital Agricultural Consultants Pty Ltd (2002)</td>
</tr>
<tr>
<td>Fruit &amp; tree nuts 7</td>
<td>Hickey, Hoogers et al. (2006)</td>
</tr>
<tr>
<td>Grapes 1.2 (Mudgee) 2.8 (Stanthorpe) 5.1 (South West QLD)</td>
<td>Barraclough &amp; Co (1999)</td>
</tr>
</tbody>
</table>
### Table 23 Estimated potential WUE gains from In-field application systems

<table>
<thead>
<tr>
<th>Valley</th>
<th>Area irrigated (ha)</th>
<th>Volume of water applied (GL)</th>
<th>Cotton</th>
<th>Broadacre</th>
<th>Pasture</th>
<th>Horticulture</th>
<th>Cotton</th>
<th>Broadacre</th>
<th>Pasture</th>
<th>Horticulture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warrego</td>
<td>1201</td>
<td>7</td>
<td>0</td>
<td>5290</td>
<td>286</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>37</td>
<td>1</td>
</tr>
<tr>
<td>Condamine-Balonne</td>
<td>51428</td>
<td>309</td>
<td>13303</td>
<td>15295</td>
<td>3029</td>
<td>309</td>
<td>40</td>
<td>107</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Border Rivers</td>
<td>57190</td>
<td>343</td>
<td>5221</td>
<td>7982</td>
<td>5930</td>
<td>343</td>
<td>16</td>
<td>56</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Gwydir</td>
<td>76900</td>
<td>461</td>
<td>3780</td>
<td>1944</td>
<td>375</td>
<td>461</td>
<td>11</td>
<td>14</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Namoi</td>
<td>59683</td>
<td>358</td>
<td>19527</td>
<td>8319</td>
<td>103</td>
<td>358</td>
<td>59</td>
<td>58</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Macquarie</td>
<td>32754</td>
<td>197</td>
<td>10006</td>
<td>10043</td>
<td>4092</td>
<td>197</td>
<td>30</td>
<td>70</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>17514</td>
<td>105</td>
<td>107</td>
<td>1137</td>
<td>790</td>
<td>105</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>296670</td>
<td>1780</td>
<td>51944</td>
<td>50010</td>
<td>14605</td>
<td>1780</td>
<td>156</td>
<td>350</td>
<td>68</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Valley</th>
<th>WUE Gains (GL) Low investment (management options)</th>
<th>WUE Gains (GL) High investment (system conversion)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cotton</td>
<td>Broadacre</td>
</tr>
<tr>
<td>Warrego</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Condamine-Balonne</td>
<td>43</td>
<td>4</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td>Gwydir</td>
<td>65</td>
<td>1</td>
</tr>
</tbody>
</table>
## Northern Basin Program: On-farm water use efficiency in the Northern Murray-Darling Basin

<table>
<thead>
<tr>
<th>Region</th>
<th>50</th>
<th>6</th>
<th>12</th>
<th>0</th>
<th>107</th>
<th>8</th>
<th>16</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namoi</td>
<td>50</td>
<td>6</td>
<td>12</td>
<td>0</td>
<td>107</td>
<td>8</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Macquarie</td>
<td>28</td>
<td>3</td>
<td>14</td>
<td>2</td>
<td>59</td>
<td>4</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>Barwon Darling</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>249</td>
<td>16</td>
<td>70</td>
<td>8</td>
<td>534</td>
<td>22</td>
<td>95</td>
<td>11</td>
</tr>
</tbody>
</table>
The total area irrigated in the Northern Murray Darling Basin varies significantly year to year, primarily due to water availability. At the time of writing this report, the 2000–01 Agricultural Census was the most recent survey of agricultural land use across the Northern Murray Darling Basin. However, 2000-01 was a record year in terms of the area irrigated under cotton and the total irrigated areas identified in the 2000-01 Agricultural Census are not ‘typical’ of the study area. The unqualified use of areas irrigated in 2000-01 would significantly overestimate the long term potential WUE gains that could be achieved.

Instead, ‘typical’ irrigated areas (Table 23) were developed using information from a number of sources including:

- Annual cotton production data reported in Australian Cotton grower;
- Audits of irrigation and Water Use undertaken for the QLD Rural Water Use efficiency; and
- Recent national reviews of vegetable production (Hickey and Hoogers 2006; Henderson 2007).

From this information, an estimate of the ‘typical’ volumes of water applied in field was calculated for each valley in the study area (Table 23).

Efficiency gains

An estimate of the potential efficiency gains has been made for each of the main crop groups in the Northern Murray Darling Basin. Gains for in-field application were estimated determining a likely efficiency gain for low and high on-farm investment scenarios and applying this to volume of water applied in-field across the study area. Efficiency gains (Table 24) were developed using information from a number of sources including:

- Major irrigation performance studies undertaken within the Northern Murray Darling Basin (summarized in Section 4 of this report);
- Efficiency gains identified by Capital Agricultural Consultants Pty Ltd (2002) in a recent study assessing the potential for improving WUE in the Murray Darling Basin;
- Efficiency gains realized through the QLD Rural Water Use Efficiency Initiative (Coutts and Bell); and
- Recent and current irrigation research (various sources) identifying the performance that could be achieved with the implementation of improved irrigation management and the adoption of new technologies and practices.
Table 24 Efficiency improvements for low and high investment scenarios

<table>
<thead>
<tr>
<th></th>
<th>Low investment</th>
<th>High investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>14%</td>
<td>30%</td>
</tr>
<tr>
<td>Broadacre – cereals</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>Pasture</td>
<td>20%</td>
<td>27%</td>
</tr>
<tr>
<td>Vegetables</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>Fruit &amp; tree nuts</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>Grapes</td>
<td>10%</td>
<td>12%</td>
</tr>
</tbody>
</table>

A degree of professional judgment was used in defining likely in-field efficiency gains. A number of trends informed the efficiency improvement values that were adopted for the low and high investment scenarios, including:

- The vast majority of cotton is surface irrigated (furrow) within the Northern Murray Darling Basin. Optimization of surface irrigation (using Irrimate™ technologies) has reported achieving WUE improvements of 13 to 15% (Raine, Purcell et al. 2005; NSW DPI 2007) and represents a significant low investment (improved management) option for cotton.
- Opportunities exist for all irrigation systems in the cotton industry to achieve an application efficiency in the order of 90% with significant on-farm and R&D investment in precision surface irrigation and system conversion to centre pivots using real time adaptive control.
- Irrigation of other broadacre crops (cereals, coarse grains etc) typically has a low application rate and operates under a deficit irrigation regime.
- Anecdotal evidence suggests that considerable opportunities exist to improve spray irrigation systems used in the pasture and Lucerne sector by improving distribution uniformity and more closely matching applied volumes to soil-water deficits. This was reflected in the experience in the Pasture and Lucerne project in the QLD Rural Water Use Efficiency Initiative.
- Many horticulture enterprises in the Northern Murray Darling Basin have microirrigation systems installed (particularly in grapes) and as a result the opportunities for system change (high investment) is lower than in other sectors. Opportunities exist for further uptake of alternative agronomic practices (low investment) such as regulated deficit irrigation.
5.2 Possible WUE gains for the Northern Murray Darling Basin

A total of 1480 GL of potential WUE gains have been identified throughout the study area (Table 25). The greatest gains to be made are in the mitigation of losses from farm dams (48%), primarily through the mitigation of evaporation losses (Figure 7). Significant gains (45%) can be realized through improvements to the infield performance of irrigation enterprises across the Northern Murray Darling Basin.

This estimate involves 100% adoption from all irrigators and represents the upper limit that could be achieved with significant capital investment required for all elements of an irrigation enterprise (on-farm storages, on-farm distribution systems and in-field application systems).

It should also be noted that a significant proportion of these gains cannot yet be realized and that further research and development of commercially applicable technologies is required (eg. in mitigating evaporation losses from large on-farm storages) or further research is required in associated management practices to support existing technologies (eg. optimal agronomic practices for cotton irrigated by centre pivots).

![Figure 7 Opportunities for WUE gains by farm sub-system](image-url)
Table 25 Possible WUE Gains by Valley (GL)

<table>
<thead>
<tr>
<th></th>
<th>Warrego</th>
<th>Condamine - Balonne</th>
<th>Border Rivers</th>
<th>Gwydir</th>
<th>Namoi</th>
<th>Macquarie</th>
<th>Barwon Darling</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farm dams</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation from large farm dams</td>
<td>2</td>
<td>199</td>
<td>73</td>
<td>45</td>
<td>62</td>
<td>39</td>
<td>48</td>
<td>468</td>
</tr>
<tr>
<td>Evaporation from small and medium farm dams</td>
<td>0</td>
<td>47</td>
<td>17</td>
<td>11</td>
<td>14</td>
<td>9</td>
<td>11</td>
<td>110</td>
</tr>
<tr>
<td>Seepage from farm dams (all storages)</td>
<td>1</td>
<td>57</td>
<td>21</td>
<td>13</td>
<td>18</td>
<td>11</td>
<td>14</td>
<td>135</td>
</tr>
<tr>
<td><strong>Total farm dams</strong></td>
<td>3</td>
<td>304</td>
<td>111</td>
<td>69</td>
<td>94</td>
<td>59</td>
<td>73</td>
<td>713</td>
</tr>
<tr>
<td><strong>Distribution Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution losses – seepage</td>
<td>0.2</td>
<td>12</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>4</td>
<td>52</td>
</tr>
<tr>
<td>Distribution losses – evaporation</td>
<td>0.2</td>
<td>12</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>9</td>
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<tr>
<td><strong>Total distribution systems</strong></td>
<td>0.4</td>
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<td>18</td>
<td>20</td>
<td>17</td>
<td>7</td>
<td>104</td>
</tr>
<tr>
<td><strong>Infield Application</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low Investment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>1</td>
<td>43</td>
<td>48</td>
<td>65</td>
<td>50</td>
<td>28</td>
<td>15</td>
<td>249</td>
</tr>
<tr>
<td>Pasture &amp; Lucerne</td>
<td>7</td>
<td>21</td>
<td>11</td>
<td>3</td>
<td>12</td>
<td>14</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Other Broadacre</td>
<td>0.0</td>
<td>4</td>
<td>2</td>
<td>1.1</td>
<td>5.9</td>
<td>3.0</td>
<td>0.0</td>
<td>16</td>
</tr>
<tr>
<td>Horticulture</td>
<td>0.15</td>
<td>2</td>
<td>4</td>
<td>0.32</td>
<td>0.05</td>
<td>1.57</td>
<td>0.44</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total infield application - low</strong></td>
<td>9</td>
<td>70</td>
<td>65</td>
<td>69</td>
<td>68</td>
<td>46</td>
<td>17</td>
<td>343</td>
</tr>
<tr>
<td><strong>High Investment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>2</td>
<td>93</td>
<td>103</td>
<td>138</td>
<td>107</td>
<td>59</td>
<td>32</td>
<td>534</td>
</tr>
<tr>
<td>Pasture &amp; Lucerne</td>
<td>10</td>
<td>29</td>
<td>15</td>
<td>4</td>
<td>16</td>
<td>19</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>Other Broadacre</td>
<td>0.0</td>
<td>6</td>
<td>2</td>
<td>1.6</td>
<td>8.2</td>
<td>4.2</td>
<td>0.0</td>
<td>22</td>
</tr>
<tr>
<td>Total Horticulture</td>
<td>0.2</td>
<td>2</td>
<td>5</td>
<td>0.5</td>
<td>0.1</td>
<td>2.2</td>
<td>0.6</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total infield application - high</strong></td>
<td>12</td>
<td>129</td>
<td>125</td>
<td>144</td>
<td>131</td>
<td>84</td>
<td>34</td>
<td>661</td>
</tr>
<tr>
<td>Total Possible WUE gains</td>
<td>16</td>
<td>457</td>
<td>255</td>
<td>231</td>
<td>245</td>
<td>161</td>
<td>114</td>
<td>1478</td>
</tr>
</tbody>
</table>
While the largest potential WUE gains across the study area can potentially be made through mitigating evaporation losses from farm dams, this is influenced by the volume of on-farm storages within highly unregulated valleys eg. the Condamine-Balonne valley. When examining the potential gains on a valley by valley basis, the largest WUE gains in most valleys would be achieved through addressing infield application efficiency (Figure 8). This is particularly the case in valleys with a higher proportion of river regulation (eg. Macquarie, Gwydir and Namoi valleys and to a lesser extent the Border Rivers valley).

![Figure 8 Possible WUE gains by valley for each farm sub-system](image)

**Figure 8** Possible WUE gains by valley for each farm sub-system

**Farm dams**

A possible WUE gain of 713 GL from mitigation of losses from farm dams has been estimated for the study area (Table 25). The greatest potential gains have been identified from the mitigation of evaporation from large farm dams (66% or 468 GL) with a further 15% (110 GL) achieved through mitigation of evaporation from small farm dams. Mitigation of seepage from farm dams has been estimated as achieving a further WUE gain of 135 GL (Figure 9).
The greatest WUE gains from on-farm storages are to be made in the Condamine-Balonne. Significant gains (relative to the area irrigated) can also potentially be made in other highly unregulated catchments (eg. Barwon-Darling valley).

Local opportunities may exist that are not evident from the valley wide data. In particular, key horticulture districts that are highly dependent on on-farm storages for irrigation supply occur in the Granite Belt (Border Rivers Valley) and the Bathurst Plains (Macquarie Valley). Storage sizes will tend towards the smaller size classes (such that evaporation mitigation technologies are likely to be feasible now) and the higher value crops may translate into a greater capacity to invest in WUE gains from on-farm storages.

A number of issues need to be considered with regard to realizing the potential WUE gains from on-farm storages, including:

- Evaporation Mitigation Technologies (EMT) to realise the evaporation gains from small storages are commercially available. The long terms durability of these products has not yet been proven.
- Significant further R&D is required to develop EMTs that can be used for large farm dams (ie. monolyaers) for large dams. Therefore the majority of potential WUE gains from mitigating losses from on-farm storages cannot be realised at this stage.
- Some opportunity to explore improved management practices to reduce losses from large farm dams. Examples of these are provided in the case studies (refer to Section 6.2.1).

Figure 9 Possible WUE gains from mitigation of losses from farm dams
**Distribution Systems**

A total of 104 GL of WUE gains from on-farm distribution systems have been estimated with 52 GL due to seepage mitigation and a further 52 due to evaporation mitigation.

Due to the difficulties associated with measuring seepage and evaporation, few studies have quantified the losses associated with on-farm distribution systems. As a result, a common distribution losses and potential gains have been applied across all on-farm water deliveries in the Northern Murray Darling Basin and variations across valleys and sectors cannot be identified. Also, limited reviews have been undertaken assessing the success of methods and technologies for mitigating losses.

On-farm distribution losses is the area of least confidence in estimating losses and potential WUE gains that could be recouped.

**Infield Application**

Potential WUE gains from in-field application systems has been estimated at 661 GL. This value is the upper limit possible with 100% adoption within the high investment scenario (significant capital investment in irrigation system conversion / redesign). A total of 343 GL of
gains was estimated from the low investment scenario (improved management of existing irrigation systems).

Figure 11 identifies the potential WUE within each sector in the Northern Murray Darling Basin.

The vast majority of potential WUE gains from in-field systems are in the cotton industry. This is due to the dominance of cotton in terms of area irrigated in the study area and is not due to any inefficiencies in the industry. This presents an opportunity for significant gains in WUE in the Northern Murray Darling Basin to be made by targeting and assisting a cohesive industry. Opportunities for adoption in the cotton industry are discussed further in Section 11.

The total area irrigated in the broadacre (excluding cotton) and pasture sectors is similar. However, the potential WUE gains are much greater in the pasture sector due to the higher application rates employed and issues associated with system performance.

The horticulture sector represents the smallest potential WUE gains, largely due to the size of the industry in terms of area irrigated within the Northern Murray Darling Basin. However, the economic return from this sector is likely to be much greater and warrants further attention.

![Figure 11 Possible WUE gains by sector for in-field application systems](image-url)

**Figure 11** Possible WUE gains by sector for in-field application systems
While the greatest potential WUE gains are to be made in cotton, the proportion of potential gains per sector varies significantly across each valley (Table 26).
Table 26 Possible WUE Gains for infield application systems (High investment) by valley and crop type

<table>
<thead>
<tr>
<th></th>
<th>Warrego</th>
<th>Condamine - Balonne</th>
<th>Border Rivers</th>
<th>Gwydir</th>
<th>Namoi</th>
<th>Macquarie</th>
<th>Barwon Darling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cotton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 (18%)</td>
<td>93 (72%)</td>
<td>103 (82%)</td>
<td>138 (96%)</td>
<td>107 (82%)</td>
<td>59 (70%)</td>
<td>32 (92%)</td>
</tr>
<tr>
<td><strong>Broadacre</strong></td>
<td>0 (0%)</td>
<td>6 (4%)</td>
<td>2 (2%)</td>
<td>2 (1%)</td>
<td>8 (6%)</td>
<td>4 (5%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td><strong>Pasture</strong></td>
<td>10 (81%)</td>
<td>29 (22%)</td>
<td>15 (12%)</td>
<td>4 (3%)</td>
<td>16 (12%)</td>
<td>19 (23%)</td>
<td>2 (6%)</td>
</tr>
<tr>
<td><strong>Horticulture</strong></td>
<td>0.2 (1%)</td>
<td>2 (2%)</td>
<td>5 (4%)</td>
<td>0.5 (0.3%)</td>
<td>0.1 (&lt;0.1%)</td>
<td>2 (3%)</td>
<td>0.6 (2%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12</td>
<td>129</td>
<td>125</td>
<td>144</td>
<td>131</td>
<td>84</td>
<td>34</td>
</tr>
</tbody>
</table>
5.3 Limitations associated with the estimate of potential WUE gains

Data limitations associated with calculating potential WUE gains

The estimated potential WUE gains are based on the best available information for the Northern Murray Darling Basin, however there are a number of limitation with the data including:

- Estimates of agriculture water use and irrigated crop areas are collected by ABS as part of the Agricultural Census currently undertaken every 5 years. At the time of this report, the most recent data was for 2000-01 and is now out of date. Cropping areas vary significantly for the Northern Murray Darling Basin (primarily due to water availability, but are also affected by commodity prices etc) and data collected every 5 years is insufficient to develop an accurate profile of the average or ‘typical’ crop mix and irrigated areas.
- As identified by Webb McKeown & Associates Pty Ltd (2007), there is some doubt about the reliability of the volumes of hillside dams. In particular, the estimates for the Namoi and Macquarie Valleys, and possibly the Condamine-Balonne, seem high. This may have resulted in an overestimate of the potential gains from farm dams by as much as 20%.
- Information relating to on-farm storage size classes is limited and difficult to obtain. The application of evaporation mitigation technologies is driven largely by storage size and this information is essential for accurately estimating potential WUE gains from on-farm storages.
- Limited information is available on the current performance of on-farm storages, distribution systems and in-field application systems and tends to be for the cotton industry only. Broad assumptions were necessary to identify potential gains in WUE.

Limitation associated with applying the estimate of potential WUE gains

The estimated potential WUE gains are intended to provide a direction for future investment in the Northern Murray Darling Basin. These estimates identify clear priorities for Research, Development and Extension.

It is not intended that the estimated potential WUE gains be used for to set actual targets for on-farm WUE gains or basin wide improvements in WUE. Further benchmarking of on-farm current practices should be undertaken to confirm or refine these estimates should be undertaken before setting such targets.
6 Opportunities for WUE gains from On-farm dams

6.1 Key Issues

‘The greatest gains will be made at the storage. The storage is our biggest loss of water. It is quite possible for us to lose 1.5 m depth of water from our storage to evaporation and seepage. This is about one-third of our water supply.’

The major system losses in open farm water storage and distribution systems, which occur on a continuous basis, are evaporation and seepage. The major factors affecting the performance of storage and distribution systems include the local evaporation potential, soil percolation rates and the dam or channel design parameters.

The storage of on-farm water represents a considerable component within the whole farm water management system for many irrigation enterprises in the study area. For example, the cotton industry relies heavily on off-allocation and overland flow harvested water and hence, requires a substantial capacity to store and distribute water around the farm. A typically irrigated cotton farm requires a large ring tank reservoir (2-7 m high and many hectares in area) to ensure a reasonable security of water supply for irrigated production.

As outlined in Section 5, on-farm storage volumes have been estimated at 4500 GL for the Northern Murray Darling Basin. Potential WUE gains of 713 GL have been calculated from mitigation of evaporation and seepage.

The volume of on-farm storages in Australia has been estimated as 8000 GL (Baillie 2007). While estimates of volumes of on-farm storages should be used with caution, it is reasonable to assume that a significant proportion of the volume of on-farm storages in Australia occurs within the Northern Murray Darling Basin.

6.2 On-farm strategies

6.2.1 Evaporation Mitigation Strategies

A number of evaporation mitigation technologies (EMTs) are available for farm dams including:

1. An impermeable cover usually floats on the water surface or can be secured to the storage or both. Covers currently available allow rainfall to enter the storage whilst also significantly reducing evaporation.
2. **Shadecloth** is usually suspended above the top water level surface of the storage with a permanent structure and cable stays. The permeability of shadecloth allows rainfall to enter the storage.

3. **Chemical monolayers** are chemicals that can be applied to the water surface. Chemical monolayers act as a barrier to reduce the rate of evaporation. The application can be carried out manually but is usually applied through an automated system.

4. **Modular covers** have a broad range and there are a number of commercial systems available. Modular systems use individual (modular), usually floating, objects as barriers to reduce the surface area of water available for evaporation. They usually cannot achieve 100% coverage of the water surface and as such they allow rainfall to enter the water storage.

Examples of various covers are shown in Figure 12.

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![Impermeable cover](image1)

**a. Impermeable cover**

![Shade cloth](image2)

**b. Shade cloth**

![Modular cover](image3)

**c. Modular cover**

![Chemical barrier](image4)

**d. Chemical barrier**

**Figure 12** Examples of evaporation mitigation systems.

Various EMTs are appropriate in different situations, depending on the surface area, location and storage operational requirements. For example, floating covers are most appropriate on storages less than 1ha in size with all year water storage. Shade cloth structures would also...
be most viable on storages with permanent water and are likely to be limited to less than 5ha in size. Chemical monolayers would be most viable on large storages (greater than 10ha) and where the dam is likely to be dry for significant periods. Modular systems are likely to be best suited to intermediate storage areas less than 10ha (Craig, Green et al. 2005).

Other options for evaporation mitigation for on-farm storages include:

- **Increasing the wall height** can effectively reduce the evaporative loss. This occurs by increasing the amount of water stored whilst effectively maintaining the same surface area, thus maintaining similar levels of evaporative loss. This is particularly effective for a ring tank where the surface area does not increase with wall height. For gully dams / hillside dams, there will be some increase in surface area with wall height.

- **Division of storage into cells.** When the storage is not full, the water can be moved into particular cells such that a greater depth is maintained, hence reducing the surface area. The use of cells within storages also lends itself to the partial use of covers.

- **Strategic management** of on-farm storages eg. preferentially storing water in more efficient storages and using inefficiently stored water first.

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**Case Study: Managing Evaporation from Farm Dams**

Activities have been undertaken at the design, operational and monitoring stages to minimize evaporation from farm dams. Key storages have been upgraded by splitting them into cells and increasing the bank height. This has reduced the surface area and the losses that occur as a result. Water is strategically managed in the storages. Water can be transferred between all storages on the farm allowing improved WUE and water management. Storages have been surveyed and accurate water level sensors have been installed to measure storage volumes. Storage volumes are recorded throughout the year. (Case Study L)

Key storages have been redesigned to reduce seepage and evaporation losses. Two storages have been split into separate cells and one storage has had its banks raised by two meters. More recent storage design and development has taken storage efficiency into account as well as storage maintenance issues. Storages are ranked in order of efficiency and water is prioritized to the most efficient storages. Water can be transferred through all storages on the farm allowing this to be implemented without effecting farm management. (Case Study J)

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### 6.2.2 Seepage from On-farm storages

Seepage is the loss of water from a dam through deep drainage through the bed and sides of the dam. Seepage is a very difficult parameter to measure directly but in some instances can be of the same order of magnitude as evaporation.
There are a number of seepage mitigation techniques including:

- Structural changes (moving or adding storage walls)
- Membrane lining
- Clay or bentonite lining.

The solution appropriate to the situation will depend upon the nature and extent of seepage problems. Soil tests or EM surveys may be necessary to locate areas where seepage may be occurring.

**Case Study: Managing Seepage from Farm Dams**

*Ring tanks have been EM surveyed to identify areas of potential seepage loss. One ring tank was identified to have a problem area in the floor. This area was excavated and a compacted clay blanket was overlaid to seal the area.* (Case Study G)

*The storage has been designed with two cells. Each cell can be emptied and filled independently reducing potential seepage and evaporation losses. Impact rolling is employed when each cell is empty. Increased compaction in the upper soil profile has reduced seepage rates.* (Case Study I)

### 6.3 Current Research and Knowledge

Recent research on mitigating losses from farm dams has focused heavily on the mitigation of evaporation losses. No significant research has been undertaken recently on mitigating seepage losses from farm dams.

A study by Watts (2005) reviewed previous studies in evaporation reduction systems and reviewed the current evaporation control technologies. The state of the current evaporation reduction systems was summarised by Watts (2005):

1. Monolayers have a long history and, despite many attempts, have not been shown to be viable and effective in the long term (Brown 1988). Retreatment is required every two to four days, depending upon the amount of turbulence on the water surface (NPSI, 2005). Their evaporation reduction efficiency varies from 0% to 40% but the reasons for this variability are, as yet, unknown. However, monolayers may be the only solution for dams with a large surface area.
2. Various floating, modular devices are effective (60% to 90% reduction) and offer viable solutions in some circumstances. However, there are cost and practical issues.
3. Complete (air-tight) surface covers are expensive and pose significant practical problems for larger dams (including unknown ecological effects).
4. Shade cloth is probably the best-bet option at this stage. It provides a significant evaporation reduction (70%) and is not reliant on a ‘perfect’ seal over the dam surface. Rainfall can easily enter the dam. If further practical design work can reduce capital
costs, then shade cloth covers will become viable in an increasing number of situations.
Economic Assessment of Evaporation Mitigation Strategies

A ‘ready reckoner’ in the form of a simple computer spreadsheet model has been developed (Heinrich and Schmidt, 2006) that:

- Calculates the cost of installing an evaporation reduction system; and
- Calculates how much water is saved from evaporating.

The ‘Ready Reckoner’ allows site specific assessment of evaporation mitigation systems including installing a cover over the water, applying a chemical monolayer or modifying the shape of the storage dam. The ‘Ready Reckoner’ performs a simple, site-specific economic assessment of the viability of evaporation mitigation systems. The user enters appropriate data to customise the ‘Ready Reckoner’ to their site. The ‘Ready Reckoner’ returns the volume of water saved (in ML) and the cost of the evaporation mitigation system used to save this water ($/ML/year).

The ‘Ready Reckoner’ provides a simple economic tool available for farmers to use to determine if an evaporation reduction system is appropriate for their situation.

Technologies for Measuring Evaporation from Farm Dams

One of the difficulties in evaluating the various evaporation control techniques is obtaining an accurate measurement of evaporation losses with and without the products installed. Recent advances in measurement technology have made it much easier to determine the amount of water lost as evaporation and seepage from your storage. Recent evaporation project work at the National Centre for Engineering in Agriculture has resulted in the development of storage depth meters, which are sensitive enough to be able to measure water loss due to seepage. The methodology utilises accurate pressure sensitive transducer (PST) linked to data loggers and automatic weather stations.

Daily calculations of seepage and evaporation losses are possible and, when coupled with a detailed land or hydrographic survey, enables the landholder to determine the actual volume of water ‘lost’ through evaporation and seepage.

These meters are now available as the Irrimate™ Seepage and Evaporation Meter. The highly accurate meter can be installed for a short period of time to enable determination of evaporation and seepage losses. Furthermore, a less accurate meter (Irrimate™ Storage Meter) can also be installed permanently to keep track of water volume in the storage and aid water management.

Estimation of evaporation is also possible using the Evaporation Ready Reckoner which is available online. This tool uses data from the SILO climate data set to estimate the evaporation for a particular location. This estimate is not a measurement, so it is not as accurate as getting an evaporation measurement at a storage location.
6.4 Gaps in Current Knowledge and Research

‘We definitely need more research into reducing losses at the storage. There are rebates available for people to put covers on swimming pools to reduce evaporation. How much more water is lost from a ring tank?’

‘Covering and lining our storages and drains would provide us with enough water no matter what the season. Currently the available options are not cost effective.’

Evaporation Mitigation from Farm Dams

Watts (2005) and Craig et al (2005) have identified a range of technical issues to be resolved for mitigation of evaporation from farm dams including:

1. There are no long-term, good-quality measurements of evaporation losses from farm dams.
2. No evaporation estimation models with a sound theoretical basis exist for farm dams in Australia. Hence, it is not possible to estimate evaporation losses accurately.
3. Fundamental research on the potential for monolayers particularly in terms of distribution characteristics, application methods, evaporation reduction performance and environmental impact.
4. Further large scale testing of commercial products in conjunction with suppliers to assess evaporation mitigation efficiency and mechanical durability.
5. Fundamental research on evaporation processes for storage dams accounting for thermal storage in the water body and advection from surrounds, leading to improved prediction of evaporation losses from weather data and storage characteristics.
6. Further testing of the instrumentation developed in this project for seepage and evaporation determination and methodologies to separate seepage and evaporation components of water loss.
7. Further development of depth sounder systems developed for storage basin mapping to provide a cheap and accurate system for mapping the storage basin when filled with water.

Current research projects undertaken by CRC Polymers, CRC Cotton and CRC for Irrigation Futures are beginning to resolve some of these issues, in particular:

- Development of technology and systems to evaluate evaporation and seepage losses from water storages.
- Development of improved monolayer based evaporation mitigation systems that can be applied to large scale water storages to reduce evaporation losses.
It is also impossible at this stage to estimate the benefit of the adoption of evaporation reduction technologies on farm dams within the Northern Murray Darling Basin (and Australia wide). This is because:

- Most State agencies do not have good data on the number, capacity, surface area or usage of farm dams in their states. Hence, it is simply not possible to quantify the magnitude of the annual evaporation loss from farm dams.
- Without either the number of farm dams or an accurate estimate of the current evaporation loss, the benefit of evaporation reduction systems, in terms of GL saved, cannot be accurately quantified.

**Seepage Mitigation from Farm Dams**

There is a need to extend the range of storages on which seepage losses have been quantified. Obtaining a better understanding of commercial storage performance will provide a more accurate assessment of the range of seepage losses experienced within the industry and enable the targeting of lower performing storages for either retirement or corrective action.
7 Opportunities for WUE gains from On-farm Distribution Systems

“We did try lining channels with bentonite to limit seepage losses. This didn’t work particularly well. However we may try SoilPam in the future to try and minimise seepage from channels and head ditches.’

A total of 104 GL of WUE gains from on-farm distribution systems have been estimated with 52 GL due to seepage mitigation and a further 52 due to evaporation mitigation.

While storage design and construction often involves a well controlled compaction process, this level of care is not common during channel construction (Raine 1999). Seepage issues are most commonly caused by unplanned or poor construction, use of unsuitable soil type, poor soil compaction and poor maintenance (Dugdale, Harris et al. 2004). Evaporation losses are a function of the volumes of water delivered and opportunity time for losses from channels over an irrigation season.

Reducing losses in distribution systems revolves around two key areas:
1. Mitigation of seepage losses in distribution systems; and
2. Mitigation of evaporation losses in distribution systems.

There are a number of methods available to remediate seepage losses. They include the use of the following:
- earth liners, such as bentonites and other soil sealants
- hard surface liners such as concrete, grouted fabric mats, flumes, pipes, tiles and bricks
- flexible membrane liners constructed from geosynthetic clay, asphalt or plastic materials.

Evaporation losses are more difficult to remediate and can only be feasibly achieved through the installation of (expensive) pipe delivery systems.

Gains can also be made in mitigating losses (evaporation and seepage) by:
- minimizing channels lengths by changing the farm layout; and
- adopting control systems for on-farm water distribution and appropriate automation, subsequently reducing the opportunity for losses to occur. Most of the successes in the case studies from this project in mitigating losses from distribution systems were achieved in this way by minimizing the opportunity for losses to occur (see below).

Consequential gains rather than deliberate gains in reducing losses from distribution systems also occur when significant changes are made to infield irrigation systems, for example:
• Replacement of surface irrigation with centre pivots / lateral move often result in some of the headwater channels being replaced with the water delivery pipes (located along the backbone of the span of the centre pivot / later move); and
• Optimizing surface irrigation will result in reduced tailwater volumes and subsequently reduced distribution losses as water is recirculated.

**Case Study: Mitigating losses in Distribution Systems**

Replacement of the water transmission channel from the ring tank to the lateral move irrigator feed channel with an underground main. Installation of various valves and pump infrastructure to allow the lateral move irrigator feed channel to be completely emptied back into the ring tank at the end of the irrigation season. The channel can hold a substantial amount of water (2,400 m long, 5 m top width). (Case Study C)

All ditches on the property including tail water sumps and delivery channels have been concrete lined. (Case Study E)

The farm design has been changed to minimize transmission losses. Crops are planted close to water sources. This has required modifying the crop rotation. (Case Study J)

The farm has been designed in three operational segments. Each segment has its own tailwater return system and accesses water through a central supply system. This system minimizes transmission losses while still allowing effective crop rotation. (Case Study I)

**Current Research and Knowledge**

Due to the difficulties associated with measuring seepage and evaporation, few studies have quantified the losses associated with on-farm distribution systems. Seepage rates of between 1 and 23 mm/day have been measured on heavy clay soils in the Goondiwindi area (Dalton, Raine et al. 2001).

Limited reviews have been undertaken assessing the success of methods and technologies for mitigating losses in the Northern Murray Darling Basin. Most studies benchmarking the distribution efficiency open channel systems and the development of strategies to overcome water losses in the distribution system have been undertaken on irrigation systems in the Lower Murray Darling Basin including studies by Akbar (2003), Douglass, Preece et al. (2000) and Sinclair Knight Merz Pty Ltd (2001).

On-farm distribution losses is the area of least confidence in estimating losses and potential WUE gains that could be recouped. For the Northern Murray Darling Basin, a limited range of distribution systems in which seepage and evaporation losses have been quantified. The success of methods for mitigating losses is uncertain.
Further R&D is required to:

- Develop technologies for accurately measuring seepage and evaporation losses (as per measurement technologies for farm dams).
- Quantify the magnitude of distribution system losses in the Northern Murray Darling basin to define the scope of the problem. Obtaining a better understanding of distribution system performance will provide a more accurate assessment of the range of seepage losses experienced within the industry and enable the targeting of lower performing systems for either retirement or corrective action.
- Reviews the performance of available seepage mitigation technologies and practices suitable for the Northern Murray Darling Basin.
8 Opportunities for WUE gains from In-field Application Systems

8.1 Key Issues

The objective of any ‘efficient’ irrigation system is to apply the required amount or depth of water at the right time and as uniformly as possible while minimising losses. The major system losses occurring infield include evaporation, spray drift in sprinkler irrigation, tailwater runoff and deep percolation below the root zone of the crop.

Two scenarios have been considered in terms of typical on-farm strategies that might be employed to achieve WUE gains:

1. Low investment scenario involves using existing irrigation systems but with improved management (eg. irrigation scheduling, optimisation of surface irrigation application rates and cutoff times, improved distribution uniformity of spray systems etc). The low investment scenario involves adopting improved management practices without requiring a significant capital on-farm investment.

2. High investment scenario involves adopting new technology and associated management regimes (eg. changing from surface to pressurized systems, major redesign of existing irrigation systems). The high investment scenario typically involves a major on-farm capital investment.

As outlined in Section 5, WUE gains of 661 GL have been identified as possible with high investment improvements to infield application systems. Potential WUE gains of 343 GL have been identified for the low investment scenario.

Adopting a volumetric basis for calculating potential gains provides a clear indication of the areas where the largest gains are likely to be made in improved WUE. However the use of a volumetric basis for estimating WUE efficiency does not provide any assessment of the overall irrigation performance in relation to crop production and economic returns and will underestimate some of the agronomic gains that are possible through improved management of in-field application systems (eg. yield improvement in cotton and pasture due to reduction in waterlogging; improved quality of vegetables through more uniform irrigation application).

This section identifies some of the key strategies that could be employed on-farm to maximise WUE for infield application systems.

The on-farm strategies associated the high investment scenario have the potential to deliver the greatest WUE gains. However, a range of factors (biological, engineering and economic) need to be considered when identifying the best strategies for improving WUE for an individual irrigation enterprise. In some cases, adopting low cost improvements to the management of an existing irrigation system (low investment strategy) will achieve WUE gains with the greatest economic return. In other cases, the physical constraints of the irrigation enterprise or the high level of performance already realised for an existing system may dictate that WUE gains can only be achieved through the adoption of alternative
technologies (high investment scenario). Other considerations (eg. labour shortages) may drive whether the low or high investment scenario is most suitable for a particular irrigation enterprise.

8.2 Cotton

92% of the irrigated cotton utilises surface irrigation (predominantly furrow), with 6% of cotton under low pressure overhead systems (centre pivots and lateral moves) and the remainder drip irrigated (2%).

80% of the maximum gains possible in the Northern Murray Darling Basin from improvements to infield application systems will be delivered through irrigation improvements in cotton.

Low investment scenarios for improving in-field performance have focused on furrow irrigation only due to its dominance.

High investment scenarios include:
1. Conversion of surface irrigation to low pressure overhead systems (centre pivots and lateral moves);
2. Conversion of surface irrigation to drip irrigation; and
3. Investing in precision surface irrigation (ie improved monitoring leading to optimised surface irrigation management practices and/or re-designed fields).

8.2.1 Low Investment - Cotton

Improving System Performance for surface (furrow) irrigation

There is increasing evidence that the performance of surface irrigation on many commercial farms is highly variable. In-field measurements on over 180 irrigation events under commercial conditions have found application efficiencies of single irrigations ranging from 35-100% with seasonal efficiencies commonly between 60-85% (Raine and Foley 2002). One of the major reasons for low efficiencies is the correspondingly low uniformity of application associated with many furrow fields. However, these uniformities and efficiencies can often be increased by the selection of more appropriate furrow inflow rates and by pulling siphons earlier to reduce potential deep drainage losses. Optimised management of commercial surface irrigation through these simple low cost changes (ie. revised flow rates and times to cut-off) has been found to improve application efficiencies for single irrigations by as much as 30% and to improve seasonal application efficiencies by up to 15%.

The performance evaluation of surface irrigation involves an assessment of both the volume and uniformity of the water stored within the root zone. Factors affecting surface irrigation performance include furrow inflow rate, the soil infiltration characteristic, field slope and
length, surface roughness and furrow geometry. A "real-time" assessment of the infiltration characteristic involving the use of a volume balance equation relating measured irrigation advance data to infiltration is available through the Irrimate™ service.

The commercial Irrimate™ in-field surface irrigation evaluation service was first introduced into the cotton industry in 2001. After one irrigation optimisation consultation, most clients were saving an average of 0.15 ML/ha/irrigation by adjusting siphon flow rates and irrigation set times (Raine, Purcell et al. 2005). In recent years, with help from their clients, the range of infield evaluation equipment has been improved and is now more user friendly. A typical set of infield equipment includes: (a) siphon flow meter, (b) 6 x water advance sensors, and (c) an in-furrow downstream flume (Figure 13). In general, measurements conducted on a couple of irrigations in a field are enough to optimise the irrigation operation for that field.

![Irrimate Flowmeter and Flume](image)

**Figure 13** Infield evaluation equipment: siphon flow meter (left) and in-furrow downstream flume (right).

Strategic soil water measurements on cracking clay soils assists in calibrating some of the capacitance probes. Achieving high WUE requires knowing what the soil moisture deficit is and knowing how to change the irrigation to apply only the required amount over the full length of the field.

There are now 15 consulting agents providing Irrimate tools and support in areas ranging from Emerald to Hillston in the cotton industry, and extending into South Australia and northern Victoria. There have been over 300 field optimisations conducted over the last 5 years. The standard full season evaluation service includes optimisation on three irrigations in a field by the local agent currently costs approximately $4500 whereas optimisation of single irrigation events costs ~ $2000. Full sets of infield measurement equipment cost ~$6000.

**Increasing within season rainfall effectiveness**

The potential to improve the effectiveness of pre-season and within season rainfall may have significant effects on water use efficiency in water limited conditions. Strategies to increase within season rainfall effectiveness (e.g. deficit irrigation, partial field wetting, in-field surface
detention, agronomic practices to increase infiltration and reduce run-off) are neither well understood nor accepted within the irrigation sector.

Commercial irrigation strategies which attempt to maintain the soil moisture content at or near field capacity have been shown to lead to excessive deep drainage even on heavy clay soils. These deep drainage losses have been attributed to an inability to store infiltrated rainfall within the crop root zone. This suggests that under water limited conditions there could be substantial benefits in maintaining a root zone soil moisture deficit at less than field capacity and hence, the potential to increase the effective rainfall.

8.2.2 High Investment - Cotton

**Conversion of surface irrigation to low pressure overhead systems (centre pivots and lateral moves)**

About 5300 hectares of cotton is currently irrigated using centre pivots and lateral move machines in Australia. This represents approximately four per cent of the irrigated cotton crop in an average year (Foley and Raine 2002).

The performance of centre pivot and lateral move machines within the cotton industry is not limited by soil type or regional characteristics. Systems will work effectively on a wide range of soil types across the full spectrum of industry climatic conditions. The centre pivot and lateral move machines available for the cotton industry are generally appropriate and effective if designed and managed appropriately.

While centre pivots have been used in the Australian cotton industry for more than 20 years, recent interest in the performance and operation of both centre pivot and lateral move machines resulted in the Cotton Research and Development Corporation commissioning a scoping study to better understand the issues surrounding the use of these (Foley and Raine 2001). The study was conducted during 2001 and involved a face-to-face survey of more than 80 per cent of the 36 cotton growers using centre pivots and lateral moves.

Key advantages of using centre pivots and later move machines for irrigating cotton include:

- **Water savings and increased yield.** The potential to apply smaller volumes on preseason irrigations, improved crop germination, better use of in-season rainfall and the ability to use deficit irrigation strategies have all been cited as reasons for the lower irrigation water use and increased CWUE with centre pivots/lateral moves.
- **Labour savings.** A major driver in adoption of centre pivots/lateral moves is substantial reduction in labour costs compared to furrow. But while labour requirements for these systems can be as little as 10 per cent of traditional surface irrigation systems, the level of agronomic management skill required is much higher.
- **Uniformity of water application.**
- **Reduced crop waterlogging.**
- **The ability to automate the system.**
- **Fertigation/chemigation opportunities.**
• Ability to grow other crops. The vast majority of growers (93%) using centre pivot or lateral move machines installed the machine to grow crops other than cotton.

While efficiencies are strongly influenced by management practices, well managed centre pivots/lateral moves commonly produce application efficiencies in excess of 90 per cent. Low pressure, static plate sprinklers on centre pivots/lateral moves typically operate at 80–90 per cent application efficiency while moving plate sprinklers have application efficiencies up to 95 per cent. Low energy precision application (LEPA) socks and bubbler emitters have been found to have application efficiencies up to 98 per cent where surface run-off is controlled with furrow dikes.

One advantage of centre pivots/lateral moves is being able to change the application method (spray plates or LEPA) and water volume applied. Using spray plates, water can be applied to the soil surface providing high germination rates with relatively small application volumes.

Inappropriate centre pivot / lateral move design and installation has been an issue over the past 30 years. The early centre pivot and lateral move machines used in the Australian cotton industry suffered from a number of problems. The machines often suffered from inadequate capacity due to a combination of economic factors and a lack of understanding regarding the peak crop water use requirements. They were operated at high pressure, using overhead knocker sprinklers, which led to high operating costs and evaporative losses. The machines also often suffered from poor hydraulic design and excessive instantaneous water application rates leading to problems with water run-off and machine bogging. Deficiencies in grower understanding of the management practices required to use these machines also affected performance.

For growers where investing in an alternative irrigation infrastructure (rather than optimize existing surface irrigation systems) is an option, investing in a centre pivot or lateral move offers greater control and flexibility of irrigation management. The comparatively lower cost and longer life expectancy of centre pivots / lateral moves compared with systems such as subsurface drip irrigation make these systems an attractive option.

**Case Study: Converting to a Lateral Move to irrigate cotton**

Two lateral moves have recently been installed to irrigate 460 ha of the total 10,400 ha used to irrigate cotton, wheat and lucerne. The aim was to improve WUE by effectively using the normally small amount of water remaining at the end of the season. For example this allows small applications of water (not necessarily fully refilling the soil moisture profile) to establish winter wheat crops. In the past this water could have been stored in the reservoir over the winter where significant amounts could be lost through seepage and evaporation. Further on-farm trials are being undertaken comparing lateral move, subsurface drip and furrow irrigation to assess the economic and water use efficiency of each system. (Case Study J)
**Case Study: Designing a new irrigation enterprise with a lateral move**

All irrigation occurs through a single lateral move irrigator (160 ha in size). Cotton is the primary irrigated crop. However, depending on commodity prices or timing of water availability sorghum or maize crops are grown under irrigation. Low energy precision application (LEPA) socks are used for irrigation throughout the season. Sprinklers are used for crop establishment, however, the sprinklers have been lowered to the ground to limit evaporation from crop foliage.

The uniqueness of this farm is that the irrigation system was designed and developed with WUE in mind, i.e. the lateral move irrigator was installed initially rather than converting from previous surface irrigation.

‘We invested in the lateral move irrigator primarily for WUE reasons. In addition, we only have two full time staff so the labour saving afforded by the lateral was also a consideration. Our irrigation system was designed with an expected reliability of 1 in 3 years. This meant that to be profitable our WUE needed to be good.’

(Case Study C)

**Conversion of surface irrigation to drip irrigation**

Approximately 3100 ha of drip irrigation was installed in the Australian cotton industry in the 1999/2000 season. These installations are owned by 31 different farm operations, ranging from smaller growers through to the major corporate operations. All of the commercial drip systems have been installed subsurface. The average area of the drip system on each farm is approximately 90 ha with the largest single installation being 790 ha. The average age of the current installations is 2.75 years with a maximum age of seven years.

A scoping study was commissioned by the Cotton Research and Development Corporation in an effort to better understand the existing drip irrigation sector within the industry and to identify future opportunities for research and development within this sector (Raine, Foley et al. 2000).

The performance of drip irrigation within the cotton industry is not limited by soil type or regional characteristics. Commercial systems have been developed which will work effectively on a wide range of soil types across the full spectrum of industry climatic conditions. Drip systems have been installed on marginal country (usually with hardsetting red soils) that had not responded well to the destructive wetting and drying cycles associated with both furrow and spray irrigation. Some growers have installed drip systems into environmentally sensitive areas, such as river zones, so that they could maintain dry spray paths and use ground rigs for pest control. A small number of drip systems have been installed principally as show pieces for the various drip installers and drip manufacturing
companies while others appear to have been installed principally for political and/or social reasons (ie. in an attempt to be seen to be doing the right thing).

The components available for SDI in the cotton industry are generally appropriate and effective if installed properly. Drip systems are not inherently more efficient at water application than surface or spray systems. Badly managed drip systems may result in lower efficiencies and higher deep drainage losses than other standard systems.

Even though there is a divergence of crop management strategies within the drip irrigated cotton sector, all of the current drip installations reported improvements in water use efficiency over traditional surface irrigation practices. The average crop water use efficiency improvement was $1.29 \text{ bales/ML}_{\text{irrig}}$ with an average water reduction of 38% compared to traditional non-optimised surface irrigated systems. These results suggest that SDI technology could be successfully used in most areas of the existing cotton irrigation sector.

Drip systems should only be considered after serious attempts have been made to optimise existing systems. On economic grounds, investment in improved surface irrigation performance or adoption of low pressure overhead spray systems will generally provide better returns.

The design, installation and management of drip irrigation systems is inherently more complex than other application systems. Hence, widespread adoption will require additional training and support of both industry professionals and growers. A major barrier to the implementation of effective SDI systems in the industry is the level of training and experience of dealers and installers.

**Case Study: Converting to Drip Irrigation in cotton**

A small trial area (8.4 ha) of sub-surface drip irrigation (SDI) has been implemented on a cotton farm on the Darling Downs. The SDI setup has proved to be uneconomical and will not be expanded for this farming operation.

‘Our small area of SDI has not convinced us that the economics are there for a large scale adoption of SDI on our farm. We have had problems with insects and mice attacking the drip lines. The water efficiency of the system was good (irrigating directly from a bore into the drip system). However we probably increased our WUE by 10-15% with production increasing by 1 bale/ha. However this is not enough to justify the large capital and operating costs.’ Difficulties associated with changing irrigation systems (prohibitive cost for subsurface drip irrigation and farm layout issues preventing conversion to centre pivots/lateral moves) have made optimizing surface irrigation the only feasible option. (Case Study G)

**Improvement of existing furrow systems**
A number of common practices significantly affect the efficiency of surface irrigation systems including:

- Longer runs (often in excess of 1000m) are included in field designs, in contrast to the shorter lengths of field required for maximum efficiency of applications.
- Commercial irrigators typically continue to irrigate after the water has reached the end of the field to ensure that the root zone soil water is completely recharged and to alleviate any concerns regarding inadequate watering.
- Irrigators generally do not have a measure of the opportunity time required to recharge the soil water deficit and the irrigation is often continued until it is convenient to be manually switched off.
- The majority of surface irrigation is currently conducted using a constant inflow rate due to the labour requirements traditionally associated with surface irrigation management and a lack of automation within this sector. Irrigation controllers and timers are not commonly used for surface irrigation systems.
- A high reliance is placed on tailwater systems to recover excess irrigation, however the use of tailwater recycling systems does not guarantee efficient operation as excessive irrigation periods may result in appreciable in-field deep drainage and other losses may occur within the recycling system.

The performance of surface irrigation (furrow and border check) is affected by the following variables (NCEA 2006):

- Soil characteristics (infiltration characteristics and soil roughness).
- Slope of the field
- Length of the field.
- Inflow rate
- Time to cut-off; and
- Desired depth of application.

The soil characteristics are essentially fixed and beyond the control of the irrigator, however, they do need to be understood and measured for surface irrigation to be optimized. Length and slope are fixed at the design stage while the remaining variables (inflow rate, cut-off times and depth of application) are management variables and able to be varied for and sometimes during individual irrigations.

Fine-tuning of the management variables (particularly cut-off times) can represent a low investment option for existing surface irrigators to improve WUE (refer to Section 8.2.1). However, optimized surface irrigation may require changes to occur both to the design (eg. significant capital invested in redesigned fields and associated laser leveling and regular relasering) and management (improved monitoring, management and control of irrigation events).

**Redesign**

Surface irrigated fields are normally laser leveled with set up costs ranging between $500-$1800/ha depending on the amount of soil to be moved, the ratio of headworks to field length, and the drainage and tailwater requirements (Raine and Foley 2002). This is significantly less than the capital costs associated with centre pivots / lateral moves (typically...
between $1700 and $2500/ha to set up) and subsurface drip irrigation systems ($3500-$4500/ha).
Improved irrigation management

Improvement of furrow irrigation performance through the process of evaluation, simulation and optimisation with the IRRIMATE™ suite of tools is the first step in achieving a high WUE.

Opportunities also exist to vary management during irrigation by altering the inflow rate (ie. using a large flow rate during the advance phase and then reducing to a ‘cutback’ flow, in line with the infiltration rate) or by controlling the number or period of surges applied.

In the near future, automation and adaptive real-time control has the potential to provide an even higher level of irrigation performance along with substantial labour savings. Recent research at NCEA has established the basis for the practical real time control of furrow irrigation. The proposed system involves:

1. automatic commencement of the furrow inflow and measurement of that inflow,
2. measurement of the advance down the furrows mid way through each irrigation,
3. real time estimation of the soil infiltration characteristic and moisture deficit,
4. real time simulation and optimisation of the irrigation for selection of the time to cut-off that will give maximum performance for that irrigation, and
5. automatic cut off of the inflow at the designated time.

All of this is done without user intervention. The system proposed has been kept simple, by using a fixed inflow and varying only cut-off time, to encourage implementation of the system. All of the sensing, communication, software and control tools are available individually within NCEA but further work is required to develop a prototype system for field validation.
Case Study: Optimising Surface Irrigation in cotton

Cotton farm in the Barwon-Darling Valley
While transmission and storage losses are the biggest loss for a cotton farm in the Barwon-Darling valley, a range of measures have also been undertaken to make WUE gains from in-field losses. All fields are laser leveled and have been designed with optimum field lengths and grades. The average field length is 550m. Irrimate™ Surface Evaluation trials were undertaken on all fields to determine the optimum irrigation practice for each field. Appropriate monitoring is also undertaken. Capacitance probes are installed in every field to assist in effective irrigation scheduling and automatic weather stations are installed on the farm to calculate evapotranspiration. (Case Study I)

Cotton farm in the Namoi Valley
In-field losses are the potentially greatest losses for a cotton and wheat property in the Namoi valley, supplied primarily from a regulated surface water supply. Key aspects of the farm have been redesigned. Delivery systems have been redesigned to increase supply capacity and allow timely irrigations and every field to be irrigated independently of the rest of the farm. Fields have been redesigned and long fields have been split in half allowing more efficient irrigation practice. Wide fields have been split to allow more effective management. An EM 38 was purchased to investigate soil types across the farm. 100% of the farm has now been surveyed. Capacitance probes are in every field to assist irrigation scheduling. The location of the probes was determined based on EM survey, and yield mapping to determine a position most representative of the field. Irrimate In-field Equipment was purchased to monitor field irrigation efficiency and investigate potential irrigation options. An assessment of the irrigation system efficiency was conducted. A section of the farm was originally irrigated using ‘pipe through the bank’ methods. This system was assessed and was replaced by a more water efficient, more labor intense siphon based irrigation. (Case Study K)

Cotton farm in the Condamine-Balonne Valley
A cotton property on the Darling Downs is focusing on improving the efficiency of their surface irrigation after a subsurface drip irrigation trial proved uneconomical. All fields have had EM surveys undertaken for soil classification. EnviroScan™ soil moisture monitoring is used in all fields – sensors are placed in the most common soil type for the field as determined through EM survey. Appropriate irrigation management has been adopted with reduced irrigation watering times. All fields undergo a continuous program of laser levelling. Field design and optimised surface irrigation has been combined with agronomic practices that improve WUE are used (i.e. more water efficient cotton varieties, deficit irrigation of grain crops to maximise rainfall, soil management to improve structure, application of feedlot manures, soil testing, controlled traffic farming). Long fallow practices are used to build up soil moisture to reduce demand on irrigation water supply. (Case Study G)
8.3 Broadacre

A range of broadacre crops (other than cotton) are grown within the Northern Murray Darling Basin including cereals, coarse grains, legumes and oilseeds. Irrigation systems used for irrigating broadacre crops include surface irrigation (furrow), centre pivots, lateral moves, hand shift, side roll, traveling gun and traveling boom.

![Figure 14](image.png)

*Figure 14* Typical surface irrigation in Northern Murray Darling Basin

Little information is available on WUE and irrigation performance for broadacre crops in the Northern Murray Darling Basin, making it difficult to identify where the greatest gains could be made in improving WUE. However it is reasonable to assume that many of the opportunities will be similar to those for the cotton industry and that similar opportunities exist to optimize surface irrigation systems (as per Section 8.2.1) and explore opportunities for system conversion (as per Section 8.2.2).

**Case Study: Improved infield performance for grain /silage production**

Surface irrigated fields have been suitably designed with laser levelling of fields undertaken to improve irrigation efficiency and reduce water losses to deep drainage and all fields have tailwater / stormwater return infrastructure. Some fields have had EM surveys undertaken to determine soil types. Soil moisture sensors (C-Probe™) are used to monitor water use and to schedule irrigation. Surface irrigation performance evaluations have been undertaken to improve irrigation management and efficiency and to compare irrigation field lengths. Yield monitoring is undertaken to identify possible problem areas in irrigation fields. (Case Study B)
8.4 Pasture & Lucerne

A range of irrigation systems are used for irrigating pasture and Lucerne in the Northern Murray Darling Basin.

The most prevalent systems are the high pressure overhead travelling winches and hand shift and side roll sprays. Some pasture is irrigated using surface irrigation (furrow and border check), particularly in the Namoi and Macquarie valleys. Subsurface drip is becoming more common in the Peel River catchment (Namoi valley). Low pressure overhead systems (centre pivots, lateral moves) are also used.

In all cases, very little research has been conducted on the performance of these systems under commercial conditions. As part of the QLD Rural Water Use Efficiency (RWUE) Initiative, Distribution Uniformities (DU) of 55 to 80% were calculated for a range of irrigation systems used in the pasture and Lucerne industries (Queensland Dairyfarmers’ Organisation 2002). It is reasonable to assume these are representative of DU within the Northern Murray Darling Basin. Anecdotal evidence suggests that field layouts and system designs are commonly implemented without regard to soil infiltration properties, prevalent wind directions and velocities and other operation constraints (Raine 1999).

Specific strategies that represent a low investment (improved management) option for pasture and Lucerne irrigators include:

- matching applied volumes to soil-water deficits;
- matching the application rates of the infiltration characteristics of the soils;
- improving the effectiveness of pre-season and within season rainfall;
- reducing spray evaporation losses through more appropriate matching of droplet size (eg. nozzle size and operating pressure) to environmental conditions (eg. wind speeds); and
- modification of sprinkler spacings and field layouts to improve distribution uniformities.

Soil moisture monitoring and irrigation scheduling have generally not been taken up by the pasture and Lucerne industries. Low adoption in the pasture industry is largely because the amount of irrigation applied and the irrigation interval are determined by the irrigation method, and the time it takes to get around the whole farm (Stirzaker 2006). However, irrigation scheduling has some benefit, particularly in adopting irrigation strategies that maximise the effectiveness of in-season rainfall.

Some scope may exist to improve the water use efficiency at the farm scale by using strategies which maximise the marginal water use efficiency (yield/ML) rather than the yield per unit area. This typically results in the application of smaller volumes of water over larger areas and is only possible where additional land is available for irrigation. Large areas of the dairy industry operate under water limited conditions where additional land is available for irrigation. However, additional work is required to adequately identify the effect of this form of deficit irrigation and the potential benefits would need to be evaluated on a crop and regional basis.

On-Farm Water Use Efficiency in the Northern Murray-Darling Basin
Figure 15 Typical irrigation systems used in Pasture and Lucerne (a) Travelling gun, (b) Side roll and (c) Hand shift
At the completion on Phase 1 of the QLD RWUE Initiative, it was estimated that a 14% improvement in WUE was achieved for the dairy industry (consisting of a 4% direct irrigation reduction and an increased production of 10% for existing water use) and a 9% improvement in WUE for the Lucerne industry. It was also identified that the potential gains could realistically be doubled in time if the program was extended (Department of Primary Industries 2003). The irrigation systems and practices used throughout QLD are typical of the systems used in pasture and Lucerne in the Northern Murray Darling Basin and would be indicative of what further gains may be possible.

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**Case Study: Irrigation Scheduling for Lucerne**

An irrigated lucerne, grain and peanut farm in the Border Rivers (QLD) valley has explored a number of options for irrigation scheduling. EnviroSCAN™ soil moisture monitoring technology was implemented on the property but has been discontinued. Instead, a detailed crop requirement / evapotranspiration water budgeting system has been put in place for irrigation scheduling and water ordering.

‘We tried soil moisture monitoring however we do not use it anymore. We did not find it to be user friendly and our fields have widely varying soil types. Hence the readings from the meters were not representative of the entire field. The cost of instrumentation to get better representation of the field was prohibitive. We had some good initial support with the soil moisture meters. However we found it difficult to interpret the data ourselves. With a shortage of labour, less skilled operators need to be efficient water managers. Hence the science around irrigation scheduling and water budgeting needs to be made available in a simple user friendly format. Simplicity of information is the key.’

The use of direct soil moisture monitoring for irrigation scheduling is not seen as appropriate or user friendly. Instead irrigation scheduling is undertaken with estimates of crop evapotranspiration from climatic observations. (Case Study D)

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### 8.4.1 High Investment – Pasture and Lucerne

No published information is available for converting to alternative irrigation systems for pasture and Lucerne in the Northern Murray Darling Basin.

Guidelines on the conversion from border-check to centre pivot irrigation for pasture have been developed for the Southern Murray Darling Basin (VIC Department of Primary Industries 2004). Major differences exist with the irrigation systems that Northern irrigators would be converting from, however, centre pivots are a likely option for alternative irrigation system and some of the findings are likely to be applicable. In particular, conversion can be economically viable for a dairy farm if water savings can be achieved and used to expand the
area of irrigated pastures on the property. Conversion is less economic when there is no potential to expand the irrigated area on the property. Highlighted in the guidelines is the importance of considering local conditions such as soil and climatic conditions. In particular, consideration needs to be given to the irrigation requirements of pasture in the Northern Murray Darling Basin to ensure design application rates are sufficiently high to apply sufficient water to the crops.

There has also been a move towards subsurface drip for irrigating pasture and Lucerne, notably in the Peel River catchment (Namoi valley). However, no published information is available assessing the feasibility of this option.

**Case Study: Converting to Subsurface Drip in Lucerne**

A 53ha farm irrigating Lucerne and oats is irrigated predominantly with subsurface drip (40ha) with the remainder irrigated using a big gun traveler. Installing the subsurface drip has resulted in WUE improvements (through increased production per ML of water applied) as well as fertilizer, energy and labour savings. Unfortunately, the subsurface drip system has had to be reinstalled with thicker walled drip lines at considerable cost due to problems with attack from weevils. As was the case with this Lucerne farm, irrigators when investing in alternative irrigation methods often embark on a learning curve (with a financial cost involved) highlighting the need for ongoing research at a local level to support irrigation system change. (Case Study K)

### 8.5 Horticulture

#### 8.5.1 Low Investment – Horticulture

Limited published information is available on the existing performance of irrigation systems in the horticulture industry in the Northern Murray darling basin. However, anecdotal evidence points to a number of opportunities that exist to improve WUE relating to system uniformity, volume of applied water and agronomic strategies.

**Spray irrigation**

Fixed and hand shift sprays are the most commonly used spray systems in the vegetable sector. Very little research has been conducted on the performance of these systems under commercial conditions. However, anecdotal evidence suggests that field layouts and system designs are commonly implemented without regard to soil infiltration properties, prevalent wind directions and velocities and other operation constraints.
Given the current lack of information on the performance and management practices adopted with these systems, it seems likely that substantial efficiency gains should be achievable by:

- matching applied volumes to soil-water deficits;
- matching the application rates of the infiltration characteristics of the soils;
- reducing spray evaporation losses through more appropriate matching of droplet size (eg. nozzle size and operating pressure) to environmental conditions (eg. wind speeds); and
- modification of sprinkler spacings and field layouts to improve distribution uniformities.

**Micro-systems**

Micro-irrigation systems (eg. drip and micro-spray) are widely used within the horticultural sector. While drip and micro-spray systems are commonly assumed to be highly efficient, the limited data available for commercial installations in the horticultural sector suggests that irrigators commonly apply excessive volumes of water leading to deep drainage, particularly when using sub-surface irrigation systems (Raine 1999). Hence, it seems likely that efficiency gains will be achieved by encouraging the monitoring of soil moisture deficits and better matching the applied volumes to the measured deficit.

**Agronomic Strategies**

Strategies to improve the agronomic water use efficiency should focus on the potential to improve both the quantity and the quality of the yield. Quality issues are most likely to dominate within the horticultural sector where the economic returns are highly correlated with produce quality.

There has been low adoption of soil moisture monitoring in the vegetable industry. This may relate to the fact that this industry typically has a large number of fields all at different growth stages (Stirzaker 2006). The number of sites that would be needed for representative monitoring and the time taken to analyse the data would be prohibitive, especially as irrigation is usually at a frequent interval. Hence, it seems likely that substantial improvements in agronomic water use efficiency could be achieved through more widespread adoption of scheduling practices.

Even where scheduling is currently practiced, the schedules are commonly based on either a fixed soil moisture potential/deficit or on a time interval which is not varied throughout the season. As most horticulture crops have a variable demand for water during the season, the potential to reduce irrigated volumes at particular growth stages without adversely affecting yields should be investigated. Similarly, the potential to improve both the quantity and quality of the produce by the optimisation of moisture stress and scheduling intervals throughout the season should be evaluated.

**8.5.2 High Investment – Horticulture**

Many horticulture enterprises in the Northern Murray Darling Basin have micro-irrigation systems (drip, micro-sprays etc) installed. This is particularly evident in the grape sector where almost 100% of wine and table grapes have drip systems installed. As a result the
opportunities for system change is lower than in other sectors. Further opportunities exist for the irrigation system upgrades and conversion in the vegetable sector.

**Vegetables – Granite Belt (Border Rivers Valley)**

The last few years have seen an evaluation and installation of drip irrigation in the Granite Belt region (Henderson 2007). These system changes have been supported by trials and demonstrations by drip suppliers, the Water for Profit program, and the DPI. Switching to drip irrigation has assisted some growers produce viable areas of vegetable crops during recent water shortages. Many of these growers have retained their solid-set systems to assist with crop establishment or to provide cooling irrigations in pre-harvest periods.

Vegetable growers have also made considerable investment in upgrading their current overhead systems. For example, several producers have purchased new sprinkler types to try and improve the distribution uniformities of their solid-set systems. Others have replaced nozzles on their travelling irrigators, or even centre pivots on the Darling Downs, to try and better match irrigation rates with soil infiltration rates. The RWUE program recorded 249 successful applications for system improvement during the FIS operating period. There has probably been as much if not more investment in improving irrigation systems in the years since, as the water shortages have become even more severe (Henderson 2007).

A number of studies have developed economic case studies for the examining the potential water use efficiency improvements and improvements in product quality that are possible with conversion to drip irrigation in vegetables (Henderson 2003; Henderson 2007).

**Vegetables – Central West including Bathurst Plains (Macquarie Valley)**

A recent study by Hickey and Hoogers (2006) has identified a number of product quality and water issues associated with existing irrigation systems in vegetables in NSW that could be avoided through irrigation system conversion. Some examples relevant to the Macquarie Valley include:
- Converting from traveling guns to centre pivot provides an improvement in uniformity facilitating the use of biological controls in sweet corn.
- Water shortages during drought have resulted in wide scale adoption of drip for seedless watermelon production in the Central West.
- Cabbages are primarily irrigated with fixed sprinklers and travelling guns, however overhead irrigation can promote the development of diseases such as black rot. This could be avoided with drip irrigation.

**8.6 Current Research and Knowledge**

It is beyond the scope of this report to provide details of all recent irrigation research and knowledge relating to infield irrigation systems for the crops irrigated within the Northern Murray-Darling Basin. However, a broad understanding of irrigation knowledge relating to the key crops is essential to put in context the research gaps and adoption issues associated with increasing WUE in the Northern Murray-Darling Basin.
8.6.1 Irrigation Research (Infield) – Cotton Industry

Much of the irrigation research conducted by a variety of organisations in the Australian cotton industry has been brought together in WATERpak, a grower resource compiled by Cotton Research and Development Corporation. WATERpak provides technical information and practical advice to help irrigators improve irrigation practices, minimise environmental impacts and increase farm profits from irrigated cotton crops. WATERpak addresses issues as broad as Assessing field scale water efficiency; Metering; Irrigation scheduling techniques and tools; Managing irrigation with limited water; Agronomic issues; Irrigation system design and Off farm impacts.

The Cotton Industry™’s Best Management Practices Program prioritises issues for attention, provides a process of identifying the potential management risks and provides an outline on how to manage those risks. WATERpak provides detailed technical and practical advice that growers maybe looking for when using the BMP Manual.

Current and recent research activities relating to infield irrigation systems in the cotton include:

- The impact of different management strategies on the yield and quality of irrigated cotton;
- The efficiency of siphon-less/bank-less (basin) irrigation systems;
- Irrigation monitoring equipment to compare water requirements and optimal irrigation scheduling for both bollgard ii® (biotechnology varieties) and conventional cotton crops;
- Variations in the plant’s response to the soil to water status under different soil and climatic conditions and the consequences for in-crop water management;
- The optimisation of crop response to water with new technologies (eg bollgard ii® crops) and changed irrigation application methods such as low deficit scheduling, overhead systems and drip irrigation;
- Measurement and modeling of deep drainage losses in cotton growing areas;
- The development of best management practices that provide practical control measures for on-farm deep drainage; and
- Optimising irrigation scheduling through the use of continuous ‘real time’ plant monitoring sensors.

8.6.2 Irrigation Research (Infield) – Other Broadacre

Limited research has been undertaken through the Northern Murray-Darling Basin relating to the irrigation of other broadacre crops (cereals, coarse grains, oilseeds etc). Research within other industries (in particular the cotton industry) relating to irrigation system design and efficiency is equally applicable to other broadacre crops. However, research undertaken by the cotton industry does not address the specific agronomic and crop water needs of the specific broadacre crops.
Through CRDC’s investment in the National Program for Sustainable Irrigation (NPSI), the project on knowledge management in irrigated cotton and grains is developing a version of WATERpak for the grains industry, which will underpin water management training for consultants and growers. WATERpak consists of a range of information that is to be disseminated through existing cotton, grains and irrigated industry networks (Cotton Research and Development Corporation 2006)

8.6.3 Irrigation Research (Infield) – Pasture

‘I am struggling to find good general information about specific crop irrigation demands. There needs to be information freely available for every irrigated crop’. (Case Study D)

Limited research has been undertaken through the Northern Murray-Darling Basin relating to the irrigation of pasture and lucerne. Research within other industries relating to irrigation system design and efficiency is equally applicable to pasture and lucerne. However, research undertaken by other industries does not address the specific agronomic and crop water needs of pasture and lucerne.

Some information on system conversion in pasture has been developed in Tatura for the Southern Murray Darling Basin however significant differences exist in terms of the different irrigation systems which pasture enterprises are converting from and does not take into account the soil and climatic conditions relevant to the Northern Murray Darling Basin.

Some limited research has been undertaken by state Departments of Primary Industry to support extension activities such as the QLD Rural Water Use Efficiency Initiatives and research and extension activities centered around Tamworth.

8.6.4 Irrigation Research (Infield) – Horticulture

Vegetables

Current knowledge relating to irrigation and WUE in the vegetable industries has been consolidated in a series of reports ((Hickey, Hoogers et al. 2006), (Hickey and Hoogers 2006), (Henderson 2007)) at the national and state levels funded by Horticulture Australia Ltd and AUSVEG. The reports provide a summary and analysis of water use in the vegetable industry in Australia as at March 2006. Included are technology case studies detailing the costs and benefits which flow from a shift to more efficient irrigation systems and issues for possible future research.

Some limited research in irrigation for vegetables has also been specifically undertaken within the Northern Murray Darling basin to support extension activities such as the QLD RWUE. Research focused on uniformity and yield of spray systems (Barber and Raine...
2001) and the economic viability of improved irrigation management strategies (Henderson 2003).
**Fruit trees and Grapes**

Recently, research has focused on agronomic practices such as regulated deficit irrigation and partial root zone drying (Kriedemann and Goodwin, Loveys 2003) that reduce water use while maintaining yield and quality. Associated research is also being undertaken on the long term effects of drip systems on soil chemistry and physical properties (Loch, Grant et al. 2005).

Irrigation research for fruit trees and viticulture has generally been undertaken in the Southern Murray Darling Basin however these techniques are applicable to horticulture growers within the Northern Murray Darling Basin.

### 8.6.5 The Future of Irrigation Research

‘It is also crucial that a component of ‘blue sky’ R&D is continued to help in the search for the next “step change” in WUE delivery to irrigation and water delivery systems’.

**Spatially Variable Irrigation Applications**

Spatially varied irrigation is the term used to describe those systems that are able to deliver differential amounts of water to different areas of the field. The notion of spatially varied irrigation is predicated on the hypothesis that the crop is non-uniform and the water requirements are similarly non-uniform, probably as a result of differences in root zone conditions. It is also assumed that yield will be maximised if each plant is supplied with water exactly matching its individual requirements.

**Prescription Irrigation**

Prescription irrigation requires the identification of the appropriate volume and timing of the irrigation required. This implies that the operator has access to detailed data and response information regarding the crop, soil, weather, environment and other production inputs and that there is adequate knowledge regarding the interaction of these variables and the economic responses to variable inputs. In this case, prescription irrigation is used to maximise the value of the other crop inputs while minimising wastage and environmental impacts. Hence, effective prescription irrigation requires the four management steps, viz: an ability to measure, interpret, control, and evaluate.

There are very few crops where detailed information is available regarding production responses to variable inputs throughout the growing season. Hence, the major stumbling block to the introduction of effective prescription irrigation systems is the necessary understanding of the crop production systems and the ability to identify the interactions between the various crop inputs, productivity gains and operating constraints/costs. The relatively recent development of crop simulation models for the cotton sector provides the first steps towards a framework which may enable the identification of optimal strategies.
These models are currently being used to identify fertiliser and irrigation requirements at the "strategic" decision level. They are also currently being used to quantify the effect of various irrigation scheduling strategies including the potential for deficit irrigation and partial root-zone drying during less sensitive periods of crop growth. However, stripped down versions of these and other models could also be used as part of the real-time decision support systems required for tactical prescription irrigation by incorporation into controllers on irrigation application systems.

Adaptive Control Systems

A control system is a system that controls the operation of a process. Control systems consist of the process being controlled, a controller, and measurement system for feedback control. It may also include simulation or decision support software.

Characteristics of an irrigation system (crop growth, soil type and climate) vary within and between crop seasons, altering the optimal amount of irrigation to be applied to the crop. To achieve this it is necessary to automatically and continuously retune the control system to retain the desired performance of the system. A control system with such an adaptive structure is called an adaptive control system. The generally accepted definition of adaptive control is a system that adjusts its controller parameters based on sensor feedback from the process such that the controlled process behaves in a desirable way.

Existing control strategies for irrigation usually initiate an irrigation, rather than decide an irrigation amount. The systems rarely account for spatial and temporal variability, and are usually open-loop, i.e. they do not monitor the response of the crop to the irrigation amount.

Adaptive Control of centre pivots / lateral moves

Work at the NCEA directed toward the adaptive control of spatially varied applications from centre pivot and lateral move machines is progressing on three fronts.

First is the development of simulation models of the machine hydraulic performance and of the depths of water applied by the machines. These models were originally conceived as diagnostic tools but will be an essential component of the decision support for the adaptive control system. The models have also been used to determine the minimum size of management zone possible with these machines, expressed as a function of the sprinkler spacing, wetted diameter of the sprinklers and the machine speed.

Sensing of the crop response to the water applied is currently seen as the preferred feed back to the machine controller. Recent work by McCarthy et al. (2006) has used machine vision to monitor internode length of cotton. Measurements on the same plants on each pass of the irrigation machine offers the possibility of real-time measurement of crop production functions for different irrigation application regimes. Hence the machine controller will be able to select the most appropriate application for particular sub-areas of the field in real-time and at a spatial resolution limited only by the number of sensors deployed and the spatial resolution of the associated modelling.
Finally, a project commenced in 2007 that will investigate control options for these machines.

**Adaptive control of Furrow irrigation**

Recent research at NCEA has established the basis for the practical real time control of furrow irrigation. The proposed system involves:

1. automatic commencement of the furrow inflow and measurement of that inflow,
2. measurement of the advance down the furrows mid way through each irrigation,
3. real time estimation of the soil infiltration characteristic and moisture deficit,
4. real time simulation and optimisation of the irrigation for selection of the time to cut-off that will give maximum performance for that irrigation, and
5. automatic cut off of the inflow at the designated time.

All of this is done without user intervention. The system proposed has been kept simple, by using a fixed inflow and varying only cut-off time, to encourage implementation of the system. All of the sensing, communication, software and control tools are available individually within NCEA but need to be assembled and a prototype system established for field validation.

Decision support software is an essential part of the system and includes the following:

- continuous inflow measurement through inference from measurement of pressure in the supply system;
- characterisation of the field by determining a soil infiltration characteristic from detailed measurements of one irrigation event;
- prediction of the current infiltration parameters from one observation of the irrigation advance during the irrigation event being controlled; and
- simulation of the irrigation and optimisation to determine the preferred time to cut off the inflow to the field, taking into account the current soil moisture deficit and the variation in the infiltration characteristic across the set of furrows.

**Solute Signature Analysis and Salt Water Movement in the Root Zone**

There is a vast body of research work already available in the area of soil solute movement and plant salt/water interactions. As we move toward the adoption of precision irrigation systems with consistently high volumetric water use efficiencies and increasingly utilize saline irrigation waters we are testing the limits of this knowledge. Two tools appear to offer significant opportunity in addressing this issue from both a theoretical as well a practical point of view:

- Solute Signatures – that uses the relative change in distribution of different solutes within the soil over time to provide better measures of performance and sustainability; and
- Three dimensional models of soil-water and solute movement. It is proposed that a combination of these tools will provide a significantly enhanced understanding of plant interactions in this environment and subsequently our capacity to manage this environment better for environmental as well as productive outcomes.
9 Economics of On-farm Investment in Water Use Efficiency Improvements

9.1 Introduction

The economics for investment in irrigation improvements were considered for both low cost and high cost investment scenarios. Low cost investment strategies included potential water use gains through the adoption / facilitation of improved management practices and surface irrigation optimization (i.e. Irrimate surface irrigation evaluations). High cost investment strategies included water use gains from on farm storages (farms dams) and changes to infield application systems. Potential volumetric gains from both of these represented approximately 90% of the potential gains determined for the Northern Murray Darling Basin. The remaining potential gains come from mitigating distribution losses. This is an area of limited knowledge and an area requiring significantly more work to consider the economic potential.

Low Cost Investment Strategies

Low cost investment strategies (management changes) were not considered in the same level of detail as the high cost investment strategies given relatively minor investment and risk. The most significant costs associated with low investment strategies involve the cost of extension services to facilitate the adoption of improved management practices (extension agency / industry cost) or consultancy services (direct cost to grower). The experience from the Rural Water Use Efficiency project in Queensland indicates that the breakeven cost for WUE gains is approximately $96 / ML of water savings to fund extension and support services.

The most notable low cost investment strategy for obtaining significant gains across the Northern basin is the optimization of surface irrigation systems in cotton. Surface Irrigation optimization otherwise known as an Irrimate™ surface irrigation evaluation is provided as a fee for service through a network of consultants. The cost of the service is $4500 per field and includes monitoring irrigation performance over 3 events. On average volumetric efficiency gains of 15% have been observed for fields where the Irrimate™ service has been applied. Considering a nominal irrigation application of 6 ML/Ha for cotton, this equates to an average a water use gain of 0.9 ML/Ha. The cost per hectare ranges depending on the field size with cotton fields normally ranging from 40 to 100 Ha. The cost of the service per hectare therefore ranges from $45 to $112 / Ha or on average $64 / Ha. Given water savings of 0.9 ML / Ha and a cost for the Irrimate™ service of $64 / Ha, then the break even cost of water savings is $71 / ML.

In comparison the Irrimate™ service ($71 / ML) is competitive with traditional extension or adoptions programs ($96 / ML) to facilitate on farm water use efficiency gains. To establish the economic viability of these scenarios the break even cost of water saved is compared with the gross margin of water applied (i.e. GM / ML) presented in Table 27. Considering the mid range of gross margins per ML water used of many crops ($185/ML - $1000/ML), it is likely that low cost investment strategies are viable in most situations.
High Cost Investment Strategies
For high cost investment strategies, a broad economic analysis was adopted that calculated the break even cost of water savings, determined from the annuity of the investment strategy and the potential water savings.

The value / cost of water saved was determined by calculating the annuity of the investment relative to the annual quantity of water saved. The annuity was based on the nett present value (NPV) of the capital and operating costs over the lifetime of the machine. The ongoing operating costs include repairs, maintenance and labour costs. The annuity of the investment was determined in terms of $/Ha/year.

The annuity was then used to determine a break even cost of water savings (i.e. $/ML/year) for a particular investment by considering the potential water use gains in megalitres per hectare (ML/Ha). Where system conversions were considered the annuity of the current system (considering operating costs only) was subtracted from the new system (including capital) to determine a difference in the annual cost. To establish the economic viability of various high cost investment scenarios the break even costs ($/ML of water saved) are compared with the gross margin per megalitre ($GM / ML) for different crops presented in Table 27.

Table 27 Gross margin per megalitre ($GM / ML) for various crops

<table>
<thead>
<tr>
<th>Crops</th>
<th>Low</th>
<th>Avg.</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton*</td>
<td>130</td>
<td>340</td>
<td>550</td>
</tr>
<tr>
<td>Broadacre</td>
<td>70</td>
<td>185</td>
<td>300</td>
</tr>
<tr>
<td>Pasture</td>
<td>30</td>
<td>290</td>
<td>550</td>
</tr>
<tr>
<td>Horticulture</td>
<td>200</td>
<td>1000</td>
<td>1800</td>
</tr>
</tbody>
</table>

Source: Marsden Jacob Associates (2003),
Broadacre includes cereals and annual row crops, Pastures includes pastures and dairy; Horticulture includes vegetables, vines and tree fruit. Average GM / ML reported is the middle value of low and high range

* Range of gross margins for cotton determined from NSW DPI farm budget calculation NSW DPI website and Hickey, Hoogers et al. (2006);

9.2 On-farm Storages
The performance of evaporation mitigation products widely varies. The major limitation is the size of storage in which physical barriers such as floating covers and shade cloth are constrained (ie. storage less than 5 Ha in surface area). For larger storages options include reconstruction of storages into cells and the deployment of monolayers which suppress evaporation losses. The performance of monolayers is the subject of ongoing research due
to the high variability of product performance (i.e. evaporation savings ranging from 0 – 40%).

Table 28 is a summary of the breakeven cost for the various evaporation mitigation technologies (EMTs).

Table 28 Breakeven cost of water savings for EMTs

<table>
<thead>
<tr>
<th>Product</th>
<th>Potential Evaporation Reduction (%)</th>
<th>Installation Cost ($/m²)</th>
<th>Operating &amp; Maintenance Cost $/ha/yr</th>
<th>Breakeven Cost ($/ML saved)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating cover</td>
<td>High - Med - Low</td>
<td>Low - High</td>
<td>Low - High</td>
<td>Low - Med - High</td>
</tr>
<tr>
<td>Shade Cloth</td>
<td>95% - 90% - 85%</td>
<td>$5.50 - $8.50</td>
<td>$112 - $572</td>
<td>$302 - $319 - $338</td>
</tr>
<tr>
<td>Monolayer</td>
<td>80% - 70% - 60%</td>
<td>$7.00 - $10.00</td>
<td>$112 - $537</td>
<td>$296 - $339 - $395</td>
</tr>
<tr>
<td>Monolayer</td>
<td>30% - 15% - 5%</td>
<td>$0.00 - $0.38</td>
<td>$826 - $4,050</td>
<td>$130 - $397 - $1191</td>
</tr>
</tbody>
</table>

Source: Craig and Green et al (2005)

Note: Estimated breakeven cost is based on 2200mm potential evaporation, all year water storage, low cost scenario and range in evaporation reduction performance.

Breakeven cost is shown to vary from $130 - $1,191 depending on product and evaporation reduction performance. Under situations where potential evaporation losses from storage exceed 2000mm/year and ‘medium’ evaporation reduction performance the breakeven cost is likely to range between $300/ML-$400/ML saved. The cost per ML water saved is influenced by the amount of time the storage holds water. Chemical monolayers can be selectively applied only in hot months or when there is water in storage which reduces cost per ML water saved. Considering the mid range of gross margin per ML water used of many crops ($185/ML - $1000/ML), it is likely that investment in these products will be viable in many situations.

9.3 Infield Application Systems

In field application systems vary across the Northern part of the Murray Darling Basin. The majority of the area is irrigated by surface irrigation systems in cotton. Other irrigation systems include centre pivot, lateral move, travelling gun, travelling boom, hand shift, solid set sprinklers and drip. Despite the current range and use of different irrigation systems the opportunity for WUE gains through system conversions in most cases is directed towards centre pivots and lateral moves in cotton, broadacre, and pasture; travelling booms in pasture and surface drip in horticulture. To determine the economics of these system changes the break even cost of water savings through volumetric efficiency gains are compared to the gross margin per megalitre (GM / ML) for the different crops.

The economic evaluation of irrigation application systems should encompass the capital, labour, pumping, maintenance and other operating costs. The capital cost of irrigation
system conversions was sourced from Schmidt (2003). Operating, repairs and maintenance and labour costs were sourced from Thompson (1997). Values sourced from Thompson (1997) were adjusted to reflect current values according to the following:

- Operating costs - multiplied by 2.25 (i.e. increase in electricity costs from $5 / ML @ 10m head to $11.25; source NSW DPI)
- Repairs & Maintenance costs - multiplied by 1.3 (i.e. data 10 years old; 3% inflation)
- Labour costs - multiplied by 1.6 (i.e. increase in labour costs from $10 /hr to $16/hr; Source: NSW DPI)

Investment strategies were considered over a 20 year investment cycle at a discount rate of 5%. The lifetime of various irrigation systems was assumed to equal 20 years except for surface drip (5 years) and subsurface drip (10 years). The variable costs described above including operating, repairs and maintenance and labour will vary depending on the amount of water applied to the crop. These were indexed according to the total application amounts used in different crops.

9.3.1 Cotton

Costs described above were applied to the following irrigation systems based on an average application amount of 6 ML/Ha for irrigated cotton. Options for system conversion in cotton include centre pivot, lateral move, subsurface drip and redevelopment of the existing surface irrigation system.

Table 29 Irrigation system comparison of costs (6 ML/Ha average application rate)

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Capital ($/Ha)</th>
<th>Operating ($/Ha/yr)</th>
<th>Repairs and Maintenance ($/Ha/yr)</th>
<th>Labour ($/Ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Pivot</td>
<td>2400</td>
<td>270</td>
<td>47</td>
<td>3</td>
</tr>
<tr>
<td>Lateral Move</td>
<td>2400</td>
<td>270</td>
<td>47</td>
<td>5</td>
</tr>
<tr>
<td>Subsurface Drip</td>
<td>5000</td>
<td>203</td>
<td>47</td>
<td>7</td>
</tr>
<tr>
<td>Surface / Furrow</td>
<td>1800</td>
<td>162</td>
<td>39</td>
<td>31</td>
</tr>
</tbody>
</table>

The breakeven cost of water savings for converting to alternative irrigation systems ranged from $1121 / ML to $80 / ML. This is compared to a GM / ML for cotton ranging from $550 / ML to $130 / ML (Table 27). Light shading in Table 30 indicates the options where the break even costs are higher than an average GM / ML of $340. The darker shading indicates options where the breakeven cost of water saved is uneconomical. For these scenarios the cost of water saved is greater than the highest return per megalitre of water (i.e. $550 / ML).

Providing water use gains can be achieved the redevelopment of existing surface irrigation systems achieved the lowest cost per megalitre of water saved. For only a 10% improvement in volumetric efficiency the cost per megalitre of water saved was much less than the average GM / ML. Conversion to either centre pivots or lateral moves indicated that for only a slight improvement in volumetric efficiency the economic viability depends on achieving a high GM
At 20 to 30% volumetric gains the cost of water saved was less than the average GM / ML. For subsurface drip irrigation economic feasibility depended on achieving volumetric gains of approximately 30%.

Table 30 Comparison of system conversion options for Cotton

<table>
<thead>
<tr>
<th>System Conversion</th>
<th>Annual Cost ($/Ha)</th>
<th>Breakeven costs ($/ML saved) for improved volumetric efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Surface to Centre Pivot</td>
<td>281</td>
<td>468</td>
</tr>
<tr>
<td>Surface to Lateral Move</td>
<td>283</td>
<td>471</td>
</tr>
<tr>
<td>Surface to Subsurface Drip</td>
<td>672</td>
<td>1121</td>
</tr>
<tr>
<td>Surface Redeveloped</td>
<td>144</td>
<td>241</td>
</tr>
</tbody>
</table>

9.3.2 Broad acre

Costs described above were applied to the following irrigation systems based on an average application amount of 3 ML/Ha for irrigated broad acre crops. Options that were considered for system conversion in broadacre crops included changes to centre pivot and lateral moves from existing furrow, hand shift and travelling gun systems.

Table 31 Irrigation system comparison of costs (3 ML/Ha average application rate)

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Capital ($/Ha)</th>
<th>Operating ($/Ha/yr)</th>
<th>Repairs and Maintenance ($/Ha/yr)</th>
<th>Labour ($/Ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Pivot</td>
<td>2400</td>
<td>135</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>Lateral Move</td>
<td>2400</td>
<td>135</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>Surface</td>
<td>1800</td>
<td>81</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Handshift</td>
<td>2000</td>
<td>169</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>Travelling Gun</td>
<td>2000</td>
<td>236</td>
<td>59</td>
<td>24</td>
</tr>
</tbody>
</table>

The breakeven cost of water savings for converting to alternative irrigation systems ranged from $792 / ML to $38 / ML. This is compared to a GM / ML for broad acre crops ranging from $300 / ML to $70 / ML (Table 27). Light shading in Table 32 indicates the options where the break even costs are higher than the average GM / ML of $185. The darker shading indicates options where the breakeven cost of water saved is uneconomical. For these scenarios the cost of water saved is greater than the highest GM / ML of water applied (i.e. $300 / ML).

Conversion of traveling guns to centre pivots or lateral move irrigators achieved the lowest cost per megalitre of water saved (Table 32). This was primarily due to the inherently high operating and maintenance costs of traveling guns. When comparing the conversion from
handshift sprinklers to centre pivots or lateral moves at least a 10% improvement in volumetric efficiency would be required to obtain water savings less than the average GM / ML of $185 for broadacre crops. When converting from surface to centre pivots or lateral moves a significant increase in volumetric efficiency (30%) would be required to reduce the cost of water savings within the GM / ML for broadacre crops. This was due to a number of factors including the relatively low operating costs for surface irrigation systems and the low application amount of 3 ML/Ha. At low application amounts large increases in efficiency are required to generate sufficient water savings to spread the costs over the water saved therefore making the cost of water saved economically feasible.

Table 32 Comparison of system conversion options for other Broadacre crops

<table>
<thead>
<tr>
<th>System Conversion</th>
<th>Annual Cost ($/Ha)</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface to Centre Pivot</td>
<td>237</td>
<td>789</td>
<td>394</td>
<td>263</td>
</tr>
<tr>
<td>Surface to Lateral Move</td>
<td>238</td>
<td>792</td>
<td>396</td>
<td>264</td>
</tr>
<tr>
<td>Travelling Gun to Centre Pivot</td>
<td>34</td>
<td>113</td>
<td>56</td>
<td>38</td>
</tr>
<tr>
<td>Travelling Gun to Lateral Move</td>
<td>35</td>
<td>116</td>
<td>58</td>
<td>38</td>
</tr>
<tr>
<td>Hand Shift to Centre Pivot</td>
<td>85</td>
<td>283</td>
<td>141</td>
<td>94</td>
</tr>
<tr>
<td>Hand Shift to Lateral Move</td>
<td>86</td>
<td>286</td>
<td>143</td>
<td>95</td>
</tr>
</tbody>
</table>

9.3.3 Pasture

Costs described above were applied to the following irrigation systems based on an average application amount of 7 ML/Ha for irrigated pastures. Options that were considered for system conversion in pastures included changes to travelling boom, centre pivot, lateral moves and drip irrigation. Existing systems used in pasture consist of travelling gun, hand shift and surface.

Table 33 Irrigation system comparison of costs (7 ML/Ha average application rate)

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Capital ($/Ha)</th>
<th>Operating ($/Ha/yr)</th>
<th>Repairs and Maintenance ($/Ha/yr)</th>
<th>Labour ($/Ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Pivot</td>
<td>2400</td>
<td>315</td>
<td>55</td>
<td>4</td>
</tr>
<tr>
<td>Lateral Move</td>
<td>2400</td>
<td>315</td>
<td>55</td>
<td>6</td>
</tr>
<tr>
<td>Travelling Boom</td>
<td>2000</td>
<td>551</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>Surface</td>
<td>1800</td>
<td>189</td>
<td>46</td>
<td>36</td>
</tr>
<tr>
<td>Handshift</td>
<td>2000</td>
<td>393</td>
<td>91</td>
<td>140</td>
</tr>
<tr>
<td>Travelling Gun</td>
<td>2000</td>
<td>551</td>
<td>137</td>
<td>56</td>
</tr>
</tbody>
</table>
The breakeven cost of water savings ranged from $729 / ML to a profit. The GM / ML for pastures ranges from $550 / ML to $30 / ML. Light shading in Table 34 indicates the options where the break even costs are higher than an average GM / ML of $290 (Table 27). The darker shading indicates options where the breakeven cost of water saved is uneconomical. For these scenarios the cost of water saved is greater than the highest GM / ML of water applied (i.e. $550 / ML for pasture crops).

Conversion of handshift sprinklers and traveling guns to centre pivots and lateral move irrigators resulted in a profit to the grower. In both cases moving to centre pivots and lateral moves indicated that the annualized cost of the system conversion (including capital) was more than offset by the relatively high operating, maintenance and labour costs of the existing systems.

Conversion from surface to centre pivots or lateral moves required an increase in volumetric efficiency of at least 20% to obtain a break even cost less that the average GM / ML (Table 27). This was primarily due to the inherently low operating costs for surface irrigation systems compared to that required for pressurized irrigation systems.

Table 34 Comparison of system conversion options for Pasture

<table>
<thead>
<tr>
<th>System Conversion</th>
<th>Annual Cost ($/Ha)</th>
<th>Breakeven costs ($/ML saved) for improved volumetric efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Travelling Gun to Travelling Boom</td>
<td>79</td>
<td>113</td>
</tr>
<tr>
<td>Travelling Gun to Centre Pivot</td>
<td>-178</td>
<td>-</td>
</tr>
<tr>
<td>Travelling Gun to Lateral Move</td>
<td>-176</td>
<td>-</td>
</tr>
<tr>
<td>Travelling Gun to Subsurface Drip</td>
<td>203</td>
<td>291</td>
</tr>
<tr>
<td>Handshift to Travelling Boom</td>
<td>198</td>
<td>283</td>
</tr>
<tr>
<td>Handshift to Centre Pivot</td>
<td>-59</td>
<td>-</td>
</tr>
<tr>
<td>Handshift to Lateral Move</td>
<td>-57</td>
<td>-</td>
</tr>
<tr>
<td>Handshift to Subsurface Drip</td>
<td>322</td>
<td>461</td>
</tr>
<tr>
<td>Furrow to Centre Pivot</td>
<td>295</td>
<td>422</td>
</tr>
<tr>
<td>Furrow to Lateral Move</td>
<td>298</td>
<td>425</td>
</tr>
<tr>
<td>Furrow to Subsurface Drip</td>
<td>511</td>
<td>729</td>
</tr>
</tbody>
</table>

9.3.4 Horticulture

Costs described above were applied to the following irrigation systems based on an average application amount of 4 ML/ha for horticulture. Options for system conversion in horticulture...
included drip irrigation and centre pivots. Existing systems used in horticulture include travelling boom, solid set, surface, handshift and travelling gun.
Table 35 Irrigation system comparison of costs (4 ML/Ha average application rate)

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Capital ($/Ha)</th>
<th>Operating ($/Ha/yr)</th>
<th>Repairs and Maintenance ($/Ha/yr)</th>
<th>Labour ($/Ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Pivot</td>
<td>2400</td>
<td>180</td>
<td>31</td>
<td>2</td>
</tr>
<tr>
<td>Travelling Boom</td>
<td>2000</td>
<td>315</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>Solid Set</td>
<td>4000</td>
<td>225</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Surface Drip</td>
<td>2000</td>
<td>135</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>Surface / Furrow</td>
<td>1800</td>
<td>108</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>Handshift</td>
<td>2000</td>
<td>225</td>
<td>52</td>
<td>80</td>
</tr>
<tr>
<td>Travelling Gun</td>
<td>2000</td>
<td>315</td>
<td>78</td>
<td>32</td>
</tr>
</tbody>
</table>

The breakeven cost of water savings for converting to alternative irrigation systems ranged from $1224 / ML to a profit. This is compared to a GM / ML for horticultural crops ranging from $2000 / ML to $41 / ML. Light shading in Table 36 indicates the options where the breakeven costs are higher than an average GM / ML of $1000 (Table 27). The darker shading indicates options where the breakeven cost of water saved is uneconomical. For these scenarios the cost of water saved is greater than the highest GM / ML of water applied (i.e. $1800 / ML for horticultural crops).

Conversion of traveling guns to centre pivots was the most economical investment which resulted in a profit. This occurred as the annualized cost of the system conversion (including capital) was offset by the relatively high operating, maintenance and labour costs associated with traveling guns. A similar benefit was also observed when converting from handshift sprinklers to centre pivots. The breakeven cost of water saved was relatively small compared to other system conversions. For handshift systems the labour costs are the dominant factor.

Most other scenarios focused on the conversion to surface drip systems. Relatively minor increases in volumetric efficiency were economical however when compared to other crops this was due to the high GM / ML of horticultural crops. Similar to other cropping scenarios conversion to pressurised systems from surface required a higher level of volumetric efficiency to reduce the breakeven costs of the water. For only a 10% saving in water the conversion from surface irrigation to drip was uneconomical.
Table 36 Comparison of system conversion options for Horticulture

<table>
<thead>
<tr>
<th>System Conversion</th>
<th>Annual Cost ($/Ha)</th>
<th>Breakeven costs ($/ML saved) for improved volumetric efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Furrow to Surface Drip</td>
<td>490</td>
<td>1224</td>
</tr>
<tr>
<td>Furrow to Centre Pivot</td>
<td>251</td>
<td>628</td>
</tr>
<tr>
<td>Travelling Gun to Surface Drip</td>
<td>219</td>
<td>548</td>
</tr>
<tr>
<td>Travelling Gun to Centre Pivot</td>
<td>-19</td>
<td>-</td>
</tr>
<tr>
<td>Travelling Boom to Surface Drip</td>
<td>266</td>
<td>665</td>
</tr>
<tr>
<td>Solid Set to Surface Drip</td>
<td>385</td>
<td>963</td>
</tr>
<tr>
<td>Handshift to Surface Drip</td>
<td>287</td>
<td>718</td>
</tr>
<tr>
<td>Handshift to Centre Pivot</td>
<td>49</td>
<td>122</td>
</tr>
</tbody>
</table>

9.4 Conclusion

To establish the economics of low cost and high cost investment strategies the break even cost of potential water savings ($/ML) was compared to the gross margin per megalitre (GM / ML) of different crops encountered across the Northern Murray Darling Basin. For the purpose of this study if the cost of water savings was below the gross margin per megalitre of a particular crop then the investment was regarded as economically feasible. Some consideration however was given where the break even cost of water savings was higher than the average GM / ML reported in Table 27. It should be noted however that this process generalizes the opportunities and economic feasibility for investment while specific investment of farm would require a more detailed economic assessment.

Low Cost Investment Strategies
Low cost investment strategies were focused on two key areas including water use gains through the adoption / facilitation of improved management practices and consulting services for surface irrigation (Irrimate) evaluations. The experience from the Rural Water Use Efficiency project in Queensland indicates that the breakeven cost for WUE gains is approximately $96 / ML of water savings to fund extension and support services. In comparison the break even cost of water savings for an Irrimate surface irrigation evaluation was determined as $71 / ML.

High Cost Investment Strategies
High cost investment strategies included the implementation of evaporation mitigation technologies (EMTs) for on-farm storages and conversion of infield irrigation systems. Whilst the development of EMTs is still occurring break even costs for medium evaporation reduction varied from $300 to 400 / ML saved. Considering the average GM / ML water used
of many crops ($185/ML - $1000/ML), it is likely that investment in these products will be viable in many situations.

Options for system conversions primarily considered a change to centre pivots, lateral moves and drip irrigation. A change to traveling booms (pasture) and the redevelopment of existing surface irrigation systems (cotton) was also considered. Conversion to centre pivots and lateral moves was economical at relatively minor increases in volumetric efficiency when converting from other pressurized irrigation systems. This was due to a reduction in operating, maintenance and labour costs. When converting from surface irrigation systems which have inherently low operating costs a higher volumetric efficiency was required to reduce the break even cost of water saved. Minor improvements in the volumetric efficiency were still economical however; a higher GM / ML would be required for the cost of water savings to be less than the average of the crops considered.

Opportunities to improve surface irrigation systems in cotton also included redevelopment of the existing surface system. Providing a water saving could be achieved through these changes then this was the most economical option. For drip irrigation systems typically a higher water saving would be required to justify the investment. The notable exception was horticulture where the GM / ML of water applied was significantly more than other crops.
10 Investment Opportunities in Research, Development and Extension

Further investment in irrigation research, development and extension is required to underpin progress towards the potential WUE gains that have been identified for the Northern Murray Darling Basin. Priority research, development and extension activities have been identified for WUE improvements from on-farm storages, on-farm distribution systems and infield application systems for key crops in the study area.

A number of reports identifying irrigation research priorities for mitigating losses from farm dams (Craig, Green et al. 2005; Watts 2005) and infield irrigation systems across the key crops in the study area (Schmidt 2005; Hickey, Hoogers et al. 2006; Cotton CRC. CRDC & ACGRA 2007) have been the basis for the synthesised recommendations made in this report.

10.1 On-farm storages

Key Issues:
- Largest area of potential WUE gains for the Northern Murray Darling Basin. Significant gains to be made in the Condamine Balonne Valley.
- Significant proportion of farm dams (Aus) occurs in the Northern Murray Darling Basin (est. 4 500 GL)
- Highly variable performance of monolayer products for large dams
- Long term mechanical durability of EMTs for smaller storages
- Limited data on seepage losses from dams

Strategies for Investment:
- Focus is on R&D (i.e. emerging technologies)
- Current R&D is effectively limited to seed funding (CRC for Irrigation Futures, CRC Polymers, Cotton CRC)
- For gains to be realised significantly more investment in R&D
  - Measurement and monitoring technologies
  - Evaporation Mitigation Technologies (EMTs)
  - Benchmarking of current performance
  - Identification of storages

10.1.1 Mitigating Evaporation from Large Farm Dams

Research & Development
• Quantify losses from on-farm storages across a range of locations and operating conditions.
• Fundamental research on evaporation processes for storage dams accounting for thermal storage in the water body and advection from surrounds, leading to improved prediction of evaporation losses from weather data and storage characteristics.
• Fundamental research on the potential for monolayers particularly in terms of distribution characteristics, application methods, evaporation reduction performance and environmental impact.
• Further testing of the instrumentation developed in this project for seepage and evaporation determination and methodologies to separate seepage and evaporation components of water loss.
• Further development of depth sounder systems developed at USQ for storage basin mapping to provide a cheap and accurate system for mapping the storage basin when filled with water.
• Information on the extent and area categories of storages across the Northern Murray Darling Basin leading to information on likely water savings from EMTs.

10.1.2 Mitigating Evaporation from Small Farm Dams

Research & Development
• Further large scale testing of commercial products in conjunction with suppliers to assess evaporation mitigation efficiency and mechanical durability.
• Support for quality control, collection and analysis of data being collected commercially by a number of irrigation consultants to facilitate better understanding of factors impacting seepage rates and regional evaporation losses from storage.

Extension
• Extension and communication of results to a wide range of irrigators and stakeholders to ensure the current high level of interest is maintained.

10.1.3 Seepage from Farm Dams

Research & Development
• Further development of appropriate measuring processes and technology (as per evaporation from farm dams).
• There is a need to extend the range of storages on which seepage losses have been quantified. Obtaining a better understanding of commercial storage performance will provide a more accurate assessment of the range of seepage losses experienced within the industry and enable the targeting of lower performing storages for either retirement or corrective action.
10.2 Distribution systems

**Key Issues:**
- Most surface water use in the Northern Murray Darling Basin involves private diversions direct from rivers (the exceptions being in the Macquarie Valley and St George Water Supply System). As a result, on-farm distribution systems are often extensive and the associated losses are borne by the irrigator rather than a water supply authority.
- Limited range of distribution systems in which seepage and evaporation losses have been quantified.
- Area of least confidence in quantifying the magnitude of losses
- Success of methods for mitigating losses uncertain

**Strategies for Investment:**
- Further development of technologies for measuring losses (parallel to farm dams)
- Quantify magnitude of losses to determine relative importance
- Investment in mitigation technologies needs to be supported by identification of losses and demonstration of success of mitigation technologies

& Development
- Further development of appropriate measuring processes and technology (as per farm dams).
- There is a need to extend the range of distribution systems on which seepage and evaporation losses have been quantified. Obtaining a better understanding of commercial distribution system performance will provide a more accurate assessment of the range of losses experienced and enable the targeting of lower performing distribution systems for corrective action.
- Evaluation of the effectiveness of mitigation strategies (including cost benefit analysis) within commercial operating environments.

10.2.1 Mitigating Losses from Distribution Systems

Research
10.3 In-Field Performance - Cotton

Key Issues:
- Predominantly surface irrigated (92% of area)
- Existing infield measurements indicate a wide range of performance measures (60 – 85% application efficiency)
- % of infield gains across Northern Murray Darling Basin are in cotton

Strategies for Investment:
- Low investment: surface irrigation optimisation
- High investment: system conversion (CP/LM); redesigned and optimised surface irrigation and adaptive control of irrigation systems

Research & Development
- Surface irrigation optimisation systems (measurement and modeling) that are more time and cost effective

Extension
- Information on the economic benefit of optimised furrow irrigation systems (particularly flow rate, cut off time and field design) and provision of farmer friendly recommendations (derived from currently used furrow irrigation optimisation tools) that will provide quantum improvements in water use efficiency.
- Improved promotion and service delivery of furrow irrigation optimization services leading to increased uptake and more affordable services.

Service Provision
- Provide detailed, practical training in irrigation measurement and management for consultants. Private consultants need to be better educated about irrigation management. While expert in pest management, many consultants believe that they lack the required levels of irrigation management knowledge to best assist growers. Training needs to be provided for private consultants, extension officers and others in the numerous aspects of more effective water and irrigation management. Further training of agronomists and growers in the industry is required, particularly in relation to plant-water relationships and the differences in crop management requirements under the various irrigation systems.
- People with more expertise in the engineering and equipment side of irrigation had a greater role to play in identifying and working through ways to more efficiently manage the system. This role included using engineering knowledge to improve existing systems, the better engineering design of new systems, the impact of practices like
increased flow rates, methods to reduce evaporation, efforts to reduce seepage, improved ring tank storage, furrow design and other developments.

10.3.2 High Investment

Research & Development

- Automated and accurate systems for flow delivery to the furrow.
- Technical and economic assessment of the potential for total system management using centre pivots/lateral moves (CPLM), including chemical application, precision management of water application (spatial and temporal), real time crop monitoring, system automation.
- Better understanding of water distribution under CPLM in response to soil variability and resulting crop growth response and profitability.
- Cheaper higher performance drip irrigation systems providing continuous precision placement of water and chemicals on predominant soil types.
- Economic evaluation of drip installations should include the whole of system life costs and include valid comparisons with optimised alternative application systems.
- Further explore opportunities for improved agronomic management in cotton with lateral moves / centre pivots.

Further work is required to confirm the Regulated Deficit Irrigation (RDI) results, further explore the application of Partial root Zone Drying (PRD) strategies using these machines, and to more fully understand the physiological response of cotton to imposed soil moisture deficits applied either by volume (RDI) or space (PRD).

Extension

- Training, information and improved knowledge on potential for centre pivot and lateral moves to improve water use efficiency, profitability and environmental sustainability leading to increased adoption of these systems.
- There is a need for the development of materials and dissemination of information to assist growers to understand the implications of centre pivot / lateral move design and managed system capacities on crop production and risk. This material should include information on peak regional evaporative rates and peak crop water use requirements in each of the cotton growing regions.
- Information on the existing solutions to the problems of wheel rutting and bogging need to be better extended across centre pivot / lateral move growers and prospective purchasers of this equipment. The skill level necessary for the successful management of centre pivots / lateral moves should be fostered and enhanced through appropriate training of personnel.
10.4 In-Field Performance – Other Broadacre

Key Issues:
- Limited information on current practice (benchmarking)
- Limited irrigation R&D activity
- Limited info on irrigation agronomy, irrigation systems etc
- Limited irrigation scheduling

Strategies for Investment:
- Low investment: Uptake of irrigation scheduling; furrow optimisation; DU of spray systems
- High investment: R&D for system conversion (address low knowledge base)

Development
- As per cotton - Automation and flow control into irrigation furrows and Furrow irrigation optimisation systems that are cheaper and less labour/time intensive to use.
- Irrigation scheduling information systems providing accurate data on soil moisture status in root zone and accounting for spatial distribution of soils leading to water applications matching crop water requirement.

Extension
- Extension material illustrating the potential for improved performance of irrigation systems (furrow, overhead and drip) in terms of water use efficiency and economics and best bet options to improve performance (Irrigation best management practice manual).

Service Provision
- Provision of low cost services for irrigation scheduling (eg. ET₀ estimates and SMS delivery)

10.4.2 High Investment

Research & Development
- Guidelines on peak crop water requirements across region leading to appropriate capacity irrigation systems.
- Technical information on setup of CPLM to take full advantage of the potential for precision water and chemical application and management.
- Cheaper higher performance drip irrigation systems providing continuous precision placement of water and chemicals on predominant soil types.
Extension

- Information on the economic, environmental and social benefits of CPLM leading to improved trust and adoption.
10.5 In-Field Performance – Pasture & Lucerne

Key Issues:
- High application rates recorded
- Mainly high pressure spray systems
- Issues with distribution uniformity
- Limited irrigation scheduling

Strategies for Investment:
- Low investment: Uptake of irrigation scheduling and address distribution uniformity of spray systems
- High investment: R&D for system conversion (low knowledge base)

10.5.2 High Investment

Research & Development
- Guidelines on peak crop water requirements across region leading to appropriate capacity irrigation systems.
- Technical information on setup of CPLM to take full advantage of the potential for precision water and chemical application and management.

Extension
- Additional promotion of the economic, environmental and social benefits of alternative application systems leading to improved trust and adoption.
10.6 In-Field Performance – Horticulture

Key Issues:
- Grapes and Fruit (~100% drip)
- High pressure sprinkler systems (small crops)
- High rate of conversion to drip in some areas (vegetables – Stanthorpe)
- Irrigation Uniformity is a significant issue (particularly sprinkler systems)
- Scope for further uptake of irrigation scheduling

Strategies for Investment:
- Low investment: Irrigation scheduling; irrigation uniformity; RDI / PRD
- High investment: system conversion to drip; further R&D required to support system design (uniformity) and management (RDI); precision irrigation

extensive benchmarking of water use in the major crops, as present data is inaccurate, or relevant only to specific regions. Encouragement for growers to install flow meters on their pressurised water delivery points to farm and crops would be an excellent start. Benchmarking should be focused on particular factors (e.g. irrigation type, crop, soil, region) and needs to be conducted over a sufficient interval to allow meaningful comparisons to be drawn.

- Develop recommendations to better manage field variability in terms of yield and product quality and its impact on productivity, water use, and dollar return per megalitre.
- Research on the optimal amount of water at the right time - Ensuring that water is used wisely during the season to optimise yield and quality and Irrigating to manipulate growth of vegetation and fruit including: Deficit irrigation and root zone drying – application of these strategies to what crops and for what benefits; Strategies for irrigating with limited waters; Irrigating for different crop stages – understanding plant growth and changing water requirements.

Extension
- Extend current irrigation scheduling and irrigation efficiency knowledge and demonstrate best practices for vegetable growers to increase the percentage of establishments using irrigation scheduling (currently 40% for all horticulture) and using management practices which account for reduced water allocations under drought.
- Provide guidelines that vegetable producers, catchment managers and environmental protection agencies can readily adopt to assist them effectively and sustainably use alternative water sources, such as recycled water, or non-potable aquifers.
- Develop guidelines on irrigation scheduling – plant based monitoring, soil based monitoring, knowing ET requirements for different crops (varieties) under different conditions.
Service Provision

- Support irrigation efficiency training and demonstration, particularly skills training to manage ‘new’ types of irrigation systems, scheduling tools and crop/soil management on a wider range of soil types than traditionally irrigated throughout Australia.

10.6.2 High Investment

Research & Development

- Identify the type of irrigation technology most suited to a particular vegetable crop and the benefits of switching over to ‘high tech’ irrigation systems, compared with the costs involved in such systems, before recommendations can be made to farmers.
- Develop more quantitative data on product quality improvements which can be achieved through use of highly efficient irrigation systems such as subsurface drip.
- Research into improved irrigation system design for vegetables including: Design of irrigation systems that precisely meet the water needs of plants (when and where); Design of systems to maximise uniformity; and Real time monitoring and control of irrigation systems.
- Research in Precision horticulture: Increasing accuracy of water requirements (eg. Yield monitoring using infrared; Salinity/soil moisture surveys using EM38.)
11 Options for Accelerated Uptake and Adoption

A range of barriers exist to prevent growers from adopting alternative irrigation technologies and practices that would lead to improved WUE on-farm.

### Barriers to Adoption: Example for Centre Pivots / Lateral Moves

The barriers to the broader adoption of centre pivots / lateral moves within the cotton industry include: the perception by growers using furrow techniques that these machines are not capable of supplying the volumetric capacities required to irrigate cotton, the lack of experience in the fulltime cotton growing sector regarding both water and crop management under centre pivot and lateral move machines, and the lack of dealer, supplier and extension support regarding the appropriate management of these machines for cotton production. Action needs to be taken on a number of levels (extension, training etc) to overcome these barriers.

Options for accelerated uptake and adoption of technologies and practices to increase WUE have been developed for the Northern Murray Darling Basin. The options include:
1. Provide additional funding for research and development (R&D) that underpins the adoption of efficient technologies and practices;
2. Support and strengthen extension, high level technical support and training activities;
3. Provide on ground funding for practice change; and
4. Benchmark irrigation performance to drive an awareness of the need and opportunity for improvements in WUE.

#### 11.1 Additional Funding for R&D

Additional investment is required in Research and Development to underpin accelerated irrigation improvements in the Northern Murray Darling Basin. R&D needs range from the development of entirely new technologies (eg. evaporation mitigation technologies) that need to be developed before significant WUE gains can be made, through to the development of management strategies to assist growers adopt existing technologies to their particular industries (eg. alternative irrigation systems).

Key R&D areas that require investment to facilitate the accelerated uptake of new technologies include:

1. Cost effective evaporation solutions – exploring polymer and other technologies as a cost effective option for reducing evaporation from storages. Ongoing cash investment is required in the existing partnership between Polymer CRC, CRC Irrigation Futures and Cotton CRC with increasing investment over time, including investment in extension. Reducing evaporation losses represents the largest potential gain in WUE in the Northern Murray Darling Basin and will not be achievable without a
significant research effort into new technologies. A long term commitment (7 – 10 years) is required to address this issue.

2. Cost effective seepage solutions for storages and channels – trials to quantify seepage losses and define the extent of this as an issue; trial existing technologies and seek alternatives.

3. Alternative irrigation systems – work reviewing the opportunities for converting to alternative irrigation systems (centre pivots / lateral moves and drip) has been undertaken in the cotton industry however further R&D is required to identify appropriate agronomic strategies and crop responses to support growers who are contemplating system changes. A focused R&D effort is also required in other industries, in particular the vegetable, pasture and grains to identify the opportunities for alternative irrigation systems and provide technical information (setup, crop water requirements etc) to accelerate the adoption of alternative systems.

4. Precision irrigation – investment is required in ‘future irrigation technologies’ (including real time adaptive control systems, plant monitoring sensors etc and associated management issues eg. soil water and solute movement) to facilitate the next leap forward in improved WUE.

A recent review of ‘Knowledge Management in Cotton & Grain Irrigation’ (Callan, Christiansen et al. 2004) found that irrigators want more information relevant to their particular set of farming conditions (i.e. soil type, location, climate). R&D programs need to be adequately resourced to ensure research addressing the priority areas above is trialed across different districts within the Northern Murray Darling Basin.

11.2 Extension and Training

11.2.1 Extension and Technical Support

Integral to the accelerated uptake and adoption of technologies that will lead to increased WUE is significant extension and specialised (engineering) technical support.

Extension role

The extension role drives an awareness of the issues and opportunities to improve WUE. Extension activities also facilitate grower participation in activities that will lead to more informed decisions for on farm investment in WUE.

R&D projects do not serve their purpose unless their outcomes are delivered to end users and put into action. The cotton industry’s extension effort has focused on the traditional “technology transfer” mode of extension to end users, an approach that generally captures those growers that are receptive to change and are early adopters of new technologies and techniques. A key challenge for the industry is improving the reach of the extension effort to improve practice and water use efficiency across all growers in all regions. The cotton industry has identified that a high priority is to develop extension programs that increase the
adoption of current proven methods that leading irrigators have adopted to improve water use (Cotton CRC. CRDC & ACGRA 2007).

**Technical Support Role**

A specialised technical support role compliments this process by providing input at the pre and post investment stage so that the full potential of the irrigation investment is realised. Problems with adoption of new technology have occurred in the past due in part to a lack of high level technical support. For example, irrigation system conversions have been undertaken where the system capacity has been designed at a level insufficient to meet crop requirements. Numerous cases of this have been reported in system conversions to centre pivots and drip in cotton. In these cases the potential gains from converting to alternative irrigation systems will not be realized. These experiences have created perceptions amongst some furrow irrigators that alternative systems are not capable of delivering the volumes of irrigation water required for their enterprises. These perceptions pose a major barrier to adoption of new irrigation technologies.

Significant potential volumetric gains in WUE have been identified as part of this project and will only be realized with a high level of engineering technical support. A role exists for engineering expertise, and in particular the National Centre for Engineering in Agriculture, to provide a high level of technical support to extension officers and agricultural advisors and industry WUE programs to ensure WUE gains are fully realized.

**11.2.2 Training for irrigation Professionals**

Callan et al. (2004) identified a need for detailed, practical training in irrigation measurement and management for consultants servicing the cotton and grains industries. While expert in pest management, many consultants believe that they lack the required levels of irrigation management knowledge to best assist growers. More expertise is needed in understanding how to reduce losses due to inefficient water management practices. People with more expertise in the engineering and equipment side of irrigation had a greater role to play in identifying and working through ways to more efficiently manage the system. This role included using engineering knowledge to improve existing systems, the better engineering design of new systems, the impact of practices like increased flow rates, methods to reduce evaporation, efforts to reduce seepage, improved ring tank storage, furrow design and other developments.

The TOPUP Professional Development series developed and presented by the National Centre for Engineering in Agriculture covers many of the key issues relevant to irrigators in the Northern Murray Darling Basin. This series is designed to service the multidisciplinary skill demands of agricultural professionals and managers. Workshops are offered on:

- Surface Irrigation Optimization
- Irrigation Fundamentals;
- Centre Pivots / Lateral Moves
- Irrigation Production and Salinity
A greater emphasis needs to be placed on skilling consultants and extension staff to facilitate change in irrigation practice and support on-farm improvements to system performance or implementation of alternative irrigation practices and technologies.

11.2.3 Training for Irrigators

In parallel to extension efforts, training of irrigators is required. The focus of these activities needs to be the entire farm irrigation system.

Callan et al. (2004) identified that there was interest in practical, advanced level training in how to measure irrigation system efficiencies and how to manage these from cotton and grain growers. Accreditation was not considered necessary for training, unless this was to become a government requirement for irrigators in the future. There was a strong emphasis on the need for courses to be practical, short, going deeply into an issue, being linked into a farm trial or actual piece of research that could be seen, and in which there was a good mix of different types of people and interests (e.g. growers, consultants, extension, resellers, researchers).

In response to this need for practical training for irrigators, a series of workshops focusing on irrigation benchmarking, budgeting, scheduling and storage and distribution systems are available through the Cotton Catchment Communities CRC Water Extension Team. The Cotton and Grain Irrigation Workshop series cover a range of irrigation related topics in a practical and informal manner. The focus is on providing high level skills for growers, farm managers and consultants, with an emphasis on practical material that can be taken away and applied in the field. The workshops directly support issues that may be identified through the BMP Land and Water Module.

Training is also provided by NSW DPI, through ‘Waterwise on the Farm’, a course for landholders, farm managers, consultants and rural retailers to improve irrigation system performance and water use efficiency.

Increasing the size, impact and footprint of the educational training of irrigators is required across all industries in the Northern Murray Darling Basin if the adoption and uptake of WUE technologies and practices is to occur.

11.3 Benchmarking

Recent surveys conducted by the cotton industry confirmed that a majority of growers regard improved water use efficiency as a high priority, but still have difficulty measuring it accurately (Cotton CRC, CRDC & ACGRA 2007). To be able to measure success against the identified goal, it is important to benchmark current performance and improve the ability to consistently measure improvement using cost effective technologies and techniques.

Benchmarking irrigation performance is a useful tool to drive an awareness of the need and opportunity for improvements in WUE amongst irrigators. Benchmarking also provides data
needed to target future R & D and extension activities.

The last major documented assessment of irrigation performance in the cotton industry that assessed the performance of all components of irrigation enterprise (storage, distribution, infield) was a study by Dalton, Raine et al. (2001). This study incorporated data from 7 farms and only undertook trials in one district (Border Rivers). No major studies benchmarking irrigation performance have been undertaken for other industries in the Northern Murray Darling Basin.

There is an opportunity to align benchmarking with the current BMP effort across the cotton industry. There is also a role for benchmarking programs within other industries that support and are integrated with R, D&E efforts to promote case studies and continue to refine BMP.

Opportunities also exist to combine benchmarking of infield performance with system performance optimization (onground practice change) leading to both a public benefit in terms of knowledge base being further extended and developed and offering immediate and low cost opportunities for irrigators to implement management changes delivering greater WUE.

A benchmarking program needs to include:

- Mapping dam areas, locations and volumes to identify problem spots and quantify magnitude of evaporation losses in the Northern Murray Darling Basin;
- Developing and deploying accurate methods of measuring evaporation and seepage loss for a range of storages and distribution systems across all districts and industries in the Northern Murray Darling Basin;
- Whole of farm audits for a Selection of growers across all performance levels, across all systems and regions.
- A central database and consistent measures of irrigation performance and WUE.

11.4 On ground funding sought for practice change

On ground funding through incentives provide an opportunity to accelerate the uptake and adoption of irrigation technologies and practices that will deliver improved WUE. By co-funding on ground practice change, this will achieve immediate improvements of WUE. The focus of an incentive program should be to build a critical mass of irrigators adopting new technologies and practices in a commercial farming environment to pave the way for other irrigators to follow. The intention is to speed up the rate of adoption and provides an additional trigger for an irrigator to consider adoption ‘now’ rather than later.

A financial incentive program should not be a mechanism to finance the change in irrigation system or practice but instead an adoption tool to trigger growers’ interest in making WUE improvements on farm and to accelerate uptake. As an adoption tool, it can be argued that a private incentive to increase engagement in addressing WUE issues provides a public good rather than a private gain.
An important consideration for a financial incentives program is to link with training, technical support and R, D & E elements. Key ingredients for success include:

- The integration of training and extension activities.
- Provision of technical specialist support (engineering) to maximize investment opportunities and potential.

Many financial incentive processes have not included the technical support aspect. The use of a financial incentive might be informed from an extension point of view (such as the purchase of a centre pivot) but there is no independent technical support to make sure that this has been done correctly (matching system design with crop water requirements etc). For example a farmer can buy irrigation technologies off the shelf with no assistance to make sure that optimal practices result or the appropriate system is selected.

Financial incentive programs for the Northern Murray Darling Basin need to target all components of the irrigation system on farm, including on-farm storages, on-farm distribution and infield systems to maximize WUE gains.

Conducting whole farm investigations to identify where significant water savings can be achieved across the enterprise should be the first step in an incentive program. Assessing WUE performance at the field level, distribution level and farm storages could be undertaken using existing farm water balance technologies (i.e. WaterTrack / Irrimate optimisation process). This could be funded under a benchmarking process to more accurately identify potential gains in different industries (R, D & E opportunities) while simultaneously determining the opportunities for on farm improvements. This approach contributes significantly to the knowledge base (public good) while identifying the strategic opportunities for individual farms to maximize WUE.

The financial incentive program would need to link with the outcomes of the whole farm audit process but also be part of a process integrating training and technical support across the areas of:

- Whole farm system audits;
- Optimisation of on-farm distribution systems;
- Management of On-farm storages;
- Evaporation and seepage monitoring;
- Optimisation of surface irrigation systems; and
- Conversion to alternative irrigation systems and associated irrigation system management (incorporating appropriate agronomic management).
Linking Financial Incentives within a broader R, D & E program: QLD RWUE

The QLD RWUE Initiative provides an example of a program where incentives were strongly linked with a major extension program and provided a significant and accelerated improvement in WUE.

The Rural Water Use Efficiency Initiative was a four year, $41 million, Queensland Government funded program (through NR&M) across the major irrigation industries – sugar; fruit and vegetables; cotton and irrigated grains; and dairy and lucerne. The first phase of the Initiative finished in June 2003. QLD RWUE included a Financial Incentives Scheme to assist growers achieve BMP and subsidise growers for their outlays in adopting new irrigation technologies.

Industry Coordinators indicated a strong linkage between irrigators being involved in activities and applying for subsidies. Survey respondents were asked to indicate how much program activities and how much the Financial Incentive Scheme impacted on their decision to make changes. Overall, 55% of respondents attribute the influence of RWUEI program activities or information on their decision and ability to make changes by a moderate amount to a lot. In the same way, 86% of respondents attributed the influence of the subsidy to making the changes by a moderate amount to a lot. This reflects this strong linkage and synergies between the extension and incentive program (Coutts and Bell).

11.5 Industry Mechanisms

There is wide variation across the different industries within the Northern Murray Darling Basin in terms of industry structures, R & D programs and extension networks. This has a major impact on the capacity of each industry to achieve significant WUE gains.

Cotton industry

The cotton industry in Australia is relatively small with approximately 1200 cotton farmers. The cotton industry is also geographically concentrated, with the majority of Australia’s cotton grown within the Northern Murray Darling Basin. The cotton industry has a proven track record in innovation and capacity for change in irrigation management. A number of organizations established within the cotton industry that are currently undertaking or funding significant work in irrigation in cotton, including:

- Cotton Research and Development Corporation (CRDC) responsible for providing leadership and investment in research, innovation, knowledge creation and transfer.
- Cotton Catchment Communities CRC. The CRC’s goals are to ensure the Australian cotton industry continually strives for high water use efficiencies using science and education to deliver profitable and practical outcomes.

The cotton industry is also well placed to deliver extension projects. The Cotton Water Team, a national cotton extension program is coordinated by the Cotton Catchment Communities CRC. Through targeted education and extension activities, the program
focuses on integrated production and environmental management strategies within the cotton industry Best Management Practices (BMP) and provides leadership within cotton farming systems and the associated field crop production enterprises of producers. The Cotton Water Team works under a range of funded projects which are undertaken on behalf of industry by State Government’s primary industry Departments and CSIRO.

Many cotton and regional irrigation consultants also provide specialised knowledge for cotton irrigators. The preference within the cotton industry is for one on one service. An opportunity exists to further develop the use of consultants.

**Extension and training programs in the Cotton industry: Advancing Water Management in NSW**

The Australian Cotton Growers Research Association (ACGRA), NSW DPI and Catchment Management Authorities have identified the key priority for initial investment needs to be in developing a highly effective water use efficiency extension team. With this being the primary objective, funds will be pooled from the cotton industry, NSW DPI and CMAs and directed to secure full time water use efficiency staff in each major cotton region and to resource these staff with adequate equipment and operating capability.

The primary aim of this project is to lift industry water use efficiency through a coordinated industry approach to advisory and education/training services in water use efficiency (WUE) incorporating demonstrations and trials and delivery of a modified Waterwise on the Farm training course that incorporates Cotton industry’s BMP guidelines. This project will contribute to a 15% increase in whole farm water use efficiency over the next five years. The project will also include development and delivery of economic information on irrigation systems and management to assist cotton grower adoption of improved systems and management.

The project will implement aspects of Stage 1 of the Cotton Knowledge Management Project, particularly the aspects of local trials for growers to evaluate on farm irrigation options and the training of the private sector to support on-farm irrigation decision making.

Longer term impacts of previous poor irrigation efficiency will be quantified for areas of the Macquarie Valley to provide economic input to growers for improving irrigation efficiency. Soil salinity will be evaluated against yield maps and EM surveys to determine in field salinity production impacts.

A major focus has been placed on optimizing surface irrigation systems. Irrimate was used to monitor irrigation performance in the Gwydir Valley during the 2006-07 cotton season and provide growers with an assessment of their irrigation performance on individual fields. Thirty irrigation events were monitored in the Gwydir Valley during the season, with application efficiency ranging between 40 and 94 per cent. Improving irrigation performance resulted in reduced application of water by up to 0.35 megalitres per hectare per irrigation, with an average reduction of 0.13 ML/Ha/irrigation (NSW DPI 2007).
Other broadacre

The Grains Research & Development Corporation is responsible delivering improvements in production, sustainability and profitability across the Australian grains industry. Traditionally, there has been very little emphasis on R&D relating to irrigation management in grains.

Recent activities and studies have seen the grains industry incorporated into programs delivered by the cotton industry when addressing irrigation issues (QLD RWUE Cotton and Grains Adoption program: Knowledge Management in Cotton and Grains program). This is an appropriate approach for the Northern Murray Darling Basin and should be encouraged further.

Pasture and Lucerne

The sector is very fragmented and lacks the cohesive identity to drive development and implementation of innovative approaches. The pasture and Lucerne industry currently has no capacity to provide a program to extend accelerated uptake of WUE technologies and practices or drive an appropriate R&D program.

Horticulture

Horticulture is distributed across a diverse range of landscapes within the Northern Murray Darling Basin from tablelands districts in the east of the basin (eg. Granite Belt, Bathurst plains etc) through to semi arid regions in the west (eg. St George). While the area for irrigated Horticulture production in the Northern Murray Darling Basin is small, production tends to occur in a number of key production centres where effort can be focused.

Limited water supplies due to reduced general security allocations or shortages due to drought has contributed to an increased focus on WUE and a promotion of improved management strategies and alternative irrigation systems.

A number of organizations are delivering R & D, and training programs for the horticulture industry including:

- In 2003, the Cooperative Research Centre for Irrigation Futures was formed as an entity to encourage a national approach to irrigation research, education and training. Through its member institutions, it provides a range of formal tertiary education courses, industry workshops and forums, research programs and training packages, many of which are appropriate for horticulture producers.
- Horticulture Australia Ltd established the HAL Water Initiative in 2003. It assists horticulture by articulating the economic and social benefits of horticultural water use. It also demonstrates the environmental credentials of horticulture and invests in projects that further enhance the sustainability and reputation of the industry. In the long term, it encourages new technology and better practices for water management, assessing the water quality impacts and requirements for major crops, and
developing and enhancing best management practices for controlling salinity, nutrients, sediments and biocides on horticultural properties.

Extension in horticulture is primarily provided by state governments’ primary industries departments.

The number of consultants with irrigation expertise operating in the horticulture industries is limited. A more developed consultancy network exists within the grape industry.

Consultants servicing the vegetable industry offer advisory and research services, ranging from one-off inquiries to irrigation system and infrastructure evaluation through to regular and intense irrigation monitoring and management. In recent years, many of these consultants have not been as active in irrigation management as in the past. This may be because, as growers become larger, they may often employ their own irrigation managers, with access to much of the automated logging and controller equipment previously the bailiwick of the consultancy firms (Henderson 2007).

11.6 Equity considerations

Before undertaking any program to increase WUE, the objectives of the program need to be clearly defined and may include:

- to drive the greatest reductions in terms of total water usage;
- to increase the financial return from the available water; and
- to assist in maintaining farm viability in conditions of reduced water supply (drought, climate change, reduced water allocations).

For example the NSW Waterwise initiative was about saying “change is coming, like it or not”, and through WaterWise the government will assist irrigators to adjust to that change. The intent was to apply a basic course across the myriad of water users and across the whole state because all irrigators would sooner or later be impacted by the change. Thus the program had a social equity component as well as a goal of improving water productivity. If water productivity were the only goal then the focus would have been on working with the bigger growers in the high value industries. In the end a huge effort was put in at the grass roots level to simply lift irrigator awareness about efficient irrigation and to challenge a culture that takes water for granted (Stirzaker 2006).

Careful consideration needs to be given to the goals, mechanisms and target audience for any program that addresses improving WUE in the Northern Murray Darling Basin.
12 Recommendations

Key recommendations relating to improving on-farm WUE in the Northern Murray Darling Basin have been identified.

**Recommendation 1: Adopt a Whole Farm Approach to Irrigation Efficiency**

Water sources for irrigation enterprises in the Northern Murray Darling Basin include regulated water supplies, extractions from unregulated rivers, floodplain harvesting and groundwater. As a result, many irrigation enterprises have had to make significant private investment in systems for storage and distribution of water on-farm. The performance of on-farm storages and distribution systems has a major impact on on-farm water use efficiency. For enterprises that are entirely dependent on unregulated water supplies and/or floodplain harvesting, the inefficiencies associated with on-farm storage and distribution can exceed efficiencies associated with in-field application systems. This contrasts significantly with the Southern Murray Darling Basin where on-farm WUE is largely driven by the efficiency of in-field application systems.

**Any projects addressing on-farm water use efficiency in the Northern Murray Darling Basin need to adopt a ‘whole farm’ approach incorporating all aspects of the on-farm irrigation systems including on-farm storages, distribution systems and in-field application systems.**

**Recommendation 2: Further work be undertaken to quantify potential WUE gains at both a farm and whole basin scale**

This report has identified significant opportunities for on-farm water use gains in the Northern Murray Darling Basin. The largest proportion of these gains include on-farm storages and infield irrigation systems. However, further work is required to accurately quantify the potential on-farm WUE gains at both a farm and basin scale. In particular:

**Volume and location of on-farm storages**

Estimates are available of the volume of on-farm storages in the Northern Murray Darling Basin. However there are concerns with the reliability of this data. Evaporation losses from on-farm storages represent a major on-farm ‘inefficiency’ for the study area yet without accurate information on farm dams it is not possible to accurately estimate the current evaporation loss and the benefit of evaporation reduction systems, in terms of GL saved, cannot be quantified with certainty.

**Measuring Technologies**

Estimating losses from on-farm storages and distribution systems requires cheap and accurate methods to determine seepage and evaporation components of the water loss and cheap and accurate technologies to accurately map individual storages to identify storage volumes even when the storage is filled with water. Technologies for these purposes (PST...
technology, depth sounder systems) have been developed by NCEA, however further testing and development is required to deploy cheap accurate and easy to use systems.

**Further Benchmarking**
A limited range of storages and distribution systems have been used to quantify evaporation and seepage losses in the Northern Murray Darling Basin. A number of studies have quantified the performance of in-field irrigation systems in the cotton industry however limited published information is available on WUE in cotton in the last few years and existing studies have not captured WUE achieved under recent climatic conditions or to reflect recent improvements that the cotton industry may have made in regard to WUE. Very limited information is available on in-field irrigation performance for other key irrigation systems and crops in the Northern Murray Darling Basin.

**Further work is to be undertaken to quantify potential WUE gains at both a farm and whole basin scale. In particular:**

*Good data is required on the number, capacity, surface area and usage of farm dams across the Northern Murray Darling Basin.*

*Technologies need to be further developed to cheaply and accurately measure evaporation and seepage losses from on-farm storages and distribution systems and to survey on-farm storages to accurately estimate storage volumes.*

*Further benchmarking is required on the current performance of on-farm storages, distribution systems and in-field application systems covering the full range of systems, crops, soil types and climatic conditions.*

**Recommendation 3: Significant investment is required in R&D to enable continued improvements in on-farm WUE**

Significant opportunities have been identified for potential improvements to on-farm WUE in the Northern Murray Darling Basin. However potential WUE gains are dependent on a combination of current practice and technology and emerging technologies. For the full potential of gains to be realised further R&D is required to refine current practices and technology and significant investment is required in R&D for emerging technologies.

**Significant investment is required in R&D to enable continued improvements in on-farm WUE, in particular:**

1. **Cost effective evaporation solutions** – exploring polymer and other technologies as a cost effective option for reducing evaporation from storages. *Ongoing cash investment is required in the existing partnership between Polymer CRC, CRC Irrigation Futures and Cotton CRC with increasing investment over time, including investment in extension.*

2. **Cost effective seepage solutions for storages and channels** – trials to quantify seepage losses and define the extent of this as an issue; trial existing technologies and seek alternatives.

3. **Alternative irrigation systems** – further R&D is required to identify appropriate agronomic strategies and crop responses for alternative irrigation systems (centre pivots / lateral moves and drip) in cotton. A focused R&D effort is also
required in other industries, in particular the vegetable, pasture and grains to identify the opportunities for alternative irrigation systems and provide technical information (setup, crop water requirements etc) to accelerate the adoption of alternative systems.

4. Precision irrigation – investment is required in ‘future irrigation technologies’ (including real time adaptive control systems, plant monitoring sensors etc and associated management issues eg. soil water and solute movement) to facilitate the next leap forward in improved WUE.

Recommendation 4: Explore opportunities for immediate gains in on-farm WUE

Decision support is required to assist irrigators in identifying whether the most appropriate option for improved on-farm WUE will be delivered through options that focus on improving the management of current irrigation systems or whether alternative irrigation technologies provide a more appropriate solution.

For those irrigators where improving the management of their current irrigation systems represents the most appropriate option at this stage, a number of opportunities exist to improve on-farm WUE including:

- Encourage the adoption of practices that minimize evaporation losses from on-farm storages (eg. preferentially using storages);
- Optimize surface irrigation systems commonly used by the cotton industry by altering cutoff times (eg. use of Irrimate™ services);
- Improving distribution systems of spray systems used in the pasture industry (eg. adopting appropriate nozzle sizes and pressures);
- Increasing the use of scheduling tools (soil water monitoring, ET based methods) to more closely match irrigation volumes to soil-water deficits.

Surface (furrow) irrigation in cotton represents approximately three quarters of the area irrigated in the Northern Murray Darling Basin. In the case of Irrimate™ surface evaluations, the breakeven cost of water savings was $71/ML, representing a relatively low cost option for improving on-farm WUE with a potentially large application in the study area.

Opportunities to implement immediate gains in on-farm WUE should be further explored and programs with appropriate extension, training and technical support to facilitate these gains should be established / extended.

Recommendation 5: Develop integrated programs to assist in accelerated uptake and adoption

On-farm WUE improvements in the Northern Murray Darling Basin will be achieved through options such as:

- Converting to alternative irrigation systems (centre pivots, drip irrigation etc) and adopting appropriate irrigation practices to optimize these systems;
• Adopting high levels of management for existing irrigation systems (eg. surface irrigation using adaptive control, matching irrigation demand to crop stages in drip irrigation in horticulture); and
• Mitigating evaporation losses from storages using a range of measures from evaporation mitigation technologies (polymers, shade cloth etc) and modifications to on-farm storages (cells, preferential use).

Many of these options involve significant changes to on-farm infrastructure and associated management. There is a real need for additional provision of services and support to assist irrigators in making these changes.

*The accelerated uptake and adoption of current practices and technology and emerging technologies to achieve WUE improvements will only occur with integrated programs that support irrigators by addressing knowledge gaps, resolving implementation issues, provide an appropriate level of ongoing management support and addressing on-farm drivers and barriers to change.*

*An integrated program of research and development; extension and high level technical support programs; training for irrigation professionals and irrigators; benchmarking and financial incentives is needed to deliver significant improvements in on-farm WUE.*
13 References


Coutts, D. J. and K. Bell Evaluation of the Rural Water Use Efficiency Initiative Adoption program. Report to: The Department of Natural Resources and Mines Queensland.


CSIRO (2006). Climate Change in the Namoi Catchment. Brochure prepared for the New South Wales Government by the CSIRO.

CSIRO (2007). Climate Change in the Central West Catchment. Brochure prepared for the New South Wales Government by the CSIRO.


Department of Natural Resources and Mines (2002). Current Knowledge and Developing Technology for Controlling Evaporation from On-Farm Storage.


Murray Darling Basin Commission (2002). Developing an Irrigation Management Information and Reporting System (IMIRS) for the Murray-Darling Basin – A Watermark Project. MDGC. Fact Sheet Number 01 (Project Number I2121).


Murray Darling Basin Commission (2002). Sustainable Groundwater Use In Irrigated Catchments – A Watermark Project. MDGC. Fact Sheet Number 01 (Project Number I2114).


Pendergast, L. and D. Midmore. Oxigation: Enhanced root function, yields and water use efficiencies through aerated subsurface drip irrigation, with a focus on cotton. Proceedings of the Australian Agronomy Conference.


Schmidt, E. e. (2005). A Scoping Study on Opportunities for Improved Application Systems. Irrigation Matters Series No. 02/05. CRC for Irrigation Futures.


VIC Department of Primary Industries (2004). From 'Border-check' to 'Sprinkler'? DPI Tatura. Agricultural Notes AG1152.


# Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Application Efficiency</td>
<td>Describes the losses occurring and includes evaporation, spray drift in sprinkler irrigation, tailwater runoff and deep percolation below the root zone of the crop.</td>
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<tr>
<td>Distribution Uniformity</td>
<td>A measure of the uniformity (spatial variability) of applied depths of water over an irrigated field.</td>
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<tr>
<td>Diversion</td>
<td>The movement of water from a river system by means of pumping or gravity channels.</td>
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<tr>
<td>Furrow irrigation</td>
<td>Used extensively for row crops such as cotton. The furrow runs down the slope of the land, between individual rows of plants, at spacings typically 0.75 to 1.5 m. The flow is let in at the top of the field and runs down the slope.</td>
</tr>
<tr>
<td>Gigalitre</td>
<td>One thousand million litres.</td>
</tr>
<tr>
<td>Net Evaporation</td>
<td>Net Evaporation from an open-water surface after compensation for precipitation.</td>
</tr>
<tr>
<td>On-farm storage</td>
<td>Privately owned storages used to harvest surplus flows or to store unused allocations for use in the following season.</td>
</tr>
<tr>
<td>Overland flow</td>
<td>Water that runs off the land following rainfall, before it enters a watercourse, and floodwater that erupts from a watercourse or lake onto a floodplain.</td>
</tr>
<tr>
<td>Regulated deficit irrigation (RDI)</td>
<td>An irrigation strategy to manipulate vegetative growth to improve fruit quality and marketable yield by controlled water stress to the plant.</td>
</tr>
<tr>
<td>Regulated streams</td>
<td>Streams where users are supplied by releases from a storage. A water licence for a regulated stream specifies a base water entitlement defining the licence holder’s share of the resources from a stream.</td>
</tr>
<tr>
<td>Ring Tank</td>
<td>Name given to farm dams constructed above ground level. Not always circular as the name suggests. A ring tank is built on flat ground and consists of a continuous bank that can be circular, square or rectangular. They are filled by pumping water in from an external source. The bank earthworks are obtained from an excavation inside the bank or from an external sump. Some stored water is below the natural surface level and has to be pumped out when needed.</td>
</tr>
<tr>
<td>Sump</td>
<td>Excavated sumps are fully cut below the natural surface level. The excavated material is generally not required for the bank but is stockpiled nearby or disposed of.</td>
</tr>
<tr>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Surface water</td>
<td>Water flowing or held in streams, rivers and other wetlands in the landscape.</td>
</tr>
<tr>
<td>Unregulated streams</td>
<td>Streams that are not controlled or regulated by releases from major storages.</td>
</tr>
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Appendices: Case Studies of Adoption of Water Use Efficiency Measures

A number of case studies have been developed that illustrate some of the water use measures adopted by irrigators in the Northern Murray Darling Basin. The case studies are a representative cross section of cropping systems, irrigation systems and sources of water found in the Northern MDB. Map 5 shows the geographic location of each case study enterprise within the Northern MDB.

Each case study was undertaken in a number of steps. Firstly a review of data and information with respect to the enterprise’s irrigation system, WUE strategies adopted and cropping production was undertaken. Secondly, the enterprise was contacted and the farm manager was interviewed in order to gauge their opinions of WUE and the success of their adoption of WUE strategies on-farm. The data, information and interview results for each enterprise were collated.

Consideration has been given to the full range of activities each enterprise has undertaken to improve their WUE. WUE measures have been identified in terms of the following:

- Planning / investigation stage;
- Design changes;
- Operational / management changes; and
- Monitoring.

Many of the case studies demonstrate significant innovation to improve WUE in areas where an ‘easy’ technical solution is not commercially available. This is particularly evident in strategies that have been adopted to minimize losses from onfarm storages and distribution systems. Significant innovation has also been demonstrated in improving the performance of infield irrigation systems by overcoming constraints that other irrigators might see as a barrier. Many of the irrigators have undergone a learning process and measures that have not been as successful have also been included in the case studies.
Map 5 Case Study Locations
Case Study A: Cotton Production (Darling Downs, QLD)

Farm Details

Case Study A is an irrigated cotton and dryland grain production farm in the Darling Downs region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 1.

The farm is approximately 450 ha in size. Overland flow is the primary water source. A 444 ML nominal ground water allocation supplements the overland flow water supply. Overland flow is collected and stored on-farm. Groundwater is also pumped into the on-farm storage.

The farm has approximately 800 ML of on-farm storage (comprising one ring tank and sump). The actual amount of irrigated area varies from year to year depending on water availability. Typically an average of 200 ha is irrigated, with this varying from zero when no water is available to 300 ha with full water availability.

Cotton is the main irrigated crop. Some grain crops are also irrigated however this is highly dependent of water availability and timing and commodity prices.

All crops are irrigated using surface irrigation (furrow). Irrigation infrastructure consists of the ring tank / sump, irrigation water supply channels, head ditches and tailwater drains.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- An electronic, storage volume sensor/logger (depth sensor) has been installed in the ring tank (Irrimate™ Storage Meter, see Photograph 3 and Photograph 2). This allows instantaneous storage volume, depth and exposed water surface area readings with continuous logging capacity over time. This property was involved throughout the early development of storage volume measurement using depth sensors and received partial funding through Condamine Alliance to trial the new technology. Considerable analysis of the data collected was undertaken by FSA Consulting. A portion of this analysis is shown in Figure 16 to Figure 19, which displays the logged storage volume over one irrigation season. Despite numerous teething issues with the new technology, the property owner was sufficiently impressed that he implemented the improved, commercially available meter at his own cost. (Monitoring)
- The farm has a continuous program of irrigation field laser levelling. (Design)
- The cotton agronomist employed by the farm owner monitors soil moisture levels in
crop (using a C-Probe™) for irrigation scheduling. *(Operational/Management)*

- Irrigation times are closely monitored (500 m fields irrigated for a maximum of 12 hours, 1000 m fields irrigated for a maximum of 17 hours). *(Operational/Management)*
- Irrigation infrastructure allows irrigation of three fields at once – this allows better irrigation timeliness. *(Design)*

Responses to Interview Questions

*Why did you decide to invest in the particular WUE measure?*

The program of laser levelling was implemented to improve irrigation efficiency / uniformity and to minimise water pooling within the field and related crop disease issues. The Storage Meter was installed so that we knew how much water we had in storage and how quickly we were using it. This allowed improved water management and use.

Monitoring of soil moisture levels and irrigation times essentially ensures that we do not waste water through over irrigation.

*Would you class the WUE measures implemented as successful?*

Yes.

*What didn’t work?*

We did try lining channels with bentonite to limit seepage losses. This didn’t work particularly well. However we may try SoilPam in the future to try and minimise seepage from channels and head ditches.

*Are you more or less inclined to invest further into WUE on your property? Why?*

I will invest further in WUE measures in an effort to save water.

*What are your future plans for implementation of WUE measures on your farm?*

We have some long surface irrigation fields (~ 1000 m). I would like to redesign these fields to shorten the irrigation run length to improve irrigation efficiency. I will continue to laser level irrigation fields.

*Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?*

Our groundwater allocation will be cut by 25% over the next two years. In recent times our total allocation has reduced from 444 ML to 222 ML. In the next five years we will probably lose more if groundwater levels in this area do not improve. Previously we have been pumping our groundwater allocation into the ring tank as the flow rate from the bore alone is insufficient to support irrigation. The groundwater would sometimes be pumped into a dry storage (if all overland flow water had been used). However with reduced allocation, we may now not pump into the dam at all (as water losses to evaporation and seepage are more pronounced with a smaller allocation) or only when overland flow water is in storage. We may need to use more direct irrigation from bore (adding bore water to overland flow irrigation water supply). However, even with a reduced allocation volume, we cannot fully utilise the full allocation from the bore by pumping direct to the field.
Has your understanding of WUE improved through the implementation of WUE measures on-farm?
Yes.

What would change with your irrigation operation if you had more access to water?
We would probably grow the same crops but with more complete irrigation. At present we are not irrigating fully (deficit irrigation).

What would change with your irrigation operation if you had less access to water?
This is already occurring with a reduction in our groundwater allocation. We would perhaps use more zero till techniques and retain stubble residues. At present this is difficult with cotton (requires full cultivation following a crop). Hence we would consider growing less cotton with more irrigation of grain crops. However irrigation of grain crops would be supplementary only (i.e. no pre-watering, apply water at times of highest water demand). A flexible approach would be required based on water availability, commodity prices, etc.

Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?
Yes – we applied for and received funding to:

- Install gates in our head ditches to regulate water flow.
- Install a drop box to control erosion where bore water flows enter the sump.
- Laser level 60 ha irrigation fields (part funding).

I also attended numerous meetings and field days that were held under the Rural Water Use Efficiency program.

In general, where do you see the greatest gains in WUE being made?
I believe that better measurement and monitoring of water use is required, especially as the cost of water increases. We need to know where water is going. We irrigate high input/high value crops like cotton to maximise returns per megalitre. Perhaps we will see a shift to higher value crops grown on smaller areas to further increase returns for water used.

What do you see as important areas of further research and development into WUE?
We need solid data which provides no nonsense information regarding the use of alternative irrigation systems for the heavy, black soils here on the Darling Downs. I have spoken with other farmers who have changed from surface to overhead irrigation (lateral move) and there are mixed opinions about the improvements in water use efficiency gained.

I also think that some effort needs to be put into trialling ‘outside the box’ ideas, such as the use of plastic mulch in a broadacre situation. This would reduce soil evaporation and suppress weeds and disease.

Conclusions
This farm is typical of an irrigated production farm on the Darling Downs in that it obtains water from different sources and stores it for use on-farm. This farm shows the effect that off-farm regulation has on-farm productivity and WUE. However it has been shown that this farm is capable of adapting to these changes through implementation of various management strategies (crops grown, WUE improvements, etc).

This Case Study highlights an irrigation farm where its management has identified, implemented and realised the benefits of improved WUE. There are examples of implemented measures from three areas of WUE. However, further measures may result in further gains in WUE (i.e. planning and investigations to analyse the benefits of field shorter irrigation run lengths).

This property highlights the drought Catch-22 situation with respect to implementing WUE on-farm. The lack of water in recent times has meant that they are very conscious of their WUE.

However the lack of water and subsequent reduction in the production of higher value irrigated crops translates into a reduction in on-farm income. This results in a lack of resources to further implement on-farm WUE. It would be expected that the lessons learnt during these dry times will be remembered if and when better times return.
Photograph 1 – Case Study A Property Aerial

Photograph 2 – Farm A PST Logger near inlet pipe
Photograph 3 – Farm A PST (depth measuring device)
Pre-Watering (139 ha)
- 221 ML
- 1.6 ML/ha
Flow Rate (Gravity Release)
- 21 ML/day
- 241 L/s

Overland Flow / Rainfall Runoff
- 73 ML
Flow Rate (Pump)
- 52 ML/day
- 605 L/s

Transfer Bore Water from Sump to Ring Tank (Pump)

Irrigation (10 ha)
- 12 ML
- 1.2 ML/ha
Flow Rate (Gravity Release)
- 7 ML/day
- 82 L/s

Bore Inflow to Sump
- 17 L/s

Average Daily Evaporation
- 5 mm/day
- 0.43 ML/day (Ring Tank)
- 0.07 ML/day (Sump)

Average Daily Seepage
- 3 mm/day
- 0.22 ML/day (Ring Tank)
- 0.04 ML/day (Sump)

Average Daily Evaporation
= 5 mm/day
= 0.43 ML/day (Ring Tank)
= 0.07 ML/day (Sump)

Average Daily Seepage
= 3 mm/day
= 0.22 ML/day (Ring Tank)
= 0.04 ML/day (Sump)

Figure 16 – Farm A – PST Depth Measurements & Water Balance – Sep-Dec 04
Figure 17 – Farm A – PST Depth Measurements & Water Balance – Dec 04 – Jan 05
Figure 18 – Farm A – PST Depth Measurements & Water Balance – Jan – Feb 05

On-Farm Water Use Efficiency in the Northern Murray-Darling Basin
Evaporation, Seepage and possible Operating Losses = 0.5 ML/day

Average Daily Evaporation

= 5 mm/day
= 0.16 ML/day (Ring Tank)
= 0.08 ML/day (Sump)

Average Daily Seepage

= 1 mm/day
= 0.04 ML/day (Ring Tank)
= 0.02 ML/day (Sump)

Irrigation

= 50 ML
Flow Rate

= 13.3 ML/day
= 154 L/s

Tailwater Return and Irrigation Water drawn from Sump

Figure 19 – Farm A – PST Depth Measurements & Water Balance – Feb-Mar 05
Case Study B: Grain/Silage Production (Darling Downs, QLD)

Farm Details

Case Study B is an irrigated and dryland grain and silage production farm in the Darling Downs region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. The total farm area is comprised of two properties. A satellite view of the farm properties showing the irrigation infrastructure and fields is shown in Error! Not a valid bookmark self-reference. and Photograph 5.

The total farm area is approximately 3,050 ha and comprises 1,200 ha irrigation and 1,850 ha of dryland. Overland flow, watercourse flood harvesting, ground water and watercourse allocation comprise the water sources for the property. This water is collected and stored on-farm in storages of 3,800 ML capacity (comprising five ring tanks and four sumps). The actual amount of irrigated area varies from year to year with water availability.

Maize silage, sorghum, wheat, maize and other minor forage crops are grown under irrigation and dryland production systems.

Surface irrigation (furrow) is the dominant irrigation method. One property utilises a centre pivot. Irrigation infrastructure consists of various ring tanks / sumps, irrigation water supply channels, head ditches and tailwater drains. The centre pivot irrigator also has stormwater capture drains directing water back to the on-farm storage.

The decision to implement centre pivot irrigation was not made by the property owners. The centre pivot was already in use the property when acquired by the current owners.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- Laser levelling of fields to improve irrigation efficiency and reduce water losses to deep drainage. (Design)
- Some fields have had EM surveys undertaken to determine soil types. (Planning/Investigation)
- Soil moisture sensors (C-Probe™) to monitor water use and to schedule irrigation. (Operational/Management)
- Surface irrigation performance evaluations to improve irrigation management and efficiency and to compare irrigation field lengths. An example of the irrigation analysis is shown in Figure 20 and Figure 21. (Planning/Investigation)
- All fields have tailwater / stormwater return infrastructure. (Design)
• Continuing program of storage volume surveys. *(Planning/Investigations)*
• Yield monitoring to identify possible problem areas in irrigation fields. *(Monitoring)*
• Preferentially storing water in more efficient storages (where possible). *(Operational/Management)*
• Storage volume monitoring currently being installed in two irrigation storages (Irrimate™ Storage Meters, possibility of further monitoring in other storages). This will enable accurate on-farm water budgeting for improved water management. *(Monitoring)*

Responses to Interview Questions

*Why did you decide to invest in the particular WUE measure?*
We wanted to reduce water use (per hectare) and increase yields. Essentially we wanted to make our water go further.

*Would you class the WUE measures implemented as successful?*
Everything we have done has been pretty good as a whole. For example we used to think that a yield of 50t/ha of maize silage was a good crop. Now we consider 75t/ha a good crop for the same amount of irrigation.

*What didn't work?*
Some have been more successful than others, however there has been some advantage in everything we have tried so I would do it all again. However we invested heavily in lots of consultancy (i.e. soil moisture monitoring, etc) so we may invest in our own soil moisture probes for irrigation scheduling, etc.

*Are you more or less inclined to invest further into WUE on your property? Why?*
We are more inclined to spend money on WUE due to the positive results we have seen. In addition as the value of water increases it becomes more cost effective to invest in WUE.

*What are your future plans for implementation of WUE measures on your farm?*
We have been thinking about increasing the use of sprinkler irrigation (lateral move irrigation) if money allows. We are presently installing volume meters in two of our on-farm storages. We may install more meters in the other storages depending on the success of the current meters.

We currently do not have any water stored on-farm so our plans have stalled – I suppose we want to fill the dams first. However we have come a long way from not thinking about how much water we use to now making every drop count.

We would like to reduce water losses from storages (evaporation / seepage). Deeper on-farm storages may be an option would like to pursue but costs of storage reconfiguration may be prohibitive.

*Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?*
Not really, however in the past not knowing how much water we had (in storage) has hindered our management – for the first time last year we ran short of water late in the irrigation season. We have also recently experienced cuts in water allocation from the creek. I don’t know if these will continue. Our water situation is very tight at present.

.Has your understanding of WUE improved through the implementation of WUE measures on-farm?
Of course.

What would change with your irrigation operation if you had more access to water?
We would definitely grow more area. We have to continue growing the same crops (we supply a feedlot). We could change the way we irrigate (utilising more centre pivot or lateral move irrigators) in order to reduce labour on-farm.

Having extra water may allow different crops to be grown (additional to our current obligations) depending on commodity prices.

What would change with your irrigation operation if you had less access to water?
We would definitely have to irrigate more area under sprinkler irrigation to reduce water use and labour. I suppose we would also have to reduce the irrigated area to compensate.

Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?
Yes. Some of our surface irrigation evaluations were funded through this program. Some fields also had EM surveys done.

.In general, where do you see the greatest gains in WUE being made?
I think the greatest gains in WUE will be through sprinkler irrigation (centre pivot / lateral move).

What do you see as important areas of further research and development into WUE?
On-farm storages lose a lot of water to evaporation and seepage. We need to have more work done to try and reduce these losses.

Conclusions

This farm is typical of an irrigated production farm on the Darling Downs in that it obtains water from many different sources and stores it for use on-farm. The farm has contractual crop production agreements which limit its efforts to improve WUE through changes to cropping programs. That is, it must produce forage and feed grains for a feedlot. Hence switching to a higher value, lower water use crop is not possible in the short term.

This Case Study highlights a progressive irrigation farm where its management has identified the benefits of improving WUE. This is demonstrated in the number of implemented planning/investigation, operational/management and monitoring WUE measures implemented. However the economic considerations associated with design changes to improve WUE are also highlighted. Property management have identified that saving water is economically important however the cost of realising these water savings must be...
considered. Hence the property is firstly maximising the efficiency of their current systems and secondly trying to justify and confirm the benefits of any proposed changes.

This property also highlights the drought Catch-22 situation with respect to implementing WUE on-farm. The lack of water in recent times has meant that they are very conscious of their WUE.

However the lack of water and subsequent reduction in the production of higher value irrigated crops translates into a reduction in on-farm income. This results in a lack of resources to further implement on-farm WUE. It would be expected that the lessons learnt during these dry times will be remembered if and when better times return.
On-Farm Water Use Efficiency in the Northern Murray-Darling Basin

Photograph 4 - Case Study B – Property 1 Satellite View

Photograph 5 – Case Study B – Property 2 Satellite View
Infiltration depth over furrow length reasonably even (infiltration depth greater at head ditch end)

Tail Drain end

Ground Surface

Required Application Depth (90mm)

Head Ditch end

Moderate amount of tailwater produced

Even application depth maintained along furrow length

Minimal water lost to deep drainage

Moderate amount of Tailwater

Figure 20 – Current Irrigation Practice (Model Screen Output)

Figure 21 – Improved Irrigation Practice (Model Screen Output)
Case Study C: Cotton/Grain Production (Darling Downs, QLD)

Farm Details

Case Study C is an irrigated and dryland cotton and grain production farm in the Darling Downs region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. A satellite view of the farm property showing the irrigation infrastructure and fields is shown in Photograph 6.

The farm is approximately 850 ha in size (160 ha irrigation, 690 ha dryland). The water supply to the property is sourced completely from overland flow. Overland flow is collected and stored on-farm in storages of 1,020 ML total capacity (comprising one dual-cell ring tank and sump). The actual amount of irrigated area can vary from year to year depending on water availability.

Cotton, sorghum and maize are grown under irrigation and dryland production systems. Cotton is the primary irrigated crop. However, depending on commodity prices or timing of water availability sorghum or maize crops are grown under irrigation.

All irrigation occurs through a single lateral move irrigator. There is no surface irrigation. Irrigation infrastructure consists of the dual-cell ring tank and sump, lateral move irrigator and water supply channel. Various drains direct overland flow waters to the sump for capture into the ring tank.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- Use of lateral move sprinkler irrigation (implemented when irrigation system initially set up, no surface irrigation). (Design)
- Use of EnviroSCAN™ soil moisture monitoring system. A subsidy to purchase and implement the system was accessed from QRAA (Queensland Rural Adjustment Authority). The EnviroSCAN™ allows accurate irrigation scheduling. (Operational/Management)
- Lowering the sprinklers to ground level to limit evaporation from crop foliage. (Design)
- Use of low energy precision application (LEPA) socks instead of sprinklers (sprinklers used for crop establishment, LEPA socks used for remainder of irrigation season). (Design)
- Replacement of the water transmission channel from the ring tank to the lateral move irrigator feed channel with an underground main. (Currently the lateral move irrigator draws from an earthen channel as the size of the irrigator means that a hose drag system cannot be used.) (Design)
- Installation of various valves and pump infrastructure to allow the lateral move irrigator
feed channel to be completely emptied back into the ring tank at the end of the irrigation season. The channel can hold a substantial amount of water (2,400 m long, 5 m top width). *(Design)*

- Design of the ring tank with dual storage cells. *(Design)*

### Responses to Interview Questions

*Why did you decide to invest in the particular WUE measure?*

We invested in the lateral move irrigator primarily for WUE reasons. In addition, we only have two full time staff so the labour saving afforded by the lateral was also a consideration. Our irrigation system was designed with an expected reliability of 1 in 3 years. This meant that to be profitable our WUE needed to be good.

*Would you class the WUE measures implemented as successful?*

Yes. I don’t think I would do much differently, especially with the lateral. Perhaps the ring tank would have been designed with the main (irrigation) cell being smaller (for management reasons) with an 8 m wall, to minimise the surface area and hence evaporation losses.

*What didn’t work?*

No, everything has worked well. The biggest change has been the use of the soil moisture probe for irrigation scheduling.

*Are you more or less inclined to invest further into WUE on your property? Why?*

The current uncertainty with water and the likelihood of Government intervention in water use means that I am less inclined to spend large sums of money on WUE.

*What are your future plans for implementation of WUE measures on your farm?*

I am interested in trialling water storage evaporation control polymers (i.e. Aquatain™). I have not planned any major infrastructure changes (i.e. storage redesign) due to cost and limited return on investment.

*Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?*

No. Perhaps in the future there may be limits imposed on overland flow pumping opportunity. However nothing has occurred yet.

*Has your understanding of WUE improved through the implementation of WUE measures on-farm?*

Yes, in particular the amount of water lost in storage. This prompted us to install the infrastructure necessary to empty the irrigator feed channel. We also learnt how much we could lose from over irrigating after we installed the EnviroSCAN.

*What would change with your irrigation operation if you had more access to water?*

We would definitely grow more crop area with more complete irrigation. We would also seriously consider growing alternative crops if we had more reliable water.

*What would change with your irrigation operation if you had less access to water?*
We would have to reduce our crop area.

Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?
No. I am involved with the Central Downs Irrigators group which has provided me with most information related to WUE.

In general, where do you see the greatest gains in WUE being made?
I see potential to improve surface irrigation. However I don’t think that the same gains could be made with lateral move irrigation. Seepage and evaporation from storages will provide the biggest water savings.

What do you see as important areas of further research and development into WUE?
Water storage seepage and evaporation mitigation strategies.

Conclusions

This Case Study farming enterprise comprises irrigated cotton production and sources its water completely from overland flow. It is characteristic of the farming systems implemented on the Darling Downs. The uniqueness of this farm when directly compared with other Darling Downs farms is that the irrigation system was designed and developed with WUE in mind (i.e. use of lateral move irrigator, cell design in ring tank). The majority of Darling Downs irrigated farms were established in times of ample water supply. Hence retrospective design changes have been, or are required to improve WUE on-farm for a lot of Darling Downs irrigation enterprises.

Most water losses on this farm occur due to evaporation and seepage losses during storage in the ring tank. However the dual-cell design of the ring tank helps to reduce these losses. WUE in water conveyance and irrigation application is very good. The earthen lateral move irrigator feed channel is a potential source of water losses however the channel emptying system installed helps to limit this loss and maintain efficiency.

The WUE measures implemented in this Case Study are based on infrastructure design changes such as the channel emptying system and the replacement of earthen channel with pipe main. These measures have been quite successful to improve WUE. However the changes have also afforded better farm management and labour efficiency. The owner of the property obviously has a focus on design changes to improve WUE as identified with his responses to the above questions. This property would benefit from more planning/investigation or monitoring WUE measures in order to support and/or justify (especially in an economic sense) the use of design changes to improve WUE.
Photograph 6 – Case Study C – Satellite View
Case Study D: Lucerne/Grain/Peanuts Production (Upper Border Rivers, QLD)

Farm Details

Case Study D is an irrigated lucerne, grain and peanuts production farm in the Border Rivers region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial view of the farm property showing the irrigation fields and river is shown in Error! Not a valid bookmark self-reference.

The farm is approximately 13,000 ha in size with 225 ha of irrigation. The balance of the property is native forest with some area utilised for cattle grazing. A large feedlot has also been established on-farm. The farm has a 2500 ML nominal river allocation through a supplemented water supply scheme. Hence there is no on-farm water storage. Water for irrigation is drawn directly from the river for immediate use. Whilst the scheme provides a reasonably reliable water supply, the actual amount of irrigated area does vary from year to year depending on water availability.

Lucerne, peanuts, maize and hay crops are grown under irrigation. Lucerne is the primary irrigated crop. However, crops grown depend on commodity prices or timing of water availability from the scheme.

Centre pivot and side roll irrigation are used on the property (approximately 50-50 split in area). The side roll irrigation is utilised to make use of available irrigation area too small or odd shaped for centre pivot irrigation. The use of overhead irrigation is due to the variation in soil types and topography in the area (which limits the use of surface irrigation). As the water is supplied through a regulated scheme, irrigation infrastructure consists of pumps direct from the river, various mainline pipe infrastructure and the centre pivot and side roll irrigators. A small amount of surface irrigation was used previously on the property. However this was decommissioned as it was perceived to be too inefficient with regard to water use.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- Preparation of Land and Water Management Plan. (Planning/Investigations)
- Use of EnviroSCAN™ soil moisture monitoring technology (now discontinued). (Operational/Management)
- Detailed crop requirement/evapotranspiration water budgeting system in place for irrigation scheduling and water ordering. (Operational/Management)
- Water metering at river pump sites. (Monitoring)
- Detailed program of irrigation equipment maintenance to maintain maximum
performance. (Operational/Management)

- Detailed benchmarking analyses of crop and equipment performance. (Operational/Management)
- Replacement of one side roll irrigator with a centre pivot. (Design)

Responses to Interview Questions

Why did you decide to invest in the particular WUE measure?
Initially we have implemented the systems so that we can accurately manage water supplies from the scheme. This is also very important as we are moving toward capacity sharing in the dam system. Under the new system we will lose water if we are inaccurate with our predictions of water requirements.

With the current labour shortage we required better information and management to enable less skilled operators to become good irrigators.

We have improved our WUE as a result however we did not set out to achieve this. There was no one main driver.

With the cost of water from the scheme rising from $6-$8 per ML to now around $40 per ML over the last 10 years and the rise in fuel costs the economic factors are more important than water use efficiency. Hence we haven’t implemented these systems to save water but more so to save money. WUE improved by default as a desired outcome.

Would you class the WUE measures implemented as successful?
Yes, however we are a long way from finished. We want to do more work on crop irrigation scheduling and water budgeting (to further develop our in-house spreadsheets and accounting, etc).

What didn’t work?
We tried soil moisture monitoring however we do not use it anymore. We did not find it to be user friendly and our fields have widely varying soil types. Hence the readings from the meters were not representative of the entire field. The cost of instrumentation to get better representation of the field was prohibitive.

We had some good initial support with the soil moisture meters. However we found it difficult to interpret the data ourselves.

Are you more or less inclined to invest further into WUE on your property? Why?
I have thought about changing irrigation systems to subsurface. However we are still in early stages of detailed irrigation system monitoring. As such I want to develop this further so that our employees can see the benefits of the record keeping in the crop performance.

What are your future plans for implementation of WUE measures on your farm?
I want to continue the irrigation system monitoring, with further development on irrigation scheduling. I am continuing to collect information about crop water use requirements that will assist this development.
Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?
Not really, our water supply is reasonably reliable. Drought has limited our water supply with zero allocation this year. We do have a small amount of carryover water for this coming year.

Has your understanding of WUE improved through the implementation of WUE measures on-farm?
Yes. As we develop our monitoring and benchmarking we can continue to improve our understanding of WUE.

What would change with your irrigation operation if you had more access to water?
Grow more crop area under centre pivots.

What would change with your irrigation operation if you had less access to water?
We would still utilise our existing infrastructure and fields. Our infrastructure is getting older however it would still available for use when water allowed. We are becoming more opportunity irrigators rather than constant irrigators due to water reliability and timing. We would reduce the crop area under side roll irrigation with limited water. There is a reduced labour requirement for centre pivot irrigation, you can grow taller crops and you have more control over irrigation application.

Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?
We went to a few field days. We did not apply for nor receive any funding for on-farm works.

In general, where do you see the greatest gains in WUE being made?
Changing the management of allocated water will provide the greatest gains in WUE in this area. Continuous sharing of the resource is, in my opinion, is most efficient way to manage the water supply. If you give the user control over the water and the storage they are better able to make the economic decisions relating to water storage. As it stands under the current system a lot of unnecessary trading and associated water losses occurs.

What do you see as important areas of further research and development into WUE?
More research into climate prediction needs to occur with focus on the drivers that influence the climate in specific areas. We have come a long way so far but more needs to be done.

I am struggling to find good general information about specific crop irrigation demands. There needs to be information freely available for every irrigated crop. With a shortage of labour, less skilled operators need to be efficient water managers. Hence the science around irrigation scheduling and water budgeting needs to be made available in a simple user friendly format. Simplicity of information is the key.

I also think that benchmarking is important. A lot of irrigators in this area think that they are okay with water use yet they do not read water meters or benchmark crop production. A lot of irrigation occurs through rule of thumb application rates that have no basis in crop performance or climate conditions. That should change in time however no-one is out there driving simple benchmarking measures to monitor water use on-farm.
Conclusions

This Case Study is typical of the upper Border Rivers region in that it is an overhead-irrigation farm sourcing water wholly from a supplemented water supply scheme. Lucerne production has historically dominated the local area however in recent times a wide variety of crops are now being grown. This is illustrated in this Case Study with peanut production occurring on this property which is outside the traditional peanut production area in southern Queensland (South Burnett).

This farm does not hold WUE as a specific priority. Changes to irrigation practices are made on an economic basis. This may reflect the historical reliability of water supply from the water supply scheme. However, WUE has been improved as a desired outcome of other works to improve management and productivity on-farm. This farm has approached the improvement of farm management, productivity and WUE from a monitoring and benchmarking perspective. The focus on-farm has been to firstly quantify current levels of performance and then identify areas of improvement. Through a continual process of benchmarking, improvements across all aspects of efficiency can and are being achieved.

The farm utilises overhead irrigation (centre pivot and side roll irrigators). This is due to the soil types and topography in the local area. With good management, the existing farm irrigation infrastructure is capable of achieving high irrigation application efficiencies. As all irrigation water is supplied direct to field through the scheme, there are no on-farm storage losses. Hence the property has a high WUE. All storage losses occur at the water supply scheme storage. Improvements in WUE of the scheme can occur when the capacity sharing system (i.e. storage is under co-operative irrigator management) is in place and operating.

An interesting point is that the use of direct soil moisture monitoring for irrigation scheduling is not seen as appropriate or user friendly. Instead irrigation scheduling is undertaken with estimates of crop evapotranspiration from climatic observations.
Photograph 7 – Case Study D – Aerial View
Case Study E:  Pecan Nut Production (Gwydir, NSW)

Farm Details

Case Study E is an irrigated pecan nut production farm in the Gwydir region of northern New South Wales.

The geographic location of the farm within the northern MDB is shown in Map 5. The farm irrigates 750 ha of pecan trees. The farm receives its water supply (high security surface water) through a supplemented water supply scheme. Hence, there is no on-farm water storage. Water for irrigation is drawn directly from the river for immediate use. Whilst the scheme provides a reliable water supply there is a nominal emergency groundwater allocation available (from a shallow alluvial aquifer) if the surface water supply is limited.

The majority of the farm (730 ha) is surface irrigated through concrete lined below ground flow over ditches. An integrated tail water return system is also in place. The property has also installed and trialled 20 ha of sub-surface drip irrigation (SDI).

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- Concrete lining of all ditches on the property including tail water sumps and delivery channels. (Design)
- Accurate laser levelling of all fields to optimised slope characteristics. (Design)
- Annual compost applications of 7.5 tonne/ha along with mulching of tree prunings and under tree grass sward support to maximise soil organic matter levels. (Operational/Management)
- Use of controlled traffic techniques for all orchard machinery operations to minimise soil compaction. (Operational/Management)
- Maintenance of a zero till orchard floor management program to support active soil biology and maximal soil organic carbon levels. (Operational/Management)
- Soil moisture monitoring and evapotranspiration monitoring systems in place to manage irrigation scheduling characteristics for all fields (50 fields in total). (Operational/Management)
- Intensive field scale yield and growth monitoring to attempt to establish peak irrigation performance. (Monitoring)
- Electromagnetic survey of entire property in order to classify soil type and management zones. (Planning/Investigations)
- Irrimate™ surface irrigation evaluations undertaken on all major field subtypes in order to identify optimal surface irrigation practice as well as identifying strategic investment opportunities for subsurface drip upgrade. (Planning/Investigations)
• Sub-surface drip irrigation evaluation trial (20 ha) – to establish potential savings and most appropriate infrastructure set up. *(Design)*

**Responses to Interview Questions**

*Why did you decide to invest in the particular WUE measure?*

We conducted a complete review of our WUE opportunities in 2007 using soil mapping, Irrimate™ evaluations and trial SDI installation. From this we have mapped out a 4 year investment program which will ultimately see at least 75% of our irrigable area converted across to SDI.

Our motivation in this program is as follows:

1. To improve our ability to maintain productivity in low water supply years – based on a presumption that the reliability of our water supply will continue to decline.
2. To obtain short term financial gains through the seasonal assignment of water savings to other irrigators within the region.
3. To free up sufficient water from sustainable WUE dividends to expand our irrigated crop area.
4. To attempt to achieve greater per hectare productivity through the active use of SDI to manage nutrient as well as soil moisture levels.

*Would you class the WUE measures implemented as successful?*

The work undertaken to optimise our irrigation scheduling and surface irrigation management has reduced water use (per irrigation) by at least 10%. In addition we have saved at least one full irrigation annually. We estimate that this has resulted in an overall water saving of around 15-20%. This has been achieved without capital investment – simply through more active and intelligent management of irrigation events and more effective irrigation scheduling.

The cost of a switch to SDI is estimated at around $5,500/ha. This may result in over 3 ML/ha savings per year in some of our worst performing surface irrigation fields.

*What didn’t work?*

So far we have not had a significant failure with implemented WUE measures on-farm.

*Are you more or less inclined to invest further into WUE on your property? Why?*

The current Federal Government policy with regard to water regulation (in particular the property rights legislation) and the water trading options currently available in this area improves our confidence to invest significantly in WUE on-farm.

*What are your future plans for implementation of WUE measures on your farm?*

As discussed earlier we intend converting at least 75% of the farm to SDI in the next 4 years. We may proceed with the entire property if we can obtain sufficient productivity gains (tonne/ha and tonne/ML).
Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?
As we obtain water from a supplemented supply direct from the river we must order irrigation water in advance of expected irrigation events. The long order lead times (4-7 days) makes irrigation scheduling very difficult. In addition rainfall events cannot be used as effectively. It is very difficult to cope with water rejections.

Has your understanding of WUE improved through the implementation of WUE measures on-farm?
Absolutely. We continue to learn from each activity we undertake.

What would change with your irrigation operation if you had more access to water?
We would expand our cropped area of pecan nuts as long as we were confident that the reliability of supply was going to stay relatively constant over time. We would only expand our cropped area if we had achieved sufficient volumetric WUE gains to release additional water from our current licence.

What would change with your irrigation operation if you had less access to water?
The installation of SDI is essentially a response to a perceived reduction in the reliability of our water supply over time.

Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?
No. However farm staff have attended Water Wise on the Farm training programs run by NSW DPI as well as attending targeted Soil Moisture Monitoring workshops run by the NCEA.

In general, where do you see the greatest gains in WUE being made?
Distribution and storage losses in the supplemented supply system (i.e. the scheme dam and the river itself) represent the single largest loss in the system.

The second most critical issue is to continually more accurately define the evapotranspiration crop factors for each crop in order to consistently improve water scheduling decisions.

What do you see as important areas of further research and development into WUE?
Research is required to improve the delivery and storage efficiency of the entire supplemented water supply system.

Conclusions

This Case Study is unique in that it is a high value tree nut production farm in the heart of the traditional cotton growing area in the northern MDB. It receives a high security water supply direct from the river with no on-farm storage. Despite the obvious water related differences with other irrigators in the region, there is still a very strong focus on WUE in order to increase production and maintain security and reliability of water supply. It is noted that the range of WUE measures implemented are well spread across the four areas.
The farm is still predominantly surface irrigated. However, the property is converting up to 75% of the farm to SDI over the next four years. The conversion to an alternative irrigation system has been made with site-specific data and information and through the installation of an operational 20 ha SDI trial field on-farm. Surface irrigation is becoming less common for high value, permanent crops such as tree nuts with many producers able to justify the conversion to alternative irrigation systems through water savings (i.e. higher water value) and productivity gains.

The estimated 15-20% improvement in WUE has provided the farm with additional flexibility. These include the option to increase cropped area or even sell the saved water on the short-term (temporary) water trade market. Hence the improvements in WUE can result in an instant additional cash flow on-farm. This property is in the advantageous position where it can capitalise on its own efforts to improve WUE. Many other irrigation properties in the northern MDB are required to improve WUE just to maintain their current levels of production as their water supply is forcibly reduced or becomes more unreliable.

The WUE limitation of long lead times in ordered irrigation water was identified. This is an issue for many farms accessing water from a supplemented water supply scheme. It was noted that considerable increases in WUE could be gained through further research into the operation of supplemented water supply schemes.

It is interesting to note that this property has enough confidence in the current state of water regulation in the area to invest considerably into WUE measures on-farm. However they also perceive a potential reduction in water supply reliability and this is a key driver for WUE on-farm (in order to maintain productivity).
Case Study F: Celery / Chinese Cabbage / Lettuce Production (Upper Border Rivers, QLD)

Farm Details

Case Study F is an irrigated vegetable farm producing celery, Chinese cabbage and cos lettuce in the Upper Border Rivers region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. The farm has a total irrigation area of 100 ha which is double cropped annually with the three vegetables grown. The farm has an independent water supply through numerous on-farm dams capturing overland flow. There are also two dams in local creeks passing through the farm. There is no groundwater in the local area.

The majority of the farm is irrigated through solid set sprinklers. There is also some subsurface drip irrigation (SDI) in place.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- Conversion of a small area to SDI from solid set irrigation. (Design)
- Flow meters have been installed on all irrigation water supply mains. (Monitoring)
- Distribution Uniformity (DU) of solid set irrigation system determined. (Planning/Investigation)
- Use of C-Probes™ in fields with direct link to computer in office for continuous soil moisture monitoring. Approximately 20 probes have been installed across the farm. (Operational/Management)

Responses to Interview Questions

Why did you decide to invest in the particular WUE measure?
We invested in the C-Probe™ soil moisture monitoring system for improved irrigation management and scheduling and increased productivity. The cost of water to us is insignificant however its supply is critical so we needed to be more efficient with our water use.

Would you class the WUE measures implemented as successful?
We measured a 25% reduction in water use with the implementation of SDI as compared to the solid set irrigation system. However the cost of SDI is a factor and we are not convinced that the economics are there to justify converting our entire farm over to drip.
The use of the automatic soil moisture monitoring system allows better irrigation management and decision making. The automation of the process means that less skilled workers to operate the irrigation system to maximise efficiency. The workers can also see the benefits of the system through improved crop performance.

We also identified that we should irrigate a smaller amount every day, not a larger amount every second day as is traditional in this area for these crops. We also identified that our soils cannot hold significant amounts of moisture so we irrigate accordingly.

**What didn’t work?**
Nothing we have tried has been a resounding failure. Prior to the use of probes we used tensiometers however they were time consuming and labour intensive.

We have one probe in each field. Where we have numerous crops at different stages of growth within the one field we have to exercise some judgement from the soil moisture data as to how much to irrigate those parts of the field.

The SDI struggles to keep up with demand in the summer months. However it performs well in spring and autumn.

**Are you more or less inclined to invest further into WUE on your property? Why?**
Neither. At this stage we invest in WUE as we see fit.

**What are your future plans for implementation of WUE measures on your farm?**
We have looked into evaporation covers for our dams to conserve water. This may become more important in the future if we have to pay for our water. At this stage we would investigate this from a water conservation perspective (for increased productivity).

In the past if we develop or redevelop fields we have paid attention to the layout of the solid set sprinklers to achieve a high DU. The cost of reconfiguring existing sprinkler layouts is cost prohibitive.

**Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?**
Under the current regulation (i.e. moratorium on new overland flow works) we are unable to build more dams to capture more water. However there is very little imposition on us as all our water is privately owned and operated. The drought conditions are also beyond our control.

**Has your understanding of WUE improved through the implementation of WUE measures on-farm?**
The implementation of the soil moisture monitoring has identified areas where we can improve WUE. Hence our understanding of WUE has improved.

**What would change with your irrigation operation if you had more access to water?**
I am not sure if we would grow more crop area. We are limited with land availability where we are. Hence we would need to acquire more land which may be separated from our current
property. There are significant hassles involved with machinery movements, etc between production farms.

*What would change with your irrigation operation if you had less access to water?*
We would definitely have to look at reducing evaporation losses from our dams, perhaps using covers. We might look at reducing the amount of celery production as it is a high water user.

*Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?*
No. We did receive some funding to install the SDI through the Water for Profit scheme run through Growcom. We are more inclined to fund WUE implementation ourselves as it is quicker and we save time on the red tape of funding applications, etc.

*In general, where do you see the greatest gains in WUE being made?*
The greatest gains could come from reducing storage losses to evaporation and seepage. Perhaps the crops we grow under irrigation could be re-evaluated (can we still afford to grow irrigated cotton in Australia?).

*What do you see as important areas of further research and development into WUE?*
Traditional irrigation practices still occur in this area without any objective measurement. This mindset needs to change. However natural attrition will generally weed out the inefficient producers as water becomes more valuable.

**Conclusions**

This Case Study highlights the implementation of WUE measures in the horticultural sector in the northern MDB. There are similarities with other irrigated crops in the northern MDB in that the entire water supply for the property is sourced from overland flow. However the higher value of the irrigated crop production means that the use of solid set irrigation system and the future use of dam covers to reduce evaporation losses can be justified.

It is interesting to note that even in the horticultural sector this particular property found it difficult to justify the conversion to SDI. They, like many other irrigators, aim to maximise the potential of their existing system first.

The issue of system capacity arose with this property in the installed SDI system. The fact that the system cannot keep up in the summer months indicates the need for additional system capacity that should have been identified in the planning stages of the implementation of this system. The capital cost of SDI means that proper design and sizing of the system is imperative to its success.

The use of C-Probes™ is extensive on this property. However the issue of locating the probes and the judgement required in applying point soil moisture data over an entire field (with variations in crops, growth stages, soil types, etc) was highlighted.
Case Study G: Cotton/Grains Production (Darling Downs, QLD)

Farm Details

Case Study G is an irrigated cotton and dryland grain production farm in the Darling Downs region of southern Queensland.

The geographic location of the farm within the northern MDB is shown in Map 5. A satellite photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 8.

The farm on average irrigates approximately 500 ha each year. River water harvesting and overland flow are the main sources of water for the property. A ground water allocation supplements the water supply. The farm has approximately 2,500 ML of on-farm storage. The actual amount of irrigated area can vary from year to year depending on water availability.

Cotton is the main irrigated crop. Grain crops (sorghum, corn, wheat, barley, chickpeas and soybeans) are also irrigated on an opportunity basis.

The majority of the crop area is irrigated using surface irrigation (furrow). Irrigation infrastructure consists of ring tanks / sumps, irrigation water supply channels, head ditches and tailwater drains. A small trial area (8.4 ha) of sub-surface drip irrigation has been implemented.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

- All pumps have water meters. (Monitoring)
- All fields undergo a continuous program of laser levelling. (Design)
- All fields have had EM surveys undertaken for soil classification. (Planning/Investigations)
- EnviroScan™ soil moisture monitoring is used in all fields – sensors are placed in the most common soil type for the field as determined through EM survey. (Operational/Management)
- Agronomic practices that improve WUE are used (i.e. more water efficient cotton varieties, deficit irrigation of grain crops to maximise rainfall, soil management to improve structure, application of feedlot manures, soil testing, controlled traffic farming). (Operational/Management)
- Long fallow practices are used to build up soil moisture to reduce demand on irrigation water supply. (Operational/Management)
- Irrigation watering times have been reduced. (Operational/Management)
Zero till farming practices used in irrigated grain production. (Operational/Management)

Ring tanks have been EM surveyed to identify areas of potential seepage loss. One ring tank was identified to have a problem area in the floor. This area was excavated and a compacted clay blanket was overlaid to seal the area. (Planning/Investigation and Design)

Yield monitoring is carried out during cotton picking. (Monitoring)

8.4 ha trial of sub-surface drip irrigation (SDI) (Design)

Responses to Interview Questions

*Why did you decide to invest in the particular WUE measure?*
We invested in these WUE measures to save water and increase production. We strive to get the best return from every input to our cropping program.

*Would you class the WUE measures implemented as successful?*
We benchmark our production on bales per ML basis. We are continually trying to improve on this benchmark.

*What didn’t work?*
Our small area of SDI has not convinced us that the economics are there for a large scale adoption of SDI on our farm. We have had problems with insects and mice attacking the drip lines. The water efficiency of the system was good (irrigating directly from a bore into the drip system). However we probably increased our WUE by 10-15% with production increasing by 1 bale/ha. However this is not enough to justify the large capital and operating costs.

There is a lot of advice out there recommending that surface irrigators should pull their syphons earlier and reduce the amount of tailwater produced. This has not worked on our property, with the variation in soil types and slopes. We need to run higher amounts of tailwater to ensure that the tail end of the field is adequately irrigated. We have short tailwater drain lengths so this does not adversely affect our WUE significantly. We have found that this has not adversely affected our yields at the top end of the field (through water logging).

We have been trialling different setups with the syphons to increase flow rates down the field. We have tried dual syphon setups with some success.

*Are you more or less inclined to invest further into WUE on your property? Why?*
We are more inclined to invest further in WUE on our farm. We are facing a 50% reduction in our bore allocation over the next few years. Hence this has forced us to consider our next steps in improving WUE just so that we can maintain our current levels of production from a reduced water supply.

*What are your future plans for implementation of WUE measures on your farm?*
Due to our current farm layout (roads, powerlines, etc) we cannot install lateral move or centre pivot irrigators. I am still unsure about the economics of such equipment anyhow, especially with reduced cropping reliability. The capital investment with that equipment is huge compared to surface irrigation. A few syphons are cheap and easy to move around to
different fields. It is not that easy to shift centre pivots or lateral move irrigators to different fields. We aim to keep improving the efficiency of our surface irrigation and to keep improving on our benchmarks. If we bought another farm that could accommodate a centre pivot or lateral move we might consider that option.

We may consider putting cells into our ring tanks to save on evaporation and seepage losses. This is especially important when storing low volumes of water as there is large surface areas of water (relative to stored volume) exposed to evaporation and seepage losses.

We will always investigate opportunities to improve WUE. For every drop of water we save we have the potential to increase productivity and profits.

*Is there anything that has occurred beyond your control that has limited or reduced your WUE on-farm?*
The reduction in our bore allocation has meant that we need to consider how we use this limited resource. We need to increase the value of this water. We have considered growing higher value crops such as vegetables or perhaps using the bore water to grow lucerne under sprinkler irrigation.

We can no longer afford the losses associated with storing bore water in our ring tanks due to its reduced supply. All future use of bore water will have to be direct from bore to field to maximise efficiency.

The Resource Operations Plan for the Condamine-Balonne has not posed any risk to our water supply or WUE. However there is uncertainty with regard to the future of water regulation so I am very cautious about large investment in WUE on-farm. It seems that we will continue to have less access to water in the future.

*Has your understanding of WUE improved through the implementation of WUE measures on-farm?*
My understanding of WUE is continually improving. We are always keen to do the best we can with the limited resource that we have. We are happy to be involved with any research or on ground works associated with improving WUE. We have a passion to continue ‘raising the bar’ as far as productivity goes.

*What would change with your irrigation operation if you had more access to water?*
We would grow more crops with more complete irrigation. If the reliability of our water improved we would consider alternative crops that may provide a better return.

*What would change with your irrigation operation if you had less access to water?*
This is already evident with our reduced bore allocation (see response above).

*Did you participate in the Rural Water Use Efficiency program 1, 2 or 3? What was that involvement?*
We were involved in the early stages of the RWUE programs. There was some interest in our SDI setup. We did host some workshops on-farm and we have attended numerous field days. However sometimes I thought that most good irrigators were aware of the practices.
required to improve WUE and were ahead of the RWUE program anyway. The program was
good to get ideas and information out there for irrigators to try on their own properties.
However there is no silver bullet and a varied approach is often best.

In general, where do you see the greatest gains in WUE being made?
The greatest gains will be made at the storage. The storage is our biggest loss of water. It is
quite possible for us to lose 1.5 m depth of water from our storage to evaporation and
seepage. This is about one-third of our water supply.

What do you see as important areas of further research and development into WUE?
We definitely need more research into reducing losses at the storage. There are rebates
available for people to put covers on swimming pools to reduce evaporation. How much more
water is lost from a ring tank?

I would like to see research on the benefits of cells in ring tanks, perhaps some trials to get
some solid data. I would also like to see some research on the benefits or otherwise of
storing water in the soil. Our soils hold water very well and sometimes we will irrigate water
on to a field instead of storing it at shallow depths in the storage.

Conclusions

This farm is typical of an irrigation production farm on the Darling Downs in that it obtains
water from different sources and stores it for use on-farm. This farm shows the impact of off-
farm regulation (reduced bore water supply) making an immediate impact to on-farm
productivity and WUE. However the farm is endeavouring to adapt to the changes with many
different options investigated to increase the value of this limited water supply.

This Case Study also identifies the difficulties in changing irrigation systems to increase
WUE. For this property, the economics prohibit any changes to irrigation system. Hence they
are doing their best to maximise the efficiency of their current system (surface irrigation).

The uncertain future of water supply in Australia also inhibits on-farm investment in this Case
Study. They are cautious about investing large sums of money into new irrigation systems
due to reduced water supply and reliability (due to climate changes, increased regulation on
access, etc).
Photograph 8 – Case Study G – Satellite View
Case Study H:  Cotton Production (Namoi Valley)

Farm Details

Case Study H is an irrigated cotton and dryland grain production farm in the Upper Namoi Valley region of northern NSW.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 9.

The farm is 407ha in size with 230 ha developed for irrigation. The farm has 170ML of on-farm storage (comprising one ring tank and two tailwater reservoirs). On average 150 ha is irrigated each year.

Lucerne is the main irrigated crop, with cereals, legumes, and cotton grown as the seasons allow.

Groundwater allocation is the primary water source. Water in a nearby creek is accessed through an unregulated allocation when flow is available.

Currently approximately 60% of the farm can be furrow irrigated and 40% using center pivots. Irrigation infrastructure consists of the ring tank, tailwater reservoirs, irrigation water supply channels, head ditches, taildrains, and tailwater return drains.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Installing a center pivot in 2006 irrigating approximately 80 ha per year. Improved efficiencies in labor, management, and water use were key factors in this decision. (Design)
2. Conducting an EM survey and soil infiltration analysis across the farm to determine areas with potentially high seepage rates. Soil infiltration analysis including soil coring, and infiltrometer ring tests. The results were used to determine suitable locations to install the center pivot. (Planning/Investigation)
3. Clay lining areas of sandy soils in the storage using clay sourced on site. The entire storage interior has also been compacted using a sheepfoot roller. (Design)
4. Pump test on all bores to determine optimum performance conditions, and check accuracy of pump meters (Planning/Investigation)
5. Regular laser leveling of fields. (Design)
6. Careful monitoring of furrow irrigations. The irrigation is stopped when it reaches the furrow in an effort to reduce deep drainage losses in the field and in the tailwater return system.
7. Continuous records of farm water storage levels. These are used to estimate seepage and evaporation losses through the season. Storage levels are measured using a gauge based on a recent storage survey and recorded manually. (Planning/Investigation)


9. Weed control is an issue on the farm and is managed using an intensive spraying program. This is conducted only when wind conditions allow it to prevent chemical drift on crops or neighboring properties. (Operational/Management Issues)

10. Using on farm storage water completely before reverting to the bore allocation. This results in reduced pumping cost and storage losses. (Operational / Management)

11. Irrigation Scheduling using an estimate of crop evapotranspiration and adherence to the farm water budget. (Operational / Management)

12. Recent surveying of the storage to determine volume. Storage volume is measured and recorded regularly using gauge boards. (Monitoring)

Response to Interview Questions

Why did you decide to invest in the particular WUE measures?
Installing a center pivot was first considered for benefits in labor requirements, management, and WUE. It was installed primarily for our lucern hay production where it offers a improved irrigation and crop uniformity, the ability to apply small volumes of irrigation, and an increase in the amount of ‘cuts’ per season.

Would you class the WUE measures implemented as successful?
In terms of WUE efficiency it is too early to tell. Our lucern crop is still being established and we are experimenting with the pivot setup. Results in the area have been positive in terms of WUE. We have experienced improvements in crop uniformity as a result of a more uniform irrigation. In terms of labor and managements improvements it has been a success.

What didn’t work?
We conducted an EM survey in the storage on a wet soil surface which did not generate any results. We have limited long term benefits from laser leveling due to being on a flood plane. Field grades are regularly impacted by flood waters.

Are you more or less inclined to invest further in WUE on your property? Why?
We are inclined to invest further. Additional pivots and improvements in storage efficiencies are areas we are currently looking at.

What are you future plans for implementation of WUE on your property?
We are inclined to install another pivot. This is mainly due to the reduced labor cost and the fact that they are easier to manage. This is especially true in lucern where we can now apply less water to establish the crop. We also have plans to reduce the seepage rates in the storage initially through rolling the base of the storage or clay lining patches of sand if required.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?

Steepness of the country limits infrastructure such as tailwater return drains. Being on the floodplain we have increased laser leveling and infrastructure maintenance cost as a result of damage from flood waters.

Has your understanding of WUE improved through the implementation of WUE measures on farm?

Definitely. Courses run by the DPI on irrigation management were a great eye opener. They highlighted factors to consider to improve WUE such as knowing your soil moisture holding capacity. The experience of local consultants has also given us valuable insight into WUE. The more you look into it [WUE] the more you learn.

What would change with your irrigation operation if you had more access to water?

We would probably look into another pivot. They are well suited to the topography of our farm allowing us to irrigate on steep grades and still provide the required infiltration.

What would change with your irrigation operation if you had less access to water?

We would look further into alternative crops. This is something that we are already doing but we would have to give it more thought. The aim is to generate more dollars per ML of water.

In general, where do you see the greatest gains in WUE being made?

Probably in high value crops. Potentially moving from cropping to horticulture.

What do you see as an important areas of further research and development into WUE?

Researching the suitability of regions for alternative high value crops.

Conclusion

This farm is typical of small irrigation operations in the Upper Namoi Valley. Its primary water source is groundwater with access to unregulated flow. This farm highlights the challenges that similar farms must face to improve WUE. Such as:

- Reliance on storages to supplement low pump capacity bores in heavy water demand periods
• Limited above ground infrastructure to minimize flood water diversions to neighboring properties.
• Family operated with limited access to external labor
• The importance of additional management and productivity factors in considering WUE measures

Despite these challenges this farm is still committed to further improving their water use efficiency and their knowledge of it. Importantly, they investigate the facts before adopting any measures. Recently they investigated sub-surface drip with initial results indicating that it would not be beneficial due to soil type. This investigative approach is important. Not all WUE measures may be applicable to certain situations.

Photograph 9 – Case Study H
Case Study I: Cotton Production (Barwon Region)

Farm Details

Case Study I is located in the Barwon region producing cotton, and wheat.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 10.

The farm is 1935ha in size with the entire farm developed for irrigation. The farm has 10,400ML of on-farm storage capacity and has been designed with a high capacity supply and tailwater return system.

Cotton is the predominant crop with 980 ha planted each year. Irrigated and dryland wheat are also grown in rotation with Cotton.

Water is accessed through class B & C unregulated river licenses. Rainfall runoff is captured in the Tailwater return system and can be held in the on-farm storage.

The farm is irrigated using furrow irrigation.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Designing the storage with two cells. Each cell can be emptied and filled independently reducing potential seepage and evaporation losses. (Design)
2. Impact rolling each cell when it is empty. Increased compaction in the upper soil profile has reduced seepage rates. (Management)
3. The farm was designed close to the river to minimize supply transmission losses. (Design)
4. All fields are laser leveled and have been designed with optimum field lengths and grades. The average field length is 550m. (Design)
5. Undertaking a feasibility study into lateral moves. At the time this indicated that furrow irrigation was more cost effective. Due to recent improvements in lateral move design lateral moves could be viable in the future. (Planning / Investigation)
6. Installing of subsurface drip irrigation on a nearby farm. This trial showed that drip irrigation was not effective in the heavy clay soils typical of this area. (Planning / Investigation)
7. EM survey of all fields and storages. (Planning / Investigation)
8. Irrimate™ Surface Evaluation trials on all fields to determine the optimum irrigation practice for each field. (Planning / Investigation)
9. Conducting a land and water management plan prior to the construction of the farm. This included the installation of piezometers to monitor the water table. (Planning / Investigation)
10. Implementing a strict weed control program in every element of the farm. (Operational / Management)
11. Capacitance probes are installed in every field to assist in effective irrigation scheduling. (Operation / Management)
12. Designing the farm in 3 operational segments. Each segment has its own tailwater return system and accesses water through a central supply system. This system minimizes transmission losses while still allowing effective crop rotation. (Design)
13. Automatic weather stations are installed on the farm to calculate evapotranspiration. (Monitoring)
14. All storages have been surveyed and installed with accurate gauge boards. Storage volumes are recorded manually through the season. (Monitoring)
15. Using WaterTrack™ Optimiser to calculate a daily whole farm water balance. This identifies water losses across the farm and allows effective water management. (Monitoring)
16. Measuring storage losses and including in the farms water budget. (Monitoring)
17. Flow meters are installed on all river pumps. (Monitoring)

Response to Interview Questions

*Why did you decide to invest in the particular WUE measures?*

Water is our most limiting factor. It is everything. Without the data to track where our water is being used we can’t determine where to make changes.

*Would you class the WUE measures implemented as successful?*

Yes. In particular ‘stacking’ water into storage cells. This has reduced our losses and improved our supply capacity. The farms supply capacity is very high which allows us to adopt optimum irrigation practices for our fields.

We have also benefited from initial measures prior to construction such as installing peizometers and seeking the advice of consultants. This has lead to a very efficient farm layout where transmission losses are minimized while still maintaining an effective crop rotation

*What didn’t work?*

Using dozers to build one section of channel. This resulted in poor construction and poor compaction and required redevelopment.

*Are you more or less inclined to invest further in WUE on your property? Why?*

Definitely. Water is liquid gold!

*What are you future plans for implementation of WUE on your property?*

We are really chasing more data. How can we implement a change without the data to back it up? We will be running the WaterTrack™ software programs across the farm,
installing Irrimate™ Storage Meters and Seepage & Evaporation Meter, Mace meters will be installed in headditches and taildrains, and we will continue to conduct Irrimate™ In-field Evaluations to determine the most efficient irrigation practices for our fields.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?

Initial design problems in the main supply channel held up our initial water use efficiency measures. We were unable to irrigate on time.

Our soils and climate constantly challenge us in reducing seepage and evaporation losses. In addition to this our low rainfall often requires us to pre water which affects our WUE figures.

The drought has limited our access to water and it has been hard to measure the efficiency of some elements. This has potentially delayed some WUE decisions.

Has your understanding of WUE improved through the implementation of WUE measures on farm?

Definitely. In particular understanding that losses can be reduced and realizing the impact that this has in terms of increased farm production. Also, identifying that transmission losses are our biggest area for improvement and can exceed in-field losses. This has allowed us to be focused on improving our delivery systems.

What would change with your irrigation operation if you had more access to water?

We would aim to increase our water security. We would also look at using the additional water on alternative cropping such as irrigated winter wheat. It is all about maximizing our return/ML.

What would change with your irrigation operation if you had less access to water?

We would maintain our current focus on WUE and continue to improve our return/ML. Further storage redesign could become cost effective with limited water access.

In general, where do you see the greatest gains in WUE being made?

Covering and lining our storages and drains would provide us with enough water no matter what the season. Currently the available options are not cost effective.

What do you see as important areas of further research and development into WUE?

- Covers and liners for storages and channels.
- Genetically modified crops with improved WUE genes. Modifying summer crops to be grown in winter could also return significant water savings.
• Further research into the benefits of different irrigations methods. Looking at the real benefits of laterals, drip, furrow etc.

Conclusion

Case study I shows a farm that has been focused on WUE since initial development resulting in an efficient farm layout. Since development the farm has adopted a strategy of continually seeking information and data on WUE performance. This proactive approach has led to the development of successful strategies to improve WUE.

Importantly, they have identified the associated production benefits of improved WUE. This understanding is reflected in all aspects of farm management.

Photograph 10 – Case Study I
Case Study J: Cotton And Wheat Production (Gwydir Valley)

Farm Details

Case Study J is located in the Gwydir Valley producing cotton, and wheat.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 11.

The total farm size is 24,000 ha with 10,400 ha developed for irrigation. The farm has 50,000ML of on-farm storage capacity and accesses water primarily through a regulated general security and supplementary allocations. A small high security license is also held.

Cotton is the predominant irrigated crop with wheat and lucerne also irrigated. Sorghum, oats (feed), and pulses are grown as dryland crops.

Furrow irrigation is the predominant irrigation practice, while 460 ha irrigated through the recent installation of two lateral moves.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Redesigning key storages to reduce seepage and evaporation losses. Two storages have been split into separate cells and one storage has had its banks raised by two meters. (Design)
2. More recent storage design and development has taken storage efficiency into account as well as storage maintenance issues. (Design)
3. Modifying the entire farm system to improve WUE. The farm adopts a 100% crop rotation in an aim to allow most crops to be planted into moisture. This saves on a pre-water / water up which have been identified as the irrigation requiring the most water. (Operational / Management)
4. Changing the farm design to minimize transmission losses. Crops are planted close to water sources. This has required modifying the crop rotation. (Design)
5. Installing a lateral move to irrigate 460 ha. The aim of this has been to improve WUE by effectively using the normally small amount of water remaining at the end of the season. For example this allows small applications of water (not necessarily fully refilling the soil moisture profile) to establish winter wheat crops. In the past this water could have been stored in the reservoir over the winter where significant amounts could be lost through seepage and evaporation. (Operational / Management)
6. Currently establishing a trial on a section of the farm using lateral move, subsurface drip, and furrow irrigation practices. The financial and water use efficiency benefit of each system will be assessed. (Planning / Investigation)
7. Assessing the irrigation system efficiency. All inflows and outflows across the farm are recorded into a spreadsheet. This allows calculation of WUE across the various elements of the farm. (Planning / Investigation)

8. EM surveys of all fields and storages. This has isolated some areas of concern in the storages which have been further assessed by digging soil pits. EM surveys in the field have been used to determine the ideal location for capacitance probes. Probes are installed where the soil type is most indicative of the entire field. (Planning / Investigation)

9. Designing a spreadsheet to determine when to order water. The aim being to minimize the surface area of water stored on farm. The effectiveness of this has been reduced by State Water’s policy of bulk releases where large volumes of water must be pumped in short time periods through the season. Water has had to be stored in storages that didn’t need to be filled. (Operational / Management)

10. Implementing the Cotton BMP Land and Water Module. (Operational / Management)

11. Adopting a zero tolerance for weeds in all elements of the farm, whilst incorporating an integrated weed management approach. (Operational / Management)

12. Irrigation scheduling using capacitance probes in every field. (Operational / Management)

13. Storages are ranked in order of efficiency and water is prioritized to the most efficient storages. Water can be transferred through all storages on the farm allowing this to be implemented without effecting farm management. (Design)

14. Constructing drainage lines in dryland fields to minimize water logging and maximize the effective use of stormwater runoff. Areas of ponded water in the field are seen as an inefficient use of water and areas of reduced productivity. (Design)

15. Surveying storages and installing accurate gauge boards to accurately measure storage volumes. Storage volumes are recorded manually throughout the year. (Monitoring)

16. Mace meters have been installed in headditch and taildrain culverts to conduct field water balances. (Monitoring)

17. Designing a spreadsheet to calculate a whole farm water balance. (Monitoring)

Response to Interview Questions

Why did you decide to invest in the particular WUE measures?

The initial driver to investment in WUE was simply that we were faced with a situation of diminished water availability. With a need to support the cost of capital, infrastructure, staff etc we really had to maximize our production with the limited volume of water that was available. For the first time we had to focus on WUE. The lessons we have learnt, regardless of how much water we have we will continue to use it efficiently, as is the need for continued WUE is now so engrained in us. Currently we are setting up trials to justify the next step. We need to look at every possible option available to us to continue to raise the WUE bar.

Would you class the WUE measures implemented as successful?

Yes. Absolutely. We have improved our WUE by 60% in our cotton production from 1 bale/ML to 1.6 bales/ML. In terms of return/ML we have increased this by over 140%. This result has been somewhat unexpected but it has been due to the fact that because
we used less water in a more efficient fashion we also gained production benefits and increased our yield as a consequence.

What didn’t work?

Everything basically worked in the first year. Since then we haven’t been able to improve further. We have stagnated at 1.6ML/day. We are now looking to new areas of on farm research to help us continue to achieve WUE gains

It should also be noted that measurement of WUE was relatively simple in the first year, as there was no in crop rainfall. It has been difficult to measure in the subsequent years due to rainfall.

Are you more or less inclined to invest further in WUE on your property? Why?

We are more inclined and we continue to invest, hence the on-farm trial of laterals, drip, and furrow. We are also looking at other factors such as nitrogen efficiency and the carbon cost of each system. We need to consider the other factors attached to WUE. What are the added benefits on factors such as fertilizer use efficiency and the consequential reduction in carbon emissions?

What are you future plans for implementation of WUE on your property?

As discussed in the last question. We will continue to look at the broad picture and consider all the associated factors. We are committed to our on-farm trial of the different irrigation options and continue to contribute to and help co ordinate future research located both on and off farm to help drive additional WUE gains.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?

Yes. Government intervention (both state and federal). State Water decisions to deliver water through a “bulk release” system have not been researched in terms of potential losses on farm because of this delivery system. Whilst water may appear to be saved at a delivery level there is no consideration to the impact of having to “wet up” additional storages on farm to handle the bulk release. This creates on farm losses through additional evaporation and deep drainage. The overall political environment at both a state and federal level also concerns us. We are very nervous to invest additional large sums of capital into improved on farm irrigation delivery systems (like lateral moves, centre pivots and drip irrigation) without the assurance that we will have water in the long term. The goal posts appear to be constantly moving.

Has your understanding of WUE improved through the implementation of WUE measures on farm?

Yes. Until we implemented WUE the perception had been that increasing WUE was difficult to understand and an extremely difficult “thing” to implement. This certainly has not been the reality and the surprisingly low financial impost of the various WUE
components implemented was an additional surprise. One difficulty is that there isn’t a standard method of calculating WUE across industries or even within the cotton industry. If there was a common standard it would be easier for all to understand.

**What would change with your irrigation operation if you had more access to water?**

Given what we have done I don’t know if we would change anything. I am not convinced that we will see more water available in the future. Because of that we will continue to improve our WUE as best we can. We now understand what the value of water is in terms of net production on farm.

**What would change with your irrigation operation if you had less access to water?**

After implementing as many financially acceptable systems to maximise our WUE we would have to begin to “down scale” in terms of staff, infrastructure and production. If I knew what our average availability for the next 10 years would be we could set up our farm efficiently around that figure. It is important to consider the whole farming system when looking at less water.

Also, there is the bureaucratic mess that we must go through to implement some WUE measures. For example, we are trying to build an additional storage that will result in water savings through additional storage efficiencies but the bureaucracy involved believe this is just to capture more water. Water for which we already have an allocation limiting how much we can take. This system must improve.

**In general, where do you see the greatest gains in WUE being made?**

Better environmental management of water. The absolute highlight in this is the work done in the Macquarie Marshes by the Burrima Group. Their research showed that a 400% improvement in efficiency can be achieved by improved management resulting in healthier wetlands for less water.

Advances in WUE must happen at all levels including the farm, industry, local councils, and the environment. Politically if there is less water for irrigation then there will be less water for everyone. Everyone should have to look at WUE in the same way as the irrigator does and they should have to report on WUE. This includes industry, councils and the environment. There are significant further WUE gains to be made through water storage loss mitigation, as well as opportunities to transfer knowledge of successful WUE stories (Case Studies) to other industries.

In terms of improvements take the example of farm storages. Most farm storages have been built close to the river on prior streams, gravel, and other unsuitable soil types. There are huge potential gains to be made by looking at these losses.

All farmers need to understand the added productive benefits of WUE. I believe that WUE is not that hard. We need a program that takes this message to growers and grower groups to ‘gear up’ all farms to improve. This has to be a basin wide approach. I believe
the cotton industry leads the pack in WUE and others need to catch up. This also applies to local councils, sporting ovals etc.

What do you see as important areas of further research and development into WUE?

There is a lot of R & D going on in more than enough CRC's and RDC's. The thing they are mostly lacking is a delivery mechanism to create adoption and to get better WUE initiatives used on the ground. It is not an easy thing to do but it has to happen. Adoption and extension needs to have a higher priority and more focused form of delivery. The current network of state based agencies are just not delivering the message. It is an embarrassment to see how much good research is being produced and it is not getting on the farm. We also need to have research driven by those who need it on the ground not just by researchers.

It is also crucial that a component of ‘blue sky’ R&D is continued to help in the search for the next “step change” in WUE delivery to irrigation and water delivery systems

Conclusion

This case study shows a farm that has invested significantly in improving WUE and has a clear perception of what needs to happen in the future. Importantly, it highlights that low cost simple measures are currently available which can result in significant advances in WUE. This farm's consideration of WUE in a broad context raises several important points:

- WUE needs to be incorporated into all decisions on the farm. Maximizing the efficient use of water must be a priority in management. For example, changing traditional crop rotation methods to increase the chances of planting a crop into a full soil moisture profile.
- Improvements in WUE can significantly increase production. WUE efficiency is linked to other factors such as reductions in waterlogging effects and nitrogen use efficiency which in turn generate an additional crop response.
- WUE efficiency must be considered on a broad scale. Significant water savings can also be achieved through efficient water management by industry, local councils, and the environment. Water savings have to be managed, proven and reported by all including the environment.
- Uncertainty surrounding future access to water needs to be rectified to facilitate further and sustainable investment in WUE.
- The impact of policy on WUE must also be considered. For example, the on-farm losses resulting from bulk releases of water by State Water.
- Work must be done to bridge the gap between research and adoption. Good research is being done which is not being adopted or supported commercially at the ground level.
Photograph 11 - Case Study J
Case Study K: Lucerne Production (Peel Valley)

Farm Details

Case Study K is located in the Peel Valley producing Lucerne and oats.

The geographic location of the farm within the northern MDB is shown in Map 5.

The farm is 53ha in size with the entire farm developed for irrigation. The farm is separated into 4 fields allowing a 3 in, 1 out rotation. Each year 28ha of Lucerne and 12ha of oats is irrigated.

A groundwater license allows access to water through a well. All water is supplied to the field through 6” underground pipe. The farm has no on-farm storage or tailwater return system.

The predominant irrigation method is subsurface drip installed on 40 ha. The remaining 13ha can be irrigated using a big gun traveler. Since recent water restrictions were imposed limiting extraction to 25% of their allocation only the subsurface drip has been used for irrigation.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Changing predominant irrigation methods from hand shift sprinkler and big gun traveler to subsurface drip. (Design)
2. Redesigning of underground supply to improve delivery efficiency. (Design)
3. Calculating system efficiency as part of the DPI Water Management program “Haymaker”. (Planning / Investigation)
5. Conducting soil test across farm as part of DPI Water Management Plan. (Planning / Investigation)
6. Using capacitance probes to assist in irrigation scheduling. (Operational / Management)
7. Only irrigating using subsurface drip in times of restricted access to water to improve WUE. (Operational / Management)
8. Flow meters are installed on the well pump. (Monitoring)

Response to Interview Questions

Why did you decide to invest in the particular WUE measures?

Our infrastructure was worn out and this forced us to rethink our current practices. On a hot windy day the evaporation losses from the big gun traveler are clearly visible. Subsurface drip on the other hand is nearly 100% efficient.
Would you class the WUE measures implemented as successful?

Definitely successful. In addition to the WUE improvements there is also improved energy efficiency with the subsurface drip. The big gun required 50hp while the drip is powered by less than 15hp. There is also a labor saving associated with moving to drip.

What didn't work?

We had significant trouble with the White Fringed Weevil. This pest normally eats through the tap root of the plants but in this case also attacked the drip lines eating straight through it. We have had to replace the entire system with thicker walled drip lines. This has been at a considerable cost. The installation cost for subsurface drip was about $1500/ac while the repair cost is approximately $1000/ac. We are yet to repair the last 25% of the farm.

Are you more or less inclined to invest further in WUE on your property? Why?

Provided we have solved our insect problems we are aiming to be 100% subsurface drip. At this stage the bugs are the only problem in a great system. Fertilizer application through the drip has also been a great advantage for us. We have saved in fertilizer, fuel, and achieved increased production by applying fertilizer directly into the root zone.

What are you future plans for implementation of WUE on your property?

As discussed above we will be installing subsurface drip in the remaining 25% of the farm which is still irrigated using a big gun traveler.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?

Bugs.

Recent water restrictions have also affected our forward planning in terms of farm management. We are no longer able to irrigate when the plant wants. This is now dictated by when the water is made available. It is now not worthwhile using the capacitance probes for scheduling. This has affected us in terms of production. Previously we had increased our production by 25% and now we are practically dryland farming. Our production has dropped from 25,000 bales to 16,000 bales.

Has your understanding of WUE improved through the implementation of WUE measures on farm?

Yes. Subsurface drip has opened my eyes to WUE. Before we could see it was needed but couldn’t do anything about it.

What would change with your irrigation operation if you had more access to water?
There wouldn’t be any changes. We would continue with our current plans to install 100% subsurface drip. For us subsurface drip is the best measure available.

**What would change with your irrigation operation if you had less access to water?**

We would definitely have to get out of the big gun traveler. Any further shortages would lead to an early retirement.

**In general, where do you see the greatest gains in WUE being made?**

Big gains can be made in better farm management. Also, lucerne is giving us high returns at the moment.

**What do you see as important areas of further research and development into WUE?**

- Seed companies are improving lucerne varieties and this must continue.
- More work needs to go into investigating other associated factors such as the optimum soil types, and soil compaction associated with alternative irrigation methods. With tractor size increasing compaction is a big factor.
- Investigating water policy and restrictions area – by – area as opposed to approaching it in large zones.

**Conclusion**

This case study is a good example of the challenges facing small irrigation properties with reduced access to water. Lucerne is a 3 year crop taking 12 months to establish. The impact of a farms inability to provide adequate water to the plant can be long term. This case study shows the importance of WUE in maintaining farm productivity.

This farmers experience in installing subsurface drip show the substantial cost of potential problems. An informed decision making process is imperative when considering a capital purchase into alternative irrigation methods.
Case Study L: Cotton and Wheat Production (Namoi Valley)

Farm Details

Case Study L is located in the Namoi Valley producing cotton, and wheat.

The geographic location of the farm within the northern MDB is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 12.

The total farm size is 11,038 ha with 9,049 ha developed for irrigation. The farm has 14,500ML of on-farm storage capacity and accesses water primarily through a regulated general security river allocation. Groundwater and supplementary licenses are also held.

Cotton and wheat are the predominant irrigated crop. Approximately 4500 ha of irrigation is planted each year.

Precision furrow irrigation is the predominant irrigation practice, while 420 ha can be irrigated by a lateral move.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Upgrading key storages by splitting them into cells and increasing the bank height. This reduces the surface area and increases the delivery capacity on farm. (Design)
2. Replacing fields with efficient storages. Strategically located storages provides improved water management and reduced system losses. (Design)
3. Redesigning the farm tailwater return and drainage system to remove water from the field quickly. (Design)
4. Redesigning delivery systems to increase supply capacity. This allows a timely irrigations and every field to be irrigated independently of the rest of the farm. (Design, Operational Management)
5. Redesigning field headditches to improve capacity (head), uniformity, irrigation management. Check structures are installed along each headditch allowing the headditch to run at maximum capacity without blowing out. (Operational / Management)
6. Redesigning fields. Long fields have been split in half allowing more efficient irrigation practice. Wide fields have been split to allow more effective management. (Planning / Investigation)
7. Seepage and Evaporation losses have been measured in 2 of 7 storages by Irrimate evaluation. (Planning / Investigation)
8. Purchasing an Irrimate Seepage & Evaporation Meter to monitor losses in storages, channels and drains across the farm. (Monitoring)
9. Purchasing Irrimate In-field Equipment to monitor field irrigation efficiency and investigate potential irrigation options. (Monitoring)
10. Purchasing an EM 38 to investigate soil types across the farm. 100% of the farm has now been surveyed. (Planning / Investigation)

11. Conducting an assessment of irrigation system efficiency. A section of the farm was originally irrigated using ‘pipe through the bank’ methods. This system was assessed and determined to be inefficient in terms of water use efficiency. This system was replaced by a more water efficient, more labor intense siphon based irrigation. (Planning / Investigation)

12. Implementing a Land and Water Management Plan through completion of the Cotton BMP Land and Water Module. (Operational / Management)

13. Adopting a zero tolerance for weeds in all elements of the farm. (Operational / Management)

14. Irrigation scheduling using capacitance probes in every field. The location of the probes are determined based on EM survey, and yield mapping to determine a position most respective of the field (Operational / Management)

15. Strategically managing water in storages. Water can be transferred between all storages on the farm allowing improved WUE and water management. (Operational / Management)

16. Fields can be irrigated at any time and are not dependant on other farm elements. This allows irrigations to be timely and efficient. (Operational / Management)

17. Groundwater is only pumped into the two most efficient storages. (Operational / Management)

18. Surveying storages and installing accurate water level sensors to measure storage volumes. Storage volumes are recorded throughout the year. (Monitoring)

19. Mace meters have been installed in all river pumps, bores, and in 12 lift pumps. Most of Mace meters can be monitored remotely from the farm office via telemetry (Monitoring)

20. Lift pumps at 2 storages and all bores can be monitored and controlled remotely. (Operational / Management)

21. Designing a spreadsheet to calculate a whole farm water balance. This spreadsheet contains 15 years of farm records. (Monitoring)

Response to Interview Questions

Why did you decide to invest in the particular WUE measures?
To increase productivity. It represents a win-win. Not only can we save water but we are growing more yield with less costs.

Would you class the WUE measures implemented as successful?
Yes. Particularly the laterals and the field redesign. Those measures have given the best return on investment.

What didn’t work?
Flow monitoring hasn’t been as successful as other WUE measures. The investment hasn’t given us the same cost/benefits we have seen from other measures such as storage and system redesign, field redesign, laterals etc
Are you more or less inclined to invest further in WUE on your property? Why?

Definitely. Laser leveling has been conducted across all fields but no we will be isolating sections of the field that can be improved. We will also continue to look into more laterals.

We are inclined to invest further in WUE measures but it is dependant on getting some capital into the farm.

What are you future plans for implementation of WUE on your property?

As mentioned earlier, we will conduct site specific field design. Looking at specific sections of the field that can be improved. We will also continue looking at our storages to improve our water management structure.

Securing our long term water supply is important. We would rather use our continuous accounting to flatten our production and maintain it over 10 years than plant each year according to water availability. We have to do this to enable us to invest in WUE measures. We need to maintain production in every year to pay off the capital investment.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?

Yes. Drought. It has impact on us in a number of ways;
1. Not being able to plan ahead
2. Lack of rainfall
   Our biggest gain has always been our ability to utilize rainfall. The drought has increased our reliance on additional water sources
3. Delivery. We are now using bores as a primary source requiring us to store this water on farm.
4. State Water’s decision to deliver water through a “bulk release”. There has been no consideration of the additional farm losses this system creates.
5. Capital investment required to improve WUE. We need capital to keep implementing changes.
6. Adapting to new technologies takes time. This is challenging for all staff involved. Limited water can make this process more unforgiving.

Has your understanding of WUE improved through the implementation of WUE measures on farm?

Yes. Dramatically. Measuring more, monitoring more, and seeing where we can make improvements.

What would change with your irrigation operation if you had more access to water?

I will answer this in terms of more reliability. If access was more reliable we would invest further into infrastructure improvements.

What would change with your irrigation operation if you had less access to water?
If we had less water but could access the same amount each year we would invest to maintain production, and look at restructuring the business. We would need to spend capital to improve but at the same time reduce our capital overheads.

Our aim would be to maintain production with improved WUE. This would be dependent upon reliability.

*In general, where do you see the greatest gains in WUE being made?*

At the field management level. System and transmission losses represent a small component of total losses compared to the field losses of 4500 ha of irrigation.

*What do you see as an important areas of further research and development into WUE?*

Research needs to be applied at the field level. This also includes researching irrigation technologies, plant varieties, crop management etc. There is the opportunity to improve WUE and increase yield.

For example consider 100ML of water saved through increased field WUE compared to 100ML saved by reducing storage losses. The water from the storage could allow a further 20 ha of irrigation. The water saved through improved field WUE would allow a further 20 ha of irrigation AND increased yield across the farm. There has to be a production gain for us to stay ahead of cost.

**Conclusion**

This case study shows a farm that has already invested significantly in WUE and intends to continue this in the future. They realise the productivity gains resulting from any WUE measures adopted. Productivity gains are a key driver in continual investment in WUE.

It is possible to determine and locate water losses in farm elements, even to within sections of a field. This farm highlights the importance of determining field losses and the potential improvements that exists at the field level.

Importantly, this farm is an example of the impact that uncertainty in water allocations has on the ability to invest in WUE.
Photograph 12 – Case Study L
Case Study M: Cotton and Wheat Production (Macquarie Valley)

Farm Details

Case Study M is located in the Macquarie Valley producing cotton, wheat, canola, and chickpeas.

The location of the farm is shown in Map 5. An aerial photograph of the property showing the on-farm storage and surrounding fields is shown in Photograph 13.

The total farm size is 1,335 ha with 520 ha developed for irrigation. The farm has 3,400 ML of on-farm storage capacity and accesses water through a regulated general security river allocation with water delivered through a group scheme channel.

Cotton and wheat are the predominant irrigated crops. Approximately 230 ha of irrigation are planted each year.

Subsurface Drip is the predominant irrigation method with furrow irrigation used when water availability permits.

Water Use Efficiency Measures Implemented

Measures implemented to improve WUE include: (WUE Category)

1. Redesigning the main storage to allow it to be completely emptied. (Design)
2. Upgrading subsurface drip to improve performance. This includes changing from a 2m row spacing to 1m spacing. (Design)
3. Upgrading of the tailwater return system to reduce transmission losses, and improve field drainage. This includes installing culverts and dropboxes to reduce erosion. (Design)
4. Redesign of farm supply system allowing a shorter and more efficient main supply channel. (Design)
5. Clay lining a section of the main supply channel. (Design)
6. Redesign of headditches to increase supply capacity to allow optimal irrigation practices. (Design)
7. Estimating storage evaporation and seepage losses and accounting for losses in the farm water budget. (Operational/Management)
8. Using an EM survey and test pits in a ‘leaky’ storage to investigate amelioration options. (Planning/Investigation)
9. Implementing a strict weed control program. (Operational/Management)
10. Scheduling irrigation using capacitance probes. (Operational/Management)
11. Prioritizing water to the most efficient storage to minimize seepage and evaporation losses. (Operational/Management)
12. Aiming to only store water in the ‘borrow pit’ of the main storage to minimize losses. (Operational/Management)
13. Metering water purchased through the group scheme. (Monitoring)
14. Conducting a water budget throughout the season. (Monitoring)

Response to Interview Questions

Why did you decide to invest in the particular WUE measures?
When we purchased the farm it was rundown and unserviceable. We needed to upgrade it in order to produce high yielding crops. Obviously there has also been water savings associated with this.

Would you class the WUE measures implemented as successful?
The clay lining of the drip supply channel has certainly been successful. The subsurface drip has also yielded consistently high in previous seasons.

What didn’t work?
Leveling the base of the storage hasn’t been successful. We still have ‘dead water’ that we cannot access and will need to drop the level of the outlet.

Are you more or less inclined to invest further in WUE on your property? Why?
We are inclined to invest further provided there is water available. Until water is available we will not invest further on farm but will be focusing on improving efficiency of the scheme. The potential saving on-farm are insignificant compared to the potential water savings at the scheme level.

What are you future plans for implementation of WUE on your property?
We would like to develop more fields using subsurface drip. Drip really suits out soils and we have been achieving high yields. We would also upgrade our supply system and storages to improve their efficiency.

Is there anything that has occurred beyond your control that has limited or reduced your WUE on farm?
Yes. The group scheme. Recently there has been a lack of area planted each season on the scheme. Irrigating a small area using the scheme results in considerable losses through the scheme supply system.

Has your understanding of WUE improved through the implementation of WUE measures on farm?
Yes.

What would change with your irrigation operation if you had more access to water?
Firstly we would improve the scheme delivery system, secondly we would focus on our on farm delivery system, and thirdly we would look to install more subsurface drip.

*What would change with your irrigation operation if you had less access to water?*

We would still focus on improving the scheme system. We cannot afford to implement on farm changes with reduced access to water.

*In general, where do you see the greatest gains in WUE being made?*

For us the greatest gains are in improving the scheme delivery system, and developing high yielding cotton varieties.

*What do you see as important areas of further research and development into WUE?*

Improving varieties to return high yields.

**Conclusion**

Case Study M is typical of irrigated farming operations in the Macquarie Valley. It shows the need to consider WUE at several different levels. In this case, significant savings in water and labor have been achieved by installing, and repairing subsurface drip irrigation. Water budgeting had shown that savings can be achieved through improvements to infrastructure and since implementing these improvements noticeable water savings have been achieved. This case study highlights the potential inefficiencies in scheme management especially in years of low irrigation demand. Attention must be given to the potential saving that can be made at the scheme level.
Photograph 13 - Case Study M