

# TECHNICAL REVIEW OF IRRIGATED AGRICULTURE IN THE MACQUARIE & GWYDIR RIVER CATCHMENTS

Prepared for

**Department of Environment  
and Climate Change (NSW)**

June 2007

Prepared by



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# Table of Contents

<b>EXECUTIVE SUMMARY.....</b>	<b>VI</b>
<b>1 INTRODUCTION.....</b>	<b>1</b>
1.1 STUDY PURPOSE.....	1
1.2 APPROACH USED .....	1
1.3 STUDY AREAS .....	2
<b>2 IRRIGATED AGRICULTURE IN THE GWYDIR .....</b>	<b>4</b>
2.1 INTRODUCTION.....	4
2.2 WATER RESOURCES.....	4
<i>Surface Water</i> .....	4
<i>Groundwater</i> .....	6
2.3 THE WATER MARKET.....	6
<i>Entitlement Trading</i> .....	6
<i>Allocation Trading</i> .....	7
2.4 MAJOR INDUSTRIES .....	7
2.5 CLIMATE AND SOILS.....	8
2.6 COTTON PRODUCTION AND ZONES .....	9
<b>3 IRRIGATED AGRICULTURE IN THE MACQUARIE.....</b>	<b>10</b>
3.1 INTRODUCTION.....	10
3.2 WATER RESOURCES.....	10
<i>Surface Water – Macquarie and Cudgegong Regulated River Water Source</i> .....	10
<i>Groundwater</i> .....	12
3.3 THE WATER MARKET IN THE MACQUARIE .....	13
<i>Entitlement Trading</i> .....	13
<i>Allocation Trading</i> .....	13
3.4 MAJOR INDUSTRIES .....	14
<b>4 COTTON PRODUCTION.....</b>	<b>15</b>
4.1 THE COTTON INDUSTRY.....	15
4.2 SUSTAINABILITY ISSUES AND YIELDS .....	15
4.3 ENTERPRISE ALTERNATIVES .....	16
4.4 COTTON OUTLOOK.....	18
4.5 PRODUCTION AND EFFICIENCY.....	19
<i>Current Cotton Production Methods in the Gwydir and Macquarie</i> .....	19
4.6 SCOPE FOR ON-FARM EFFICIENCIES.....	20
<i>Possible On-farm Options for Improvement</i> .....	21
<i>Blue Sky Options for Improvement</i> .....	23
4.7 SUMMARY .....	24

<b>5</b>	<b>MAJOR ADJUSTMENT MECHANISMS.....</b>	<b>25</b>
5.1	OPTIONS FOR ADJUSTMENT.....	25
<b>6</b>	<b>FUTURE SCENARIOS.....</b>	<b>26</b>
6.1	INTRODUCTION.....	26
6.2	SCENARIOS.....	26
6.3	FUTURE IMPACTS.....	27
<b>7</b>	<b>REFERENCES.....</b>	<b>28</b>

## List of Tables

<i>Table 1: Licence Types and Number.....</i>	<i>5</i>
<i>Table 2: Gwydir Regulated River Available water determinations General Security.....</i>	<i>5</i>
<i>Table 3: Macquarie Licence Types and Numbers.....</i>	<i>11</i>
<i>Table 4: Macquarie Regulated River Available Water Determinations - General security.....</i>	<i>11</i>
<i>Table 5: Macquarie Regulated River Available Water Determinations - High Security.....</i>	<i>11</i>
<i>Table 6: Broadacre Income on Cotton Farms (2003-04).....</i>	<i>16</i>
<i>Table 7: Typical Broadacre Gross Margins (2006-07).....</i>	<i>17</i>
<i>Table 8: Summary of on-farm efficiency options.....</i>	<i>24</i>
<i>Table 9: Estimates of Volumes bought under Wetlands Recovery.....</i>	<i>26</i>

## List of Figures

<i>Figure 1: Gwydir Catchment</i> .....	2
<i>Figure 2: Location of Macquarie Catchment</i> .....	3
<i>Figure 3: Unit Shares of Gwydir Regulated River</i> .....	5
<i>Figure 4: Lower Gwydir Groundwater Source</i> .....	6
<i>Figure 5: Irrigated and Dryland Cotton Areas and Yield in the Gwydir</i> .....	7
<i>Figure 6: Zones within the Gwydir</i> .....	9
<i>Figure 7: Unit Shares of Macquarie Regulated River</i> .....	11
<i>Figure 8: The Lower Macquarie Groundwater Sources (LMGS)</i> .....	12
<i>Figure 9: Irrigated Cotton Areas and Yield in the Macquarie</i> .....	14
<i>Figure 10: Comparison of Typical Annual Crop Performance</i> .....	18
<i>Figure 11: Cotton Forecasts</i> .....	18
<i>Figure 12: Crop WUE (bales/ML) for subsurface drip (SDI), traditional furrow &amp; overhead (LMIMs)</i> .....	21

## Acronyms and abbreviations

CRDC	Cotton Research and Development Corporation
DECC	Department of Conservation and Climate Change
Ha	Hectares
IPART	Independent Pricing and Regulatory Tribunal
km	Kilometres
M	Million
ML	Megalitre
NSW DPI	NSW Department of Primary Industries
WUE	Water Use Efficiency

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## **EXECUTIVE SUMMARY**

### **Study Purpose**

The Department of Environment and Climate Change (DECC) wish to consider the possible future changes in irrigation enterprises, especially cotton, within the Macquarie and Gwydir.

The specific objectives of the project are:

1. to determine whether, and for how long, irrigated enterprises are likely to persist in their current locations, given current practices and technical constraints, particularly those that relate to the condition of their natural resource base;
2. to determine whether, and for how long, irrigated enterprises are likely to persist in their current locations, given their capacity to overcome these constraints through the adoption of improved technology and practices; and
3. to determine whether irrigated enterprises could expand into new areas within the catchments, given current technology and practices as well as improved technologies and practices.

### **Irrigated Cropping in the Gwydir and Macquarie Valleys**

Broadacre irrigation in the Gwydir and Macquarie valleys is dominated by cotton. This degree of dominance of cotton is extreme in the Gwydir Valley where almost 100% of the area under irrigation is devoted to cotton production.

To date there is little evidence to suggest that there will be significant change of long term cropping patterns in either valley. Change has occurred due to the drought and very low volumes available for irrigation. This reduction of availability is of a significantly larger order of magnitude than any buy-back program is planning.

There continues to be substantial investment undertaken by cotton companies in the areas and discussions with local agronomist suggest that irrigators will plant cotton if they believe that there is access to adequate water supplies.

The irrigated entitlement holders that are likely to initially participate in a buyback of water in the Gwydir and Macquarie Valleys are those that use water intermittently, opportunistically or not at all. The level of activation associated with trading and existing buy backs under the RiverBank process may have activated the entitlement volumes held by this type of licence holders.

## **Sustainability Threats**

Agronomists within the cotton industry identified water availability as the single largest threat to long term production levels.

Although climate change is uncertain, there are several key projections that have relevance to cotton producing regions:

- higher temperatures;
- potentially lower rainfall, although confidence levels are not high;
- in the Gwydir a potential increase in summer dominance of rainfall;
- a general increase in climate variability;
- higher atmospheric CO<sub>2</sub> levels;
- higher potential evaporation; and
- river flows may become more variable.

Climate change is considered a risk to the industry and may require increased water use efficiency. Increased variability may have the effect of ensuring that irrigators pursue cropping strategies that are based on annual cropping and maximising returns per megalitre (ML) each year by planting the crop with the highest returns given variable volumes available. Detailed investigation of climate change adaptation strategies would require detailed farm modelling.

At a farm level, there are few serious threats to the sustainability of cotton production. The main insect, *Helicoverpa*, is currently controlled through the release of genetically resistant Bollgard®, which has dramatically reduced insecticide use. Fusarium wilt is considered to be a future threat to the industry and much research is being directed towards developing resistant varieties. Salinity is not deemed to be a major concern in cotton growing areas; and is controlled by managing deep drainage and low irrigation intensities.

## **Changes Required for Significant Change**

There may be future competition from other crops. Although cotton offers the best returns per ML for irrigated crops options at present, future availability of water and changes in relative commodity prices may lead to the substitution of cotton for other crops. For example, the development of grain-based ethanol production in Australia combined with lower water requirements for sorghum may result in increased areas sown to sorghum at the expense of cotton. This type of shift is depends on many factors such as commodity prices, management expertise and infrastructure / equipment exchangeability. Equipment exchangeability between row cropping enterprises is high with the cotton picker the only specialised piece of machinery for cotton production.

It is unlikely that irrigated enterprises will expand into new areas within the catchment in the short to medium term. The establishment of any new irrigation areas has a significant capital costs at \$2,000 to \$3,500/ha (to develop a 400ha cotton farm). These vary with the amount of soil to be moved in landforming, size dam size requirements.

If there are significant reductions in water there are on-farm efficiency options within current irrigation configurations to achieve significant improvements in distribution and also application savings.

Examining system level savings within each valley is another water savings option. This has happened at a project scale, that is, on small infrastructure projects such as piping a channel for stock and domestic water. Larger adjustments over the medium to longer term may include some consolidation of irrigation to areas that are closer to the river. Changes could reduce system losses in open channels in these schemes.

The scarcity of water in the current drought, policy change on water trading out of joint supply schemes, and the availability of funds for infrastructure refurbishment and reconfiguration are likely to drive these changes in a strategic manner beyond open buy backs.



# 1 INTRODUCTION

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## 1.1 Study Purpose

The Department of Environment and Conservation wish to consider the possible future changes in irrigation enterprises, especially cotton, driven by currently-available but not yet implemented technology, or technologies that are reasonably likely to be available in the future within the Macquarie and Gwydir.

An understanding of these issues will provide insights into the adaptation to changes in water availability within the Macquarie and Gwydir river catchments.

The specific objectives of the project are:

1. to determine whether, and for how long, irrigated enterprises are likely to persist in their current locations, given current practices and technical constraints, particularly those that relate to the condition of their natural resource base;
2. to determine whether, and for how long, irrigated enterprises are likely to persist in their current locations, given their capacity to overcome these constraints through the adoption of improved technology and practices; and
3. to determine whether irrigated enterprises could expand into new areas within the catchments, given current technology and practices as well as improved technologies and practices.

## 1.2 Approach Used

The focus of this study was to:

- Review the irrigation sector in each Catchment;
- Identify possible adjustments to reduced water access;
- Review desktop studies of cotton water use efficiency and savings options; and
- Discuss possible adjustment in valleys with local agronomic experts.

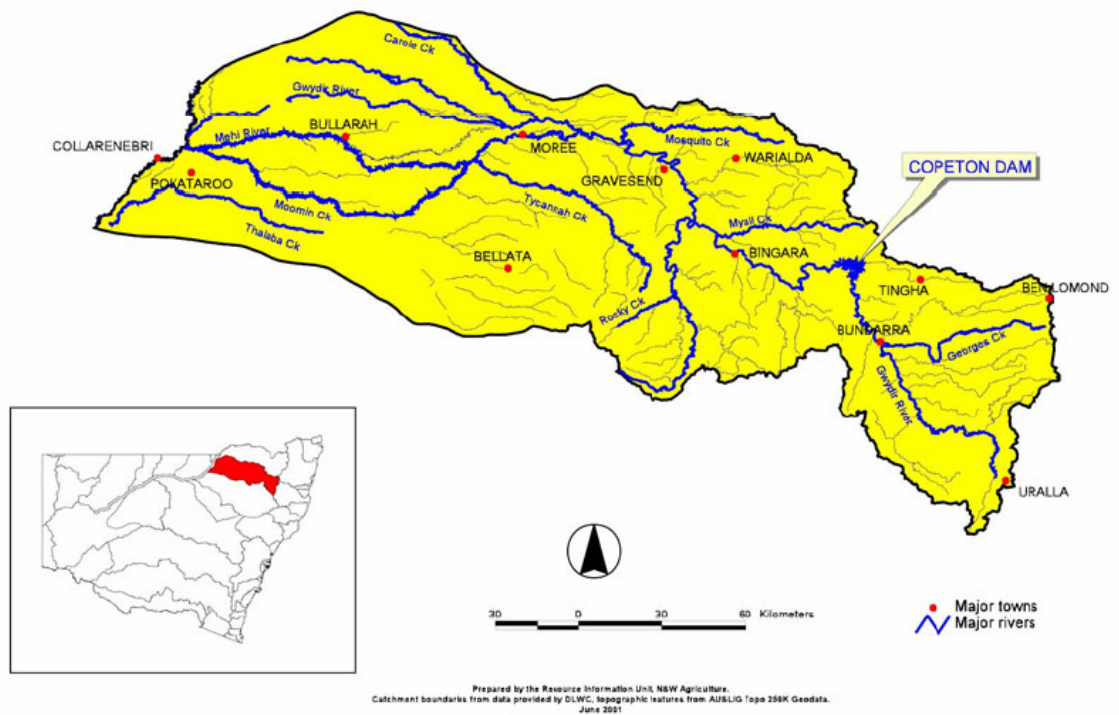
The study is primarily a desktop study involving review of the existing literature related to the Gwydir and Macquarie Valleys.

### 1.3 Study Areas

The two study areas are located in Northern NSW and are the subject of the report as there are significant wetlands in each catchment. The Gwydir catchment is shown in Figure 1 and the Macquarie in Figure 2.

Within the Gwydir cotton is grown downstream of Copeton Dam. Further detail is provided in Section 2.

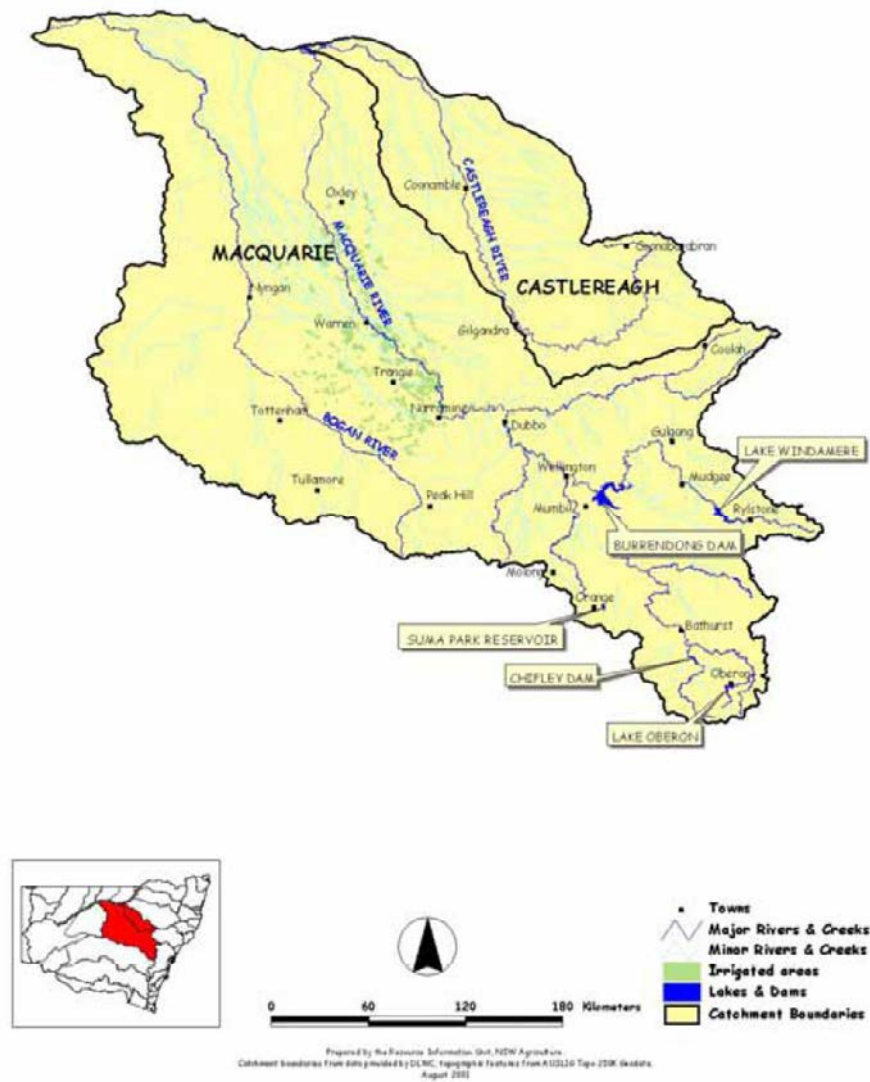
**Figure 1: Gwydir Catchment**



Source: Hope (2003a)

Within the Macquarie cotton is grown in the western parts of the catchment from Narromine to beyond Warren. Further detail is provided in Section 3.

**Figure 2: Location of Macquarie Catchment**



Source: Hope (2003b)

## 2 IRRIGATED AGRICULTURE IN THE GWYDIR

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### 2.1 Introduction

Dam sites planning and construction on the Gwydir River began in the 1960s. In 1967 the Copeton Dam Act was passed to authorise construction of a dam on the Gwydir River at a point about 30 km southwest of Inverell.

The first stage, completed in 1972, provided initial pondage of up to 110,000 ML. Stage 2, completed in 1973, provided storage capacity of 860,000 ML while the final stage involved the installation of gates and increased the capacity to 1.36 million ML. Yield from the dam is averaging about 340,000 ML per year and is distributed via the Meehi River and Moomin and Carole creeks, which depart from the Gwydir main stream near Moree. Regulation of the water is made possible by the Tareelaroï weir and regulator, Boolooroo, Combadello and Gundare weirs and the Mallowa Creek regulator.

Following construction of Copeton Dam, irrigation developed rapidly; rising from 1,500 ha in the early 1970s to over 60,000 ha by 1980. No new irrigation licences were issued after March 1979.

### 2.2 Water Resources

#### Surface Water

The Gwydir Water Sharing Plan (WSP) applies to waters between the banks of all rivers, from Copeton Dam downstream to the junction of the Gwydir River and its effluent rivers with the Barwon River.

#### *Stock and Domestic*

From the WSP the water requirements of holders of domestic and stock rights are estimated to be 6,000 ML/yr.

It is estimated that the share components of regulated river (high security) access licences authorised to extract water from this water source will total 19,293 unit shares.

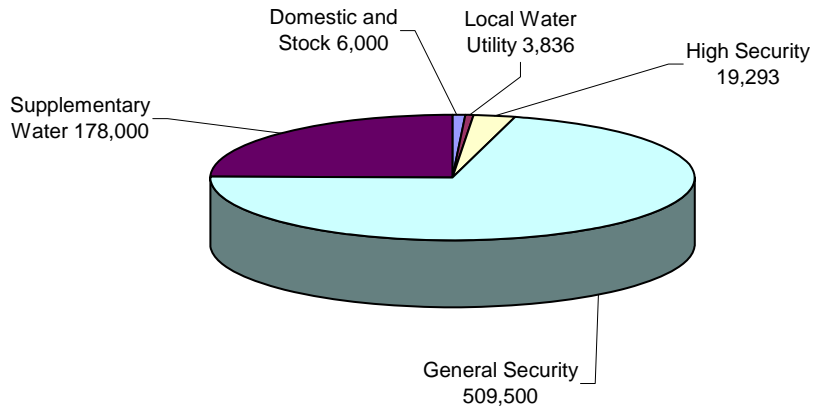
#### *General Security*

It is estimated that the share components of regulated river (general security) access licences authorised to extract water from this water source will total 509,500 unit shares.

It is estimated that the share components of supplementary water access licences authorised to access water from this water source will total 178,000 unit shares.

The Gwydir Integrated Quantity and Quality Model (IQQM) indicates a long-term average annual extraction volume of 392,000 ML. Figure 3 and Table 1 illustrates the unit shares on the Gwydir (DNR 2007).

**Figure 3: Unit Shares of Gwydir Regulated River**



**Table 1: Licence Types and Number**

Licence Type	Number
Domestic And Stock	98
Local Water Utility	4
Regulated River (General Security)	167
Regulated River (High Security)	13
Supplementary Water	162
<b>Total</b>	<b>444</b>

The Gwydir catchment has a continuous accounting system that was implemented in 1998. This system allows licensees with individual general security accounts to be credited with up to 150% of their allocation.

**Table 2: Gwydir Regulated River Available water determinations General Security**

Year	Allocation	Water Made Available (ML)	Water Used (ML)
2004/05	0.046	23,448	19,277
2005/06	0.219	111,488	123,470

Source: DNR (2007).

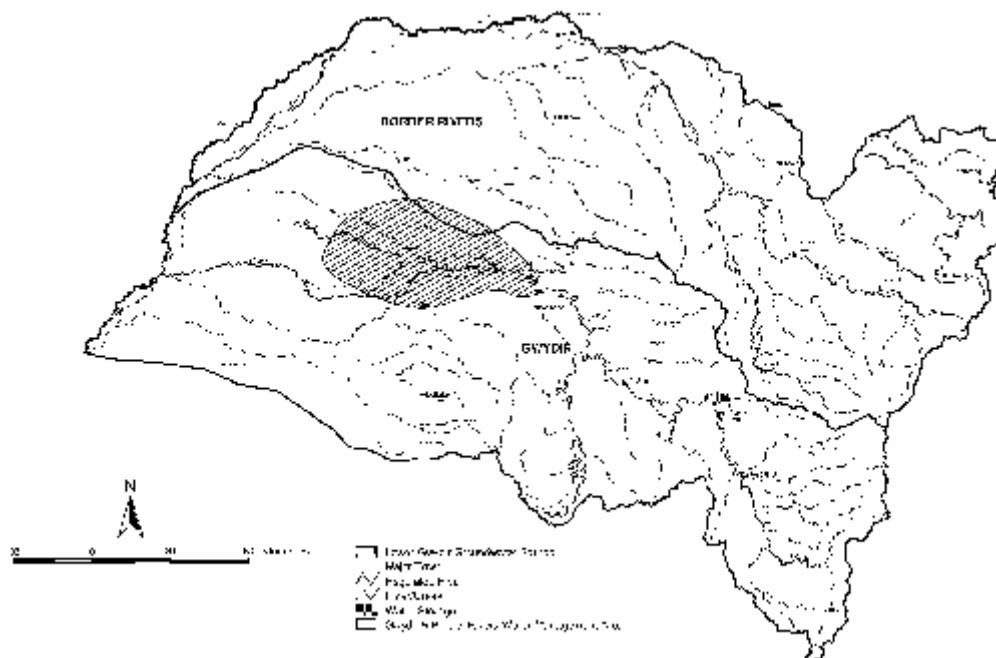
**Unregulated River**

The WSP for the Rocky Creek, Cobbadah, Upper Horton and Lower Horton Water Source has a water requirement of approximately 5,509 ML per year.

## Groundwater

The Lower Gwydir groundwater plans commenced on 1 October 2006. The extraction limit for this groundwater source is initially 32,300 ML/yr.

**Figure 4: Lower Gwydir Groundwater Source**



Source: Department of Natural Resources.

### 2.3 The Water Market Entitlement Trading

Historical entitlement trading in the Gwydir is thin and lumpy. The price paid for General Security entitlement has reportedly increased dramatically over the past decade, declining slightly since 2004. Moree Real Estate suggests that the price increased steadily from around \$1,000/ML in the late 1990's to a peak of \$3,000/ML in 2004 and has subsequently declined to around \$2,500.

On-line water trading information reports 4 permanent trades in 2005/06 - 2 for General Security and 2 for the related Supplementary Access entitlement. It indicates a price of \$2,500/ML of General Security. This corresponds to an estimated market value if the cost of capital is 9% and the expected long term annual return is around \$250 ML/yr.

Moree Real Estate has used hedonic pricing to value water licences shares separate to the value of land and improvements and found an implied value for General Security licence shares of approximately \$2,400/ML. There are very limited volumes of High Security entitlement on issue in the Gwydir and no reported market transactions.

## Allocation Trading

Information from the on-line trade information and the Waterexchange suggest a seasonal pattern in allocation prices consistent with a summer cropping regime.

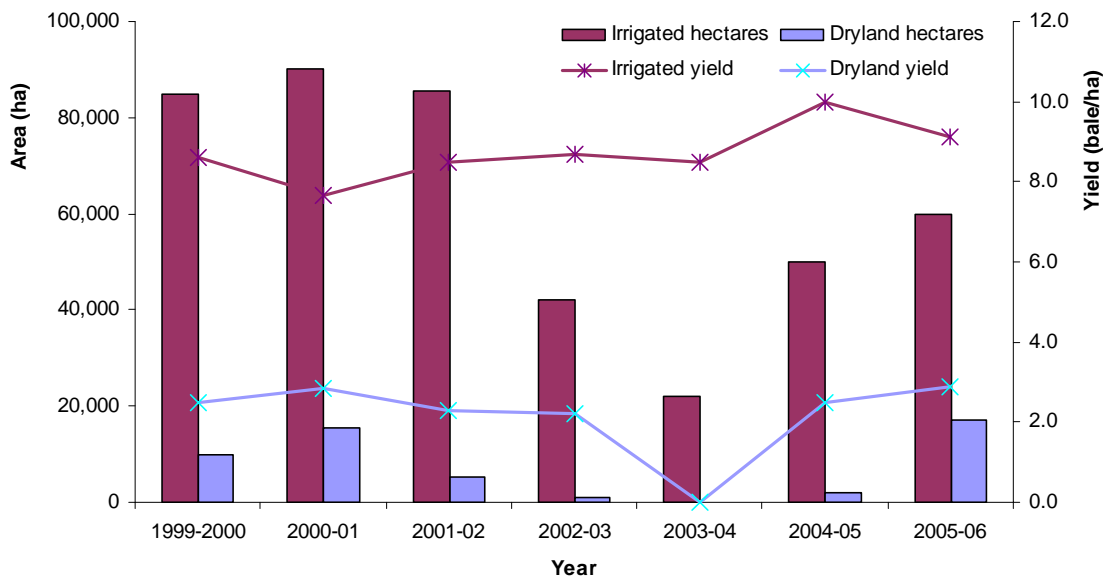
Moree Real Estate provided a price estimate for assignment/allocation of \$200-\$300/ML in the Gwydir for the 2005/06 season.

### 2.4 Major Industries

Irrigated agriculture covers just 1.7% of the area of the catchment but contributes 43.5% of the total agricultural production.

Industry figures suggest nearly 90,000 ha were irrigated between 1999/00 and 2001/02. This includes all sources of water (groundwater, regulated and unregulated supplies, farm dams and reticulated water supplies). This figure has dropped significantly during the drought.

**Figure 5: Irrigated and Dryland Cotton Areas and Yield in the Gwydir**



Source: CRDC (2006).

Cotton's degree of dominance is extreme in the Gwydir Valley where almost 100% of the area under irrigation is now devoted to production. Cotton is the major irrigated commodity in the catchment and irrigation water is mostly sourced from regulated surface supplies. The industry also utilises supplementary flows. Supplementary licences allow extraction during announced periods when flows exceed other obligations and environmental needs.

The Gwydir cotton industry has 173 growers and approximately 700 other employees on cotton farms. The area irrigated varies considerably depending on climate and access to water as shown in Figure 5.

Cotton growing returns are made up of two components: lint and seed. For every 227 kg bale of lint there is about 310-320 kg of seed worth maybe \$200/tonne. Assuming a yield of 9 bales/ha, and prices for lint and seed of \$400/bale and \$200/tonne respectively, the gross return would around \$3,600/ha.

## 2.5 Climate and Soils

The catchment receives more than 60% of its annual rainfall in the months November to March. A shorter wet spell can be experienced in June-July when a further 17% of the average annual rainfall is received.

The soils east of Moree are associated with sediments of recent alluvial origin and can be described in terms of terrace, levee and channel soils. A feature of these soils is their silty texture with the upper horizon characterised by a rough pedologic fabric. Exchangeable sodium levels are lower than in the grey clays west of Moree.

Salinity of soils in the lower Gwydir Valley is generally low and not likely to adversely affect plant growth. However there is some increase in salinity from east to west and the brown clays have higher levels of soluble salt than the grey clays. Due to the position of soluble salt in local soils, flushing is likely to move salts through the profile and minimise the prospect of salting under permanent irrigation. The irrigation soils of the Gwydir Valley have massive clay subsoils, suggestion varying degrees of deep percolation. As such, the soils are susceptible to waterlogging following prolonged rainfall or excessive irrigation. Appropriate design and management can avoid the latter.

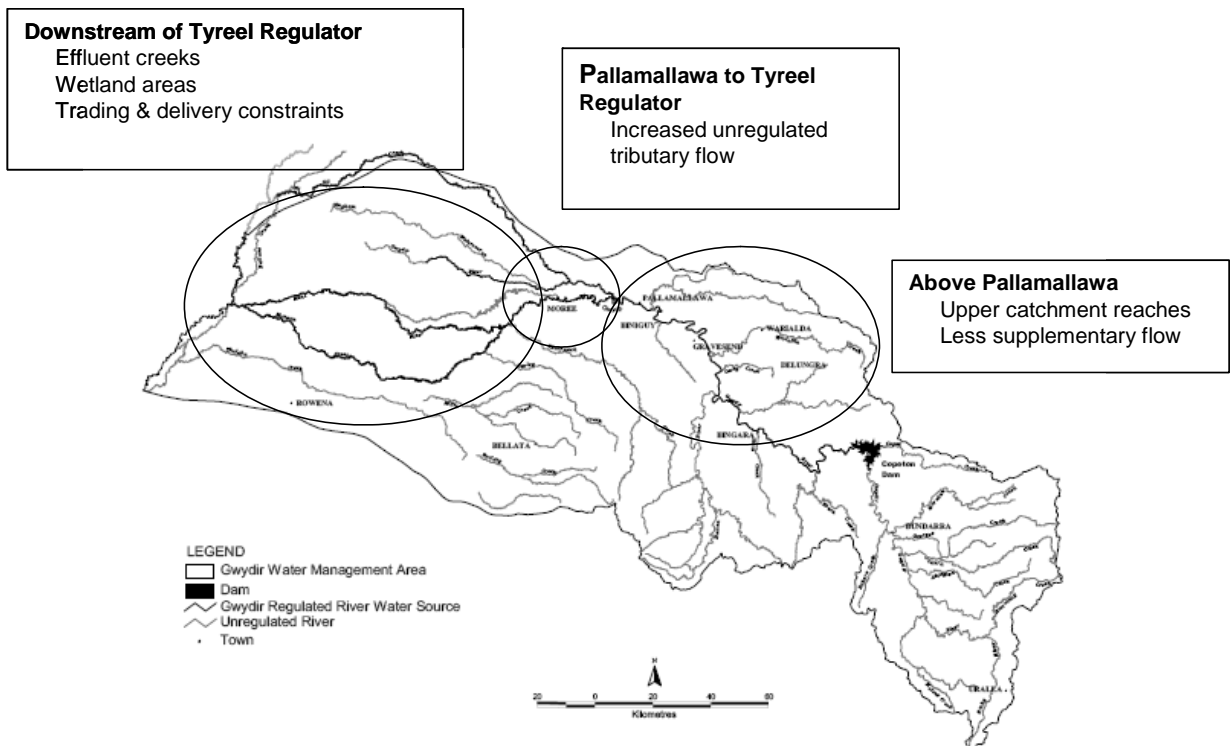


## 2.6 Cotton Production and Zones

There are three broad zones within the catchment that are used to discuss futures of irrigation (Figure 6). These are:

- above Pallamallawa which is in the upper catchment;
- Pallamallawa to Tyreel which has increased unregulated tributary flow; and
- downstream of the Tyreel Regulator which has wetland areas and many effluent creeks.

**Figure 6: Zones within the Gwydir**



Source: Base map from Gwydir WSP.

### 3 IRRIGATED AGRICULTURE IN THE MACQUARIE

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#### 3.1 Introduction

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.

Water released from the dams for irrigation is ponded by Dubbo, Narromine, Gin Gin, Warren and Marebone weirs and regulators and by Reddenville Break Block Dam. All weirs except Marebone Weir are fixed in height and do not regulate the river. These weirs raise the height of the river so that pumping can occur or so that water can be diverted into a channel for off-river irrigation. The weirs are also used to allow water to tributaries for stock and domestic and environmental flow management.

#### 3.2 Water Resources

##### Surface Water – Macquarie and Cudgegong Regulated River Water Source

The Macquarie and Cudgegong Water Sharing Plan applies water between the banks of all rivers from the upstream limit of Windamere Dam water storage downstream to the junctions of the Macquarie River and its effluent rivers with the Barwon River.

The water requirements of holders of stock and domestic rights are estimated to be 14,265 ML/yr.

**High Security** It is estimated that the share components of regulated river (high security) access licences authorised to extract water from this water source will total 19,419 unit shares.

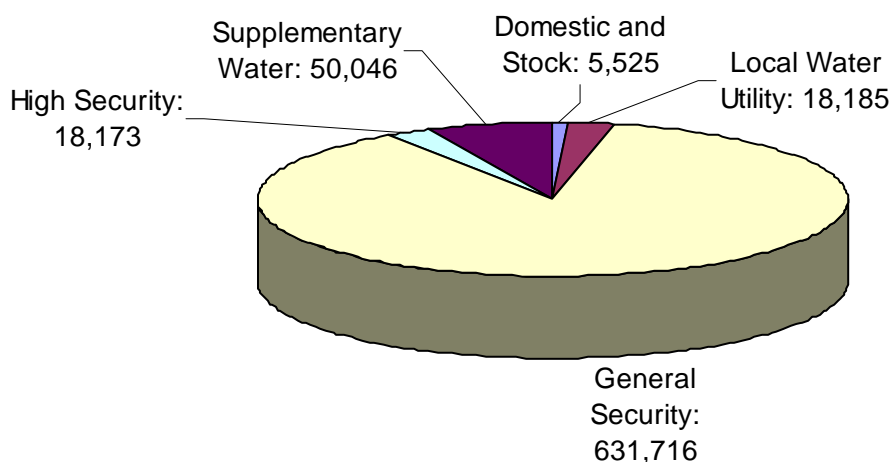
**General Security** It is estimated that the share components of regulated river (general security) access licences authorised to extract water from this water source will total 632,428 unit shares.

**Supplementary** It is estimated that the share components of supplementary water access licences authorised to access water from this water source will total 50,000 unit shares.

The Macquarie IQQM indicates a long-term average annual extraction volume of 391,900 ML.

Figure 7 and Table 3 provides a breakdown of the categories of unit shares in the Macquarie regulated river (DNR 2007). General security rights dominate the entitlement volume.

**Figure 7: Unit Shares of Macquarie Regulated River**



**Table 3: Macquarie Licence Types and Numbers**

Licence Type	Number
Domestic And Stock	293
Local Water Utility	9
Regulated River (General Security)	558
Regulated River (High Security)	71
Supplementary Water	550
<b>Total</b>	<b>1,481</b>

Table 4 and 5 illustrate the recent history of available water determinations in the Macquarie (DNR 2007). The long-term average annual extraction volume indicates a reliability of 50-55% for general security licence holders.

**Table 4: Macquarie Regulated River Available Water Determinations - General security**

Year	Allocation	Water Made Available (ML)	Water Used (ML)
2004/05	0.09	57,254	33,838
2005/06	0.44	276,442	143,567

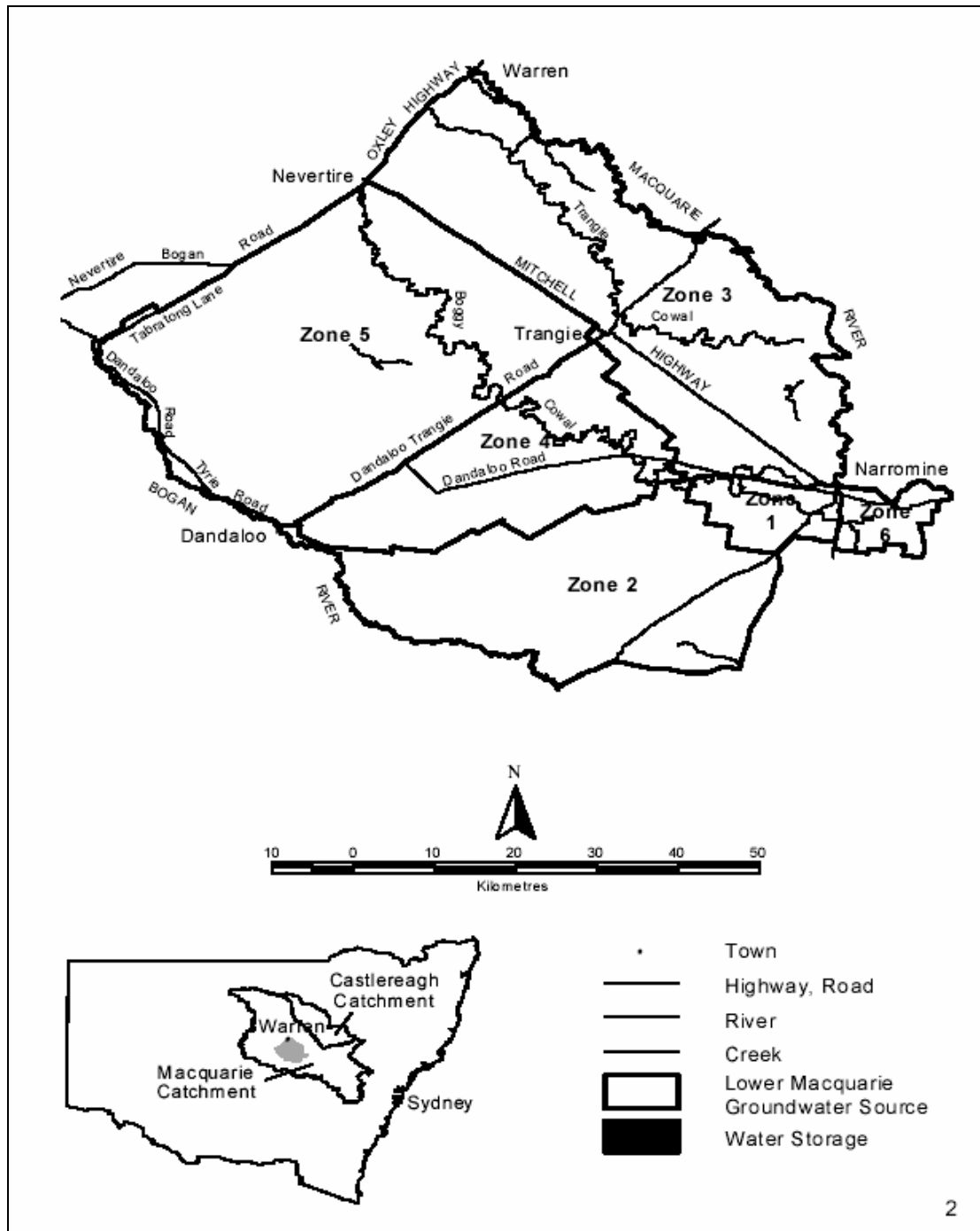
**Table 5: Macquarie Regulated River Available Water Determinations - High Security**

Year	Allocation	Water Made Available (ML)	Water Used (ML)
2004/05	1	13,828	10,039
2005/06	1	13,828	9,168

## Groundwater

Under the Lower Macquarie WSP, the share components of aquifer access licences authorised to extract water from these groundwater sources totalled 65,524 ML/yr, distributed across six zones.

**Figure 8: The Lower Macquarie Groundwater Sources (LMGS)**



Source: Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003.

### 3.3 The Water Market in the Macquarie

#### Entitlement Trading

The market for entitlement is thin. Records for the period July 2000 to February 2006 identify only 118 'permanent' trades of licences, for a total of 28.4 GL of general security shares and 667 ML of high security shares. These volumes represent turnover of less than 1% of issued entitlement in a year.

The price information provided indicates several trades at \$800/ML to \$820/ML between 1998 and 2000. The price subsequently fell to around \$600/ML in 2000 and was steady at that level until 2003, when it began to trend upwards, peaking at \$1,430/ML in early 2005.

The observed market values of \$1,300/ML to \$1,500/ML for General Security entitlement corresponds with imputed values based on a cost of capital of 8% to 9%, constant reliability of 50% and an expected long term average allocation price per ML of around \$150. The reliability is an important determinant of price and will vary between regulated water sources.

A recent, large volume entitlement transfer (over 14,000 ML) is reported on the Department website. It is likely to represent a corporate transfer between related parties.

#### Allocation Trading

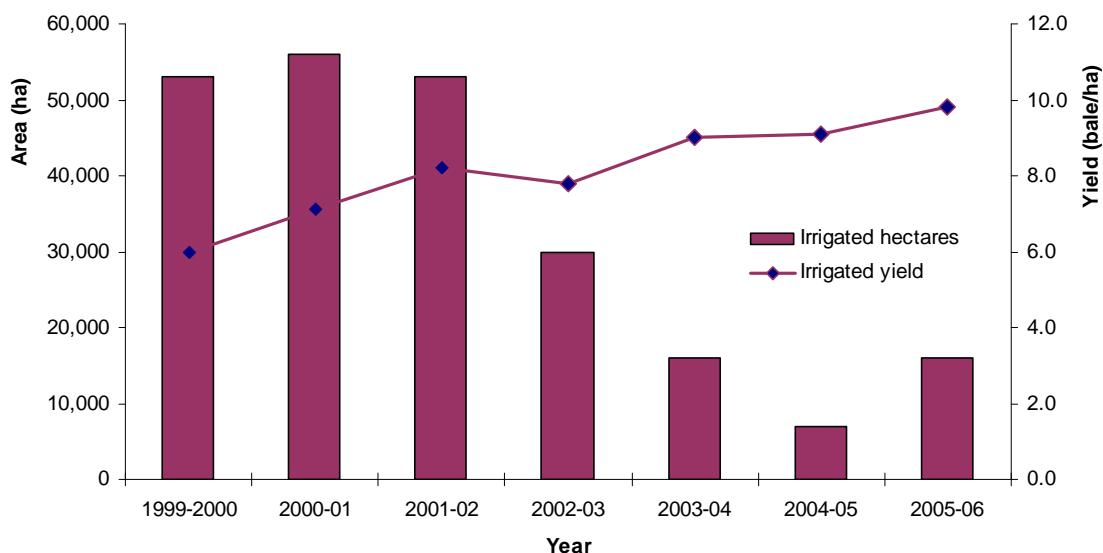
The market for general security and high security allocation is relatively active, and shows significant seasonal variation (volumes and number of trades) reflecting the timing of announced allocations and summer cropping demand. Prices tend to rise between June and January then fall away in the new year.

The Warren Secretariat suggested that the February 2006 price for assignment is around \$95/ML (consistent with other reported price sources), and that prices range from \$50/ML to \$150/ML depending on the season and the price of cotton.

### 3.4 Major Industries

In 1996–97, ABS figures suggest nearly 60,000 ha were irrigated each year from all sources of water (that is, groundwater, regulated and unregulated supplies, farm dams and reticulated water supplies).

**Figure 9: Irrigated Cotton Areas and Yield in the Macquarie**



Source: CRDC (2006)

Yields have been increasing over time. Possible reasons for this include an increased emphasis placed on management when facing limited water availability and also technology change in the industry.

Other summer crops grown in the Macquarie include Grain Sorghum, Maize, Mungbean, Sunflower and Soybean. The largest area devoted to these crops was Grain Sorghum in 2007 at 3,280 ha (NSW DPI)<sup>1</sup>.

<sup>1</sup> The areas covered include Dubbo, Mudgee, Orange, Warren and Wellington.

## 4 COTTON PRODUCTION

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### 4.1 The Cotton Industry

The irrigated cotton industry grew significantly during the 1980s and 1990s; however, recent seasonal conditions and commodity prices have combined to soften the momentum of that growth.

The capital and management intensity of efficient cotton irrigation favours the growth of large corporate entities. Large corporate agricultural entities undertaking significant irrigation activities include:

- Auscott, owned by J.G Boswell Company of California;
- Cubbie Station, privately owned and mooted to be listed in the near future;
- Clyde Agriculture Limited, a subsidiary of the UK based Swire Group;
- Twynam Agricultural Company owned by the Kahlbetzer family; and
- Tandou Ltd (TAN) publicly listed.

These have extensive exposure to irrigated cotton in western NSW, north-west NSW or south-west QLD. The largest 10 producers account for around 20% of the total cotton crop.

Declines in water use by the cotton industry since 2000 reflect drought conditions and reduced irrigation allocations. Cotton is an annual crop and capable of being grown opportunistically.

There are two major listed cotton ginners in Australia: QLD Cotton (QCH) and Namoi Cotton (NAM). Both have a narrow operational focus (ginning and marketing). QLD Cotton is the largest single cotton ginner in the world. It operates 8 gins in Australia with a capacity of 1.2 million bales. Namoi Cotton is a listed grower cooperative and has 12 gins with a total capacity of 1 million bales.

### 4.2 Sustainability Issues and Yields

Key sustainability issues include insect control, soil nutrient management and irrigation management. These issues are often linked to management skills and vary with soil types. There are often no discernable differences or trends when considering different sub-catchments within valleys.

Professionals within the cotton industry see water availability as the single largest threat to long term production levels. Climate change is considered a risk to the industry and may accelerate a move to increase water use efficiency. Although cotton offers the best returns at present, future availability of water and changes in relative commodity prices may lead to the substitution of cotton for other crops.

For example, the development of grain-based ethanol production in Australia combined with lower water requirements for sorghum (according to DPI gross margins) may result in increased areas sown to sorghum at the expense of cotton. This type of shift is dependant on many factors such as commodity prices, management expertise and infrastructure / equipment exchangeability.

Environmentally, there are few serious threats to the sustainability of cotton production. The main insect, *Helicoverpa* is controlled through genetically resistant Bollgard®, dramatically reducing insecticide use. Fusarium wilt (*Fusarium oxysporum*) is considered to be somewhat of a threat to the industry and much research is being directed towards developing resistant varieties. Salinity is not deemed to be a major concern in cotton growing areas; however, this may alter if excessive deep drainage continues to occur.

#### Water costs

NSW Agriculture estimates that water costs are approximately 6% of total variable costs per hectare for a cotton crop (NSW DPI 2006). A typical cost of \$128/ha if doubled would reduce gross margin by 14%.

The entitlement charges for the Macquarie regulated river to June 2007 are \$2.87/unit share and \$4.96/ML usage charge. For the Gwydir, it is \$2.95/ML for the general security entitlement and \$4.70/ML for usage (IPART 2006).

### 4.3 Enterprise Alternatives

Cotton is the dominant enterprise in both valleys. Grazing still occurs in this part of the catchment, particularly on land adjacent to wetlands. Cereal, pulse and oilseed cropping also occur. These may all be watered on a limited scale, especially cereals and chickpeas.

There are few irrigated cropping alternatives that generate the gross income associated with cotton. In 2003/04 the average gross value product from broadacre cotton farms was \$1.18 million from cotton and \$1.26 million for all irrigated enterprises (Table 6). It is interesting to note that dryland activities contribute more to farm revenue than other irrigated crops. This highlights the reliance on cotton for income from irrigated farms that produce cotton.

**Table 6: Broadacre Income on Cotton Farms (2003-04)**

	\$	% of GVIP	% of GVP
GVIP for Cotton Activity	1 183 653	94%	66%
GV Irrigated Production	1 264 716		70%
GVP	1 794 794		

Source: ABS (2006)

(a) Gross Value of Irrigated Production.

(b) Gross Value of Production.



Alternative crops in the Gwydir could include sorghum, sunflowers and some early or late watering of winter cereals. There are limited high security entitlement based operations. There is a significant pecan nut producer near Moree and some olives in the upper catchment. The limited amount of high security water and the reliability of general security mean that permanent plantings are unlikely to be attractive.

In the Macquarie the options are more diverse and more people are watering cereals such as wheat and, in years when prices are sufficient, canola. Chickpeas have also recently been irrigated.

Table 7 provides a comparison of the gross margins obtained from various summer crop options and also wheat. It should be remembered that water is only one input into the crop and the gross margin/ML obtained for wheat is relatively high as much of its water use is met by winter rainfall.

**Table 7: Typical Broadacre Gross Margins (2006-07)**

	<b>Income \$/ha</b>	<b>Water Costs (\$/ha)</b>	<b>Gross Margin (\$/ha)</b>	<b>Gross Margin (\$/ML)</b>
Cotton	\$3,241	\$55	\$1,041	\$149
Sunflowers (Surface Irrigated)	\$1,000	\$31	\$574	\$143
Maize (surface irrigated)	\$1,500	\$56	\$695	\$97
Grain Sorghum	\$1,000	\$30	\$327	\$86
Wheat	\$1,260	\$27	\$647	\$190

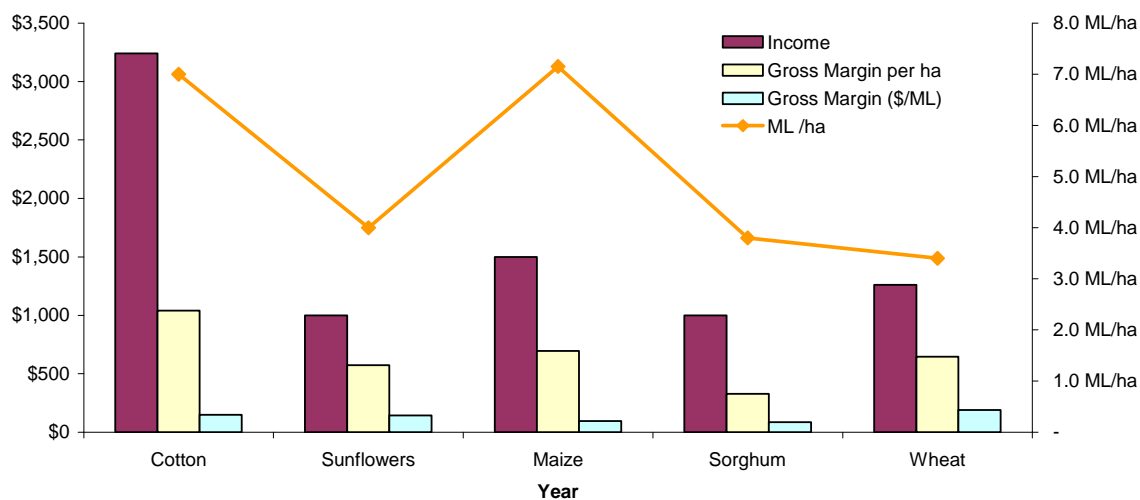
Source: Based on NSW DPI (2006). Water costs adjusted for Macquarie Valley regulated water charges and prices adjusted after discussions with Chris McCormack<sup>2</sup>.

Figure 10 provides an illustration of the income that can be obtained from a cotton crop. The gross margin is high per hectare and also comparable to other crops on a per ML basis.

However, a key difference between the summer crops is the current size of the markets for cotton compared to markets for sunflowers, maize and sorghum. In Australia in 2005/06 there were 98,000 tonnes of sunflowers produced and 380,000 tonnes of maize, with a combined value of approximately \$140 million. The gross value for cotton in 2005-06 was \$1.3 billion, and in 2000-01 it was close to \$2 billion. The number of farms growing cotton dropped to 250 in 2002-03, but increased again to 620 in 2004-05 (ABARE 2006).

<sup>2</sup> Agronomic Business Solutions P/L, June 2007.

**Figure 10: Comparison of Typical Annual Crop Performance**

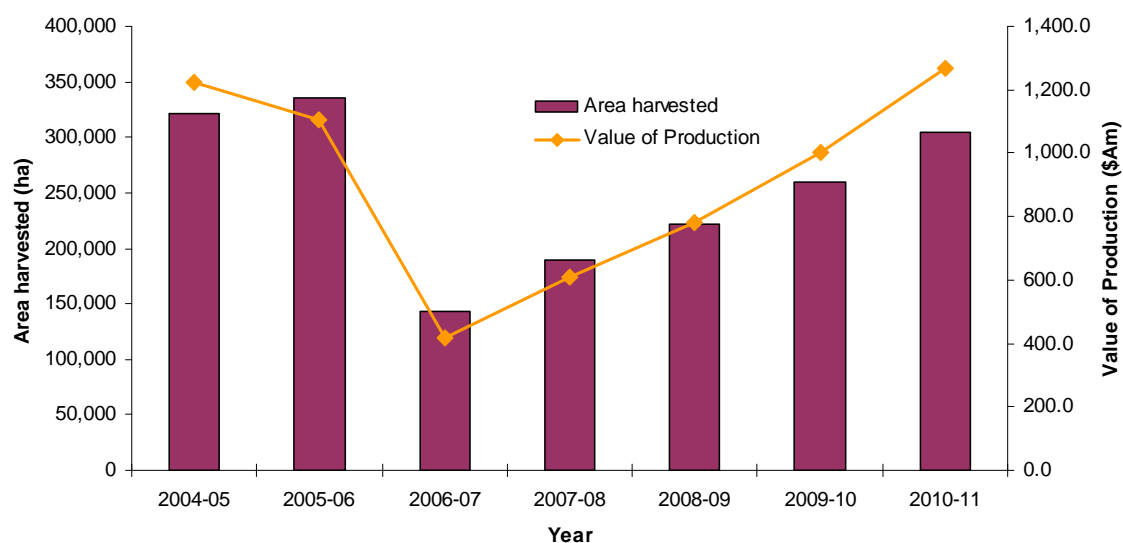


Source: NSW DPI 2006 and pers. comm. McCormack (2007).

#### 4.4 Cotton Outlook

ABARE expects growth in world cotton consumption in 2006-07 to exceed production, leading to a decline in stocks. Reflecting this, the Cotlook 'A' price index is forecast to increase by 5% in 2006-07 (2007). Australia's crop over the past twelve months has fallen to historically low levels. The area planted to cotton in 2006-07 is estimated to have fallen by 57% to 143 000 hectares — the smallest area planted since 1983-84. This is expected to increase to previous levels over the next 4 years (Figure 11). The estimates reflect a confidence that irrigators will continue to plant cotton if water is available.

**Figure 11: Cotton Forecasts**



Source: ABARE 2007.

#### 4.5 Production and Efficiency

Cotton was quickly adopted when it was recognised as a crop that could make large-scale irrigation viable in the Gwydir and Macquarie. This viability was based on a high response to applied water and complementary inputs, large export markets and relatively poor returns from the existing enterprises. Sheep and cattle enterprises and to a lesser extent wheat and sorghum, had less capacity to give a worthwhile return on investment in irrigation.

#### Current Cotton Production Methods in the Gwydir and Macquarie

##### **Cotton Production**

Cotton is a summer crop with the growing season (planting to picking) lasting approximately 6 months, extending from August/September to March/April. Before cotton can be sown, a range of activities are undertaken to prepare the seedbed and ensure conditions are favourable for germination.

This process begins with removing the existing cotton stubble which is root/cut/mulched in May/June. If compaction or hardpans exist the beds may be 'middle or side busted'. Following this, a cultivator reforms the beds and simultaneously applies Nitrogen (N) in the form of urea or gas. A knockdown (glyphosate) and possibly a pre-emergent (trifluralin) are applied prior to pre-irrigation. The practice of pre-irrigation is changing under low water availability conditions.

Planting occurs mid September once the soil temperature is warm enough for satisfactory germination (14°C at 10cm for 3 days) and is accompanied by herbicide and insecticide application. On-going monitoring for pests, soil moisture levels and weeds are conducted throughout the growing season. An inter-row cultivation is generally performed 1-2 months post planting, though this is also changing with Roundup Ready® technology.

The cotton receives a further 4 to 8 irrigations spread over the November to March period, generally occurring every 2-3 weeks. 10 insecticide applications are generally performed over the growing season with conventional varieties, while BT varieties such as BollgardII® may only require only 4 applications.

A defoliant is applied March-April May when approximately 60% of the bolls are open, promoting even maturity of the crop and aiding harvesting operations by reducing vegetative matter. The crop is picked shortly after the defoliate is applied when the majority of bolls have opened and fully matured.

##### **Irrigation Practice**

The Australian cotton industry is currently dominated by surface irrigation with producers using either every furrow or alternate (skip row) configurations (Raine & Foley 2002). Recent survey data supports this, indicating that 95% of cotton is irrigated via furrow irrigation with the balance comprising drip and sprinkler (ABS 2006). Cotton traditionally has been grown on 1 metre beds. However, alternative

options are being implemented depending on desired outcomes and local conditions. Narrow row or 4 rows per 2 m bed configurations are often used in the Macquarie (McCormak pers. comm. 2007)

Irrigator responsive to reduced water availability is tied directly to total water needs of the crop. These needs are first satisfied from rainfall, then from seasonal allocations, and finally by purchases of traded water. In the short run, cotton growers tend to reduce the area planted to cotton in years when they expect relatively low seasonal allocations.

The broad options open to a cotton irrigator are:

- leaving land fallow and demanding less water;
- applying less water to the crop and risking some yield loss;
- switching to less water demanding crops; and
- investing in more efficient irrigation techniques.

#### 4.6 Scope for On-farm efficiencies

##### *Water Use Efficiency*

Water Use Efficiency (WUE) is a term often used to express the effectiveness of irrigation water delivery and use. There are different definitions used when discussing WUE. In this discussions ML per hectare and also ML per unit of output are used

WUE in the industry has remained relatively stable over the last 10 years, with water consumption ranging from 0.8 to 1.2 ML/bale (mean of 1.04ML/bale). This corresponds to 8.1 ML/ha to 9.5 ML/ha, with a mean of 8.6 ML/ha (CRDC 2006).

Large variations exist between farms. For example, according to the CRDC producers in the top 20% bracket (based on operating profit) used 10 ML/ha and the bottom 20% consumed 14.9 ML/ha.

This range highlights the effect of management and the scope for improvement throughout the industry.

Although the top 20% of producers applied more water per hectare, they were more efficient per unit of output than the average (0.86 ML/bale vs. 0.9 ML/bale). The bottom 20% of producers in terms of profit used 1.41 ML/bale.

It is difficult to establish 'normal' WUE in the Gwydir and Macquarie irrigation valleys as the CRDC comparative analysis only separates these valleys for 2004 and 2005. Benchmark figures for 2004 indicate that WUE between the valleys are similar, with average consumption of 6.4 and 7.0 ML/ha for the Gwydir and Macquarie respectively. Gwydir irrigation water use may be lower on average as there is typically more in crop rainfall further north in the State.

## Possible On-farm Options for Improvement

### Improved cotton varieties

The cotton CRC is currently funding a CSIRO research trial that is comparing water use under BollgardII® and conventional cotton systems. Preliminary results indicate that BollgardII® varieties may be more water efficient than conventional varieties, using around 10% less water under full irrigation and producing higher yields (Roth, undated). The water use per hectare difference is debateable; however, higher yields will increase efficiency if measured as output per ML.

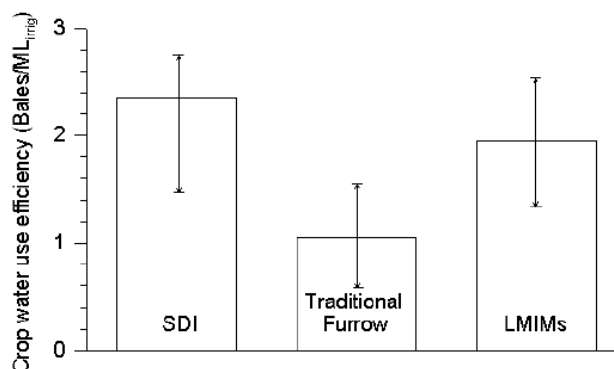
### Irrigation efficiency

There is scope for improvement in terms of WUE through improved irrigation management. A study conducted by Smith et al. (2005) revealed that surface irrigation application efficiencies range from 17 to 100% (mean 48%), with substantial losses to deep drainage (42.5mm per irrigation on average). This variation in efficiency between farms is supported in Figure 12. Significant improvements can be achieved through careful monitoring of soil moisture, increasing furrow flow rates and reduced irrigation times. Application efficiencies in the range of 85-95% are achievable, emphasising the potential for improvement.

### Irrigation methods

Although crop and water management is the most significant factor that determines WUE, further increases may also be obtained through method of irrigation. Grower survey data indicates that overhead and sub-surface drip irrigation can provide considerable increases in WUE (Figure 12). However, it is clear that a large range exists and therefore water savings between the different systems is largely influenced by management.

**Figure 12: Crop WUE (bales/ML) for subsurface drip (SDI), traditional furrow & overhead (LMIMs)**



Source: R Raine & Foley 2002.

Note: Cross bars represent highest and lowest values reported by growers.

The main impediment to adoption of overhead and subsurface drip irrigation is set up cost. Surface irrigated fields generally cost between \$500-\$1800/ha, while overhead and subsurface drip systems cost between \$1700-\$2500/ha and \$3500 - \$4500/ha respectively (Raine & Foley 2002). Recent installations have been over \$5,000/ha (McCormack pers comm. 2007).

**Surface  
irrigation  
configuration**

The cotton CRC, in collaboration with other research bodies, is currently funding research to determine the relative efficiency of furrow systems compared to siphon-less or bank-less systems. Results to date suggest that the furrow system is the most efficient, outperforming bank-less head ditch and bank-less channel systems on all indicators (Roth, undated).

Alternate furrow irrigation (also known as skip row or wide-spaced irrigation) is an option that producers are looking towards to conserve water and has been trialled in both cotton and soybean. However, no improvement has been observed on cracking clay soils (Fairweather et al. 2002). This practice is not common in the Macquarie.

**Infrastructure:  
Channel**

Increasing the distribution efficiency of on-farm channels is another area that can be addressed to improve overall WUE.

Meter inaccuracy has been identified as a contributor to system losses, accounting for up to 25% in open channel systems (Land and Water Australia 2003). This is addressed by installing more accurate meters. This gives farmers more information regarding the water flows onto the farm and hence has the potential to improve on-farm efficiency.

Seepage represents a further loss from the system. Data suggests that seepage losses can range between 1.5 -11mm/day depending on soil type (Fairweather et al. 2002). On a wider scale, seepage and evaporation losses from open channel systems in the Murray-Darling Basin are estimated to be around 5 and 10% respectively (Land & Water Australia 2003).

A survey based study conducted by Australian National Committee of Irrigation and Drainage (ANCID 2001) investigated a number of physical solutions to reduce channel seepage including:

- Earth liners (bentonites and other soil sealants)
- Hard surface liners (concrete, grouted fabric mats, flumes, pipes, tiles and bricks)
- Flexible membrane liners constructed from geo-synthetic clay, asphalt or plastic materials.

The study also examined groundwater intervention techniques such as:

- core trenches (vertical barriers designed to restrict flow into surrounding soil);
- groundwater pumping;
- vegetation (grown next to channels to manage the adverse impacts of seepage); and
- tile drains.

Unfortunately the study does not present quantitative measurements regarding the effectiveness of the various technologies.

**Infrastructure:  
Storage**

On-farm storages are an important part of an irrigation system and assist in countering the variability of water supply. However, large losses occur from on-farm storages via surface evaporation and seepage (Fairweather et al. 2002).

Water loss from on-farm storage via evaporation can be up to 40%, representing a significant loss from the system (Craig et al. 2005). The magnitude of this loss has turned the focus of current research towards developing methods to mitigate surface evaporation. Surface evaporation can be reduced in two ways:

1. Increase the depth of storage to reduce the surface area subject to evaporation; and/or
2. Application of a protective layer over the water surface.

Although increasing the depth of storage to reduce surface evaporation is effective, the economic costs and benefits are likely to greatly vary.

Despite current availability various technologies that reduce evaporation, few of these are used commercially due to expense and practical problems. Shade or plastic covers are suitable for dams up to 5ha and have been shown to reduce evaporation losses by 70-90% (Craig et al. 2005). However, such covers can cost between \$7-12 per square meter (Considine 2007).

A major research project funded by the Cotton Catchment Communities CRC is currently investigating the potential for chemical films known as 'monolayers' to reduce surface evaporation in dams greater than 5ha. Monolayers are cost effective however need to be re-applied and at best reduce evaporation by 10-40% (Considine 2007). At present a silicon based monolayer developed by Ultimate Agri Products is commercially available, costing around \$80/month to treat a 1 hectare dam (ECOS 2007).

Seepage loss from dams is essentially determined by hydraulic conductivity. Adding compacted clay layers will decrease hydraulic conductivity and in turn seepage losses from storages. This involves lining the storage with materials of high clay content followed by compaction (Fairweather et. al. 2002). Similarly, a dam may be lined with bentonite, naturally occurring clay or gypsum. A range of commercial flexible liners are available such as woven polythene, black polythene, pvc, HDPE and butyl rubber and bentonite based composite materials. Each method varies in its effectiveness and durability (Yiasoumi 2004).

### **Blue Sky Options for Improvement**

**Biotechnology**

Monsanto is currently applying to the Office of the Gene Technology Regulator (OGTR) for a licence to test water use efficiency traits in cotton. The main objective is to identify the gene(s) that improve cotton performance under water stressed conditions (Cotton Yearbook 2006).

## 4.7 Summary

Table 8 provides a summary of possible options to increase water use efficiency.

**Table 8: Summary of on-farm efficiency options**

<b>Option</b>	<b>Current</b>	<b>Potential Efficiency Gain</b>
Varietal improvement	Conventional /Bollgard.	A possible 10% increase in WUE via adoption of Bollgard varieties (Roth undated).
Surface irrigation efficiency	Application efficiency ranges from: <ul style="list-style-type: none"> <li>▪ 17 – 100%, with an average of 48% (Smith et al. 2005).</li> <li>▪ 35 -100% (Dalton et al. 2001, cited in Smith et al 2005).</li> </ul>	Application efficiencies between 85-95%. Achieved through: <ul style="list-style-type: none"> <li>▪ carefully adjusting flow rate and matching cut off with advance time; and</li> <li>▪ ensuring applications do not exceed soil water deficit via accurate measurements and monitoring (Smith et al. 2005).</li> </ul>
Irrigation method	95% of cotton is surface/furrow irrigated. Grower data indicates average crop WUE of around 1.1 bales/ML <sub>irrig</sub> , (Raine and Foley 2002).	<i>Overhead irrigation:</i> Average crop WUE of 1.9 bales/ML <sub>irrig</sub> (72% increase) - equates to a saving of 3.1ML <sub>irrig</sub> /ha. <i>Subsurface drip:</i> Average crop WUE of 2.4 bales/ML <sub>irrig</sub> (218% increase) - equates to a saving of 2.56ML <sub>irrig</sub> /ha (Raine and Foley 2002).
Channel: Seepage and evaporation	Loss estimated to be 5 and 10% respectively for open-channel systems (Land and Water Australia)	Various technologies exist to reduce conveyance losses included clay lining. No quantitative measurements provided of the effectiveness of technologies (ANCID 2001).
Channel: Meter inaccuracy	Mis-measurements may be approximately 25%.	Not known – depends on changes to irrigation management as a result of more accurate information.
Storage	Evaporation loss of around 40% (Craig et al. 2005).	Covers / shades: Reduction in evaporation loss between 70-90% (Craig et al. 2005). Monolayers: 10-40% reduction in evaporation (Considine 2007). Reconfiguration and reducing surface area is most common approach.

There are many options available for increasing the water use efficiency of cotton irrigation and summer crop irrigation in general. The adoption of these will depend on the financial implications. These may change with reduced volumes, changes in commodity prices and the change in the cost of technology. Any full investigation of the likelihood of adoption will require modelling.

There would have to be significant change in water access or costs to see widespread adoption of on-farm overhead irrigation systems. Efforts are more likely to target improved management of current systems and review of storage configurations to increase depth.



## 5 MAJOR ADJUSTMENT MECHANISMS

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### 5.1 Options for Adjustment

Any change in water availability will generally:

- change the total volume of water available for irrigation;
- affect the time when diversions can occur; and/or
- change water access for individual irrigators (even where total diversions are not reduced).

Other studies of impacts of reduced water allocations have generally estimated the reduction in total gross margin. For example ACIL estimated a reduction in gross margin of 1.2% which was significantly less than the proportionate fall in water use of around 6%. This is due to assumptions that enterprises with the lowest opportunity costs are cut to reduce water usage. This type of assumption has more validity in the southern irrigated regions of NSW.

Some irrigators may be able to substitute water from other sources, including:

- storing surface water runoff from rainfall and irrigation run-off in farm dams; and
- pumping groundwater.

Long run responses involve evaluating a series of investment options to enhance yield per ML. These could include:

- irrigation configurations;
- adoption of new varieties; and
- precision application of fertilisers.

If significant amounts of infrastructure are required to switch to other crops, this lack of flexibility could lead to less elastic demand for water. Some farming systems require 'lumpy' capital infrastructure.

The reliability of supply of water is an important constraint in determining what activities an irrigator can choose. This is likely to decrease in both systems over time possibly reducing the ability for any change to systems which do not provide flexibility.

In the short run the best options for farms that face significant reduction in water availability are:

- reduce cotton area;
- increase winter cropping;
- if a small volume, trade remaining allocation to other irrigators;
- match crops to soil types to reduce irrigation per ha; and
- invest in improvements in on-farm and, in some cases, delivery infrastructure.

## 6 FUTURE SCENARIOS

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### 6.1 Introduction

The future scenarios on water entitlement purchases have been based on numbers provided by DECC.

### 6.2 Scenarios

Table 9 shows the estimated water volume associates with the Wetlands Recovery Volumes. These are relatively small amounts of allocation or entitlement. It can be safely said that these impacts would not be felt by irrigators.

**Table 9: Estimates of Volumes bought under Wetlands Recovery**

<i>Catchment</i>	<i>Budget</i>	<i>Price</i>	<i>General Security</i>	<i>Total</i>	<i>Percentage</i>
Gwydir	\$5,000,000	\$2,500	2,000 ML	509,816 ML	0.4%
Macquarie	\$8,000,000	\$1,500	5,333 ML	631,716 ML	0.8%

#### ***Type of water purchase***

Specific market instruments that could be used by governments to source water include bilateral negotiation; government standing in the water market; competitive tender; auction-based tendering; and compulsory tender.

These may have different effects on sellers. It should be noted that the Gwydir is a relatively mature market and there has been active trading in the recent past. It is reasonable to expect that there is little inactive water available. There may be some excess entitlement on some holdings but the recent drought has highlighted the value of water to holders and it is probable that holders have traded water at least on a temporary basis.

The processes used to source water for the environment will have different impacts on industry. A general buy back is unlikely to have specific impacts within a sub-catchment unless there are few irrigators operating there and there are significant existing issues affecting system delivery efficiency, such as long channel lengths to farm gate.

### 6.3 Future Impacts

#### ***Broadacre irrigation will remain***

There may be future competition from other crops. Although cotton offers the best returns per ML at present for fully irrigated crops, future availability of water and changes in relative commodity prices may lead to the substitution of cotton for other crops. The recent the drought has exposed many irrigators to other cropping options at a time of low water availability and high prices for feed grains.

The development of grain-based ethanol production in Australia combined with lower per hectare water requirements may result in increased areas sown to sorghum or corn at the expense of cotton. This type of shift depends on many factors such as commodity prices, management expertise and infrastructure / equipment exchangeability.

#### ***New areas are unlikely***

It is unlikely that irrigated enterprises will expand into new areas within the catchment in the short to medium term. The establishment of any new irrigation areas has significant capital costs at \$3,000 to \$3,500/ha (to develop a 400ha cotton farm). These vary with the amount of soil to be moved in landforming and required dam size. If there are significant reductions in water use, efficiency improvements are possible using currently available technology and practices.

#### ***Consolidation to reduce system losses***

Over the medium to longer term, there may be a consolidation of irrigation to areas that are closer to rivers to reduce system losses in open channels. The scarcity of water in the current drought, policy change on water trading out of joint supply schemes and potential funds available for infrastructure refurbishment and reconfiguration are likely to drive these changes.

Beyond the initial volume targets of buy-back schemes currently being implemented, significant adjustments should take account of impacts and effects on the overall system delivery efficiency. This will require understanding of the system, collaboration with entities responsible for delivery, investors in infrastructure and staged planning in conjunction with the community. The current buy backs will provide crucial information regarding future adjustment.

## 7 REFERENCES

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- ABS (2006) Characteristics of Australia's Irrigated Farms 2000-01 to 2003-04.
- ANCID (2001) Open channel seepage and control: Current knowledge of Earthen Channel Remediation in the Rural Water Industry, volume 2.2, Australian National Committee on Irrigation and Drainage.
- Considine, ML (2007) 'Putting a thin lid on evaporation losses', ECOS 2007.
- Craig, I, Schmidt, E, Green, A & Scobie, M (2005) 'Controlling evaporation from on-farm storages', Proceedings from the Irrigation Association of Australia (IIA) 2005 Conference, Townsville, May 18-20.
- CRDC (2006) Australian Cotton Comparative Analysis: 2005 Crop, Cotton Research and Development Corporation 2006.
- CRDC (2005) Australian Cotton Comparative Analysis: 2004 Crop, Cotton Research and Development Corporation 2005.
- CRDC (2004) Australian Cotton Comparative Analysis: 2003 Crop, Cotton Research and Development Corporation 2004.
- CRDC (2003) Australian Cotton Comparative Analysis: 2002 Crop, Cotton Research and Development Corporation 2003.
- Centre for Water Policy Research (undated) Cost Benefit Analysis of Alternative Water Allocation Arrangements in the Gwydir Valley of NSW
- IPART (2006) Bulk Water Prices for the State Water Corporation and Water Administration Ministerial Corporation.
- NSW DNR (2007) website accessed:  
[www.wma.dnr.nsw.gov.au/wma/DeterminationSearch.jsp?selectedRegister=Determination](http://www.wma.dnr.nsw.gov.au/wma/DeterminationSearch.jsp?selectedRegister=Determination)
- NSW DPI (2006) Surface Irrigated Cotton Farm Enterprise Budgets – Northern Zone.
- NSW DPI (2006) Various Enterprise Budgets.
- NSW DPI (2007) The NSW Grains Report.
- Productivity Commission (2004) Responsiveness of Demand for Irrigation Water: A Focus on the Southern Murray-Darling Basin.
- Fairweather, H, Austin, N & Hope, M (2002) Water Use Efficiency: An information package, Irrigation insights number 5, Land and Water Australia.

Hope (2003) Gwydir Catchment Irrigation Profile. Water use advisory Unit, NSW Agriculture.

Raine, SR & Foley, JP (2002) 'Comparing application systems for cotton irrigation – What are the pros and cons?' Field to fashion, 11<sup>th</sup> Australian Cotton Conference, 13-15<sup>th</sup> August, Australian Cotton Growers Research Association Inc. Brisbane (Invited paper).

Roth, G (undated) 'Towards sustainable and profitable water use in the Australian cotton industry', Cotton Catchment Communities CRC.

The Australian Cottongrower (2006) 'Looking down the biotech pipeline', in Cotton Yearbook 2006, The Australian Cottongrower 2006, vol 26, No.5.

Yiasoumi, B (2004) 'Leaking farm dams', Agfact AC.24, second edition, 2004.