Water use efficiency in irrigated agriculture

An Australian Perspective
AWP Knowledge Framework

The Australian Water Partnership is committed to enhancing sharing of knowledge and tools for sustainable water management to improve water planning, allocation and governance by governments, industries and civil society. This knowledge product supports the AWP Knowledge Strategy and contributes to the Australian Perspective Series under the Australian Bookcase. The other tiers within this bookcase are the Australian Journey Series and Guide Series. For more information, visit waterpartnership.org.au

About the Authors

RMCG is a 30 year old Australian environmental and agricultural consulting business. It provides policy, planning and technical consulting services to ensure a healthy future for the environment, industry and communities. RMCG’s experience is based around a solid understanding of agriculture, water supply, the environment, communities and industry, which comes from working with farming families, community groups, water agencies/local government and individual businesses. RMCG has played an active role in water supply and management changes which have occurred within the Murray-Darling Basin over the last twenty years. RMCG has over 50 consultants and for this project utilised five of its most experienced water specialists – Rob Rendell, Matthew Toulmin, Charles Thompson, George Warne, and Anne-Maree Boland – who have worked in the Australian irrigation water industry for 30–45 years each.

RMCG also coordinated a number of other Australian water experts in preparing this document: Campbell Fitzpatrick and David Harriss have worked for Victorian and New South Wales Government (respectively) water policy and management organisations for over 35 years and are recognised as Australia’s leading experts in that field. Clive Lyle, Tim Cummins and Geoff McLeod are all independent technical specialists working mostly at the field and regional level with over 30 years’ experience in irrigation water management. Greg Holland (Jacobs, now with RMCG) is a groundwater specialist with 30 years’ experience in developing groundwater management plans and understanding associated irrigation practices. Murray Smith, Alisa Willis and Jeff Parish have 20–40 years’ experience in regional water management agencies delivering water to farmers – Smith has been involved in the biggest canal modernisation and infrastructure water use projects in Australia (Colleambally and Goulburn Murray Irrigation districts); Willis and Parish have worked extensively in the modernisation of pipeline delivery systems to horticulture on the Murray River. Liz Mann, John Lacy and Evan Christen are field-based technical experts in agronomic practices associated with irrigation farming – Mann has experience in broad acre crops using drip irrigation for tomatoes and maize; Lacy is Australia’s best known expert in the rice industry; and Christen has worked throughout Asia and Africa on practical farm irrigation practices. Phil Price (Price Merritt and Associates) is a leading irrigation designer along the Murray River regions.

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An Australian Perspective
# Table of Contents

Preface viii  

1 Context 1  
1.1 Four Australian themes on water use efficiency 1  
1.2 Framework 1  
1.3 Structure of this Guide 4  
1.4 Definitions of water use efficiency 5  
1.5 The approach of these guidelines to water use efficiency 8  
1.6 Drivers of water use efficiency initiatives 8  
1.7 Other critical factors 12  
1.8 Return-flows 14  

2 Water law and governance 17  
2.1 Policy and legal framework 17  
2.2 Promoting water use efficiency 18  
2.3 The role of water law 19  
2.4 Institutional arrangements 19  
2.5 Full cost recovery 20  
2.6 Water law 20  
2.7 Bulk water allocation framework 21  
2.8 Developing water markets in water entitlements and water allocations 21  

3 Water resources planning and management 25  
3.1 WaterGuide 25  
3.2 Basin planning 26  
3.3 Components of a basin plan 27  
3.4 Environmental rights and entitlements 28  
3.5 Water accounting 28  

4 Delivery systems 31  
4.1 Level of service 31  
4.2 Canal delivery systems 33  
4.3 Piped systems 39  
4.4 Efficient use of groundwater 44
5 Farm irrigation and drainage systems
  5.1 Surface irrigation systems
  5.2 Contour bays to bankless channel checks
  5.3 Sprinkler Irrigation Systems
  5.4 Centre Pivot and Linear Move systems (CPLM)
  5.5 Drainage
  5.6 Irrigation scheduling

6 Case studies
  6.1 Water scarcity and water trading
  6.2 Sunraysia drainage flows – from 300mm/ha to <50mm/ha
  6.3 Murray Irrigation and delivery efficiency – from 50–60% to 85–90%
  6.4 Coleambally Irrigation delivery efficiency – from 70% to 90%
  6.5 Drivers of water use efficiency in South Australia
  6.6 Rice and water use efficiency – from 0.4t/ML to 1.0t/ML
  6.7 Centre pivot irrigation for dairy
  6.8 Processing tomato productivity – from 2.5t/ML to 17t/ML
  6.9 Simple practical applications of water use efficiency

References

Tables

| Table 1   | Irrigation sector – pillars and building blocks | 2 |
| Table 2   | Techniques used for irrigation scheduling      | 59 |
| Table 3   | Total area under irrigation (ha)               | 68 |
| Table 4   | Average area under irrigation (ha)             | 68 |
| Table 5   | Sunraysia crop variety (ha)                    | 68 |
| Table 6   | Irrigation systems in Sunraysia over time      | 71 |

Figures

| Figure 1  | Water use efficiency indices for engineering approaches | 15 |
| Figure 2  | Water use efficiency indices for production approaches | 16 |
| Figure 3  | Consistent objectives and elements of water reform in Australia | 18 |
| Figure 4  | Six elements of WaterGuide                          | 25 |
| Figure 5  | Typical efficiency losses through an irrigation system | 35 |
Figure 6  Stages of groundwater resource development in a major aquifer and their corresponding management needs 46
Figure 7  Irrigation Essentials framework 57
Figure 8  Dethridge wheel supplying and measuring water to a farm channel 62
Figure 9  Southern connected Murray-Darling Basin trading zones 63
Figure 10  Rice area and price indicator, Australia, 1988–89 to 2015–16 64
Figure 11  Water use by sector over time – Southern Connected Basin, key products only 65
Figure 12  Water use between sectors by climate scenario – Southern Connected Basin 66
Figure 13  Control of perched water table by subsurface drainage 69
Figure 14  Drip irrigation has largely replaced furrow irrigation 70
Figure 15  Dethridge wheel 74
Figure 16  Flood irrigation through contour layouts 74
Figure 17  Evaporation basin for the Wakool Tullakool Sub-surface Drainage Scheme; Rising saline water tables in WA 75
Figure 18  Water regulators fitted with ‘Drop-board’ control systems 76
Figure 19  Centre pivot irrigator 79
Figure 20  Laser levelling using laser controlled level adjustment 80
Figure 21  Jeff Parish OAM 85
Figure 22  NSW Riverina rice production 1970/71 – 2014/15 88
Figure 23  Average tomato yields over time 93
Figure 24  Percent (%) of tomato production via subsurface drip irrigation 95
Figure 25  Comparison of Australian and Californian tomato production 96
Figure 26  Number of growers and total national production 96
Figure 27  Contractor using mini laser leveller in Cambodia 97
Figure 28  Wheat on raised beds in Bangladesh 97
Figure 29  Direct seeded rice in Bangladesh 98
Figure 30  Strip tillage of mung bean into rice stubble; Established crop in Bangladesh 99
Figure 31  The Chameleon soil water monitor in Mozambique 100
Figure 32  Coloured test strip showing levels of nitrate 100
Figure 33  The FullStop soil water nitrate monitor 100
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin planning</td>
<td>Water resource planning at a whole of catchment or basin scale.</td>
<td>3.2</td>
</tr>
<tr>
<td>Capped resources</td>
<td>A resource management tool where the water available for consumptive use is limited to a defined volume or percentage of the available resource. Any new development therefore has to access water through trade from an existing user.</td>
<td>1.6.4</td>
</tr>
<tr>
<td>Centre pivot</td>
<td>A large-scale mechanical overhead pumped irrigation system anchored at one end and so rotating to cover a circle.</td>
<td>5.4</td>
</tr>
<tr>
<td>Contour bays</td>
<td>An early development of flood irrigation to provide a series of separate bays within a larger paddock each defined by a similar horizontal contour boundary.</td>
<td>5.2</td>
</tr>
<tr>
<td>Dethridge wheel</td>
<td>A simple vaned rotating water wheel with a revolution counter used to measure flows from a supply channel onto farms.</td>
<td>6.3.3</td>
</tr>
<tr>
<td>Drainage</td>
<td>The movement of water from the surface of a paddock, either by natural means or by artificial surface or sub-surface drainage.</td>
<td>5.5</td>
</tr>
<tr>
<td>Environmental entitlements</td>
<td>Rights to hold and use water resources held in storage to generate ecosystem outcomes.</td>
<td>3.4</td>
</tr>
<tr>
<td>Evaporation</td>
<td>The loss of water through conversion of the water from a liquid form to a water vapour – affected by the surface area of water exposed and the relative temperature of the water and air.</td>
<td>4.2.4</td>
</tr>
<tr>
<td>Full cost recovery</td>
<td>The recovery of the costs of water supply from end-users. This can include both ongoing annual operating costs, and a value of the capital costs incurred as a return on capital and depreciation.</td>
<td>2.5</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Water resources available below ground in defined aquifers.</td>
<td>4.4</td>
</tr>
<tr>
<td>Irrigation scheduling</td>
<td>A structured decision process to optimise irrigation practice to maximise production.</td>
<td>5.6</td>
</tr>
<tr>
<td>Laser levelling</td>
<td>The creation of larger on-farm irrigation areas/bays that can be commanded by a single irrigation flow by the levelling of the previous surface using lasers to establish the consistent level and grade to allow uniform application of irrigation water.</td>
<td>5.2.1</td>
</tr>
<tr>
<td>Leakage</td>
<td>The loss of water from a supply channel or pipe through a break or fault in the material.</td>
<td>4.2.4</td>
</tr>
<tr>
<td>Level of service</td>
<td>The quality of the irrigation service provided measured in terms of reliability, consistency, order time, flow rate and duration of irrigation delivery of water.</td>
<td>4.1</td>
</tr>
<tr>
<td>Linear move</td>
<td>A large-scale mechanical overhead pumped irrigation system that travels in a straight line covering a rectangular area.</td>
<td>5.4</td>
</tr>
<tr>
<td>Millennium Drought</td>
<td>The Millennium Drought occurred throughout South East Australia in the period 2001–2009. This led to changes in water resource management and a re-emphasis on providing water for environmental flows.</td>
<td>6.1.2</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
<td>Section</td>
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<td>-----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Outfalls</td>
<td>Discharge points from gravity-fed irrigation systems that allow excess water to exit the supply system, either to a creek or drainage system.</td>
<td>4.2.4</td>
</tr>
<tr>
<td>Property rights to water</td>
<td>A legal right to access and use water and to sell it to other parties recorded through a formal register.</td>
<td>2.3</td>
</tr>
<tr>
<td>Return flows</td>
<td>Inadvertent or emergency flows from irrigation systems that are surplus to irrigation requirements that in immature resource management settings may provide flows for other users or the environment. Return flows may have negative impacts if they pick up salinity and other pollutants and discharge these to river systems, including wetlands, or lead to raised groundwater levels.</td>
<td>1.8</td>
</tr>
<tr>
<td>Salinity</td>
<td>Presence of salt in surface or groundwater and soil that may impact on productive capacity or resource quality.</td>
<td>5.5.5</td>
</tr>
<tr>
<td>Seepage</td>
<td>The loss of water from a channel by the passage of water through the finely grained bank and bed material and ineffective lining.</td>
<td>4.2.4</td>
</tr>
<tr>
<td>Service point</td>
<td>A supply arrangement from an irrigation supply system to an individual farm property – usually through a metered outlet.</td>
<td>4.1.1</td>
</tr>
<tr>
<td>Southern Connected Basin</td>
<td>The southern part of the Murray-Darling Basin within SE Australia covering New South Wales, Victoria and South Australia that acts as a single coordinated resource management and water trading unit.</td>
<td>Figure 8</td>
</tr>
<tr>
<td>Tail end</td>
<td>The extreme end of a gravity-fed irrigation supply system – often at risk of poor levels of service if users up-stream take excess supply.</td>
<td>4.1.2</td>
</tr>
<tr>
<td>Water allocation</td>
<td>The annual water allocated to a water entitlement that can be traded in the annual water markets in Australia.</td>
<td>2.8.4</td>
</tr>
<tr>
<td>Water entitlement</td>
<td>A legal right (ownership) to access a nominated volume of water within a resource catchment or groundwater resource unit and to trade all or part of that entitlement through water markets.</td>
<td>2.8.3</td>
</tr>
<tr>
<td>Water markets</td>
<td>A mechanism to allow water entitlements to be traded between parties, subject to agreed rules and terms, in Australia.</td>
<td>2.8</td>
</tr>
<tr>
<td>Water ordering</td>
<td>A formal mechanism to allow individual customers to gain access to water from an irrigation supply system within defined terms and specifications regarding timing, duration, volume and flow-rate.</td>
<td>4.2.2</td>
</tr>
<tr>
<td>Water trading</td>
<td>The exercise of exchange of access to water within water markets. This can be for permanent rights of access to an entitlement or temporary access to ‘allocation’ water in any one season.</td>
<td>2.8.5</td>
</tr>
<tr>
<td>Water use efficiency</td>
<td>The efficiency by which water is utilised in irrigated production. A variety of indices can be used, including engineering measures of relative water loss and/or agronomic/economic measures of the value of production/unit of volume of applied water.</td>
<td>1.4</td>
</tr>
<tr>
<td>Water flow and volume units</td>
<td>Australia uses the metric system and has adopted the megalitre (ML) as the primary unit of volume in irrigation. The unit of water flow adopted is ML/day. One ML =1,000 m³ or 10⁶ litres. Large volumes are measured in Gigalitres (GL). One GL = 1 million m³ (MCM) or 10⁹ litres. For flow, 1ML/day = 11.57 litres/sec. 1 cubic metre/sec (cumec) = 86.4 ML/Day.</td>
<td>Multiple sections</td>
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## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full term</th>
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<tbody>
<tr>
<td>CEO</td>
<td>Chief Executive Officer</td>
</tr>
<tr>
<td>CICL</td>
<td>Coleambally Irrigation Cooperative Limited</td>
</tr>
<tr>
<td>CIT</td>
<td>Central Irrigation Trust</td>
</tr>
<tr>
<td>CPLM</td>
<td>Centre pivot, linear move</td>
</tr>
<tr>
<td>D&amp;S</td>
<td>Domestic and stock supply</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization (of the United Nations) b</td>
</tr>
<tr>
<td>GL</td>
<td>Gigalitre</td>
</tr>
<tr>
<td>GMID</td>
<td>Goulburn-Murray Irrigation District</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>Ha or ha</td>
<td>Hectares (10,000m²) or 2.47 acres</td>
</tr>
<tr>
<td>HDPE</td>
<td>High-density polyethylene</td>
</tr>
<tr>
<td>HLPW</td>
<td>High Level Panel on Water</td>
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<tr>
<td>HRWS</td>
<td>High reliability water shares</td>
</tr>
<tr>
<td>LEPA</td>
<td>Low energy precision application</td>
</tr>
<tr>
<td>LoS</td>
<td>Levels of service</td>
</tr>
<tr>
<td>MDB</td>
<td>Murray-Darling Basin</td>
</tr>
<tr>
<td>Megalitre</td>
<td>ML, 1 million litres or 1,000m³</td>
</tr>
<tr>
<td>MIL</td>
<td>Murray Irrigation Limited</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NViRP</td>
<td>Northern Victoria Irrigation Renewal Project</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operations and maintenance</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory control and data acquisition</td>
</tr>
<tr>
<td>SDG</td>
<td>Sustainable Development Goal</td>
</tr>
<tr>
<td>SMDB</td>
<td>Southern Murray-Darling Basin</td>
</tr>
<tr>
<td>SMS</td>
<td>Short message service (i.e. phone text)</td>
</tr>
<tr>
<td>t/ML</td>
<td>Tonnes per megalitre</td>
</tr>
<tr>
<td>TCC</td>
<td>Total channel control</td>
</tr>
<tr>
<td>WUE</td>
<td>Water use efficiency</td>
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</table>
Preface

The United Nations High Level Panel on Water

In April 2016, the UN Secretary-General and President of the World Bank Group convened a High Level Panel on Water (HLPW) – consisting of eleven Heads of State and Government and one Special Adviser – to provide the leadership required to champion a comprehensive, inclusive and collaborative way of developing and managing water resources, and improving water and sanitation related services.

The core focus of the HLPW was the commitment to ensure availability and sustainable management of water and sanitation for all, Sustainable Development Goal (SDG) 6, as well as to contribute to the achievement of the other SDGs that rely on the development and management of water resources. One initiative was for members to prepare ‘roadmaps’ for improved management of water and sanitation under SDG 6.

On this basis, the Australian Government Department of Agriculture and Water Resources (now Department of Agriculture, Water and the Environment) charged AWP with the:

“Preparation and supply of an authoritative and practical report on techniques and technologies to significantly improve irrigation water use efficiency, focussed in particular on guidance for governments, farmers and the operators of irrigation districts in developing countries.”

This Guide is the product of that commission.

On 14 March 2018, the HLPW mandate ended with the release of their outcome package consisting of an open letter to fellow leaders, an outcome document, short summaries of key initiatives undertaken by the Panel and a “galvanizing” video. However, the time-limited life of the HLPW did not end its influence. This Guide was initiated under the mandate of the HLPW but is now promoted by the Australian Government through the Australian Water Partnership.

The Australian Water Partnership has also commissioned a companion booklet on ‘The Irrigation Efficiency Paradox’ that addresses Australia’s approach to promoting the adoption of greater water use efficiency as a way to manage water scarcity and increase production whilst at the same time supporting the environment. The issue of ‘irrigation water-use efficiency and return flows’ is commented on in this Guide but is addressed in greater depth in the companion booklet.
1 Context

1.1 Four Australian themes on water use efficiency

Water scarcity is focusing world attention on the importance of water-use efficiency (WUE) to support increasing water demand from irrigated agriculture, urban and industry supply, and for environmental values. Australia has grappled with this challenge over the last 100 years.

This Guide sets out practical lessons and recommended approaches based on how Australia has responded to that challenge. Significant improvements in WUE in irrigated agriculture in Australia have occurred over many years, generally as a by-product of increasing production and productivity and adoption of technology, often with a focus on reducing labour costs.

Recent experience confirms it is possible to return water to the environment while maintaining the social and economic benefits of irrigated production. These guidelines are based around four main messages:

1. Irrigation water use efficiency is an ongoing journey, not a one-off change – different steps and responses will be applicable and appropriate at different stages.

2. Change needs to occur at a range of different levels:
   a. The legal and policy frameworks for water supply to agriculture with clarity on access rights for users and the environment
   b. Water resource management at a basin-scale to understand the characteristics of the resource
   c. Irrigation delivery system management to deliver agreed levels of service to irrigators and to measure where and when the water is used
   d. Irrigation system management on-farm to deliver optimal outcomes.

3. The term ‘water-use-efficiency’ means a range of different things to different people – from an engineering term (a measure of the proportion of water lost in a distribution system) to a commercial focus on the value of production for each ML of water applied.

4. The intensity of focus on WUE is driven by water scarcity and growing competition for available water resources.

1.2 Framework

1.2.1 High Level Panel on Water – a focus on agriculture

The target of the High Level Panel on Water (HLPW) was to help deliver SDG 6 to ensure the availability and sustainable management of water and sanitation for all. The HLPW set out a proposed approach for improved management of water and sanitation entitled ‘Water Use Efficiency for Resilient Economies and Societies Roadmap’. This proposed the publication of practical measures to assist governments and other entities seeking to improve their water-use efficiency, with the objective of obtaining more benefit for their society from less water. The Roadmap confirmed:

Agriculture commonly uses 70-90% of freshwater resources in most countries. Where water scarcity exists, more than 90% of water consumption on average goes to irrigated agriculture. Actively improving water use efficiency in irrigated agriculture is critical because agriculture will need to produce 60% more food globally by 2050, and 100% more in developing countries, using diminishing water resources.
Because agriculture is the largest water user, efficient and sustainable irrigation is necessary to achieve global food security goals. Under this Roadmap, practical guidance material will be made available on how to improve water use efficiency in irrigation districts.

This Guide provides this ‘practical guidance material’ through the description of practical, simple and cost-effective options, techniques and technologies to improve WUE in irrigated farming in the context of broader river, catchment or basin level water management goals based on Australia’s experience.

The guidance material is aimed at providing practical advice to governments, irrigation district operators and farmers on how to identify options and opportunities to reduce water use while maintaining and enhancing incomes, production and productivity.

1.2.2 ADB guidance note

The approach also implements the aims and targets of other organisations such as the Asian Development Bank (ADB). They confirm their analysis and objective as follows:

Producing more food with less water. Latest estimates suggest that food production in the developing world must double by 2050. By that year, according to ADB’s Asian Water Development Outlook 2016, urban and industrial water demand will have increased from the present 20% of total regional demand to 40%. Water use in irrigation (now about 80% of the total) must become more productive, particularly as climate change makes water even less available.

This analysis was the driver for the development of a guidance note by the ADB on sustainable development in the irrigation sector. This sets out five pillars and building blocks (Table 1) that can also provide a robust framework for WUE in irrigation.

1.2.3 Four areas for water use efficiency

The ADB framework of pillars and building blocks confirms that effective and sustainable water use requires coordinated and simultaneous action and progress across four areas:

1. **Policies and legal structures**: creating a robust framework to enable water to be used effectively, efficiently and productively in an environmentally sensitive manner.

2. **Water resource management framework**:  
   a. Understanding and accounting for water resources  
   b. Allocating water resources through Water Sharing Plans.

3. **Distribution system**: delivering water to the farm. This function is split between levels:  
   a. Headworks management  
   b. Main distribution system  
   c. Local supply network.

4. **On-farm system**: the management and use of water to produce irrigated outputs.

This guidance focusses on elements 3 and 4 but is keenly aware that effective progress in these areas is dependent on robust legal systems and an effective water resource management framework.
Table 1. Irrigation sector – pillars and building blocks

<table>
<thead>
<tr>
<th>Pillar</th>
<th>1: Government Water Policy Institutions</th>
<th>2: The Water Resources Manager</th>
<th>3: The Irrigation Manager</th>
<th>4: The Farm Irrigation System Manager</th>
<th>5: The Farm Production unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Suitable Government policies and capacity</td>
<td>Water managed and shared sustainably at the river basin level</td>
<td>Appropriate modernisation and O&amp;M of the command area with agreed LoS</td>
<td>Appropriate modernisation and O&amp;M of the WUA irrigation system with agreed LoS</td>
<td>To produce more food and increase household income</td>
</tr>
<tr>
<td>Building blocks</td>
<td>1.1 Relevant policies and laws</td>
<td>2.1 Water resources data</td>
<td>3.1 LoS and water sharing to WUA</td>
<td>4.1 LoS to individual farmers</td>
<td>5.1 Crop information</td>
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<tr>
<td></td>
<td>1.3 Readiness for reform and innovation</td>
<td>2.3 Delivering water to canal, offtakes and other users</td>
<td>3.3 Management, O&amp;M</td>
<td>4.3 Management, O&amp;M</td>
<td>5.3 Increasing agricultural productivity</td>
</tr>
<tr>
<td></td>
<td>1.2 Water management institutions</td>
<td>2.2 River basin water balance</td>
<td>3.2 The planned modernisation</td>
<td>4.2 The planned modernisation</td>
<td>5.2 Irrigation technologies and performance</td>
</tr>
<tr>
<td></td>
<td>1.4 Financing</td>
<td>2.4 Management, O&amp;M</td>
<td>3.4 Water User Group consultation and participation</td>
<td>4.4 WUA performance and farmer participation</td>
<td>5.4 Socio-economic impacts</td>
</tr>
</tbody>
</table>

1.2.4 The water-food-energy nexus

WUE also needs to be seen in a wider framework that looks at water use within a nexus that also addresses food security and energy consumption. As the UN’s water initiative (UN Water, 2020) confirms:

“The water-food-energy nexus is central to sustainable development. Demand for all three is increasing, driven by a rising global population, rapid urbanisation, changing diets and economic growth. Agriculture is the largest consumer of the world’s freshwater resources, and more than one-quarter of the energy used globally is expended on food production and supply. The inextricable linkages between these critical domains require a suitably integrated approach to ensuring water and food security, and sustainable agriculture and energy production worldwide. As water resources become more stretched, the energy and food sectors’ dependence on water, means that decision-makers in all three domains are now increasingly focusing on water resource management, ecosystem protection and water supply and sanitation as part of their policy and practice.”
1.3 Structure of this Guide

This Guide is organised into six chapters:

Chapter 1: Introduction and framework

This initial chapter has two parts:

- **Context:** The first part sets out the context and objective of this Guide. It also identifies the framework for the analysis and sets out some common themes that inform the remainder of the Guide.
- **Definitions and drivers:** The second part confirms the common approaches to defining water use efficiency and the key drivers for adopting changes.

These provide a framework for the practical advice in the following chapters.

Chapter 2: Water law and governance

This chapter identifies the enabling framework needed to promote the desired change in WUE, which includes:

- Water Law covering property rights and registers.
- Water sharing plans and water accounting requirements.
- Full cost recovery charging arrangements.
- Robust institutional arrangements.

Chapter 3: Water resources planning and management

This chapter covers basin-scale water resource management, which includes:

- Water resource assessment.
- Implementing water sharing plans.
- Water accounting practice including metering and measurement.
- Catchment management practice including storage management.
- Managing water scarcity.
- Environmental considerations.

Chapter 4: Delivery systems

This chapter focusses on irrigation delivery systems and covers three main areas:

- **Levels of Service:** Determining the appropriate LoS; What standards are sought by individual crop/system types, noting that this may change by season? What are the implications for WUE?
- **Design and operation of systems:** What are the different characteristics and issues for WUE of different irrigation delivery systems? i.e. piped, channel supply, groundwater bores.
- **Management issues for irrigation districts:** What factors around the ownership and management of irrigation districts constrain or promote greater WUE?

Chapter 5: Farm irrigation and drainage systems

This chapter focusses on WUE on-farm and covers four main areas:

- **Delivery efficiency:** What factors drive greater WUE in terms of the delivery efficiency (ML used delivered)? How does this vary with the irrigation system adopted, for example:
Water use efficiency in irrigated agriculture: An Australian Perspective

- Rice contours
- Border check/furrow
- Centre pivot/linear move
- Sprinklers/drip.

- **Agronomic**: What factors drive greater production in terms of the quantum of product per unit of water applied?
- **Value of production**: What factors drive greater production in terms of the value of the product per unit of water applied?
- **Farm drainage systems**: How does the design and operation of farm drainage systems affect WUE?

**Chapter 6: Case studies**

The final chapter provides practical, illustrative case studies that help explain and expand the advice outlined in the earlier chapters.

The case studies look at demonstrated WUE improvements that Australia has made over the last 50 years at four levels:

- **Industry**: How irrigated sectors have greatly increased production per ML of water applied, for example:
  - The rice industry has increased production from 0.4 tonnes per megalitre (t/ML) in the 1970s to 1.0 t/ML on average with better quality rice.
  - In the processing tomato sector yields have seen a seven-fold increase over the last 50 years, from 2.5t/ML to 17t/ML.

- **Water distribution**: Delivery efficiency has improved so that Coleambally Irrigation has reduced losses in their supply system from 100,000ML/yr to less than 20,000ML/yr.

- **On-farm efficiency**: Improved on-farm irrigation practice means that drainage flows in the Sunraysia region of over 3 ML/ha in the 1980s have now reduced to less than 0.5ML/ha.

- **National**: Irrigation development has moved from low-value grazing crops and rice to high-value horticulture and changed locations. Flexibility from water trading allows the rice industry to use water efficiently when there is plenty, but to scale back activity and water use in years of scarcity to allow higher value horticulture to be maintained.

**1.4 Definitions of water use efficiency**

A series of different approaches, terms and metrics are used to promote and measure WUE. An early task in any project is to clarify the framework adopted – this section sets out an analysis of the main approaches. There are two broad uses of the term, as adopted by the New South Wales Department of Agriculture for the Australian National Program for Sustainable Irrigation (National Program for Sustainable Irrigation, 2003):

- An engineering term to measure the relative efficiency of a system related to the proportion of water losses in delivery.
- A production term to measure the relative level of production from the use of that water, referred to as a ‘Water use index’.

The following sections review the key approaches. Figure 1 and Figure 2 at the end of this section provide more detail on the range of indices commonly employed.
1.4.1 Engineering: focus on the delivery system

The first approach is an engineering and water resource management framework. Here the focus is on the relative efficiency of the storage and delivery systems. This approach measures the ratio between the volume of water captured and released (from the storage or river) and the volume that gets delivered to the farm.

Here the two units are similar – the volume of water released into the supply system and the volume of water delivered on-farm, so the metric is ‘Volume-delivered’/‘Volume-released’, expressed as a percentage. Under this approach, the major concerns are to reduce ‘losses’ from:

- evaporation in storage and distribution;
- leakage and seepage, i.e. losses to surface or groundwater from the distribution system prior to delivery on-farm; and
- outfalls, where surplus water is supplied beyond the volume required and is therefore released back into the drainage or supply system.

Standard, extensive earthen channel distribution systems typically operate at around 60 percent efficiency on these terms, whereas modern piped supplies can generally meet values in excess of 90 percent.

The objective, therefore, is to increase the percentage of the water that is released into supply that is actually delivered to the farmer. This generally requires a program of system modernisation with channel lining or piping, where significant improvements can be made by responding to locations with significant leaks and seeps.

1.4.2 Engineering: focus on the farm system

The engineering efficiency approach can also be applied on-farm. Here it can be used to measure the percentage of the water delivered to the farm that is ultimately applied to the crop. This measures the relative losses on-farm in managing the water supplied. The approach can also be used to measure the percentage of the water applied that is actually taken up by the plant (measured as the ratio between water consumed and water applied) known as the Water Input Efficiency (WIE).

\[ \text{WIE} = \frac{\text{Irrigation water taken up by the plant}}{\text{Irrigation water applied}} \]

1.4.3 Production: agronomist approach

The next approach to targeting WUE is concerned with the relative amount of the crop grown with the available water. Here the assessment is in terms of the quantum of production for each volume unit of water applied, i.e. it measures the production of output per unit of water input, in terms of tonnes/m³.

The target can be either:

- using less water to grow the same crop; or
- using the same water to grow a larger crop.

Under this approach, a number of risks need to be managed:

- That excess water is applied beyond the crop water demand leading to accessions to the groundwater through deep drainage beyond the root zone.
- That evaporation in application reduces the proportion of water reaching the crop.
- That the application system does not deliver a uniform volume and flow to the plant, e.g. flood irrigation tends to over-water the head of the bay and under-water the foot.
- Spray irrigation is affected by weather conditions, e.g. wind leading to spray drift.
In this case, the Water Conversion Index (WCI) measures the productive quantity generated by the water applied (measured as mass per unit of water applied).

$$WCI = \frac{\text{Quantum of product (kg or tonnes)}}{\text{Water applied (m}^3\text{), e.g. kg/m}^3\text{.}}$$

The FAO also defines the measure as a Water Requirement Ratio (WRR) (FAO, 2020) where:

$$WRR = \frac{\text{Irrigation water requirement per year}}{\text{Irrigation water withdrawal per year}}.$$

### 1.4.4 Production: farm business

The previous approach was concerned with the quantum of product grown per unit of water applied. This is a physical measure of efficiency which agronomists tend to focus on. By contrast, the next metric looks at the produce in terms of its value. Under this approach the metric is the $ value per unit of irrigation water applied.

$$WCI = \frac{\text{Value of product}}{\text{Water applied, e.g. } \$/\text{m}^3}$$

A focus on the metric of $/m^3 will drive water use to higher value crops because growing a high-value crop inefficiently, even with water wasted, may generate a higher farm income than a low-value crop grown efficiently. This is what a farm business focuses on.

This focus on higher value products may drive demand for greater water reliability, and additional storage infrastructure, which may impact on other water users or the environment, or both and a significant change to on-farm water application systems, e.g. a change from flood irrigation to sprinkler or drip irrigation.

### 1.4.5 Water-food-energy nexus

A wider focus takes account of the energy inputs and outputs of the system, i.e. the water-food-energy nexus. Under this approach, the focus is on measuring either the energy inputs to the system and/or the energy value of the food produced from the available water, e.g. kj energy/volume of water applied.

The approach allows an assessment of the total energy balance, taking account of the energy inputs as well as the outputs – this gives an advantage to gravity irrigation system. Flood irrigation for rice production comes out with a high score under an assessment of food energy per unit of input.

$$\text{Energy efficiency} = \frac{\text{Megajoules of food energy}}{\text{Megawatt hrs of energy input}}$$

### 1.4.6 Holistic: regional economic

The final approach reviewed here can be termed a whole-of-system or holistic approach. Under this approach the WUE is assessed in terms of the total value generated by that water across uses and users, including environmental, social and economic outcomes.

This approach recognises that secure high-quality water resources are critical for a wide range of different values and that driving optimal WUE in one sector needs to take into account the impacts on all other uses and users, including the environment.

This whole-of-system approach helps drive robust water resource allocation decisions as it emphasises the trade-offs and interconnections that exist between uses. For example, improved production efficiency in irrigation may free up water for growth in urban water supply or for the environment.

Generally, it is necessary to convert all outputs and outcomes under this approach into a monetary value to allow an aggregate, whole-of-system analysis that is then reported in terms of the gross regional domestic product (GRDP) per volume of available water resource.

$$\text{Regional outcome} = \frac{\text{GRDP}}{\text{Water Volume}}$$
1.5 The approach of these guidelines to water use efficiency

The previous sections show that there are many different ways of expressing WUE, such as:

- engineering, as a percentage (%) ratio to measure losses;
- agronomic, in terms of tonnes per unit of water;
- farm business, in terms of cost ($) per unit of water;
- energy, in terms of food energy produced per energy input; and
- regional economic, in terms of GRDP per unit of water.

Each of these measures has value and provides a tool to support decisions about a different aspect of WUE. Therefore, in any debate or evaluation of WUE, it is critical to be clear on what aspect is being measured or monitored.

The aim of this Guide is to provide tools and advice for irrigation managers and practitioners that have proven to be effective in the Australian context in promoting WUE at a practical level.

This Guide therefore focusses on three core issues and approaches to WUE:

1. Distribution efficiency – what can be done to reduce losses in irrigation water delivery systems?
2. On-farm – how can water be used to maximise the level of production per unit of water, in tonnes/unit of applied water?
3. On-farm – how can water be used to maximise the value of production in $/unit of applied water?

Any structural change in irrigated agriculture has to be viewed within the wider context of water resource availability and allocation, and the associated framework of legal and regulatory policies.

1.6 Drivers of water use efficiency initiatives

The second critical part of the process is to understand the drivers that promote active uptake of greater WUE so that we are able to target those initiatives effectively. This assessment follows the four-element structure outlined in Section 1.2.3:

2. Water resource and headworks managers.
3. Infrastructure operators and managers (the tertiary or WUA aspects are important but are not considered as Australia does not have expertise in this area).
4. On-farm irrigators.

In analysing those drivers it is helpful to recognise that irrigation schemes typically progress through four phases (Doolan, 2016). The appropriate approach to WUE in any scheme will depend on which phase the system is in:

1. Development phase where water is not limited.
2. Water is limited, without a robust framework of rights, allocations or security.
3. Water is limited, within a robust policy framework.
4. Water is limited and able to be traded.
It is much easier to influence and achieve WUE if there is scarcity, until that happens it is harder. However, the policies put in place by central agencies prior to and during water scarcity are critical to the management of WUE.

1.6.1 Governments: policy and legal
The interest by government agencies in WUE can be driven by a range of factors:

- Regional prosperity: government agencies are often keen to increase regional prosperity and can issue grants and subsidies to promote greater productivity and overall production. That tends to support higher value activities, which in turn can provide incentives for farmers to invest in upgraded irrigation practices.

- Water constraints: government agencies may recognise and respond to risks of water resource scarcity. This leads to greater emphasis on water sharing plans, water accounting and the promotion of greater WUE to minimise the impact of conflict and shortages.

- Full cost recovery: government agencies may seek to obtain a return on previous government investments and to promote financially sustainable and viable infrastructure operators. Those charges will also drive greater incentives to make full and better use of the scarce resource.

- Urbanisation: growth in urbanisation means that there are fewer people in agriculture. That leads to a restructuring of typical production units with amalgamation of properties, introduction of mechanisation/automation and a focus on greater WUE.

The ability of government agencies to influence WUE depends upon the scarcity of water. The main tools available to governments to drive reform are around policies and regulations, such as water law/policy, water rights, implementation of water measurement, full cost recovery and an allocations framework, and the implementation of water sharing plans and water accounting. Governments also play a core role in planning and financing major infrastructure investment.

Central agencies often use incentives to encourage WUE, for example:

- Funding support for on-farm works to promote adopting more efficient watering systems.
- Subsidies to infrastructure operators to leverage WUE in delivery systems.
- Extension and research to encourage uptake of best practice in WUE.

1.6.2 Water resources and headworks managers
A prerequisite for improved WUE is accurate water measurement at all levels in an irrigation system. Without accurate water measurement the ability to achieve raised levels of WUE is limited. Accurate measurement greatly improves water resource accounting, measurement of delivery systems performance and of water supplied to the farm.

Water resource managers have the responsibility to manage and allocate water resources in accordance with established policies and objectives. They face pressures from their suite of clients to maximise the volume available for use and its reliability and certainty, including both consumptive users and the environment.

That creates pressures to increase yields and reduce losses. It also increases incentives to promote water accounting and the development of water sharing plans.
1.6.3 Infrastructure operators

Irrigation infrastructure managers in Australia normally operate in the public sector or within co-operatives (rarely within the private sector). They face pressures to reduce ongoing costs, with labour normally their largest operating cost. This tends to drive investment in system automation, which generally results in both reduced labour costs and increased delivery efficiency and higher levels of service.

The introduction of ‘full-cost recovery’ charging and independent economic regulation generates a dynamic whereby end-users have an incentive to challenge the infrastructure managers to meet agreed levels of service. Those levels of service (e.g. a consistent higher flow level) are an essential prerequisite for irrigators to invest in improved WUE on-farm.

Maintenance of irrigation schemes has often been under-resourced, and this lack of maintenance has led to a reduction in service quality and water-use inefficiencies. Many systems are now being “modernised” or “rehabilitated”. How well this process achieves WUE in the long-term depends upon:

- the design of the system;
- the funds available as farmers rarely provide the funds required; and
- the capacity and skills of the institutions responsible for managing the assets.

A core driver of system modernisation is to enhance the levels of service at the farm supply point/s, in particular the rate and consistency of flow. The aim is to improve the LoS to a level close to ‘water on-demand’, i.e. water being available for delivery to farmers within a few hours of being ordered. This LoS is essential to provide the quality of supply required to promote on-farm initiatives. So, investment can deliver both water savings and improved performance.

In any modernisation the future operating and maintenance costs are limited by the users’ ability to pay through their water charges. The Australian experience would suggest that around 5 percent of the gross income generated by the farmer is typically accepted as a reasonably affordable charge. When the amount is greater than 10 percent this is considered to be less affordable. This means that the modernisation program and the levels of service delivered vary with the value of the crop grown and subsequently on WUE.

Finally, infrastructure operators have incentives to invest in reducing losses where they can realise the water savings as a negotiable asset that can be converted into a monetary value.

1.6.4 On-farm irrigation

Prior to water shortage

In an era prior to water shortages and basin planning, the major drivers of changed irrigation practice are production imperatives with little concern about the volume of water used or the WUE.

Production can be increased by:

- individual farms getting bigger through property consolidation;
- irrigating a greater percentage of the land or by having multiple crops;
- changing to higher value crops; and
- productivity improvements by improving inputs and more intensive irrigation scheduling.

Increased production and farm returns generally requires a change in the farm irrigation system to reduce labour inputs, to allow an operator to expand the production that a single person can manage alone without having to hire employees. This includes reducing the anti-social hours associated with certain labour-intensive irrigation systems.
Sometimes the practices required to increase production – particularly ‘irrigation scheduling’ – can require a higher labour input and significant time in training, which can be counterproductive to the overall labour reduction. This can be an impediment to the adoption of WUE practices and shows the trade-off between economic efficiency and water-use in a period prior to water shortages.

Changing to a higher return enterprise is generally associated with better on-farm systems, which are usually more expensive but can now be afforded. These investments are designed to drive productivity improvements and often also generate WUE improvements.

Thus, WUE is generally a by-product of the farmer’s drive for increased production when water is not limited.

A focus on reducing costs can also have a limited, but effective, impact on WUE. For example:

- Full cost recovery charging can play a role in encouraging greater WUE, provided it is levied on the actual water used and not on the total volume of the entitlement.
- A charge on actual water use encourages WUE by enabling farmers to lower their input costs by adopting WUE practices. Whereas a charge on entitlement can tend to promote a “use it or lose it” mentality with paddocks watered, whether or not this promotes optimal outcomes. However, for most high-value crops water charges are often less than 5 percent of total input costs and may be still insufficient to drive improved WUE by itself.
- Farmers who pump water can reduce costs by installing more efficient systems, however this is often insufficient to generate improvements in irrigation systems’ WUE.

The amount a farmer can afford to spend on an improved irrigation system is related to the value of the crop produced. Experience in Australia is that the total of farm operating costs and the capital costs (depreciation or repayments) should not exceed 15–20 percent of the gross income. Therefore, there are limits to the practices able to be adopted.

### Capped resources

The second stage is where water resource policy has placed a cap on the aggregate volume of water that may be diverted for consumptive use. There are two scenarios:

- A capped resource, but limited rights: at this stage the individual irrigator has limited legal rights to the water, and water-sharing plans are rudimentary. Irrigators are less likely to invest in WUE initiatives, as they have no certainty about their ability to capture or use the resulting surplus.
- A capped resource plus clear property rights: here the irrigator can see that they can realise the benefits of investment in higher productivity irrigation systems. This allows them to maximise the value of production for a given allocation volume.

However, there is only pressure for greater WUE when an individual farmer’s allocation or water-right is less than their demand. Farmers will only look seriously at WUE if they don’t have enough to meet their planned production. This creates the dilemma that the drive for WUE is much stronger if farmers face a limit on the volume of water they can access for any given irrigation season.
Water scarcity

Once a resource is capped and there is competition for the resource, then a different set of incentives apply:

- An irrigator owns an asset that has value and so has incentives to use that water or to sell it to someone else who seeks to grow their enterprise.
- An individual irrigator can also generate a return on investment in greater WUE through generating a saving that he can either use to expand production, or sell to another water user.
- The irrigator can also judge the relative returns available from production on-farm or from sale of the entitlement on the water market.

However, any such incentives rely on a robust policy and water resource management framework comprising:

- a capped resource to limit access to additional water;
- a clear process for allocating that resource between groups and individuals (water sharing plans);
- clear legal rights to the land and water to give the certainty required to create the confidence needed to invest on-farm;
- measurement of water and accounting to record the volume of water actually taken and used;
- full cost recovery charging by the irrigation system managers for ongoing maintenance of the water supply system; and
- Land use planning and associated legal frameworks to facilitate the amalgamation of property holdings.

1.7 Other critical factors

1.7.1 Restructuring, labour costs and economies of scale

For most irrigators, WUE is a by-product of a larger imperative that seeks to increase yields, production and income, expand the area irrigated, and reduce unit labour costs.

Examples from Australia are:

- Laser-grading of irrigated paddocks allowed for more efficient flood irrigation of a much larger area. This allowed expansion both of the area and the volume that one irrigator could manage, often by a factor of six. This also led to more efficient water use as there was more consistent watering across the paddock, with fewer areas water-logged through over-watering or dry from being at the end of the bay or physically too high.
- Conversion of furrow to sprinklers. Once again, the main driver was labour utilisation:
  - On a small property of less than 10ha there was fast uptake, as the enterprise relied on off-farm income, which created a strong incentive to minimise the labour input required to irrigate a set area
  - On larger properties above 30ha in size, there was strong uptake to minimise labour input costs to promote profitability
  - On medium-sized properties between 10ha and 30ha there was much slower uptake of the conversion, as this sized property was typically managed by one person who could manage furrow irrigation on a property of this scale.
- Conversion from furrow to drip:
  - The processing tomato sector used to rely on furrow irrigation with multiple siphons from the supply channel. This limited production to around 4,000 tonnes per owner due to the labour time required to manage the system. This was a significant business limitation
The conversion to sub-surface drip now allows production rates well above 20,000 tonnes/owner with reduced labour costs. The yield per hectare has doubled and the yield per unit of water has increased by a factor of three. The gross margin (in $/tonne) has marginally improved, but the returns per owner have increased proportionally to the increased tonnes.

As a result, the sector now has one quarter of the number of farmers growing the same total production on half the area with one third of the water.

A common driver in all these cases was the imperative to achieve economies of scale by increasing the scale of production, while controlling costs. In order to achieve this, the irrigator must be able to increase the size of the property managed. This requires clear property rights over land and the ability to acquire and amalgamate neighbouring properties. Historic irrigation delivery systems may impede this aggregation due to the presence of intervening supply infrastructure. That, in turn, can act as a prompt for delivery system reconfiguration.

1.7.2 Risk

Any assessment of irrigation practice needs to recognise the asymmetric risk around watering decisions:

- Under-watering: If an irrigator misses an irrigation cycle or under-waters, they risk incurring a significant private loss from damage to the crop or at the very least reduced yields, particularly for high-value crops.

- Over-watering: If an irrigator over-waters, then with most production systems there is limited downside in terms of yield and private returns. In addition, the approach may create:
  - positive third-party impacts from the provision of flows for other users; and
  - adverse public outcomes from increased drainage flows and risks of increased salinity from raised ground water levels.

The asymmetric nature of this decision means that most irrigators will tend to promote production imperatives before WUE initiatives.

1.7.3 Technology

In many cases, an investment in technology to drive greater production will also lead to greater water use efficiency.

Technological developments have also driven modernisation and automation of supply infrastructure. For example, the modernisation program for the major gravity-fed systems in northern Victoria was dependent on a suite of innovations in system management, including:

- newly designed flume gates with continuous level monitoring;

- solar-powered actuators on regulators and gates; and

- wide-area radio network to link decentralised regulators and so allow integration and automation of controls.

The wide-scale adoption of smartphones and apps has also allowed irrigation managers to access and control orders and systems from anywhere.

However, it is worth recording that investment in technology does not always lead to greater WUE. For example, an early change in irrigation practice sees a move from the use of a hand-held hose to a low-level sprinkler system, as this allows a single operator to manage a much larger area within the same amount of time. However, this generally results in a higher overall level of water application, as an operative with a hand-held hose has a strong incentive to minimise the water applied per plant. Whereas with a sprinkler system the incentives are to “set and forget” given the asymmetric risks identified above.
1.8 Return-flows

1.8.1 The issue

Return flows from irrigated production systems can generate positive values for third parties:

- Irrigators further down the system can access the return flow for production either from river or drainage systems or from the groundwater.
- The environment can also use the flows for ecosystem outcomes such as artificial wetlands or groundwater dependent ecosystems.

In these circumstances, promoting increased WUE in delivery systems and irrigation could lead to negative impacts on third parties where there is a poorly defined water access regime.

For example, if an irrigator upstream in a supply system improves their WUE, then the outcome could be that this first irrigator uses the water saving to expand their own total irrigated area. This would effectively use the supply that was previously available to the other parties.

On the other hand, the return flows can carry a range of unwanted pollutants, including pesticides, herbicides and excessive nutrients back to water sources used by others.

1.8.2 Analysis

This issue raises a challenge for the water policy framework. Ideally, all parties should have a secure water access right at an acceptable water quality that takes account of delivery efficiency. That should be aligned with the objective to drive changes in irrigation efficiency not to create hurdles.

For example:

- The environment should have access to clearly defined flow rights at a defined water quality that are managed as an explicit entitlement. It should not have to rely on uncertain access to flows as a by-product of inefficient irrigation.
- Irrigators downstream should have defined access rights that do not rely on uncertain return flows.

The scenario demonstrates the problems created by the absence of a mature, well-developed water budgeting and accounting policy. In the absence of that clarity, it is not possible to know what the implications will be of implementing an enhanced WUE program either in delivery systems or on-farm.

Finally, return flows often demonstrate adverse water quality issues either from contamination with farm chemicals (fertilisers and pesticides) or from increased salinity due to raised groundwater levels. That degrades the value of the access for both irrigation and ecosystems.

1.8.3 Case study: Northern Victoria Irrigation Renewal Project

Australia dealt with this challenge explicitly in the modernisation of the irrigation delivery system across northern Victoria in the Northern Victoria Irrigation Renewal Project (NVIRP).

This $2 billion investment relied on an increase in delivery system efficiency from around 65 percent, to more than 85 percent, to generate 425GL of water savings to be shared between irrigators, the environment and urban water customers in Melbourne.

The assessment underpinning the investment included a formal referral under the Environment Protection and Biodiversity Conservation Act 1999 to identify any potential adverse impacts from the proposed modernisation on key environmental sites. This recognised that the reduced return flows from the improved WUE might impact on certain wetlands that had established artificial
ecosystems as a result of the previous poor water use. That disbenefit was recognised in the cost benefit analysis and, as a result, additional environmental entitlements were set aside to maintain flows to identified high-value sites.

Figure 2. Framework for water use efficiency (adapted from Barrett Purcell & Associates 1999).

Water balance

The re is many irrigation efficiency definitions in the literature most of which share a common element, i.e., the calculation of a water balance at the appropriate scale.

Water balance calculations require that vertical and horizontal boundaries of the system being investigated be precisely defined. The water balance quantifies the volume of water moving into the defined boundaries of the area under consideration, the change in the volume of water within the boundaries and the volume that moves outside the boundaries. As noted earlier, this considers the practical elements of the water balance in each of the identified components, as follows:

**Outside scope, as affected by**
- management
- climate
- soils
- water quality
- varieties
- pests… etc

**Application losses**
- off-target
- deep percolation
- evaporation
- non-recycled surface run-off

**Farm Storage Losses**
- evaporation/transpiration
- seepage
- operational losses
- leakages

**Distribution losses**
- evaporation/transpiration
- seepage
- operational losses
- leakages

**Conveyance losses**
- evaporation/transpiration
- seepage
- operational losses
- leakages

**Storage losses**
- evaporation/transpiration
- seepage
- operational losses
- leakages

**Crop production**

**Water Consumed by Crop**

**Water retained in Soil** (directly available to crop)

**Water Applied** (delivered to field)

**Total Water Input**

**Irrigation Water Use Index (WUI)**
- Applied kg/ML

**Crop WUI** kg/ML
- ET mm or ML/ha

**Total Input WUI kg/ML**
- Water input efficiency %
- Application efficiency %
- Irrigation rate mm or ML/ha
- Farm efficiency %

**Field Canal/Conduit efficiency %**

**Farm WUI kg/ML**

**Farm supply rate ML/ha**

**Conveyance efficiency %**

**Water delivered** (to farm gate)

**Water released**

**Reservoir**

Figure 1. Water use efficiency indices for engineering approaches (National Program for Sustainable Irrigation, 2003)
<table>
<thead>
<tr>
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<th>UNITS</th>
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<tr>
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<td>Gross return</td>
<td>$</td>
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<td></td>
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<td>mm</td>
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<td>Crop WUI</td>
<td>Yield</td>
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<td>Irrigation water use indices (WUI)</td>
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<td></td>
<td>Drainage volume</td>
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Figure 2. Water use efficiency indices for production approaches (National Program for Sustainable Irrigation, 2003)
2 Water law and governance

2.1 Policy and legal framework

The main route that government has to drive water reform is through promoting relevant policies and regulations. This involves legally recognised water rights, mandating monitoring and measurement, full cost recovery and an allocations framework, and the implementation of water sharing plans and water accounting.

The interest by governments in WUE is driven by a range of factors:

- **Regional prosperity:** To increase regional prosperity and provide incentives to promote greater productivity and overall production. This supports higher value activities which enable farmers to afford to invest in upgraded irrigation practices.

- **Water scarcity:** This leads to greater emphasis on water sharing plans, water accounting and the promotion of greater WUE to minimise the impact of conflict and shortages and provide for wider public benefits.

- **Food production:** Maintaining the irrigation system to deliver desired LoS in support of food production/farmer incomes.

- **Full cost recovery:** Obtaining a return on previous investments and to promote financially sustainable and viable Infrastructure operators. Water charges also drive incentives to make full and better use of the scarce resource.

- **Urbanisation:** Greater urbanisation means that there are fewer people in agriculture. That leads to a restructuring of typical production units with amalgamation of properties, introduction of mechanisation/automation, and a focus on greater WUE.

Governments often use incentives to encourage WUE, for example:

- Grants for on-farm works to promote adoption of on-farm investments aimed at improving WUE

- Subsidies to infrastructure operators (there is significant government investment in infrastructure) – governments commonly use this funding to leverage improvements in water use efficiency in delivery systems

- Extension and research to encourage uptake of best practice in WUE.

The ability of governments to influence WUE depends upon the scarcity of water. In Australia, little emphasis was placed on WUE until water was scarce.

In Australia, four overarching areas have been pursued consistently over more than three decades of water reform with the aim of increasing productivity and efficiency, while also ensuring the health of river and groundwater systems (Doolan, 2016). These are:

- Transforming water allocation.

- Improving environmental management.

- Reforming pricing of water services.

- Modernising institutional arrangements.

These in turn rely on extensive community and stakeholder input that has resulted in progress and understanding across a range of areas related to improved water information and knowledge, including water accounting and model development. These four areas are represented graphically in Figure 3.
2.2 Promoting water use efficiency

Robust water law and allocation frameworks will promote efficient water use because they:

- enable water users to plan rationally for future water supplies;
- protect the rights and entitlements of water users sharing common supply systems;
- permit the orderly and rational transfer of resources between water users sharing common sources; and
- promote clarity on the costs of services to drive optimal levels of service.

The design of frameworks needs to include the following considerations and elements:

- People’s rights to access and use of water should be clearly and unambiguously defined.
- There is a rational system for allocating bulk water entitlements to supply authorities.
- There are procedures to make specific allocations for environmental purposes.
- Water allocations are enforceable at law through proper measurement, monitoring, reporting and enforcement arrangements.
- The State should retain powers to ensure that water sources are protected against overuse and degradation, and uses are consistent with the long-term protection of the resource.
- There are review procedures to enable the decisions of government agencies that affect water user to be reviewed.
• There are consistent procedures for consultation on, objections to, and appeals against administrative decisions taken under water legislation.

### 2.3 The role of water law

The high-level objective of this Guide is to assist governments to establish water laws that enable the use of the national or state/provincial water resources to become more efficient to meet the changing needs of their societies.

It is the role of the water law to establish the water resource management framework and institutional arrangements to direct the decisions, operational policies and behaviour of water supply authorities and water users to drive continuous improvements in WUE.

The primary task of water legislation should be to establish a rights regime to regulate the extraction of water from common pool resources to avoid overuse, facilitate efficient use, and to provide public goods and services, including environmental health of the water resource.

Water law should define the rights of water supply authorities and individuals to control the use of a water resource. The system needs to specify:

• rights to use and earn income from the water;
• rights to transfer the water to other users;
• powers to enforce the water rights regime; and
• obligations to protect the resource and the environmental values that depend on it.

Clearly defining the water allocations to headworks and irrigation distribution system operators and to farmers can:

• create incentives to use water efficiently and conserve the resource for the future;
• enable the benefit of efforts and investments in efficiency measures to be captured;
• enabling water to be transferred to high-value uses; and
• provide signals to guide investments.

### 2.4 Institutional arrangements

Efficient institutions are needed in order to facilitate efficient operations. While responsibility for water resource management and policy is still bound up within the same body that allocates and manages the water itself, it is difficult to develop the clarity and efficiency of operation required.

A key part of Australia’s water reform journey has been to reform and modernise its institutional arrangements. That has involved separating out the different functions and activities into separate bodies with clear allocation of roles and responsibilities, such as:

• policy and standard setting retained within central agency;
• water resource management allocated to dedicated agency;
• service delivery of irrigation supplies devolved to local bodies with skills and local accountability (public or private); and
• price regulation managed by an independent economic regulator.
2.5 Full cost recovery

A core element of government policy regarding WUE is to require a contribution from water users to cover the costs of the services they receive.

Clarity on the real costs of supply will drive more efficient investment decisions. A requirement on water users to pay for the services they receive will drive efficient use of those services. Developing a cost recovery regime will promote a debate on the level of service that water users require and are willing to pay for – that will expose issues regarding costs and efficiencies that all underpin good WUE.

The incentive for WUE is enhanced where the savings can be realised and traded.

2.6 Water law

The law specifying the water rights regime needs to be comprehensive and systematic. For example:

- It should be comprehensive in that framework for vesting rights to the water should cover all sources of water in a river basin and be the only head of power for assigning the rights to take and use water, i.e. for urban, irrigation, domestic, industrial, hydroelectric and extractive industry uses.

- It should be systematic in that the aggregate of the rights to take water must not exceed the aggregate divertible physical resource (having regard to environmental needs). The allocation framework should also be capable of allocating the available water resource over the full range of climatic conditions and particularly during droughts.

Writing water law is neither a technical or academic process. It is a practical endeavour shaped by the starting point of the existing laws, the political system it sits within, the abundance or scarcity of the water resources themselves, the interests and capabilities of the existing water agencies, the interests of water users and the customs and culture of the country.

There are two fundamental requirements for making substantial improvements in water law. The first is to identify and demonstrate a systematic approach that is clearly superior to the existing arrangements. The second is to solve the political problems of transitioning from the old to the new arrangements.

The first requirement can only be met by providing detailed information to water users and decision makers about the shortcomings of the existing arrangements. Steps that might be involved include:

- preparing inventories that describe the water resources of the basin in terms of quantity, variability and quality;
- descriptions of the environmental and other public values supported by the resources;
- water accounts that document water use and water use trends;
- projections of future water supply and demands taking into account population growth and climate trends;
- an evaluation of the future reliability of supplies given the above; and
- an evaluation of the engineering, institutional and legislative measures that may be taken to secure future needs.

The process used to collect and evaluate the above information needs to be designed to build capabilities and stakeholder trust in the data and analysis provided.

The second requirement is met when opinion leaders and decision makers at multiple scales acknowledge the problems and agree that reform is a better path to follow than persisting with the old ways.
The transition can also be managed by ensuring the water legislation is enabling rather than prescriptive. In practice this means that the new legislation permits the old water sharing arrangements to be progressively translated into the new using legislated processes.

Meeting these two fundamental requirements cannot be left to chance. The mechanisms of inventories of the country’s water resources, water demands and use, and environmental values need to be developed. Opportunities to progress reform of water allocation arrangements need to be recognised and taken. Events such as severe droughts, financial crises and institutional failures may provide the catalyst for changing and improving existing arrangements.

2.7 Bulk water allocation framework

The water allocation framework needs to be structured around a hierarchical approach that defines harvesting and storage rights at the bulk supply level and then ascribes individual rights based on a share of that bulk right.

Water supply authorities need to hold enduring unattenuated bulk water rights to water held in storages or catchments. This transfers responsibility for managing seasonally variable water availability to the water supply authorities, and rewards supply authorities that manage their water efficiently.

The bulk rights should:

- specify a bounded share of the water resource at a primary source of harvesting or from a point of extraction;
- be explicit in that it is available at a certain location from a specified source;
- be exclusive in that it refers to the bounded share of the resource, which is granted to the authority and no other authority;
- be tradeable in part or full to other authorities, which means that reallocations of the resource can occur; and
- not exceed the divertible physical resources in aggregate.

These requirements can be met if the instrument specifying the bulk rights include rules that explicitly define the:

- amount of water that can be drawn from the source;
- share of the capacity of the storages that supply the entitlement;
- share of the inflows from the catchment that can be harvested to supply the entitlements and passing flow obligations;
- share of the capacity of the carriers which can be used to supply the entitlement; and
- share of evaporation and transmission losses which can be used to supply the entitlements.

2.8 Developing water markets in water entitlements and water allocations

2.8.1 Water markets help water use efficiency

If water is scarce then absolute water efficiency (‘more crop per drop’ applied (kg/ML)) and economic WUE (‘more cash per splash’ ($/ML)) can be significantly improved by the introduction and encouragement of water markets between users. If water for irrigation is scarce and available water can be traded between irrigators of different crops, logically water will be traded to those irrigators that have the greatest need, i.e. with the greatest economic return per unit of water.
Alternatively, governments could simply determine national priorities for irrigated crops and determine which farmers or districts get priority access to water during drought periods. In Australia during the last extended drought periods, the allocation system – combined with markets – was allowed to work (markets were opened up between river valleys, irrigation districts, states and irrigators) and to a significant extent enabled the best possible outcome in terms of optimising resources and maximising the value of irrigated crop production.

However, markets only work in Australia because water markets are based on strong governance, good water measurement (supply meters and hydrometric networks) and clear water entitlement and water allocation regimes.

2.8.2 Strong governance a key pre-requisite to water trading

Water markets, or the trade in access to water, are often cited as a solution to dealing with water shortages, and to ensure the greatest income is derived by an area or even a nation from limited available irrigation water. However, for a water market to work requires that an irrigation district, a river valley or any other defined trading area has clearly defined and well administered water-entitlements for all users, and a method for measuring the amount of water taken by each water user, particularly water market participants (both buyers and sellers). This protects the buyer, the seller and all other users or dependents on flows in the river in the defined trading areas.

In Australia, the governance of water access regimes uses two important terms and instruments to define the long-term ownership and annual availability of water – the water entitlement (or water-share) and the annual water allocation.

2.8.3 The water entitlement

The entitlement is a perpetual share of the water available in a water system expressed in volumetric terms. It is described in a legal certificate on a state registry and is the equivalent of a land title. Entitlement certificates are usually issued for a term such as 15, 30 or 99 years and are subject to regular review by governments as the understanding of the water source improves. Although water entitlements are issued under terms similar to licences, any change that undermines the yield of water entitlements can be subject to the payment of compensation by governments.

The classes of water entitlements within a given water source vary in priority. For example, the Water Sharing Plan in the Murrumbidgee Valley in NSW confirms the number of entitlements on issue and recorded in the State Water registry:

- 23,816ML of Town Water Entitlements
- 417,631ML of High Security water
- 1,891,895ML of General Security water entitlements.

The town water and high security water entitlements receive annual allocations each water year before any allocation is made available for General Security entitlements.

The entitlements issued in any Australian river valley or groundwater system are now defined in published and legally enforceable water sharing plans (or similar state instruments). The volumetric units issued are finite in number, are based on the understanding of the historic sustainable yield of a catchment or water source, and define water sharing arrangements. Increasingly environmental entitlements or ‘base environmental flow rules’ for river systems are also clearly defined by State and Federal Government agencies within water sharing plans.
State administrators have developed these entitlements in great detail and now have electronic State registers comparable to land titles that define shares of available water within a well-defined water system down to a document defining each share, i.e. an individual water-owner’s share.

Water entitlements issued for a river valley with a reliable flow, with large upstream water storages that capture water for later release, are obviously more valuable than entitlements to extract water from rivers with more ephemeral flows, because water users can request releases of water from dams at the precise time they need the water for irrigation or other uses.

Traditionally these water entitlements for irrigation were issued to land owners and were tied to each land title of farmland adjacent to the rivers, or for each farm within defined irrigation areas with channel schemes diverting and delivering water from the rivers. The volume of water access was based on a variety of methods, usually the ‘deemed irrigable area’, family-living area needs, or the basic requirement to provide water to a farm household and to provide water for livestock.

2.8.4 Annual water allocation

An owner of 100ML of water entitlement cannot access the whole 100ML of water in an irrigation season, unless an allocation of 100 percent is announced by the relevant State Authority. The allocation is the annual announced proportion of entitlements in a particular water source available to users in that irrigation season.

As irrigation commenced in earnest in Australia in the late 19th century, the periodic droughts forced governments to recognise that water needed to be rationed between users, particularly in dry years when river flows dwindled. As a result, all Australian irrigators have held a nominated volume of water (or water entitlements) since Water Acts were introduced in Australian states progressively from the 1870s. Water entitlements within irrigation districts were usually expressed as a volumetric limit or, in the case of individuals diverting directly from rivers, as a limit to the area that could be irrigated and/or the size of the pipe connected to the pump used to lift water from the river.

All Australian water entitlements issued included the specific right of Government to reduce access to water in times of prolonged drought.

By 1990, almost all Australian irrigation entitlements were expressed as both a priority class and as a number of ML. This represented the water available during a year when State Governments announced an annual allocation of 100 percent of entitlements held. In years other than years of below average inflows, the full entitlement was expected by irrigators to be available for use during the water year.

2.8.5 Annual trade

As early as 1938, some irrigators in the NSW Murray districts sought special NSW ministerial approval to transfer unused annual allocations between farms as some farmers ran out of available allocations. However, such requests were unusual and in most seasons farmers seeking more water in an irrigation season could convince governments to allow an ‘overdraw’, or simply to announce increased allocations (or Sales water) – often announcing allocations of 120 percent or even 200 percent of the entitlements held – based on the knowledge there would be widespread underuse on many other farms.

By 1990, irrigation water use was growing in all irrigation districts across SE Australia, and there were much lower annual surpluses in systems to enable extra allocations or to allow overuse. If farmers wanted to increase irrigated production, the only method available was to purchase another whole irrigation farm with the entitlements attached or stapled to the title and grow irrigated crops on that farm too. Some irrigation districts specifically did not allow ownership of multiple irrigation farms, so increasing production was very difficult.
More and more farmers felt the annual allocations provided were simply not enough to optimise their farm production and requested that State Governments allow transfers of water between families owning neighbouring irrigation farms, and then between farmers within irrigation districts. This trade was embraced by farmers and quickly grew to a trade in annual allocation between farmers in different irrigation districts along a river valley, and eventually, in the late 1990s, even between irrigators in different connected river valleys, and eventually irrigators wishing to trade water allocations in different states.

Today the annual trade in announced annual allocations is huge, with annual trade volumes sometimes exceeding the volume of water allocated in some systems (each ML is often traded more than once in an irrigation season).

The capacity to buy or sell water is considered a central part of operating a modern irrigation business in Australia and has enabled many businesses to survive during drought periods either through accessing extra water to keep crops alive, or through the sale of the small drought-impacted announced allocations available for very high values per ML to provide valuable income. Annual allocation prices vary enormously. In the 2007–08 drought, annual allocation prices peaked at almost AU$1,000/ML as owners of orchards rushed to purchase water to keep permanent plantings alive. In a recent wetter season, prices in the NSW Murrumbidgee Valley at the conclusion of the 2015/16 water year (in May 2016), have fallen to just AU$5/ML as opportunities to use the water, or even to store the water, for a following season were very limited.

In the early 21st century, new classes of water users and water owners appeared. For the first time, irrigation farmers operated successfully without owning any water entitlements – they simply depended on purchasing annual trade of allocations each year. Likewise, a new class of water owner appeared in Australia. These were investors who did not own farmland, but simply traded allocations to irrigation farmers recognising water prices on allocation markets rise and fall with seasonal allocation, growing conditions, and the market value of irrigated commodities.
3 Water resources planning and management

3.1 WaterGuide

This practical Guide is directly aligned with the parallel ‘WaterGuide’ published by the Australian Water Partnership. WaterGuide is offered by Australia as providing the elements of an organising framework for decision makers (Aither, 2018).

The framework helps stakeholders appreciate and integrate the various elements of sustainable water resource management and use through six key interrelated stages (Figure 4):

1. Engage stakeholders and ensure participatory management.
2. Understand the water resource and risks to water availability.
3. Understand water demand.
4. Allocate water between users.
5. Ensure user access to water.
6. Enhance system efficiency.

Figure 4. Six elements of WaterGuide (Aither, 2018)
3.2 Basin planning

This Guide focusses on those elements of basin planning that are most important for WUE.

3.2.1 Aims of basin planning

River basin planning provides a process to consider and resolve competing demands for access to water resources at a catchment scale. As that water gets scarcer and competition becomes more intense, the importance of that resource planning and management becomes more critical.

Robust planning and management are required to maximise the value of water to meet economic, social and cultural objectives, while maintaining the health and productivity of the water source. That planning and management can be undertaken at a basin, sub-basin, or aquifer level.

A river basin plan aims to manage a basin as a whole system. This recognises that water resources and their management have impacts across political and other administrative boundaries. The process of developing a basin plan involves government agencies, water users, non-governmental organisations, communities, industries, conservation and interest groups.

The development of a basin plan provides for:

- the development of clear objectives;
- the sharing of resources between consumptive uses and the needs of the environment;
- the development of solutions to issues of common concern; and
- the monitoring, evaluation and reporting on the success of interventions.

Most importantly, basin-scale planning can consider and adapt to the impacts of a changing climate and environment.

3.2.2 Impact on water use efficiency

Effective water resource planning and management at a basin/catchment scale will drive greater WUE because:

- a coordinated plan provides a shared basis for decision-making about sustainable extractions;
- clear water entitlements underpinned by legislation and a basin plan will give water users greater confidence that they will have access to the resource and can plan for use when they need it – this will promote investment in higher value crops, water use industries and enterprises;
- a basin plan will include strategies for demand management across users and uses – demand management strategies can promote water conservation and WUE, rather than a ‘use it or lose it’ mentality;
- a formal process of assessment, monitoring and accounting ensures that allocations are not exceeded – this creates incentives to make best use of the available water; and
- competing demands for water resources across users and the environment create incentives for the resource manager to invest in ways to maximise the available resource and reduce losses in storage and transmission.
### 3.3 Components of a basin plan

#### Developing vision and objectives

A basin plan provides for the management of the water resource to meet economic, social, environmental and cultural outcomes into the future. It is important that the vision for the long-term state of the basin is developed and agreed with stakeholders.

#### Stakeholder and community engagement

Community engagement is pivotal at all stages in the development and implementation of a basin plan. Engagement with non-government organisations, water users, communities, industries, stakeholders, conservation and interest groups ensure that the plan reflects the needs and the objectives of the full community, maximises support for the plan, and reduces risks.

Stakeholders can bring important information that increases understanding by all parties and informs decision-making. Engagement builds consensus, leading to long-term collaborative relationships, and can reduce the risks of conflict between competing users. It provides for transparency and builds trust between government and non-government stakeholders.

#### Understanding the water resource and future risks

It is essential to understand the factors that will impact on water availability and water quality. This step involves:

- identifying the water resources within the plan area; and
- the collection and assessment of existing hydrologic and relevant catchment data, as well as the social, ecological and socioeconomics of the basin and identifying gaps in the data.

This provides the baseline assessment of the water resources of the basin against which future development and climate scenarios can be tested, and against which policy and technical interventions can be measured. This data must be agreed and understood by stakeholders, otherwise there will be no confidence in the outputs that will be used in contentious issues including allocating water between users.

#### Developing long-term strategies

A water management plan always involves a trade-off between the amount of water that can be allocated for consumptive use and the amount required to maintain the ecological processes for the sustainable productivity of a river or aquifer. Long-term strategies within a basin plan include strategies for managing both supply and demand.

Supply strategies may include new dams and weirs, managed aquifer recharge, rainwater harvesting, and the recycling and reuse of return flows.

Demand management strategies include clarity on entitlements and property rights, and may include water pricing and water trade, water restrictions where necessary, time-sharing of access to available water, and education. Where a water resource is overallocated, a plan can also include a transparent process to reduce total water extraction.
Implementation

Implementation is giving effect to the components of the plan.

Government agencies will be responsible where legislation is required to regulate access to water. This will include the establishment and management of entitlement systems and registers, the monitoring of water use and compliance with conditions of access, and pollution control programs. Both government and non-government agencies are involved in the implementation of supply and demand measures within a plan, while river operators are responsible typically for flood management strategies.

Monitoring, evaluation and reporting

A successful basin plan requires transparency, monitoring and reporting, and regular review.

A monitoring, evaluation and reporting framework is used to assess the success of the strategies and actions taken to meet the plan’s targets and objectives and the vision for the basin. The framework provides for adaptive management and revisions to components of the plan when needed.

3.4 Environmental rights and entitlements

As pressure on existing resources and the natural environment increases, water allocation and use decisions must acknowledge the fundamental importance of water for the environment as the basis for system health. So, a central challenge for water resource planning is how to ensure that environmental flows and ecosystem requirements are allocated and protected.

There are several tools to deliver these outcomes:

- Limit the total of consumptive extractions to a level at which the river health is ensured – that requires extensive research to determine the level of diversions which can be allowed while still protecting identified aspects of the river health and related ecosystems.
- Minimise impacts from the use of the river system as an irrigation delivery system – this can include a number of tools including a translucent dam policy, which requires that a nominated percentage of inflows are automatically released, or maintenance of minimum flow rates at nominated river reaches.
- Allocate entitlements to the environment to explicitly manage water for the environment as if it were another market outcome – this model has been implemented successfully where attempts have been made to ‘rebalance’ the level of consumptive use and a proportion of the prior irrigation licences have been transferred to an environmental manager.

A Guide to Managing Water for the Environment, published by the Australian Water Partnership, offers further practical advice on improving the management of water for the environment within an SDG timeframe (i.e. by 2030).

3.5 Water accounting

3.5.1 Need for water accounting

Water accounting is critical when water is scarce so we can share that water according to agreed rules, and manage any disputes over the use of that water. That certainty about rights of access to water and the rules for its allocation are essential for users to have confidence to invest in WUE to drive higher production.
In retrospect, it was fortuitous that Australia had a major drought at the beginning of the 20th century (the Federation Drought of 1901/02) at the same time that politicians first intervened in irrigation. This meant that accounting for water was front and centre of mind when the irrigation systems in Victoria were first set up. Australia is reaping the benefits now. Therefore scarcity, accounting and WUE fit tightly together.

If efficiency is to be improved, there has to be a process for identifying, measuring, recording and communicating information about water availability, supply and use so that everyone involved has a shared information base to manage a scarce resource.

Water accounting systems are evolving to meet those needs. Increasingly, they draw on the principles of financial accounting, and they revolve around the concepts of water assets and water liabilities. For water resource managers, a water asset is typically the physical water that is available to provide future benefits to those who are legally entitled to use water. A water liability is a commitment to provide water to a user. The liability is reduced once the water has been delivered.

3.5.2 Metering and measurement
The ability to measure water at all levels of a river or supply system is a prerequisite of all water accounting systems. The National Framework for Non-urban Water Metering in Australia (DAWR, 2009) provides an Australian standard aimed at providing confidence that water meters used in the field provide measurements within error limits of ±5%.

The National Framework outlines national standards for meter construction, installation and maintenance. It calls for the use of certified installers, maintainers and validators, and it includes requirements for compliance, auditing and reporting. These requirements serve to assure all water users that the available water is being shared fairly. They also provide water users with the tools, and the incentives, to improve their WUE.

3.5.3 Water accounting standards
Water data is collected by many different organisations, but the data can only be meaningfully pooled if they each collect their data with reference to national or international standards or guidelines.

In Australia, for example, the Bureau of Meteorology has been collaborating with the water industry to develop and promote water information standards and guidelines. This has resulted in The Australian Water Accounting Standards (Bureau of Meteorology, 2018), which prescribe how general-purpose water accounting reports should be prepared, presented and assured.

Because standards alone cannot cover every situation, it is also helpful to have a framework of guiding principles for preparing water accounting reports. Australia’s Water Accounting Conceptual Framework for the Preparation and Presentation of General Purpose Water Accounting Reports (Bureau of Meteorology, 2014), for example, was developed by the Water Accounting Standards Board in consultation with water industry experts, financial accountants, and financial accounting standard setters.

Water accounting for water resource managers
Water resource managers need to manage their systems and inform water users as to what resources are available.

All water resource managers should measure, record and communicate water information. Quality assured water accounting reports provide business certainty for water users. Users will then have confidence in their business decisions and that their resource manager’s commitments will be honoured.

Water resource managers in different situations will have different accounting requirements.
The basic requirement is to track and record changes over time. Managers should start each accounting period with an opening statement of their water assets and water liabilities. During the course of the accounting period they should then measure and record all inflows and outflows, which for a surface water system will include:

- **Inflows:** rainfall, inflows to storages, regulated inflows from tributaries and unregulated inflows from tributaries.
- **Outflows:** including evaporation, deliveries to irrigation managers, direct diversions by farm irrigation system managers, end of system outfalls and unaccounted losses (necessary to balance outflows against inflows).

Water resource managers should finish each accounting period with a closing statement of their water assets and water liabilities.

**Water accounting for irrigation managers**

Irrigation managers need to account for their inflows from water resource managers and their outflows in the form of deliveries to their customers. The difference between the sum of these volumes should be accounted for as conveyance losses.

Ideally, the water accounting framework established by the government water policy institutions should recognise these conveyance losses as a separate entitlement. If water is scarce, irrigation managers should then have an incentive to reduce their losses and free that water up for consumptive use.

Metering and monitoring are core tools to create incentives for irrigation system managers to seek and deliver greater efficiency in delivery systems.

**Water accounting for farm irrigation system managers**

Farm irrigation system managers prepare farm water budgets at the start of each irrigation season. These are derived from the planned areas for different crop and pasture varieties for the coming season, combined with expected irrigation water use per hectare for each of the varieties.

Total plantings must be matched with available water resources. If water is scarce it is likely to be the limiting resource, in which case a water market would provide the manager with more flexibility in setting total area of plantings.

During the course of the season, the manager will use a combination of forecast evapotranspiration rates and real-time soil moisture monitoring data to apply the right amount at the right time. If seasonal conditions result in less water availability than was budgeted for, the farm irrigation manager may use regulated irrigation deficits or abandon some plantings, or, if there is a water market, purchase additional water.

**Water accounting for the farm production unit**

The farm production unit should keep records of crop yields and crop returns for each hectare of land planted to a particular crop or pasture variety. Similarly, they should keep records of yields and returns for each megalitre applied to each variety. If water is the limiting resource, they will have an incentive to develop or adopt agronomic practices that increase the yields or returns per unit of irrigation water supplied.
4 Delivery systems

4.1 Level of service

4.1.1 The level of service

The level of service (LoS) of an irrigation system is critical to increasing food production and maximising the efficient use of water. A well determined LoS will deliver the allocated water flexibly, reliably and equitably throughout the entire design area, according to the crop water needs.

There is widespread evidence that there is demand for a good LoS. For example, it is common for farmers to invest in groundwater development even where it is more expensive than surface water so that they can decide when to irrigate, the flow rate and the quantity (subject to constraints on the groundwater resource).

The LoS has six elements. These are critical for farmer crop planning and enterprise decision-making, enabling the move to higher value crops even if this involves higher input costs. These same elements should also form the basis for government decisions to modernise irrigation supply systems:

- **Volume**: the seasonal supply volume (the quantity, seasonal variability and water quality).
- **Offtake**: delivery or service point conditions (channel capacity, off-take flow rate, off-take elevation).
- **Scheduling**: relative flexibility of supply (continuous flow, rotation, on-order, or on-demand).
- **Reliability**: control and operation of structures to supply the intended quantity and flow consistently.
- **Equity**: how to ensure water supply to the lower end of canals.
- **Cost**: this will determine the willingness of the farmer and government to invest.

The concept of LoS applies at the offtake points within the irrigation system, but also applies at other offtake levels within the system. For example, LoS is relevant from the main canal to distributaries through successive levels until water is delivered to the individual irrigator.

The LoS that is created by the infrastructure, management systems, and operational policies determines the level of WUE that is possible in terms of ‘crop per drop’.

4.1.2 Instantaneous water on demand

LoS means getting the water when, where and how you want it. Farmers by choice would like to get water instantly without having to order, just simply by starting irrigating. This is known as ‘water on demand’ and in an ideal world this would be provided to farmers and WUE would be maximised.

In practice, it is often either technically impossible (in the case of canal supplied system) or too expensive (in the case of pipeline supplies) to provide water on demand. Historically, canal-based systems have provided a relatively poor LoS, with long order periods and unreliable flow rates, which has inhibited the ability of farmers to achieve a high level of WUE. The simple test to determine if the LoS is adequate is to see if the farmers at the end of the system receive adequate water supply. Invariably, these farmers receive an inadequate LoS.

Over the years, farmers have adapted their operations to improve their LoS by:

- converting to groundwater supply or direct river diversions where possible, despite the higher costs;
- constructing small on-farm storages despite the loss of land and cost of additional pumping;
• accepting or encouraging delivery losses in the system despite water shortages;
• utilising the inherent flexibility in rice paddy irrigating by allowing a range of water levels even though it reduces yields; and
• physically interfering with the system by installing temporary weirs, altering structures, or pumping directly from canals to obtain an advantage.

However, with modern technology, management systems and modernised infrastructure, it is possible to develop supply systems that almost provide water on demand and effectively enable farmers to adopt very high WUE.

4.1.3 Ordering system and key practices

A key practice that determines the LoS is the type of “ordering system” that is implemented. This can range from a simple local arrangement between neighbouring farmers to a sophisticated web-based ordering system, including remote controlled smart meters connected to the operation of the canal structures.

The provided ordering system, and hence the LoS, is affected by the following practices:

• The capacity of the canal or the pipeline which must be optimised – there is an optimum capacity where the cost is affordable, and the flexibility is sufficient to allow farmers to decide when to irrigate:
  ◦ in the case of large canals/pipelines, capacity is related to the peak crop water demand
  ◦ in medium canals/pipelines, capacity is related to the peak demand, but also must consider whether irrigation is concentrated
  ◦ at a particular time of the day (e.g. daylight) which requires increased capacity
  ◦ for small canals/pipelines (e.g. <30 customers), capacity is related to the delivery rate of each outlet and the number of outlets that can operate at one time.

• Conjunctive use of groundwater: where groundwater is also used, a simpler ordering system can be implemented and farmers can still obtain a high LoS by mixing and matching supply with groundwater pumping.

• Storages within the supply system can increase LoS – midstream to even flows and tail end to collect excess water, although modern technology can minimise the need for these.

• On-farm storages – many systems utilise farm storages and on-farm pumping to enable better LoS. However, these should be minimised and, with pressure pipelines, should not be necessary.

• Interconnection within pipe supply systems – the use of interconnected pipes in the network (often referred to as ring mains) provides flexibility and increases the LoS.

• The installation of meters (often “smart” meters that can be remotely controlled) enables real time monitoring and operation of the system.

• Communication systems (mobile phone network) can be used to ensure water is delivered on time and at the right place and volume.

• The organisation skills and management practices are key to the implementation of LoS

• Sufficient revenue to fund maintenance and the operations to deliver the LoS.

Delivering the optimal level of service involves a balance between costs, water charges and LoS. There will be a debate between all parties – government, delivery organisation and the farmer – about the proper balance between these three aspects. The adoption of water charging that reflects the full operating costs will help ensure a proper balance between revenue/costs and LoS.
4.2 Canal delivery systems

4.2.1 Design of canal delivery systems

Canal Capacity

Canals, also known as channels, remain the most cost-effective way to distribute large volumes of irrigation water where the landform is relatively flat, where gravity supply negates the need for costly pumping. In Australia, irrigation canals:

- vary greatly in size, catering for flows between 10,000ML/day and 20ML/day. Typically, pipelines start to become a potential economic alternative at flow rates less than 20ML/day (or where the topography or soils are not suited to a gravity canal system); and
- are generally earthen, although lined in areas with more permeable soils. The canal size and lining are fundamental to address water weed growth, silt deposition, bank integrity, etc., and ensure LoS.

The larger the canal capacity the greater the opportunity to utilise unused canal capacity as active storage that may be called on immediately to increase the LoS offered to irrigators. This enables efficient delivery to meet crop demand on time. Thus, understanding channel capacity relative to crop demand is fundamental to achieving WUE.

Service Points: type and size

Service points provide the connection to the irrigation scheme and are the source of water supplying a particular property or irrigation block. They play a defining role in the LoS provided to that property or block as they control the flow rate and its consistency. Typically, in Australia all irrigation service points are metered to allocate the water resource and account for water resources for management and billing purposes. Service points with higher flow rates typically provide more flexibility for on-farm irrigation decisions and provide capacity for more efficient irrigation events.

In 2010, the Australian Government – with the support of State and Territory Governments – implemented the National Framework for Non-urban Water Metering (DAWR, 2009) which “provides a nationally consistent basis for water metering. The National Framework aims to deliver the primary objective agreed by Australian, state and territory governments to provide an acceptable level of confidence that measurement performance in the field is within maximum permissible limits of error of ±5%.

The National Framework outlines:

- Implementation of national standards for meter construction, installation and maintenance
- Use of certified installers, maintainers and validators
- Requirements for compliance, auditing and reporting.

The National Framework also specifies that:

- All non-urban meters shall comply with the national metering standards by 1 July 2020, unless otherwise exempted by the relevant jurisdictional government department or agency
- Any meter installed after 30 June 2010 must comply with the national metering standards
- Any meter installed prior to 1 July 2010 shall be replaced with a compliant meter by 1 July 2020. Replacement shall be undertaken at the earliest opportunity, such as when major maintenance is required on the non-compliant meter.”
Service points may range in capacity from flow rates as little 1ML/day for small horticulture properties, up to 30ML/day for larger broad-acre irrigation properties.

The size and number of service points on a particular canal also feeds into considerations around decisions to achieve the desired LoS, for example:

- Consideration of LoS impact on the automation efficiency and the capacity to exercise the necessary level of control to actively utilise spare canal capacity.
- The ability to provide accurate data to target channel remediation.
- Consideration of channel structure sizing, locations and functionality.

**Structures and Control**

Regulating, check and overflow structures also play a key role in defining the LoS that can be offered to customers. The general form of these structures is described below with increasing levels of control to the irrigation scheme operator and LoS to the irrigation customer:

- Manually read and adjusted infrequently.
- Remotely read and manually adjusted more frequently.
- Remotely read and adjusted frequently during work hours.
- Automatically operated 24 hours per day during the irrigation season.

Key factors to consider in addition to levels of service offered include:

- occupational health and safety factors, e.g. associated with manual operation of gates or the insertion or removal of ‘drop boards’ in check structures; and
- skills and training needs and subsequent support services.

All of these factors can then be considered within a traditional cost-benefit analysis in association with capital and operating costs, including costs associated in making a transition from one level of service to the next or a step change.

**Communication system**

Typically, the radio communication system deployed to support increasing LoS (i.e. from remote reading through to full system automation) will have increasing levels of redundancy to guarantee LoS and address areas of key operational risks.

At its most basic level, the telemetry network provides for the flow of data to a control centre where management decisions can be made, through to a fully automated system that makes regular adjustments to control structures to optimise canal operations and system efficiency whilst guaranteeing the required customer LoS.

**4.2.2 Water ordering**

A good water ordering system is fundamental to achieving WUE.

Traditionally, water ordering has been a function of the time taken for water released from a dam higher in the catchment to be delivered to a farm’s service point. Typically, in Australia this has ranged from 1–10 days. Clearly this has challenged the capacity to deliver the necessary irrigation timing to optimise crop yield.
While weather forecasting has improved significantly over the past twenty years, rainfall forecasts can be extremely patchy, particularly when forecasting more than a couple of days in advance. For example, actual rainfall may fall well short of that forecast which then leads to significant under irrigation, reducing crop yield. Conversely, it could also lead to over irrigation (where rainfall is higher than forecast) with soils becoming waterlogged and anaerobic for a period of time with subsequent crop yield reductions.

As a consequence, the period required for the placement of water orders has a direct impact on crop yields and farm productivity. The shorter the water ordering period, the higher the LoS through increased flexibility in irrigation decisions guided by crop stage, soil moisture and weather conditions.

4.2.3 Management issues for irrigation districts

Figure 5 provides an indication of a typical water supply arrangement in Australia from a public dam to an irrigation district with:

- 70 percent of the water released from the dam being diverted from a river offtake at the main diversion point to the irrigation district;
- 49 percent of the water released from the dam being delivered to the farm offtake (after passing through the irrigation district’s water distribution infrastructure); and
- only 37 percent of the water initially released from the dam being actively used by the irrigated crop.

Figure 5. Typical efficiency losses through an irrigation system (Rubicon, 2015)

The largest water losses typically occur during the transport of water. However, all systems are different and a first step in reducing system losses is to understand the system’s water balance, i.e. what water is going where, how and when.

A well-founded water balance will support targeted investment decisions that deliver water savings that drive enhanced economic and/or environmental outcomes. Options that deliver the lowest cost per megalitre of recovered water are more likely to be supported. However, investments for water savings often deliver multiple benefits (and sometimes disbenefits) and have different timeframes over which these may be realised.
An irrigation district’s water balance typically comprises the following elements:

1. Bulk diversions/system inflows to the district (measured and billed/accounted for).
2. Deliveries to individual customers (measured and billed).
3. Credited outflows – credits for passing water through the system.
4. Rainfall.
5. System losses.

Items 1, 3 and 4 are generally readily determined, assuming that there is some form of relatively accurate measuring device at the intake point to the irrigation district.

### 4.2.4 Understanding losses

The main components of total system losses are shown below:

- **System outfalls/overflows (8–12%):** this is the volume of water passed through outfall structures or escapes for which the irrigation district receives no credit, i.e. uncontrolled spill events. It may be the result of rainfall rejection, where irrigators don’t take ordered water, or a system failure.

- **Unauthorised use (2–10%):** this is the volume of water that is actively diverted from a district’s distribution infrastructure and is not billed or formally recognised or acknowledged in some form.

- **Measurement of water usage (5–25%):** ideally, water usage would be measured by a prescribed water meter that was fit for purpose with a reliable accuracy of ±5%.

- **Channel seepage (10–15%):** seepage is water lost through micropores in channel beds and banks in earthen channel systems.

- **Channel leakage (25–30%):** leakage is the loss of water through the banks of a channel, and around oффtakes that service individual properties, via macro-pores.

- **Evaporation from channels (5–15%):** this system loss element is readily calculated from the normal channel surface area and recorded evaporation rates.

Each loss causation factor may comprise fixed and/or variable elements:

- **Fixed:** not dependent on flow rates and delivery volumes, but does depend on season length and climate.

- **Variable:** dependent on flow rates, delivery volumes, climate and season length.

### 4.2.5 Addressing your system losses

Options for addressing the six main loss factors are outlined below. All potential interventions should be rigorously assessed on a cost-benefit basis. The fundamental building blocks should be the consistent measurement and accounting of water, water product definition and associated levels of service.

**System outfalls/overflows**

This loss is generally reflective of the level of management control over the irrigation distribution system and the capacity to utilise spare channel capacity. It also reflects the policies of the irrigation district regarding levels of service (e.g. water ordering), water tariffs, the ability to re-regulate ordered water which is not taken by a customer, etc.
Interventions may range from changes in system management (potential low capital cost but potentially high political cost) through investment in infrastructure (to exercise higher levels of monitoring and control), to full channel automation.

All irrigation scheme members need to understand that once water is diverted into a district their collective actions ultimately drive the success and long-term viability of the district. Unauthorised use reflects the lack of adequate systems to identify and control such use. Interventions may include:

- Moving compliance staff between areas of the irrigation district to ensure that familiarity with customers doesn’t lead to perverse outcomes.
- Undertaking an audit of outlets/supply points from the channel system and matching them against the accounting and billing systems.
- Customer education – unauthorised use should be described as stealing from your neighbours.
- Introduction of a penalty framework for customers identified as stealing water:
  - loss of benefits, e.g. tariff discounts, share in water savings, etc.
  - penalty tariff for estimated volume of stolen water
  - suspension of water delivery services.

To be successful, irrigation district policies need to be well understood and supported by the majority of irrigation customers.

**Measurement of water usage**

The reliable measurement of water usage is a fundamental building block in establishing broader policy frameworks at the basin, irrigation district and farm scales, to ensure equity between water users, defining the water product, levels of service and water pricing.

In the absence of accurate water metering, a repeatable and rigorous method for determining usage should be adopted. If water bailiffs are responsible for determining this water usage then water bailiffs should be moved regularly between management areas to minimise risks of collusion.

Upgrading or implementing appropriate metering technology comes at a high cost in terms of the upfront capital cost as well as the ongoing operating and maintenance cost. These costs need to be carefully considered against other factors such as sustainable water tariffs.

**Channel seepage and leakage**

The first task in exploring opportunities to address this potential loss component is to identify priority areas prone to loss. This may involve simple visual inspections, electro-magnetic surveys or ‘pondage tests’. To undertake a pondage test, a section of channel is blocked off with embankments or regulators and then filled with water. The water loss rate is calculated from the rate of water drop taking account of evaporation and rainfall.

Lack of channel bank maintenance will generally exacerbate leakage rates over time, but the interaction can be complex. For example, silt deposits can lead to reduced seepage rates but can lead to the growth of water weeds and so reduced channel delivery capacity. Equally, the removal of weeds and silt to improve levels of service can exacerbate seepage rates.
Intervention options include:

- rationalising/decommissioning or reconfiguring open channels; and
- Channel lining (compacted clay, HDPE, etc) – the use of HDPE and other synthetic liners should also be considered against safety, environmental and maintenance factors.

Opportunities to reduce evaporation losses are largely related to the scale of the channel infrastructure footprint. Interventions may include:

- rationalising/decommissioning channels where alternative supply options exist;
- replacing open channels with pipelines where cost effective;
- shortening the irrigation season from the introduction of new/alternative crops or the use of alternative sources of water supply during non-irrigation periods; and
- reducing the infrastructure footprint during non-peak irrigation periods.

The viability of any option needs to take account of wider implications of any option for service levels/peak flow requirements, avoidance of costs associated with management of weeds, and potential reductions in system outfalls/overflows.

### 4.2.6 Irrigation district modernisation

Modernisation of an irrigation district can involve a range of elements including:

- reducing system operating losses to increase water available to irrigators and/or the environment;
- increasing levels of service offered to irrigation customers to increase the productivity and profitability of their irrigated farming enterprise. For example:
  - Increasing peak flow rates available on-farm
  - Reducing water ordering periods (i.e. the time between placing the water order and having it delivered to optimise the timing of the crop irrigation and maximise yield)
  - Implementing an instantaneous water accounting system so that irrigators know how much water they have left
  - Web based irrigation scheduling tools, etc;
- consolidating the district footprint to reflect optimal supply and demand features by removing inefficient supply channels and infrastructure; and
- converting smaller channel systems to piped supply. This is particularly applicable for smaller systems (area less than 5,000ha or flow < 500l/sec) on sandy soils supplying higher value sectors.

A critical element in successfully implementing a modernisation program is engaging with customers to tailor the program and garner broad support. This should also include extension programs so that the necessary skills are developed and applied in the right areas to maximise the benefits from the modernised system. This is likely to apply from the managers of the irrigation district down to the individual farmer using the modernised system.

Modernisation of an irrigation district is likely to result in:

- fewer staff but with higher skills levels;
- a more complex (and sometimes more expensive) asset base;
- a more expansive asset management system and asset maintenance program;
- the need to maintain some inventory of key ‘switch out’ components or a contractual arrangement for the supply of such components within an agreed time that aligns with customer service levels; and
• a revised water tariff framework that assists, drives and supports the implementation of the modernisation program and sustains the water delivery business.

4.3 Piped systems

4.3.1 Piped systems

Piped systems may involve higher initial capital construction costs but can also provide higher levels of service. It is helpful to see piped systems in two classes:

• High pressure systems where the end user has sufficient pressure in the supply to drive most end uses, e.g. drip-fed irrigation of perennial plantings such as vineyards or orchards.
• Medium- or low-pressure systems where the supply feeds an on-farm storage and the end user has to re-pump the supply for his own use.

Piped systems involve lower levels of losses from seepage, leakage and evaporation in distribution and reduce opportunities for unauthorised access.

4.3.2 Levels of service

The customer’s LoS needs to be clear in terms of the overarching rights to access the system and to order water:

• Delivery system entitlements are defined in terms of:
  ◦ Peak order flow rate in terms of litres/sec; and
  ◦ The aggregate flow in terms of megalitres delivered over 7 days or per day.
• Water ordering: keeps delivery commitments within the available system capacity. It evens out demand and delivers a more predictable, reliable service to customers. There are options for how it is implemented in practice:
  ◦ Water availability can be dictated rigidly by the system operator, either by time shifting orders or restricting supply. This has advantages for system operation but can compromise farm efficiency by delivering the wrong amount at the wrong time.
  ◦ Under water on demand the crops receive the right amount at the right time, but this requires greater system capacity and flexibility.
• Timing: Farmers have preferred watering times:
  ◦ Aligned with peak and off-peak electricity tariff times in low pressure districts where farmers have an electric pump
  ◦ Related to time of day in high pressure systems, e.g. noon to 6pm (hottest part of the day) in table grape growing regions where cooling sprays are popular
  ◦ Daylight for checking the on-farm system (check sprinklers for snails, leaks)
  ◦ Fit in with other farm activities/personal commitments, e.g. working off-farm.
• Editing and cancelling orders: maintaining high WUE requires flexibility. This means that farmers must be able to edit or cancel orders without penalty in the event of:
  ◦ Rain forecasts can be unreliable (orders may be cancelled if rain arrives early)
  ◦ The time needed for surface irrigation is seldom known precisely when irrigation starts
  ◦ Changed conditions, e.g. wind (affects distribution of water from sprinklers).

4.3.3 Water metering

A key policy for WUE is the use of water measurement. Metering is required at all levels for water resource accounting, delivery systems and at the farm gate. Water meters enable water accounting and checking of system efficiency and performance. This informs maintenance programs by providing data on:

• losses between water source and customer meters;
• Level of service (flow rate, pressure) issues; and
• Pump performance.

Meter selection

Select the meter size, type and output to suit the intended purpose. Consider meter cost, life expectancy and accuracy over the flow rate range against significance of usage. Size the outlet assembly to avoid excessive head loss. Oversizing reduces accuracy and adds unnecessary cost. Consider water quality issues.

Farm outlets

Design standard outlet assemblies:

• More than one assembly size may be needed if there are different sized properties/delivery shares, e.g. unusually large farm due to amalgamation.
• Outlets and meters may be dedicated or shared, used by several farmers in turn. Shared meters leave consumption open to dispute.

Meter reading

A decision on the frequency of manual meter reading involves a balance between:

• cost of reading;
• risk of prolonging time taken to detect meter failure (lost revenue);
• financial cost of delaying billing; and
• water accounting needs, e.g. updating district or farm usage for reporting.

Remote monitoring is advantageous where it:

• involves bulk meters and high use farm outlets, remote and inaccessible meters;
• avoids labour input for manual meter reading and meter reading data entry;
• provides current water use and flow rate data which can be made available online from anywhere;
• informs system operator and farmer decision-making;
• historic data informs decisions, fault-finding, etc. (avoid saving too much data); and
prompts detection of many types of meter failure – reduces the need for conservative (i.e. in favour of the farmer) usage estimation.

**Meter maintenance**

Programmed maintenance schedule: Program bulk usage meter calibration regularly (e.g. annually). Provide in-field farm meter accuracy checks as this improves farmer confidence. Plan meter replacement. Mechanical meters should be retired at a given volume and serviced if within that. Electronic meters are more expensive and replaced upon irreparable failure.

4.3.4 Operation

**Automation**

System automation is used to reduce labour costs and increase delivery efficiency. This can be achieved by pump station automation and automating the opening/closing of farm outlets. Orders feed into the predictive component of demand in channel automation.

**Opening outlets**

Outlets can be opened automatically, e.g. controlled by radio/SCADA. This approach, generally:

* responds to orders (avoids non-compliance with irrigation water orders);
* places greater responsibility on the system manager in case of failure to open;
* suits on-farm irrigation systems which can be set up in advance (reduces farmer work load); and
* avoids staff driving around opening/closing valves in the field.

To avoid pump and pipe damage, it is important to stagger both the starting and the stopping of large flow rate orders by a few minutes to avoid sudden pressure changes or water hammer.

**Alarms**

Alarms can be triggered by on-site telephone dialler (voice message) or SCADA SMS. Alarms target appropriate staff escalating to the next listed recipient if there is no response.

**Field staff**

The benefits from retaining field staff include:

* Can be in the field 7 days a week.
* Check channel regulator and offtake debris screens daily.
* Manually read mechanical meters and functioning electronic meters with communications issues.
* An information source for farmers.
* Act as eyes and ears in the field, including during emergencies, e.g. SCADA communications failure.
* Traverse the entire network.
* Deter and report theft, non-compliance with irrigation orders, leaks.
* Conduct maintenance.
Compliance

Non-compliance, such as taking water at the incorrect flow rate and/or time, reduces the LoS to customers and reduces the opportunity for the system operator to sell water. This can manifest as poor pressure and flow rate, leading to lost crop production.

Emergency management

Emergency management plans should be in place and should include communication protocols and preparation of critical spare infrastructure.

4.3.5 Design

Design criteria

Establish the basis of design, considering a range of factors such as:

- Current and future expectations of the system.
- New or replacement? Integrated with existing infrastructure?
- Basis of capacity, e.g. 10mm/day x farm area plus 5% losses.
- Demand pattern, e.g. annual/seasonal and daily, district level down to farm level.
- Adequate “spare” capacity to enable flexibility in deliveries – this can also reduce system management and operating costs.
- Design to a target demand and assess whether this results in a realistic capital and operating expense benefit/cost ratio.
- Consider operating expense (labour, energy), maintenance vs capital cost, e.g. smaller pipe with higher head loss requires higher pump operating pressures.
- Design with consideration of full flow rate range from near zero to maximum capacity – size pipe generously, do not under-design.
- Performance will deteriorate with age. Water quality aspects should also be considered, e.g. silt and the need to scour pipes. Air valves are also critically important.
- Domestic and stock (D&S) and other uses.
- Increased system capacity for smaller spurs considering level of service can deteriorate when there can be less averaging of demand across outlets.
- Maximum and minimum outlet flow rates to share network capacity equitably.
- Network storage – this may be small (D&S tanks) to large (dams). Channels can also be a form of network storage. Network storage can reduce peak demand and therefore infrastructure flow rate capacity. If on-farm storage is of sufficient size it can reduce peak demand flow rates to a minimum of average demand flow rates.
- Storage and booster pump stations may be an alternative to having higher capacity at the head of the system that remains under-used most of the year.
- Need for backflow prevention.
Design optimisation

- Risks:
  - Water Hammer: Conduct surge analysis. Installation of appropriate surge prevention measures may avoid unexpected costly system damage and reduced asset life.
  - Freezing water meters: Be able to drain pipes in winter if there’s a risk of freezing.
  - Sedimentation in pipes: Consider future need for treatment, e.g. chemical injection, air scouring or pig extraction points.

- Metered Outlet Assembly – will outlets be shared or one outlet per farm?
  - Outlets shared between several farms have lower capital and maintenance cost than one outlet per farm, but limit the flexibility of water delivery timing for those farmers and tend to increase risks of disputes regarding water usage and access.

- System start-up and shut-down:
  - Incorporate pressure sustaining/anti-drainage measures to avoid unplanned pipe network draining. Speeds up system re-start, e.g. after district power outage.
  - Scour valves to drain the system in a timely fashion to allow emergency maintenance.
  - Protect old infrastructure fed from a new high-pressure system, e.g. discharge into a pressure breaker tank and gravity feed the old pipe. Large expensive pressure reducing valves can experience pressure control issues.
  - Specify preferred pipe sizes, pressure rating and materials.
  - Practical and cost-effective to install and maintain.
  - Lower pressure-rated pipe may be difficult to install without damage and may be susceptible to crushing by tightening repair fittings.
  - Some pipe and fitting sizes are less common and more costly than larger.
  - Beware of incompatible fittings/pipe of the same nominal diameter.
  - Need specialised equipment or expertise to install? Can it be repaired urgently? e.g. welded PE.

- Critical spares:
  - Pipe, fittings, etc, kept to allow prompt repairs, minimising disruption to supply.
  - Limit pipe sizes, valve and air valve sizes, etc, to avoid the need to buy and store a large quantity of bulky expensive stock, e.g. PN12 DN225, 300, 375 & 450 PVC-o.
  - Pipe such as PVC must be protected from exposure to UV during storage.

- Air valves:
  - Air entrapment causes unnecessary pipe failure, loss of pipe network performance and reduces asset life.
  - Appropriate selection and installation are essential for optimal performance.
  - Oversizing may reduce air valve efficacy, e.g. valves intended to manage rate of system filling.

- Remote monitoring:
  - Reduces the need for field investigation, data is available quickly.
  - Detect and investigate network performance and LoS.
Data for more than one device can be sent from one remote monitored site, e.g. install a pressure sensor by a farm outlet or install two farm outlets in close proximity

- Detect theft, leaks, etc
- Data can be used in automated system control
- Historic data allows trending, retrospective investigation
- Locate sensors strategically, e.g. highest/furthest places in the network.

- Operating costs, e.g. mobile network vs radio. Radio has higher initial cost, lower operating costs. Beware of unnecessary data harvesting. Spurious data can clog communication systems and result in high unplanned expense.

- Data Warehousing – consider the intended future purpose of the data:
  - Considerable expertise is required to design effective SCADA systems. Ensure uniform standards, compatibility throughout
  - Equipment validation/calibration
  - Harvesting inaccurate data may result in lost opportunity, false sense of security and wasted resources
  - Pump station capacity may deteriorate over time. Provide pump redundancy and critical spares (control equipment, variable frequency drives, etc) to reduce risk of total failure. Design and operate the system to prolong pump life and protect pumps from damage.

### 4.4 Efficient use of groundwater

#### 4.4.1 Groundwater levels of service

Groundwater is often preferred as a water source because the farmer has greater control over the timing of access to the resource. This means they have a high LoS, with access to water on demand at variable flow rates. This compares with being a member of large surface water supply system where they often face long order periods and an uncertain flow rate controlled by a third party.

This level of control and high effective level of service can enable a very high level of WUE.

#### 4.4.2 Groundwater and surface water systems

Groundwater may be the sole water source for irrigation or may be used jointly with surface water. When used conjunctively, it can play a role to smooth out the supply/demand balance across seasonal patterns of water availability, or across longer term wet and dry sequences.

Efficiency in the supply and use of groundwater sources relies on effective governance and resource management arrangements. That is also true of surface water resources. However, the management of groundwater differs significantly due to the differing physical processes and infrastructure involved in water storage and delivery.

Large-scale surface water supplies are harvested and stored in publicly owned dams. The distribution network of shared channels or pipelines may be public or private depending upon the scale of the scheme. Achieving efficiencies in water delivery requires attention to the operation and maintenance of that infrastructure.
By contrast groundwater resources are stored in aquifers with recharge occurring naturally (in most cases) when rainfall exceeds evapotranspiration. Access to the resource is normally from private production bores across multiple properties overlying the source aquifer. This structure of private bores accessing a shared resource creates risks that are different from those faced in surface water systems such as:

- the ‘rule of capture’ – if unregulated, pumpers are effectively granted exclusive rights to that portion of the groundwater that they pump;
- increased levels of pumping reduce the level of the aquifer, leading to an incremental increase in the cost of pumping for all users of the connected resource; and
- the pumping can lead to adverse impacts on surface water systems and environmental assets that depend on groundwater.

These differences in the nature of the two resources mean that there are generally different arrangements for resource management although increasingly there is a holistic approach that brings together the management of both sources of water.

4.4.3 Planning controls

Effective planning controls are required to achieve efficient access and use of groundwater. These include:

- an understanding of the resource defined in terms of the total volume available for consumption, and recharge rates over an extended period;
- setting of resource condition limits which are upper limits to the level of pumping that should not be exceeded;
- an entitlements and allocation framework that is consistent with these resource condition limits; and
- monitoring and compliance measures to ensure that abstraction is maintained within these limits.

The extent of the planning required for a particular aquifer depends on the scale of the resource and the level of development. Less emphasis is required for the management of small aquifers, or larger aquifers which have little development. For major aquifers, increasing levels of development require an increased commitment to management as illustrated in Figure 6.

4.4.4 Water use efficiency

Robust planning arrangements provide economic incentives for irrigators to use water efficiently in a capped resource with clear entitlements and relatively high levels of development. However, all groundwater users have a shared interest in achieving high levels of efficiency because:

- groundwater is generally more costly to pump than surface water;
- pumping costs increase as the season progresses because intensive local extraction leads to increased seasonal drawdown, and increased lift; and
- in some circumstances, seasonal drawdown results in irrigators losing access to groundwater, with impacts on crop yield and/or increased capital costs to lower pumps or deepen bores.

There are also incentives for efficient irrigation in aquifers with relatively low yields and brackish water. Low yielding bores constrain the area of crop that can be irrigated. Efficient application of the limited water supply will enable greater productivity/unit volume of water.
Where groundwater is brackish, there is potential for salt to build up in the rootzone and impact upon productivity. Efficient irrigation in this context must meet crop water needs, and in conjunction with rainfall, provide leaching to prevent salt accumulation.

Figure 6. Stages of groundwater resource development in a major aquifer and their corresponding management needs (Tuinhof et al., 2006)
5 Farm irrigation and drainage systems

5.1 Surface irrigation systems

Surface irrigation systems include all methods where water is applied to the soil by overland gravity flow. Irrigation water might be conveyed to the field by pipeline (pressurised or gravity) or open channel. Water application is defined by the soil moisture content of the profile and not by the operator, i.e. the drier the soil the more water will be applied regardless of any design application. These systems would include:

- border check;
- lasered contour;
- furrow;
- bankless channel; and
- level basin drain back systems.

One adage governs all design criteria: Fast Water On – Fast Water Off.

‘Fast Water On’ means that all systems should be designed to allow for the flow of water onto the field in the shortest practical time. ‘Fast Water Off’ means that systems should be designed to allow drainage in the fastest and most efficient way possible. The aim of fast water-on and fast water-off is to make sure that the applied water does not exceed the root zone of the plant, reducing accessions to water tables and wasted water.

5.1.1 Water-on

Flow rate

Ensure a flow that matches the bay area and soil type. Any soils with slow to moderate drainage of the sub-soil can be suitable for surface irrigation. Clay profiles (uniform cracking clays in particular) are ideally suited to surface irrigation, however any soil type where the sub-soil allows some drainage is suitable. The following flow rates will result in the highest application efficiencies:

- Heavier Clay soils – ensure a flow rate onto the bay at no less than 4–5ML/day per hectare of bay area.
- Loamy and sandier surface soils – ensure a flow rate onto the bay of 6–10ML/day per hectare of bay area. Watch for erosion at the turnout (bay outlet).

The conveyance system must be designed to carry the design flow rate. Ensure that the system design flow rate is matched to the total area to be irrigated and that the estimated total demand can be met within an acceptable tolerance for the crop to be irrigated. Modern systems are designed so that the entire system flow rate is turned onto one bay at a time.

Watering times

These are dependent on flow rate and prior soil moisture levels. However, the design should aim to reduce maximum ponding times on bays to under 12 hours, and depending on crop and system type as low as 8 hours. Rice in tropical areas does not require ponding and should be irrigated according to these design guidelines.
Channels

Channels are generally constructed in a trapezoidal shape for ease of construction. Ensure that they are well constructed and maintained. Reduced WUE is mainly a result of poor channel construction and maintenance. Channel failure can be catastrophic and lead to yield loss and even crop failure. Ensure all structures are sized correctly for the design flow rate and limit velocity to 0.7 m/sec at design flow. Bay turnouts (bay outlets) should be designed to minimise velocity and turbulence.

Pipelines

Surface irrigation pipelines are generally low-head systems and are typically constructed from low pressure pipe materials. High volumes and low pressure rated pipes can lead to catastrophic pipeline failure due to surge pressures. Systems should be analysed for surge (water hammer) as part of the design process. A key to protecting pipelines is to operate valves and pumps very slowly. Pump start up and shut down should preferably be controlled automatically (with variable speed drives). As a rule of thumb, start up and shut down should not be less than 5 minutes and, depending on the system, possibly 10 minutes. Bay turnout valves and inline valves should also operate over similar time spans.

Laser Grading / GPS machine control

Either of these technologies is essential to ensure that the field is even, and that ponding cannot occur at any location on the bay. Bay slope is only important for the drainage phase. Maximum slope for border check is 1 in 80 (for a 30 m wide border check bay).

5.1.2 Water-off

The drainage phase should not be impeded in order to limit the intake opportunity time – and hence maximum ponding time – so do not restrict water flow off bays, and ensure that there is no ponding on bays due to uneven layout. Where very flat or zero slopes are used, consider furrow or raised beds to assist drainage.

Drains

Design both for drainage from bays and also to take into account rainfall runoff, particularly in tropical areas. Ensure that no water ponds onto bays at the peak design flow rate. Ensure that all structures are designed for the peak flow to limit erosion of the bed material. Consider the cumulative runoff in bankless channel systems where the supply flow is increased by runoff from the upstream bay. Allow for up to 60 percent of the applied water to runoff from a bay in these systems.

Recycling

Surface irrigation systems – especially border check – can suffer from poor distribution uniformity without loss to drainage. Runoff from well designed and constructed irrigation bays can range from zero to say 20 percent of the applied water. Zero runoff on border check for instance will result in a very low intake opportunity time at the lower ends of the bays and hence poor uniformity. Runoff from surface irrigation systems is unavoidable and arguably necessary for highest distribution uniformity.

Drainage Pumps

Without effective drainage recycling, it will be difficult to achieve the highest WUE. Pumps must be designed to cope with the peak runoff and should be capable of widely varying flows, from minimal bay runoff to high rainfall runoff flows. The minimum capacity of the drainage recycling system should match the supply flow rate. The pumps should be designed to deliver water back to the conveyance system.
commanding as much of the irrigated area as possible. With runoff at 20 percent of the applied water, the reuse system should command a minimum of 20 percent of the irrigated area.

In practice reuse, water quality may be degraded (e.g. with salinity, nutrients, sediments, pesticides) and the system should be designed to command a greater percentage of the irrigated area so that contaminant loads can be managed. Poor quality runoff water may require diluting with supply water. In this case ensure that the reuse point is as close to the supply point as possible.

5.2 Contour bays to bankless channel checks

5.2.1 Historic development

The most common form of flood irrigation adopted by dryland farmers in SE Australia in the 1920s and 1930s was contour bay irrigation. This utilised the natural lay of the land to create near-level bays with a small bank around the edge of each, across the landscape, that are filled with water and progressively drain into the next slightly lower contour bay (North, 2008).

As the channels were being constructed, water entitlements were issued and supplies of water were made available, farmers had to develop their own farms to enable irrigation. This was almost universally to enable flood irrigation of broad acre crops and pastures. There were several common features of the large SE Australian irrigation areas and districts:

- **Flat terrain**: The natural landscape in most SE Australian large-scale irrigation areas was flat, with natural falls typically of 1:1000 to 1:2000 away from the gravity channel supply system which had been constructed to follow the ridge lines.

- **Poor drainage**: Drainage of both the soils and the landscape was initially poor. Often sub soils were saline, increasing the risk of soil salinisation if surplus irrigation water was not drained from the landscape. Over time district drainage schemes were constructed to assist in relieving water-logging caused by heavy rainfall and over-irrigation.

- **Limited resources**: Most farm-scale equipment was not suited to large scale earth moving. Earth moving to create irrigation layouts and irrigated beds was extremely time consuming and expensive, and the bulk-removal of the very fragile layer of topsoil to establish new grades for irrigation layouts using mass-earthmoving equipment exposed hard clay subsoil which was difficult to irrigate.

Overtime, contour bays have been extended and improved:

- To terracing, which extended the scale of the bays to a larger area.
- Laser levelling then sought to provide a single irrigation bay across a whole paddock.
- Bankless channels, the latest form of this development. Bankless channels have a supply channel down one side of the paddock and no bank on the inside. Check gates are placed across the channel at each contour bank to control the water. These allow flooding of each bay, but the key is the fast bay drainage back into the supply channel. On long bays farmers will often have a small toe-furrow drain to speed the drainage. The drainage ends up in a drainage channel where the water can be recycled.

5.2.2 Best practice

Best practice for contour irrigation for good water use efficiency meets the following points:

- Use a whole farm plan.
- Design the bays so they can be watered and drained within 10–12 hours.
- Most Murray Valley farmers have a 3–5cm slope within each bay.
- Bankless channel technology allows the use of drive-over banks which allows for more efficient and easier crop management.
• In Murrumbidgee Valley it is more common practice to terrace the bays – each bay is flat and the drop down or step to the next bay ensures good drainage.

• A number of farmers have erected beds that have well drained furrows. This allows the growing of any crop because of the double drainage properties (the beds and the terrace). Summer crops such as cotton and corn are commonly grown on beds.

• The big advantage of a terraced bankless approach is that it eliminates the high labour of siphon irrigation of furrows but retains the ability to supply high volumes of water (25–30MLs) and good drainage. The beds also allow easier double cropping i.e. cotton or corn followed by a winter crop.

5.3 Sprinkler Irrigation Systems

Sprinkler irrigation systems include all methods where water is applied to the soil from sprinkler heads and pressurised pipeline systems. The most common application of this irrigation method is in horticulture, especially vegetable growing, with small impact or rotary sprinklers on short risers. These systems can also provide frost protection and crop canopy cooling.

Water application is controlled by the operator depending on system flow rate and time of application. These systems would include:

• fixed sprinklers (also pop up sprinklers);
• moveable systems (side roll, lateral pipes, hand move); and
• mobile systems (generally high pressure such as travelling irrigators).

Centre Pivots and Linear Move systems (CPLM) are not included, as the design criteria are quite different. Mini sprinklers and sprays are typically included under micro-irrigation systems where the design concepts again differ.

A number of key design and operational parameters should be met:

• **Soil types:** Sprinklers are best used on lighter soil types. Avoid use on heavier clay soils.

• **Uniform application:** This is critical for highest WUE. If half of the system applies more water than the other half then one half of the crop is either over-watered or under-watered. Two main measures of uniform application are used:
  ◦ Distribution Uniformity – a measure of how uniformly water is applied to the area being watered, expressed as a percentage (aim for 70–90 percent). It should not be confused with irrigation efficiency as over- or under-watering can still occur, but these are system management parameters
  ◦ Christiansen’s Uniformity Coefficient – a numeric judgment of the overall performance of an irrigation system’s ability to apply water evenly. It looks at the average deviation from the average depth of water applied. Desirable UC ranges from 70 percent for low value crops to greater than 90 percent for high-value shallow rooted crops.

• **Application Rate:** Try and match application rate (mm/hr) to the infiltration rate of the soil. Use only broad guidelines for topsoil texture. Top soil texture is only one of many factors affecting infiltration rate. Aim to avoid ponding and localised runoff from application rates higher than the soil can handle.

• **Pressure:** Ensure sprinklers operate at their design pressure. Overpressure will create misting with higher loss to the atmosphere and higher operating cost with lower application efficiency. Insufficient pressure will result in large droplet sizes, extremely poor uniformity and potential crop loss. This may lead to surface crusting on some soil types.
• **Filtration:** Blocked nozzles are the number one cause of underperforming systems. The size of the filter mesh orifices must be no greater than one quarter of the sprinkler nozzle diameter. In systems with automatic valves, the manufacturer’s specification must be followed, or a minimum of 80 mesh used.

• **Water Quality:** Ensure best quality water and match filtration to water quality. Avoid sprinkler irrigation using saline water. Consult ample references for maximum allowable salinity to avoid leaf scald in various crops.

• **Flow Velocity:** The higher the velocity, the greater the risk of damage through surges and water hammer. This risk particularly applies to pipes subject to uncontrolled starting and stopping. System failure can lead to water loss and crop failure. Generally, adopt Maximum Velocity = 1.5m/s although higher velocities may be justified:
  ◦ Pressure loss through fittings should not exceed 10 percent of total losses
  ◦ Pressure variation at the outlets must not exceed 20 percent of the outlet operating pressure at any point in the system or 15 percent of the outlet operating pressure over 80 percent of the zone outlet positions.

• **Laterals:** Design laterals to ensure that the volume of water discharged from each sprinkler on the lateral is within 10 percent of the volume discharged from the average or design discharge. This 10 percent difference in volume of discharge is equivalent to a 20 percent change in pressure.

• **System audits:** Carry out system audits and checks frequently. Simple, ongoing maintenance is essential to achieve and maintain higher water use efficiencies.

5.4  **Centre Pivot and Linear Move systems (CPLM)**

5.4.1  **CPLM**

Large-scale irrigation systems now often involve overhead delivery systems that move across the field. There are two main types:

• **Centre Pivots** are anchored at one end and rotate covering a circle. They can span a circle with a radius of over 500m, irrigating more than 100ha.

• **Linear Move** systems travel in a straight line covering a rectangular area. They can span up to 1,000 metres in width irrigating a length of up to 2,000 metres, covering an area of 200ha.

In this section they are referred to as CPLM (Centre pivot, Linear Move). Water is pressurised by an external pump and applied through various types of sprinklers. CPLM are commonly used where:

• flood/furrow irrigation is not suitable, such as:
  ◦ where the soil type is sandy and highly permeable and so flood irrigation tends to over-water the head of the bay and under-water the tail
  ◦ where the field topography is undulating and so difficult to command without extensive laser levelling;

• the high-value crops justify the additional cost of precision application; and

• labour costs are high and power prices reasonable.
5.4.2 Risks to water use efficiency

The potential disadvantage of the systems in regard to WUE is that the fine overhead spray system can lead to excessive evaporation, particularly in windy conditions. Equally, a fine droplet size can lead to ‘crusting’ of the soil surface and so excessive run-off.

5.4.3 Spray heads

A wide range of emitter nozzles and application heads are available for CPLM. Older systems had impact sprinklers mounted above the span pipes, but modern systems now favour low pressure static or moving plate sprinklers suspended below the pipes. The different types of moving plate devices available include:

- spinners (low operating pressure but fast rotation);
- rotators (higher operating pressure but slower rotation); and
- wobblers (medium to low pressure with multi-path streamlets).

Application heads can be grouped into either:

- over-crop sprinklers; or
- low energy precision application (LEPA) attachments.

Over-crop sprinklers

Over-crop sprinklers are typically suspended on rigid dropper pipes that hold the sprinkler head at spacings of 2.4–3 metres (8–10ft), just above the full crop height. While this form of sprinkler head and configuration is the simplest to design and use, it suffers from high evaporative losses both from the soil and plant surface.

LEPA

LEPA systems apply water at low pressure either directly onto the soil surface or below the crop canopy in order to eliminate evaporation from the plant canopy and reduce the wetted soil surface area and so evaporation. These systems commonly operate at very low pressures (10–20psi) and, hence, have reduced pumping energy costs.

LEPA application heads are suspended from the main pipe by flexible hose at either one or two crop row intervals. Drag socks come in both double- and single-ended options. Double-ended socks are used to reduce the risk of washing irrigation bay structures away.

The replacement of older sprinkler technologies on existing CPLM is a relatively simple and cost-effective way of improving system performance and reducing risks of excessive evaporation. The larger the number of streamlets produced by the emitter, the smaller the droplet size and the lower the drop impact energy applied to the soil surface. However, the lower the sprinkler head pressure, the larger the droplet size.

Modern low-pressure sprinklers impart roughly 60 percent of the energy of old ‘top of pipe’ high-pressure impact sprinklers. Low pressures and large numbers of streamlets typically provide the best result in reducing the application rate, reducing the impact energy imparted to the soil and increasing the throw distance. This design also reduces evaporation, minimises surface crusting and so reduces runoff.

Corner infill devices ensure that centre pivots extend the irrigation to include the full paddock area. This maximises the area of production.
5.4.4 Rutting and bogging

CPLM represent a considerable investment in tyres and wheels, so growers should also ensure that they have the necessary equipment to re-inflate, replace or otherwise repair tyres on the machine. This typically involves having spare tyres, along with lightweight jacks and blocks. However, the wheel-tracks also create risks of rutting and bogging. There are a number of potential solutions.

**Boombacks**

Boombacks are used to suspend the emitters at a distance of 3–6 metres behind the machine towers to reduce the risk of irrigation water intercepted by the tower causing wheel rutting or bogging. They also improve the uniformity of sprinkler application to the crop near the towers.

**Tyres and wheels**

Larger tyre sizes are often sold as a way to reduce wheel rut formation. However, while there is some difference in ground pressure from larger tyre sizes, they do not generally reduce rutting as much as boombacks, which reduce the wetting of the wheel-track area. Larger wheel and tyre sizes also increase loading upon gearboxes and drive trains.

High speed ratios are also sometimes sold as a solution to wheel rutting. However, high speed drive-train combinations may produce start-up torques that are greater than the design specification for the machine, leading to increased occurrences of motor burnout and gearbox failure.

Larger width tyres may also result in tyre centrelines that overhang from the gearbox attachment points, thus increasing the risk of failure. Where larger and wider tyres are used, the power cable size and hydraulic lines should be increased in capacity to cope with the greater power requirements.

5.4.5 Management tips

1. Pest management – ensure all electrical and control components are protected from pest (particularly rat) attack.
2. Do not move CPLM machines unnecessarily especially after rainfall events.
3. Set machine speed to irrigate desired volume in one pass.
4. Consider larger tyre and wheel sizes (i.e. three- and four-wheel towers to spread the load). Boombacks are more effective than tyre size in reducing rutting.
5. Fit pressure regulators – they ensure all sprinklers are supplied with water at the same pressure in order to minimise variation in water application. Reduce sprinkler flow rates immediately adjacent to towers to 80 percent of their existing flow rates to reduce risks of bogging.
6. Auditing and checking – constantly monitor the system to maintain optimal operations.

5.5 Drainage

5.5.1 Design optimisation

Poor drainage results in low WUE by limiting crop production due to waterlogging, salinity or flooding. This reduces the productive and economic measures of WUE of t/ML or $/ML applied. This promotes the need for investment to minimise risks through:

- laser levelling to counter poor surface drainage;
- installation of subsurface tile drains;
• construction of raised-bed cropping; and
• Greater emphasis on irrigation scheduling.

5.5.2 Overview of the drainage process

Drainage is the removal of water from a field. It is required to prevent crop damage after rainfall, flooding or large irrigation events. Drainage of excess water involves a combination of surface drainage (across the soil surface) and subsurface drainage (vertically down through the soil profile). Poor surface drainage is generally caused by a lack of slope. Poor subsurface drainage is caused by high water tables or by low soil permeability.

Crop root-zones require oxygen. If the root-zone is saturated for too long then no air exists between soil pores and most crops die or at least productivity is reduced. This is called waterlogging. Excess water must be able to drain from the root-zone. For most crops (rice is an exception) this needs to occur within a few hours to a few days to prevent crop loss. This rate of removal depends on crop type and time of year.

Adequate subsurface drainage is also important to remove excess salt within the root-zone. The subsurface drainage rate is strongly related to soil permeability and management. Irrigation can be managed to increase the leaching fraction, and soils can be modified to increase permeability. However, the soil’s inherent characteristics are the most important factor.

In many irrigation schemes, natural drainage rates need to be increased with the construction of artificial drainage to protect crops. However, improvements in irrigation efficiency mean that the design of new drainage systems are now more related to the removal of rainstorm events than excessive irrigation events.

Drainage water is both a potential contaminant to the environment and a wasted resource. Providing it is of suitable quality, it may be harvested and re-used for irrigation (if necessary diluted with other water). Re-use of drainage flows improves overall WUE, saves nutrients that would otherwise be lost, and reduces the risk of contaminants entering creeks and rivers.

5.5.3 Influences on surface drainage

The need for surface drainage is affected by a number of factors. Decisions on optimal drainage and crop selection require a judgment on the balance of what is feasible and cost effective:

• Rainfall: drainage is provided primarily to clear rainfall from the irrigated crop and so prevent waterlogging and crop loss.

• Soil type: heavy clay soils hold the water on the paddock surface for longer, inundating the root zone and halting growth. By contrast, sandy soils drain freely reducing the need for surface drainage.

• Topography: the shape of the paddock surface will determine whether the rainfall drains off or collects in hollows and depressions. This factor was one of the drivers for laser levelling of paddocks in irrigation areas.

• Crops: there is considerable variation in the tolerance of different crops to ponding and salinity. Stone fruits and citrus are highly sensitive, pasture and field crops are relatively tolerant.

5.5.4 Influences on subsurface drainage

The following influences are important to consider in determining drainage requirements:

• Crop type: crops vary in sensitivity to waterlogging. Stone fruits and citrus are highly sensitive, pasture and field crops are relatively tolerant.
• **Irrigation method:** poor irrigation management of any system will create waterlogging:
  ◦ Pressurised irrigation, such as sprinklers and drip, can be designed and operated to provide precise and uniform irrigations that will match the soil moisture deficit
  ◦ Well-designed flood systems are less precise but can provide acceptable performance especially for waterlogging tolerant crops or those on raised beds
  ◦ Recapture and reuse of surface drainage water also improves WUE.

• **Climate and seasonal impacts:** waterlogging in summer has a greater impact on crops than during winter dormant periods. Therefore, high rainfall events during summer (e.g. summer storms) can be a major factor in determining drainage needs, i.e. the soil needs to be capable of removing excess water fast enough to prevent crop loss.

• **Soil class:** soils are the most important influence on subsurface drainage. Soil permeability generally decreases with increased clay content and this is reflected in soil classes. The key characteristics that determine subsurface drainage rates are the ratio of sand/silt/clay, the level of gravel/rock and the presence of organic matter.

• **Indicators:** indicators of good subsurface drainage are low mottling of subsoils, low soil salinity, low clay content and good soil structure and the pH of soil profile (high acidity tends to suggest high leaching or high rates of subsurface drainage). Conversely, high pH is indicative of a sodic or dispersive nature and low permeability.

5.5.5 **Impact of irrigation water salinity**

Salt in irrigation water will accumulate in the root-zone to a level that is determined by the level of dilution (leaching fraction). Increasing the leaching fraction (by applying more irrigation water) can be used to maintain soil salinity below threshold levels that impact on crop production depending on the level of salinity in the applied water. However, the soil’s subsurface drainage rate must be capable of providing the leaching fraction required.

This is easier for lighter more permeable soils and more difficult for heavier soils. Heavier soils cannot be managed by applying a leaching fraction as this results in excessive waterlogging.

5.5.6 **Interventions**

Laser levelling is commonly adopted to create a steady ‘fall’ across a paddock to ensure optimal irrigation and effective surface drainage. Artificial surface drains are constructed to remove excess surface water when natural slopes do not remove water at a fast enough rate to prevent crop damage.

Artificial subsurface drainage is used to increase natural drainage from soils that have restricted drainage due to high water tables or impeding subsurface layers. They are installed to increase subsurface drainage rates and leaching fractions.

Poor drainage rates also increase the importance of high-quality irrigation scheduling, with the need to match irrigation application rates more closely to the drainage capacity of the soils by location. In areas of poor drainage, it may be necessary to construct raised cropping beds to minimise risks of water logging.

Surface drainage systems are always needed. However, where the following are in place, then subsurface drainage should not be needed:

• Modern efficient irrigation farm systems.
• Productive agriculture, i.e. good farm practices.
• Effective irrigation scheduling.
5.6 Irrigation scheduling

5.6.1 Impact of improved irrigation management on water use efficiency

Irrigation scheduling involves the decision process whereby the farmer makes decisions on when and how much to irrigate, based on the collection of data and analysis.

This section describes the practical, simple and cost-effective options, techniques and technologies behind irrigation scheduling to improve WUE in irrigated farming and the property level.

WUE at the farm level considers the management and use of water to produce irrigated outputs. WUE focuses on:

- optimising the amount of applied water taken up and used by the crop; and
- minimising losses as water moves to the plant.

Measurement of WUE at a farm level may include Irrigation Water Use Index – crop yield/irrigation water applied (kg/ML).

Water Conversion Index (WCI) measures the productive value generated by the water applied (measured as mass per ML applied).

\[
WCI = \frac{\text{Quantum of product (kg or tonnes)}}{\text{Water applied (m3 or ML, e.g. kg/ML)}}
\]

- Irrigation Rate – water applied/area (ML/ha)
- Economic Water Use Index – gross return/total water applied ($/ML)

Water Conversion Index (WCI) where the metric is the $ value per ML.

\[
WCI = \frac{\text{Value of product}}{\text{Water applied, e.g. $/ML}}
\]

5.6.2 Drivers for better irrigation management

There are many reasons for irrigators to adopt improved management and technologies. Farmers will seek to improve their decision-making on how they irrigate and the frequency and timing to:

- ensure that they optimise the production (yield) and quality of the crop;
- increase their availability of labour and flexibility with its use;
- save water during periods of limited water availability;
- help manage problems in relation to salinity, water tables and/or crop vigour; and
- manage the risk associated with under or over watering.

5.6.3 Irrigation essentials

In order to ensure that irrigators use water wisely there are a number of steps they need to consider. The irrigation essentials document produced by the National Program for Sustainable Irrigation (NPSI, 2012) outlines the critical process for irrigators to undertake to ensure making the most of their water resource. Five key factors influence irrigation management decisions:

1. Business planning.
2. Irrigation planning.
3. Irrigation management.
4. Crop and soil management.
5. Monitoring.
Business planning

Irrigation farmers need a sound business plan due to the high costs of irrigation, the reliance of individual irrigators on water providers, and the limited flexibility of some production systems:

- External influences: there is a need to understand how external issues affect your business such as government policies (regulations, water trade, infrastructure upgrades, irrigation delivery service), international food and water policies, consumer demands and commodity markets.

- Business fundamentals: understanding the internal factors impacting your business such as finance (equity, capital), personal attributes (attitude to risk and new technology), operational health and safety, farming systems, water delivery infrastructure and water rights.

Irrigation planning

Investigation and planning is essential to ensure that the right crops are irrigated and that the irrigation system and design matches the crop production and soil type/landscape:

- Site suitability: irrigators must understand their site, particularly soil type and variability, topography, climate, water supply (quality, reliability and access or delivery), salinity and depth to ground water.

- Production system and crop selection: crops need to be selected that suit the local condition based on the history of irrigated production and water supply, marketing opportunities and any new farming systems and crops.

- Irrigation and drainage system: make sure that the irrigation methods and crops are suitable for the site and the irrigation design manages surface and subsurface drainage to reuse water where feasible and minimise adverse environmental impacts.
**Irrigation management**

The practicalities of irrigation require regular decisions about when to irrigate and how much to irrigate. These decisions must balance the overall availability of water with the needs of the crop and the capacity of the chosen irrigation system to deliver water, how, where and when required:

- **Water budget:** it is critical to prepare a water budget that compares total crop water requirements with water availability, rainfall, evapotranspiration (ETo), and on-farm storages to ensure sufficient water will be available.

- **Irrigation schedule:** the irrigator must determine the most appropriate techniques or tools to help make decisions about when and how much water to apply (right time, right amount) for the climate, soil and crop. There are many different options with advantages and disadvantages some of which are described below.

- **Specific irrigation strategies:** consider the role of specialist irrigation strategies like dealing with drought, ensuring sufficient leaching of salts, avoiding frost or boosting crop production or quality. There are a number of ways that irrigation management can be used to manipulate the growth of crops and/or manage the external environment.

**Crop and soil management**

For optimal plant growing conditions, soils must function as required (i.e. they make water freely available, provide good drainage, aeration and nutrition, and are free from salinity and other features which limit growth). This requires a detailed understanding both of plant needs and soil condition:

- **Plant performance:** understand crop growth and development cycles, seasonal requirements, and how to maximise vegetative or fruit growth. Determine and meet plant nutrient requirements while ensuring as little fertiliser is wasted as possible (using techniques like fertility testing, scheduling and split applications).

- **Soil condition:** make sure your soils provide optimal growing conditions. Manage soils to retain or improve their structure, soil carbon and soil biology levels, their pH and drainage, and reduce compaction. Leach residual salts from the rootzone or consider alternative water sources.

**Monitoring**

Irrigated farms are complex operations with numerous inputs and many possible combinations. This makes it important to keep close track of the performance of the irrigation system and production efficiency using monitoring to enable continuous fine-tuning:

- **Monitoring and evaluation:** monitor and respond to important aspects of system performance, management, production and the environment. Every property and business is different. Pick key performance indicators that will be of most use and ensure they cover production and finances (e.g. gross margins or yield/ML), the environment (e.g. water quality or soil salinity) and human aspects (e.g. number of accident-free days).

- **Continuous improvement:** periodically review all aspects of business and irrigation management to continuously improve decision making and system performance.
5.6.4 Techniques used for Irrigation Scheduling

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
</tr>
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<tbody>
<tr>
<td>Experience</td>
<td>The farmers experience of a particular crop and block goes a long way in knowing how much and when to water.</td>
<td>Farmers don’t always get it right and often they over irrigate early in the season and under irrigate later in the season. Things change over time – soils become poorer draining, Spring is drier, new crops are grown.</td>
</tr>
<tr>
<td>Calendar</td>
<td>The start of the irrigation season and regular irrigations can be based on the calendar. This is a simple method for scheduling.</td>
<td>Irrigation commencement varies from year to year as does the amount required as the weather is highly variable.</td>
</tr>
<tr>
<td>Weather</td>
<td>Using weather-based scheduling ensures that irrigation application and frequency changes as the weather changes. ET can be relatively easy to calculate and takes account of major events (eg heatwave, rainfall). There is good information available for many crops.</td>
<td>Weather based scheduling needs to take into account a number of different factors including evaporation from the ground, the stage of plant growth and impact of soil types. If there are a large number of unknowns the approach can be imprecise. It is important to have an understanding of soil moisture in addition to the weather.</td>
</tr>
<tr>
<td>Soil</td>
<td>Soil moisture can be measured by many different methods (ranging from a shovel to sophisticated technology) which means that there is a method appropriate to every budget. Soil monitoring can be a good integrator of water stress for the plant.</td>
<td>Need to calibrate the technology and make sure that the sensor is appropriately sited to represent what the plant is experiencing. Can be expensive and tedious to maintain and interpret equipment.</td>
</tr>
<tr>
<td>Plant-based</td>
<td>Plant-based measurements provide the best assessment of how the plant is responding to water availability. It is a direct measure that takes in to account weather, soil type and many other factors.</td>
<td>It can be difficult to measure water availability of plants and measurement of water stress may occur too late to prevent loss of yield and/or quality.</td>
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Irrigation scheduling is deciding when to irrigate, how long to irrigate for, and how much water to apply. The aim is to apply the right amount of water at the right time but deciding when and how much can be daunting questions.

A series of approaches are used, either on their own or in combination:

- Calculating crop water requirements based on climate, especially evapotranspiration – an important document used to determine irrigation requirements based on weather is *FAO Irrigation and Drainage Paper 66* (Steduto *et al*., 2012), and a useful tool is IrriSAT by Australia’s Commonwealth Scientific and Industrial Research Organisation.
• Monitoring soil moisture levels in the root zone – there are many devices that can be used to measure the wetness of the soil including technology that measures: i) the weight of water in the soil (gravimetric soil water content); ii) the volume of water in the soil (volumetric soil water content); and iii) the pressure to extract water from the soil (soil water potential or soil water suction). It is critical that soil moisture monitors are placed in the root zone of the plant as the measure aims to be a surrogate for what the plant is experiencing. A summary is provided in Irrigation Insights 1 – Soil Water Monitoring (Charlesworth, 2005).

• Monitoring the plants themselves is often considered the best assessment for irrigation management. However, this is difficult to achieve and even harder to base irrigation decisions on. Some plant measures include the monitoring of leaf extension and plant/fruit growth, and the monitoring of leaf temperature. There have been significant advances in the use of remote sensing to monitor temperature and scheduling needs.

• The key to good scheduling is to use a range of tools and indicators while maintaining the basics, such as weather forecasts and visually inspecting the crop.
6 Case studies

The following case studies provide examples of how the lessons from the issues and analysis outlined in the previous chapters have been applied in practice. The case studies cover three main categories:

A. Policy issues

1. Water scarcity and water trading: Increasing scarcity in the total volume of water available for irrigation has driven the growth of water trading, which has shifted water between locations and sectors. Variability in the volume of water available between seasons creates uncertainty for irrigators planning their plantings. This has led to the development of announcements from resource managers to inform irrigators about projections for the coming season. Both drive greater WUE.

B. Distribution system issues

2. Sunraysia drainage flows: This region has seen a significant conversion from a concrete-lined manually operated channel supply stem with furrow irrigation at farm level, to pressurised pipelines with remote control combined with sprinkler/drip irrigation. There was early adoption of sprinklers driven by the aging infrastructure supply system, labour constraints and concern over raised salinity levels. This has seen historically high levels of drainage flows reduced effectively to zero.

3. Murray Irrigation and delivery efficiency: There have been significant improvements in system delivery efficiency to increase available supplies for irrigators, yet the system is still earthen canal-based with many manually operated controls and regulating structures, as well as water measurement by the traditional Dethridge meters still in operation.

4. Coleambally Irrigation delivery efficiency: This used government funding to convert to a fully automated canal-based delivery system, with the water savings generated providing the basis for the funding.

5. Water use efficiency in South Australia: Jeff Parish helped steer the transformation of the pumped and piped irrigation trusts in South Australia’s Riverland. This is his personal story. He started as an assistant clerk and ended up as CEO. His most important legacy was to change the culture from one that put engineering convenience first to one that put farmers at the centre of decision-making.

C. Sectoral examples

6. Rice and water use efficiency: This sector has transformed its water use because of controls over where rice could be grown to stop salinity risks, and by the need to reduce input costs. This has involved laser grading of rice bays and control systems that can vary flowrates over 24 hours. As a result, irrigators now grow one crop per year of 10 tonnes per hectare with around 1 tonne per ML of water applied.

7. Centre pivot irrigation for dairy: The dairy sector has had to increase farm productivity per ML to compete with other water users (e.g. cotton and horticulture) and as a measure to reduce production costs in order to remain competitive with international commodity prices. That means producing more feed per ML of water. That has seen a transformation of production systems, from direct grazing of irrigated perennial pasture to the irrigation of more water efficient annual crops such as maize, which are then mechanically harvested, stored and then fed to the cattle. Those annual crops then require best practice irrigation systems with fast flow outlets or centre pivot irrigators.
8. **Processing tomato productivity:** The processing tomato sector used to rely on furrow irrigation with multiple siphons from the supply channel. This limited production to around 4,000 tonnes per owner due to the labour time required to manage the system. Conversion to subsurface drip now allows production rates well above 20,000 tonnes per owner with reduced labour costs. The yield/ha has doubled and the yield/ML has increased by a factor of 3. As a result, the sector now has one quarter of the number of farmers growing the same total production on half the area with one third of the water.

9. **Simple practical applications:** This case study shows how simple changes can improve production and water use efficiency in irrigated production across sectors in developing countries.

### 6.1 Water scarcity and water trading

This case study demonstrates the importance of water trading and information provision for WUE. In both cases the importance of these factors is driven by water scarcity.

Australia has managed significant water scarcity at two key periods in its history. The first time was during and following the Federation Drought in 1901/02. This led the Prime Minister Alfred Deakin to institute much of the current government policy on water entitlements. This included a formal allocation system whereby water was allocated against entitlements, and monitoring of farm-scale irrigation by the use of meters designed in 1912 by the Chief of the Victorian State Rivers and Water Supply Commission, John Dethridge, specifically to suit Australian conditions.

![Figure 8. Dethridge wheel supplying and measuring water to a farm channel (source: Victoria, 1936. State Rivers and Water Supply Commission photographer / Public domain)](image)
Following this, Australia embarked on building storages and irrigation development which continued up until the late 1980s. However, in the second half of the 20th century, governments ceased issuing new licences and irrigators became much more aware of the need for more efficient use of water. By the 1990s it became clear that a limit to sustainable water extraction had been reached in south-eastern Australia, and that further development and expansion of irrigated crops could only occur at the expense of existing development.

This helped promote a system of water trading on both a permanent basis and a temporary or annual basis. Although trade had been allowed between neighbours and between farmers within defined irrigation districts, the State and Federal Government agreed to encourage – then to enforce – open trade between users up and down river systems, between rivers and between states (in fact between any users), provided the water supply systems were hydraulically well connected. This enabled the growth of high-value irrigated crops such as horticulture in regions that previously did not have irrigation. This was at the expense of irrigation water volumes previously available each year in the traditional expansive flood-irrigation districts of Murray Irrigation (NSW) and the Goulburn-Murray Irrigation District (GMID) in Victoria.

The following map identifies the key water trading zones for six separate river systems in three states: NSW, Victoria and South Australia. Because year-round flows from all regulated rivers are maintained from large upstream storages, water allocations can normally be traded between licenced owners and users in different zones, river valleys and states – often thousands of kilometres apart – both upstream and downstream.

Figure 9. Southern connected Murray-Darling Basin trading zones (Alexandra, 2018)
6.1.1 The Millennium Drought

The Millennium Drought occurred throughout SE Australia in the period 2001–09. This again focused irrigation sectors and water policy officials on refining management of water scarcity. Two significant and related initiatives occurred in response:

- Basin Plan: A new interstate Murray-Darling Basin Plan was established, which restored water to the environment through government investment in water saving initiatives, and the direct purchase of water entitlements from farmers.

- Water trading: An active water market led to lower value irrigation sectors stopping or dramatically reducing their water use. The total production levels of some commodities collapsed.

For example, total annual rice production in NSW effectively ceased in 2006/07 and the regional rice mill was mothballed. The small amount of water available to the sector was traded away each year from traditional rice growers to higher value crops, often in other irrigation districts, other river valleys or even other states. Despite increasing rice yields per ML applied, the recovery in rice production following the Millennium Drought period has been modest – impacted by a combination of water trade to other crops and water purchased by governments from rice growers for the environment.

![Figure 10. Rice area and price indicator, Australia, 1988–89 to 2015–16 (ABARES, 2019)](image)

Figure 10 highlights the steady rise in annual production up to 2001, the impact of the drought between 2002 and 2009/10, and the return to lower aggregate levels of production due to the reduction in the size of the consumptive pool as a result of water reforms such as the Basin Plan.
6.1.2 Trade driving water use efficiency

The experience of the rice industry after 2001 is part of an ongoing process whereby water use has shifted between sectors as water scarcity has become more evident. This is demonstrated in the following figure which splits the last fifty years into five key periods:

- **1970s and 80s – Growth:** This period saw the construction of storages and expansion of irrigation development. There was a significant growth in overall irrigation activity mainly in lower value mixed grazing for sheep and cattle.

- **1990s – Cap and trade:** After 1995 there was a cap on the overall level of consumptive demand based on 1993 levels of development. This prompted the activation of little used ‘sleeper licences’ and promotion of water trading. The period up to 2001 saw major expansion in the rice sector and in dairy, mainly at the expense of the mixed grazing sector.

- **2003–2005 – First drought:** This period saw a substantial reduction in rice production, but dairy holding its own.

- **2006–2009 – Millennium Drought:** This much more severe drought saw the collapse of rice production and also a severe reduction in water use by the dairy sector.

- **2013–2016 – Recovery:** Staged recovery since 2013 has seen some bounce back by both rice and dairy, but to a lower overall level of production due to the reduction in the overall size of the consumptive pool. Mixed grazing is now a very small component. What is evident is the inexorable growth in the horticultural sectors over time, with little evidence that the droughts had any impact on levels of production.

![Figure 11. Water use by sector over time – Southern Connected Basin, key products only (RMCG, 2017)](image)

This demonstrates how water trading drives greater WUE by creating a process to allow scarce water resources to be reallocated between sectors.
6.1.3 Information driving greater water use efficiency

The amount of water available within the southern Murray-Darling Basin varies enormously from year to year – from an aggregate total as low as 2,000GL/yr up to a figure three times as much, at or in excess of 6,000GL.

Figure 12. Water use between sectors by climate scenario – Southern Connected Basin (RMCG, 2017)

This variability also drives trade and reallocation of water use between sectors depending on the climate scenario. Figure 12 shows:

- in drought sequences the large majority of the available allocation will be utilised by the horticulture sectors, while dairy and other sectors cut back;
- as the total allocations increase, the initial growth is in the dairy sector;
- after that the major growth is in rice production and in other annual summer crops; and
- in wet sequences, an increasing proportion of the available allocation will be carried over for use in following seasons as a form of insurance policy.

What has evolved is an equilibrium with three broad industries utilising the different reliability water:

- Horticulture relying on accessing water with a very high reliability in all years.
- Dairy managing with a medium reliability over most seasons.
- Rice and other summer crops taking a lower reliability product only in years of raised allocations.

Of course, the lower value crops, such as rice, use the least reliable water. There is a limit to how much a farmer can spend on irrigation infrastructure and operating costs – typically 20–30 percent of gross revenue – therefore the lower the value the enterprise, the less that can be spent.
Counter-intuitively the low return crops can be less WUE compared to the high-value crops. Although conversely, the high-value crops focus on gross production and not WUE per se.

However, for this dynamic to take effect, irrigators need good information about the projected water allocation for the future season in order to make informed decisions about whether to plant or sell the allocation obtained. Therefore, each of the states has developed structured processes to announce projected allocation levels at routine points of the calendar year. For instance, the Northern Victoria Resource Manager reported on 15 May 2018 that:

“The Murray system is expected to start with a seasonal determination of at least 40 per cent for High Reliability Water Shares (HRWS)... All of the northern Victorian systems are expected to have seasonal determinations of 100% HRWS by mid October 2018 under average inflow conditions.” (NVRM, 2018).

This information gives the farmer the ability to plan and to consider alternative options, for example whether:

- to plant and if so, what crops and how large an area;
- to carry over the allocation for the following season; or
- to trade the allocation on the market.

This impacts on WUE by providing farmers with the tools to make good decisions.

6.2 **Sunraysia drainage flows – from 300mm/ha to <50mm/ha**

6.2.1 **Drivers for change**

The Sunraysia region in northwest Victoria centred around Mildura has transformed its irrigation systems from channel supplies and furrow irrigation with large water losses, to a pressurised pipe system with modern sprinkler/drip farm irrigation systems for high-value crops. As a result, prior high drainage flows averaging around 300mm/ha are now nearly zero.

The change was driven by four major factors:

- **Asset condition:** Ageing concrete-lined channels – the supply channels had degraded over time and were in need of substantial maintenance, and as a result water loss through seepage and leakage were unacceptable.

- **Labour:** A traditional 10-hectare block (farm) could be managed by one person if irrigated by furrow, but this left little time for the irrigator to manage higher value crops with higher demands for labour. Adoption of sprinklers automated irrigation and gave more time either for other work on the property or for the owner to earn an off-farm income.

- **Salinity:** The characteristics of the soil and the proximity to the River Murray meant that poorly controlled furrow irrigation led to raised water tables and increased risks of soil salinity and saline groundwater being forced into the river. These risks led to strict controls over where irrigation could take place and the scale of irrigation allowed.

- **Value:** Growth of high-value crops – such as wine-grapes, table-grapes and more recently almonds – have all generated returns that drive scale in enterprises and automation of production.
6.2.2 Sunraysia district

Sunraysia comprises two distinct production areas and systems:

- The older pumped irrigation districts, which are now consolidated and managed by one large operator – Lower Murray Water.
- Private diverters, who are licensed to pump water directly from the river using their own infrastructure.

There has been a significant growth in the total irrigated area in Sunraysia over the period since 1997, but all of this growth has taken place in the private diverter sector.

Table 3. Total area under irrigation (ha) (Mallee CMA, 2016)

<table>
<thead>
<tr>
<th></th>
<th>1997</th>
<th>2015</th>
<th>Change</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Districts</td>
<td>17,485</td>
<td>17,430</td>
<td>-55</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Private</td>
<td>22,220</td>
<td>55,585</td>
<td>+33,365</td>
<td>150%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39,705</strong></td>
<td><strong>73,015</strong></td>
<td><strong>-33,310</strong></td>
<td><strong>84%</strong></td>
</tr>
</tbody>
</table>

Although the total number of properties has declined over this period the average size of properties has increased markedly, reflecting the move from smaller traditional blocks (farms) in the irrigation districts, to much larger corporate developments as private diverters.

Table 4. Average area under irrigation (ha) (Mallee CMA, 2016)

<table>
<thead>
<tr>
<th>Average area (ha)</th>
<th>1997</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td>44</td>
<td>124</td>
</tr>
<tr>
<td>Districts</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 5. Sunraysia crop variety (ha) (Mallee CMA, 2016)

<table>
<thead>
<tr>
<th>Districts</th>
<th>Area</th>
<th>Percent (%)</th>
<th>Private diverters</th>
<th>Area</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table grapes</td>
<td>4,740</td>
<td>38%</td>
<td>Almonds</td>
<td>20,470</td>
<td>43%</td>
</tr>
<tr>
<td>Wine grapes</td>
<td>3,485</td>
<td>28%</td>
<td>Wine</td>
<td>6,645</td>
<td>14%</td>
</tr>
<tr>
<td>Dried grapes</td>
<td>2,080</td>
<td>17%</td>
<td>Olives</td>
<td>3,510</td>
<td>7%</td>
</tr>
<tr>
<td>Seasonal crops</td>
<td>1,095</td>
<td>9%</td>
<td>Citrus</td>
<td>3,490</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>655</td>
<td>5%</td>
<td>Other</td>
<td>5,110</td>
<td>11%</td>
</tr>
<tr>
<td>Citrus</td>
<td>230</td>
<td>2%</td>
<td>Vegetables</td>
<td>4,640</td>
<td>10%</td>
</tr>
<tr>
<td>Almonds</td>
<td>150</td>
<td>1%</td>
<td>Field crops</td>
<td>4,075</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12,435</strong></td>
<td><strong>1%</strong></td>
<td><strong>Total</strong></td>
<td><strong>47,940</strong></td>
<td><strong>9%</strong></td>
</tr>
</tbody>
</table>

6.2.3 Drainage impacts

The level of irrigation induced drainage is a good indicator of relative irrigation WUE. The older irrigation districts in Sunraysia provide a good example where any excess irrigation water drains vertically through the sandy soils profile below the root zone of the crop, and accumulates on the underlying clay to form a perched water table.

Without subsurface drainage, these perched water tables cause production losses as a result of water logging and salt accumulation. Control of perched water tables is achieved by installing horizontal tile drains on a grid 13–40 metres apart, with interceptor drains on the slopes.
6.2.4 Prior production drivers
The key historic drivers that drove earlier irrigation practice and outcomes included:

**Delivery system**
- Concrete-lined channels had deteriorated and leaked.
- Earthen channels in high intake soils leaked.
- Manual water control structures with wooden boards gave poor control of water.
- Pumps from the river into the channels had limited options for delivery rates.
- There was limited ability to change flow – twice a day modification at most.
- Farmers had to order in advance and did not get the water when required.

**Farm irrigation system**
- Furrow irrigation of sandy soils led to over-watering to ensure adequate flows across the paddock.
- There was no reuse system – surplus water just flowed off.
- Slow irrigations on highly permeable soils led to waterlogging and over irrigation.
- Farmers had little control over the timing of irrigations or the flow rate. As a result, irrigators had an incentive to take the full irrigation when it was available rather than what the crop required.
- Farmers typically spent about 600 hours each year physically managing their own on-farm irrigation. This left little time to upgrade those systems or invest in new production systems.

**Farm production system**
- Most farmers predominantly grew sultana grapes for dried fruit, which were tolerant to waterlogging and poor timing of irrigation.
- This was a lower value commodity crop which did not generate a high enough return to promote improvements.
- Most properties were small in size (e.g. 10ha) and run by a single owner operator.
6.2.5 Drivers of change

In the 1950s and 1960s, the availability of electricity, pipelining and efficient pumping technology had a dramatic impact on efficiency. Growers could now install their own pumps on the supply channels or from the river. Increased pressure allowed more uniform application via sprinklers to be used. This saved water, time and improved crop yields.

By the early 1980s, a sufficient area of sprinkler irrigation had been developed for farmers to put pressure on the system manager to change the way the piped irrigation systems were operated. As a result, services were changed from centrally controlled, inflexible rostered deliveries, to a system based on individual orders from irrigators. For the first time the district growers could decide how much water to apply and how often. Tailoring of irrigation to each individual block provided further production benefits, so more and more growers began to install pressurised systems.

The changes on-farm meant that water supply systems were no longer fit-for-purpose – they had been designed for high flow, rostered, infrequent furrow irrigation, but they were now being asked to supply low flow, frequent pressurised systems, including drip systems. Capacity constraints were initially used to refuse approval for drip systems, particularly at the end of the supply systems where there was a mix of furrow and newer technology, but over time these constraints were resolved. There was also increased adoption of irrigation scheduling using tensiometers and soil inspection to decide when and how much water to apply.

Drip irrigation systems began to be adopted at a large scale in the early 1990s. Growers were initially concerned about filtration, frost, and the ability to access water at the high frequency required. But with experience, improvements in technology and the lower overall costs, drip became the most popular system for new perennial horticultural development. Some drip irrigated areas have been irrigated for several years without any need for artificial drainage but may be at risk from large summer rain events.

Figure 14. Drip irrigation has largely replaced furrow irrigation (source: C. Thompson)

6.2.6 Recent developments

There has been a dramatic shift in the irrigation method – from furrow and overheads sprays to drip. This is true both of the older traditional districts and larger increasingly corporate private diverters.
Table 6. Irrigation systems in Sunraysia over time (Mallee CMA, 2016)

<table>
<thead>
<tr>
<th>Districts (ha)</th>
<th>1997</th>
<th>Percent (%)</th>
<th>2015</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip</td>
<td>770</td>
<td>4%</td>
<td>6,045</td>
<td>49%</td>
</tr>
<tr>
<td>Low level sprinkler</td>
<td>2,690</td>
<td>16%</td>
<td>4,005</td>
<td>32%</td>
</tr>
<tr>
<td>Overhead sprinkler</td>
<td>4,335</td>
<td>25%</td>
<td>1,585</td>
<td>13%</td>
</tr>
<tr>
<td>Furrow</td>
<td>9,370</td>
<td>55%</td>
<td>800</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>17,165</td>
<td></td>
<td>12,435</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Private (ha)</th>
<th>1997</th>
<th>Percent (%)</th>
<th>2015</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip</td>
<td>3,160</td>
<td>15%</td>
<td>35,205</td>
<td>73%</td>
</tr>
<tr>
<td>Low level sprinkler</td>
<td>3,220</td>
<td>15%</td>
<td>4,630</td>
<td>10%</td>
</tr>
<tr>
<td>Overhead sprinkler</td>
<td>9,160</td>
<td>43%</td>
<td>5,710</td>
<td>12%</td>
</tr>
<tr>
<td>Furrow</td>
<td>5,855</td>
<td>27%</td>
<td>2,395</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>21,395</td>
<td></td>
<td>47,940</td>
<td></td>
</tr>
</tbody>
</table>

This shows that drip irrigation has gone from 10 percent of the total area to 68 percent of a greatly expanded area over a 20-year period. The transformation is particularly noted amongst the larger corporate private diverters.

The change was driven by a number of factors:

- The 1990s saw the implementation of salinity management plans, which included incentives, development guidelines, training courses and more extension on soils, irrigation systems and scheduling.
- Metering of unmetered outlets accelerated.
- The 1990s/2000s saw the introduction and expansion of a water market, changes in water charging regimes, and a river basin-wide cap on extractions. This put a price on water and provided a strong incentive to improve WUE.
- Redevelopment from traditional dried vine fruit to wine grapes and the high wine grape returns that occurred in the 1990s provided an opportunity for upgrading of irrigation systems.
- Pressurised irrigation led to labour saving. In order to expand their business, growers had to be able to manage larger areas than furrow would allow. Adopting sprinklers and drip allowed this.
- Automated soil probes and scheduling services were introduced and this provided more accurate measurement of soil water content in real time.
- The high level of control offered by high technology systems, knowledge of soil characteristics combined with a pursuit for improved quality saw growers and researchers explore new techniques such as partial rootzone drying, subsurface drip, regulated deficit and ‘open hydroponics’ which involves continuous low flow drip irrigation with fertigation.
- From 2006–2009, the district experienced very low water allocations and around 30 percent of districts were dried off. As these areas gradually return to irrigation, flows may increase.

6.2.7 Drainage flows

Improved irrigation WUE has reduced drainage flows from 2–3ML/ha per year in the 1980s to less than 0.5ML/ha per year in more recent times.

Record summer rainfall in 2010/11 resulted in a short spike in drainage flows, but drainage flows quickly reverted to low flows reflecting much higher irrigation efficiency than 40 years previously.
6.2.8 Practices today that lead to improved water use efficiency

**Delivery system**

The modernised delivery systems now actively promote increased WUE through:

- Pressurised pipe irrigation supply.
- Sufficient capacity to meet peak plant demand.
- Improved control and speed technology for the large pumps diverting water from the river into the supply system to give the ability to quickly match changes to flow demands from very low to peak flows.
- Automatic ability to change flow – pressure sensor combined with ordering of water.
- Farmers now almost have water on demand, they merely have to order slightly ahead of time and now get the water when required.
- The water is delivered with sufficient pressure so that farmers do not need to pump themselves – though some elevated locations require supplemental pumping.
- Farmers need to balance the benefits of pumped systems and automation with higher energy costs.

**On-farm systems**

- Mix of under tree sprinkler and drip (drip is not always the best).
- No need for reuse system – no excess irrigation water is applied.
- Still need drainage for rainfall events.
- Farms can inject fertiliser into the irrigation system.
- Farm pumping systems have direct suction lines into the canals and operate automatically.
- Scheduling water using technology including tensiometers, neutron probes, weather data, etc.
- Ability to apply water when required.
- Can apply different quantities at each application.
- Can vary applications according to the crop and soil in different parts of the farm.
- Farmer spends only 50–100hrs/year physically monitoring the irrigation – a relatively small time input leaving them with time to spend on higher value activities.

6.3 Murray Irrigation and delivery efficiency – from 50–60% to 85–90%

6.3.1 Delivery efficiency

Murray Irrigation Limited (MIL) represents a good example of the modernisation of a traditional channel supply system to improve delivery efficiency. It comprises a very extensive gravity-fed channel system to supply broad acre farming (pasture for sheep and rice paddies). Murray Irrigation used to operate at a delivery efficiency of around 50–60 percent. It has invested in technology to achieve substantial WUE gains and now operates at 85–90 percent efficiency. Farmers have also invested significantly to improve on-farm efficiency.
6.3.2 The Murray Irrigation District

Murray Irrigation is the largest farmer owned irrigation business in Australia. Key aspects of that business include:

- Australia’s largest main supply channel with a capacity to divert 10,000ML/day into the NSW irrigation region from the River Murray at Mulwala.
- A wide variety of irrigated soils ranging from permeable loams suited to a wide variety of irrigated enterprises, through to heavy, impermeable clay soils.
- 724,000ha area of operations throughout a low winter-dominant rainfall (225–400mm) area.
- 832,000ML of water used on-farm (average of last five years).
- Very small numbers of lifestyle or small area irrigated farms.
- Traditionally irrigation for both summer and winter pastures, augmenting yields on winter cereals through spring irrigation, and the growing of a single summer rice crop.
- 1,115 farm businesses now own the 2,208 original surveyed landholdings supplied.
- Each farm is able to irrigate approximately 30–50 percent of the total farm area.
- 2,858km of gravity-fed earthen supply channels managed from three offices.
- 1,421km of gravity-fed earthen drainage channels.
- The system was first constructed in the 1930s with the opening of the Tullakool irrigation area in the late 1930s and, after a construction break during the Second World War, expanded through the construction of extended channel networks up until 1964.
- MIL was transferred from a NSW State Government owned ‘Areas and Districts’ to an unlisted public company with irrigator shareholders in 1995, under the terms of a special-purpose NSW Act. The company does not pay distributions of profit, but is committed to providing the lowest cost, sustainable irrigation supply services to its shareholder customers. Non-customers cannot own shares in MIL.
- Investment in delivery system automation has reduced losses from:
  - poor measurement of water within the channel system;
  - poor measurement onto farm;
  - delivery channel seepage and leakage; and
  - end-of-system outfalls or escape flows through more than 200 outfall structures.

6.3.3 Practices in the 1970s and 1980s

**Water use efficiency**

- MIL’s area of operation was a State Government-owned irrigation scheme known as the Murray Areas and Districts.
- It was difficult to assess losses in the channel supply system during the 1970s and 1980s. The volume of bulk water diverted from the river was estimated – based on offtake gate settings – even though the water delivered onto farms was metered through Dethridge outlets (Figure 15), that measured flows from a supply channel onto the farm.
• Murray Irrigation lost an estimated 15–30 percent of the total water diverted into supply-channel escapes, or outfall channels, which discharged into previously dry creeks, forests, unproductive farmland, old lake beds, or even back into the River Murray. This water was lost to the system but was sometimes harvested by irrigators downstream of the escape structure.

• During the 1980s, the rice industry loosened limits on the farm areas dedicated to rice production. As a result, the area planted to rice within the Murray Areas and Districts grew rapidly. In 1991/92, MIL is estimated to have diverted 1.9GL, its largest diversion volume ever recorded. Most of this water was used for rice and pasture production.

• Farm irrigation systems were basic, typically taking advantage of the near-flat landscape – simple raising banks that followed the natural contours to create a series of irrigation bays, each slightly lower than the bay next to it. Water was diverted into the highest ‘contour bay’, and when fully submerged, it was then released into the next contour bay, and so on.
• Irrigation was slow and inefficient. Any surplus diversions ended up escaping from the irrigation farm layouts into local waterways, roadways, adjoining farms, and other low-lying areas. Farm efficiencies were rarely measured, and the slow movement of water across some soil types led to water logging and water losses into shallow water tables.

• The contribution of poor irrigation practices to rising water tables in the region caused significant productivity losses and mobilised thousands of tons of salt, previously locked in the soil profile into the Murray-Darling Basin creek and river systems.

• Drainage from irrigation farms was poorly managed with significant surpluses of water being applied to crops. The extra water applied resulted in several observed problems:
  ◦ Seepage under irrigated paddocks through to subsurface aquifers, causing regional saline water tables to rise, particularly where the groundwater was saline
  ◦ Flows escaping into local roadways, creeks and neighbouring farms causing local flooding and waterlogging outside the targeted irrigated crop areas
  ◦ A loss of water that could potentially have been used to grow more area of irrigated crops.

The excessive irrigation applications and flooding from the river system combined to cause such problems that large engineering interventions were required. In the case of MIL’s Tullakool district, the problems became so severe that a 2,200ha sacrificial basin was developed and a network of subsurface pumps were installed to pump very saline groundwater to these evaporation basins from the surrounding irrigated farmland.

Figure 17. Evaporation basin for the Wakool Tullakool Sub-surface Drainage Scheme (source: Joe Coventry); Rising saline water tables in WA (source: ArcGIS Story Maps)

The Tullakool scheme is Australia’s largest privately owned and operated salt interception scheme and now protects more than 60,000ha of farmland from rising saline water tables within MIL’s area of operations.

A key driver of the practices common throughout the 1970s and 1980s was the belief that investing in water-saving practices was not viable, because in all but the worst drought periods there was more than enough irrigation water to meet demand. This resulted in a number of supply and irrigation practices that underpinned ongoing high loss levels, and significant underperformance of irrigation infrastructure owned by water supply authorities, as well as inefficiencies in farm-supply supply systems employed to irrigate crops.
Drivers for poor WUE in the Delivery System

- Some earthen channels were poorly constructed, using porous materials and poorly compacted, leading to high through-bank losses.
- Earthen channels crossing highly permeable and sandy landscapes led to high seepage.
- Regulation of water using infrequent (daily) adjustment of crude control structures used wooden drop-logs that were often difficult to remove and to replace. Figure 18 shows one such regulator in the NSW Murrumbidgee Irrigation Area in the 1920s providing water flow and level control. Hundreds of these inline structures were used from the first days of Australian channel supply system construction and were still the primary method of controlling and regulating levels in supply channels until the early part of the 21st century.

Figure 18. Water regulators fitted with ‘Drop-board’ control systems (source: State Library of NSW, Series 09: Irrigation, ca. 1921-1924)

- The daily offtake volumes from rivers through inlet structures were rarely adjusted in response to changing weather, such as storm events, causing significant unwanted flows in channel supply systems.
- Limited ability to change flows to meet actual irrigation demand – changes to flows were limited to one change per day. There was no capacity on-farm to store surplus water for reuse in a future irrigation.
- During peak irrigation periods, farmers had to order four days in advance, and so often ordered water they did not need to be sure of having water available. In the event the water was not taken, it often “escaped” out of the supply system into local creeks and wetlands as an unseasonal and unwanted flow.
- Water levels in the channel varied over the day and so flow rates to farmers were inconsistent. This limited opportunities to improve water use on farm. Rice growing throughout the NSW Riverina became increasingly popular, because as a ponded crop, any variation in supply caused by a variable and unreliable irrigation supply was less likely to adversely impact crop performance and yield (provided the required water eventually got to the crop).
In the 1970s and 1980s, there was limited incentive for water supply authorities to save water in the channel system as any measures to reduce system losses in such a crude supply network usually reduced service levels to farmers, causing complaints. There was no reward for investing in and encouraging more water-efficient operations and it was easier for managers and operators of channel systems to regularly over-order from the river, and to over-supply every channel leading to increased system losses (through high daily escape flows) that were never recorded, or acknowledged.

Reasons for poor WUE on-farm

- Irrigation water was rarely rationed, with allocations often increased to 100 percent or even 120 percent to encourage more water use.
- Water was largely applied with crude contour irrigation layouts with almost no levelling, requiring long periods of deep inundation for irrigation bays and thus very inefficient irrigation areas.
- Farmers had no reuse system. Any surplus water simply flowed off-farm into nearby low-lying areas. District drainage schemes were built progressively from the 1970s in response to the problems caused by over-irrigation and the large runoff events caused by heavy rainfall on just-irrigated paddocks.
- The layouts were flat and the irrigation water very slow-moving, causing waterlogging and over irrigation, particularly on more permeable soils.
- Because water was being ordered from dams more than five-days travel time away, often irrigation water was applied late, or water was ordered “just in case” and not actually used.
- Because contour irrigation usually requires irrigation bays to be filled sequentially, starting with the highest irrigation bay, the first bay irrigated is often irrigated for much longer periods than other bays, thus limiting the types of irrigated crops that can be grown.
- Because flows in supply channels were set and inspected just once a day, and there was no remote sensing of levels, flows often varied during the 24 hrs before the next reset and it was difficult to maintain uniform application rates from the supply system and therefore to maintain constant channel supply levels on-farm and into the contour irrigation system.
- Farmers in the NSW Murray were spending typically 600 hours per annum physically applying irrigation water. This was around 100 days at six hours a day – almost a full-time job in itself during the irrigation season. Labour was a significant constraint on more efficient irrigation practices, and because water was (relatively) cheap and plentiful, management and investment to improve water efficiency simply to save water was considered a low priority, except in the rare times of severe water shortage.
- The poor supply system performance and the cost of labour were cited as key factors for farmers to concentrate on growing a flooded, intensively irrigated crop such as rice. It required less area than other crops, and the irrigation supply was simpler and easily managed by a single operator. Additionally, poor irrigation supply systems and short-term water shortages were less likely to reduce yields than for other irrigated crops such as row-cropped corn.

Farm production system

- The NSW Murray Irrigation Areas and Districts were established in the 1930s and 1940s, when the large grazing stations were broken up for subdivision and provided to prospective irrigators to become owner-operators.
- Some parts of the scheme were specifically reserved, and properties provided under favourable terms, to soldier settlers and others to support deliberate closer-settlement policies of successive State and Federal Governments. New entrants were often inexperienced in farming and particularly inexperienced in extensive flood irrigation farming.
• Irrigation in the NSW Murray Irrigation Areas and Districts was initially used predominantly on pastures (mainly annual species irrigated in the Spring and Autumn) that were tolerant to waterlogging and intermittent timing of irrigation. The irrigated pasture was used to support extensive grazing operations, including sheep grazing for meat and wool.

• Throughout the Murray Irrigation Area, the average property was just over 300ha in size, with some larger properties in the west of the region, with one or two very large farming enterprises of more than 10,000ha in the far west.

• Annual water use was typically 400–500ML per irrigated landholding. The irrigation rate in the 1970s and 1980s was only 1.5ML/ha when averaged over the whole property, as most farmers irrigated less than 50 percent of the farm area each year, and some irrigated as little as 10 percent of the farm area each year.

• The area of rice grown per property grew through the 1970s and 1980s from a limit of 20ha.

6.3.4 Drivers of water use efficiency

Certain factors have driven the marked improvement in water use efficiency across MIL over time.

• **Clarify loss allowance**: MIL was formed in 1995. At the time of separation from the NSW Government, the new company was issued an operating licence and a bulk supply licence, which specified irrigator entitlements and also an allowance to reflect the losses incurred in operating the 3,300km canal system known as the Conveyance loss allowance. For the first time since the water was first supplied to irrigators in the 1930s, the supply organisation that operated the channels had a reason to invest in and improve water delivery efficiency as it could access and control the water savings.

• **Control of escape-flows**: The next step was to actively improve the understanding and measurement of losses from escape flows, i.e. the oversupply that was deliberately released out of the ends of the channel system almost every day. Following a series of drier than normal years – with real limits on available water and the installation of the first remote flow measurement on key channel outfall or escape structures – the new company’s distribution staff responded by reducing daily bulk orders for each supply channel. Improvements in efficiency were almost immediately evident. A sure sign of the success was that the long-term beneficiaries of the longstanding ‘free water’ flows complained bitterly as a number of informal (but regular) supplies from old lagoons and water courses supplied for more than 50 years by the 200+ escapes in the supply system dried up.

• **On-farm improvements**: The third driver of improved WUE has been the investment on-farm by the irrigators themselves. It is estimated that for every 1km of MIL supply channel, there are 3–4km of on-farm channels. In response to the increase in value of irrigation water and periods of shortage, irrigation farmers have responded with extensive investment in rebuilding on-farm supply systems, irrigation layouts and by installing reuse systems. Farmers have also piped internal channels to reduce seepage and to improve control of irrigation flows. Field irrigation has also improved dramatically:
  ◦ For flood irrigators, higher flow channels constructed to high engineering standards to enable rapid irrigation combined with laser-controlled grading of irrigation bays to create even field grades that enable rapid and evenly-applied irrigation of crops.
  ◦ A variety of other water-saving and yield-enhancing technologies continue to be adopted to replace flood irrigation for many broad-acre irrigators. These include centre pivot spray irrigation, lateral-move overhead spray irrigation, installation of underground dripper-tape and under-tree spas in the case of horticultural and vine-crops.
Reduced drainage flows: The community drainage systems installed throughout the middle of the 20th century are now used only during extended periods of heavy rainfall in the irrigation districts, because of the improved on-farm management of irrigation water and the near-universal practice of recycling surplus irrigation water. The improved management of water within supply schemes, improved on-farm irrigation application, and the dramatic reduction in uncontrolled flows leaving irrigated farmland have been significant contributors to reduced waterlogging and the related scourge of salinity, which was once such a threat to farm viability in the Murray Irrigation area.

As a result of decreased application of irrigation water and improved farm irrigation practices, the groundwater levels have dropped in all Murray Irrigation areas. Because water table levels have fallen dramatically in the Wakool District, most subsurface pumps in the Wakool Tullakool Subsurface Drainage Scheme have been turned off. The future operation of the scheme will be focussed on controlling salinity and high water table levels by pumping volumes of saline water from shallow aquifers. Because of changes to irrigation management practices, both on-farm and in the way the delivery system is operated, groundwater levels are now up to 10 times lower than was envisaged in the 1980s when the salinity management scheme was constructed.

6.3.5 The modern water supply system

Extensive investment since the mid-1990s in Murray Irrigation’s supply system and on-farm has led to great improvements in the performance of the channel supply scheme and dependent irrigation farms. The MIL supply system of today has a number of features which improve delivery efficiency and provide irrigators with a better LoS:

Supervisory Control and Data Acquisition (SCADA): The modernisation investment in the channel supply system includes remote monitoring at hundreds of points enabling water managers to understand, in near real time, exactly what the water flows and supply levels are throughout the system. Many points are also able to be adjusted remotely or through automated control without the need for an operator to visit the site.
• **New assets:** There are more than 2,000 concrete water control structures regulating water flows and levels throughout MIL’s area of operations. In recent years, the outmoded wooden drop-boards and other control structures have been replaced with steel and aluminium control structures (gates) with neoprene seals and solar-powered motorised lifting mechanisms that enable total control of flows, including completely sealing off of sections of channel, if required.

• **On-farm systems:** During the same period, farm supply systems and farm irrigation layouts have also been extensively modernised. This has enabled farmers to apply more water, irrigate greater areas and to operate more than one farm. Farmers now have larger channels, much larger, laser-levelled irrigation bays, better control structures and often on-farm remote control and automation of irrigation supply systems. Laser levelling creates irrigation fields with accurate and defined falls enabling rapid, evenly-applied and efficient flood irrigation.

• **Production:** As a result, rather than concentrate on rice growing systems that were dependent on inefficient flooded contour bays, irrigators now grow a wide variety of summer and winter irrigated crops, including rice, irrigated wheat, maize, cotton and even some large area orchards. The WUE continues to improve for all irrigated crops, including rice. The measurement of production across the spectrum (tons, bales, litres), is increasing against the volume of water applied. On-farm, the investment in technology has also significantly reduced the hours spent by irrigators managing water application to all crops. Typically, a farmer operating as a sole-trader within MIL’s area of operations now spends only 50–100 hours per year physically managing irrigations – a relatively small-time input, and much of this work can be done from the comfort of the farmer’s kitchen table.

![Image: Laser levelling using laser controlled level adjustment](source: Wandering Australia)

6.4 **Coleambally Irrigation delivery efficiency – from 70% to 90%**

6.4.1 **Coleambally Irrigation**

This is a case study of an irrigation supply company with an earthen channel supply delivery system that went from 70 percent delivery efficiency to over 90 percent.

Coleambally Irrigation is a good example of a channel-supply irrigation district that has converted to an automated delivery system in order to reduce system water losses. The funding for the roll out of the conversion was sourced largely from government in exchange for a share of the water savings generated. However initial development phases were funded by its own customer members.
The modernisation was based on adoption of Total Channel Control (TCC) technology – a product designed, manufactured and delivered by Rubicon Water – which delivers a suite of benefits, including:

- Enhanced levels of service at the farm-gate with:
  - near real-time water ordering period;
  - increased on-farm delivery capacity with many outlets now delivering up to 30ML/day; and
  - equitable volumetric and service levels to customer/members.

- Improving delivery efficiency from below 70 percent to above 90 percent. This has delivered:
  - a benefit for customer/members from a share of the water savings;
  - additional flows for the environment; and
  - reduced accessions to groundwater and subsequent reduction in salinity risks.

- Improved monitoring, recording and reporting of performance to enable better use of the system and knowledge to guide future system investment decisions and better targeting of maintenance programs.

### 6.4.2 Description of the district

Coleambally Irrigation Cooperative Limited (CICL) is a registered co-operative wholly owned by its own customers. The Coleambally Irrigation Area is located in the NSW Riverina and was established between 1958 and 1970. On 9 June 2000, the NSW Government transferred ownership of all assets to local irrigators and the company began as an irrigator owned and operated enterprise.

The characteristics of the Coleambally Irrigation Area are as follows:

- Services a total area of ~450,000ha
  - 98,000ha of which is intensive irrigation
  - 300,000ha of which is mixed irrigation and dryland farming.

- Delivers water to over 490 farms owned by over 290 individual farm businesses.

- Holds around 490,000ML of water entitlements of which approximately 360,000ML is of General Security and over 117,000ML of conveyance water for delivering customers’ water – supplied from the Murrumbidgee River.

- CICL’s delivery system relies on gravity across:
  - 41km of main canal and 477km of supply channels
  - 734km of drainage channels.

- Has a water delivery system which is automated and managed via a TCC system, solar-powered and fully computerised with broadband communication.

### 6.4.3 Practices in the 1970s

The typical water use efficiency practices of the Irrigation Area in the 1970s are described below:

- The delivery efficiency of the irrigation area was less than 70 percent when it was built, with over 100,000ML lost through a combination of outfalls/overflows, metering errors, leakage, rainfall rejections and evaporation.

- The irrigation area is laced with ‘prior streams’, sandy/permeable soils, which resulted in high groundwater accessions and so raised groundwater levels and salinity.
• Irrigation customers were required to place forward water orders to allow for the time taken for water released from the upstream dam to be delivered to the main irrigation offtake.

• Customers near the top of the irrigation delivery network received considerably better services than those towards the end of the system. So, to ensure the service was as equitable as possible, CICL maintained higher flows in channels, which led to higher channel outfalls/overflows.

The Government policy environment at the time reflected the following:

• Desire to drive economic development through the use of irrigation water for agriculture.

• Soils mapping undertaken at a scale which facilitated the design and development of the irrigation system and facilitated the land release of irrigation farms.

• Costs associated with water delivery were poorly understood resulting in low water charges.

• Very limited environmental compliance requirements, either at the farm or the scheme level.

• The irrigation scheme was owned and operated by the government.

The irrigation delivery network comprised:

• Earthen channels, with some channels in high intake soils that leaked.

• Manual water control structures (limited control of water management).

• Check structures that used wooden drop boards to raise channel levels to supply offtakes to farmers.

• Offtake flows from the river weir into the main supply channel of the irrigation area was only varied twice a day, i.e. there was not much flexibility.

• Utilised metering technology at the river offtake which was poorly calibrated and unreliable (although compliant at the time).

• Utilised metering technology at farm outlets which was calibrated and unreliable (although compliant at the time), i.e. largely used Dethridge wheels for measuring on-farm water deliveries. These were later found to have an inherent measurement error of between +21 percent to -5 percent, leading to poor levels of customer equity and of accounting and billing for water use.

• Limited ability to change flow – twice a day modification within the channel system.

• Farmers had to order water four days in advance and sometimes did not get the water when required (particularly towards the end of channel systems).

• Water levels in the channel varied and flow rates to farmers were inconsistent reducing the efficiency of on-farm irrigation.

• In the event of rainfall, farmers would often turn off the outlet supplying water to their farms resulting in unused water flowing to waste through outfalls and the drainage network.

• Farm meters were read quarterly with farmers required to monitor/estimate their actual usage between readings.

• Monitoring usage was largely a manual process (notwithstanding spreadsheet functionality once this facility became available).

• Usage was manually transferred to the billing system – introducing another opportunity for error.

• Water trading was complex and expensive to facilitate due to the manual interaction at every level of the process.
On-farm irrigation systems largely comprised the following:

- Contour irrigation with almost no levelling, significantly reducing irrigation efficiency.
- No reuse/recycle system, with excess irrigation applications flowing directly to the drainage network.
- Slow irrigations could lead to waterlogging and over irrigation.
- Slow irrigations on highly permeable soils often exacerbated groundwater accessions, rising water tables and raised salinity.
- The relative inflexibility of the supply system limited the choice of the crops that could be grown – the system was more suited to crops such as pastures and rice.
- Could not easily vary irrigation application rates, i.e. largely full irrigation each time (increasing inefficiency and drainage discharge).
- Flows varied over the day creating difficulty in maintaining uniform application rates or water levels in the contours.

In terms of the farm production systems:

- Water was used predominantly on pastures (mainly annual species irrigated in the Spring and Autumn) that were tolerant to waterlogging and more resilient to the limitations of the available irrigation system of the day.
- Were adapted to lower value enterprises geared to sheep grazing for wool and fat lamb production. Rice was later proven to suit this type of irrigation delivery system and provided higher returns.
- Properties were generally in the order of 220ha in size and typically held approximately 1,440ML of water allocation, but used in the order of 1,000ML per annum.
- Reflected the owner/operator structure, characteristic of most farming enterprises.

6.4.4 Practices today that lead to improved water use efficiency

WUE practices across the Irrigation Area have changed significantly since the 1970s:

- **Delivery systems:** The uncontrolled outfalls/overflows from the channel system have been reduced by over 90 percent and irrigation induced drainage from farms has also been meaningfully reduced. Groundwater levels have dropped significantly across the entire irrigation area with a related reduction in salinity because of the targeted management of more permeable soils and a reduction in groundwater accessions.

- **On-farm:** The on-farm irrigation systems have been vastly improved with laser levelling of paddocks, incorporation of concrete farm channel structures and reuse/recycle systems. Centre pivot irrigators and trickle irrigation systems are also becoming more prevalent within the area, although surface irrigation technologies still dominate. On-farm irrigation efficiency has lifted by an estimated 30 percent from that of the 1970s.

- **Information and surveys:** CICL initiated a wide range of initiatives to address rising groundwater levels and salinity. This included surveys of the entire intensively irrigated area to assist/guide the development of the CICL Land and Water Management Plan and policy with regard to rice water usage. This survey identified soils of high permeability and provided guidance to farmers on how best to develop and irrigate their property. The surveys were also useful in identifying ‘prior streams’ which have naturally filled with sand or more permeable material over time. Farm scale plans facilitated improved property irrigation layouts, e.g. avoiding highly permeable soils for paddy rice production.
• Electrical conductivity imaging: Also undertaken across the entire irrigation channel network to identify potential high seepage loss sections of channel. This also assisted with the formulation of channel maintenance programs.

6.4.5 Policy improvements
The government policy environment changed over time and reflected the following:

• Government providing irrigators with a ‘property right’ in water. As a result, CICL and its customer members became the owners of their entire water allocation and unlike some irrigation districts, CICL received no credit for water which went into its drainage network, sending an appropriate market signal to invest in water saving initiatives.
• This property right included the volume of water that had been historically used to deliver the customers’ water from the river offtake to the farm – commonly referred to as ‘conveyance water’.
• Introduced full cost recovery to recover government costs associated with the storage, release and management of irrigation water supplies, i.e. placed a higher value on water.
• Introduced a regulatory framework for environmental performance for irrigation scheme operators, including nutrient and chemical levels detected in drainage water discharged from irrigation schemes. Government supported this with a funding program (Land and Water Management Planning).
• The above initiative incentivised both the farmer owners and the system operator to focus their efforts on improving the efficiency of total water use, and thus drive enhanced economic, environmental and social outcomes.

6.4.6 Delivery system improvements
CICL’s irrigation delivery system was altered, extended and enhanced over time with targeted investment from internal sources and government. The staged development is summarised below:

• Upgraded control and measurement of the delivery systems, with remote operation. This included metering of the main river offtake, outfalls, overflows and key regulating structures.
• Extensive testing of the accuracy of the on-farm metering devices and targeted rollout of new, remotely-operated on-farm metering technologies.
• Developed and implemented an incentive program to encourage customers to adopt the modernised technology and manage the initial reduction in water delivered to their property.
• Implemented training programs for staff and farmers in the use of the new technologies to increase on-farm efficiencies.
• Systematically converted channel systems to TCC as channel regulating structures and on-farm meters were commissioned.
• Implemented channel maintenance programs to manage weed growth, aimed at maintaining the higher level of reliability from the introduction of the TCC.
• Implemented a level of redundancy in the telemetry network to ensure system stability.

CICL’s adoption of the total channel control system and associated initiatives has generated a delivery efficiency greater than 90 percent.

CICL also adopted a pricing regime largely driven by delivery shares (i.e. the customers’ capacity share of the delivery system to supply their water allocation). The water savings generated by the modernised system is now largely apportioned based on customers’ delivery shares, hence incentivising them to retain their holding within the irrigation area and realise direct member benefits.
6.4.7 On-farm improvements

Farm irrigation systems also adapted to a changed government policy environment and the new levels of service offered by the modernised irrigation system. These included:

- Irrigation farms are generally laser-levelled to increase irrigation efficiency.
- Concrete control structures with neoprene seals were incorporated within the on-farm irrigation system.
- Full farm reuse/recycle systems – all excess irrigation water collected and reused on farm (noting the remaining drainage system is still needed to manage rainfall events).
- Scheduling water using technology, including tensiometers, neutron probes, weather data, etc.
- Ability to apply water when required by the crop to optimise yield at volumes that increase irrigation efficiency as TCC promotes the active use of spare capacity within the system to facilitate changes in on-farm demand.
- Can vary irrigation applications according to the crop and soil in different parts of the farm.

Farm production systems have also adapted to the investment in modernising the irrigation system including:

- Growing a wider range of crops including rice, irrigated wheat, maize, cotton, grapes, pulses, etc.
- Operations are becoming automated and mechanised with significantly reduced manual labour inputs.
- Farming operations are increasing in size with increased productivity (i.e. amalgamation of older traditional farming operations).

Niche crops are able to be grown (e.g. organic onions, potatoes, etc) because the delivery system now provides a higher LoS in terms of reduced water ordering times, consistency of on-farm flows, etc.

6.5 Drivers of water use efficiency in South Australia

This case study provides a vivid personal story of the process followed in the development of the piped and pumped irrigation districts in South Australia. The story of this transformation journey is told by Mr Jeff Parish, who was brought up on an irrigation farm and worked his way up from his first appointment as a field officer in 1966 to become Chief Executive Officer (CEO) of the Central Irrigation Trust (CIT) from 1997 until his retirement in 2011. Jeff was a “Champion for Change” during his tenure as CEO.

Figure 21. Jeff Parish OAM (source: Stock Journal)
6.5.1 The Riverland

The CIT in the Riverland of South Australia operates and manages 13 irrigation districts on behalf of the farmers that own them. Many of the districts were established by State and Federal Governments to resettle returned soldiers from World War I and World War II.

The districts are mostly made up of privately-owned family farms that grow horticultural crops such as grapes, citrus, stone-fruits, nuts and vegetables.

The crops are irrigated with water sourced from the River Murray at the lower reaches of the Murray-Darling Basin. Water is pumped from the River Murray and delivered to farms through low-, medium- and high-pressure pipeline schemes, electronically metered at the farm outlet.

This case study focusses on the Berri Irrigation Area, and on one particular part of the area known as “the 90-foot lift”. It got its name from the height by which the water was pumped from the river to discharge into the original open channels. It supplied 90 percent of the Irrigation Area.

6.5.2 The historical arrangements

The Berri Irrigation Area originally formed part of a very large sheep station from the mid-1800s. The area expanded rapidly from 1918 to accommodate soldier settlers after World War I.

Early steam and wood gas pumps delivered 2.1 million gallons per hour to supply about 450 farmers irrigating 8,000 acres by furrow, supplied through 64 miles of lime mortar and concrete lined open channels. Four “general irrigations” were provided each year, but reliability was highly variable.

From 1959 to 1978, a new electric pumping station supplied five general irrigations to enable 6 inch (150mm) irrigations in spring and summer at a fixed annual rate per acre, plus “special irrigations” which could be purchased for hours of irrigation at the beginning and end of general irrigations and about monthly during winter.

Irrigation efficiency was so low, and wastage so high, that water tables rose to levels that threatened production on up to 30 percent of irrigable land. As a result, a comprehensive drainage scheme was installed in the 1950s to maintain groundwater levels 4 feet 6 inches (about 1350mm) below the surface and farmers installed internal tile drainage schemes to protect vines and trees.

Weekly irrigations replaced the system of general and special irrigations in the early 1980s when the farmer’s right to 30 inches (750mm) of irrigation per year under general irrigations was converted to hours of irrigation per year for delivery in the irrigation weeks that they chose.

“When I worked in the Berri Office from 1969–1978, the officers in charge had backgrounds in administration or engineering. Irrigation systems were managed within strict rules to maximise the efficiency of the pumping stations and channels. On the other hand, farmers were expected to be respectful and appreciative for having water delivered to their farms and I frequently witnessed strict adherence to supply rules and the lack of regard for the needs of the farmers.”

6.5.3 The new arrangements driving water use efficiency

“I was raised on a local irrigated farm and I was determined that if I ever finished up in charge then the needs of farmers would come first. My chance came in 1978 when I was offered the position in charge of the Berri Irrigation District.

Replacement of the open channels and upgrading of the pumps had commenced in 1975, and by the time it was completed in 1983 the pumping station could deliver 5,000 L/sec to a large tank on the
90-foot lift. From there, water could be delivered through 103 kilometres of now fully closed pipelines through fully metered irrigation outlets to farms.

My main contribution to irrigation was to change the culture of the district from one driven by the priorities and needs of the system to one focussed on the needs of the farmers themselves. My aim was to provide farmers with access to any quantity of water, 7 days a week and 24 hours a day for any duration, at any flow rate (from 1 L/sec to 80 L/sec) subject only to system availability.

My new approach faced opposition from senior engineers who were very unhappy with the way I operated pumping stations with frequent starts and stops to reflect changing demand. On the other hand, for the first time ever farmers could water directly according to their crop needs. I am pleased to say that the new approach eventually became the norm and has been continued by CIT to this day.

The new approach generated major benefits for water use efficiency – system losses were reduced, wastage was reduced, production yields improved greatly, and the environmental impact from drainage and overflows reduced. Farmers could even plan against rainfall forecasts for the first time.

The advice I would give to anyone contemplating replacing open channels and canals with pipeline systems to deliver water to farms is as follows:

- Make the farmers your first priority and ensure you are constructing and planning systems designed to benefit optimal crop production, water use efficiency and environmental outcomes.
- Upsize the ends of pipelines. In Berri the minimum supply capacity to the last 10 farmers on the ends of systems was increased from 57 L/sec to 114 L/sec under new pipelines. Had we not made this change, the new water delivery benefits would not have been possible for farms at the end of systems.
- I have a personal preference for medium-pressure systems using a large balancing tank. I think they are more robust than high-pressure, more efficient than low-pressure, and don’t waste electricity supplying high-pressure to farms that do not require it.”

### 6.6 Rice and water use efficiency – from 0.4t/ML to 1.0t/ML

The rice growing industry in Australia has dramatically improved WUE and productivity by a factor of 2.5. In the 1970s, the average yield was 0.4t/ML, while current yields are 1t/ML, with better quality rice.

#### 6.6.1 The rice industry

The irrigated rice sector has been a central plank of the annual cropping sector in southern NSW since the 1970s. It has some key characteristics:

- It is an annual crop and so the area planted each year can be adjusted to reflect the level of allocation of water and the price on the water market.
- The farm system involves a ponded summer irrigation system with one crop a year sown in Spring and harvested in Autumn.
- Note there is almost no rainfall contribution to the crop – all water is supplied by irrigation.
- The large majority of the rice is grown in either the Murrumbidgee or NSW Murray irrigation districts.
- Levels of production have fluctuated widely over time to reflect the availability and price of water.
An analysis of the level of water use and rice production over the last 20 years shows a number of clear phases:

- A period of steady overall growth over 30 years from 1970 to 2001, with total production rising from 200kt to 1,800kt, but with some annual variation to reflect the level of allocation in each season.
- A profound collapse in the level of production from 2002/03 to 2009/10 as the Millennium Drought hit, water use was reduced, and water prices rose in the market (with an exception in 2005/06 with fully utilised carryover from a late season increase in allocation the year before).
- Recovery over the four years 2010–2014, but to a lower level of production than before the drought and with greater variation in response to the level of allocation.

The timing and level of announced allocation has an impact on the area of rice sown. Historically, the level of water use for rice production was directly correlated with water availability, with decisions on the level of rice production based on allocation announcements in October/November. The level of rice production now tends to collapse when announced allocations early in the season are below 30 percent because the price of water makes the sale of the allocation more attractive than production.

### 6.6.2 Practices in the 1970s

Traditionally, the rice sector used 18ML/ha to grow a 7t/ha crop. That was equivalent to a production rate of 0.4t/ML. Key practices that underpinned this included:

- **Delivery system to the farm:** A manually operated system based on an earthen canal supply. This involved a long order period and could not be adjusted to deliver either constant or variable flows to meet production requirements. The small-scale Dethridge wheels only allowed low flows.

- **Farm irrigation system:** simple on-farm irrigation systems:
  - Contour irrigation with almost no levelling and thus very inefficient irrigation areas
  - No reuse system – excess water just flowed off into the drains
  - Highly permeable soils leading to excess accessions to the water table with risks of raised levels and salinity
Water use efficiency in irrigated agriculture: An Australian Perspective

Variable flows over the day so difficulty in maintaining uniform application rates or water levels in the contours

Use of a continuously ponded production system involving a period of up to 5 months. This precluded the option of double cropping the same paddock, for example, with a winter cereal. As a result, the individual farmer spent about 600 hours per annum physically doing the irrigation. This limited their ability to invest time in developing their systems or alternative crops or markets.

6.6.3 Practices that lead to improved water use efficiency

Opportunities for improvement in WUE existed at three levels:

- Water distribution from the source to the farm.
- The water application system on the farm.
- The efficiency of grain production per unit of water applied.

As a result, the WUE in irrigated rice production has increased to 1t/ML. Key practices that underpinned this are outlined below.

**Delivery system to the farm**

The modernisation of delivery systems has reduced water transmission losses by reducing seepage losses and end of system flow losses, commonly referred to as ‘escape flows’. The upgrading of internal regulating structures and their automation has increased daily flow rates to individual farms and reduced the order period between water ordering and water delivery.

As described previously under Coleambally Irrigation (section 6.4) and Murray Irrigation (section 6.3), the key impacts are:

- The delivery system can provide a guaranteed flow based on the timing and flow rate ordered by the farmer.
- A water ordering system that is online.
- Farmers now have water when required subject to providing orders slightly ahead of time
- A ‘dividend’ of extra allocation from the water savings achieved.

**Government policy:**

- Soil testing that only allow areas of impermeable soils to be irrigated for rice.
- Full cost recovery which incentivises both the farmer and the system operator to become more efficient.

**Farm level irrigation infrastructure**

Infrastructure improvement on-farm included:

- the farm distribution system to reduce losses and provide flows at an optimal daily flow rate.; and
- the farm irrigation layout, or application technology that underpins the production system.
Typical improvements to farm distribution systems included enlargement to earthen channel or pipe systems and internal regulating structures to enable delivery of higher flow rates, removing vegetation from the supply system and promoting the capture and reuse of runoff water to augment the main irrigation supply.

Modern rice farm irrigation systems now include:

- Laser-levelled contour bays of 5ha.
- Concrete control structures with neoprene seals within the farm.
- Full farm reuse system – all excess irrigation water collected and reused.
- Drainage for rainfall events.
- Water scheduling using tensiometers, neutron probes, weather data, etc.
- Ability to apply water when required.
- Maintaining different levels in the contour bays at each application to reflect the plant requirements.
- Varying applications according to the crop and soil in different parts of the farm.
- As a result, the farmer now spends only 50–100 hours/annum physically managing the system.

### Farm production system

Historically, the vast majority of the rice crop was grown in a fully ponded environment. This involved the seed being pre-germinated and sown into a pre-flooded field. The field remained ponded throughout the crop growing season (a period of around 5 months). This precluded the option of growing a crop before the rice crop or the establishment of a winter crop immediately after the harvesting of the rice crop.

The development of shorter season rice varieties, sowing dry rice into a prepared seed bed and the adoption of improved irrigation layouts has provided the opportunity to intensify the crop system (three or four crops in two years) and the production of higher yielding winter crops in the irrigation layouts previously used for rice production.

#### 6.6.4 Key Strategies

Key strategies employed by growers to improve WUE are outlined below.

**Paddock selection – soil type**

Growing rice on soils with low sub-soil porosity will reduce the movement of water below the crop root zone within the soil profile. A soil test can map soil variability and the sodicity of the soil. This can then be used to determine where higher water losses are likely to occur within a field. These areas can then be eliminated from the area to be sown to the crop. This policy initiative by regional growers and the Department of Primary Industries was a major driver of change.

**Agronomy – time of sowing, nutrition and weed control, achieving the key crop checks**

A low yielding rice crop will use a similar volume of water to a high yielding rice crop. So adoption of best management agronomy strategies that result in higher grain yields will improve crop WUE in terms of the tonnage grown per ML of irrigation water applied.
Irrigation management – delayed permanent water

Historically, the vast majority of rice was pre-germinated and sown into a ponded field. An increasing number of growers are now sowing dry rice seed into a prepared seed bed. The crop is then watered intermittently to promote germination and early growth. The field is subsequently ponded prior to the crop commencing panicle initiation. This delay in the application of the permanent water reduces water loss from evaporation and sub soil seepage.

Crop system management strategies

Double cropping involves sowing winter crops immediately before the rice crop and immediately following the rice crop. This requires growing a shorter season rice variety which produces a lower grain yield, but also uses less water. The following cereal crop requires less water, as it utilises the sub-soil moisture that remains in the soil profile after the rice crop. This results in a higher WUE for the sequence of crops. This approach also generates a higher return for the investment made in the land and the associated irrigation layout:

• Operations are becoming automated and mechanised with limited manual labour inputs.
• Properties are increasing in size with higher production levels per farm.
• Niche crops are able to be grown because of the delivery system now provides a high LoS.

6.7 Centre pivot irrigation for dairy

This case study reports on an irrigated dairy farm of 500ha used to supply feed for 700 cows. Conversion from flood irrigation to centre-pivot has reduced water use and boosted yields.

6.7.1 Water use

The farmer has been converting the irrigation systems from flood to centre pivots over the last 10 years. Some of the farm is located on sandier soil, which has a higher than average water soil infiltration and deep drainage under flood irrigation. Converting to pivots has therefore saved around 30 percent of the previous water use, for example:

• Lucerne (Alfalfa) now only requires 6ML/ha, whereas under flood it required 9ML/ha.
• Annual crop water use has reduced from around 5ML/ha to 3.5ML/ha.
• Water use for a mix production of annual crops and millet is now 7ML/ha down from about 10.5ML/ha.

6.7.2 Costs

Pivots are fully automated and are designed to apply 13mm/day, using flows of around 7–8ML/day. The cost of the pivots was around $4,000/ha, which is the average of two pivots of 50ha installed in 2013. This led to an initial loss of production during installation, as the area required drying-off over summer for works to occur.

The property also now has additional costs that include:

• pumping costs of $50/ML with the use of 50:50 off-peak and peak power rates; and
• pivots and their pumps which require repairs and maintenance.
6.7.3 Higher yields
Once installed, the new system has provided increased crop yields:

- Lucerne increase from 10t/ha to 12t/ha.
- Annual pastures (all grazed) from 3 cows/ha to 4 cows/ha.
- Millett (grazed) from 5 cows/ha to 10 cows/ha.

This is because the pivots enable irrigation to be applied without causing ponding and waterlogging. Irrigations as low as 5mm are possible and this means that soil moisture can be maintained at optimum levels without the excessive wetting and drying that is associated with flood irrigation.

6.7.4 Other benefits
Other benefits of converting from flood to centre pivot have included:

- 2.5km of channel has been removed saving maintenance, spraying, excavation, fixing blow outs. This saves $2,500/year in costs.
- There is a more effective production area as a result of removing the channels and reduced maintenance and replacement costs of channel structures.
- Eight outlets from the main supply channels have been rationalised down to two.
- The new system can be managed with fewer staff. The previous multiple small irrigation bays of around 2ha in size had high labour costs.
- Reduced vehicle cost and other saved farm operations.
- The old surface drainage collection and reuse system remains in place, but now only runs after rain, so there are saved pumping costs.
- Overflow from the dairy effluent pond can go through pivots and provides a fertiliser benefit.

6.8 Processing tomato productivity – from 2.5t/ML to 17t/ML
The processing tomato sector is a story of the transformation of a sector from high water use and labour costs to one that matches world’s best practice in production efficiency. Over the last 50 years yields have increased seven-fold, from 2.5t/ML to 17t/ML.

6.8.1 Practices in 1970s
The Australian processing tomato industry in the 1970s comprised 1,400 farmers producing 150,000 tonnes of tomatoes per year. The production was around 25t/ha using 10ML/ha of applied water, with crops irrigated via flooded furrows. The tomatoes were hand harvested. Water use was high, and yields were well below those achieved by world leading producers in California (Figure 23).

Farm production system
The typical farm production system was based on:

- using 10ML/ha to grow 25t or around 2t/ML;
- small properties of 5ha in size typically using 60ML/annum and producing 120t; and
- the owner/operator managing all production functions during the year but employing pickers.
Delivery system to the farm

- A traditional earthen channel manually operated supply system delivered varying flows.
- The flow rate was often insufficient to enable farmers to apply water efficiently.
- Farmers were often unable to irrigate on the day they required.

Farm irrigation system

- Furrow irrigation with almost no levelling and thus very inefficient irrigation areas.
- No reuse system – surplus water just flowed off.
- Flows varied over the day and so it was difficult to maintain uniform application rates.
- Little ability to vary application rates over time.

6.8.2 Practices today

The industry has transformed to a position where there are now only 15 growers producing a total of 250,000 tonnes per annum with industry yields of up to 100t/ha.

The Australian processing tomato industry has remained viable by increasing productivity despite increasing pressure from other producers, notably in Italy and the USA. In 1982/83 the average yield was 29t/ha, in 2017/18 this was 95t/ha. Average yields have increased at an annual growth rate of 3 percent across this 35-year period. Growers are now using between 5.5 to 6.5ML/ha on a subsurface drip irrigated system to grow a 100t/ha tomato crop, i.e., a 10-fold increase in yield and productivity.

Note: Average yields were down in 2002/03 due to drought and the lack of irrigation water, so only 62 percent of the area was irrigated. Average yield also dropped during the 2010/11 season due to the impact of heavy summer rain, and local flooding. Total production also decreased in 2016/17 as a result of crops lost to summer floods.

Figure 23. Average tomato yields over time (Mann, 2018)
6.8.3 Drivers of change

Key practices that have underpinned this transformation are:

**Government policy**

- Government grants to adopt farm efficient irrigation systems.
- Introduction of charging for water supply based on full cost recovery, which has incentivised both the farmer and the system operator to be more efficient.

**Delivery system to the farm has been enhanced**

- The delivery system can now provide a guaranteed flow at far higher rates, i.e. typical flows of 15–20ML/day.
- A water ordering system that is accessible 24 hrs a day and is online.
- Farmers now have water when required subject to providing orders slightly ahead of time. Some farmers near main channels have pumped systems that suck water direct from the channel system—effectively providing water on demand.

**Farm production systems have been transformed**

- Farm irrigation systems were traditionally furrow irrigated with almost no land levelling. Almost all properties are now laser-levelled to ensure adequate drainage for weather events, with beds ranging in size from 1.52–1.65m widths, typically 400m in length. Irrigation blocks are between 6–10ha in size, with a total of 100–120ha per pump site being the most cost-effective installation.
- With the adoption of subsurface drip irrigation, farmers have been able to scale up their production with farming businesses now producing up to 100,000 tonnes.
- Automatic pumping systems with automatic water filtration.
- Fertigation – fertiliser is injected via the drip irrigation system to match crop requirements.
- Automatic controllers and individual valves are provided for each block, enabling the farmer to schedule the start and run times of each individual block without actually attending the field.
- Using drip tapes, which effectively wet the root-zone of the tomato plants, there is no excess irrigation water applied, hence no reuse system required, although a drainage system is still provided to enable management of large in-season rainfall events.
- Scheduling application of irrigation water to match the water deficit through careful monitoring, including soil probing and using technology including tensiometers, neutron probes, weather data, etc.
- All on-farm operations related to planting, tomato picking, weed control and soil preparation are increasingly automated and mechanised with limited manual labour inputs.
- The planting of crops across the entire production region is scheduled by the processing factories to ensure that the delivery of the crop at harvest is spread across the entire season, with processing factory’s daily operating capacity maximised.
- Ability to apply water when required and to vary applications according to the crop and soil in different parts of the farm. Typically irrigation systems are designed to deliver a maximum of 12mm per day to the crop. This is managed by altering the length of each irrigation. Farmers manage forecast periods of high evapotranspiration by applying water above the daily crop water use. This results in a buffer of soil moisture to cover occasional days of evapotranspiration above 12mm per day.
Subsurface drip irrigation

- WUE has improved across the industry, primarily due to the adoption of subsurface drip irrigation. In 1999, 48 percent of the tomato growing area was irrigated using subsurface drip irrigation. By 2009/10, this proportion had increased to 80 percent, and in the past season over 99 percent of the area was irrigated via subsurface drip irrigation. In addition, subsurface irrigation systems have improved in design – improving water distribution, water delivery efficiency and system durability.

![Figure 24. Percent (%) of tomato production via subsurface drip irrigation (Mann, 2018)](image)

- Drip Irrigation is permanently installed at a depth of 20–30cm. The system consists of one drip line per bed. This is installed using GPS which enables the farmer to remove residue from old crops, remove weeds, and reform beds with confidence that the drip tape remains in the centre of the bed.

- Subsurface drip also enables easier management of the crop. Because the drippers are carefully located well below the surface, after crop establishment the soil surface remains dry. This limits the growth of weeds and prevents a moist microclimate forming around the plants, which is conducive to some plant pathogens.

- Irrigators now have greater control over how much water is applied and its timing. They prefer seasons when summer rainfall is very limited. The farmer is not required to physically irrigate the crop but is able to use their time to carefully monitor the growth of the crop and adjust crop inputs, including water and fertiliser.
6.8.4 The processing tomato sector

Tomato production in Australia is now equal to the best in the world in terms of yield per hectare, quality of fruit, and WUE per hectare and per tonne produced. Figure 25 compares average processing field tomato crop yields between Australia and California over time and shows a convergence between the two locations.

Figure 25. Comparison of Australian and Californian tomato production (Mann, 2018)

- The Australian processing tomato industry in the 1970s comprised 1,400 farmers producing 150,000 tonnes of tomatoes per year for processing into tomato paste and canned tomatoes. The industry has transformed itself to the position today where there are only 15 growers nationally producing 250,000 tonnes per annum using a lower volume of irrigation water. There are now two main processing factories, both in the state of Victoria and close to farm production areas – SPC with an intake of 50,000t/yr, and Kagome with an intake of 200,000t/yr processing capacity.

Figure 26. Number of growers and total national production (Mann, 2018)
6.9 Simple practical applications of water use efficiency

This case study reports on the application of the lessons in this Guide in practice, with particular reference to experience in developing countries.

6.9.1 Irrigation system

Being able to control the water on the land – whether irrigation or rain – is critical. There are two basic steps that can be taken, outlined below.

**Levelling**

Levelling of the land in rice production allows the irrigation water to spread evenly and for rainfall to be better retained. This can reduce water use and increase yields due to the greater uniformity of water application, better crop growth, more effective use of fertiliser, and a reduction in weed growth. For example, for rice crops in Cambodia, it was found that 20 percent less water was applied after levelling and that yields increased by 15 percent.

**Raised beds**

The use of raised beds, or ridge and furrows, is a very important technique that can improve irrigation WUE greatly. The water can be applied faster and more uniformly, resulting in more uniform plant growth and reduced water use. Beds, or ridge and furrows, also provide a better soil moisture environment for seeds and small plants as they do not become waterlogged.

Use of land levelling and raised beds, or ridge and furrows, will also result in broader benefits such as reduced waterlogging, better drainage and aid in the management of water tables, and soil salinity problems.

Figure 27. Contractor using mini laser leveller in Cambodia (source: J. Hornbuckle)

Figure 28. Wheat on raised beds in Bangladesh (source: J. Hornbuckle)
6.9.2 Agronomic Options

**Direct seeding**

For rice growing, the most critical water saving opportunity is the direct seeding of rice rather than transplanting seedlings. Direct seeding saves water because the seeds can be planted earlier in the wet season as the fields do not need to be puddled and ponded with water as is needed for transplanting seedlings.

This earlier planting means that the rice seedlings can use the early rainfall to establish and the crop can grow to maturity with less risk of a shortfall of rain at the end of the growing season. Taking this approach reduces rice crop failure and enables multiple cropping if the wet season is good. Direct seeding also dramatically reduces labour by up to 50 percent and increases net income by up to 30 percent.

Figure 29. Direct seeded rice, Bangladesh (source: E. W. Christen)

**Row planting**

At the correct spacing, row planting is a simple yet important contribution to good agronomy. When farmers broadcast seed by hand it generally leads to poor uniformity and they tend to over apply seed as a means of early weed control. By switching to row planting, farmers can apply the right amount of seed. They can also control weeds more easily as the crop is in rows, often using simple hand tools that make weeding relatively quick. This is especially true for rice growing.

**Good quality seeds**

Combined with row planting, it is important to use good quality seed. This is a critical aspect in most developing countries. The use of good quality seed means that a higher crop yield is obtained per unit of water used by the crop, compared to low quality seed and low yielding varieties.
Minimum tillage

This is another agronomic method that, combined with direct seeding and row planting, leads to much reduced cost of production and improved timeliness of planting, improved soil fertility and reduced water use. Reported water savings are 30–50 percent in wheat and rice.

![Image of minimum tillage](image)

Figure 30. Strip tillage of mung bean into rice stubble; Established crop, Bangladesh (source: M. E. Haque)

6.9.3 Irrigation water management

Farmers often apply too much irrigation water, especially when the crop is small. This can have the following negative consequences:

- The young plants do not develop a healthy and deep root system and so cannot sustain high yield or cope with periods of water stress.
- Fertiliser is washed out of the root zone before it can be used by plants.

Most irrigation farmers also do not make good use of in-season rainfall as they are not able to evaluate what effect the rainfall has had on soil moisture.

There are two practical tools that can help farmers to understand when and how much to irrigate:

- The Chameleon™ indicates water availability in soil at different depths by way of coloured lights. This shows farmers the best time to irrigate. Sensors are buried at three depths in the plant root zone. These monitor how dry the soil is in the same way a plant does.
- The FullStop™ monitors nutrient levels in soil, showing the availability of nutrients and also leaching as a result of over-watering. From the FullStop farmers learn how to better manage water and fertiliser applications together. The FullStop is used in pairs and placed at depths of one third and two thirds of the expected root zone. The FullStop captures and stores samples of the water percolating down through the soil. The captured water can then be tested for fertiliser (nitrate) using coloured test strips.
Irrigators using these monitoring tools have fundamentally shifted irrigation and fertiliser management practices and water productivity has increased 50-100 percent. Labour for irrigation has also reduced, allowing other work to be done to diversify and increase income. A further benefit is that the supply of water to canal tail-end farmers has improved so that they can produce reliably and conflict over water has reduced.
References


Australia
water partners for development

The Australian Water Partnership is an Australian Government international cooperation initiative helping developing countries in the Indo-Pacific region, and beyond, work towards the sustainable management of their water resources.