IRRIGATION ESSENTIALS UPDATED

Research and innovation
for Australian irrigators
2012

NATIONAL PROGRAM FOR
Sustainable Irrigation

National Program for Sustainable Irrigation

The National Program for Sustainable Irrigation (NPSI) focuses research on the development and adoption of sustainable irrigation practices in Australia. The Program is managed by the Cotton Research and Development Corporation, on behalf of the program's partners.

- Cotton Research and Development Corporation;
- Australian Government Department of Sustainability, Environment, Water, Population and Communities;
- Gacoyne Water Cooperative, Western Australia;
- Goulburn-Murray Water, Victoria;
- Horticulture Australia Limited;
- Harvey Water, Western Australia;
- Land & Water Australia*;
- Lower Murray Water Authority, Victoria;
- Ord Irrigation Cooperative, Western Australia;
- Grains Research & Development Corporation;
- Sugar Research & Development Corporation;
- South Australian Research and Development Institute;
- SunWater, Queensland; and
- Western Australian Department of Water.

* Land & Water Australia was a partner until the end of July 2009.

Published by: National Program for Sustainable Irrigation
Contact: Guy Roth, guyroth@roth.net.au
Title: Irrigation Essentials Updated
Product code: NPSI 06-12-1
ISBN: 1 921025 36 0

Printed by: Hyde Park Press

First printed, December 2009; UPDATED version printed, June 2012

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NPSI Knowledge Harvest products

- Irrigation Essentials Updated
- Modernisation. Enhancing water supply systems
- Using Recycled Water for Irrigation
- Vital Role for Australian Irrigation
- Irrigation in Australia. Facts and Figures
- Planning Tools. Future scenarios and ecological risk assessments

See www.npsi.gov.au/projects/3295

- Modernising Irrigation Forum

See http://npsi.gov.au/products/PN30149 & 30150.

Special thanks to the following for supplying images: Cotton RDC; CSIRO (Steve Attard, Keith Bristow, Heather McGinness); Tony Clancy; CQU (David Midmore); DAFWA (Alec McCarthy); DPI Vic (Ian Goodwin); Grain & Graze – Grains RDC; Maurie Haines; Land & Water Management (David Hine); Arthur Mostead; Peter R Day Resource Strategies; Ross Nicholls; NPSI; NSW DPI (Janelle Montgomery); Ricegrowers Association of Australia; RMCG (Anne-Maree Boland); Roth Rural & Regional; SARDI (Mark Skewes); Sugar RDC; and Vegetables WA (Georgia Thomas).

SUBS/Hyde/2012

Contents

Preface

NPSI

Australian irrigators have a great history of supporting research into improved irrigation practice and applying the results on farm.

A history of collaboration

Australian irrigators and governments have collaborated for decades to improve irrigation efficiency and productivity through applied research. (See Appendix 1)

There have been numerous collaborations between government agencies (federal and state), research and development corporations, research institutions, industry groups and natural resource management bodies, including:

- National Irrigation Research Fund (via the Water Resources Advisory Council)
- National Program for Irrigation Research & Development (NPIRD) from 1993 to 2002
- National Program for Sustainable Irrigation (NPSI) from July 2002 to June 2012.

The latter has been a consortium between irrigation commodities (Horticultural Australia Ltd, and the Sugar, Cotton and Grains Research and Development Corporations), water companies (Sunwater, Goulburn-Murray Water, Harvey Water, Lower Murray Water Authority, Ord Irrigation Cooperative, Gascoyne Water Cooperative), and government organisations (Department of Sustainability, Environment, Water, Population and Communities, WA Department of Water and SA Research and Development Institute).

See Appendix 2 for more information.

Coverage

The programs have looked at all aspects of irrigation from whole-of-catchment management, through storage and delivery systems, to on-farm practice.

They have covered the full gamut of irrigation industries, including sugar, horticulture (fruit, vegetables, nuts and nursery), cotton, rice, dairy, grains and viticulture; across the breadth of Australia. They have delved into leading edge technologies and explored the interactions between irrigation, the environment and the future.

The National Program for Sustainable Irrigation aims for:

- **Sustainable Production.** Improved irrigation water use efficiency and enhanced ability to respond to changing levels of resource availability over time.
- **Sustainable Futures.** Reduced environmental impacts, more sustainable ecosystems and more prosperous communities.
- **Applied Knowledge.** Improved skills, knowledge and decision making of end users which leads to practice change, and more efficient and sustainable use and management of water.
- **Research Leadership.** A national approach to irrigation related R&D in Australia, which includes a strong focus on a skilled human resource base and enhanced R&D capacity and collaboration.

Significance

The program's direct links with industry cannot be underestimated. Research projects were informed by the urgency of seasons and markets as well as natural resource decline and catchment vulnerability. This meant that the potential for moving information into knowledge and adoption was very good. Different time spans and needs meant that every research funding decision influenced both investors and researchers. Research and development projects had multiple, engaged audiences.

Research, and the process of program funding by many partners, has:

- improved the technology and innovation available for irrigators;
- enabled the transfer of knowledge from one sector or commodity to another;
- increased the consideration of natural resource management linkages; and
- achieved a knowledge sharing culture across industries and regions.

This has resulted in:

- more efficient use of water;
- greater productivity (yield and quality) from irrigation water;
- reduced impacts on the environment;
- increased human capacity, skills and better irrigation management decisions; and
- a national approach to irrigation research, including the Cooperative Research Centre for Irrigation Futures, which NPSI helped initiate.

Economic assessments of the research program have shown benefits to outweigh costs by 8-14 to one. A key feature has been the improvements in water use efficiency. That has saved water, lowered operating costs and increased net incomes. It has meant less salt returning to rivers supplying irrigation water, and more resilient farms during drought. See Appendix 1 for more information on water use efficiency.

Some of the keys to success for the programs have been:

- co-investment from a range of sectors and interests;
- collaboration regarding management;
- strong ties between research, industry and government; and
- great R&D teams.

MORE INFORMATION

All NPSI products are available on-line at www.npsi.gov.au

This report

This report captures the key principles of sustainable irrigation at the farm scale. It provides a blue-print for planning and managing irrigation enterprises, and includes insights into the technology involved and signposts to where to go for further information.

In a world where irrigation will increasingly be relied upon for food and natural fibre production to satisfy the needs of a growing population, products like Irrigation Essentials, and the research behind them, will be of lasting value.

– NPIRD & NPSI Program Coordinators: Brett Tucker, Murray & Liz Chapman, and Guy Roth

About this NPSI Knowledge Harvest document

The NPSI Knowledge Harvest brings together information from across the National Program for Sustainable Irrigation (NPSI) projects, highlighting key findings and promoting wider understanding.

Key themes within the Harvest are:

- Irrigation Overview – facts, figures and key concepts about irrigation.
- Water Delivery Systems – the efficient storage and distribution of water for irrigation.
- On-farm Irrigation Essentials – principles for efficient irrigation.
- Recycled Water – recycling treated effluent and stormwater for irrigation.

This document is a key part of the On-farm Irrigation Essentials theme. It summarises the fundamental principles underlying efficient and profitable irrigation, gives examples of leading-edge technologies and directs readers to sources of more detailed information.

The principles provide a checklist for irrigators and a framework for the adoption of new technologies. They also provide a common language for discussions across different irrigation systems, commodities and regions. They will be of use to irrigators, advisers, researchers and policy makers in Australia and in countries developing their irrigation industries.

INTRODUCTION

Irrigation essentials – essential themes for for good irrigation management.

Water, a global issue – the fundamental importance of efficient water use.

Irrigation essentials

Australian irrigators and their industry bodies are well aware of their dual roles as producers of food and natural fibres and as managers of water resources.

For decades, they have invested in research to continually improve their operations and remain at the forefront of world irrigation practice. This research has developed technologies and practices that save water, make management easier, and improve productivity.

Efficient irrigation is crucial if irrigators are to remain globally competitive and retain access to precious water resources.

Australian irrigation research has led to new technologies and detailed management guidelines that help irrigators adapt these techniques to suit individual farms (See 'Monitoring and evaluation', for a list of guidelines).

This report harvests the key principles of efficient irrigation from the National Program for Sustainable Irrigation and other research, along with examples of leading-edge technologies. These are the 'irrigation essentials' of the future. Some are commonsense but others are the result of intense study and testing by both researchers and growers over a long period.

These principles will be of value as a foundation checklist for all irrigators and a framework for the adoption of new technologies. They provide a common language for discussions between irrigators, advisers, researchers and policy makers across different irrigation systems, different commodities and regions.

What counts is how these principles combine to influence overall farm performance.

For effective irrigation management, it is important for irrigators to have at least adequate performance in all the irrigation essentials, and to score well in those that are priorities for their circumstances. Pursuing a single principle to extremes may compromise the others or leave the enterprise vulnerable to an overlooked risk.

The irrigation essentials are grouped under the headings of:

- Business planning
- Irrigation planning
- Irrigation management
- Crop and soil management
- Monitoring

The irrigation essentials provide:

- **A foundation checklist for all irrigators**
- **A framework of key principles, technical information and case studies relevant to all irrigators**
- **A structured way to think about excellence in irrigation management**
- **A common language between commodities, regions, researchers and irrigators.**

Water – a global issue

The importance of the 'irrigation essentials' is underlined by the critical situation the world is facing in feeding its growing population.

Global water resources will be subject to extreme pressure, with 'megacities' competing with farmers for increasingly scarce water supplies as river basins and aquifers dry up and as the climate becomes more erratic. Global demand for water is expected to nearly double in coming decades.

World-wide, irrigation uses a total of 2.7 million gigalitres to produces about 40% of the world's food crops, according to the International Commission on Irrigation and Drainage.

Climate models indicate that while fresh water will be abundant in places such as Canada, Russia and Brazil, in the rest of the world it will become increasingly scarce and competition between urban, environmental and rural uses will escalate as the world's urban-based population swells to seven billion or more.

Britain's Hadley Centre predicts that 40-50% of the world may be in regular drought by 2100, up from 10% today. Regions that rely on glacial snowmelt for irrigation face acute shortages. These regions include the Indian grain bowl, central Asia, the western US and South America west of the Andes.

A clear need is emerging for a global approach to recycling all water, renovating infrastructure, increasing water use efficiency (on and off-farm), rehabilitating damaged river basins and ending the universal waste of food and water.

In this context, further research and the application of 'irrigation essentials', become critically important, not just to increase on-farm water use efficiency and performance, but to feed the world's population, protect crucial water resources and avoid the resulting instability and conflicts that the United Nations and other bodies have warned about.

These issues will play out at scales from global, to national, to river basin (e.g. the Murray Darling), and to local and farm levels. Irrigation Essentials will help irrigators deal with the challenges ahead and to profit from the opportunities they present.

USEFUL REFERENCES ON THE NPSI WEBSITE:

» Vital role for Australian irrigation PN22081
» Irrigation in Australia. Facts and figures PN22088

www.npsi gov.au

The average human now consumes 1.24 megalitres of water a year for food, clothing and other uses. This is expected to rise sharply with living standards and economic growth.

Source: Chapagain AK and Hoekstra AY (2004) 'Water Footprint of Nations. Report 16'. UNESCO – Institute for Water Education. Netherlands

OVERVIEW	
	Main themes – the fundamental requirements for sound irrigation.
	Key principles – essential ingredients for effective irrigation.

Main themes

The Irrigation Essentials framework has five main themes:

- **Business Planning** – aligning business capacity with market opportunities
- **Irrigation Planning** – site selection and system design
- **Irrigation Management** – optimal production and water use efficiency
- **Crop and Soil Management** – productive soils and optimal plant growth
- **Monitoring** – continual evaluation and improvement

Each theme contains several key principles, 12 in total, which are explained on the following pages.

IRRIGATION Essentials	Theme	Key principles
	Business Planning	External influences
		Business fundamentals
	Irrigation planning	Site suitability
		Production systems and crop selection
		Irrigation and drainage systems
	Irrigation management	Water budget
		Irrigation scheduling
		Irrigation strategies
	Crop and soil management	Plant performance
		Soil condition
	Monitoring	Monitoring and evaluation
		Continuous improvement

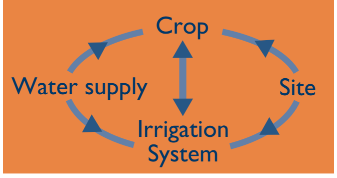
Key principles

Business planning

Every farming enterprise needs a sound business plan but the high capital costs of irrigation, the reliance of individual irrigators on water providers, and the limited flexibility of some production systems (such as perennial crops) highlight its importance for irrigators. There are also some unique aspects to be considered such as opportunities to trade water and the impact of government water policies on farm planning.

- **External influences** – Understand how external issues affect your business; issues such as government policies (regulations, incentives, water trade or buy-back schemes, and delivery infrastructure upgrades), climate change and variability, resource efficiency (land, labour, water and energy), international food and water policies, consumer demands, commodity markets and access to specialist irrigation services.
- **Business fundamentals** - Be on top of the internal factors affecting your business; such as finance (equity, capital, succession plans), personal attributes (e.g. attitude to risk, and openness to new technologies), occupational health and safety issues, farming systems (their flexibility and risk profiles), water delivery infrastructure and water rights, and business / market options. A 'skills stocktake' of available information and knowledge, skills and abilities, education and training, experience, and equipment is very helpful.

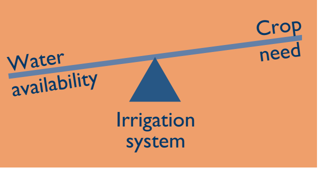
Irrigation planning



Investigation and planning is essential prior to establishment. Irrigators must find the right site and match the production system, crop choices and irrigation design with soils, the landscape, and the availability, security and supply of irrigation water. As external conditions like drought or shifts in commodity markets change it is necessary to revisit these issues and revise fundamental plans.

- **Site suitability** – Understand your site. Assess, understand and update information about soil type and variability, topography, climate, water supply (quality, reliability and access or delivery), salinity and depth to groundwater, and any necessary site preparation or soil amendments. Understand the nature and reliability of the water delivery system.
- **Production system and crop selection** – Select crops that suit your situation. Note the local history of irrigated production and water supply, marketing opportunities, and any new farming systems or crops. Determine the relative importance (profit sensitivity) of high-volume production compared with high-quality produce.
- **Irrigation and drainage system** – Match the irrigation methods, crop choices and site characteristics to design a system for optimal water use efficiency. Subject to local and state regulations, plan to manage surface and sub-surface drainage to reuse water where feasible and minimise adverse environmental impacts.

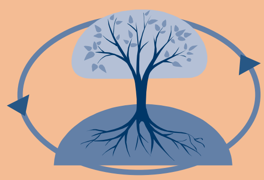
Irrigation management



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** – Prepare a 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** – 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.
- **Specific irrigation strategies** – Consider the role of specialist irrigation strategies like dealing with drought, avoiding frost or boosting crop production or quality.

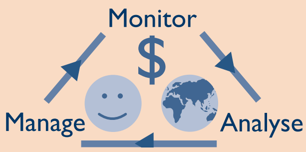
Crop and soil management



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.

Planning, management and monitoring are needed to sustain irrigated production and the environment.

Irrigation essentials

The Irrigation Essentials themes and principles are summarised below.
Each of the principles is discussed in the following theme-based sections.

Business planning

External influences – Understand how 'big picture' irrigation and marketing issues affect your business.

Business fundamentals – Be on top of the internal factors affecting the future of your business.

Irrigation planning

Site suitability – Understand your site; its suitability for irrigation and the availability of water.

Production system & crop selection – Select crops that suit your situation.

Irrigation & drainage system – Design an irrigation system to fit the site and crops.

Irrigation management

Water budget – Prepare a water budget; to be confident of achieving your irrigation goal.

Irrigation scheduling – Develop rules for scheduling irrigations; guidelines for deciding when, and how much, to irrigate.

Irrigation strategies – Use special irrigation strategies for special effects.

Crop & soil management

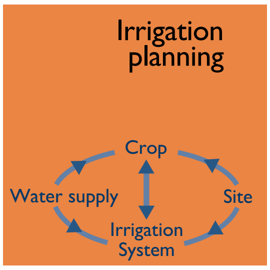
Plant performance – Understand and manage your crop's water and nutrient needs.

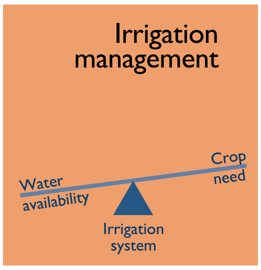
Soil condition – Improve your soil to provide optimal growing conditions.

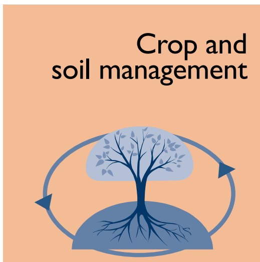
Monitoring

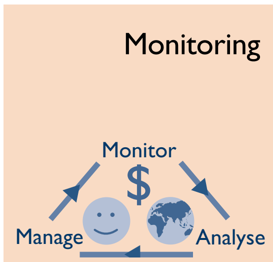
Monitoring and evaluation – Monitor and respond to critical performance indicators.

Continuous improvement – Periodically review business performance and irrigation management.









BUSINESS PLANNING

External influences – national water reform and global pressures.

Business fundamentals – internal aspects of irrigation enterprises.

External influences

Understand how 'big picture' irrigation and marketing issues affect your business.

- **Water reform**
- **Food and water demand**

Water reform

Water reform has been on the agenda for Australian and State governments for several decades.

The reforms aim to promote more efficient and sensitive use of water for both food production and the environment. The core elements include 'caps' on water extraction ('sustainable diversion limits'), conversion to volumetric allocations and promotion of trade in water entitlements and allocations.
For more information on current Australian Government programs see 'Water for the Future' at www.environment.gov.au/water/.

Water reforms provide irrigators with new opportunities and expose them to new risks.

There is now greater freedom to buy and sell water – either permanently or as a temporary (seasonal) trade. Subject to various regulations, water can move between irrigators, between irrigation regions and between users (e.g. shifting from irrigation to environmental flows or to urban consumers). In some regions, the total amount of water available for irrigation is decreasing following the realisation that allocations exceed the current sustainable yield of water. This is causing both stress and hardship in many irrigation areas.

Determining the best use of reduced water supplies will depend on the value of the water to others compared with using it in the farm business. The issue of whether to sell, buy or use water can be fraught with emotion, which sometimes clouds decision making.

NPSI researchers have developed risk management kits to help irrigators in several commodities.

Climate change models predict that there will be less water available for irrigation in many regions in the future. That message has been driven home by droughts in the early 21st Century. The ability to trade water has given many irrigators an option for managing this change.

Irrigators making long-term plans must also consider their region's likely future, its prospects for future access to water, the volumes available, the manner in which it will be delivered (e.g. on-demand and pressurised or low-pressure with a long lead time) and the availability of farm services. The latter includes appropriately skilled staff and labour, processing and marketing services, as well as irrigation expertise.

MORE INFORMATION

- Accessing and using water: www.derm.qld.gov.au/water/index.html
- Water intensive development: www.pir.sa.gov.au/wid
- Wealth from Water: www.dpiw.tas.gov.au/inter.nsf/WebPages/LBUN-8M54FC?open

Food and water demand

The operating environment has changed so much and water trade has facilitated that change. Growers manage risk because they have to.

– Anne-Maree Boland, Irrigation Researcher.

Increasing global populations coupled with less water being available for agriculture threaten our ability to feed the world's population into the future.

A solution will require radical innovations in irrigation, supported by strong future prices for irrigated commodities. However, the current situation for many irrigators is quite the opposite. They are increasingly exposed to global competition, especially in regard to price, and food imports are increasing. Commodity prices are variable and irrigators are being forced to vary their production mix in response.

Besides understanding the requirements of their chosen crops, they must increasingly understand current markets, the preferences of different consumers (e.g. for 'environmentally friendly' or 'organic' produce), and the opportunities to enter alternative supply chains.

Irrigators whose production systems are based on annual crops now make yearly assessments of the water available to them, its cost and the returns from alternative crops before deciding what mix of commodities they will grow in the coming season.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Implications of water reforms for the national economy (CIE12, 2004)
- Scenarios of the future: Irrigation in the Goulburn Broken Region. Irrigation Insights 8 (PR071385)
- Irrigation Risk Management Kits (for Dairy Farmers, Rice Farmers and Permanent Horticulture).
- Vital Role for Australian Irrigation (PN22081)

www.npsi gov.au

Irrigation is crucial to food security.

TECHNICAL MATTERS

NPSI's risk management kits help irrigators answer six questions:

- How often will I be short of water?
- How much will it cost me to use temporary water trade to avoid being short of water?
- Am I better off trading permanent or temporary water?
- How much can I afford to pay for temporary water?
- How do the alternatives to water trade compare?
- What are the main drivers for my water trading decisions?

CASE STUDY

Grains integral in mixed irrigation systems

Irrigated cereal production has traditionally accounted for only a small part of Australian production, with wheat grown primarily in rotation with higher-value crops, such as rice in the Riverina and cotton in northern NSW and Queensland. That is changing with the use of high-yielding cereals that can be grown on reduced water allocations while returning sound profits.

Dr Daniel Rodriguez, from the Queensland Department of Primary Industries and Fisheries, said cotton production utilised 6 ML of water per hectare, but irrigated grains used only 3 ML.

"This situation has prompted an increasing number of cotton producers to regard themselves as 'irrigation growers' focused on maximising returns per megalitre," he said.

Don Gaydon of CSIRO said Australian rice growers had always produced a variety of crops in rotation and have been efficient water users.

"But recent shortages have caused many to question whether rice should always be the priority for irrigation water," he said.

Rice and cotton remain the most valuable crops and can be produced in years when water supply is high, but growers must now have plans in place to ensure they can continue farming when water levels are low, which is where winter grain crops have a role.

For annual crops. when water is plentiful it pays to irrigate and fertilise for maximum production of the highest value crop. When water allocations are low, then it can be more profitable to spread available water and use it to top-up rainfall, e.g. partially irrigating winter grain crops instead of getting poor returns from an under-irrigated summer crop.

Varying irrigation and crop selections on an annual basis, in response to water availability and prices, can increase average farm profits in the long term.

"Good grain prices have kept a lot of rice growers afloat during the past few seasons," Don said.

Researchers are helping growers decide which crops to grow in times of varied water availability by enhancing software models (APSIM – Agricultural Production systems SIMulator – and the related APSFarm) to assess the costs and benefits of alternative crops grown under different water regimes.

Other research-based programs aimed at further helping irrigators with these decisions include assistance with new benchmarking tools for better comparisons (WaterTrack RapidTM), training on alternative irrigation systems (such as centre-pivots and drip), and upgrades to the popular WATERpak guide for irrigators.

Janelle Montgomery, from the NSW Department of Primary Industries, said irrigators had improved the application efficiency of their furrow irrigation through simple on-farm management practices, such as increasing flow rates and being stricter on water cut-off times.

"However, growers should evaluate their systems before they make adjustments to ensure any changes are actually worth undertaking," she said.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Increasing the resilience of Eastern Australian irrigated farm businesses (NPSI2612, 2012)

www.npsi gov.au

Source: Melissa Branagh-McConachy GRDC

CASE STUDY

Dairy adaptation

In the 2007/08 drought, a dairy farm of 260 ha, running 360 head of cows producing 113,000 litres of milk, had access to only 400 ML of its usual 750 ML of irrigation water, so the decision was taken to buy-in additional feed. This led to change in the farmers' whole farming system – they moved to annual pastures, hay and additional feeds to avoid having to water perennial pastures in summer. A grant of $20,000 supported laser levelling of the irrigation paddocks for greater water use efficiency.

The enterprise was also active in the water market, selling water early in the season (with some prices around $700/ML) and buying water after rain later in the season (for $200/ML). The sales were influenced by a need to meet commitments for interest payments on their debt. The farmers monitor the sale price of temporary water on a weekly basis during the irrigation season and take the decision not to buy water when buying feed is cheaper than buying water.

Source: Dealing with irrigation drought. Mallawaarachchi A & Foster A (2009) ABARE Research Report 09.6

Business fundamentals

Be on top of the internal factors affecting the future of your business.

- **Finance and operations**
- **Personnel**

Finance and operations

The level of operating surpluses, debt and the cost of servicing it, and the market value of assets will dictate the ability of any farm enterprise to access finance and invest in capital upgrades to irrigation systems or replace permanent plantings.

The structure of the business and its succession plans will affect its operators' willingness to take risks and to test new technologies, practices or commodities.

The nature of any existing irrigation infrastructure and the basic production system that is in place (i.e. annual or perennial plantings) will further influence the capacity of a business to change. With a flexible system, small changes may be introduced and tested before moving on to more significant change, but where capital works are more expensive, the risk is proportionately higher.

How growers access their water further influences the range of business options available to them. Irrigators must allow for the reliability of supply, the water pressure (e.g. to drive sprinklers or for a drip irrigation system), and any need for on-farm storage. If water is provided as part of a district irrigation system, farm operations need to fit with those of the supply system.

Personnel

The availability of labour may influence decisions about what crops are grown and the degree of (labour-saving) technology that is introduced.

Irrigation enterprises should also conduct a stocktake of the skills and expertise available to them (either through staff or accessible consultants and service providers). It should cover commodity production, irrigation management and commodity marketing. If there are shortcomings the next step should be to assess the availability of relevant training or education programs.

Business owners also need to be clear about their objectives, their own skills and personal drivers, and their attitudes to risk.

As new technologies emerge in irrigation, management is likely to become more complex. Increased automation may increase the level of sophistication required in terms of technical understanding and decision making in order to get the best results.

Changes to irrigation systems may introduce new health and safety issues, and may require a workforce with different skills – such as computing. Management considerations such as these must feature in decisions about system selection and in any audit of staff skills.

Depending on the skills available to them, irrigation farmers can also explore options for vertical integration (getting more involved in the post-farmgate supply chain, such as processing and marketing) or diversification into other forms of irrigation, alternative commodities and water uses.

USEFUL REFERENCES ON THE NPSI WEBSITE:

» Knowledge management in irrigated cotton and grains (PN21938, 2008)
» Understanding irrigation decisions. Irrigation Insights No 6 (PR0061174, 2006)

www.npsi gov.au

MORE INFORMATION

- More than a decade's worth of benchmarking data, such as income, expenses and gross margins, is available for cotton production. See www.crdc.com.au

CASE STUDY

Irrigators may grow different crops (e.g. cotton, sorghum, maize or wheat) depending on water availability and commodity prices.

Branching out from cotton near Dalby, Queensland

Over the past 30 years cotton has been the main crop on a 780 ha family farm near Dalby, Queensland.

Constant changes in commodity prices and input costs, together with reductions in bore water allocations (they are expected to drop from 70% of full allocation to less than 50% within the next three years), are making farmers seriously consider their medium and long-term options.

The manager of the case study farm has started growing maize, soybean, mungbean, sorghum and wheat opportunistically, depending on the amount and timing of water available for irrigation.

The long-term economic benefits from this change in farm business strategy were recently simulated as a cumulative cash flow per hectare, helping the manager and his neighbours to have an informed discussion about options to improve the design of their businesses.

Source: Daniel Rodriguez, DEEDI, Qld

CASE STUDY

Flexible production

The Irrigated Cropping Forum and the Grains Research and Development Corporation developed a series of case studies investigating how the growers of irrigated crops optimised profit and water use efficiency. Flexibility was one of the main themes to come from the project. Excerpts from their report follow.

The Ellwoods

Nick and Nicola Ellwood manage 600 ha of land near Jerilderie, NSW, with entitlements to 1,480 ML of water for irrigation. In a long-standing rice growing area, they also grow faba beans, canola, wheat, lupins and peas, as well as being 'opportunistic' sheep farmers (using them to graze stubbles in summer). All of the water on the property can be captured and recycled via drains and dams.

Nick has tried different irrigation layouts to rapidly deliver high volumes of water. Irrigation bays can take 20 ML/day and the water will be on and off in six to eight hours. Flexibility is another design priority, with beds able to be sown to a variety of crops.

Through a run of dry years the property has been run as a dryland venture with winter crops. Irrigated summer crops are grown if the opportunity arises.

Machinery and management are also focused on flexibility and efficiency. Seeding relies on 2 cm GPS autosteer equipment that allows inter-row sowing into stubble (which retains moisture and improves water use efficiency), as well as saving on inputs and optimising flexibility regarding sowing time.

The Sutherlands

Ian and Sharon Sutherland are also rice growers. They farm 660 ha in the Coleambally Irrigation Area, NSW, with a water entitlement of 4,190 ML and would traditionally grow two crops of rice a year, averaging 9-10 tonne/ha. The heavy rice crops have proven to be good at cleaning up weeds and seed wheat has been sown, taking advantage of that outcome.

Drought and a review of the property's capability (soil testing indicated some parts were not highly suited to rice) has ushered in a reduction in rice production and greater emphasis on seed crops in winter. As well as different varieties of wheat, oats and canola are also grown for seed, along with faba beans. Maintaining high-quality seed without the benefits of rice cropping is proving a challenge and sheep are agisted seasonally to assist in weed control.

The irrigation layout is designed to be flexible, allowing high flow rates to get large volumes on and off quickly, and to permit alternative crops to be sown and harvested. Ian has considered introducing pressurised irrigation with spray or drippers, but has not been able to justify the cost of such a change. Increasing automation is another option he is exploring to further improve management and flexibility.

Source: Groat M & Groat M (2008)
'Lifting irrigated cropping profitability and water use efficiency.' GRDC & Irrigated Cropping Forum.
www.icf.org.au

Irrigation planning

IRRIGATION PLANNING

Site suitability – key site characteristics

Production systems and crop selection – business objectives and decisions

Irrigation and drainage systems – system options and design

Site suitability

Understand your site; its suitability for irrigation and the availability of water.

- **Site characteristics**
- **Water characteristics**

Site characteristics

Basic site characteristics dictate the suitability (or otherwise) of any location for irrigation. For example:

- Soil type – A soil survey or equivalent is recommended to guide planting decisions and the design of irrigation systems. Soil constraints such as salinity, sodicity or acidity should be noted for remediation (before establishment if possible), special management or designated 'not suitable' for certain crops. The soil's water-holding capacity should be determined as a guide to irrigation management.
- Landform or slope – Surface or furrow irrigation requires gently sloping and consistent grades, while pressure-compensated drip systems may be used even on steep ground.
- Underlying geology and groundwater – Locations with poor drainage and relatively shallow watertables are more susceptible to salinity and rising groundwater.
- Climate – Rainfall, temperature and wind will guide how much irrigation is needed, but the incidence of frosts, hail, heat waves and storms should also be considered.

Soil type and landform influence the irrigation design in this banana plantation.

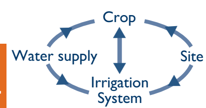
RAW

Readily Available Water (RAW) is the amount of water that a plant can easily extract from the soil (expressed as millimetres of water per centimetre of soil depth). The higher the RAW number, the more water is available to the crop.

As soil dries it holds water more strongly, making it harder for plants to take up the remaining water. The level at which plants have used the readily available water is referred to as the 'refill point'.

RAW varies with soil type, crop type, root depth and irrigation system. Coarse sands will have lower RAW values than well-structured loams.

More information: WATERpak at www.cottonandgrains.irrigationfutures.org.au/



MEASURING SALINITY

Salinity is measured as Total Dissolved Salts (TDS) in either milligrams per litre (mg/L) or the equivalent, parts per million (ppm); 100 mg/L = 100 ppm.

Electrical Conductivity (EC) is a good indicator of TDS. It is measured as EC units (equivalent to micro Siemen per centimetre) and can also be expressed as milli Siemen per cm (mS/cm) or the equivalent, desi Siemen per metre (dS/m); 1mS/cm = 1dS/m.

NB: 1,000 EC units = 1 mS/cm = 1,000 uS/cm = 1 dS/m = 640 mg/L

Water characteristics

The quality, quantity and reliability of water supplies needs to be factored into decisions about the choice of crop and irrigation system and its design. For example:

- Quality – Salinity may limit the range of crops that may be grown. Some crops (e.g. citrus) are more susceptible to salinity (especially on their leaves) than others. Contaminants, such as sediment and dissolved salts, can block drippers, necessitating filtration or chemical treatment.
- Quantity and availability – The amount of water available at different times of the year will govern the area or type of crop that may be irrigated.
- Security and variability – If water supplies are not reliable it is important to know the potential range of availability and to plan a system that is sufficiently flexible to accommodate 'dry' years or seasons.
- Supply – Whether supplying their own water (e.g. from a bore) or receiving it via a district irrigation system, irrigators need to know the 'service levels' associated with water supply. How quickly water can be delivered and the consistency of supply (stable flow rates, volumes and pressures) will influence system design and its management.

Any regulatory issues about water allocations must also be assessed. For private diverters there may be issues about interactions between surface waters and groundwaters. The physical interactions must be understood along with any regulatory matters such as the transferability of allocations between surface and groundwaters. NPSI research has shown that in some situations interflow (sub-surface lateral flow) may mean that surface waters and those classed as groundwater are effectively the same resource but are subject to surface and groundwater allocations.

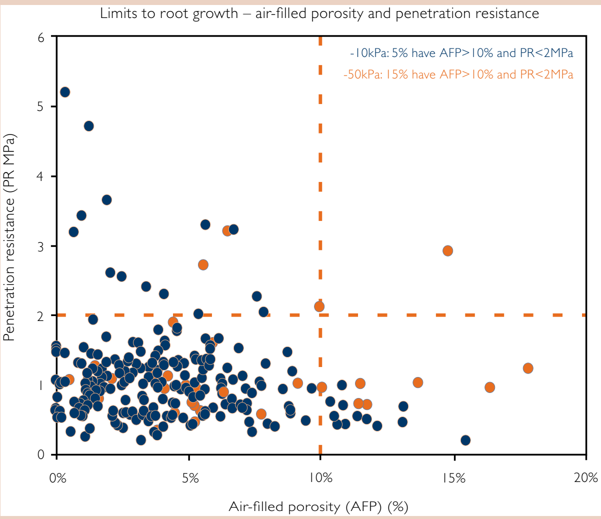
NPSI research is also developing tools to help understand such interactions. One example is a heat tracer which is inserted in sediments in streams, channels or dams to record differences due to water interchanges between groundwater (which usually has a stable temperature) and the surface water (the temperature of which varies on a daily basis). The tool will help identify water movements between the surface water and groundwater, improving understanding of the relationship between the two resources.

Site preparation is the key

A NPSI project that set out to identify and characterise sub-soil structural decline induced by drip irrigation in vineyards found, instead, that virtually all of the sub-soils examined already had such poor structure that further decline was unlikely.

Rather than developing recommendations for avoiding irrigation-induced soil structural decline, the research highlighted the need to create favourable sub-soil structure before planting and to maintain it in the long term, as well as adopting practices in existing vineyards that improve subsoil structure.

The study examined how easily roots could grow in the soil and how permeable soils were for water and air movement.



Measures of 'penetration resistance' provide a guide to the level of soil compaction and how easily roots can penetrate soils. The 'air-filled porosity' of soil is an indicator of the availability of oxygen to growing roots.

For root growth to occur, penetration resistance should be less than 2 MPa and air-filled porosity should be greater than 10%.

Penetration resistance and air-filled porosity of subsoil cores at field capacity (-10 kPa) and near the refill point (-50 kPa) are shown below. Eighty-five per cent of subsoils sampled placed serious constraints on root growth over the full range of soil water contents.

Management such as reduced traffic and under-vine cover crops in winter can help reduce compaction and improve sub-soil structure.

Source: Rob Murray, University of Adelaide

For more information see the Soil condition section of this report.

Salinity limits

South Australia has a threshold target for salinity of 800 EC in the River Murray at Morgan. It has been estimated that if the Murray's salinity exceeds 1,000 EC for the irrigation season, the resulting loss in production from the Sunraysia to the Lower Lakes would be worth $117 million.

Researching how to minimise crop losses due to salinity has been a focus for NPSI and is discussed further in the Soil condition section of this document.

Source: Biswas T et al (2009) 'Technical Report SRD8. Root zone water, salinity and nutrient management under precision irrigation.' SARDI, Adelaide.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Salinity management practice guidelines (PN22225, 2009)
- Managing soil salinity – case study (NPSI1911, 2011)
- Groundwater and Surface Water Interactions in the Fractured Rock Areas of South West Western Australia. (NPSI510, 2010).
- Quantifying surface water and groundwater exchange (UNS5127).

www.npsi gov.au

TECHNICAL MATTERS

Farm dams

In some situations, farm dams are used to store water from seasonal rainfall or other supplies for later use. This reduces some supply risks, but may also limit efficiency through increased evaporative loss and seepage.

Programs such as Dam Ea$y, developed by the Sugar CRC, assess the economic and physical feasibility of dam construction.

Water losses through evaporation from Australia's two million farm dams could be as high as 1.3 million megalitres according to research conducted by the Cooperative Research Centre for Irrigation Futures. Farms dams may lose 40% of their water to evaporation

Losses to evaporation can be reduced through:

- better location and design of dams (e.g. having a small surface area to volume ratio or by increasing wall height to reduce evaporation);
- sealing to avoid seepage; and
- applying various surface covers to reduce evaporation.

Physical covers such as shadecloth and floating modules offer the highest level of protection, but are usually the most expensive.

Chemical covers have a lower capital cost, but may need to be re-applied frequently (every 2-10 days), depending on the product and climate.

Exciting research into chemical (polymer) covers is, however, showing great promise. New ultra-thin films, only a molecule thick and referred to as monolayers, have been tested and a solid form of one chemical (EX3) has been effective in generating savings of 40-60% in small and medium scale field trials and 40% on a large (16 hectare) farm dam. More research is needed before commercialisation, but the chemical would be applied as a large initial dose, followed by smaller daily applications. It has no adverse effect on water fleas, algae or rainbow fish and no ecological concerns are expected as a result of its use.

Farmers can estimate water losses by comparing water in and water out, and then calculating the potential losses or by checking the rate of movement in water height. A more accurate way to estimate evaporation is through the Bureau of Meteorology website at www.bom.gov.au, which gives a general figure for each district, or else by direct measurement (e.g. with Irrimate at www.irrimate.com.au).

A Ready Reckoner calculator is now available to estimate evaporation losses and compare the costs of different methods of reducing water losses from dams. A feature of this program uses Google Earth to zoom in on a farm dam and get evaporation figures. The calculator is available at : //readyreckoner.nceaprd.usq.edu.au/ or via the NPSI website.

An online Farm Dam Management Resource Kit provides information on evaporation and seepage, economic assessments, using dams to enhance biodiversity or for aquaculture, and improving water quality. See ncea-linux.usq.edu.au/farmdammanagement/

The NPSI Water Storage Evaporation webpage presents a series of fact sheets on different types of physical and chemical covers to reduce evaporation, along with technical reports and calculators.
See www.npsi.gov.au/national-program-sustainable-irrigation/water-storage-evaporation

Source: Debbie Atkins, CRC Irrigation Futures

New technology to reduce evaporation from large water storages.
E Prime, A Leung, D Tran, D Solomon, G Qiao & I Dagley (CRC for Polymers)

MORE INFORMATION

- Farm Dam Evaporation Resource Kit – ncea-linux.usq.edu.au/farmdammanagement/
- CRC Irrigation Futures information – www.irrigationfutures.org.au. Search for farm dams
- CRC for Polymers – www.crcp.com.au

Production system and crop selection

Select crops that suit your situation.

- **Water availability**
- **Agronomy**
- **Production objective**

For me, quality is more important than yield and is a lower risk.

Irrigator, assessing options in response to reduced water allocations.

Water availability

Annual crops suit irrigation systems that have variable or less-reliable water supplies. Decisions about what crop and area to sow can be made seasonally, depending on water availability.

In contrast, perennial or permanent plantings are more likely to require secure water supplies to ensure the capital invested in them is not lost in a drought. Water trades offer some ability to maintain perennials without a reliable allocation, but doing so introduces risks about price and availability.

Water that is very secure is likely to cost more than less-reliable resources and so may tend to be applied to high-value crops. Crops that have very precise water requirements for optimal production may require water to be available at short notice (on-demand) and under pressure, e.g. to suit a drip system. Again, there is likely to be a link between the cost of such supplies and the value of the crops that require them.

Agronomy

Market prices, the availability of local cropping expertise and processing or marketing options all play a part in crop selection. So, too, does the agronomy of the crops being considered – their physiology, their seasonal growth patterns (including any 'triggers' such as cold to induce fruiting), vulnerability to pests or diseases and their environmental requirements (such as soil pH, drainage or vulnerability to heat stress or salinity). As an example, grape vines may be selected for the tolerance of different root-stock to salinity, (which may change as the vines age), and their ability to keep salt concentrations in fruit below critical quality limits.

If the crop has unique requirements, the level of the irrigator's knowledge will also be important in choosing the right cropping option. Shifting to new crops may increase the risk for an irrigator unless good agronomic advice and secure markets are available.

How a crop grows will also be influenced by the type of irrigation systems used – see the next section for more information.

HYDROPONICS

Used mainly in horticulture, hydroponics is the growing of plants in dilute nutrient solutions without soil. It is 'perpetual irrigation', with root systems gaining all their nutrients from the solutions in which they grow. It is particularly suited to high-value crops that benefit from very precise management. Aquaponics integrates fish farming with hydroponics, recycling water between the two.

Production objective

For some commodities, the primary goal is to produce high volumes (e.g. canned fruit), while for others the priority is quality (e.g. shiraz grapes destined for top-end wines). In the former, the irrigation system must be able to provide ample water to drive the fruit production; in the latter, irrigation must be carefully managed and timed (and may even be consciously restricted at some times) to achieve high-quality fruit. The production goal must be compatible with the irrigation system and water supply.

Irrigation and drainage systems

Design an irrigation system to fit the site and crops.

- **System options**
- **Design**
- **Drainage**

System options

Irrigation systems include surface flow, sprinklers or various forms of micro or drip irrigation. Each has its own special applications and relative pluses and minuses.

Surface (e.g. flood or furrow) irrigation is suited to heavy soils that have limited deep drainage, and to the application of large volumes of water to large areas. Their energy costs are low, usually relying on gravity to move water. They are unsuitable for porous soils or 'fussy' crops whose water requirements are quite narrow.

Sprinkler systems range from under-tree to fixed overheads, to rain guns, linear move and centre pivots. They can water large areas and be reasonably precise in how they deliver water. They require water under pressure to operate (and thus have high energy costs), have high infrastructure costs and can be an obstacle to flexible crop husbandry. In some regions, remnant native trees may pose problems before the likes of centre-pivots can be employed.

Micro-irrigation systems include mini-sprinklers, drip or trickle, and sub-surface irrigation. They allow very precise water delivery to plants and their roots. They can be used in a variety of conditions and can maintain high-value crops in various soils. They require a pressurised water supply and can be relatively expensive to install but also provide high levels of water use efficiency.

Higher technology systems and pressurised water delivery have underpinned improvements in water use efficiency in many regions. They give irrigators much more control over where water goes, how much is applied and how much is lost to runoff, drainage or evaporation.

Sprinkler systems can irrigate large areas, but need water under pressure to operate.

MORE INFORMATION:

- DPIV System Selection & Design Guidelines at www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_farmwater_efficient_irrigation_wheel
- A compendium of technical information on drip irrigation is available at www.irrigation.org.au See the Drip Special Interest Group
- Growers Guide to centre pivots and lateral moves. moreprofitperdrop.wordpress.com/

CASE STUDY

Furrow design improves efficiency

Research in sugar crops showed that shifting from U to V-shaped furrows, improving irrigation scheduling in sugar crops and moving to minimum tillage results in:

- less deep drainage (a 50% reduction on highly permeable soils); and
- lower water use (saving from 3-15 ML/ha) without reducing yield (effectively increasing water use efficiency from 4-8 tonnes of cane/ML to 12-15 tonnes/ML).

An environmental trade-off is the need for a herbicide application to control weeds.

A current research project is indicating that gains in water use efficiency may also be possible by using overhead low pressure irrigation systems.

In a trial, the overhead low pressure system and a furrow system yielded 23.5 and 24.1 tonne/ha respectively, but the former used less water, giving a water use efficiency of 8.7 compared to 6.4 tonne cane / ML.

The overhead low pressure system maintained yield, but lost less water through run-off or drainage which is expected to also reduce the export of dissolved nutrients and chemicals from the field. In short: the same yield, less water and less environmental impact.

Source: Attard SJ, Inman-Bamber NG, Hesp C, (2009) Use of overhead irrigation in the lower Burdekin uses less water and does not penalise yield. Proceedings of the Australian Society of Sugar Cane Technologists 31, 230-239.

Source: Increasing Irrigation Efficiencies in the Australian Sugar Industry. (PR97006, 1997) Holden JR, Mallon KM. BSES.

TECHNICAL MATTERS

Cotton and deep drainage

For many years it was believed that deep drainage from furrow irrigation was not an issue with the cracking clays predominantly used to grow cotton in Australia. However, results from Cotton Catchment Communities CRC deep drainage research projects and evaluations of commercial irrigation systems are showing that deep drainage is a reality in furrow-irrigated fields within cotton-grain farming systems.

The extent of deep drainage is highly variable. It depends on soil type and uniformity and the condition of the field being irrigated, the irrigation management practices used and the seasonal conditions. Deep drainage does not necessarily happen with every irrigation event and is much reduced once the plants are well established and transpiring.

Irrigators are now aware of deep drainage and are managing it through improved irrigation practices (e.g. levelling, shorter rows and optimising flow volumes).

Source: 'Deep drainage myth busters' Cotton CRC Water Team (Brotherton E, Harris G, Smith P & Wigginton D), www.cottoncrc.org.au

Sub-surface drip irrigation

Well-managed sub-surface drip irrigation supplies water directly to the root zone at the rate required for optimal growth.

Among its challenges are emitter flow rates exceeding the infiltration capacity of the soil, limited lateral water movement in some soils, losses through deep drainage (depending on soil type and irrigation management) and damage by vermin. In some vineyard applications, up to 50% of buried drip emitters can cause soil tunnels due to their high flow rates. Drip irrigation has limited suitability for establishing small seeded crops.

A variation on drip irrigation, capillary root zone irrigation, uses different materials to produce a wider lateral wetting pattern and operates at much lower flow rates (30 mm/hr compared with 3,200 mm/hr with drip tape) to reduce drainage and tunnelling.

Field experiments have shown the two systems to perform similarly, even though they rely on different soil wetting methods. Computer modelling showed that capillary root zone irrigation worked best in coarse textured soils, where it could maintain a small saturated zone high in the soil profile, from which water could move by capillary action.

Source: 'Investigation of the efficiency and long term performance of various sub-surface irrigation configurations under field conditions' (Charlesworth PB) (CSU14, 2003) Charles Sturt University.

CASE STUDY

Processing tomatoes thrive on drip

Louis and Geraldine Chirnside own a 1,250 ha grain and horticulture property near Kerang in Victoria. Most of the property is used for grain production, but 150 ha is devoted to processing tomatoes, all of which is under sub-surface drip irrigation.

"Drip irrigation is good because you can build it in an odd shape depending on the layout of any paddock," Louis said.

Over the years, and benefiting from experience in the US, the irrigation system has evolved from replacing drip tape every few years to leaving it in place for up to nine years. It is now buried deeper (20-25 cm, twice as deep as originally) so soil can be cultivated above it and global positioning systems are used to ensure the tape is kept in the centre of the tomato beds. Californian tomato growers and processors visited several years ago and now are also benefitting from higher yields per megalitre by using drips.

The sub-surface drip costs about $5,000/ha to install, uses 5.5-6 ML/ha/yr and produces around 90 tonne/ha of tomatoes.

The Chirnsides and other growers have also found that overhead sprinklers are more efficient than drip during crop establishment, offering savings of 0.8-1.3 ML/ha or 16-26% of the total crop requirement. However, high capital and labour costs have meant that not all growers have been able to adopt this practice.

Soil moisture is monitored using G-bug equipment at 20, 40, 60 and 80 cm depths, and an imported ET gauge measures plant evapotranspiration.

"Monitoring makes us as efficient as possible. Combined with manual probing it gives us a guide to what is happening under the soil surface," Louis said.

Source: Horticulture Water Initiative (HAL). Environmental performance in the processing tomato industry. www.horticulture.com.au/water

Louis and Geraldine Chirnside inspecting their tomato crop.

Some of the Chirnsides' processing tomatoes.

CASE STUDY

Centre pivot proves best

Kain Richardson and his parents manage 223 hectares near Daylesford in central Victoria. They grow around 3,400 tonnes of potatoes a year over about 70 ha as part of a potato, cereal, pasture rotation.

Taking advantage of government incentives through a 'Water for Growth' program, the Richardsons installed 4.8 ha of drip tape and 5.6 ha of solid set micro sprays, replacing overhead gun and lateral irrigation. After four years, the trial appeared a success.

"On the drip areas we had a water saving of 50-65%, a fuel saving of 40-50%, our yield was similar and our quality had improved. This included better cooking grades and uniformity," Kain said.

Averaging 59 tonne/ha on 3-3.5 ML/ha of water provides a return of nearly 20 tonne/ML – compared to 7-8 tonne/ML under gun irrigation.

A fully automated soil moisture monitoring system was also installed, with tensiometers at 15, 25 and 35 cm depths. They take a reading every 15 minutes and report to a computer via a radio link. A graph is generated from the data, enabling Kain to interpret the results and adjust irrigation as required.

However, the drip tape must be pulled up and relaid each year before and after harvest and that proved too big a shortcoming. It required a major commitment of labour over a short period and it was difficult retaining good quality staff for the arduous task. It also interfered with harvesting, eroding the profits from increased water use efficiency.

After several years of trialling drip tape, the Richardsons concluded that in their shallow soils, and for crops such as potatoes, which are sown into a fresh paddock each year, it would be a better overall outcome to move to centre pivot irrigation. The flexible, transportable system is efficient, and much cheaper and easier to operate, making it a more profitable and manageable option.

Kain Richardson has trialled new irrigation systems for potato production.

Source: Horticulture Water Initiative (HAL)
www.horticulture.com.au/water

TECHNICAL MATTERS

Trickle tricks

Through greater control of water distribution, trickle (or drip) irrigation has the potential to improve water and nutrient use efficiency, reduce off-site impacts and to increase production – but does not always result in those outcomes.

Research in the sugar industry has shown that the wetting profile from trickle emitters varies greatly, depending on soil characteristics and their water content. As a result there could be areas of over-watering (leading to water-logging and potential deep drainage losses) and areas that are under-watered.

The research shows it is crucial to tailor the design of trickle irrigation systems to soil type and crop water demand (which depends on growth stage and weather).

The soil properties governing wetting patterns are highly variable, so it is better to identify wetting patterns in the field and design around them than it is to try and predict them from mapped soil qualities.

More information:

Drip Irrigation Special Interest Group, www.irrigation.org.au/index.cfm?/about-ial/drip-irrigation-sig

Source: Guidelines for efficient and sustainable trickle irrigation systems. (CTC10, 2001). Thorburn P & Bristow, K CSIRO

Design

The chosen irrigation system and its design must match:

- the water supply and delivery system;
- the soil type and landform; and
- the crop requirements.

The degree of automation, maintenance requirements and compatibility with farming operations (e.g. sowing or harvesting) are other considerations, along with cost and operating expenses (e.g. energy).

The system must also suit the management skills and the goals of the irrigator: a poorly managed and maintained drip system can be less efficient than well-managed flood irrigation on the right soils.

Well-designed systems traditionally strive to achieve high levels of uniformity in water delivery, typically aiming for 85-95% consistency over the paddock. This ensures all the plants are watered evenly, eliminating gaps that otherwise lower water use efficiency.

Energy consumption has a major impact on running costs and greenhouse emissions. It is important to match pumps and motors to the size of the job and to maintain the entire system regularly.

While traditional irrigation design aims for high uniformity in water delivery, some new innovations vary the distribution of water in a precisely controlled manner to match (or manipulate) the varied needs of plants.

BETTER DESIGN

For publications, training courses and other resources to assist with irrigation system design, see Irrigation Australia at www.irrigation.org.au.

HOME IRRIGATORS

Every home gardener is an irrigator. They may hand-water the pot plants and seedlings, give some trees a deep soaking during dry spells, have drippers, micro-sprinklers or a soaker hose among the shrubs, and irrigate the lawn (water restrictions permitting) with a variety of sprinklers (or – if it's a new lawn – install sub-surface drip).

Like gardeners, commercial irrigators also match their irrigation method to crop requirements. In addition, they must factor in the nature of their water supply, management factors and market demand for the produce they grow.

MORE INFORMATION:

- WaterRight Gardens Tool at www.sydneywater.com.au/SavingWater/InYourGarden/2
- Save Water Alliance at www.savewater.com.au

CASE STUDY

Pressurisation brings benefits

Historically, the Harvey Irrigation Area in south-west WA was dominated by dairy cows grazing surface-irrigated pastures. An innovative rehabilitation program has seen the water distribution system convert to pressurised pipes fed by gravity, which avoids the financial and greenhouse costs of pumping.

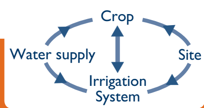
The improved supply has enabled irrigators to consider alternative on-farm practices.

NPSI research trials showed that centre-pivot irrigation could reduce water use by 15% and grow more pasture, of better quality, to produce more milk (both per hectare and per megalitre of water).

Deep drainage was not detected under the surface or the centre-pivot irrigation, but the latter also avoided surface run-off. This is an additional advantage as irrigation drainage from dairy pastures can be high in dissolved nutrients and is controlled in some catchments.

Although experienced in managing their previous systems, the region's farmers found there was plenty to learn in order to get the best from their centre-pivots. This research had a 12 to 1 benefit to cost ratio.

Source: 'Changing irrigation systems and management in the Harvey Water Irrigation Area'. Moore K, Chester D, Kuzich R, Nandapi D, Rivers M.



CASE STUDY

Drip feeding cotton and grain

Stewart Crawford, Narromine cotton and grain grower.

Large areas of red soils as well as the more common grey clay soils are used to grow cotton.

These red soils have high infiltration rates and a lower water-holding capacity than the grey clays and surface crusting or sealing is a common problem, resulting in poor water infiltration following rainfall or surface irrigation.

Stewart Crawford farms near Narromine in the Macquarie Valley, NSW. He has been one of the pioneers of sub-surface drip irrigation in broadacre crops, using it to grow irrigated cotton and grain crops such as corn, sorghum and wheat. Stewart installed his first 50 hectares of sub-surface drip tape nine years ago and now has 175 ha.

The drip irrigation provides greater control of water and nutrient application rates can be changed daily to match weather conditions and crop growth needs. The irrigation water is pumped from a bore into a storage dam. This ensures a reliable water supply if there are any problems with the bore.

"A reliable water supply is a must for drip irrigation because of the initial large capital investment," Stewart said.

"The drip system needs to be growing a crop every year to pay back that initial investment quickly. The bottom line is that with sub-surface drip irrigation water use has halved, fertiliser use has reduced and yields have increased."

One of the consequences of the drip system has been a reduction in deep drainage, meaning that less salt is leached from the soil profile. Sometimes the soils have elevated salt levels at the end of the season near the surface, but winter rains usually leach these out by summer crop planting time. While it is not causing any problems, it is important to be mindful of the issue.

Stewart has also experimented with the depth of the drip tape.

"The sub-surface drip tape depth is critical. Six to eight inches is ideal in red soils. If the tape is too deep, subbing water upwards towards seeds can be problematic. In black soils the tape can be deeper (10-12 inches)."

Source: Guy Roth

See the full case study at: www.cottoncrc.org.au/soils

Stewart's 'must dos' include:

- **Design is critical to get enough water, uniformly, to all the crop.**
- **Pressure is your friend.**
- **Dripper placement is critical.**
- **Start with good soil structure and maintain it with minimum tillage and trash retention.**

Part of Stewart's irrigation system.

Drainage

Excess irrigation water will drain away below the crop (deep drainage) or flow off as surface water. If drainage below the root zone is impeded there may be a rise in the underlying watertable, inducing waterlogging and salinisation and calling for the installation of a sub-surface drainage system or bores.

Understanding the site's soil and near-surface geology will help in the design of drainage before problems occur.

Drainage water is both a potential contaminant to the environment (taking with it salts, nutrients and farm chemicals) and a wasted resource. Providing it is of suitable quality it may be harvested and re-used for irrigation (even if it must be 'shandied' with other water to be of suitable quality). Re-use improves overall water use efficiency, saves nutrients that would otherwise be lost and reduces the risk of contaminants entering creeks and rivers.

Because of the off-farm aspects, local regulations, such as controls on building dams, may apply to drainage management.

Irrigators may also be involved in managing drainage water after it has left their property. To minimise off-site impacts, many producers capture drainage on-farm, where the land is suitable to do this, and provide some first stage treatment, such as constructing wetlands to remove nutrients and sediments.

Subject to regulations and water quality, drainage water can be a useful resource.

MORE INFORMATION

- SmartCane Riparian and Wetland Areas on Cane Farms at www.canegrowers.com.au/page/Growers_Toolkit/smartcane/About_BMP__SmartCane/bmp-wetland/
- Managing Riparian Lands in the Sugar Industry at lwa.gov.au/products/pr010157
- Managing Riparian Lands in the Cotton Industry at lwa.gov.au/products/pr030555

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Subsurface Drainage Design and Management in Irrigated Areas of Australia. Irrigation Insights No 2. (PR020277, 2002) Christen EW, Hornbuckle JW. CSIRO.
- Investigating improvement to irrigation drainage systems. Nutrient removal from rural drainage systems using wetlands. (EF040703, 2004)
- Waste water recycling in nurseries. (PF050872, 2005)

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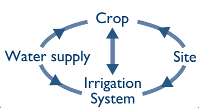

TECHNICAL MATTERS

Managed inundation of native wetlands

Drainage water from irrigation areas is often thought to create difficulties for the environment, but that is not always the case.

The landscapes in irrigation areas are usually considerably modified from natural conditions and, in some cases, native plants and animals now rely on irrigation water for survival.

Irrigation creates new habitat areas (e.g. in channels and irrigated fields) that may help support native aquatic animals and birds. These 'constructed wetlands' tend to support species that are adaptable and not generally under threat. More at risk are the sensitive species that rely on areas of intact woodland or wetland vegetation (e.g. patches of vegetation or wetlands that have become isolated from rivers or overland flow).

In irrigation areas, some of these remnant woodlands and wetlands (and their associated species) rely on surplus irrigation water for survival.

Research in the Riverina has identified areas of Black Box (Eucalyptus largiflorens) woodland in this situation. Black Box woodland communities were one of the most widespread floodplain vegetation types in the Riverina before agricultural development and, despite broadscale clearing, remain one of the most common remnant types. It is thought that these woodlands flooded naturally about once every two to 10 years, for 2-6 months, depending on location.

Black Box trees suffer and eventually die without sufficient flooding, or where water is ponded for too long.

Studies indicate the availability of groundwater is a crucial factor affecting tree health. If the roots of black box can draw on good quality groundwater then flooding is less important to their survival. However if that is not the case then they will require flooding at least once every 10 years to avoid decline. During drought and in times when groundwater levels drop, then flooding may be needed every one or two years to ensure survival.

Changes affecting tree health also alter the understorey and affect native animal and bird populations. Managed flooding of these areas is recommended to ensure the survival of the native plants and animals that live in them, and to enhance and maintain the biodiversity value of irrigation landscapes.

MORE INFORMATION

- Heather McGinness, CSIRO Sustainable Ecosystems.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- The effect of changing irrigation strategies on biodiversity. (CSE 5029. 2011) Arthur AD, McGuiness HM & McIntrye S.

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Irrigation drainage can help maintain biodiversity.

Irrigation management

IRRIGATION MANAGEMENT

- Water budgets – calculating water requirements
- Irrigation scheduling – the right amount of water at the right time
- Irrigation strategies – dealing with drought

Water budget

Prepare a water budget; to be confident of achieving your irrigation goal.

Budgets

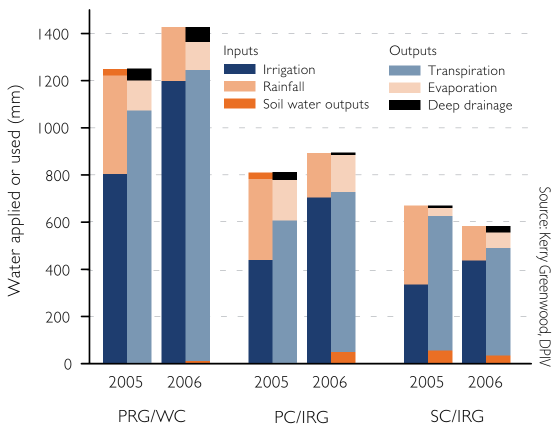
The first step in irrigation management is to develop a water budget. The budget compares the amount of water a crop will require (the 'theoretical crop water requirement') with the water that is expected to be available.

It is a crucial tool in times of drought and in assessing options for water trading.

Budgets can be modified during a season if circumstances change. They can be used on an annual basis or broken down into monthly intervals (like a cash-flow budget for water).

Water budgets must allow for all components, including all potential water sources (e.g. rainfall, irrigation and re-use), the initial store of water in the soil and losses such as evaporation from farm dams. Besides the direct plant requirements, they should also factor in drainage and any need to leach salt from the root zone.

Evapotranspiration (ETo) is an important factor. It includes the water used and transpired by the plant and that which is evaporated from the soil. It is multiplied by a crop-specific coefficient (Kc) to determine the crop water requirement. The international standards for these calculations can be found in the Food and Agriculture Organization's Irrigation and Drainage Paper 56.



Annual water budgets for three pasture mixes (PRG/WC – Perennial ryegrass and white clover; PC/IRG – Persian clover and Italian ryegrass; SC/IRG – Subterranean clover and Italian ryegrass).

MORE INFORMATION:

- Crop evapotranspiration. Guidelines for computing crop water requirements FAO Irrigation and Drainage Paper 56. RG Allen et al. 1998. www.fao.org/docrep/X0490E/X0490E00.htm
- Water budgeting tools assembled by the horticulture industry at www.horticulture.com.au/drought
- Water budgeting tools for viticulture at waterandvine.gwrdc.com.au

CASE STUDY

Our philosophy has become you can't manage what you can't measure. We know how much water is going on a crop, what yield we're likely to get out of it, and how much water is on the farm. That's got to be better for our farm business.

– Brett Bidstrup

Budgeting pays off

Water budgets have been integral components to responses by irrigation farmers to drought-induced water deficiencies.

Brett Bidstrup runs a 3,000 ha farm with a mixture of grazing with dryland and irrigated crops near Condamine in Queensland. The property has a 'licorice all-sorts' mixture of soil types, which are variously suited to corn, cotton, peanuts and watermelons.

Working with consultants and advisers, Brett accurately mapped farm dam storages to know exactly how much water was available for use. Additionally, electromagnetic surveys and in-field water use efficiency assessments were used to characterise different soils and their irrigation requirements. C-probes were used to monitor soil water to better schedule irrigations, and water use efficiency was further enhanced by adjustments to the in-field irrigation system to match water applications with soil type.

Andrew Greste manages a 6,000 ha dryland and irrigated property in the Namoi Valley, NSW. Every paddock is managed to conserve moisture through practices such as no till, stubble retention and using chemicals rather than cultivation to control weeds. As a result, the in-field water use efficiency rates very well.

To improve whole farm efficiency, Andrew turned his attention to on-farm water storages where water budgets indicated there was most room for improvement, by reducing evaporation and seepage losses. Storage areas were reduced and storages were developed closer to fields to reduce delays and losses in getting water to crops. Andrew also avoided having to wet dry storages to further reduce losses.

'The drought's changed the way we think about water. We don't think of ourselves as irrigation farmers, rather as dryland farmers with the ability to irrigate some paddocks when water is available,' Andrew said. 'There hasn't been one magic solution to water use efficiency, but we've made lots of little changes that have added up to something significant. They way we think about the farming system has probably had as much impact on our water use efficiency, our productivity and what we grow as the practical things.'

Both these farmers have shown the value of water budgets and the importance of taking a holistic approach to irrigation, where a number of factors are manipulated for best overall effect.

Source: Cotton Australia www.cottonaustralia.com.au/library/casestudies/

CASE STUDY

WaterSense

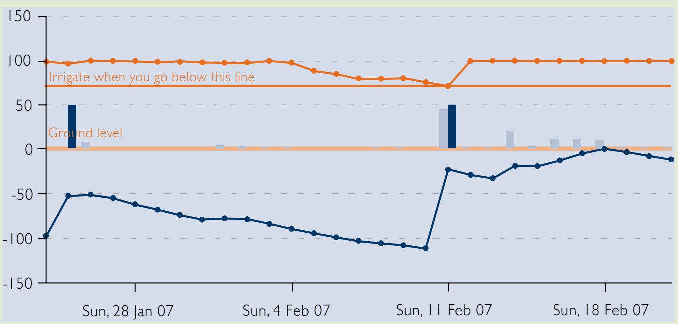
Monitoring systems such as EnviroSCAN have made it possible for sugarcane growers to monitor the soil water balance in real time for a limited number of fields.

CSIRO's WaterSense web-based irrigation management tool allows irrigators to calculate the daily soil water balance in several fields simultaneously, and to schedule irrigation accordingly. WaterSense can produce graphs to help with irrigation scheduling decisions.

Source: Haines MG, Inman-Bamber NG, Attard SJ & Linedale AI. 'Enhancing Irrigation Management Planning with EnviroScan and WaterSense'.

WaterSense Irrigation Schedule

- *Blue line below zero represents soil water deficit.*
- *Grey vertical bars above zero indicate the date and amount of rain recorded.*
- *Dark blue vertical bars above zero indicate the date and amount of irrigation applied.*
- *The red (dotted) line above zero represents biomass accumulation potential (crop growth rate %).*
- *"Irrigate when you go below this line" indicates crop growth rate has declined below the selected per cent potential biomass accumulation.*
- *X axis represents daily date, month and year.*
- *Y axis has two interpretations: Below zero, shows accumulated water deficit (mm); or Above zero, represents irrigation and/or rain (mm) and the estimated biomass accumulation rate (%).*



Irrigation scheduling

Develop rules for scheduling irrigations; guidelines for deciding when, and how much, to irrigate.

- **When and how much**
- **Soil water monitoring**
- **Innovative irrigation systems**

When and how much

Irrigation scheduling is deciding when to irrigate and how much water to apply (or how long to irrigate for). The aim is to apply the 'right amount of water at the right time' but deciding 'when' and 'how much' can be daunting questions.

Monitoring the crop, weather and soil can help. Three basic approaches are used, either on their own or in combination:

- Calculating crop water requirements based on climate, especially evapotranspiration.
- Monitoring soil moisture levels in the root zone.
- Monitoring the plants themselves.

The key to good scheduling is to use a range of tools and indicators, while still keeping track of the basics, such as keeping a close eye on weather forecasts and visually inspecting the crop.

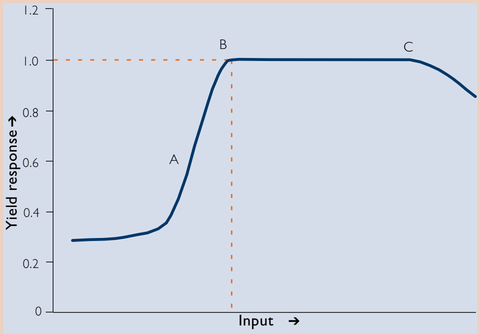
TECHNICAL MATTERS

Insurance irrigation

There can be a fine line between under-watering and meeting the crop's needs. Over-watering guards against the risk of poor yields, but can be wasteful.

In the graph, it is 'safer' to operate between B and C than to aim for B and risk being at A. The steep response curve and the variability and uncertainty inherent in irrigation, make it difficult to optimise yield per volume of irrigation water. Monitoring can help ensure irrigators reach B, without moving too far toward point C.

Source: Stirzaker RJ (1999) 'The problem of irrigated horticulture: matching the biophysical efficiency with the economic efficiency.' Agroforestry Systems 45: 187–202



CASE STUDY

Monitoring irrigation effectiveness

Alan Blight manages a 20 ha avocado orchard at Wanneroo (50 km north of Perth).

Research programs were indicating that this property was using more water than the trees required, so Alan reduced his irrigation application volumes. However, the trees then began to show symptoms of salt toxicity.

To better manage his irrigation and monitor levels of soil salinity Alan bought 12 FullStop wetting front detectors in 2000 and installed them at depths of 30 cm and 60 cm. He later added more devices installing them at 15 cm.

Over a season, it was apparent that salinity levels rose during the growing season from a winter low (from 1 to 3-5 dS/m). With the aid of the monitors, Alan aims to keep soil water salinity below 3 dS/m through increased irrigation when required.

Some FullStops were triggered regularly by the wetting front, while others were not, indicating variability in how different parts of the orchard were irrigated. Testing with cups showed that was the case and was due to wide variation in water application efficiency by different sprinklers. Alan has some capacitance probes as well (at 60 cm).

Because of the sprinkler variability, he believes he is better off with 50 FullStops, as relying on a few capacitance probes runs the risk of them being in a wrong position and giving misleading information.

More recently, Alan has installed new irrigation to improve the uniformity of application and added some Motte lysimeters for additional monitoring.

Source: 'Soil Solution Monitoring in Australia.' (Falivene S, 2008) CRC Irrigation Futures Series No. 04/08.

Soil water monitoring

The wetness of soil can be worked out by:

- The weight of water in the soil (gravimetric soil water content), e.g. 0.3 g water per 1 g dry soil (measured by comparing the weight of a soil sample before and after drying). No allowance is made for soils of different weight, so readings are not comparable across different soil types. Gravimetric soil water content is measured directly by drying soil samples in laboratory ovens. Some other measures are determined indirectly by measuring properties of the soil that vary with wetness and can be measured in the field.
- The volume of water in the soil (volumetric soil water content), determined by multiplying the gravimetric soil water content by the 'bulk density' of the soil (the mass of soil per unit volume). It is measured in cubic centimetres of water per cubic centimetre of soil and allows for the differing weight of different soils. Some volumetric approaches that can be applied in the field are neutron moderation (neutron probes), heat dissipation and soil dielectrics (capacitance probes or devices such as EnviroSCAN).
- The pressure needed to extract water from the soil, referred to as soil water potential or soil water suction. This measure (expressed in kilopascals – kPa) is used because some soils hold water more tightly than others, and all soils hold water more tightly as they dry. It represents the energy plants must exert to draw water from the soil. Soil water suction can be measured by porous media (e.g. gypsum blocks) or wetting front detectors (e.g. FullStop), which are devices that detect when water moves down through the soil to them.

Soil pits help determine the rooting pattern of crops.

The key to sound monitor placement is to understand the root structure of the irrigated plants – how deep they go and how widely they spread.

Having a monitor (such as the FullStop) at the bottom of the root zone is a common first step.

By knowing the volume of the root zone, the soil type and soil water content, it is possible to determine the amount of readily available water (RAW), which is an important aid to accurate irrigation scheduling.

Solute samplers (that detect nutrients and salts) are built into some soil-monitoring devices and can help determine if nutrients are being lost below the root zone or if salts are building up.

A review of solute monitoring in Australia concluded that:

- There are stories of genuine successes and enthusiasm from irrigators, but the momentum has not been sustained. Only a minority of growers carry out solute monitoring.
- Solute monitoring has proceeded in fits and starts, and a number of groups have focused on modifying existing equipment. It is not clear if lack of adoption is linked to deficiencies in the tools themselves or simply a lack of awareness of the tools.
- Even if solution samples are taken routinely, there is no unambiguous way to interpret the results and make definitive recommendations.

Source: Falivene S, 2008

Gypsum blocks measure soil water suction.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Information Package on Soil Water Monitoring. Irrigation Insights No 1 (PR000236, 2000).
- LongStop – A more sensitive wetting front detector (PN21170, 2008).
- Knowledge and tools to manage fertigation technologies (DAN5027)

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CASE STUDY

Siting soil water probes

To have confidence in any soil water (moisture) monitoring tool, it is important to know it is in a representative part of a field.

A moisture probe that is in an unrepresentative spot can result in over or under irrigating the major soil type present unless the particular location, and its differences, are factored into scheduling decisions.

To gain confidence in their soil water monitoring setup, irrigators can use Electromagnetic Induction (EM) surveying in conjunction with soil sampling. EM surveys detect the electrical conductivity of soil; this is related to soil texture, soil water and salinity. 'Ground truthing' soil surveys are used to calibrate the EM readings and help interpret EM survey maps.

These maps enable irrigators to select monitoring sites that are representative of the majority of the irrigated area. Using EM surveys to assist in siting moisture probes gives growers more confidence with scheduling decisions.

For furrow irrigation it is also important to understand the slope of the irrigated area and the location of any high or low spots. A terrain (or slope) map can be prepared, along with a map of any areas that have been cut or filled to level them. When combined, the resultant map shows the areas with the most common soil type and slope. Monitoring devices should be located in these areas if irrigation scheduling is to meet the needs of the majority of the irrigated area.

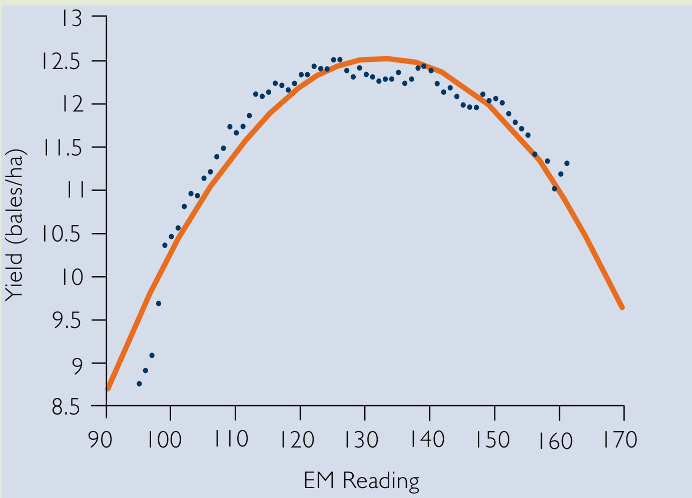
A user of EM surveys, Andrew Parkes of Moree, NSW, has found a close correlation between yield maps and EM readings.

By analysing the data, it was evident that the most common soil type was the area with highest yields – the field was being irrigated appropriately for the major soil type. The graph below shows the cotton yields from different soil types (as indicated by the EM reading). Soils with low water-holding capacity (low EM readings) yielded less and there was some decline in yield for higher clay content soils with high EM readings (that may have been over-watered), but the most common soils (in this case, having EM readings ranging from 120 to 140) all had maximum yield.

More accurate irrigation scheduling has enabled Andrew to increase water use efficiency in terms of production and profit per megalitre of applied irrigation water.

Relationship between EM reading and cotton yield (bales of cotton/ha).

Source: Montgomery J, Carrigan E, Wiggington D 'Irrigation scheduling. EM Surveys for probe placement.' Cotton CRC



WATER DEPTH

Irrigators often measure water applications by volume, usually as megalitres per hectare (ML/ha). Alternatively it can be measured by depth, for easier comparison with rainfall and evaporation.

One megalitre applied over one hectare is equivalent to 100 millimetres of water.

1 ML/ha = 100 mm.

CASE STUDY

Scheduling change

Irrigators involved in NPSI research have found that improved monitoring of soil moisture can lead to changes in irrigation scheduling, resulting in improvements in irrigation efficiency and environmental improvements.

Hans Loder, a wine grape grower in the Coonawarra region of South Australia, has applied the benefits of EM38 mapping and enhanced soil moisture monitoring to adjust irrigation practices.

Wetting front detectors help identify when water is moving beyond the rootzone, enabling Hans to reduce the run time for irrigation shifts and reduce deep drainage – improving irrigation efficiency and the environment. Solusamplers monitor salinity enabling the application of leaching irrigations, if and when needed. Relocating sensors on Enviroscan probes has improved the correlation between vine performance and recorded soil moisture, permitting better use of the Solusamplers and, in conjunction with IRES (Irrigation Recording and Evaluation System software), improved irrigation management.

Hans believes improved system maintenance and performance has been possible as a result of the monitoring program, giving a more uniform application of water and reduced variability in vineyard performance.

TECHNICAL MATTERS

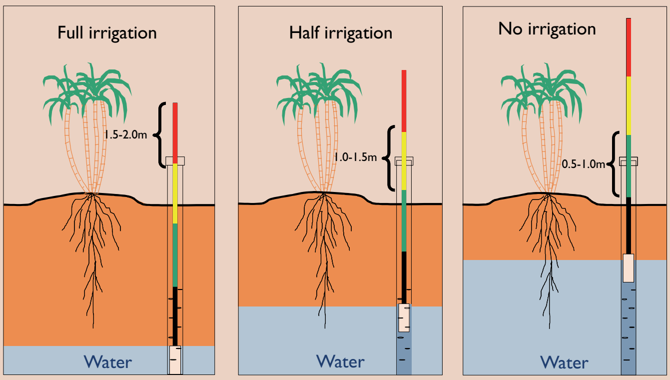
Taking advantage of shallow, fresh watertables

More than 200,000 ha of irrigated land in northern Australia, usually in near-coastal areas, has the potential to supplement applied water by exploiting shallow, fresh watertables. These can contribute significant amounts of water to crops, especially deep-rooted plants such as sugar cane. Research has shown that:

- Irrigation can be reduced where watertables are shallow and fresh. In many situations, irrigation is unnecessary when the watertable is 1 m deep. However, watertables at 2 m will supply little water to crops unless their roots are active and close to the watertable.
- In the Ord Irrigation Area, the low permeability and fine texture of the soil greatly reduces the upward flow of water and commonly restricts roots to the top 1 m of the soil profile. Watertables will generally have little impact on irrigation management unless they are shallower than 1 m deep.
- Float poles in shallow wells can be a practical way to monitor watertable depth, so it can be used in irrigation management.
- Cropping system models can capture the impact of shallow watertables on crop responses to irrigation, and give valuable insights for irrigation scheduling.

A coloured float pole can be used to indicate the depth of the watertable for irrigation management purposes.

Source: 'Improved irrigation scheduling for crops underlain by shallow, fresh water tables.' (CTC026, 2004) Thorburn P. CSIRO



Innovative irrigation systems

The use of new monitoring technologies by irrigators has resulted in much improved irrigation scheduling and, with technical advances in delivery and control options, has opened up opportunities to get the most out of all forms of irrigation systems, be they surface, sprinkler or micro-irrigation.

The focus has been on the efficient and uniform delivery of precise amounts of water across a whole field.

Innovations in irrigation practice now build upon that base. Two examples are:

- **Precision irrigation**: The efficient and accurate delivery of different amounts of water across a field to precisely meet the varied needs of different plants.
- **Intensive fertigation** (open hydroponics): Fertigation (supplying nutrients via irrigation water rather than traditional applications) is 'stepped up a notch' – supplying nutrients on an almost continuous basis through daily, or even more frequent, irrigated applications.

Both approaches aim to better meet the plants needs in order to increase crop yield or quality and, hopefully, profit. Monitoring and control are important facets of each approach.

The increasing sophistication of irrigation scheduling and irrigation systems poses a challenge.

Social research indicates that for wide adoption and effective implementation, new farming systems and management technologies must be designed with management in mind. They need to be easy to use and should provide benefits in terms of property management, water use efficiency and productivity.

Making high-tech irrigation systems easy to manage, as well as being effective in operation, must be a goal for all developments in irrigation technology.

Precision irrigation

Crop yields normally vary across a field because of differences in soils, water availability, plant vigour, pests, diseases and plant genetics.

The goal of precision irrigation is to meet the specific needs of plants in different management zones across a field, to achieve higher overall production, better quality produce or increased Water Use Efficiency. Scheduling for precision irrigation deals with questions of when, how much and where to irrigate. It relies on having real-time information on whatever may be limiting production; at all times and all parts of a field.

It relies on:

- acquiring accurate data by monitoring (in-situ or remotely) soil, plant and weather characteristics, and how they vary across a field for;
- interpretation (often using computerised simulations or other decision support tools);
- controlled application (varying the rate or length of irrigation – possibly via automatic controllers linked to field sensors); and
- evaluation (monitoring the actual applications, soil-water outcomes [including salinity] and crop responses) to fine tune future applications.

Determining an appropriate scale at which to operate is a first step. The scale chosen for monitoring must relate to the scale at which management is possible, e.g. individual trees or an irrigation block.

Precision irrigation has been found to improve water use efficiency, with gains of 8–20% recorded over a run of seasons. It has the potential to increase yield; but analysis of a range of applications has shown variable and inconclusive results in that regard. The profitability of precision irrigation overall is thus uncertain. Substantial in-field variability in the yield or quality of a high-value crop may be necessary to justify the innovation.

Precision irrigation with automated systems may reduce labour requirements but increase the complexity of irrigation decisions and the risks in irrigation. These factors will also be evaluated by irrigators when contemplating the relative advantage of a change in irrigation system.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Defining precision irrigation: a new approach to irrigation management (PN22263, 2009).
- Long-term sustainability of precision irrigation (PN20656, 2008).
- Review of Precision Irrigation Technologies and their Application (NPSI 6-10).

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USEFUL REFERENCES ON THE NPSI WEBSITE:

- Introduction to Open Hydroponics (EF050987, 2005).
- Open Hydroponics: Risks and Opportunities (ER050978, 2005).
- Integrated Advanced Fertigation (CT07041-HAL, 2009).
- Managing fertigation technologies in citrus orchards (CPN30194, 2009)
- Preliminary Investigations into Open Hydroponics Irrigation for the Citrus Industry (2010))
- Knowledge and tools to manage fertigation technologies in highly productive citrus orchards for minimal environmental footprint. (DAN5027, 2011)
- Guidelines for fertigating citrus orchards. (NPSI05-12, 2012)

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Intensive fertigation

Intensive fertigation (or open hydroponics) refers to systems where plants are grown in soil, but managed as though they were being grown hydroponically. There is considerable interest in the technique, e.g. for tree crops such as citrus, which are traditionally grown in light textured, free-draining soils.

The soil anchors the plants, but nutrients are provided as mineral salts dissolved in the irrigation water via high-frequency drip irrigation. The nutrient solution is usually adjusted to a specified pH. Dripper placement and frequent deliveries of small amounts of water restrict the active root zone to a much smaller volume than normal. The soil is held near field capacity at all times by regular pulsing of water through the system or operating the system continuously throughout the day. As a result, a pH-adjusted nutrient solution is more or less continuously available to plant roots.

These types of systems, first introduced to Australia from Spain, seek to match the supply of mineral nutrients to the plants' needs and growth stages, and can potentially significantly increase production, improve fruit quality or permit an earlier harvest.

However, if these systems are not managed appropriately, production losses, leakage of nutrients, acidity and root zone salinity build-up may result. Plants with restricted root systems which are grown accustomed to ready access to adequate water are also vulnerable if water supply or water quality deteriorate. Open hydroponics can be complicated systems and require high levels of technical competency to operate.

There is little publicly available information or reviewed technical articles about the systems, and specialist consultants are often required to advise on their management. A recent review of scientific literature concluded that modern fertigation strategies were 'unsupported by objective public-domain data' and that the 'long term impact of such strategies under Australian conditions is unknown'.

A comparison of 'best practice' irrigation and open hydroponics found that seasonal differences had more impact on fruit yield and size distribution than did the differences in irrigation and nutrient supply. Acidification of the nutrient solution did not increase shoot biomass or nutrient accumulation within the shoots.

Drip irrigation gives growers good control over water applications.

CASE STUDY

Modified drip for better citrus

Alan Whyte manages 55 ha of citrus on his 2,000 ha property north of Wentworth, NSW, on the Darling River. At the end of the 2003 drought, river water ranged from 2,000 to 5,000 EC and had a pH of 9.4-9.5. Something had to be done.

Alan and other farmers tried sinking bores, which had not been done before in the region. Not every bore was successful, but three were and Alan had access to water that was much fresher and of neutral acidity that could be used to dilute water from the Darling.

The real breakthrough came with the adoption of Spanish hydroponic technology that allowed Alan to manage the irrigation water alkalinity by adding acid to maintain pH between 6 and 6.5. His fertigation mixture varies with the growth and fruiting stage of the trees to manipulate crop physiology, and trees are pruned to open the internal areas of canopies.

"The aim is to get fruit over the three-dimensional volume of the tree," Alan said. "Our fruit quality is much better than industry averages and now we produce heavy crops of large fruit each year."

The drip system uses about 5.5 ML/ha averaged over the irrigated area, but it varies depending on the type and age of trees. In a subsequent drought, Alan got by on 4 ML/ha of poor-quality water, producing smaller fruit (5 mm less in diameter). Mature tangelo trees averaged 50-60 t/ha, but can produce up to 80 t/ha. However, increased production of tangelos from Peru has reduced their profitability and most tangelo plantings have now been removed.

To get the most from his hi-tech irrigation system, Alan has upgraded its computer-communication components. He has wireless network coverage across all planted areas with Ethernet data systems, which has recently been updated with low-cost 'off-the-shelf' components.

"All irrigation control systems, all soil moisture monitoring systems and monitoring via IP cameras are integrated and assembled as live internet web pages," said Alan.

"They are readily accessible from anywhere on the property by anything with a wireless connection and from anywhere in the world with an Internet connection."

Source: Horticulture Water Initiative (HAL), www.horticulture.com.au/water

Alan Whyte has modified the irrigation of his tangelo trees.

Irrigation strategies

Use special irrigation strategies for special effects.

- **Deficit irrigation**
- **Drought survival for perennials**

Deficit irrigation – less canopy, better production

Different irrigation strategies can be employed to achieve specific outcomes, such as optimising fruit quality.

Deficit irrigation – in effect starving plants of water at critical times in the growth cycle – can be used to manage for better crop production by manipulating plant cell growth and cell division or to encourage fruiting.

In this approach, canopy cover is reduced, fruiting is promoted and water use efficiency is increased.

Two deficit irrigation techniques pioneered for perennials, such as grapevines, peaches and pears, are:

- **Regulated deficit irrigation**: Water is always applied to the same area, but application rates are varied during critical periods of plant growth, e.g. after fruit set. The aim is to maintain plant water status to control reproductive growth and development, vegetative growth and/or improve water use efficiency. The approach was first developed to increase fruit yield by redeploying energy-storing sugars from shoot growth to fruit growth.
- **Partial rootzone drying**: This technique was developed for use in vineyards. Water is applied in differing quantities to areas around the plants, creating alternate dry and moist zones, e.g. by using dual (independently operated) dripper lines. It is usually applied for an entire irrigation season.

  The aim is to maintain plant water status to control vegetative growth or improve water use efficiency without harming reproductive growth and efficiency in the plant. The effect is achieved by triggering hormonal and other chemical responses in plants. The initial intent was to achieve desired concentrations of sugars in grape berries and other fruit quality attributes.

  Partial rootzone drying works best in soils with good levels of readily available water (where rapid depletion is less likely) and good infiltration rates. The irrigated side of orchard plants should be swapped when water extraction in the 'dry' side becomes negligible, which may range from days to weeks depending on crop type and soil characteristics.

Deficit irrigation can require high levels of management and expertise, which has restricted its adoption.

DEFICIT IRRIGATION

Regulated deficit irrigation imposes water stress on the plants (a plant deficit) during a particular stage of crop growth and development in order to stimulate a particular response, such as decreased growth and increased flowering or fruiting.

Partial rootzone drying imposes a soil water deficit on one side or other of the plant's root zone, which triggers a growth response, but the plant as a whole continues to take up water.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Partial Rootzone Drying and Regulated Deficit Irrigation. Irrigation Insights No. 4 (PR020382, 2003).
- Implementing partial rootzone drying (NPSI Factsheet 2005/2, 2005).

www.npsi gov.au

Drought survival for perennials

In times of water scarcity it may be necessary to allocate water to critical periods (e.g. flowering or fruit set) or to crucial parts of the property.

Pruning of tree crops is another option to reduce water demand and measures such as mulching can help conserve water. Where salinity levels are high, it will be necessary to also plan for leaching applications to wash accumulated salts from the rootzone.

The key to drought survival is to understand the plant's water needs and the availability of water to meet them. The first step is to prepare a water budget, and include contingencies for differing likelihoods of water availability.

Key questions to work through are:

- Is it practical and profitable to obtain additional water at the time it is needed? Can the water be bought, obtained from undeveloped resources or secured by reducing losses such as evaporation from farm dams?
- Can the crop be maintained on less water? Will there be sacrifices in quality or yield? What is the effect on likely income? Can watering be reduced through mulching, better weed control, deficit irrigation, installing more efficient irrigation systems, thinning fruit or cutting back on fertilisers?
- Must the area irrigated be reduced? Is it more economic to let some perennials die (and replace them later), or try to keep them alive? This could include heavy pruning, mothballing blocks – keeping them alive but not productive, bringing forward plans to replace vines or trees, and prioritising blocks for watering on the basis of their age, vulnerability to drought, or their productivity and/or profitability.

These decisions have technical and financial aspects and all involve social and family considerations. Considerable human stress surrounds such issues and the personal and business dilemmas they present to individuals. Talking things through with others and getting an outside view can help; just making a decision on a drought strategy is important. Then the mind can be turned to making it work.

For more information and useful tools such as the following decision-making tree, see:

- www.horticulture.com.au/drought
- www.gwrdc.com.au/site/page.cfm?u=16

"It is critical to make decisions and commit to them."

"Making decisions helps to manage stress."

– Irrigators at a northern Victoria drought forum

Citrus trees can be heavily pruned to reduce demand.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Improving the water use efficiency of horticultural crops (PR9903828, 1999).

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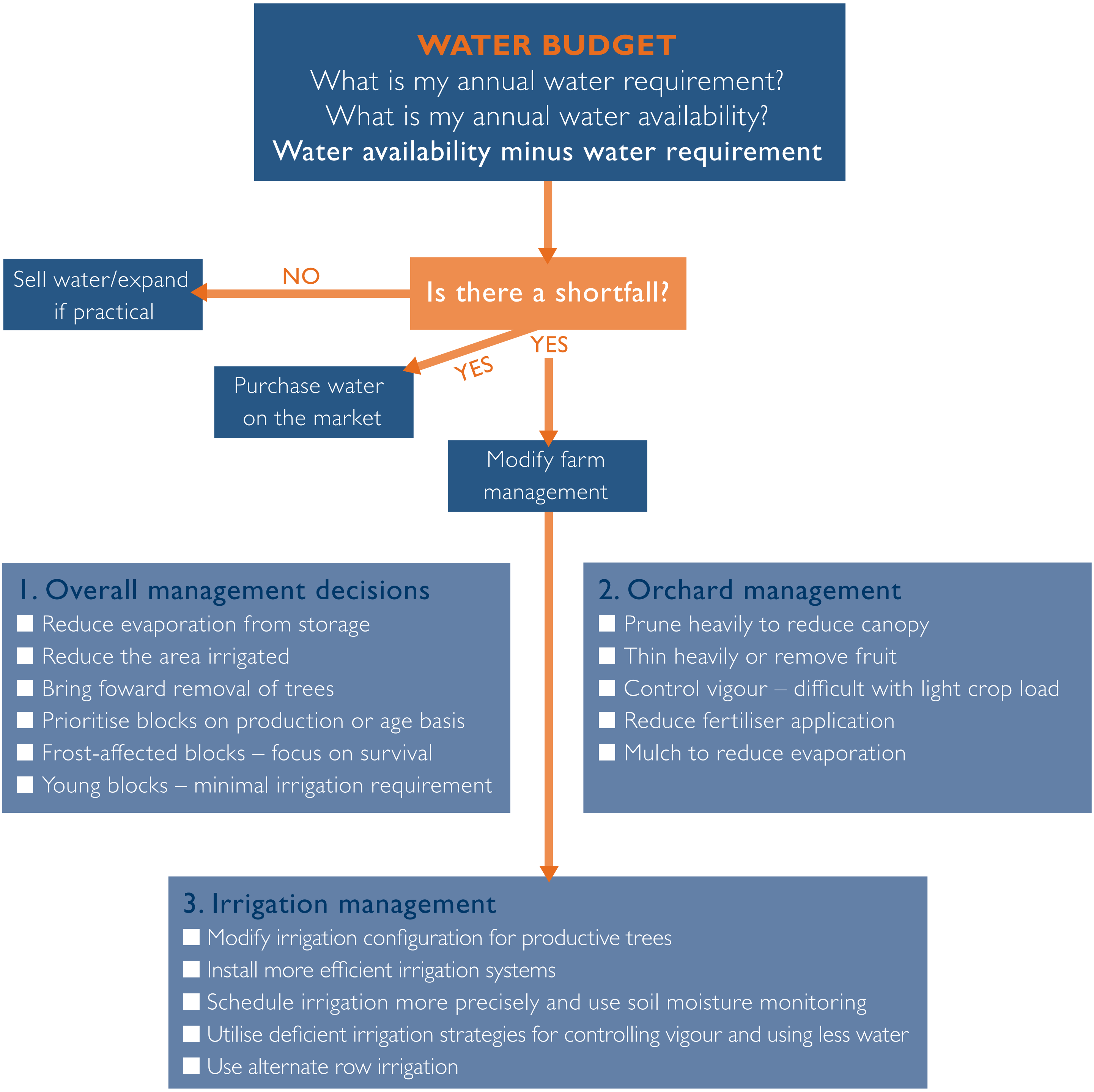
Drought management decision-making tree

(An example of perennial horticulture)



Source: Horticulture Water Initiative (HAL)
www.horticulture.com.au/water

CASE STUDY

Canopy management for avocados

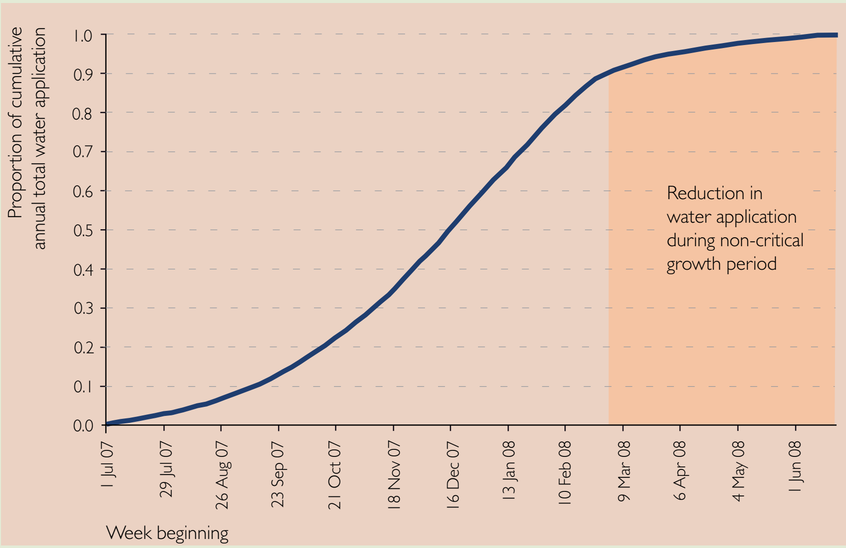
Canopy management is one of the techniques available to avocado growers to reduce water use.

Mature trees that have not been thinned use more water compared to other growth stages. It is recommended that canopied trees be cut-off (stumped) between 1.2 m and 1.8 m above ground, then allowed to regrow using reduced irrigation frequency.

Stumping can be used as a water conservation method in avocados.

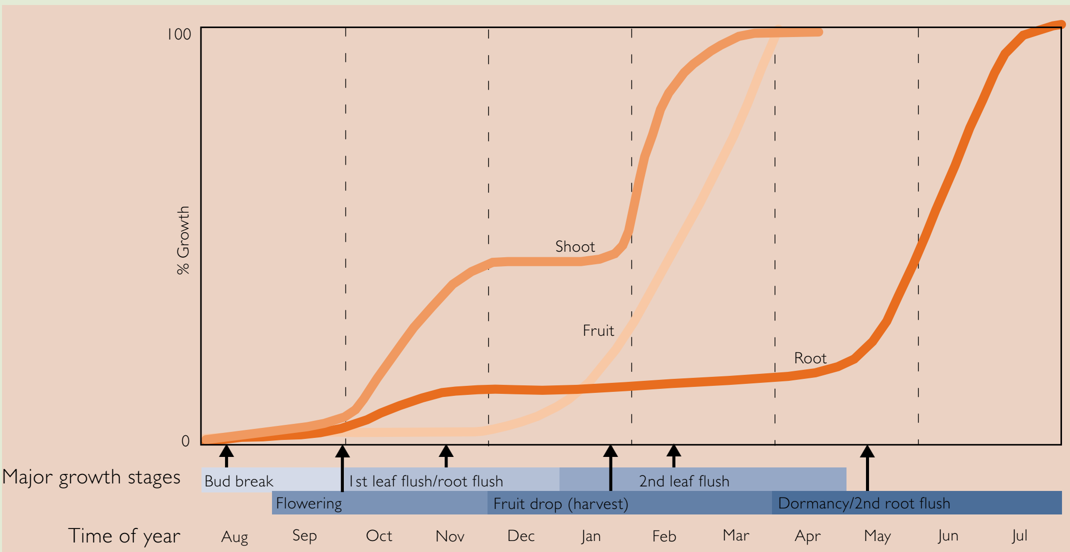
MORE INFORMATION

- Guidelines for managing under limited water supplies. Avocados. Horticulture Water Initiative at www.horticulture.com.au/areas_of_Investment/Environment/Horticulture%20Water%20Initiative/water_overview.asp



Water requirements for avocados depending on growth stage.

Source: Horticulture Water Initiative (HAL) – Alec McCarthy, DAF-WA, www.horticulture.com.au/water



Avocado growth curve.

Source: Anne-Maree Boland.

CASE STUDY

Almond Case Study – Riverland, SA

The owner of a 40 ha property has a small area under wine grapes and 35.5 ha of almonds (a salt-sensitive crop) irrigated by a highly automated drip system.

Designed to achieve optimal production, the system irrigates with pulses of water – water is applied for an hour, followed by a break of an hour to avoid water-logging.

Soil moisture monitors, soil salinity probes, leaf monitoring, kernel measurement and crop nutrient removal analysis (nutrient budgeting) are all used to make irrigation scheduling and fertigation decisions in this highly capitalised operation.

The property has around 10,000 almond trees, half of bearing age. In 2007/08, the water available was only 60% of that recommended for almonds. Additional temporary water was bought to keep young trees alive and mature trees in production (although yields dropped by 10-15%); the extra 260 ML cost $250,000.

Without the additional water a decision would have been required about which less productive stands were allowed to die. As the young trees grow, so to will their water requirements – up from 1 ML/ha/yr to 10-16 ML/ha/yr when mature.

Source: Dealing with irrigation drought. Mallawaarachchi A & Foster A (2009) ABARE Research Report 09.6

WATER TRADING

A study of water trading in the Murray-Darling Basin has shown that having a market for water has given irrigators greater flexibility in dealing with drought. It has allowed some farmers to sell their allocation and earn an income during the drought, while others were able to buy badly needed water to keep their crops viable. A total of 1,062 GL was traded within the Basin in 2007/08, 50% more than was traded in 2004/05.

Perennial horticulturists were the most frequent purchasers, with broadacre farmers the most common sellers. The fact that the Basin has a great diversity of irrigation industries has underpinned the resilience of the region.

Source: Dealing with irrigation drought. Mallawaarachchi A & Foster A (2009) ABARE Research Report 09.6

Soil management can help offset the early impact of drought.

Crop and soil management

CROP AND SOIL MANAGEMENT

Plant performance – growth and productivity

Soil condition – structure, salinity and available water

Plant performance

Understand and manage your crop's water and nutrient needs.

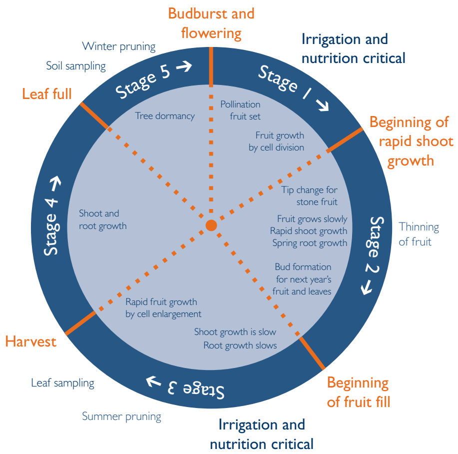
- **Plant growth**
- **Nutrition**

Plant growth

Understanding the development stages of plants, how they change through seasonal cycles and how different crops function, is crucial to effective irrigation.

Knowing how plants develop enables the application of water to be timed and measured according to the plants' needs and it enables irrigators to manipulate plants to improve yield or quality. In perennials, in particular, a good yield in one year may be at the expense of next year's crop, and plant management needs to be attuned to that.

Source: Boland, A.M., Zhierl A. and J. Beaumont (2002). 'Guide to Best Practice in Water Management – Orchard Crops'. Department of Primary Industries, Victoria.



Development stages for pome and stone fruit.

Nutrition

Traditionally, fertilisers were applied to irrigated crops in a similar manner to dryland crops. However, with modern irrigation techniques that allow the precise delivery of water it is possible to use the same technology for the precise delivery of dissolved mineral nutrients within the irrigation water supply (fertigation).

Fertigation is common for some tree crops (e.g. citrus) and may range from simply using the irrigation to distribute nutrients that were previously broadcast, to intensive (almost continuous) fertigation as discussed under Innovative irrigation systems. Fertigation can lead to greater efficiency and opportunities to fine-tune plant nutrition, reduced in-field traffic and fuel savings. It may also reduce the loss of nutrients through leaching and runoff to the environment - where they can pollute waterways and aquatic ecosystems or contaminate groundwater. Nutrients should be injected in the last half of an irrigation cycle to reduce leaching risks, though still ensuring they are flushed from the irrigation system before the cycle concludes. Soil nitrate levels above 150 – 200 mg/L should be avoided, as above that there is reduced uptake by trees, increased loss to the environment and possibly increased risk of reduced fruit quality.

The trade-offs include capital costs for mixing tanks and injection equipment, more time spent mixing fertilisers and having to use higher grade fertilisers to avoid blocked drippers. The more frequent the applications of dissolved nutrients, the more complex are the decisions about rates and timing, and the importance of ensuring incompatible nutrients are not mixed together resulting in mineral precipitation. Fertigation needs should be assessed based on tree nutrient status and other indicators such as tree vigour, yield and fruit quality.

MORE INFORMATION:

Guidelines for fertigating citrus orchards. M Treeby, S Falivene, V Phogat & M Skewes.

Other NPSI projects of interest include:

- Impact of Open Hydroponics Irrigation in the Citrus Industry (SRD9).
- Knowledge and tools to manage fertigation technologies in highly productive citrus orchards for minimal environmental footprint (DAN5027).
- Effect of irrigation management on nitrate movement (CEA5166).

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Open Hydroponics – Risks and Opportunities (EF050989, 2005)
- Guidelines for fertigating citrus orchards (NPSI05-12, 2012)

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Soil condition

Improve your soil to provide optimal growing conditions.

- **Soil structure and texture**
- **Organic matter**
- **Salinity**

Root systems that are not constrained by poor soil structure will support the growth of productive plants that are buffered against adversity and allow growers a full window of management options.

– Rob Murray, Researcher, University of Adelaide

MORE INFORMATION:

- Soil Health Knowledge Bank at soilhealthknowledge.com.au

Soil structure and texture

Soil structure and texture are key determinants of water infiltration rates and the amount of readily available water within a soil, and the resultant root growth and root function. They are critical to good water use efficiency.

- Texture (the mix of different sized soil particles, i.e. clay, loam and sand) has a significant influence on the water-holding capacity of soil. It is very difficult and expensive to change.
- Structure (the manner in which particles are assembled and the amount of air – or pores – within the soil) has a significant influence on infiltration and drainage, and the ease with which plant roots can penetrate the soil to take up water and nutrients. It can be modified, e.g. by tillage or deep-rooted plants.

Infiltration and water availability

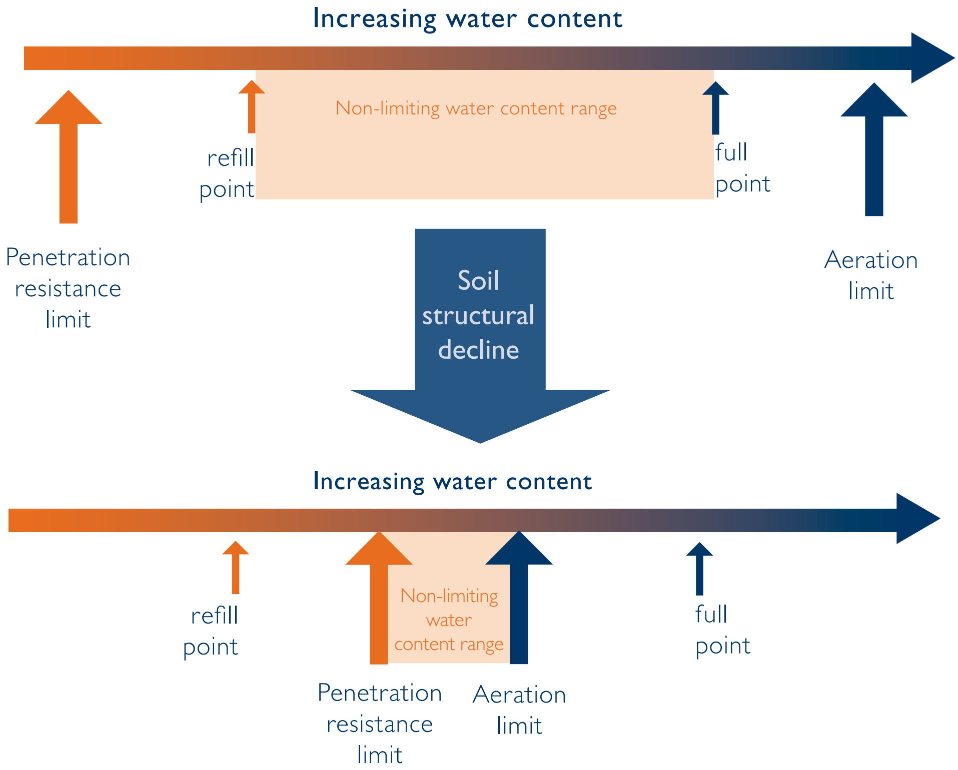
When designing an irrigation system, the water application rate should not exceed the infiltration rate of the soil if over-watering and run-off losses are to be avoided. Soils with low infiltration rates (e.g. less than 1 mm/hr) result in poor uptake of water and are prone to extended periods of waterlogging.

It is also important to consider the fate of water that passes beyond the rootzone and is subsequently lost as 'deep drainage'. Artificial drains may need to be provided or efforts made to improve the water-holding capacity of the soil, e.g. by increasing organic matter levels.

Sub-surface constraints, such as compacted clay or rock layers, can restrict the suitability of a site for irrigation by limiting infiltration and root growth. Modification of the subsoil (e.g. ripping impervious layers or adding lime to counter acidity) may be an option before establishment or else raised beds may be constructed to aid infiltration and drainage.

Representation of the closing 'window' of available water caused by soil structure decline.

Source: Rob Murray [after Letey J (1985) 'Relationship between soil physical properties and crop production'. Advances in Soil Science. 1. 277-294].



Aeration and penetration

Soils with penetration resistance of approximately 0.5 MPa will result in unrestricted root growth but those with values over 2.0 MPa are virtually impenetrable. Soils with plenty of pores (spaces within the soil) enable roots to grow freely and ensure there is ample oxygen available for the roots to respire. This feature is measured as air-filled porosity and should be above 10% for adequate aeration and root growth.

Good soil structure improves the capacity of plants to make the best use of water. Poorly structured soils are impenetrable to roots when dry and become waterlogged easily, depriving roots of oxygen, when wet. Penetration and aeration problems effectively narrow the range of conditions in which plant roots, and hence plants, can prosper.

Continued page 46

TECHNICAL MATTERS

'Oxygation' helping crops breathe easy

Soils with lower infiltration rates may become waterlogged, especially under drip irrigation, creating an unhealthy environment in which roots do not get enough oxygen. An innovative response is to inject air into the irrigation supply, this is known as 'oxygation'.

Preliminary results under drip irrigated cotton and pineapples have been positive and trials have since been conducted at sites across Australia and in several different crops including strawberries, tomatoes, capsicums, lawn, lucerne, grapes, macadamias, figs and apricots. A 'best practice' manual and a calculator to help with oxygation decisions has been developed at the Centre for Plant and Water Science at CQ University and will be available at their website once completed.

More information:

- Optimising delivery and benefits of aerated irrigation water at lwa.gov.au/projects/2633

"Roots essentially close down their function if they don't have enough oxygen and, ironically, if they don't have enough oxygen they don't take up water. They can be surrounded by water but they can't take up the water; and if they can't take up water they can't take up nutrients."

– David Midmore, Researcher, Central Queensland University.

CASE STUDY

Sweeter pineapples

In January 2008, Central Queensland University's Centre for Plant and Water Science applied an oxygation treatment to a pineapple plantation that was established in October 2007 at Yeppoon.

Two treatments, oxygation (12% by volume of air into the irrigation stream) and no oxygation, were replicated seven times in the field. Researchers harvested all the fruit from 2 m strips in each of the 14 plots, and growers harvested commercial fruit from the remainder of each plot.

Yields in the researcher-harvested plots were 14% greater in the oxygated plots than in the non-oxygated plots, and fruit sweetness (brix*) was significantly greater too. Oxygation improved water use efficiency as water use was found to be slightly less in the oxygation plots. The commercial yields also showed an advantage from using oxygation, but the increase was only 8%. Soil respiration (the amount of CO_2 released by plant roots or the breakdown of organic matter in the soil) increased with oxygation.

* Brix. The amount of sugar in a liquid as a percentage of mass; e.g. 12% Brix is 12 g of sugar and 88 g of liquid in 100 g of solution.

Table: Effects of oxygation on yield and brix of pineapple.

Treatments	Sample yield (t/ha)	Commercial yield (t/ha)	Brix (%)*
Control	67.98	45.04	12.85
Oxygation	77.52	48.79	13.66

Source: Midmore D. CQUniversity

A pineapple field with randomised oxygation treatments, and (above) the venturi aeration apparatus used for oxygation.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- 'Guidelines for managing soil structure in irrigated vineyards.' NPSI 7-10
- 'Research Bulletin. Subsoil structure in irrigated Australian vineyards.' PN30194.

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STAGES OF WATER HOLDING

The following stages are important trigger points for irrigation and water management:

Wilting point (lower limit) – The point at which plants are not able to extract water from the soil and growth has ceased.

Refill point (upper limit) – The point beyond which extracting water from the soil is sufficiently hard that plants begin to experience unacceptable levels of stress. Determined by the irrigator, this may vary between crops and between growth stages in the same crop.

Field capacity (full point) – The point at which pores (large and small) within the soil are mostly filled with water, after excess water has drained through the profile.

Saturation – All soil pores are full and contain no air. Excess water flows off or drains away.

Readily Available Water (RAW) – The volume of water between the refill point and field capacity.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Long term sustainability of precision irrigation (NPSI810, 2010)
- Long term sustainability of precision irrigation – rootzone case study (NPSI2111, 2011)
- Long term sustainability of precision irrigation – vineyards case study (NPSI2011, 2011)
- Soil management for Australian irrigated agriculture. npsi.gov.au/projects/2635

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Continued from page 44

Improving soil structure

Tips for improving soil structure under irrigated vines are applicable to many crops. They are:

- Stop degrading soil structure; e.g. reduce compaction by vehicles (especially on wet-soils), reduce the time that soils are very wet, and reduce any impacts from salinity by leaching salts (see below) or applying gypsum.
- Stabilise soil structure; e.g. improving organic matter levels or adding calcium (often as gypsum – and preferably within irrigation water to help it get to where it is needed).
- Regenerate soil structure; e.g. grow and regrow roots to maintain porosity with winter crops etc, and mound up soil for roots to grow into (and include grass cover crops in winter and mulches in summer - subject to them fitting with irrigation, leaching and pest control programs).

Organic matter

Soil organic matter (the sum of organic compounds in the soil, including micro-organisms, decaying matter and the resultant humus) generally improves soil structure, water-holding capacity and the uptake of nutrients by plants. It can also improve infiltration rates and the aeration of soils, promoting root growth.

The addition of mulch or incorporation of crop wastes can enhance soil organic matter levels; reduced cultivation will slow the rate at which organic matter breaks down and slow the release of carbon (as CO_2) from the soil. Living mulches (or cover crops) such as legumes or grasses, can enhance soil organic matter and soil structure, but they may also increase water use.

In row cropping systems, the nature of interactions between inter-row and row components must be understood to assess any trade-offs between water use and increased water-holding capacity.

CASE STUDY

Building better soils

Producers trialling techniques promoted by Bruce Cockcroft to build 'super soils' (as discussed opposite) have seen enough benefit to push ahead with further changes on their properties.

James Cornish grows peaches, apples and pears in the Murray Valley, northern Victoria. He has used lime and gypsum as well as deep ripping to prepare soils and has banked soil along tree lines. Management changes have included minimal traffic to avoid compaction, slashing grass and throwing the residue into tree lines, and encouraging winter grasses. Irrigation flow rates have been adjusted to match soil permeability and avoid compaction.

From trialling the changes, James has noticed improvements in soil structure and permeability, leading to improved irrigation efficiency and healthier trees and root systems. A resultant improvement in yields is anticipated, along with longer lived trees.

Through involvement in the trials, James says he has come to realise how easy it is to degrade soils and how little change is needed to protect and improve them.

CASE STUDY

Super soils

Improving soil structure is a way to increase food production without increasing demand for water resources, according to NPSI researcher, Dr Bruce Cockroft, pictured below. It requires high soil organic matter and high biological activity (due to fungi, bacteria, very fine roots and root hairs).

The most productive soils around the world tend to be medium–light in texture (e.g. sandy loams), high in organic matter (at or above 10%), and porous with a good, stable structure (permitting easy root growth and water storage). They tend to be young (less than 1–2,000 years old) and may contain lime. Australian soils tend to be very old, often over 80,000 years in age, and low in organic matter (which is readily consumed by earthworms and micro-organisms before it can build up and stabilse at higher levels). They often have poor structure in which soil particles coalesce restricting root growth and the flow of water.

Bruce is convinced that rhizosheaths are a central part of improving soil structure and productivity.

A rhizosheath is the layer of soil particles that adheres to the roots of some plants (ryegrass is an excellent example). Exudates from the roots (mucilage), fine root hairs, soil fungi and other microbes bind the soil together to form the rhizosheath, which is the site of intense biological activity, high levels of organic matter and high concentrations of nutrients.

It is thought that soils with a lot of rhizosheaths become 'super soils' with a strong, stable, open structure due to the cementing effect of mucilage, high levels of biological activity and high levels of organic matter (above 7%) which is concentrated and protected within the rhizosheath. Coupled with the nutrient levels of the rhizosheaths, the well-structured soils become highly productive. The swelling and contracting of soil due to non-compacting irrigation and rainfall helps in the re-arrangement of soil particles to improve structure.

Working mainly with perennial, but also some annual horticultural crops, Bruce believes 'super soils' should be producing 120 tonne/ha or more of crop. He recommends management practices including:

- pre-establishment treatments including the sowing of ryegrass to build up organic matter, mounding up the growing bed to form 'raised beds' and liming if required, ryegrass cover crops in autumn and winter, with mulching in summer, zero till and minimal traffic to reduce soil compaction,
- good drainage and irrigation to ensure no slaking or crusting occurs in the soil, and revised fertilisation and crop management to capitalise on the more productive soils, e.g. pruning to reduce the leaf to fruit ratio.

USEFUL REFERENCES ON THE NPSI WEBSITE:

- Soil management for Australian irrigated agriculture. npsi.gov.au/projects/2635
- Soil management - case study NPSI1411
- Soil management for Australia's irrigated horticulture. Various videos PN30184, PN30185, PN30186, PN30188
- Bruce Cockcroft, Field Trip presentation. vimeo.com/5088343
- A review of Dr Bruce Cockcroft's Work for Australian Irrigated Horticulture (PN21945, 2007)

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USEFUL REFERENCES ON THE NPSI WEBSITE:

- Salinity management practice guidelines (PN22225, 2009).
- Using recycled water in horticulture. A growers guide (PX061131).

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Salinity

Leaching

Salinity problems occur in irrigation areas when salts in the soil are mobilised or additional salts are imported in irrigation water and concentrate in the rootzone. Its effects (reduced vigour and yields, and even the death of plants) may be made worse by water-logging from rising groundwater and by sodicity (high levels of sodium which causes a breakdown in soil structure).

The main management response to soil salinity is to wash the salt from the rootzone with fresh water. If rainfall is too low for that to occur naturally, then a 'leaching fraction' is applied as an additional irrigation.

Care must be taken when leaching salt to ensure the excess irrigation water does not cause the watertable to rise or to flush the salt into surface waters or vulnerable areas. Leaching is most successful in freely draining, uniform soils and when the irrigation system has uniform or well-controlled distribution. If there are large cracks in the soil, or other 'preferred pathways' such as old root channels, the leaching fraction may drain through them instead of dissolving the salt and moving it deeper in the soil.

Precise irrigation technologies improve the capacity of irrigators to balance these issues. They may also contribute to the initial problem, as in tightly managed, highly efficient systems very little water (apart from heavy rainfall) moves beyond the rootzone. Similarly, reducing irrigation during drought may lead to a build up of salt, requiring the application of a leaching fraction.

In Mediterranean climates, it takes less additional water to leach salts in winter (riding on the influence of rainfall) than it does in summer. This is partly because, in winter, 'preferred pathways' that water may otherwise flow through tend to be closed as the soils are wetted and nearer field capacity. A leaching calculator is under development by SARDI to help growers estimate the amount of water needed as a leaching fraction.

Trials in vineyards have examined different ways of redistributing mid-row rainfall to under the vines, to increase the leaching of salts. Innovations such as a mid-row mound and plastic matting have variously reduced salinity in the soil or, as sodium or chloride, in the leaves and fruit. The research demonstrated a relationship between the salinity of soil water and that of a soil paste extract, as well as the chloride level in leaf petioles.

Vulnerability

Some crops are more vulnerable to salinity, while others are more 'tolerant' – and salinity can affect crops in different ways. High soil salinity levels make it harder for plants to extract water from the soil and higher salt levels in plants cause stress and disrupt plant physiology.

In citrus, salt-stress reduces tree growth and affects the functioning of the leaves. In grapevines, besides affecting vine vigour, it also results in high salinity levels in the berries which translates into unacceptable levels of sodium and chloride in wine. Some annual vegetable crops appear more sensitive to salt at germination and in the early seedling stage than they are at maturity.

In many regions it is important to monitor the salinity of irrigation water to understand the salt load being added to plants and the salinity levels in rootzones. Recycled water and surface waters may be higher in salts in specific seasons. Modern tools, such as suction cups and wetting front detectors, make it easier to monitor salinity than having to use soil samples. For more information see 'Soil water monitoring' earlier in this report.

MEASURING SALINITY

Salinity is usually measured in deci-Siemens per metre (dS/m), or in electrical conductivity units (EC units). 1 dS/m is equivalent to 1,000 EC units or 640 mg/litre (ppm) of dissolved salts. Seawater is 50,000 EC units.

SODICITY

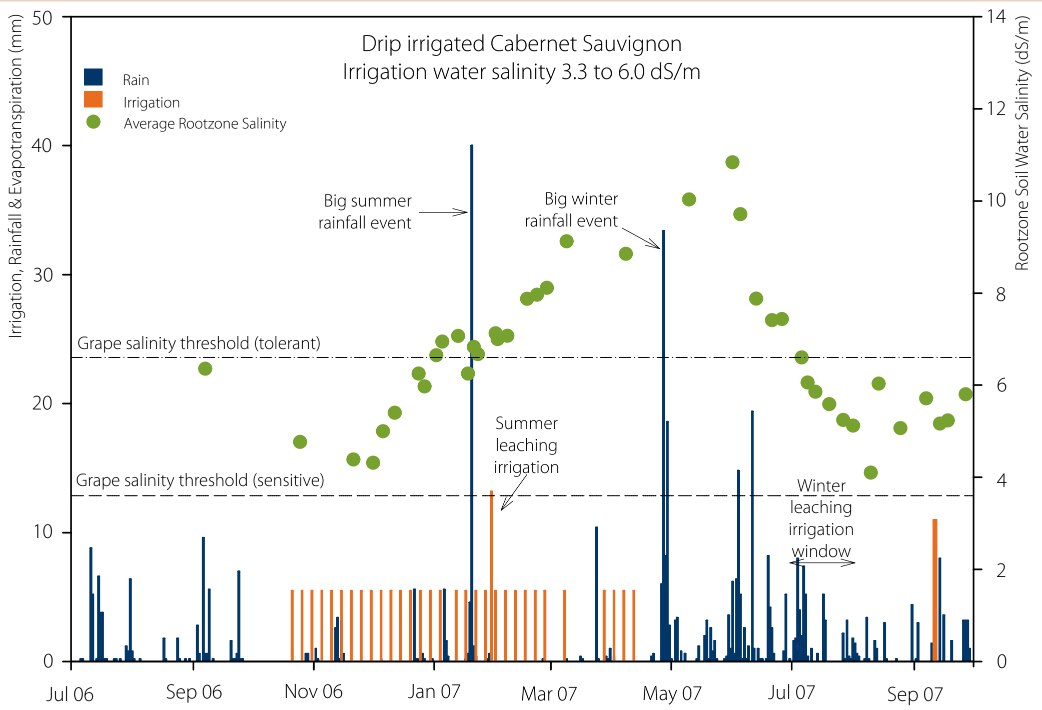
Sodic soils have high levels of 'exchangeable sodium' relative to calcium and magnesium. Sodic soils 'disperse' when wet – collapsing soil structure, blocking soil pores and making it difficult for roots or water to penetrate. Irrigating with saline water may contribute to sodicity by building up excess sodium, depending on its sodium adsorption ratio (SAR – the ratio of sodium to calcium and magnesium together). Water with a low SAR (e.g. relatively high levels of calcium) may displace sodium with calcium.

TECHNICAL MATTERS

Measurements of root-zone salinity in 2006/07 at Currency Creek

The graph shows how rootzone salinity decreased following the onset of winter rains. Irrigation at that time will be more effective in flushing salts from the rootzone than during summer.

Source: Biswas T, Bourne J, Schrale G, & McCarthy M (2009) Salinity Management Practice Guidelines. NPSI & SARDI



> *A bucket of water during the wettest winter month may be as effective as three buckets in summer.*
>
> *– Tapas Biswas, Researcher, SARDI*

Salinity thresholds

Crop yields tend to be stable up to a certain level of soil salinity, called the 'threshold value', after which they decline. The threshold value, and rate of subsequent decline, vary between crops. The following table indicates the threshold values for selected crops to achieve 100% and 75% of possible yield. The lesser figure is included because in crops such as grapes, reduced yields can be associated with high-quality fruit, so growers may aim to grow less fruit but of a superior quality.

Table: Horticultural Crop Thresholds (ECsw) for Root-zone Salinity as measured by the SARDI suction cup.

Crop	Threshold for maximum production (dS/m) 100% yield	Threshold for reduced yield levels (dS/m) 75% yield
Orange	3.4	6.6
Grapefruit	3.4	6.6
Lemon	3.4	6.6
Apricot	3.2	5.2
Peach	3.4	5.8
Carrot	2.0	5.8
Onion	2.4	5.6
Potato	3.4	7.6
Tomato	5.0	10.0

Source: Biswas T, Bourne J, Schrale G, & McCarthy M (2009) Salinity Management Practice Guidelines. NPSI & SARDI

MORE INFORMATION

- For more information about soils see www.healthysoils.gov.au

"It's easy to think that irrigation is just about managing the water. But it's the solutes in the water that ultimately define the limits to efficient irrigation. Under irrigation in semi-arid areas will result in salt build up in the root zone. Over irrigation will see losses of nutrients and potential rising in saline watertables."

– Richard Stirzaker, Researcher, CSIRO.

Researchers and irrigators investigate salinity management options.

Source: lwa.gov.au/news/2009/jun/19/teaching-irrigators-pass-salt

MONITORING

Monitoring and evaluation – data for decision making

Continuous improvement – review and action

Monitoring and evaluation

Monitor and respond to critical performance indicators.

- **Monitoring, recording and evaluation**
- **Making better decisions**

Monitoring, recording and evaluation

All aspects of an irrigation enterprise should be monitored so management may be fine-tuned in an ongoing and timely manner. Some important considerations in designing a monitoring program are:

- Have a comprehensive set of information available, e.g. from the performance of the system and how it is managed, down to daily decisions about irrigation timing.
- Ensure that monitoring data is analysed and applied – do not collect expensive data for the sake of it or if the analysis is itself too complicated to apply.
- Do not plan a monitoring system from the bottom up (a "what can I monitor?" approach). Start with the end-use in mind ("What decisions do I need to make and what information will help?") – then collect the data needed.
- "Pull it together." With complex systems it is useful to look at them from different angles to get a full picture – the view from one set of information may be misleading or only half the story.
- Some things cannot be measured (or valued) easily. A change to an irrigation system may make overall management much easier and simpler. It might be hard to measure and not have a direct cost saving immediately, but the improvement in personal wellbeing may be a life saver.

"We like to think of irrigation as a precision activity with off-the-shelf solutions for farmers. Yet the business of growing plants profitably puts us firmly in the complex domain where our aim should be to monitor the things that help us to learn. It is only by consistent monitoring that we can understand how the system is operating and where we could do better."

– Richard Stirzaker. Researcher, CSIRO

Examples of the issues irrigators need to consider and the sort of monitoring that may help:

Issue	Measurement	Tools/Methods
Crop Production	• Plant development • Plant growth • Crop performance (yield, quality)	• Crop development stage • Crop yield (tonnes) per hectare • Pack out of crop – size, quality
Irrigation Scheduling	• Weather – evapotranspiration, rainfall • Irrigation events • Soil water monitoring • Plant-based indicators, e.g. fruit size, leaf, temperature • Water movement in profile, drainage	**Weather-based** • SILO – calculation of potential evapotranspiration www.derm.qld.gov.au/services_resources/item_list.php?category_id=8 • BoM – rainfall records and temperature forecasts www.bom.gov.au/ **Irrigation events** • Excel-based records of irrigation events, duration and calculated water volumes **Soil water monitoring** • Irrigation Insights – Soil Water Monitoring (Charlesworth) • IPART (Irrigation and Reporting Tool) – a tool to evaluate the uniformity of water application in irrigation systems. 139.86.208.170/kmsi/public_search.php • Irrimate – a package to help assess water use efficiency. www.irrimate.com.au/ • Rural Water Use Efficiency – Tools and calculators – systems to help irrigators improve irrigation performance. www.seq.irrigationfutures.org.au/news.asp?catid=4 • OVERSched – a tool to help schedule centre pivot and lateral move irrigation. www.irrigationfutures.org.au/OVERsched/OverSchedv1-0.html **Monitoring soil salinity** • www.pir.sa.gov.au/pirsa/more/factsheets/fact_sheets/salinity/monitoring_soil_salinity_for_irrigated_horticulture **Plant-based indicators** • Records of leaf extension, trunk diameter and fruit diameter • Monitoring of leaf temperature **Water movement** • Monitoring of drains • Assessment of soil water, e.g. changes in depth, Longstop • Monitoring of soil solution samplers
Irrigation System	• System performance – pumps, filters, leakages, blockages, uniformity • Application efficiency • Energy efficiency • Water use efficiency	• Chapman, M., Chapman, L., and Dore, D. (2007). National Audit of On-farm Irrigation Information Tools www.environment.gov.au/water/publications/agriculture/irrigation-information-tools.html
Salinity	• Salinity of water applied • Plant performance, leaf analysis • Soil salinity	• Records of irrigation water salinity (EC, Na, Cl) • Assessment of plant tissue Na and Cl • Records of soil ECe, sodicity
Nutrients	• Fertiliser applied • Plant performance, leaf analysis • Soil analysis	• Records of fertliser type, application time and volumes • Assessment of plant tissue nutrient – N, P, K and trace elements • Assessment of soil chemical parameters – pH, N, P
Environmental Impact	• Depth of water tables • Assessment of surface/subsurface drainage • Movement of salts • Leaching of nutrients – nitrates, phosphates	• Water table flags • Infiltration tests • Soil solution samplers - Soil solution monitoring in Australia Falivene, S. (2008). CRC for Irrigation Futures Irrigation Matters Series No. 04/08. November 2008. www.irrigationfutures.org.au/news.asp?catID=12&ID=880

Tools to help irrigators with monitoring and decision making include:

- irriGATEWAY – a CSIRO site hosting several tools, including IrriSAT SMS, a remote scheduling tool – www.irrigateway.net/Default.aspx
- IPART (Irrigation and Reporting Tool) – a tool to evaluate the uniformity of water application in irrigation systems – 139.86.208.170/kmsi/public_search.php
- Irrimate – a package to help assess water use efficiency – www.irrimate.com.au/
- Rural Water Use Efficiency – Tools and calculators – systems to help irrigators improve irrigation performance – www.seq.irrigationfutures.org.au/news.asp?catid=4
- OVERSched – a tool to help schedule centre pivot and lateral move irrigation – www.www.irrigationfutures.org.au/OVERsched/OverSchedv1-0.html
- Vegetable irrigation scheduling (VISS) – www.vegetableswa.com.au

Making better decisions

Irrigation is a complex business and irrigators are continually learning about new options and issues. Monitoring and evaluating the effectiveness of alternative management responses is one of the most powerful methods of learning – especially if ideas are shared and other irrigators or advisers are sounded out for their input. A number of industry or regional packages have been developed to help irrigators. These tools and guidelines lend themselves to group discussion, as well as individual adoption.

Useful resources for irrigators include:

- More Profit Per Drop: www.moreprofitperdrop.com.au/.
- SaveWater in primary industries: www.savewater.com.au/how-to-save-water/primary-industries
- Cotton WATERpak: www.cottoncrc.org.au/content/Industry/Publications/Water/WATERpak.aspx
- Cotton industry: www.crdc.com.au
- Dairy industry: www.dairyingfortomorrow.com/index.php?id=61
- Grains industry: www.grdc.com.au
- Horticulture: www.horticulture.com.au/water
- Rice: www.rga.org.au
- Sugar industry: www.srdc.gov.au
- Viticulture: www.gwdrc.com.au
- Irrigation Australia: www.irrigation.org.au
- National Water Commission: www.nwc.gov.au
- Irrigation Essentials: www.irrigationessentials.com.au
- NSW DPI Irrigation resources: www.dpi.nsw.gov.au/agriculture/resources/water/irrigation
- Qld DERM Rural water use efficiency: www.derm.qld.gov.au/rwue/index.html
- SA PIRSA Efficient water use: www.pir.sa.gov.au/wid/water_resource_management/efficient_water_use
- Recycled water: www.gwrdc.com.au/www and lwa.gov.au/files/products/national-program-sustainable-irrigation/pn30123/pn30123.pdf
- Tas DPIPWE: www.dpiw.tas.gov.au/inter.nsf/WebPages/JBAS-8M73Z5?open
- Vic DPI Irrigation: www.dpi.vic.gov.au/agriculture/farming-management/soil-water/irrigation
- WA DAF Water irrigation: www.agric.wa.gov.au/PC_92487.html?s=855974751

TECHNICAL MATTERS

Five strands of knowledge

Research was undertaken to link 'five strands of knowledge' that have traditionally been treated separately into an adaptive decision-making framework. The five strands are:

- Existing knowledge and accumulated experience – growers' understanding, e.g. of their soils, crops, water and production systems.
- Atmosphere – compare actual water applications with the theoretical crop requirement based on climate.
- Wetting Front – measure at a minimum of two depths.
- Soil Moisture – measure tension at a 'damp' location; somewhere that wets and dries.
- Salt and nutrients – monitor the wetting front (via FullStop) to see if concentrations are rising or falling.

No single indicator is sufficient on its own. Using several helps to 'triangulate' problems for better management.

CASE STUDY

Up-skilling irrigators – expert irrigation systems

VegetablesWA has developed the Vegetable Irrigation Scheduling System (VISS) to increase irrigation scheduling efficiency and improve water management by vegetable growers on the Swan Plain (WA).

It uses real-time weather data and property-based crop factors (e.g. growth stage and time of planting) in a web-based computer system to calculate daily water requirements for vegetable growing in sandy soils.

An SMS service is also available, sending daily evaporation and weather information to growers' mobile phones.

This is a complex, technological leap for growers and the industry has determined it requires one-to-one extension, or work in small groups, to demonstrate the benefits and to promote grower adoption of the tool.

The VegetablesWA project includes a social aspect in recognition of the initially complex decision making that can accompany innovative advances until growers are familiar with the new technology.

Other hi-tech scheduling approaches have also been developed elsewhere in Australia (e.g. IrriGATE and IrriSATSMS by the CRC for Irrigation Futures).

A project involving grain and cotton industries (Water Smart Cotton and Grains) demonstrated IrriSAT SMS, a remote scheduling service, to farm consultants. Feedback from the consultants was that the information from the service enabled greater accuracy in irrigation scheduling – especially as a result of improved estimates of evapo-transpiration (thanks to automated local weather stations). Uploading data for numerous properties was onerous however, and may be a priority for future developments.

Source: Georgia Thomas, VegetablesWA

One-to-one extension is being used to promote complex technology.

Continuous improvement

Periodically review business performance and irrigation management.

- **Essentials checklist**
- **Future research and information**

Essentials checklist

Continuous improvement in irrigation practice will arise from researchers linking with irrigators for practical outcomes. Irrigators can use the 'Irrigation Essentials' as a guide to identify, prioritise and manage issues on their properties.

Soundly performing irrigation operations are well balanced in how they tackle the range of 'Irrigation Essentials'. Irrigators can use the following check-list to assess their performance.

- Score the relevance of each issue to their property as High (3), Medium (2), or Low (1).
- Provide a self-assessment rating of High (3), Medium (2), or Low (1) for each issue. How well is the issue currently managed?
- Review the ratings:
  - Are there sound ratings across the themes or are there uneven scores overall?
  - Are there any low ratings for topics that are highly relevant – if so, they are priorities for action.

Themes	Irrigation Essentials	Issues	Relevance	Rating
Irrigation Essentials	Key principles			
Business Planning	External influences	Water reform		
		Food and water demand		
	Business fundamentals	Finance and operations		
		Personnel		
Irrigation Planning	Site suitability	Site characteristics		
		Water characteristics		
	Production systems and crop selection	Water availability		
		Agronomy		
		Production objective		
	Irrigation and drainage systems	System options		
		Design		
		Drainage		
Irrigation Management	Water budget	Budget		
	Irrigation scheduling	When and how much		
		Soil water monitoring		
		Advanced irrigation		
		Precision irrigation		
	Irrigation strategies	Deficit irrigation		
		Drought survival for perennials		
Crop and Soil Management	Plant performance	Plant growth		
		Nutrition		
	Soil condition	Infiltration		
		Organic matter		
		Salinity		
Monitoring	Monitoring and evaluation	Monitoring		
		Better decisions		
	Continuous improvement	Essentials checklist		

Future research and information

Australia has been well served by irrigation research. Investments in research, development and extension have significantly improved productivity, water use efficiency and environmental outcomes, benefitting irrigators, regional communities and all Australians.

The partners in the National Program for Sustainable Irrigation are strong advocates for ongoing irrigation research and collaborative ventures that achieve high-quality outcomes in an efficient manner. They understand that the future of irrigation farmers, regional communities, the environment, Australian consumers and the world's growing population rely on it.

The National Program for Sustainable Irrigation is closing, concluding several decades of collaborative, multi-industry and multi-regional research. As part of the legacy of those endeavours, the NPSI website will be maintained into the future, offering comprehensive information from irrigation research.
See www.npsi.gov.au.

Partners in the National Program for Sustainable Irrigation have been active in highlighting the priorities for on-going research and the most appropriate way to administer it.

The next phase of national irrigation research will now be driven by the Water Use in Agriculture RD&E Strategy, developed through the Primary Industries Standing Committee as part of the Australian Government's National Primary Industries Research, Development and Extension Framework.
The strategy presents a vision in which: Australia achieves world-leading farm water productivity while enhancing environmental and social sustainability through all stakeholders working together to maximise benefits from RD&E.

MORE INFORMATION:

Water use in agriculture RD&E strategy, at http://www.daff.gov.au/agriculture-food/innovation/national-primary-industries

NPSI KNOWLEDGE:

The NPSI website will be maintained as a source of great information about irrigation and water management.

See www.npsi.gov.au.

Appendix I

Water use efficiency

Why water use efficiency matters

Improving water use efficiency has been a driving force for government and commercial endeavours for several decades but the term can mean different things to different people. For example, to governments water use efficiency may be a key to optimising production from water resources, while for irrigators it may contribute to optimal profit for their business.

There may also be confusion about what is being measured and differing perceptions of the implications of measured changes in water use efficiency.

To address that confusion the National Program for Sustainable Irrigation has promoted uniform terminology and definitions. They are detailed in its Irrigation Insights Number 5 'Water Use Efficiency' and summarised here.

Having a common language allows easier communication and a more informed discussion of some important concepts.

The emphasis in this document is on water use efficiency and the productive use of water in an agricultural context. Other uses (e.g. the maintenance of wetlands) are important, but are better assessed by other indicators.

Measuring efficiency

Even when terminology and definitions of water use efficiency are agreed, there can be misunderstandings arising from other factors.

Perceptions of efficiency and saving

'Efficiency' can mean using less water to grow a crop or pasture for optimal yield so that surplus water is available for other uses, i.e. 'saving water'. Alternatively, it can mean increasing the amount of crop or pasture produced from the same volume of water, i.e. more output from the same amount of water; but no actual 'saving' of water.

Scale matters

The scale of assessment can influence the measurement of efficiency. Inefficiencies at one scale may disappear when a larger area is considered. For example, 'inefficient' use of water in the upper reaches of a catchment may mean that more water drains back into the river. If it is of acceptable quality, this water can be used for environmental benefits or by downstream irrigators. Its use downstream for irrigation would improve the apparent efficiency of the system overall.

In that scenario downstream irrigators, urban centres and the environment could 'lose' water on which they rely if up-stream water use efficiency was improved and all gains were channelled into increased production.

TERMINOLOGY

Water use efficiency (WUE) is a generic label for any performance indicators used to study water use for crop production.

The indicators may be either:

- efficiencies – derived by dividing figures in the same units, e.g. the volume of water used (output in ML) divided by the volume of water supplied (input in ML); or
- indices – where inputs and outputs are measured in different units, e.g. crop production (output in tonnes) divided by the volume of water supplied (input in ML).

Whichever is used, it is important that it is comprehensively defined and specifies the area and the period of time over which inputs and outputs are measured, e.g. ML/ha/year.

Timing counts

The period of time over which measurements are taken can affect the calculated efficiency.

If a property is 'inefficient' in water use in individual irrigation events but captures all the run-off and later re-uses it, its long-term efficiency will be much higher.

Similarly, if a second crop (e.g. wheat) uses water stored in the soil from a preceding irrigated crop (e.g. rice), the total efficiency for the paddock will be higher than that of the original crop alone. The efficiency of a 12-month period will be higher than that of individual irrigations or seasons.

Assessments over different time periods (e.g. a year, a growing season and a single irrigation event) and between years of differing rainfall, will provide different insights about water use efficiency. Assessments over several years will provide useful information for irrigators.

Rainfall matters

Parts of Australia receive significant amounts of rain during the irrigation season, which affects the amount of irrigation water required. When making water use comparisons it is important to be clear on whether rainfall has been included in the calculations.

WATER BALANCE

A water balance measures the volume of water moving into a defined boundary (such as a dam or river), changes within that boundary (e.g. evaporation and seepage) and the volume leaving the boundary (e.g. extraction or flow), in a specified period.

A water balance is necessary before calculating where efficiencies may be improved. The accurate measurement of as many variables as possible will give decision-makers more confidence before committing to a course of action.

Storage, delivery and application

To understand efficiencies and where they can be achieved, it is important to consider the whole irrigation system as well as its individual parts:

- water storages;
- water distribution systems;
- field applications and crop agronomy; and
- the system overall.

Storage efficiency

Dams and reservoirs lose water through:

- evaporation, influenced by climate (sunlight, temperature, wind and humidity), storage design (e.g. surface area relative to total volume) and management (e.g. if it is kept full over summer); and
- seepage, influenced by linings, soil type, geology, depth of stored water, depth to groundwater and storage management (e.g. wetting and drying cycles).

A storage water budget requires information on:

- inflows (from streams and rainfall);
- losses (from evaporation, seepage and overflow); and
- outflows (as regulated releases or extractions).

To measure the efficiency of a storage over a season or year (storage efficiency) the amount of water released is divided by the amount of water entering the storage.

Measure	Input / Output
Storage Efficiency	Water released / Water entering

The management of storages, distribution systems and on-farm irrigation are all linked and there may be efficiency trade-offs between the components: savings in one area may affect efficiency in another.

How water is held and released and how it is accounted for in storages (e.g. continual accounting versus 'use it or lose it') can influence the decisions of irrigators.

Distribution (conveyance) efficiency

Water may be 'lost' on the way to the farm (a 'conveyance loss') or during distribution on the farm (including any temporary storage in on-farm dams).

Distribution systems (pipes and channels) lose water through:

- leakage and seepage;
- evapotranspiration (evaporation from water and soil and the transpiration of water by plants, including weeds); and
- operational losses (e.g. surplus delivered water that cannot be used).

Contamination (e.g. by salt, chemicals or nutrients) can also make water unsuitable for use.

It is often difficult to account for all these factors. For example, the volume of water initially entering the system may not be known accurately, let alone the volume of drainage waters re-entering the system. There may also be significant variability within a system and some factors will have to be calculated (based on informed assumptions) rather than measured.

'Conveyance efficiency' measures how efficiently water is delivered to farms. It is calculated by dividing the amount of water delivered to farms by the amount of water originally released into the supply system. Factors such as the adequacy of the water supply, its reliability and the consistency of supply are also of importance to end-users when considering the performance of a water delivery system.

Measure	Input / Output
Conveyance Efficiency	Water supplied to farms / Water released to the supply system

Moving large volumes of water and meeting the differing supply needs of numerous end users is inherently difficult and requires skilled management. System performance is a factor of system design and management. A simple, low-tech system with sound management can be more efficient and effective than a high-tech system with inadequate management.

Improving crop WUE

Generally, to improve crop water use efficiency requires:

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

However, sometimes it is desirable to limit the amount of water a plant transpires, e.g. to improve fruit quality or stimulate yield ('regulated deficit irrigation'). For more information see other Irrigation strategies in the report Irrigation Essentials.

Leaching fraction

Every time irrigation water is applied, so is salt. Repeated irrigation may cause salt to build up in the soil profile. If that occurs, a 'leaching fraction' – water applied to wash the salt through the profile and beyond the reach of the crop roots – will be required to maintain healthy soil and plant vigour.

The need for a leaching fraction depends on the salinity of the irrigation water and the amount of water moving beyond the root-zone from irrigation (the efficiency of the irrigation) and/or rainfall. The need to leach salt out of the crop root zone is one of the factors that can reduce water use efficiency.

For more information on monitoring and managing salinity, see other Knowledge Harvest papers regarding On-Farm Irrigation Essentials.

Efficiency trade-offs

It can be difficult, though not impossible, to maximise different efficiency measures at the same time. Trade-offs may have to be made. It is therefore useful to employ several different indicators in order to gain a true appreciation of overall 'efficiency'.

For example, although some advanced 'regulated deficit irrigation' techniques deliberately under-water plants, in most circumstances under-watering will result in lower yields. Usually with under-watering, water use efficiency (as measured by Water Input Efficiency – water consumed / water applied), would be high, but the Water Use Index (kg produced/ML applied) may be low. There may also be environmental consequences to consider, such as increasing salinity because salt is not being leached from the root zone.

On-farm – field efficiency

Water applied to paddocks is lost as a result of:

- evaporation;
- surface runoff that isn't recycled;
- deep drainage beyond the root zone; or
- 'off-target' application, e.g. sprinklers affected by wind drift.

Uniform distribution of irrigation water in a field helps improve water use efficiency.

The biggest challenge in determining efficiency is measuring all the components for a water balance:

- Deep drainage is particularly difficult to measure and is usually estimated by calculating what is left over after all the other water uses and losses have been estimated.
- Evaporation and crop transpiration are usually calculated from other information, not measured.
- Soil water (moisture) levels, before and after irrigation, are also often estimated.
- Accounting for rainfall should focus on 'effective rainfall' – the amount that is ultimately available for use by a crop. This may be rainfall during just the growing season, or a variation of it such as rainfall from events above a certain volume (i.e. excluding light showers) or excluding storm run-off.

To prepare a water balance for a paddock requires measures or estimates of:

- water stored in the soil before irrigation begins and at the end of the water-use period;
- irrigation water applied and the area it was applied to;
- rainfall during the water-use period;
- water transpired by the crop or pasture;
- water that left the area as run-off; and
- water lost in deep drainage, below the rootzone.

Irrigation is not only about achieving maximum plant growth. It may also be managed to control crop quality, plant physiology or health, or soil parameters that create good conditions for root growth. For example, irrigation water may be applied to cool a crop and avoid heat stress – or to ward off frost damage. It may be used to prepare soil for tillage or prevent wind erosion. When assessing irrigation efficiency, it is important to define why the water is being applied.

Indicators such as these may be applied at a paddock, farm or system level.

MORE INFORMATION:

For more information see NPSI Irrigation Insights Number 5 'Water Use Efficiency' or the benchmarking tools available for irrigated cotton and grain farmers at www.cottonandgrains.irrigationfutures.org.au/

Whole-of system efficiency

'Losses' in one part of an irrigation system (such as surface run-off) can become 'inputs' to another part (such as for downstream use).

At a small scale, systems often need to be regarded as 'open': water leaving the system may be re-used elsewhere for a variety of purposes (including environmental). At a larger scale, that re-use is recorded and the system is regarded as a 'closed' system. It can be hard to develop a water balance at that bigger scale, but it will give a different perspective of the efficiency overall.

A whole-of-system analysis is more likely to highlight environmental issues associated with water extraction and water contamination.

Some common ways to measure water use efficiency on farms are:

Measure	Input / Output	Units
Irrigation Water Use Index	Crop yield / Irrigation water applied	kg/ML
Gross Production Water Use Index	Crop yield / Total water applied (including rainfall)	kg/ML
Crop Water Use Index	Crop yield / Crop evapotranspiration	kg/mm
Gross Production Economic Water Use Index	Gross return / Total water applied	$/ML
Irrigation Rate	Water applied / Area	ML/ha
Water Input Efficiency	Water consumed by the crop / Total water applied	

Conclusion

Water use efficiency is an important and valuable concept. It can be determined at a variety of scales and can help identify ways to improve the productive use of scarce water supplies and the environment.

The analysis necessary to develop water budgets and subsequent efficiency measures is valuable in itself – giving deeper insight to the way in which water is used and stimulating ideas on how that use may be improved.

The work of the National Program for Sustainable Irrigation in developing and defining a set of efficiency measures has been crucial in providing a common language for the discussion of water use efficiency and opening the door to a deeper understanding of all that is involved.

MORE INFORMATION

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- www.cottoncrc.org.au/content/Industry/Publications/WaterandIrrigation/WATERpakS2efficientirrigation.aspx

Appendix 2

About NPSI

The National Program for Sustainable Irrigation provides research and innovation to improve the environmental and productive performance of irrigation in Australia.

The program funds and manages research projects across Australia, working at the property level with farmers, at catchment level with policy makers and planners, and at scales that cross state and territory borders.

Our vision

Australian irrigation that is valued for its environmental, economic and social contribution.

Our mission

To invest in research, development and its adoption to improve the productivity and sustainability of irrigation in Australia.

Outcomes

- Improved irrigation water use efficiency and enhanced ability to respond to changing levels of resource availability over time.
- Reduced environmental impacts, more sustainable ecosystems and more prosperous communities.
- Improved skills, knowledge and decision making of end users, which leads to practice change, and more efficient and sustainable use and management of water.
- A national approach to irrigation related to R&D in Australia, which includes a strong focus on a skilled human resource base and enhanced R&D capacity and collaboration.

Our values and guiding principles

- Scientific innovation and excellence.
- Practical knowledge ready for adoption.
- Leadership, integrity and collaboration across the irrigation industries.
- Commitment to sustainable irrigation industries, communities and management of natural resources.

Partners

NPSI is a collaboration between 14 funding partners. Investment Partners include irrigator groups, water authorities, commodity groups, state government agencies, Research and Development Corporations, Cooperative Research Centres and the Australian Government.

- Cotton Research and Development Corporation;
- Australian Government Department of Sustainability, Environment, Water, Population and Communities;
- Gacoyne Water Cooperative, Western Australia;
- Goulburn-Murray Water, Victoria;
- Horticulture Australia Limited;
- Harvey Water, Western Australia;
- Land & Water Australia (until end of July 2009);
- Lower Murray Water Authority, Victoria;
- Ord Irrigation Cooperative, Western Australia;
- Grains Research & Development Corporation;
- Sugar Research & Development Corporation;
- South Australian Research and Development Institute; and
- SunWater, Queensland;
- Western Australian Department of Water.

Resources

To view NPSI research reports and case studies, visit www.npsi.gov.au

NPSI's partners

Australian Government
Cotton Research and Development Corporation

Australian Government
Department of Sustainability, Environment, Water, Population and Communities

GASCOYNE WATER
IRRIGATING THE FUTURE

GOULBURN-MURRAY WATER

GRDC
Grains Research & Development Corporation
Your GRDC working with you

HAL
Know-how for Horticulture™

Harvey Water

Australian Government
Land & Water Australia

LOWER MURRAY WATER

Ord Irrigation Cooperative Ltd

Government of South Australia

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Australian Government
Sugar Research and Development Corporation

SunWater
Making Water Work

Government of **Western Australia**
Department of **Water**